# Assessing the costs and benefits of individual transferable quota management in the Tasmanian southern rock lobster fishery, Australia

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*“Such is oft the course of deeds that move the wheels of the world: small hands do them because they must, while the eyes of the great are elsewhere”*

J.R.R. Tolkien – The Fellowship of the Ring

# DECLARATIONS

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## Statement of co-authorship

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# ABSTRACT

Understanding how fishers behave and make decisions is critical in determining how best to manage fisheries. If the response of fishers to management measures can be predicted, unexpected and undesirable outcomes can be avoided. Individual transferable quota (ITQ) management has been introduced in many international fisheries, with the purpose of accounting for human behaviour, as it theoretically generates behavioural incentives that are aligned with management objectives (e.g. reducing fishing costs). The ability of ITQ systems to meet continuing economic, ecological and social objectives therefore is centred on ensuring fisher behavioural incentives remain aligned with those objectives. This thesis used the Tasmanian southern rock lobster (TSRL) fishery in Australia as a case study to assess changing fishing practices and behaviour of fishers under ITQ management and how this had evolved through time. The aim was to improve general understanding of how ITQ implementation and design may affect fisher decision-making and improve certainty in fishery management outcomes.

It is critical that an ITQ system is able to manage interactions with all ecosystem components (e.g. non-target species) as required under ecosystem based fisheries management (EBFM) principles. The TSRL fishery to some extent, was more successful than other fisheries in accounting for these interactions, due to the selective and benign nature of potting. In many sustainably certified fisheries, input controls continue to be used in place of ITQ systems to manage ecosystem components, particularly in non-selective fisheries (e.g. trawl). The continued use of input controls however, can reduce the security of a fisher's ITQ right through loss

of access and potentially separate their incentives and behaviour from management objectives.

Successful ITQ management also requires the managing authority to set a binding total allowable catch (TAC). Between 2008 and 2010, the TSRL had a non-binding TAC, which reduced the price of quota on the market and caused a reactivation of latent effort, increase in fleet capacity, reduction in economic efficiency and dissipation of economic rent, as fishers engaged in a competitive race to fish during times of high revenue. Changing fishing practices such as “double night fishing” during these years also had the potential to lead to localised stock depletion through concentration of effort, however the format of the commercial logbook prevented a precise assessment of the fleet-wide extent and impact of double night fishing. Consequently, this research highlighted the importance of being able to collect fine-scale spatial and temporal data on fishing effort in order to enhance decision-making.

It is also important in an ITQ system that those actively fishing own the majority of their quota units. An implicit assumption behind the theory of ITQs is that those fishing are quota owners, however in many developed ITQ fisheries, with free transferability of quota units, the majority of the fishing is undertaken by lease quota fishers. Following analysis of the physical risk tolerance of both quota owners and lease quota fishers in the TSRL fishery, it was evident that their behavioural drivers were divergent. Lease quota fishers were more responsive to changes in expected revenue than quota owners, leading in some areas to significantly higher risk tolerance levels. In other words lease quota fishers were more prepared to take greater risks at sea than quota owners when expected revenue was high. This result was not entirely unexpected as lease quota fishers face high costs of leasing quota and an increasing “cost price squeeze” between what that must pay to lease quota and what they are paid for their catch. Consequently, their behavioural incentives and underlying business structures are likely to be different. This was also evident in a series of economic experiments that were conducted to examine the propensity of groups with varying numbers of quota owners and lease quota fishers, to coordinate to prevent assignment problems that cause economic rent dissipation. Heterogeneous groups of lease quota fishers and quota owners were less successful in coordinating with communication than homogenous groups of quota owners. This was because lease quota fishers were less likely to adopt a socially-optimal strategy for preventing rent dissipation compared with quota owners due to having: (i) inequality in wealth; (ii) insecurity of tenure and; (iii) asymmetric information exchange. It was only through the institution of income-sharing cooperatives that lease quota fishers chose to coordinate because income-sharing offset the incentive to over-appropriate the resource, if participants doubt that others would do the same. While requiring external validation in the field, the results highlight the importance of recognising and understanding the differing behavioural incentives of lease quota fishers and quota owners. They also highlight the need for managers to consider the trade-offs associated with allowing free transferability of quota units and whether this meets overarching management objectives.

While contributing to further discussion and debate on the costs and benefits of ITQ management, this research highlighted the importance of understanding behavioural incentives of different types of fishers in order to inform management decision making. This type of research now and in the future has the potential to inform and ultimately improve the design and implementation of ITQ management systems.

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# Chapter 1: General Introduction

## 1.1 Incentive-based management and individual transferable quotas

Fisheries management measures and policies are often introduced with the aim of managing fishing fleets and their human overseers, as opposed to the fish stocks they are targeting (Wilen, 1979; Branch et al., 2006). Consequently, it is important to take account of how management measures and institutions might affect the behaviour and decision-making of fishers during fishing operations. Historically, the behavioural response of fishers to management measures and policies has been largely overlooked by fisheries managers during decision-making (Fulton et al., 2011). This has resulted in a litany of unexpected and perverse outcomes in many developed fisheries due to the inherent divergence between individual incentives and socially-optimal objectives (Hilborn et al., 2004a). For example, restrictions on vessel engine size and length in the Northern Prawn Fishery in Australia led to fishers increasing the head rope length of their trawl nets in order to maintain fishing efficiency, raising the overall costs of fishing, while lowering the net economic returns to the fleet and failing to prevent effort expansion (Kompas et al., 2004; Grafton et al., 2006). In order to reduce behavioural uncertainty and align economic incentives with societal objectives for sustainability, many governments and fisheries managers have chosen to take a "rights-based approach" to fisheries management through the institution of individual transferable quotas (ITQs).

In providing fishers with a guaranteed fixed proportion of the total allowable catch (TAC) for a given fish stock, ITQs theoretically remove the incentive for fishers to apply excessive capital and labour in order to maximise catch, replacing it with an incentive to reduce costs and change their fishing behaviour in order to maximise profit (Branch et al., 2006; Branch, 2009; Costello et al., 2010). For example, the relaxation of constrictive input (i.e. effort) controls which often accompanies the imposition of the ITQ system can create incentives for fishers to reduce fishing intensity and add value to their product by landing it fresh rather than frozen and/or targeting fish stocks at times when the market prices are highest (Chandrapavan et al., 2009; Hamon et al., 2009; Parslow, 2010). ITQs also supposedly encourage less efficient owners to sell their quota units to more efficient owners, reducing over-capacity and improving overall fleet efficiency (Branch et al., 2006). Furthermore, it is speculated that stewardship of the resource should arise because the value of a fisher's quota share is directly dependent on the long-term state of the stock, creating an incentive for fishers to conduct themselves in a manner that maximises the net present value of the fishery (National Research Council, 1999; Costello et al., 2010; Grimm et al., 2012).

Recent studies suggest that ITQs have been largely successful in achieving a variety of their economic and ecological objectives. For example, Costello et al. (2008) showed that landings of fish were less likely to collapse to low levels under ITQ management relative to non-ITQ management and the magnitude of this effect increased the longer a fishery was managed under ITQs. In a comprehensive review of the environmental, economic and social performance of 15 fisheries in the U.S. and Canada following the introduction of ITQ management, Grimm et al (2012) highlighted improvements in economic efficiency, per-vessel revenue, season length, sea safety and the probability of not exceeding the TAC. Similarly, Essington (2010) and Melnychuk et al. (2012) were able to show that ITQs reduced the probability of TAC overruns by consistently maintaining annual catches around quota limits and target reference points. In a review of the ecosystem effects of ITQs, Branch (2009) highlighted the positive effects of ITQ management on target species, provided TACs were set appropriately based on scientific advice and were accompanied by effective governance and enforcement. These results highlight the overall success of ITQs relative to traditional forms of management in improving ecological outcomes for target species and the economic efficiency of fishing fleets.

While the design of ITQ systems can supposedly take account of how different incentive structures can achieve a complex array of divergent ecological, economic and social objectives (Lynham et al., 2009) they have often been criticised in failing to deliver on a number of these objectives (e.g. Copes, 1986). These criticisms have been primarily caused by the institution of ITQ management prior to a comprehensive assessment and critical analysis of design based on the overriding objectives (economic, ecological and social) of all stakeholders (Costello et al., 2010) and the structural inflexibility of ITQ systems to change once instituted (Copes, 1986; Copes and Charles, 2004). This has led to criticisms in relation to ITQ systems dealing with ecological issues such as incentives to misreport catches, high-grade or discard fish of lower-market value (Copes, 1986) and manage the broader effects of fishing on non-target, threatened, endangered and protected (TEP) species and habitats (Gibbs, 2008). In addition to social issues such as the concentration of quota units among large vertically integrated companies, the demise of small fishing communities (Eythorsson, 2000; Stewart and Callagher, 2003) and the rise in the number of absentee landlords and lease quota fishers caused by the free transferability of quota units (Connor and Alden, 2001). Not to mention the exorbitant costs of leasing quota units, barriers to entry and the disproportionate concentration of wealth among quota owners (Pinkerton and Edwards, 2009). Finally, economic issues such as assignment problems, caused by within-season stock externalities and congestion externalities that in the absence of spatially and temporally delineated ITQs leads to dissipation of economic rent (Boyce, 1992; Costello and Deacon, 2007; Deacon and Costello, 2007). Consequently, the ultimate success of an ITQ system in addressing current diverse stakeholder objectives and future dynamic societal values may rest profoundly on its initial design and adaptability, as well as the use of a cross-disciplinary toolkit of management measures to address inadequacies (Degnbol et al., 2006).

## 1.2 The introduction of individual transferable quota management in the Tasmanian southern rock lobster (*Jasus edwardsii*) fishery in Australia

Individual transferable quotas (ITQs) were introduced in the Tasmanian southern rock lobster (TSRL) fishery in 1998. This was due to a perceived failure of previous input control management to constrain fishing effort and prevent over-capitalisation and stock depletion (Ford, 2001). The present-day fishery consists of approximately 225 fishing vessels that target the southern rock lobster (*Jasus edwardsii*) within Tasmanian coastal waters using pots. There are currently 312 licences and 10,507 quota units in the fishery and fishers must own at least one and hold a minimum 15 quota units to go fishing. To limit the concentration of ownership there is a maximum limit of 200 quota units, which represents around 2% of the catch (Ford, 2001). Residual input controls include seasonal closures to protect both male and female moulting lobsters, minimum size limits and gear restrictions. With a revenue of AUD $65.2 million in 2009/2010 (ABARES, 2011) and an estimated 700 people directly employed in the commercial rock lobster fishing, processing and handling sectors in 2006/2007 (van Putten and Gardner, 2010) the fishery is an important contributor to the Tasmanian economy.

Following the introduction of ITQ management, there were two contrasting periods of stock abundance, which led to changes in fishing strategies and profitability in the TSRL fishery. In the early-to-mid 2000s, catch per unit effort (CPUE) increased, the fishing fleet rationalised by 40%, and fishers reallocated their effort spatially towards inshore areas and temporally towards winter months where and when the market price of lobsters was higher (Frusher et al., 2003; Chandrapavan et al., 2009; Hamon et al., 2009). In the late-2000s a prolonged phase of low recruitment and depletion of legal sized stock, led to declines in catch rates and a non-binding TAC. This reduced the quota lease price, increasing capitalisation and the size of the fishing fleet as fishers competed with each other to take their quota share during times (e.g. November) and within areas (e.g. King Island) of higher CPUE (Linnane et al., 2010a; Emery et al., 2014).

## 1.3 Importance of understanding fisher behaviour under individual transferable quota management

While ITQs have been introduced in over 121 different fisheries in at least 22 countries (Chu, 2009; Deacon, 2012), empirical research examining the impact of this form of management remains scarce (Thébaud et al., 2012). Fishery-specific analyses are required that not only assess the ecological, economic and social impacts of ITQs following their immediate implementation, but also as the ITQ system evolves through time. This will enable fishery managers to gain a greater appreciation of the residual or emerging negative externalities of ITQs and how these may be effectively addressed using a cross-disciplinary toolkit of management measures (Fulton et al., 2011). This will allow future management decision-making regarding ITQ implementation and design to be informed by scientific evidence (Thébaud et al., 2012).

Improved outcomes of ITQ management reside in a more effective understanding of human behaviour (Fulton et al., 2011). It is not enough to simply institute an ITQ system under the belief that fisher incentives and behaviour will now, and into the future, remain aligned with management objectives. This is simply not true, with the level of alignment likely to vary across fisheries and through time based on external factors such as the level of monitoring, control and surveillance, the nature and number of target species or even the extent of heterogeneity in behavioural drivers across the fishing fleet. Quantitative analyses of the responses of fishers to the adoption and evolution of ITQ management are required to reduce unexpected and undesirable outcomes and ultimately improve decision-making and the success of fisheries management (Fulton et al., 2011; Thébaud et al., 2012).

## 1.4 Study objectives and thesis structure

The specific aim of this research was to quantitatively assess changing fishing practices and fisher behaviour under ITQ management in the TSRL fishery to improve general understanding of how ITQ implementation and design may affect fisher decision-making and improve certainty in fishery management outcomes. As a consequence of this aim, assertions could then be made on the effectiveness of ITQ systems more generally in achieving key fisheries management objectives. The thesis is structured around six core research chapters with Table 1.1 providing a brief overview of each chapter's aims, results and significance for future management.

**Table 1.1**: Brief overview of thesis chapters

| Chapter | Title | Aim | Results | Management implications |
|---|---|---|---|---|
| **Two** | *Are input controls required in individual transferable quota fisheries to address ecosystem based fisheries management objectives?* | Assess whether international ITQ systems can effectively manage fishing impacts on all ecosystem components (target, non-target, threatened, endangered and protected [TEP] species and habitats) as required under EBFM objectives. | Input controls were retained across a range of ITQ fisheries, with non-selective fisheries such as trawl employing more input controls than selective fisheries such as purse-seine. Spatial closures were also increasingly used in ITQ fisheries to meet EBFM requirements. | The continued use of input controls, particularly closures weakens the security characteristic of the ITQ and the ability of fishers to manage their right for their future benefit.<br>Re-introducing input controls in ITQ fisheries has the propensity to modify fishing incentives and behaviours so that they separate from societal objectives for sustainability, which was one of the foremost reasons for introducing ITQ management. |
| **Three** | *Does "race to fish" behaviour emerge in an individual transferable quota fishery when the total allowable catch becomes non-binding?* | Examine whether the presence of a non-binding TAC in the TSRL fishery re-introduced open-access inefficiencies through altering individual fishing incentives and behaviour. | The presence of non-binding TAC:<br>(i) Led to the fishery functioning as a regulated limited entry fishery between 2008 and 2010.<br>(ii) Reduced the price of quota on the market causing a reactivation of latent effort and increase in fleet capacity.<br>The low price of quota also proved a barrier to investment hindering the economic efficiency of the fishing fleet. | Underlined the importance of appropriately setting the TAC to prevent unexpected and undesirable changes in behaviour and fishing practices. |

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| | | | Fishers engaged in a competitive race to fish during times when CPUE was high increasing the potential for economic rent dissipation. | |
| **Four** | *Managing inshore stocks of southern rock lobster for a sustainable fishery* | Assess the nature, extent and accurate recording of "double night fishing" (DNF) effort and compare differences in catch composition, size structure and effects of handling on growth of lobsters between double night and standard shots. | Not possible to determine full extent of DNF from logbook so depth loggers were utilised. DNF effort not as widespread as envisaged with only 17% of all shots recorded as double night shots. Under-reporting was low (< 1 shot per trip). There was no significant difference in the size composition, extent of injuries, bycatch of double night to standard shots. While effort was slightly higher for DNF than standard fishing trips there was no difference in the CPUE. | Illustrated that in order to determine the full extent of DNF the logbook requirement that fisher's record "shot type" and "date of month" needed to be removed and replaced with recording the time and date of first pot set and first pot hauled for each shot. The logbook also needed to prevent fishers from combining shots across a calendar day by reporting double the number of pots. This would allow assessment of fine-scale effort, and correction for potential bias from DNF in the stock assessment process for the fishery. |
| **Five** | *Fishing for revenue: how leasing quota can be hazardous to your health* | Determine whether the introduction of ITQ management has improved sea safety through equally decreasing the physical risk tolerance of quota owners and lease quota fishers in the TSRL fishery. | Fishers in general were averse to physical risk however this was offset by increases in expected revenue. Lease quota fishers were more responsive to changes in expected revenue, which led to significantly higher physical risk tolerances than quota owners in some areas. This appeared to be related to the costs of leasing quota. | ITQs may not improve sea safety if the fishery is dominated by lease quota fishers as they are motivated by an economic incentive to fish in hazardous weather conditions.<br>It is important that decision-makers consider behavioural differences among quota owners and lease quota fishers when developing and/or modifying regulations. |

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| | | | | Preventing a large-lease dependent fishery from developing in the first instance should be considered through restrictions on the transferability of quota units. |
| **Six** | *An experimental analysis of assignment problems and economic rent dissipation in quota-managed fisheries* | Assess whether groups consisting of varying numbers of lease quota fishers and quota owners can cooperate with or without communication, to resolve assignment problems caused by heterogeneity in the economic value of catches across time and space that leads to economic rent dissipation. | An inability to communicate led to economic rent dissipation among all groups.<br>The advent of communication improved coordination among homogenous groups of fishers.<br>Groups containing both lease quota fishers and quota owners were less successful in preventing rent dissipation. Lease quota fishers were less likely to adopt a socially-optimal strategy for preventing rent dissipation than quota owners due to: (i) inequality in wealth; (ii) insecurity of tenure; and (iii) asymmetric information exchange. | Highlighted the difficulties heterogeneous fishers may have in solving assignment problems under quota management, particularly as many ITQ fisheries are increasingly characterised by a growing number of lease quota fishers. |
| **Seven** | *An experimental analysis of the success of income sharing fishery cooperatives in resolving assignment problems that cause* | Assess whether groups consisting of varying numbers of lease quota fishers and quota owners can cooperate following the institution of fishery closures or income-sharing fishery cooperatives with | The introduction of fishery closures reduced economic rent dissipation among most groups. Fisheries dominated by lease quota fishers were less successful due to the differential values that lease quota fishers placed on | Income-sharing among fishery cooperatives are able to successfully align the incentives of heterogeneous groups with objectives to reduce economic rent dissipation.<br><br>Fishery closures can improve cooperation |

| | | | | |
|---|---|---|---|---|
| | *economic rent dissipation* | communication, to resolve assignment problems caused by heterogeneity in the economic value of catches across time and space that leads to economic rent dissipation. | the resource relative to quota owners. Income-sharing fishery cooperatives were equally successful across all groups in reducing economic rent dissipation. This was because income-sharing offset the incentive to over-appropriate the resource if participants doubt others would do the same. | among groups to reduce economic rent dissipation but the benefits are limited for heterogeneous groups consisting of mainly lease quota fishers. |
| **Appendix** | *Handle with care: an analysis of the effects of appendage damage on the growth and productivity of the southern rock lobster (Jasus edwardsii).* | Assess the effect of different types of injuries (e.g. leg or antenna) on the growth of undersize male and female lobsters from southern areas of Tasmania. | The effect of different types of injuries on the growth of undersize female lobsters could not be differentiated from zero but for undersize males with either antenna or leg injuries, annual growth was reduced by 7%. Annual growth of undersize male lobsters with both types of injuries was reduced by 40%. With an estimated 6% of undersize male lobsters damaged during commercial fishing in southern areas of Tasmania it was predicted that annual lost productivity and revenue due to damage was 1.6 tonnes or $72,905 respectively. | Highlighted the effectiveness of current management measures, sorting procedures and the biology of the species in reducing the capture and excessive handling of undersize lobsters. |

# Chapter 2: Are input controls required in individual transferable quota fisheries to address ecosystem based fisheries management objectives?

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## 2.1 Abstract

This study examined the use of Individual Transferable Quotas (ITQs) to effectively manage fishing impacts on all ecosystem components, as required under Ecosystem Based Fisheries Management (EBFM) principles. A consequence of changing from input controls to output-based (catch) management is that the control of the regulating authority tends to be reduced, which may affect outcomes for ecosystem management. This study reviewed the use of input controls across six fishing methods in 18 ITQ fisheries, which have been independently accredited as ecologically sustainable by the Marine Stewardship Council (12 fisheries) or under Australian environmental legislation for Wildlife Trade Operation (six fisheries). Input controls were retained across a range of ITQ fisheries, with non-selective fisheries such as trawl, gillnet and line employing more input controls than selective fisheries such as purse-seine, pot/trap and dredge. Further case-studies confirmed the widespread and recent use of input controls (spatial and temporal closures) with the aim of managing ecosystem impacts of fishing. The retention of input controls, particularly closures affects the security (quality of title) characteristic of the fishing use right and the theoretical ability of fishers to manage their right for their future benefit. The security characteristic is weakened by closures through loss of access, which undermines industry trust and incentive for long-term decision making. In reducing the security of ITQs, individual fisher incentives and behaviour may separate from societal objectives for sustainability, which was one of the foremost reasons for introducing ITQ management.

## 2.2 Introduction

### *2.2.1 The race to fish*

The well documented difficulties in marine fisheries management have been attributed to the open access (common property) nature of the resource, (Gordon, 1954; Scott, 1955) the inherent biological variability and uncertainty within marine ecosystems (Cochrane et al., 1998; Holland and Herrera, 2009) and/or poor governance and compliance (Hilborn, 2004; Hilborn et al., 2004a; Mace, 2004). Open access creates a "race to fish" where overcapitalised fishing fleets of increasing size and power controlled by "economically rational"(Fujita and Bonzon, 2005) individuals seek to maximize harvests until the point where average revenue equals average cost (bio-economic equilibrium) (Hilborn et al., 2003). This tends to be collectively disastrous yet economically rational because the benefits from resources left behind for conservation do not directly accrue to that individual (Fujita and Bonzon, 2005; Acheson, 2006).

The traditional approach to fisheries management involved reducing the level of harvest through restricting fishing inputs (effort) such as maximum gear length. These top-down ("command-and-control") regulations "frequently failed in their objective to limit fishing effort because harvesters are often able to substitute unregulated inputs for controlled ones, causing a gradual expansion of effort..." (Grafton et al., 2006) p. 700. If anything, the race to fish and accompanying perverse incentives are exacerbated by traditional top-down management creating a downward spiral of shorter fishing seasons, excessive harvests, collapsed stocks and increasingly destructive and high-risk (dangerous) fishing practices (Fujita and

Bonzon, 2005; Costello et al., 2008). A good example was the United States North Pacific Halibut Fishery. Under top-down regulation, the fishing season was gradually reduced from 47 to four days due to an inability to effectively restrain effort, which resulted in gear conflicts, hazardous fishing practices, higher discard rates and reduced market value through excess fishing costs and supply.(Huppert, 2005).

### *2.2.2 Incentive-based management*

The realisation that many fisheries were overcapitalised, economically inefficient and biologically unsustainable led to the advocacy of a shift in fisheries management style from top-down (command-and-control) to bottom-up (incentive-based). Incentive-based approaches to management are an attempt to align individual fisher behaviour with the overall societal goals for the fishery such as ecological sustainability (Grafton, 1996; Hilborn, 2004; Hilborn et al., 2004a; Grafton et al., 2006; Hilborn, 2007; Grafton et al., 2010). This is achieved through providing fishers, communities or cooperatives with secure, durable and tradable harvesting or ownership rights. Such rights eliminate the competitive "race to fish" by reducing levels of overcapitalisation and increasing economic efficiency and profitability (Symes and Crean, 1995; Grafton, 1996; LeDrew, 2003; Grafton et al., 2006). Often termed dedicated access privileges or catch shares they are not full private property rights but a use right (hereafter referred to as a fishing use right) that allows access to the fishery and a percentage of the TAC for an individual species (Costello et al., 2008; Essington, 2010).

There are a variety of forms of fishing use rights. These include: individual quotas (or Individual Transferable Quotas [ITQs] when transferable) allocated to individual fishers, Individual Vessel Quotas (IVQs) allocated to fishing vessels or Enterprise Allocations (EA) allocated to fishing corporations. Where rights are allocated to groups or communities they are termed Community Development Quotas (CDQ) and where they are allocated over a specific geographical area they are termed Territorial User Rights to Fish (TURFs) (Branch, 2009). These are also collectively termed rights-based management systems.

ITQs are the most frequently adopted fishing use right; where a proportion of the Total Allowable Catch (TAC) set for a particular species is allocated in advance, usually for a given fishing season (but possibly for a longer period) to individual fishers, enterprises or vessels as quota units. Within each season, ITQ holders can maximise their return by catching their quota units and/or engaging in trade.

Theoretically, providing a tradable, guaranteed share of the TAC acts as an incentive for fishers to become stewards of the resource and promote its sustainability because they are financially rewarded for good stock management (Grafton et al., 2006; Essington, 2010). This incentive is dependent on the strength of the durability, exclusivity, transferability, security (quality of title), divisibility and flexibility (property right) characteristics[1] of the fishing use right. When these

[1] The property right characteristics are defined using the classification provided by Ridgeway et al., (2010):
*Quality of Title (Security)* refers to the certainty, security and enforceability of the right.
*Durability* refers to the length of time a right owner might expect to exercise "ownership".
*Transferability* refers to the extent to which a right can be transferred by selling, leasing or trading.
*Exclusivity* refers to the extent that other participants are prevented from injuring or interfering with an owner's rights.
*Divisibility* refers to the possibility of dividing the right into narrower forms of rights or quota into smaller amounts.
*Flexibility* refers to the ability of rights holders to freely structure their operations

are strong the incentive structure of fishers will be more closely aligned with existing capacity and the opportunities or desire to fish (Ridgeway and Schmidt, 2010). However if one or more of the characteristics is diminished, the benefits of incentive-based approaches to fisheries management may be reduced (Grafton et al., 2000). For example, if the durability of a fishing use right is weak (i.e. only lasts for a limited time period) then fishers will theoretically have less incentive to reduce catches in the short-term because of the increased likelihood of not receiving future benefits. In reality, few ITQ management systems are strong in all of these characteristics but are tailored to practically manage the resource and meet alternative socio-economic and political objectives other than optimising economic yield of harvests (FAO, 2005).

Although ITQs have been introduced in over 121 fisheries (Costello et al., 2008) in at least 18 countries (Chu, 2009), their acceptance remains contentious (Copes, 1986; McCay, 1995) and less than 2.7% of the total value of world fish catch is harvested under such systems (Diekert et al., 2010).

### *2.2.3 Ecosystem Based Fisheries Management*

Around the time that fisheries economists started to advocate forms of rights-based management as a workable solution to the widespread failures in fisheries management, (Parsons, 2005) there was a growing faction of scientists, governmental departments and Non-Government Organisations (NGOs) who advocated Ecosystem Based Fisheries Management (EBFM) and Ecosystem Approach to Fisheries (EAF) paradigms.

The ecosystem effects of marine fisheries are the subject of much scrutiny, in particular, the depletion of target fish stocks (Myers and Worm, 2005; Worm et al., 2006), collateral effects on non-target and threatened, endangered and protected (TEP) species (Baum et al., 2003; Hays et al., 2003; Lewison et al., 2004) and direct and indirect impacts on ecosystem habitat, structure and function (Jennings and Kaiser, 1998; Pauly et al., 1998; Frank et al., 2005; Bearzi et al., 2006; Castilla, 2010) (hereafter referred to as ecosystem components). The ecosystem approach takes a broader perspective to that of conventional management by recognising all ecosystem components, their interactions and focusing on the importance of ecosystem health in the exploitation of resources (Grafton et al., 2010; Rice and Ridgeway, 2010). Fishing is included under a holistic management framework that seeks to reconcile the often competing goals and multiple objectives of all stakeholders with environmental requirements (Frid et al., 2006; Nomura, 2008). The EAF is inherently precautionary, adaptive and seeks to promote resilience in ecosystems to ensure that ecosystem goods and services are available to future generations (Parsons, 2005; Grafton et al., 2010).

The growing advocacy for EBFM led to the international consideration and adoption of a range of legal instruments concerning sustainable development. These included: (i) the 1992 Convention on Biological Diversity, which aimed to promote conservation of biological diversity and sustainable use; (ii) the 1995 United Nation Fish Stocks Agreement (UNFSA), which obligates states to apply the principles of ecosystem based management and the precautionary approach to fisheries management; (iii) the 1995 FAO Code of Conduct for Responsible Fisheries, which, although was non-legally binding, extended the principles of UNFSA in recommending fisheries introduce measures to ensure protection of both target, non-target species and their ecosystems; (iv) the 2001 Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem, which established the EAF and led to the formulation of technical guidelines by the FAO on its application and; (v) the 2002 World Summit on Sustainable Development where States recognised and reinforced their commitment to the ecosystem approach by placing a timeframe on its application.

Since the UNFSA, various countries have implemented aspects of EBFM and the EAF in their fisheries policy and legislation including Canada (Parsons, 2005; Parsons, 2010), Australia (SEWPAC, 2010) and the United States (Marasco et al., 2007; Holland, 2010). These have predominately taken the form of holistic ocean policies and networks of marine protected areas. For example, in Australia a key component of the 1998 Oceans Policy was to develop "Marine Bioregional Plans" with the intent to introduce a "Nationally Representative System of Marine Protected Areas" (NRSMPA), which are enacted through the *Environment, Protection and Biodiversity Conservation Act 1999* (EPBC Act).

While national governments have responded to the international commitment to address EBFM, fisheries scientists have discussed the expansion (and/or replacement) of single-species performance measures and reference points to include ecosystem considerations, such as non-target (bycatch) species and predator-prey relationships (Hall and Mainprize, 2004; Jennings, 2004; Marasco et al., 2007). Although debate continues, recent literature reviews (Hall and Mainprize, 2004; Parsons, 2005) indicate there is no clear assessment methodology currently available that would enable the replacement of single-species indicators with ecosystem metrics. This is due to the complexity of ecosystem dynamics (such as determining key interactions among species) and lack of underlying theory and data to explain the behaviour of these ecosystem metrics. This has led to the conclusion that ecosystem approaches to management should be introduced incrementally through the extension of single-species performance measures and reference points, while taking broader ecosystem considerations into account (Babcock and Pikitch, 2004; Parsons, 2005; Marasco et al., 2007). A presumed result, being lower, more precautionary set TACs for target species with adaptive management plans to account for interactions with non-target species and ecosystem uncertainties.

Proponents of rights based management concur with this "evolutionary rather than revolutionary" (Marasco et al., 2007) approach to expand successful single-species indicators to include ecosystem considerations (Mace, 2001; Jennings, 2004; Mace, 2004). This is due to their conviction that the failure of single-species management to address ecosystem principles was due to ineffectual governance (political will) to set appropriate fishing mortality limits and a failure to recognise and manage people (Mace, 2001; Hilborn, 2004; Mace, 2004). They argue that without resolving the "key drivers of unsustainable outcomes", (Grafton et al., 2006) p. 706 which are inappropriate incentives and ineffective governance, EBFM or any alternative overarching management strategy will similarly fail to meet its objectives.

### *2.2.4 ITQs and EBFM*

ITQ systems are primarily designed to increase economic rent from the harvest of specific (target) species. The increasing emphasis on EBFM has meant that ITQ systems are now scrutinised for their ability to successfully incorporate ecosystem considerations such as bycatch species.

Although ITQs are intended to assist in improving several broad economic and ecological outcomes of fisheries management (Grafton, 1996; Arnason, 2002; Festa et al., 2008) recent collective studies by Essington (Essington, 2010), Chu (Chu, 2009), Branch (Branch, 2009) and Costello (Costello et al., 2008) highlight that outcomes are mixed. In examining the efficacy of catch shares in preventing stock collapse (defined as the catch falling below <10% of the historic maximum) Costello et al (Costello et al., 2008) concluded that only 9% of fisheries would have collapsed by 2003, compared to 27%, had all non-ITQ fisheries switched to ITQs in 1970. When analysing biomass levels of harvested populations however, Chu (Chu, 2009) found variable changes, with eight out of 20 analysed stock biomasses continuing to decline after the introduction of ITQs. While not able to separate the influence of the TAC from the influence of ITQs on stock status, these results led to the presumption that alternative and complementary measures to ITQs are required to ensure sustainability in some stocks. Similarly, Essington (Essington, 2010) found that catch shares did not result in improved ecological stewardship and the status of exploited populations, when assessed using indicators such as higher population levels or lower exploitation intensity. Instead their primary effect was to reduce inter-annual variability among indicators, so that fishing fleet behaviour and fish populations were more predictable. This may be an indication that ITQ management systems are more stable than alternatives. When assessed qualitatively, Branch (Branch, 2009) found that ITQs have a positive effect on target species if the TAC is set at an appropriate level and enforced, but the effect on habitat and non-target species may be positive or negative.

The value of a harvesting right for a single target species or the economic return to quota holders is not affected by fishing practices which are detrimental to other ecosystem components (Hilborn, 2004; Grafton et al., 2006). These "negative externalities" from fishing are not financially linked to individual fisher decision making because they don't directly affect their asset value (Gibbs, 2009). Concurrently, fishers cannot extract sufficient payment from consumers for the conservation of marine biodiversity (Brady and Waldo, 2009). Proponents of fishing use rights have previously advised of their inability to prevent negative externalities (or market failure) due to the impracticality of creating economic incentives for all ecosystem components (Hilborn, 2004; Hilborn et al., 2005b; Grafton et al., 2006). Moreover there is now a growing body of literature that supports the theory that management systems only utilising fishing use rights (particularly ITQs) are incapable of meeting EBFM outcomes. Outlined here are some of the prevailing reasons:

(i) the quota holder is unable to see any economic benefit, through either a decrease in their asset value or extraction of sufficient compensatory payment from consumers for considering ecosystem considerations in fishing practices (Acheson, 2006; Brady and Waldo, 2009; Gibbs, 2009; Gibbs, 2010).

(ii) the increased prevalence of leasing is decoupling quota-holders from at-sea operations (absentee ownership). This propagates a shift in incentives towards covering lease debt and making a profit at any cost (Gibbs, 2008; Gibbs, 2009).

(iii) the inherent unpredictability of resource availability can reduce the incentive for quota-holders to invest in ecosystem components due to a lack of assurance that their activities will be rewarded in the future (Acheson, 2006).

(iv) the relationship between fishing effort and the TAC is generally weak, especially in multispecies fisheries and when it is set incorrectly positive. Therefore reliance on a sole TAC is unlikely to reduce the impacts of fishing effort on other ecosystem components (Gibbs, 2010; Reiss et al., 2010).

(v) in the absence of a correctly set TAC, the inability of market mechanisms to reduce pressure on stocks due to the often positive correlation between species rarity and value, where consumers may continue to pay a premium price as resources diminish, allowing potentially unsustainable fishing to continue (Courchamp et al., 2006).

(vi) the incentive to reduce marginal costs can result in increased spatial concentration of effort with exploitation of near-shore fishing areas and/or higher-yield grounds leading to localised depletion (Copes, 1986; McCay, 1995).

(vii) established quota management systems are inherently inflexible to modification (Copes, 1986; Copes and Charles, 2004) and the incorporation and maintenance of ecological components such as bycatch species within the system is cost prohibitive, time consuming and labour intensive.

These factors may impede the ability of a sole ITQ system to meet ecosystem based outcomes (Copes and Charles, 2004; Degnbol et al., 2006; Gibbs, 2008; Brady and Waldo, 2009; Gibbs, 2009; Smith et al., 2009; Gibbs, 2010) and require fisheries managers to retain or reintroduce effort constraining input controls that would otherwise be removed through the shift in management style from top-down to bottom-up. This supposition was the impetus for this review on ITQ fisheries and comparing the extent to which different types of input controls, across fishing methods are being utilised to meet EBFM requirements. The ramifications of input control use will also be addressed. It should be noted that while this paper primarily examines ITQ systems many of the issues concerning the use of input controls to meet EBFM targets are just as relevant to non-transferable individual quota systems.

## 2.3 Methods

### *2.3.1 Fisheries selection*

To undertake this review, ITQ fisheries that have been independently assessed as meeting EBFM targets were selected using two existing accredited classification systems: the MSC certification and the Australian WTO accreditation. To become certified under the MSC guidelines the fishery must meet three core principles: (i) that the fishing activity must be at a sustainable level; (ii) that fishing operations should be managed to maintain the structure, productivity, function and diversity of the ecosystem on which the fishery depends; and (iii) that the fishery must meet all the local, national and international laws and must have a management system that responds to the changing circumstances and maintains sustainability[2]. The prohibitive costs associated with MSC accreditation may favour overrepresentation of large wealthy industrial fisheries (Gulbrandsen, 2009; Goyert et al., 2010) so to offset this potential bias and due to author familiarity, one Australian ITQ fishery across each fishing method was selected whose WTO assessment was approved under the EPBC Act. The EPBC Act requires all Australian Commonwealth fisheries and State export fisheries to undergo a strategic assessment to ensure current management is ecologically sustainable and in accordance with the principles of EBFM. Fisheries are assessed against guidelines[3] whose purpose are aligned with international objectives to ensure ecologically sustainability. Under the guidelines, sustainability is achieved through an integrated approach that considers all

[2] A copy of the MSC standards is available online at http://www.msc.org/about-us/standards/standards
[3] A copy of the current Guidelines for the Ecological Sustainable Management of Fisheries (2nd Ed, 2007) can be found at: http://www.environment.gov.au/coasts/fisheries/publications/pubs/guidelines.pdf

impacts on ecosystem components and emphasises the use of the precautionary approach to ensure future viability.

For each fishery, the nature of the quota management system and the subsequent strength of its characteristics (security, exclusivity, transferability, durability, flexibility, divisibility) were examined. Fisheries that allocated quota to individuals, vessels or enterprises were included under the umbrella of ITQ managed fisheries. Some fisheries that had in-principle restrictions on permanent transferability of quota (but could still lease quota annually) were also included due to an ability to circumvent these restrictions.

The aim was to review three ITQ fisheries for each of the six fishing methods (trawl, pot/trap, dredge, line, gillnet, purse-seine), comparing the input controls of two accredited under MSC and one under Australian WTO. There was a lack of representation of ITQ fisheries using dredge and gillnet methods with MSC certification so one supplementary MSC accredited ITQ fishery was added to both trawl and line methods. In summary this study reviewed eighteen ITQ fisheries, from six countries, split across six fishing methods to assess to what extent input controls were being used to meet EBFM requirements.

### *2.3.2 Input control review*

Input controls are management controls that aim to directly constrain fishing catch by reducing the efficiency of effort (Morison, 2004)[4]. In this review they were

[4] For the purposes of this review "input controls" are defined using the classification proposed by Morison (2004) who advised that management controls that aim to directly constrain any aspect of fishing effort are

categorised as one of closures (temporal or spatial), gear restrictions (number, size or add-on [i.e. bycatch reduction device]) or other (move-on provisions). Vessel size limits and gear types (purse-seine, trawl etc.) were also included as a separate category. The presence or absence for each category of input control was reviewed across each fishery and category of ecosystem component - target species, non-target species, TEP species and habitats.

To determine which input controls were used in each fishery online searches of relevant fisheries management authority and governmental department websites[5] were conducted. Public certification and updated surveillance reports assisted in the identification of input controls for all MSC accredited fisheries[6]. Annual management arrangements booklets and WTO status reports provided most of the required information for the Australian State and Commonwealth fisheries. (DPIPWE, 2006; AFMA, 2009; AFMA, 2010d; AFMA, 2010c; AFMA, 2010a).

Following this assessment, recent fishery case-studies where input controls were used to address ecosystem components were selected for further consideration and researched using the same methods outlined above.

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input control measures. This includes four matters of *who* fishes, *where* and *when* they can fish and *how* they can fish. Under this definition previously termed "technical and/or conservation measures" are included under the umbrella of input controls.

[5] These included the: Australian Fisheries Management Authority (http://www.afma.gov.au) and Department of Primary Industries, Parks, Water and the Environment (http://www.dpiw.tas.gov.au) for Australian fisheries. Fisheries and Oceans Canada (http://www.dfo-mpo.gc.ca/fm-gp/index-eng.htm) for Canadian fisheries. The Norwegian Ministry of Fisheries and Coastal Affairs (http://www.fisheries.no/) for Norwegian fisheries. The Ministry of Fisheries (http://www.fish.govt.nz/en-nz/default.htm) for New Zealand fisheries. The Ministry of Economic Affairs, Agriculture and Innovation (http://www.minlnv.nl/) for Dutch fisheries and the National Marine Fisheries Service Alaska Regional Office (http://www.fakr.noaa.gov/) for U.S. fisheries.

[6] Public certification and surveillance reports are available at http://www.msc.org/track-a-fishery/certified

## 2.4 Results

### *2.4.1 Review of input controls across fishing method*

The outcomes of the review are presented in Table 2.1. Although fishing use rights regulated each of the 18 fisheries reviewed, input controls remained in place for the majority of key target species across fishing methods (Table 2.1). A greater amount of input controls were in place to address target species than any other ecosystem component. The predominant input controls addressing ecosystem components were spatial closures and gear add-ons such as seabird mitigation devices and Bycatch Reduction Devices (BRDs) (Table 2.1).

Of the fishing methods reviewed, trawl had the largest quantity of input controls. All four trawl fisheries had spatial closures in place for target species and three out of four for protecting habitats. In the New Zealand hoki fishery, widespread spatial closures were in place to manage potential interactions with endangered Hector's and Maui's dolphins and protect vulnerable habitats such as seamounts (MFish, 2010). The Commonwealth Trawl Sector (CTS) of the Southern and Eastern Scalefish and Shark Fishery (SESSF) in Australia had 13 spatial closures and two temporal closures in place protecting target, non-target and TEP species as well as habitat (AFMA, 2010d). The Australian mackerel icefish fishery, operating in sensitive Antarctic waters, had a two month temporal closure and a ban on day fishing to protect marine birds (AFMA, 2009). In the Norwegian North Sea and north-east Arctic saithe fisheries, real-time temporal closures were implemented when catches contained proportions of undersize target species greater than 15% (Piling et al., 2008). All four fisheries had restrictions on trawl mesh size, with two fisheries requiring the inclusion of a BRD or sorting grid and one fishery implementing compulsory move-on provisions to both reduce interactions with juvenile target and non-target species.

All three pot/trap fisheries had restrictions on maximum pot/trap size with associated escape gap requirements. They also had spatial closures in place to either protect spawning areas, juveniles or prevent localised depletion of target species. Except for a spatial closure to protect rockfish species in the Canadian sablefish fishery there were no closures mitigating impacts on non-target and TEP species (Furness et al., 2010). The Tasmanian rock lobster fishery in Australia was the only pot/trap fishery to have a maximum usage limit on gear and seasonal closures to protect breeding females and soft-shelled male lobsters (DPIPWE, 2006). However, it did not have any provisions to protect specific habitat whereas the other two fisheries had closures on seamounts or coral conservation areas.

Both scallop dredge fisheries were different in their approach to management and therefore use of input controls. The eastern offshore scallop fishery in Canada was managed by a vessel size limit and remained open throughout the annual fishing season, except on the Georges Bank where there are temporal closures implemented to protect non-target species (Caddy et al., 2010). There were no measures in place to protect specific habitats or TEP species. The Bass Strait Central Zone Scallop Fishery (BSCZSF) in Australia was managed by temporal and spatial closures and remained closed throughout the nine month fishing season unless survey results indicated more than one viable area in terms of size, discard rate and density (AFMA, 2010c). This measure was in place to maintain the viability of both the target species and representative habitat.

All four line fisheries had mandatory seabird mitigation devices in place. Temporal and spatial closures for target species were also in place in three out of the four line fisheries. In the U.S. sablefish and halibut fisheries there were a number of overlapping marine reserves, seamount closures and coral conservation areas protecting habitat and a temporal closure to protect walruses in the Bering Sea (North Pacific Fishery Management Council (NPFMC), 2009; International Pacific Halibut Commission (IPHC), 2010). In Canada, conservation zones to protect rockfish and their habitat had been established which affect the pacific halibut fishery (Chaffee and Turris, 2009). The scalefish hook sector of the Gillnet Hook And Trap Sector (GHATS) in the SESSF had the greatest number of input controls in place with 12 spatial closures implemented to protect target, non-target and TEP species (AFMA, 2010d). There were also two temporal closures in place to protect pink ling (a target species) and deepwater dogfishes (TEP species) until the end of 2010. Additionally, fishers using auto-longline gear in this sector had a maximum hook limit (AFMA, 2010d).

**Table 2.1**: Review of input controls in individual transferable quota fisheries that have been certified as meeting ecosystem based fisheries management targets under Marine Stewardship Council and Australian Wildlife Trade Operation standards.

| Fishery | | | Hoki | Mackerel Icefish - Heard Island & McDonald Island | North Sea and North East Arctic Saithe[d] | South-East Trawl [SESSF[e]] | Sablefish[f] | Eastern Offshore Lobster | Tasmanian Southern Rock Lobster | Eastern Offshore Scallop | Bass Strait Central Zone Scallop | North Pacific Sablefish | North Pacific Halibut | Pacific Halibut | Scalefish Hook [SESSF] | Dutch Fisheries Organisation Sole Gillnet[h] | Shark Gillnet [SESSF] | Spring Spawning Herring[j] | North Sea and Skagerrak Herring[j] | Southern Bluefin Tuna |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | | | New Zealand | Australia | Norway | Australia | Canada | Canada | Australia | Canada | Australia | USA | USA | Canada | Australia | Netherlands | Australia | Norway | Norway | Australia |
| Method | | | Trawl[b c] | Trawl | Trawl | Trawl | Pot/Trap[g] | Pot/Trap | Pot/Trap | Dredge | Dredge | Line | Line | Line | Line | Gillnet[i] | Gillnet | Purse-Seine | Purse-Seine | Purse-Seine |
| Certification | | | MSC | MSC | MSC | WTO (Aus) | MSC | MSC | WTO (Aus) | MSC | WTO (Aus) | MSC | MSC | MSC | WTO (Aus) | MSC | WTO (Aus) | MSC | MSC | WTO (Aus) |
| Target | Closures[a] | Temporal | X | | X | X | | | X | | X | | X | X | X | | | X | X | |
| | | Spatial | X | X | X | X | X | X | X | | X | | X | X | X | X | X | | | |
| | Gear Restrictions | Number | | | X | | | | X | | | | | | X | X | | | | |
| | | Size | X | X | X | X | X | X | X | | | | | | | X | X | | | |
| | | Add-Ons | | | X | X | | | | | | | | | | | | | | |
| | Other | Move-On Provisions | | X | | | | | | | | | | | | | | | | |
| Non-Target (Bycatch) | Closures | Temporal | | | | X | | | | X | | | | | X | | | | | |
| | | Spatial | | | | X | X | | | | | | | X | X | X | X | | | |
| | Gear Restrictions | Number | | | X | | | | X | | | | | | | X | | | | |
| | | Size | X | X | X | X | X | X | X | | | | | | | X | X | | | |
| | | Add-Ons | | | X | X | | | | | | | | | | | | | | |
| | Other | Move-On Provisions | | X | | | | | | | | | | | | | | | | |
| Threatened, Endangered or Protected (TEP) | Closures | Temporal | | X | | | | | | | | X | X | | | | | | | |
| | | Spatial | X | | | X | | | | | | | | | X | | X | | | |
| | Gear Restrictions | Number | | | | | | | | | | | | | | | | | | |
| | | Size | | | | | | | | | | | | | | | | | | |
| | | Add-Ons | X | | | | | | | | | X | X | X | X | | | | | |
| | Other | Move-On Provisions | | | | | | | | | | | | | | | | | | |
| Habitat | Closures | Temporal | X | | | | X | | | | X | | | | | | | | | |
| | | Spatial | X | | X | X | | X | | | X | X | X | | | | | | | |
| | Gear Restrictions | Number | | | X | | | | | | | | | | | | | | | |
| | | Size | X | X | X | X | | | | | | | | | | | | | | |
| | | Add-Ons | | | | | | | | | | | | | | | | | | |
| Combination | | Vessel Size | | | | | | | | X | | | | | | X | | | | |
| | | Gear Type | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | | | |

| *Notes:* |
|---|
| [a] Spatial or temporal closures were only applied to target species unless specifically written they were implemented to protect non-target, TEP species and/or habitat. Voluntary closures or closures to prevent gear conflicts (eg: Norway 'Flexible Areas') were not included in the review. |
| [b] Any input controls for trawl relating to gear restrictions (size and number) were assumed to assist in the protection of target, non-target and habitats |
| [c] Any input controls for trawl relating to gear restrictions (add-ons = Bycatch Reduction Devices [BRD]) were assumed to assist in the protection of target and non-target species. |
| [d] The North Sea and North-East Arctic Saithe fisheries in Norway aren't exclusive trawl fisheries but trawling makes up the majority (78% in the North Sea and 40% in the North-East Arctic) of the national landings compared to other gears [71] |
| [e] In Australia, the Southern and Eastern Scalefish and Shark Fishery (SESSF) includes three sectors - the Commonwealth Trawl Sector (CTS), Gillnet Hook and Trap Sector (GHATS) and Great Australian Bight Trawl Sector (GABTS). Within the GHATS there is a scalefish hook sector, a shark hook/gillnet sector and a fish trap sector. |
| [f] The Sablefish Fishery in Canada isn't an exclusive pot/trap fishery but traps makes up the majority (60% in 2007) of the national landings compared to other gears (Furness et al., 2010). |
| [g] Any input controls for pot/trap relating to gear restrictions (size and number) were assumed to assist in the protection of target and non-target species. |
| [h] The MSC accreditation covered only those vessels part of the Producer Organisations of Dutch gillnet fishery for sole who comply with the Sole Gillnet Local Management Plan (44 out of around 60). The review reflects the input controls regulating these fishers only. |
| [i] Any input controls for gillnets relating to gear restrictions (size and number) were assumed to assist in the protection of target and non-target species |
| [j] The Spring-Spawning Herring and North Sea and Skagerrak fisheries in Norway aren't exclusive purse-seine fisheries but purse-seineing makes up the majority (57% in Spring-Spawning and 86% in North Sea) of the national landings compared to other gears (Piling et al., 2008). |

Both gillnet fisheries had input controls regulating mesh size and total net length with the Dutch sole gillnet fishery also regulating maximum number of nets. Because the Dutch sole gillnet fishery takes place in the North Sea it is also managed by the European Commission (EC), which restricts the number of days at sea (Southall et al., 2009). The fishery also had a spatial closure in place to manage bycatch of plaice but there were no management measures for TEP species or habitat. In comparison, the gillnet sector of the GHATS in the SESSF had 16 spatial closures to protect breeding populations of school shark (target species), stocks of deepwater sharks, snapper and mulloway (non-target species) and breeding populations of Australian sea lions and great white sharks (TEP species) (AFMA, 2010d).

Purse-seine fisheries had the least amount of input controls of all fishing methods reviewed. There were no input controls regulating the Australian southern bluefin tuna fishery (AFMA, 2010a) and only a temporal closure managing the target species in both the Norwegian spring-spawning and North Sea/Skagerrak herring fisheries (Pilling et al., 2009b; Pilling et al., 2009a).

### *2.4.2 Case studies examining the recent use of input controls within reviewed fisheries*

A diversity of top-down management or input controls continue to be used in ITQ fisheries that have been certified as sustainable under various accreditation systems. Although this review cannot ascertain with certainty that ITQ fisheries are increasingly using input controls to manage EBFM targets, recent policy and management measures within ITQ fisheries to ensure protection of ecosystem components suggests increasing use, especially widespread temporal or spatial closures.

For example, widespread set net (eg. gillnets) and trawl spatial closures, which impact on the hoki fishery, were implemented in 2008 by the New Zealand Ministry of Fisheries (MFish) to mitigate adverse fishing impacts on Hector's and Maui's Dolphins (Baker et al., 2002). Since the early 1970s, Hector's dolphins have been incidentally caught during gillnet and inshore trawl fisheries with research estimating there were only 7,270 South Island Hector's dolphins and 111 Maui dolphins remaining in the wild in 2007, which is equivalent of 27% of the population size in 1970 (Slooten, 2007). Fishing is the dolphin's greatest known threat with population viability studies in 2007 suggesting that if protected areas were not expanded dolphin populations would continue to decline to 5,475 individuals by 2050 (Slooten, 2007). Consequently, MFish responded with *inter alia* controversial spatial closures to prohibit and restrict trawling and set netting in areas around the North and South Islands, and a ban on drift netting in the Waikato River (MFish, 2010).

Similarly in Australia, significant spatial closures were introduced in 2010 by the Australian Fisheries Management Authority (AFMA) to reduce the risk of Australian sea lion mortality during shark gillnet fishing. The Australian sea lion (*Neophocoa cinerea*) is Australia's only endemic seal species, with evidence suggesting the overall population is highly depleted relative to pre-European colonisation of Australia (Goldsworthy et al., 2010). Of the 76 known breeding areas (colonies), 48 occur in South Australia where the species is most numerous (Goldsworthy et al., 2010). Scientists believe that the shark gillnet fishery of the GHATS poses as one of the Australian sea lions greatest threats because it is a year-round fishery with relatively high fishing effort, can affect all seal age classes and its fishing effort almost completely overlaps with seal foraging effort off South Australia (Goldsworthy et al., 2007). Population viability studies have suggested that the majority of sea lion colonies (which vary in vulnerability) are exposed to unsustainable levels of bycatch mortality, resulting in probable range declines and subpopulation extinction, with an estimated 374 mortalities occurring each breeding cycle (17.5 months) (Goldsworthy et al., 2010). Consequently, AFMA developed an *Australian Sea Lion Management Strategy* in 2010, which *inter alia* introduced widespread spatial closures covering a total of 6,300km$^2$ around all 48 colonies, with the size of individual closures around each colony varying according to risk (AFMA, 2010b).

Still in Australia, the nomination of three species of deepwater dogfishes (or gulper sharks) for listing as threatened under the EPBC Act prompted AFMA to develop a *Upper-Slope Dogfish Management Strategy* in 2010. These three species of gulper shark: Harrison's dogfish (*Centrophorus harrissoni*), Endeavour dogfish (*Centrophorus moluccensis*) and Southern dogfish (*Centrophorus zeehaani*), typically inhabit the upper-slope habitats of the ocean (200-650m) and interact with multiple fishery sectors in the SESSF, including the CTS and scalefish hook sector of the GHATS (Wilson et al., 2009). A comparative review to support management options reported substantial declines of greater than 90% in populations of these and other gulper sharks over the past several decades, predominately attributable to persistent fishing in the SESSF (Wilson et al., 2009). Given the historical decline in population size and low resilience of gulper sharks to overfishing, AFMA developed a management strategy in early 2010 with a stepwise implementation. A new daily catch limit of 15kgs (with a total trip limit of 90kgs for extended fishing trips) and two new closures to trawl fishing off Western Australia and to all fishing methods on two seamounts off New South Wales have already been implemented (AFMA, 2010e). Further closures are planned but are dependent on the outcomes of a federally funded research project mapping gulper shark distribution and movement, with the outcomes due by the end of 2010.

In Canada, the serial depletion of some species of rockfish *Sebastes* spp. including the inshore quillback rockfish (*Sebastes maliger*) and yelloweye rockfish (*Sebastes ruberrimus*) led to the formation of a conservation strategy in 2002 by the Department of Fisheries and Oceans Canada (DFO). Rockfishes (particularly quillback and yelloweye) have been intensively fished off British Columbia since the 1970s and managed by DFO as two areas - the "inside" or protected waters east of Vancouver Island and areas "outside" these coastal waters (Yamanaka and Logan, 2010). Due to the nature of their life history traits and historically poor management across a range of groundfish fisheries (e.g. halibut, cod, rockfish) that target and incidentally catch rockfishes, their populations declined, particularly in "inside" areas around Vancouver Island (DFO, 2009; Marliave and Challenger, 2009). The introduction of fishing use rights did not arrest this decline and consequently DFO developed a conservation strategy in 2002, which aimed to account for all rockfish catch, decrease fishing mortality, establish closed areas and improve stock assessment and monitoring. This was achieved primarily through two initiatives, (i) the commercial groundfish integration pilot program in

2006, which ensured all groundfish species were managed by ITQs with 100% at-sea and dockside monitoring and; (ii) the creation of 164 rockfish conservation areas, which were closed to predominately line fishing methods in 2004 and 2007. The total area closed is around the target of 20% for outside areas and 30% for inside areas, with further closure initiatives now underway in the outside areas (Yamanaka and Logan, 2010).

These case studies are all recent examples of negative bycatch externalities managed through targeted fishery closures. In this case there is a clear link between the identified threat and response. As the focus has shifted towards EBFM, there is an increasing attempt to manage negative habitat externalities (and to some extent negative bycatch externalities) both directly through fishery closures and indirectly through the imposition of broad-based MPAs as part of holistic ocean policies. For example, in 2000 the New Zealand government released its *New Zealand Biodiversity Strategy* with aim of developing a policy on MPAs and having 10% of New Zealand waters to the outer edge of the EEZ in some category of MPA by 2010. The objective of the New Zealand MPA policy is to protect biodiversity and this has been linked to the establishment of a comprehensive and representative network of MPAs, with implementation expected to commence in waters beyond the territorial sea from 2013 (Helson et al., 2010). Similar policies on MPAs have also been adopted and implementation commenced over the last decade in Australia (Baelde, 2005), Canada (Parsons, 2005; Guénette and Alder, 2007) and Norway (The Norwegian Ministry of Fisheries and Coastal Affairs, 2010). The increased use of MPAs as part of national ocean policies is of interest to this study because of the potential for larger impacts on fishing businesses than could be achieved by more targeted management. This issue is addressed in some cases, for example in the U.S. with the continued use of non-bottom contact gear within some MPAs (Hourigan, 2009).

## 2.5 Discussion

### *2.5.1 Structural inflexibility in quota management systems*

The results of this review and the case studies indicate that input controls are used in conjunction with output controls to manage ecosystem components across a range of ITQ fisheries certified as sustainable under various accreditation systems. The continued use of input controls may be a result of inherent structural inflexibility and associated costs of incorporating and maintaining non-target species within quota management systems.

To support this argument, this section will briefly explore the theory of structural inflexibility in quota management systems such as ITQs leading to the increased use of input controls to meet EBFM targets. Established ITQ systems are inherently inflexible to modification (Copes, 1986; Copes and Charles, 2004; De Young, 1999) with in-season adjustments to TAC limits and alterations to an existing allocation to incorporate new scientific data (such as stock structure) time consuming, costs prohibitive and labour intensive. For example, there is scientific evidence supporting regionalised stocks for a variety of SESSF species in Australia managed under a single TAC and ITQs (Slope Resource Assessment Group, 2009). Currently, stock assessments are conducted for each distinct stock and then recommended biological catch limits combined to form a single TAC. Due to varying levels of depletion between some distinct stocks, AFMA is obliged to introduce quasi-TACs[7] with associated trigger limits and input controls. As the reallocation of quota is a time-consuming and costly process, the SESSF industry had opposed it until their efficiency and hence profitability was reduced by the introduction of quasi-TACs and input controls. Consequently AFMA is now exploring options to reallocate ITQs among these stocks. Similarly, regional management of the Tasmanian Rock Lobster Fishery in Australia has been resisted despite substantial spatial variations in growth, recruitment and abundance (DPIPWE, 2009). Splitting the ITQ system between regions is not considered practical or cost-effective by the management authority so spatially distinct input controls are being contemplated (DPIPWE, 2009).

The increased emphasis on EBFM over the last two decades has highlighted the need for tangible, efficient and cost-effective management to address ecosystem components. This will require fisheries managers to be flexible and resourceful in implementing mitigation measures to meet a variety of EBFM targets. The inflexibility of ITQ systems to modification makes it difficult to achieve these goals through sole output-based management. This is not to say that it hasn't occurred, as examples include: the arrow squid fishery in New Zealand, which uses bycatch quotas for sea lion interactions (Diamond, 2004); the Alaskan demersal longline fishery, which uses quotas to manage interactions with the endangered short-tallied albatross (Witherell et al., 2000); and groundfish fisheries in British Columbia, which use individual bycatch quotas for prohibited species (Diamond, 2004). Currently there are no examples of output-based management controls being used to manage habitat degradation although they have been proposed

[7] A quasi-TAC in this context is not recognised or enforceable through legislation but a target for the fishery.

(Holland and Schnier, 2006; Holland, 2007). The major drawbacks of this approach include the incorporation and maintenance costs, such as increased requirements for scientific information to set defensible quotas for non-target species, which are usually cost prohibitive (Gibbs, 2008). Additionally, bycatch interactions are largely unpredictable and spatially and temporally segmented, especially for TEP species, which weakens the justification for fleet-wide quota management throughout the fishing season. Therefore while it is possible to include certain ecosystem components such as bycatch species into the quota management system the inherent initial inflexibility and associated incorporation and maintenance costs justify to some extent the continued and increasing use of input controls to manage for EBFM targets.

### *2.5.2 Consequences of input control use in ITQ fisheries*

The ramifications of an increased use of input controls (predominately spatial closures) within ITQ fisheries is that the "security" characteristic of the use right may be weakened. This has the capacity to diminish the overall incentive structure of fishers towards environmental stewardship and disjoint their fishing behaviour with societal objectives. An ITQ is a use right, which contains an intrinsic spatial access component (Gibbs, 2007) that is potentially undermined through input controls (Yandle, 2007). The cumulative effect of increasing numbers of fishery closures and national networks of marine protected areas to manage ecosystem components *inter alia* is the displacement of fishing from historical (sometimes prime) fishing areas, increasing the variable costs of fishing and reducing overall profitability. The displacement of effort to fishing areas that remain open can increase the propensity for localised depletion of stocks, and reductions in the overall TAC (Yandle, 2007). In reducing fleet profitability or diminishing the security and certainty of rights, fishers will have less incentive to manage for future profits and incorporate ecosystem components into quota management systems.

Given that stewardship involves modification of human behaviour, the fisher's perception of the strength of their fishing use right is important. Increasing "command and control" approaches to management undermines industry trust and re-establishes perverse incentives against sustainability because fishers are less confident about their ability to receive the future long-term benefits from present conservation strategies. In other words the security element of the fishing use right is reduced. This could be more of an issue now, than in the past because many ITQ fisheries are characterised by a greater proportion of lease fishers than owner/operators who lease in available quota each fishing season (Pinkerton and Edwards, 2009; van Putten and Gardner, 2010). These fishers may have less incentives to support long-term sustainability because they do not necessarily share in the long-term benefit of rebuilding or protecting stocks (Bradshaw, 2004a; Yandle, 2007) and are normally characterised by the need to cover fixed debt costs (Bromley, 2005).

It is probable that non-selective fisheries that have the propensity to interact negatively with a range of ecosystem components will be more affected by these scenarios than selective fisheries such as purse-seine and pot/trap. While it may be fishery specific, other factors including: the importance of fisheries to the national economy, the level of public concern for ecosystem components, available governmental funding for fishery displacement programs and the period of time and resources available for fisheries management to respond may change the outcome(s).

## 2.6 Conclusion

It is generally accepted that the introduction of ITQ management assists in reducing fleet overcapitalisation and promoting an increase in economic rent. However it is less clear whether ITQs assist in meeting progressive EBFM targets. When ecosystem components such as bycatch species are not included in the ITQ system, fishers do not have a direct incentive to modify their behaviour to avoid harmful interactions with them because it doesn't directly affect their asset value or ability to successfully catch target species. This issue is compounded in ITQ fisheries where different people own the use right and catch the fish.

The extent to which input controls are being used in certified ecologically sustainable ITQ fisheries varies across fishing method. Non-selective fishing methods such as trawl, gillnet and line are managed by greater a number of input controls than purse-seine, pot/trap and dredge fisheries. Further case-studies confirmed the widespread and recent use of input controls (spatial closures) in an attempt to manage non-target and TEP species interactions. Concurrently, many developed countries with ITQ fisheries are implementing fisheries spatial management to protect benthic habitats, while also developing overarching networks of marine protected areas with the presumption that these assist in protection of ecosystems.

The political imperatives of fisheries management are changing as increased numbers of stakeholders and consultation processes place greater expectations on conserving and utilising ecosystem components. The complex nature of output control allocation, implementation and then maintenance, is likely to favour the introduction of input controls to address EBFM issues rather than modification of the existing output control system. Furthermore, interactions with non-target, TEP species and habitats are usually spatially and temporally segmented and may be more appropriately managed by input controls.

The increasing use of spatial and temporal fishing closures in ITQ fisheries erodes the security characteristic of the fishing use right through loss of access to parts of the resource. Reductions in the strength of the security element have the potential to reduce alignment between industry incentives and societal objectives for sustainability because fisher confidence in receiving the future benefits is eroded. This could be even more apparent in ITQ fisheries with a large proportion of lease fishers and a clear division between capital and labour with differing incentives. Input controls generally involve "command and control" style management which undermines industry trust and are often are perceived to reduce profitability. Conversely, it is equally clear from this review and others that ITQ systems are insufficient to ensure the sustainability of non-target and TEP species and achieve the environmental objectives of EBFM (Gibbs, 2008; Gibbs, 2010; Gibbs, 2007; Smith et al., 2009). This is not surprising given that ITQs were historically introduced to manage fishing effects on target species. Given the importance of ensuring the sustainability of all ecological components under an EBFM policy framework it is likely that competing objectives (such as ensuring the strength of property right incentives is maintained) will need to be balanced through a combination of different management instruments (Gibbs, 2010; Smith et al., 2009).

Further exploration of management options is warranted given the challenges in both meeting EBFM objectives and protecting the security characteristic of the fishing use right in output control fisheries. A developing area is the incorporation of ecological components into market-based management systems. Spatial closures pose special problems due to displaced effort and exclusion from preferred grounds. These have been addressed by compensatory payments to displaced fishers or government funded structural readjustment packages. Ecological offsets are another developing area where fishers finance alternative sustainability actions to counterbalance their impact on specific ecological components.

# Chapter 3: Does “race to fish” behaviour emerge in an individual transferable quota fishery when the total allowable catch becomes non-binding?

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## 3.1 Abstract

Successful individual transferable quota (ITQ) management requires a binding (constraining) total allowable catch (TAC). A non-binding TAC may result in a shift back towards open access conditions, where fishers increasingly compete ("race") to catch their share of the total harvest. This process was examined by comparing fishing fleet behaviour and profitability in the Tasmanian southern rock lobster fishery (TSRLF), Australia. Between 2008 and 2010 the TSRLF had a non-binding TAC and effectively reverted to a regulated limited entry fishery. Fishers' uncertainty about future profitability and their ability to take their allocated catch, weakened the security characteristic of the ITQ allocation. The low quota lease price contributed to an increase in fleet capacity, whilst the more limited reduction in quota asset value proved a barrier to investment, hindering the autonomous adjustment of quota towards the most efficient fishers. In the TSRLF, catch rates vary more than beach price and are therefore more important for determining daily revenue (i.e. price x catch rate) than market price. Consequently, fishers concentrated effort during times of higher catch rates rather than high market demand. This increased the potential for rent dissipation as fishers engaged in competitive race to fish to be the first to exploit the stock and obtain higher catch rates. The history of this fishery emphasises the need for a constraining TAC in all ITQ fisheries, not only for stock management, but also to manage the security of the ITQ allocation and prevent unanticipated and undesirable changes in fisher behaviour and fishery profitability.

## 3.2 Introduction

Open access fisheries resources are sub-tractable and non-excludable. In other words, resources harvested by one person are not available for another to harvest and it is difficult to exclude people from using the resource (Ostrom et al., 1994; Acheson, 2006). The behavioural incentives under open access are for fishers to maximise revenue by being the first to harvest the fish and to discount any conservation ideals because the benefits do not directly accrue to them (Fujita and Bonzon, 2005; Leal, 2005). While this is economically rational behaviour it is collectively disastrous (Acheson, 2006). With an incentive to catch their share of the harvest first and gain a competitive advantage over their counterparts, fishers are motivated to invest in additional fishing inputs (e.g. larger boats, improved fish detection technology). Such investment however will only alter the division of economic returns among operators, not increase the total returns to the fishery (Grafton, 1996). In the long-term, any innovation that produces a competitive advantage for an individual would be similarly adopted by others, resulting in a cycle of increased fishing costs, resource degradation and dissipation of economic profit (Wilen, 2005; Wilen, 2006). This has been termed the "race to fish" and creates a number of inefficiencies, which are described in Table 3.1, including: overcapitalisation of the fishing fleet, gear conflict among fishers, hazardous fishing practices at-sea, reduced market value of catch and discounting of conservation principles.

Individual transferable quota (ITQ) management attempts to remedy these inefficiencies by altering the incentive structure and therefore behaviour of fishers from maximising catch and discounting conservation ideals to maximising value and practicing resource stewardship (Fujita et al., 1998; Fujita and Bonzon, 2005; Grafton et al., 2006). Under an ITQ management system, fixed proportions or shares of the TAC are allocated to individual fishers, enterprises or vessels as quota units, which can be freely traded or leased. ITQs are not a full private property right but a use right (hereafter termed ITQ allocation). While fishers can decide when and how to use the quota units, they do not own the resource itself, and cannot decide how much of the resource can be harvested in aggregate (Criddle and Macinko, 2000). While ITQs have been controversial (see Copes, 1986; McCay, 1995; Symes and Crean, 1995; Bromley, 2005; Bromley, 2009) they have been largely effective in eliminating the race to fish inefficiencies (see Table 3.1 for some examples) and have been introduced in over 121 fisheries in at least 18 countries (Costello et al., 2008; Chu, 2009).

The effectiveness of ITQ management in modifying behaviour is based on having effective governance (Hanna, 1999), a strong monitoring, control and surveillance (MCS) system in place (Parslow, 2010) and most importantly, a binding (constraining) total allowable catch (TAC) set by the managing authority (Kompas et al., 2009). If the TAC is excessive it can inhibit the sustainability and economic efficiency of an output controlled fishery. For example, TACs set in the northern zone of the South Australian rock lobster fishery between 2003-2007 did not constrain the catch (i.e. non-binding), resulting in an increase in effort by 11% (between 2004-2007) and decline in the catch per unit effort (CPUE) by 28% (between 2002-2007) (Linnane et al., 2010a; Linnane et al., 2010b). Multispecies TACs were rarely binding in the Australian Commonwealth south-east trawl fishery, with some as low as 30% over the period 1992-2005. This lead to an increase in fishing effort, a decline in the total value of the catch and an increase in the number of species classified as overfished (Elliston et al., 2004; Kompas et al., 2009). For many jointly managed fish stocks in Europe, TACs were consistently set higher than scientific advice due to the collective-bargaining nature of decision-making among countries, increasing the probability of stock collapse (O'Leary et al., 2011).

A non-binding TAC can have serious ramifications for the biological sustainability, economic efficiency and profitability of an ITQ fishery. Consistently non-binding TACs can result in effort gravitating back to the open access equilibrium and re-impose race to fish behaviours as the fishery effectively operates as a regulated open access or limited entry fishery (Kompas et al., 2009). A non-binding TAC can also increase uncertainty, as fishers are less confident in their ability to take their allocated catch each season and in the fishery's future outlook. This weakens the security characteristic of the ITQ allocation, misaligning the incentive structure theoretically regulating individual behaviour and increasing a fisher's inherent discount rate (Emery et al., 2012).

Investigating the extent to which these race to fish behaviours re-emerge was the impetus for this analysis using the Tasmanian southern rock lobster fishery (TSRLF) in Australia as a case-study.

The TSRLF is a single species fishery targeting southern rock lobster (*Jasus edwardsii*), which is considered the premium of Australia's lobsters (Bradshaw, 2004b). The fishery is an important contributor to the Tasmanian economy, with a revenue of $65.2 million in 2009/2010 (ABARES, 2011) and an estimated 700 people directly employed in the commercial rock lobster fishing, processing and handling sectors in 2006/2007 (van Putten and Gardner, 2010). ITQ management was introduced in 1998 and all quota units were allocated to active fishers based on lobster pot ownership, with a minor share of the quota allocation based on catch history (Hamon et al., 2009). There are currently 312 licences and 10,507 quota units in the fishery and fishers must own at least one and hold a minimum 15 quota units to go fishing. To limit the concentration of ownership there is a maximum limit of 200 quota units.

Hamon et al., (2009) provide a comprehensive assessment of fishing fleet behaviour and profitability in the TSRLF following the institution of ITQs in 1998 until 2006. Substantial stock rebuilding followed the introduction of ITQs, with catch rates increasing and the number of vessels and amount of effort (potlifts) required to catch the binding TAC declining in the first decade of management (Gardner et al., 2011). In subsequent years this pattern reversed, the CPUE declined, fishing effort increased and the TAC became non-binding between 2008 and 2010 (Linnane et al., 2010a; Gardner et al., 2011). The non-binding TAC was caused by: (i) large-scale environmental factors causing an unprecedented and unanticipated period of poor growth of the legal sized stock and recruitment of new lobsters (Linnane et al., 2010a) and; (ii) market failure caused by imperfect information, which led sellers to place too high a value on quota units each season, consequently, not all quota units were leased (Gardner, personal communication). In 2008 the TAC of 1,523 tonnes was under-caught by 33 tonnes (97%) and effort was 14% higher than in 2005. This led to the regulatory authority reducing the TAC in 2009 to 1,470 tonnes and again in 2010 to 1,323 tonnes. However, the TAC remained under-caught by 116 (92%) and 124 tonnes (91%) in 2009 and 2010, using 18% and 19% more effort respectively than in 2005.

By analysing fishing fleet size, efficiency and profitability over the period 2001-2010, the TSRLF provided a unique case-study for examining whether race to fish behaviour emerged in an ITQ fishery when the TAC was non-binding. This study found that changes in fishing fleet behaviour and profitability were evident when the TAC was non-binding in the TSRLF. Fleet capacity increased through the reactivation of latent effort and reduced market value of quota. The low price of quota on the market (theoretically zero, as supply exceeded demand) also proved a barrier to investment and hindered the autonomous adjustment of quota towards the most efficient fishers. In an attempt to increase revenue, fishers engaged in a competitive race to fish during times of higher catch rates rather than high market demand increasing the potential for rent dissipation. These changes in behaviour resulted in the fishery effectively reverting to a regulated limited entry fishery in the years when the TAC was non-binding. The results of this study highlight the importance of a constraining TAC for all ITQ fisheries to prevent unanticipated and undesirable outcomes in fisher behaviour and fishery profitability.

## 3.2 Methods

### *3.3.1 Data*

In order to assess fishing fleet behaviour and profitability in the period 2001-2010, fishery data was collated. Fishery data containing information on rock lobster vessels, quota holdings, beach price and catch and effort are compiled in several databases, which are maintained by the Department of Primary Industries, Parks, Water and Environment (DPIPWE), Tasmanian Government. Catch and effort data are derived from the compulsory rock lobster logbook, which was used to examine CPUE, spatial and temporal effort allocation and catch per fisher and vessel. Beach price data was derived from processor records, which provided the monthly amount and price of rock lobster purchased from fishers. All price data was adjusted to account for inflation (i.e. deflated) using the Australian consumer price index with March 2011 used as the reference period in time. The amount of quota owned in each year was derived by subtracting quota units leased in and/or adding quota units leased out from quota held at the end of the fishing season.

### *3.3.2 Rationalisation of fishing fleet*

The length (m) and GRT of each vessel were used to analyse the evolution of the fleet between 2001 and 2010. Under an ITQ management system rationalisation is supposed to occur as more efficient fishers purchase quota from non-efficient fishers. The fishing fleet was divided into three length categories following Hamon et al. (2009). For those vessels with missing GRT values an average was used of all vessels in that length category for that quota year.

A Pearson's chi-squared test ($X^2$) was used to evaluate whether the observed number of new vessels in the bottom 10%, 20% and 40% of total catch and CPUE differed from the rest of the fleet. New vessels were classified as those that fished in either 2008, 2009 and/or 2010 but not in either 2006 or 2007.

**Table 3.1:** Inefficiencies caused by open access with respective examples and how individual transferable quota management attempts to correct them to improve efficiency

| **Open access inefficiencies** | | **ITQ efficiencies** | |
|---|---|---|---|
| **Description** | **Example(s)** | **Description** | **Example(s)** |
| (i) *Overcapitalisation of the fishing fleet* caused by additional entrants and fishers investing in excessive inputs in order to increase fishing power. | The number of active vessels in the Alaskan halibut and sablefish fisheries increased from 2,744 and 371 in 1985 to 4,206 and 822 in 1990 respectively (Hartley and Fina, 2001). | (i) *Transferability of quota units* encourages less efficient owners to sell their quota to more efficient owners, reducing overcapitalisation of the fishery (Copes, 1986). | In the Alaskan halibut and sablefish fisheries, the number of vessels participating in the fisheries declined by more than one half and two-thirds respectively after the fifth year of ITQs (Hartley and Fina, 2001). |
| (ii) *Competition, gear conflict and loss* caused by the inability to exclude others from accessing the resource at the same spatial and temporal scale. | In the Atlantic wreckfish fishery, the rapid pace of fishing intensified conflicts among fishers fishing relatively small fishing grounds (Gauvin et al., 1994). | (ii) *Durability and security of catch shares* allow fishers to determine their most economical configurations of equipment and manpower to harvest their quota units (Copes, 1986; Symes and Crean, 1995) reducing the amount of gear set (and lost) and crowding on fishing grounds (Hartley and Fina, 2001). | In the Alaskan Halibut fishery, fish mortality due to lost or abandoned gear declined from 554.7 metric tonnes in 1994 to 125.9 metric tonnes in 1995 following the introduction of ITQs (National Research Council, 1999). |
| (iii) *Reduced market value* caused by condensed temporal fishing opportunities inhibiting the ability of | In the Atlantic wreckfish fishery the rapid pace of landings in 1990 produced record low prices, as markets | (iii) *Durability and security of catch shares* allow fishers to maximise value by increasing the quality of product | Following the implementation of ITQs in the TSRLF, fishers increased the proportion of effort allocated to winter |

| | | | |
|---|---|---|---|
| fishers to distribute their effort according to market-based incentives | were not able to absorb the quantity of wreckfish available in such a short period of time (Gauvin et al., 1994). | through improved handling, adding value to the product, changing product form (frozen to fresh), or fishing when market prices are high (Branch et al., 2006). | months when the price was higher and fished in shallower water, where the lobsters were more likely to be completely red in colour, fetching premium prices (Hamon et al., 2009). |
| (iv) *Hazardous fishing practices and reduced safety at sea* caused by condensed temporal fishing opportunities accompanied with incentives to catch fish as quickly as possible. | In the period 1991-1996 the annual fatality rate of Alaskan commercial fishers was 140/100,000 full-time equivalent fishermen which was 28 times the average annual fatality rate for all workers in the U.S (Lincoln and Conway, 1997). | (iv) *Durability and security of catch shares* allows flexibility in temporal effort allocation, allowing fishers to give greater consideration to weather conditions, vessel condition or other safety factors in deciding whether to fish (Criddle and Macinko, 2000). | Following the institution of ITQs in the Alaskan Halibut fishery, search and rescue missions for Halibut fishers decreased by 63% (National Research Council, 1999). |
| (v) *Lack of conservation ethic* caused by the inability to extract any individual benefit from current conservation actions in the future. | In the New England Groundfish Fishery fishers constantly opposed catch restrictions (and consequent stock rebuilding) because the costs and benefits of such action would not be equally apportioned among all licence holders (Hilborn et al., 2005a). | (v) *Durability and security of catch shares* allows the future resource productivity to be capitalised in the value of quota units. This ensures fishers have an interest in ensuring the value of their asset (quota unit price) remains protected through sustainable management of the fishery (Hannesson, 2005; Brady and Waldo, 2009). | In the New Zealand east coast rock lobster fishery, industry successfully requested that the regulator lower the commercial catch to rebuild the stock and to restrict harvesting to a shorter winter period to improve the detection of illegal fishing activities (Breen and Kendrick, 1997). |

Changes in the concentration of held and owned quota among fishers was examined using two indices of concentration: the adjusted Gini Coefficient (GC) and normalised Herfindahl-Hirschman Index (HHI). These indices are commonly used in economics to measure inequity in wealth distribution and in this application provided a measure of concentration in quota holdings and ownership among fishers, which was previously used by Stewart and Callagher (2011) and Connor (2001) for New Zealand fisheries.

The GC is a relative measure of inequality (Gini, 1912) and provides a numerical gauge of the shape of a distribution plotted as a Lorenz curve (Lorenz, 1905) and how far it departs from perfect equality (Smith, 1990). In this study, the GC ranges from zero to one, with zero representing equal concentration (i.e. all fishers own an identical number of quota units) and one representing total concentration (i.e. a single fisher owns all quota units). On the Lorenz curve equal concentration among fishers would be represented by a 45° line. As the number of quota units owned by fishers becomes increasingly concentrated, the line becomes more concave (Seekell, 2011) or log-normal (Smith, 1990).

The GC for each quota year was calculated as follows:

$$\text{Gini} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\left|X_i - X_j\right|}{2N^2\overline{X}}$$

Where $x_i$ *is* an observed value, $N$ is the number of observer values and $\bar{x}$ is the mean value. The GC for each quota year was then multiplied by n/(n-1) to correct for small sample bias (Deltas, 2003) as follows:

$$\mathrm{Gini}_N = \mathrm{Gini}\frac{N}{N-1} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\left|X_i - X_j\right|}{2N\overline{X}(N-1)}$$

The HHI is relative measure of market concentration which sums the squared proportionate shares of all firms. In this study, the HHI ranges from 1/n to one, where n is the number of firms in the market. According to the Horizontal Merger Guidelines issued by the U.S. Department of Justice and the Federal Trade Commission in 2010, a HHI below 0.15 represents an unconcentrated market, a HHI between 0.15-0.25 indicates a moderately concentrated market and a HHI above 0.25 a highly concentrated market (Anonymous, 2010).

The HHI for each quota year was calculated as follows:

$$\mathrm{HHI} = \sum_{i=1}^{N} s_i^2$$

Where $s_i$ is the market share of firm $i$ in the market and $N$ is the number of firms in the market.

Because the HHI depends on the number of firms in the market the index is not suitable for comparing across different sectors/markets (quota years) with an unequal number of firms (fishers) (Khurshid et al., 2009) The normalised HHI is not affected by the number of fishers competing in the quota market and takes into account the relative size and distribution of quota amongst fishers, approaching zero when a large number of fishers with relatively equal amounts of quota make up the fishery. The HHI increases both as the number of fishers in the quota market decreases and as the concentration in quota held between those fishers increases (Stewart and Callagher, 2011; Khurshid et al., 2009). The normalised HHI ranges from zero to one and is calculated as follows:

$$\text{Normalised HHI} = \frac{(HIH - 1/N)}{1 - 1/N}$$

The objective of using these indices was to examine the change in the concentration of quota distribution (both held and owned) through time in the TSRLF as the TAC became non-binding.

### *3.3.3 Fishing to market*

Effort allocation was analysed through time to examine its effect on the profitability of the fishery. The profit of the fishery is based on the variable costs of fishing trips (i.e. fuel, food, labour), annualised fixed costs (i.e. vessel registration, licence fees) and the revenue generated from fishing. Under an ITQ system fishers will theoretically seek to maximise their profit by reducing their variable costs and increasing revenue. Actual data on variable and fixed costs for the period examined were not available but a value for average total cost per potlift of AUD $30 was available from a previous survey (van Putten and Gardner, 2010).

A profit time series for the TSRLF was generated using monthly total catch multiplied by mean beach price to determine revenue and the monthly total potlifts multiplied by AUD $30 to determine cost. Profit for each quota year was then simply the sum of the monthly revenue minus the sum of monthly cost.

As the stock has become scarce and the TAC non-binding it was expected that fishers would seek to maximise their revenue to offset increased variable costs of fishing. Revenue per potlift is a function of CPUE and beach price. In the TSRLF, CPUE is influenced not only by stock health but management measures such as temporal closures for both male and female lobsters. Beach price is not only influenced by international market demand but the market category of the rock lobster, which is affected by the spatial and temporal parameters of fishing (Hamon et al., 2009).

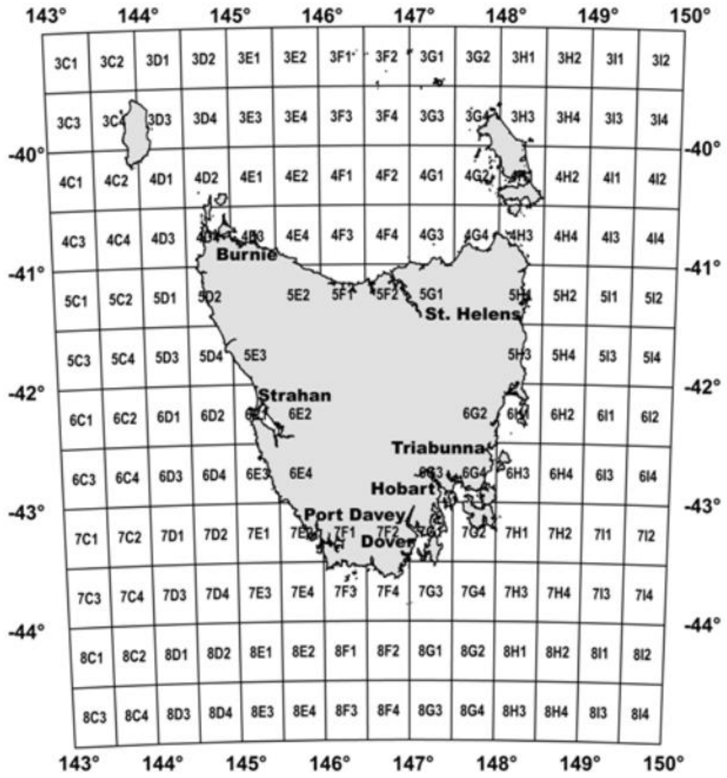
In order to examine whether fishers were responding more positively to revenue in the years when the TAC was non-binding, a general linear regression model on log transformed data was fitted using R (version 2.13.0) (R Development Core Team, 2011) to compare daily effort (number of potlifts) in the fishery when the TAC was binding (2001-2007) to the period when it was non-binding (2008-2010). Variables expected to influence daily effort included: time period (binding or non-binding), fishing block (location) and month (all categorical variables) along with expected catch-per-unit-effort (CPUE), beach price and revenue (all continuous variable). Fishers were anticipated to respond positively to expected revenue (AUD$) under the assumption that they either share information or are knowledgeable about the historical CPUE at particular locations/time periods and/or current beach price for lobster. Expected CPUE for a given day was derived by multiplying the daily total potlifts in each block by the total kilograms of lobster caught for the current day and previous four days (to compute a five-day rolling average). Expected mean beach price was determined by calculating the average price paid weighted by the quantities bought by processors per month State-wide. Expected revenue (AUD$) was then derived by multiplying the monthly mean beach price State-wide by a five-day rolling average of catch-per-unit-effort (CPUE) for a given day in each block fished.

### *3.3.4 Competitive fishing and gear conflict*

The spatial and temporal distribution of fishing effort was analysed to examine how fleet behaviour changed as the TAC became non-binding. Fishing location is recorded in the logbook using one-degree squares (e.g. area 3C), which are then divided into 30'x30' blocks (e.g. block 3C1, 3C2, 3C3, 3C4) as depicted in Figure 3.1 It was at this finer scale that subsequent analyses were undertaken.

The relationship between fishery spatial effort (i.e. number of blocks fished), CPUE and exploitable biomass was analysed using simple linear regression. The concentration of effort (number of potlifts) both spatially (across fishing blocks) and temporally (across months) was analysed using the adjusted GC and normalised HHI as outlined above, to assess the propensity for increased competition and gear conflict among fishers as the TAC became non-binding. In order to examine the prevalence of "racing behaviour" at the re-commencement of the fishing season in November after the temporal closure, a dummy variable was inserted into the general linear model described above. This identified whether a given day was in the first two weeks (14 days) following the re-commencement of the fishing season in November.

**Figure 3.1:** Tasmanian southern rock lobster fishery map with designated 30 x 30 fishing blocks




## 3.4 Results

### *3.4.1 Rationalisation of fishing fleet*

Transferability of quota units theoretically allows for their redistribution to more efficient fishers and a subsequent reduction in fishing capacity. The size of the fishing fleet continued to decline following the imposition of ITQs, from 239 to 203 vessels between 2001 and 2007 (Table 3.2). After the TAC became non-binding however, the size of the fleet increased to 237 vessels by 2010. In the 2010 fishing season, 50 new vessels, which had not fished in either 2006 or 2007 had entered the fishery. These included three vessels with a length of ≤10m, 37 vessels between

10-18m and 10 vessels >18m. The number of pots used by fishers is regulated and varies from 0 to 50, depending on the size and gross tonnage of the vessel. The increasing contribution of vessels >18m to overall gross registered tonnage in the TSRLF (Table 3.3) is probably a reflection of fishers' endeavours to increase their effort by investing in vessels that are authorised to set the maximum number (50) of pots.

**Table 3.2**: Number of vessels in each length class in the Tasmanian southern rock lobster fishery

| Length Class | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| <=10m | 9 | 8 | 7 | 7 | 5 | 4 | 3 | 5 | 6 | 6 |
| 10-18m | 215 | 210 | 209 | 202 | 199 | 193 | 185 | 187 | 200 | 205 |
| >18m | 15 | 17 | 17 | 23 | 20 | 17 | 15 | 18 | 24 | 26 |
| Total | 239 | 235 | 233 | 232 | 224 | 214 | 203 | 210 | 230 | 237 |

**Table 3.3:** Contribution of vessel length classes to total gross registered tonnage in the Tasmanian southern rock lobster fishery

| Length Class | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| <=10m | 1.4% | 1.2% | 0.8% | 0.9% | 0.9% | 0.7% | 0.6% | 0.9% | 0.9% | 0.7% |
| 10-18m | 83.9% | 83.6% | 84.2% | 78.1% | 78.9% | 81.4% | 84.0% | 81.9% | 77.6% | 77.2% |
| >18m | 14.7% | 15.1% | 15.0% | 21.0% | 20.2% | 17.8% | 15.4% | 17.1% | 21.6% | 22.1% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

A total of 57 new vessels fished in either 2008, 2009 and/or 2010 that did not fish in either 2006 or 2007. The number of new vessels taking proportionally small of amounts of catch was significantly higher than expected in 2008, 2009 and 2010 ($p<0.001$) and the number of new vessels with lower CPUE was significantly higher than expected in 2010 ($p<0.001$) but not 2008 and 2009 ($p>0.05$). This suggests that most new entrants are taking small proportions of total catch with low efficiency.

Unrestrictive transferability of quota units theoretically allows for their redistribution to more efficient fishers and an increase in concentration. This occurred in the TSRLF between 2001 and 2007 where concentration increased among licence holders who both held and owned quota units (Figures 3.2 and 3.3). In contrast, after the TAC became non-binding in 2008 the concentration of held quota among licences decreased and the concentration of owned quota stabilised. It should be noted that the number of quota owners declined over the period (2001-2010) from 315 to 312.

The amount of quota held by licence holders at the end of the fishing season is a proxy for catch concentration (Figure 3.2). Both the GC and HHI indicated that concentration increased between 2001 (0.47 and 0.0022) and 2007 (0.55 and 0.0034) before falling to 2010 (0.49 and 0.0028). The slight increase in the HHI in 2010 relative to 2009 is due to one licence holder procuring a sizeable portion of the quota for that season. Because the HHI is more sensitive to distributive changes in the top clients than the GC it consequently increased, while the GC continued to decline. The proportion of catch taken by the top 20% of quota holders was 43.6% in 2001, increasing to 52.4% by 2007 before falling to 48.9% in 2010 (Figure 3.3a). Intensifying resource scarcity has reduced catch concentration in the fishery because: (i) catch is distributed between a greater number of fishers and; (ii) it is more difficult and greater skill is required to catch the same amount as in previous years.

The amount of quota owned by licence holders is used in ITQ fisheries to assess the rate of autonomous adjustment in the fishery. Significant concentration of quota ownership has not occurred in the TSRLF due to the implementation of a rule that limits maximum ownership to 200 quota units. Both the GC and HHI increased slightly between 2001 (0.26 and 0.0007) and 2007 (0.34 and 0.0012) before remaining fairly stable to 2010 (0.35 and 0.0013) (Figure 3.2). The proportion of quota owned by the top 20% of quota owners was 32% in 2001, increasing to 38.3% by 2007 before remaining stable at around 38% for the next three fishing seasons (Figure 3.3b). The presence of a non-binding TAC, which acts as barrier to investment, coupled with the inability of fishers to procure significant amounts of quota has probably stagnated the concentration of ownership in the TSRLF between 2008 and 2010.

**Figure 3.4**: Change in the concentration of owned and held quota units among licence holders in the Tasmanian southern rock lobster fishery throughout the study period. Concentration was measured using both the adjusted Gini Coefficient and normalised Herfindahl-Hirschmann Index

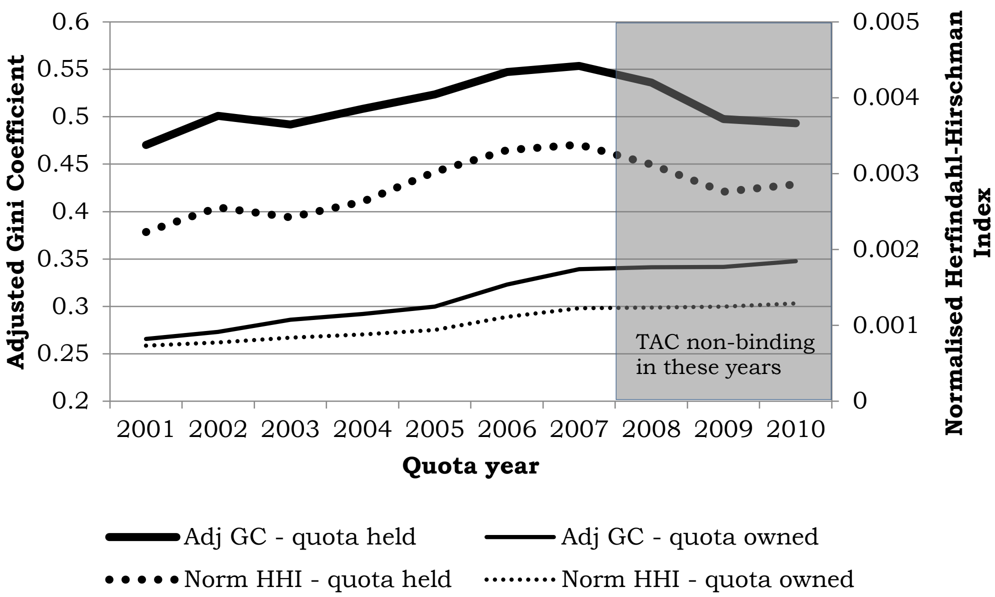
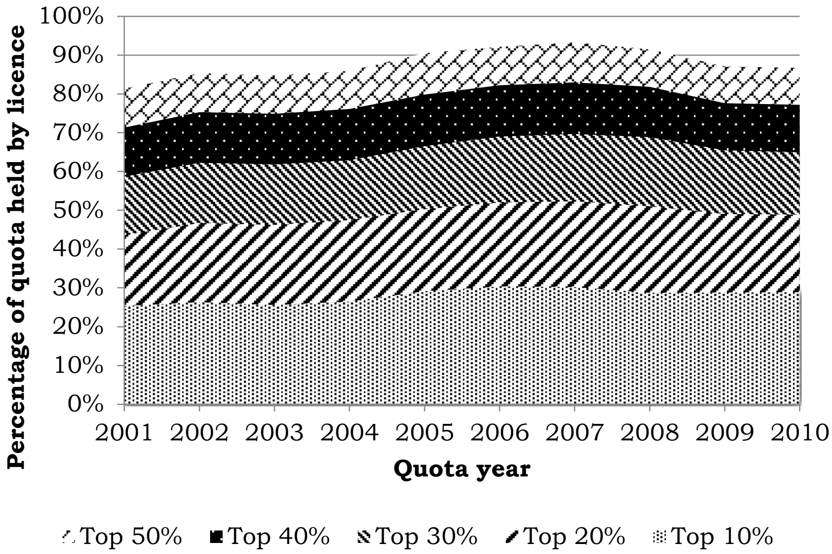
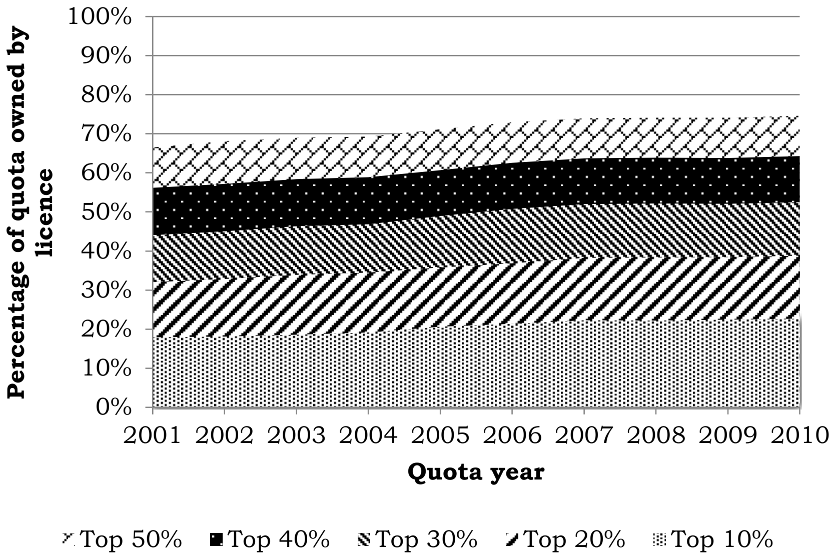


**Figure 3.3a and 3.3b:** Change in the concentration of held [owned] quota units among a percentage of the top licence holders (as in size of quota held [owned]) in the Tasmanian southern rock lobster fishery throughout the study period

**a.**




**b.**



### *3.4.2 Fishing to market*

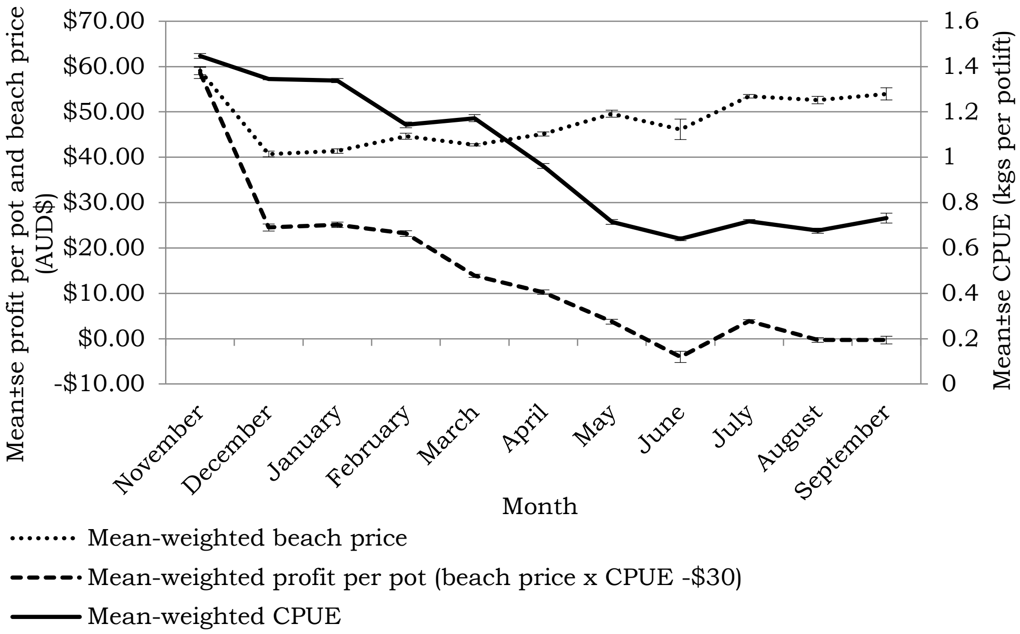
Under an ITQ management system, fishers are expected to target those times of the year with higher profit per potlift (i.e. fishing to market), which is influenced by the CPUE, beach price and costs.

In the TSRLF, there is an historical wide deviation in monthly CPUE caused by the seasonal closures in place to protect female lobsters from 1 May to 15 November and for males from 1 October to 15 November. Furthermore, the re-opening of the fishery in November is characterised by high CPUE caused by newly moulted lobsters recruiting to the fishery (Figure 3.4). CPUE then declines throughout the year with a slight increase in July consistent with a fish-down effect and restricted access to female lobsters from May. Beach price follows an opposite trend, remaining high in November following the re-opening of the fishery, before declining in December and then rising throughout the remainder of the year (Figure 3.4). Because southern rock lobster is an internationally traded commodity, the price received by Tasmanian fishers is unaffected by the amount of the catch landed in the TSRLF (Hurn and McDonald, 1997).

Variations in overall profit per potlift in the TSRLF are due more to fluctuations in CPUE than beach price. Accordingly the daily effort (i.e. number of potlifts) of fishers responded positively to changes in expected CPUE ($0.312 \pm 0.037$, $p<0.000$) and expected revenue ($0.008 \pm 0.001$, $p<0.000$) rather than expected beach price ($-0.006 \pm 0.001$, $p<0.000$) (Table 3.4). In the years when the TAC was non-binding, this effect strengthened as fishers expended significantly more effort on days when expected revenue (CPUE x beach price) was higher than in the years when the TAC was binding.

Fishers expended significantly more effort on days when expected CPUE was high than low and significantly less effort on days when beach price was high. This latter unexpected effect is due to rock lobster fishers fishing more on low beach price days for reasons not captured in this model.

**Figure 3.4:** Variation in CPUE, beach price and profit per potlift by month in the Tasmanian southern rock lobster fishery throughout the study period



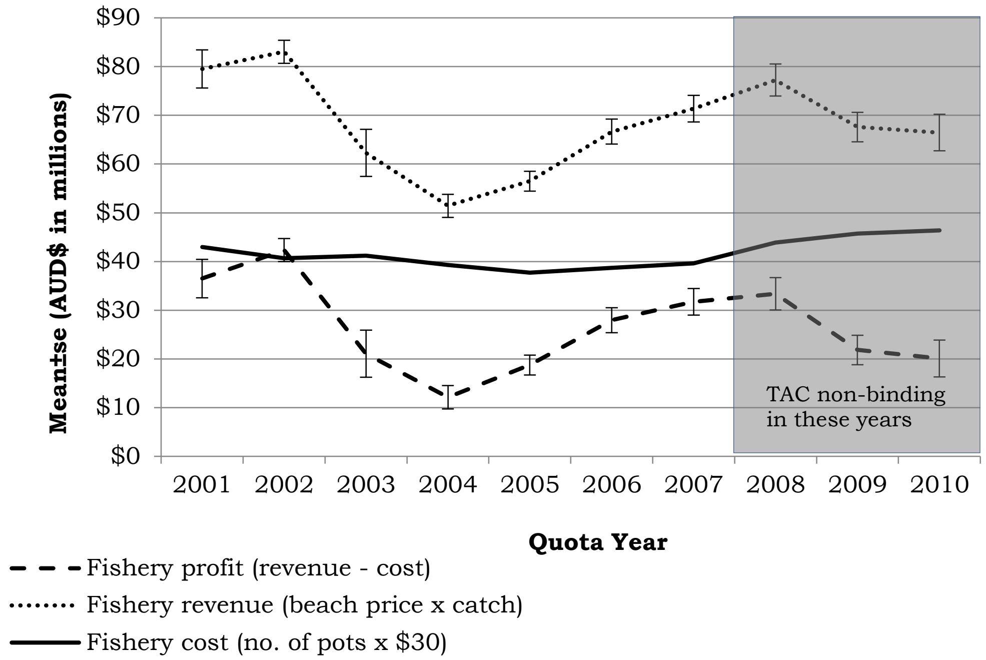

Despite the increased effort on days when expected revenue was higher, the profit of the fishery declined from AUD $33.4 ± 2.2 million in 2008 to AUD $20.1 ± 2.9 million by 2010 due to large-scale declines in recruitment across south-eastern Australia, causing declines in catch rates and overall higher costs of fishing (Linnane et al., 2010a) (Figure 3.5).

**Table 3.4:** Results from the general linear regression model

| | *Without November Racing* | | | *With November Racing* | | |
|---|---|---|---|---|---|---|
| | Coefficient | Standard Error | P value | Coefficient | Standard Error | P value |
| Intercept | 5.2585 | 0.056 | <0.000 | 5.3708 | 0.0572 | <0.000 |
| CPUE | 0.3117 | 0.0373 | <0.000 | 0.2355 | 0.0384 | <0.000 |
| Beach Price | -0.0056 | 0.0009 | <0.000 | -0.007 | 0.0009 | <0.000 |
| Revenue | 0.0084 | 0.0008 | <0.000 | 0.0089 | 0.0008 | <0.000 |
| TAC Binding True | 0.0146 | 0.0209 | 0.4855 | -0.0085 | 0.021 | 0.6866 |
| TAC Binding True : Revenue | -0.0041 | 0.0004 | <0.000 | -0.0034 | 0.0004 | <0.000 |
| Nov Racing True : TAC Binding False | | | | 0.3156 | 0.0361 | <0.000 |
| Nov Racing True : TAC Binding True | | | | 0.1946 | 0.0262 | <0.000 |
| Observations | 41124 | | | 41124 | | |
| Adjusted $R^2$ | 0.4605 | | | 0.4619 | | |

Dependent variable: number of potlifts (effort)
Other significant variables in the model: season, fishing block (area)

**Figure 3.5:** Variation in the Tasmanian southern rock lobster fishery's profit, revenue and costs throughout the study period



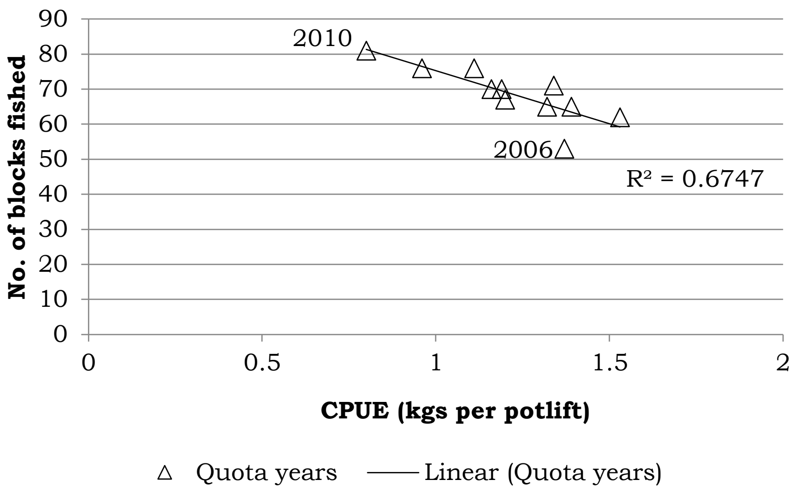

### *3.4.3 Competitive fishing and gear conflict*

ITQ management is supposed to reduce spatial and temporal gear conflict among fishers competing with each other for a greater share of the harvest (National Research Council, 1999).

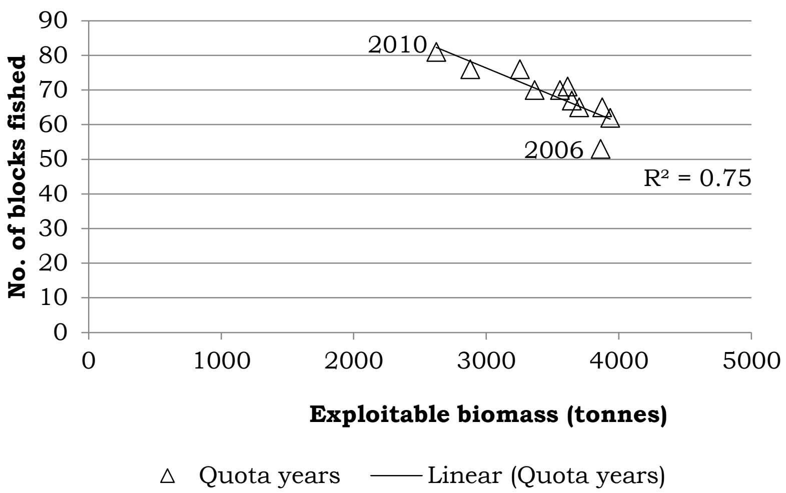
Between 2001 and 2006 the number of blocks fished fell from 70 to 53 as higher catch rates increased fisher spatial selectivity. By 2010 however, the number of blocks fished increased to 81, as fishers expanded effort spatially in an attempt to catch their quota allocation. This trend was reflected in a strong negative correlation between the number of blocks fished and increasing CPUE and/or exploitable biomass between 2001 and 2010 (Figures 3.6a and 3.6b). Relative fishing effort in these new blocks was low, with 26 out of 81 fishing blocks in 2010 having less than 500 potlifts (~10 shots) compared to 11 out of 53 in 2006. This pattern of fishing effort was reflective of explorative fishing, which was probably motivated by lower catch rates in historical fishing grounds.

**Figure 3.6a and 3.6b:** Comparing the relationship between CPUE (kgs per potlift) [exploitable biomass (tonnes)] and number of blocks (30' x 30') fished in the Tasmanian southern rock lobster fishery

**a.**




**b.**



As the TAC became non-binding more blocks were fished with corresponding effort levels reflective of explorative fishing behaviour. This prohibited directly comparing concentration of effort among blocks fished solely each year or month (i.e. n. = variable). This is because any increase in the indices in the years when the TAC was non-binding could be a reflection of a greater number of blocks being fished with small amounts of effort and not an indication of spatial concentration of effort. Therefore all blocks (n. = 101) and just those blocks fished in all years (n. = 44) between 2001 and 2010 were analysed to examine if effort had become more spatially concentrated. Fishing effort had not contracted spatially as the TAC became non-binding (Figure 3.7) but was reasonably stable through time. The GC (measuring concentration among units) indicated for those blocks fished all years that concentration slightly increased from 0.57 in 2001 to 0.62 in 2006 before declining somewhat to 0.59 by 2010. Similarly the HHI, rose from 0.026 in 2001 to 0.033 in 2006 before falling slightly to 0.028 by 2010. Similar patterns were evident for both indices when examining all blocks (Figure 3.7).

While there was no indication that effort became spatially concentrated when the TAC was non-binding, there was evidence suggesting it became temporally concentrated between November and February, which are months characterised by higher catch rates and revenue per potlift. As depicted in Figure 3.8, between 2006 and 2010, fishing in summer and spring increased by 11% and 3% respectively and fishing in autumn and winter decreased by 8% and 7% respectively. In 2010, 43% of total effort was expended in summer months compared to just 28% in 2005. Both indices indicated that concentration was less during the period when catch rates were high and the TAC was binding (2004-2006) compared to when catch rates were low and the TAC was non-binding (2008-2010) (Figure 3.9).

**Figure 3.7**: Comparing the concentration of effort (no. of potlifts) throughout the study period. Results are shown for (i) concentration among all blocks (n. 101) and (ii) concentration among blocks fished across all years (n. 44). Concentration was measured using both the adjusted Gini Coefficient and normalised Herfindahl-Hirschman Index

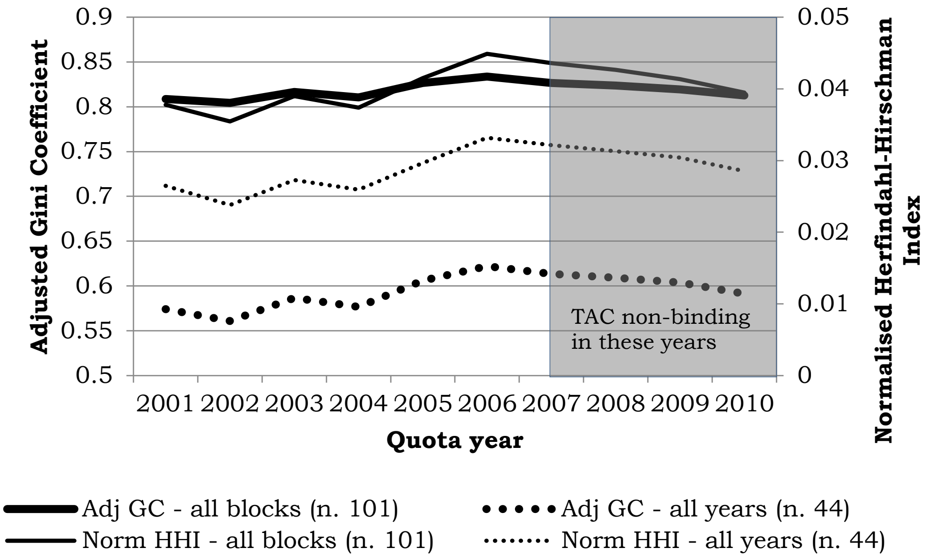
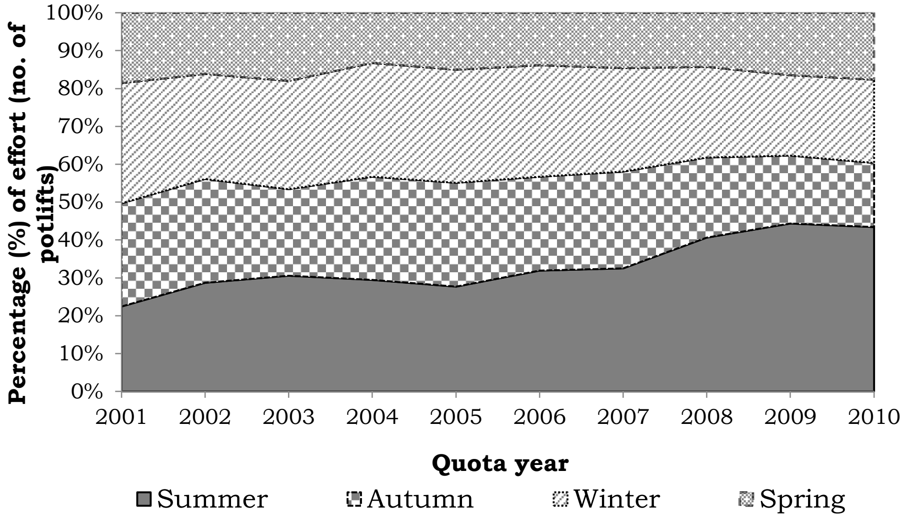
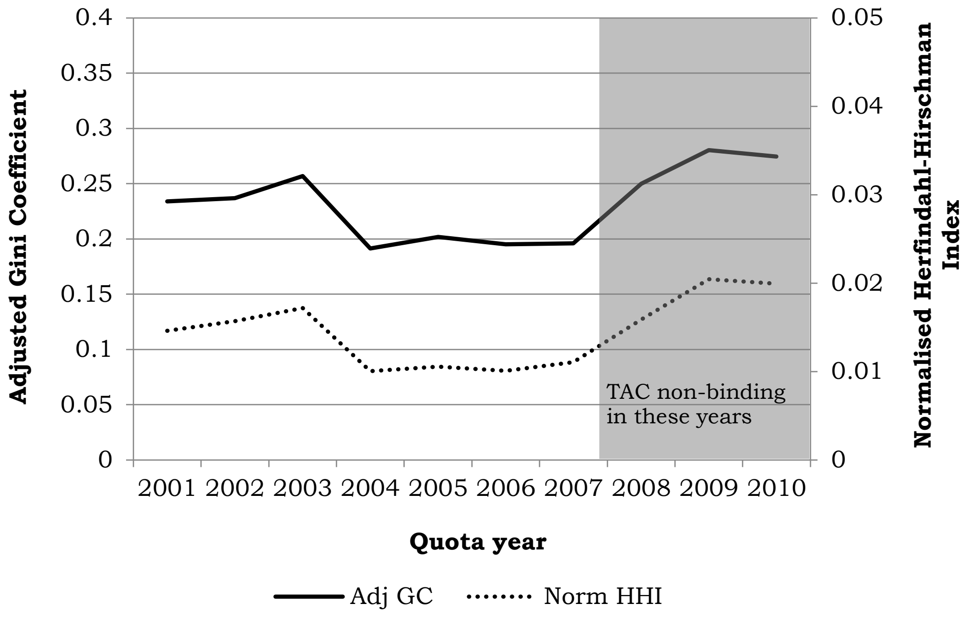



**Figure 3.8:** Comparing the concentration of effort (no. of potlifts) among seasons in the Tasmanian southern rock lobster fishery during the study period



The adjusted GC decreased from 0.25 in 2003 to 0.19 in 2004 before remaining stable until the TAC became non-binding, rising to 0.28 by 2009. Similarly the normalised HHI decreased from 0.017 in 2003 to 0.01 in 2004 before remaining stable until the TAC became non-binding, increasing to 0.02 by 2010. On average there was 3,725±1,679 more potlifts and 68±23 more active vessels per day between November-February 2010 than the corresponding months in 2005. These months therefore had the potential to experience increased competition and gear conflict among fishers, reflective of competitive race to fish behaviour.

**Figure 3.9:** Comparing the concentration of effort (no. of potlifts) among all months fished (n. 11) throughout the study period. Concentration was measured using both the adjusted Gini Coefficient and normalised Herfindahl-Hirschman Index.

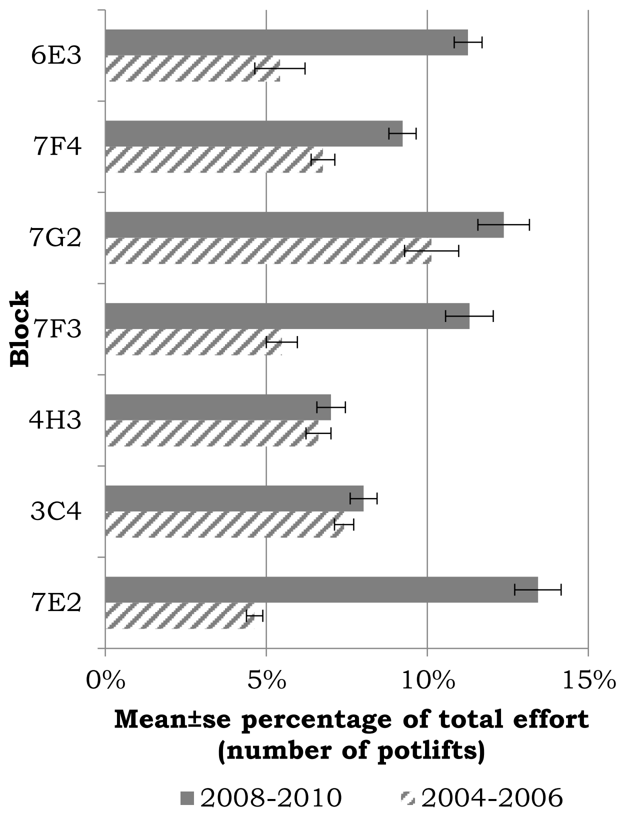



Racing to fish behaviour is usually evident at the commencement of a fishing season, however in the TSRLF fishing effort declined at the start of the season

(March) during the years where the TAC was non-binding. Many TSRLF fishers report that the reduction in fishing effort at the start of the season is due to exhaustion from lengthy periods of time spent at sea in the preceding months trying to catch their quota. The historical profit per potlift was also lower in March than November, when the fishery is reopened after a temporal closure (Figure 3.4). Consequently the propensity for racing to fish behaviour was higher in November. To examine this possibility a dummy variable was inserted into the general linear regression model, which identified whether a given day was in the first two weeks (14 days) following the re-commencement of the fishing season in November. In the years where the TAC was non-binding there were 34% more potlifts in the first two weeks following the re-commencement of the fishing season than in the years where the TAC was binding for the same fishing covariates, suggesting that fishers are now targeting this period in order to benefit from the higher expected revenue (Table 3.4). To further expand upon this analysis, the proportion of total effort expended in the first two weeks of the opening of the fishery after the temporal closure was compared between 2004-2006 and 2008-2010 in the seven blocks with the highest effort historically. As is evident in Figure 3.10, average effort in the first two weeks of November was higher in all areas in the years when the TAC was non-binding. In the block with the highest fishing effort historically (7E2), the percentage of total effort in the first two weeks of November increased from 5% to 13%.

While spatial concentration of effort did not increase in the years when the TAC was non-binding, overall fishing effort has grown and is now more temporally concentrated in the months of November to February, particularly in the first two weeks of November. Therefore the propensity for competition and gear conflict among fishers appeared to be higher during these fishing seasons.

**Figure 3.10:** Comparing the percentage of total effort expended (mean ± se) in the first two weeks of November between 2004-2006 and 2008-2010 for those seven blocks with the highest historical effort (2001-2010) in ascending order.




## 3.5 Discussion

ITQs alter the incentive structure of fishers from maximising their share of the catch to maximising profits from their share of the catch (Asche, 2001). The effectiveness of this management system in modifying behaviour is based on having: (i) an adequate level of fisheries governance (Hanna, 1999), (ii) appropriate TACs set for all relevant species (Kompas et al., 2009) and; (iii) a robust MCS system in place (Parslow, 2010). These three factors interact and influence a fisher's perceived strength of the property-right characteristics of their ITQ allocation. The "security" characteristic is defined as the certainty, security and enforceability of the ITQ allocation (Ridgeway and Schmidt, 2010). A fisher's perception of the security of their ITQ allocation is revealed in their discount rate, which they apply to future income or catches as reflected in the market price of quota (Batstone and Sharp, 2003). If a fisher's confidence in the management system or state of the stock is uncertain or perceived weak, their discount rate will increase, leading to behaviour focused on maximising current catches with less regard for future catches. In other words, fishers are less likely to consider the long-term implications of their fishing decisions on the stock, reverting to practices ITQs are meant to eliminate (Wingard, 2000; Brady and Waldo, 2009).

Observed changes in fisher behaviour in the TSRLF, included: a concentration of effort temporally, an increase in fishing to revenue, reduced quota investment and an increase in fleet capacity. These were consistent with the theory that uncertainty about future profitability and ability to take their allocated catch weakened the perceived security of the ITQ allocation. This led to higher discount rates and overall lower valuation of the stock, modifying behaviour with various ramifications for the fishery.

Higher discount rates caused by uncertainty affected the value of quota on the market after 2007. The average lease price of rock lobster rose from AUD $15/kg in 2001 to AUD $21/kg in 2006, consistent with increasing value of quota units under an ITQ system of management. Due to the existence of non-binding TACs however, it fell to AUD $8.50/kg by 2010. This had two important consequences for the fishery. First, it acted as an incentive for the reactivation of latent effort and associated increases in fishing capacity. Latent effort refers to licences and associated vessels not currently utilised (or "idle") in the fishery but with the potential to become active without any restrictions (OECD, 2006). The number of vessels in the fishery in 2010 increased by 17% from 2007 and the contribution of vessels over 18m to the total GRT of the fleet increased by 7% over the same period. Because the total fixed costs of the fishery are positively related to the size of the fishing fleet (Hamon et al., 2009) it is feasible that the total fixed costs in the fishery have increased as effort gravitated towards the open access equilibrium. Second, it impeded the redistribution of quota from less to more efficient fishers. Concentration of quota holdings (or catch) declined as the TAC became non-binding due to a greater number of fishers buying small amounts of quota. Concurrently, the concentration of quota ownership stalled as the reduced sale price of quota diminished the incentive for owners to sell their quota. Both of these probably increased the overall inefficiency of the fishing fleet between 2008 and 2010.

During the period 1999-2007, the TSRLF was characterised by a growing number of lease-dependent fishers who operated large catch businesses and expended greater amounts of effort fishing their quota units (van Putten and Gardner, 2010). The low quota lease price between 2008 and 2010 facilitated the entry of new lease fishers, which had a number of ramifications for the fishery. Firstly, it created a greater division between capital/labour (Bradshaw, 2004a) with information-exchange implications for regulatory authorities who now discuss and receive fishery advice from quota owners who no longer fish. Secondly, lease fishers theoretically practice less resource stewardship because they have no long-term investment in the fishery (Parslow, 2010; Sumaila, 2010) and are less financially viable than those owning quota (Pinkerton and Edwards, 2009). This could potentially lead to the adoption of hazardous fishing practices and issues of non-compliance (van Putten and Gardner, 2010). Thirdly, and following on from the stewardship implications above, lease fishers would theoretically be more resistant to management attempting to promote TAC reduction and stock rebuilding, as this reduces supply of leased quota and thus increases quota lease price. Given that the ITQ allocation is a usufractory right that provides no guarantee that others who participate in the fishery will refrain from practices that prevent the sustainable utilisation of the resource (Criddle and Macinko, 2000), a growing number of lease fishers not guided by the same incentive structure theoretically regulating the behaviour of quota owners will further weaken a fisher's perceived security of their ITQ allocation.

ITQ rights in the TSRLF are not perfectly delineated and there is no centralised coordination of fishing effort, therefore individual harvesting strategies have the potential to dissipate part of the fishery's profit (Costello and Deacon, 2007). This can occur particularly when harvesting decisions are commensurate with a high discount rate. This is due to the economic heterogeneity of some stocks across space and time, which creates an incentive for individual fishers to compete for those higher valued portions of the stock (Copes, 1986; Costello and Deacon, 2007) as well as production externalities, where a fisher's effort imposes costs on others through (i) reducing the stock density and/or (ii) congesting the fishing grounds (Boyce, 1992).

There are substantial variations in the recruitment, growth and abundance of rock lobsters around Tasmania, with high productivity and slow growth rates in the south and low recruitment and high growth rates in the north. Temporal closures to protect both moulting and egg-bearing female lobsters also create variations in the seasonal catch rate of lobsters. These fishery characteristics create disparity in the value of quota throughout the fishing season. While not empirically analysed, it is probable that excessive effort has been attracted to periods of higher revenue per potlift, increasing the marginal cost of effort due to production externalities and causing the total catch to not be taken at minimum overall cost. The substantial increase in the percentage of total effort allocated to particular areas in the first two weeks in November between 2008 and 2010 compared to the preceding years was evidence that fishers are attempting to increase the value of their quota units by engaging in a competitive race to fish. This was also evident in the New Zealand southern scallop fishery where fishers under ITQ management, in not fully internalising the costs of their effort decisions (i.e. reducing the stock density), allocated excessive effort too early in the season, with consequent losses ranging from 10-20% foregone profits per firm (Bisack and Sutinen, 2006).

In racing to fish at those times or locations where the value of quota is highest, fishers expend resources they would not have otherwise used if their fishing effort was coordinated or the stock was fully delineated in space and time (Costello and Deacon, 2007; Deacon and Costello, 2007). Consequently the TSRLF would probably benefit from assigning ITQ rights (i.e. quota units) to harvest that are delineated for specific areas at particular times, which Costello and Deacon (2007) maintain will reduce the dissipation of economic profit caused by competition. This is similar to the principles of Territorial User Rights Fisheries (TURFs). TURFs assign fishers or corporations exclusive rights to harvest and manage a spatial area during the fishing season, which if tradable, theoretically maximises efficiency, while mitigating and possibly eliminating the externalities that cause fishers to compete amongst themselves in spatially undelineated ITQ systems (Cancino et al., 2007).

Spatial management of the TSRLF has been considered and would improve stock rebuilding and prevent the concentration of effort (DPIPWE, 2009). A complete spatial and or temporal delineation of ITQ rights in the TSRLF however is probably financially and logistically prohibitive. Alternative options to reduce excessive effort include formally agreed rules or the formation of a cooperative that coordinates effort. Coordinated (or centralised) management has proven successful in both Japan (Cancino et al., 2007) and Turkey (Berkes, 1986; Hannesson, 1988), however issues include the added transactions costs of coordination (Cancino et al., 2007) and achieving consensus among fishing groups, which given the size and heterogeneity of the fishing fleet in Tasmania could be a severe barrier to implementation.

## 3.6 Conclusion

The obvious, "traditional" race to fish behaviours, which are characteristic of open access fisheries are unlikely to instantaneously reappear in an ITQ fishery when the TAC becomes non-binding. These behaviours include: large increases in fishing inputs, constant conflicts between fishers (e.g. setting gear in same location) and market gluts. Rather, the impacts of a non-binding TAC are likely to be more subtle and occur across multiple fishing seasons. For example, capacity may rise gradually, first through the reactivation of latent effort, increasing total fishery fixed costs and secondly through fishers slowly procuring additional inputs (e.g. more fishing gear) that allow them to maximise fishing power, increasing their variable costs. Effort may also gradually shift to times or areas when and where the quota unit value is highest (e.g. opening of fishery) (Bisack and Sutinen, 2006) leading to "racing" behaviour in order to be the first to exploit the stock. This can lead to the maximum potential economic profit of the fishery not being attained if species are overfished during times or areas of high revenue and/or conversely at times or locations where they are less valuable.

These changes in behaviour were evident in the TSRLF between 2008 and 2010 as the fishery effectively operated as a regulated limited entry fishery. Fishing fleet capacity increased, through the reactivation of latent effort and/or desire of fishers to increase fishing inputs (i.e. set the maximum number of pots). The low value of quota on the market (theoretically zero as supply exceeded demand) attracted a large number of new lease fishers to the fishery, who were not theoretically guided by the same incentive structure regulating the behaviour of quota owners.. The autonomous adjustment of quota towards the most efficient fishers stalled through greater participation in the fishery and the low price of quota acted as a barrier to investment. In an effort to maximise revenue, fisher's concentrated effort temporally between November and February, when CPUE and therefore the unit value of quota was highest. In the absence of spatially and temporally delineated ITQ rights or a centralised authority coordinating effort, the potential for rent dissipation increased (Costello and Deacon, 2007) as fishers engaged in costly competition. The resulting production externalities (i.e. reduced stock density and congestion of fishing grounds) are not internalised by fishers because they are not reflected in the market price of quota (Boyce, 1992) increasing the overall costs of fishing. The percentage of total effort expended in the first two weeks of November (which had the highest mean monthly revenue per potlift), increased substantially relative to the preceding years, which was an indication that fishers are competing in an economic wasteful race to fish in order to be the first to exploit the stock. Finally, a non-binding TAC probably prolonged the rebuilding of stocks in the fishery, which provided no certainty to fishers about their future profitability.

These changes in fishing fleet structure and behaviour may not be as apparent if the data was solely examined on a yearly or fishery-wide scale, as they have gradually developed over the last few seasons. Consequently there is a need to examine effort at a finer spatial and temporal resolution over longer time periods and in the case of the TSRLF, the use of spatial management could be investigated to prevent the dissipation of economic profit. Spatial management or even a centralised authority coordinating effort would improve economic profit in the fishery, however there are substantial implementation issues. Advantageously, in the 2011 fishing season the TAC was substantially lowered to 1,103 tonnes and was binding. This should improve fishery profitability as the market price of quota would reflect the true value of the stock, thereby removing barriers prohibiting the autonomous adjustment of quota to the most efficient fishers and increasing technical efficiency through the removal of excess capacity.

The history of the TSRLF illustrates the importance of appropriately setting the TAC for all ITQ fisheries to prevent unanticipated and undesirable changes in fisher behaviour and fishery profitability. In conjunction with a strong MCS system and effective governance, a binding TAC is not only required to maintain stock health but to manage a fisher's perceived security of their ITQ allocation. This will ensure that "race to fish" behaviours, prevalent under open access do not gradually reappear in ITQ fisheries.

# Chapter 4: Managing inshore stocks of southern rock lobster for a sustainable fishery

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## 4.1 Abstract

The Tasmanian commercial southern rock lobster fishery (TSRLF) is a quota controlled pot fishery operating all around Tasmania. The annual commercial catch is around 1.5 million animals taken by approximately 230 vessels (Hartmann and Gardner, 2011). In addition, there are approximately 21,000 licensed recreational fishers (Lyle and Tracey, 2010). Inshore stocks have been declining for a number of years, and total legal biomass of the whole fishery has been in decline since 2007 (Hartmann and Gardner, 2011). Fishing effort and life history demographics of the stock vary dramatically from region to region, and from inshore to offshore. This presents a number of challenges for fisheries assessment and management.

Serious concerns that fishing two shots per night (double night fishing) was depleting inshore stocks were raised by members of the southern rock lobster fishing fleet starting in 2007, through a range of forums. This concern heightened as state-wide fishing effort continued to rise while catch rates fell. Requests from the peak industry body the Tasmanian rock lobster fishing association (TRLFA) to ban it were complicated by the lack of scientific information on the effect and difficulty in defining a suitable approach to regulation and enforcement. As a result, the TRLFA requested that the Institute for Marine and Antarctic Studies (IMAS) conduct research into the practice of double night fishing.

It was not possible to determine the full extent of double night fishing in the rock lobster fishery using logbooks, so depth logger and observer data from volunteer double night fishers were used to assess the extent of this practice. Of the 13 fishers who volunteered to participate in the depth logger study, only three fisher's

deployed two night shots on greater than 20% of their total days fished. Double night fishing was not widespread in the southern rock lobster fishery. There was no evidence from this survey that limiting or prohibiting double night fishing would result in different future biomass.

Fishers conducting double night shots had higher effort but this was modest in scale. The average number of shots per day on double night fishing trips (1.6 shots) was slightly higher than on standard fishing trips (1.5 per day) but trip length (days) was similar. A double night fisher completed an average of 3.4 more shots per trip than a standard fisher. Average soak time was lower in double night shots (9.5 hrs) than standard shots (12.5 hrs). While effort was slightly higher for double night fishing than standard fishing trips there was no difference in the catch per unit effort (CPUE). This indicated that there was an economic incentive for fishers to engage in double night fishing because they achieved higher catches per unit of labour and capital. In a fishery with a constraining total allowable catch (TAC), increasing efficiency by reducing fixed costs makes the fishery more profitable. This observation also implied that fishers conducting double night shots would be able to remain viable in situations with lower catch rates, such as in depleted inshore areas. This was consistent with the original concern of industry but critically the scale of the effect was deemed small.

Mean length of lobsters caught in double night shots was 2.5mm higher than in standard shots; however the variation in lobster length per month was up to 30 mm, which was a much larger source of variability. The abundance and diversity of bycatch between double night and standard shots were similar, and mortality of lobsters caused by octopus in pots was lower on double night shots. This practice did not increase damage due to handling or discarding. Growth of lobsters from all types of fishing that sustained an injury such as limb loss was reduced by 0.6 mm $yr^{-1}$ for females and 1 mm $yr^{-1}$ for males. As double night fishing did not increase the amount of damage to lobsters, it appeared no more likely to reduce growth rates through injury and discards than standard fishing.

Results indicated that the effect of double night fishing effort on inshore biomass was minor relative to the larger issue of total catch (and thus effort) as regulated through TAC. Damage due to handling and discarding appeared reduced through double night fishing because the average weight of lobsters was slightly higher (thus fewer lobsters per unit quota) and catch rates were equivalent to standard night shots. In 2010/11 double night fishing did not appear to be as widespread as discussed prior to the project. Interestingly, many fishers who self-identified as double night fishers actually rarely conducted this type of fishing. Rather, they sometimes set and hauled their gear late into the night, rather than completing two full shots during the night.

It was difficult to determine whether the true extent of this activity was captured without broader participation of the fishing fleet and clearer recording of shot times in the logbook. As a result it was recommended that the logbook be adjusted so that fishers no longer record 'shot type' and 'date of month' and instead record the time and date of first pot set and first pot hauled for each shot. The logbook should also be amended to prevent shots being combined across a calendar day by reporting double the number of pots. This would allow assessment of fine-scale effort, and correction for potential bias from double night fishing in the stock assessment process for the fishery.

## 4.2 Introduction

### *4.2.1 Background*

Serious concerns over the effects of two shots per night (double night fishing) and the depletion of the inshore component of the southern rock lobster stock had been raised by members of the TRLFA between 2007 and 2010 through a range of forums. In 2007, industry first flagged the issue through the Crustacean Fishery Advisory Committee (CFAC). This resulted in a discussion paper of the key issues surrounding this practice which, was distributed in April 2008 along with a questionnaire gauging the broader fishing community's concern. There were 97 respondents to the questionnaire, of which 26% practiced double night fishing and 65% were concerned about the practice. In July 2008 the CFAC considered the responses to the questionnaire, determining that it was a serious issue, but there was not enough industry support to pursue a legislative outcome. In a meeting in October 2008 the TRLFA passed a motion that double night fishing should be banned. TRFLA posted the results of this vote to the Department of Primary Industries, Parks, Water and Environment (DPIPWE) requesting a ban on this practice. DPIPWE acknowledged that there was not enough scientific evidence to determine whether double night fishing had detrimental effects, and requested TRFLA to consider how it could be regulated. TRFLA urgently requested that IMAS conduct research into the practice of double night fishing.

### *4.2.2 Objectives*

The overall objective was to examine whether changing fishing practices were responsible for declining southern rock lobster stocks. Specific aims were to:

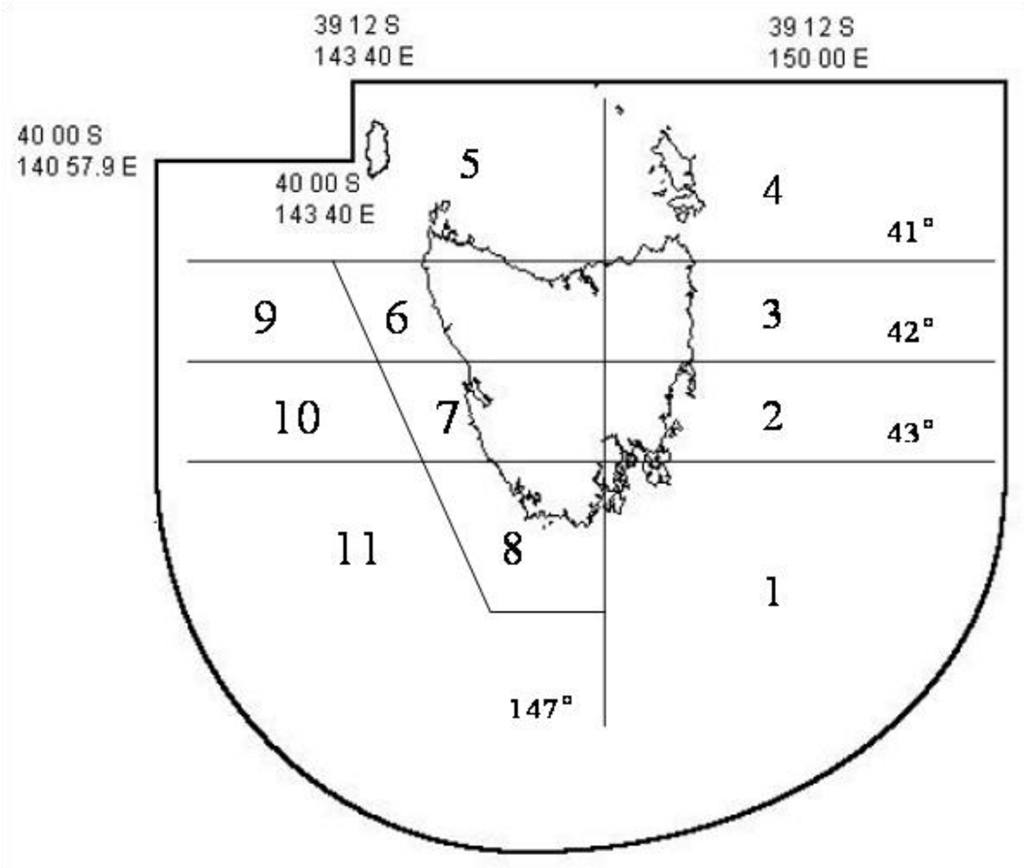
- Determine the extent of declines in the inshore stock by changing the current stock assessment model to assess stocks at a finer scale (<30m and >30m);
- Assess whether increased effort in double night shots was adequately recorded in estimates of CPUE; including differences in catch composition, size structure and the effects of handling on growth in assessments;
- Assess the cost-effectiveness of double night fishing and compare short and long-term benefits;
- Develop a management strategy evaluation, presenting options based on the results of the study.

## 4.3 Methods

### *4.3.1 Examine declines in inshore stocks by changing the current stock assessment model to assess stocks at a finer scale*

The current model used to generate stock assessments of the southern rock lobster stock in Tasmania was to be modified to assess the stock in 19 areas rather than the existing 11 areas. The current model assesses the stock using eight inshore areas, below 64 m and three offshore areas encompassing fishing grounds >64m (Figure 4.1). Through this project the eight inshore areas were divided into 16 areas, delineating the existing areas at 30m. Economic data was also set to be used to allow cost-benefit analyses of the change to inshore fishing and double night shots.

**Figure 4.1:** Tasmanian southern rock lobster fishery stock assessment areas numbered 1-11.




## *4.3.2 Assess whether increased effort in double night shots is currently recorded in estimates of CPUE.*

This objective required three approaches to determine whether the extra fishing effort in double night shots was adequately recorded in the DPIPWE logbooks, and ultimately captured in the stock assessments estimates of CPUE.

- *Compare the effort recorded by observers to the effort reported in the compulsory DPIPWE logbooks, assessing whether the logbook format is adequate and the reporting is comprehensive.*

The existing observer program was extended to include boats fishing two shots in a night. Observers collected data from six observer trips, representing 67 days fishing on vessels undertaking double night shots. Observers used a headset and recording device to record the details of all of the lobsters caught. Details included tag number (new or previously tagged), size, sex, colour, maturational status, damage to limbs and carapace, shell condition. Higher order data on shot depth and location, number of shots and time of shooting and hauling were also recorded.

To discern whether a shot was a double night or standard shot the time of set and haul was examined. The logbook didn't provide this information, so the data from depth loggers was used to formulate a suitable definition and compare fishing behaviours recorded in the logbook with fishing behaviour recorded on the boat. The definition of a double night fishing event used in this report was where a fisher hauls and then resets their pots between the hours of 10pm and 3am on any given night. Thus a double night fishing event was always two paired shots within the one night. This definition was chosen because it encompassed a greater number of double night shots than alternative time slots.

- *Record double night fishing activity using data loggers on pots and compare this to effort recorded in the logbooks*

The names of 25 fishers thought to practice double night fishing were provided by the TRLFA. These fishers were then contacted and asked whether they would be willing to participate in the project by deploying data loggers. In total 13 fishers assisted with data collection using the loggers across 2010 and 2011. These fishers were provided with full briefing details and two data loggers, which were attached to two pots. The data loggers were retrieved at regular two month intervals to download records of fishing activity and then returned to fishers.

The Sensus Ultra data loggers recorded the following variables at 60 second intervals:

1. PSI (pressure), which was used to determine depth of the pot and therefore whether a pot was onboard or set underwater
2. Time
3. Water temperature

The data collected was then downloaded into a secure IMAS depth logger database. The sampling period reflected fishing trips completed between May 2010 and March 2011, not including the Tasmanian southern rock lobster fishing season closure between 30 September and 15 November 2010.

The level of reporting was examined by comparing the total number of shots recorded in the logbooks and depth loggers across all volunteer fishers. Depth logger data was also examined to determine whether there was any difference in the (i) mean number of shots per day and length of trip; (ii) CPUE and; (iii) soak time of double night and standard shots and/or fishing trips, with the effect of individual fisher and month of trip included as additional factors. The change in percentage of catch from night shots in inshore areas was also examined by dividing the fishery into 30 inshore 30' x 30' blocks using the logbook.

- *Record the size structure and composition of night-time shots and assess whether capture increases limb loss and limb loss influences growth.*

Observer data was used to examine: (i) whether there was any difference in the size structure of double night shots compared to standard shots; (ii) whether there was any difference in the discard rate between double night and standard shots and; (iii) whether there was any difference in the by-catch composition of double night and standard shots in terms of abundance and diversity. The rate of octopus-induced mortality was also analysed. The data was acquired from IMAS long-term rock lobster database (CRAYBASE) for these analyses.

The rate of injury was directly compared between standard and double night shots before examining whether there was any cost of injury to growth using CRAYBASE by comparing annual growth rates of both male and female lobsters who had moulted at least once prior to the first recapture. Geographic variation in growth was also included in this analysis. Males were assumed to moult between August-October and females between March-May each year. A male or female lobster that was initially caught in those months was assumed to have moulted already that season and if recaptured in those months was assumed to not yet have moulted.

### *4.3.3 Assess the cost effectiveness of double night fishing*

Results from Aims 1 and 2 would be incorporated into the Tasmanian rock lobster stock assessment model and bio-economic model to assess the cost and benefit of different fishing scenarios.

### *4.3.4 Develop management strategy evaluations based on the outcomes of the project*

While it was anticipated that a formal management strategy evaluation would be undertaken, the results were such that this wasn't required. Instead industry were consulted about the methods to determine whether the logbooks adequately recorded fishing effort and changes in fishing effort. Outcomes were presented to the CFAC and DPIPWE at CFAC 53 in March 2011.

## 4.4 Results

### *4.4.1 Determine whether double night fishing may be causing declines in stock*

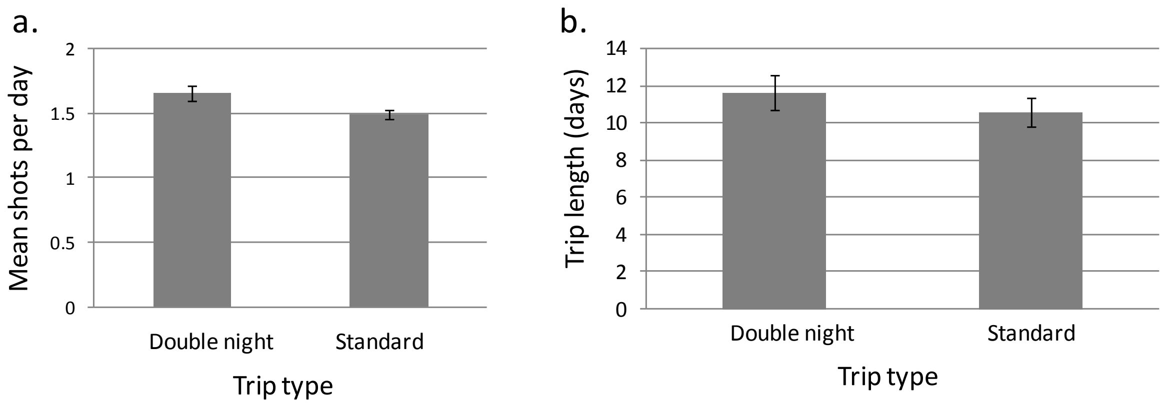
One of the key goals of this work was to determine whether the extra effort reported to occur due to the advent of double night fishing was adequately recorded in estimates of CPUE. If double night fishing by the Tasmanian southern rock lobster fishing industry was resulting in a decline in stock, then the possible mechanisms for this would be that it: (i) increased effort and; (ii) increased CPUE. Each of these were examined.

- *Effort*

At the outset, it was presumed that double night fishing would result in an increase in fishing effort, as it was reported to double the number of shots a fisher undertook on a given night. Through 12 months of sampling however only a slight increase in effort through this practice was found (Figure 4.2). There was no information on the spatial distribution of double night fishing. Inshore catch rates have declined, as have all catch rates throughout the fishery.

Effort was assessed in three ways: (i) observers onboard vessels where the skipper had volunteered that they undertook double night fishing; (ii) depth loggers attached to pots on boats undertaking double night fishing and; (iii) analysis of compulsory industry logbooks. The most comprehensive source of data was from the depth loggers which recorded 1,029 fishing shots (up to February 2011), recording the time of each pot set and hauled during a trip. The average number of shots per day was slightly higher (1.65 ±0.06 shots per day) on double night fishing trips than standard fishing trips (1.49 ±0.04 shots per day, $F_{1,62}$=12.32, $p < 0.001$, Figure 4.2).

**Figure 4.2:** Effort comparison (mean ± SE) of (a) shots per day and (b) trip length between double night and standard fishing trips from depth logger data.




There was no difference in the length of trip between fishers undertaking double night fishing or standard fishing. ($F_{1,16}$=1.57, $p > 0.05$, Figure 4.2). For most months the length of both double and standard night fishing trips was similar, although in August double night fishing trips were longer (Figure 4.3).

It was expected that double night fishing would encompass three shots per day – two overnight in addition to a day shot. Instead it was found that many fishers who classify their fishing practices as double night fishing did a maximum of two shots in a day, and often only one shot per day. The key difference in their fishing behaviour is that they hauled and reset their pots during the night, rather than in the morning like fishers undertaking the standard and widely accepted day and night shot.

An average 3.5 more shots were completed on double night compared to standard fishing trips (Figure 4.4). Not surprisingly, to fit these extra shots in, soak time was lower on double night fishing trips (Figure 4.4).

**Figure 4.3:** Trip length (mean ± SE) in days of double night compared to standard fishing trips by month

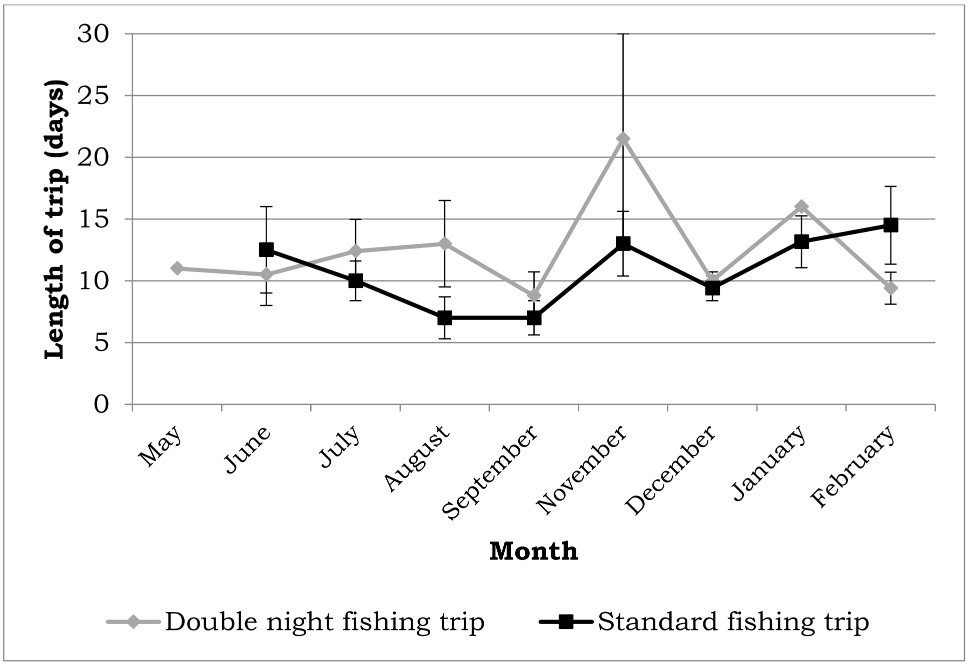
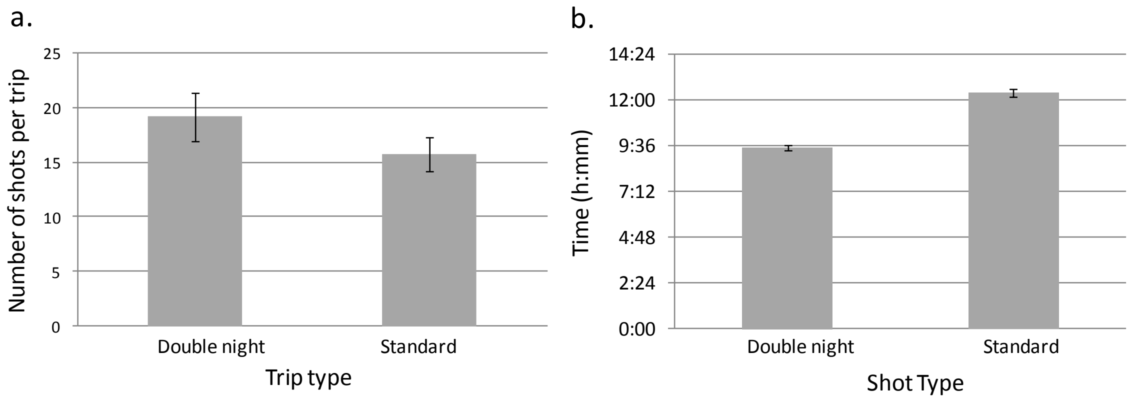


**Figure 4.4:** A comparison of: (a) the number of shots per trip (mean ± SE) and (b) soak time (mean ± SE) of double night to standard fishing trips




- *Catch*

The proportion of the catch from the fishery taken in night shots varied since 2000, ranging from 73% to 83% (Figure 4.5). It was highest in 2010 and second highest in 2001, suggesting recent changes in fishing practices are not the sole cause of the increase in the proportion of catch taken at night. There were other changes in fishing behaviour that have occurred over the past ten years. Out of the 30 fishing blocks used to report catch and effort, there were increases in the percentage catch from night shots of 23 by an average of 8.46% (Figure 4.6). The greatest proportional increases in night catch were in south and south-east areas of the State (Figure 4.6).

**Figure 4.5:** Total catch and percentage of night and day shots between 2000 and 2010 quota years.

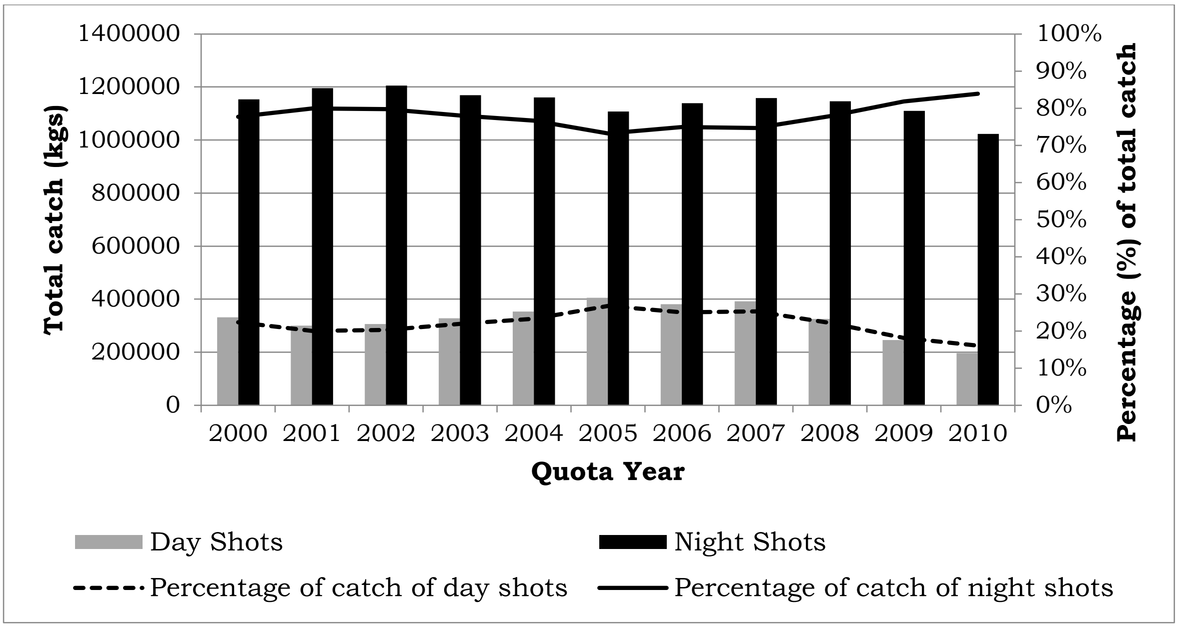
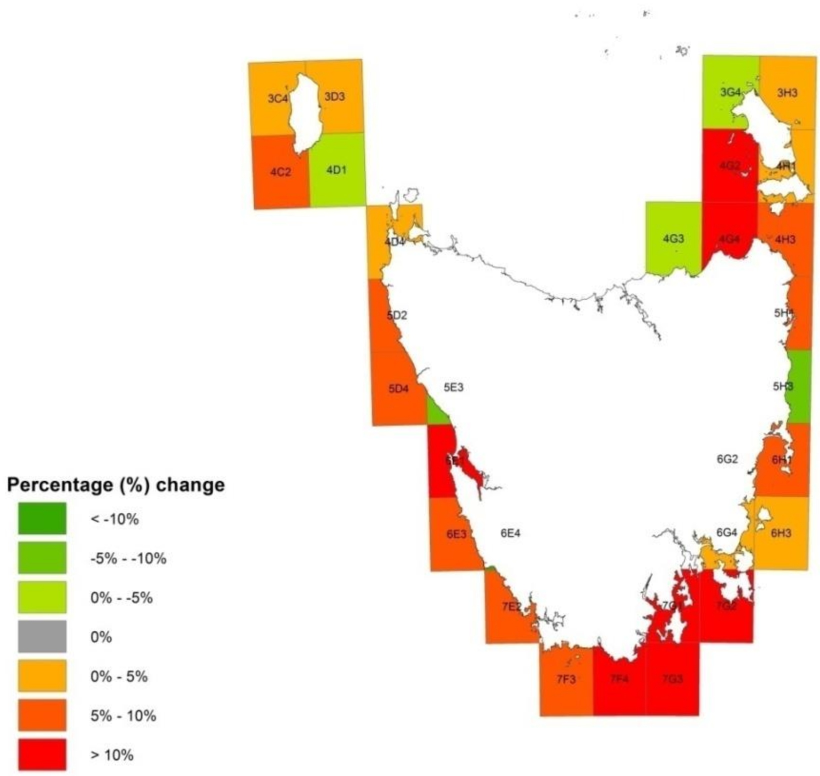


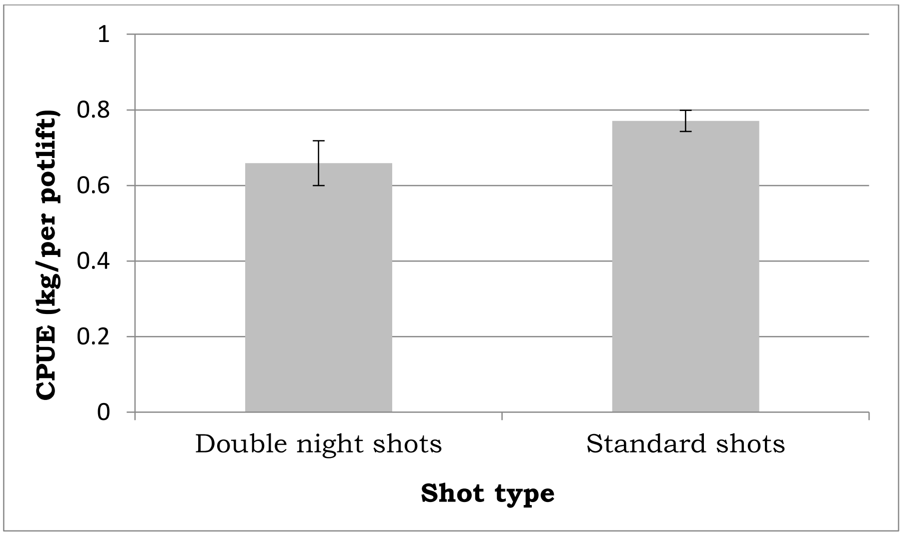

**Figure 4.6:** The change in the percentage of night shot catch taken from inshore areas between 2005 and 2010 quota years.



- *CPUE*

There were a total of 426 out of 1,424 shots from depth logger data which could be matched to the logbook on a shot-by-shot basis, encompassing only 40 of the 246 double night shots recorded by the depth loggers. There was no difference in CPUE between double night and standard shots ($F_1$=0.88, $p > 0.05$, Figure 4.7).

**Figure 4.7:** Catch per unit effort (mean ± SE) of all double night compared to standard shots from depth logger and logbook data.




- *Stock abundance*

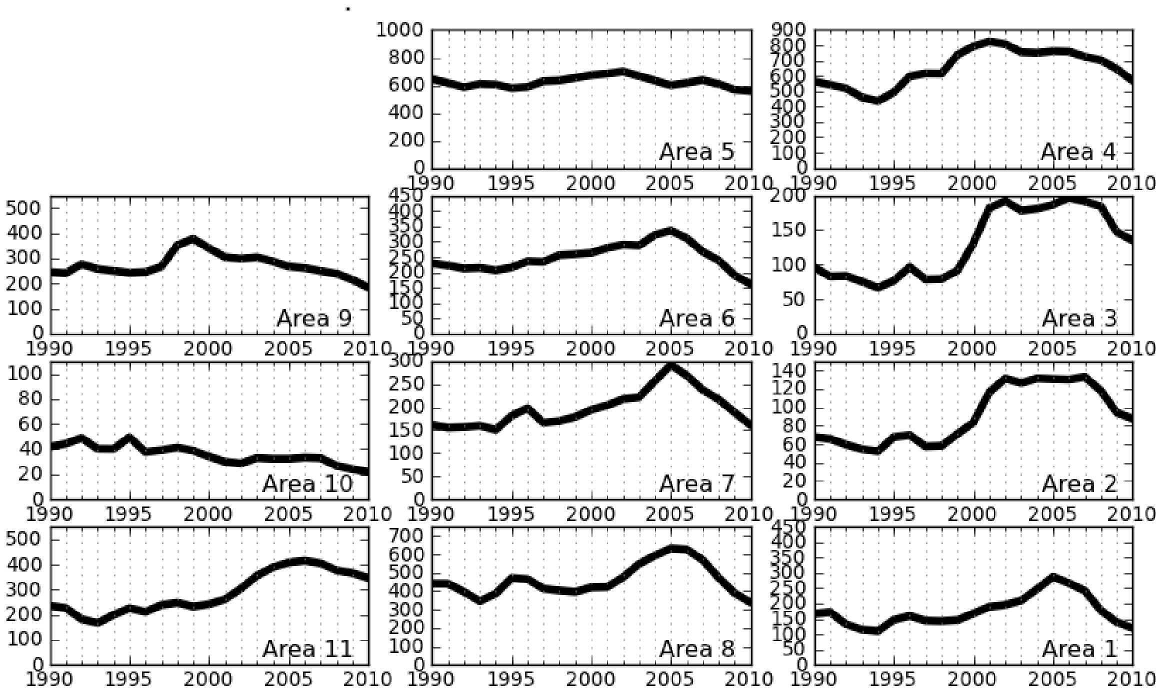
Prior to this project the stock assessment model contained 11 assessment areas, 8 inshore and 3 offshore on the west coast deeper than 64 m (Figure 4.1). It was planned to further divide inshore stocks above and below 30m to provide a higher resolution for inshore areas. This split was attempted; however there were insufficient tag returns from individual areas once the split was carried out to obtain reliable estimates of growth rates, recruitment and movement between areas. Consequently, results from the divided model were too unreliable to provide useful information.

There were recent declines in biomass in all areas, except area 10 (Figure. 4.8a). These trends were a function of both growth of legal-sized stock and low recruitment of new lobsters in to the stock (Hartmann and Gardner, 2011). Fishers were concerned that an increase in double night fishing was masking real trends in catch rate data. To address this concern an analysis of catch rates restricted to day shots only was conducted. This analysis showed that overall catch rates had declined by 13% state-wide, and catch rates for day shots had declined by 19% state-wide (Hartmann and Gardner, 2011).

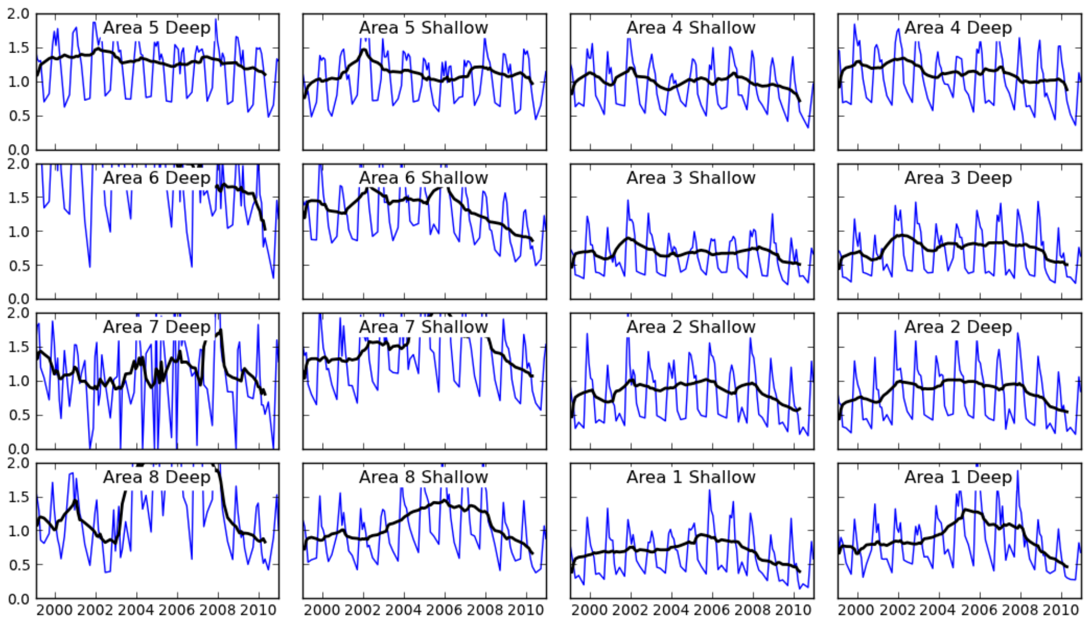
Fishers were also concerned that an increase in inshore fishing (partly due to double night fishing) was masking real trends in CPUE as these areas were seeing greater CPUE decline than elsewhere. Catch rates have been decreasing in both deep and shallow water at similar rates throughout most of the state (Figure 4.8b).

**Figure 4.8:** Biomass and catch rates in the TSRLF by area. (a) Exploitable biomass (tonnage of legal sized lobsters estimated from the stock assessment model and (b) CPUE in the eight areas split by depth. The blue line shows the monthly CPUE with clear seasonal trends whilst the black line shows the average-annual CPUE.

**a.**




**b.**



### *4.4.2 Assess whether increased effort in double night shots is currently recorded in estimates of CPUE*

- *Compare the effort recorded by observers to the effort reported in the DPIPWE logbooks assessing whether the logbook is adequate*

As part of the rock lobster licensing requirements from DPIPWE, it is compulsory to fill in standardised logbooks for all fishing catch and effort. The current structure of the logbook precludes determining the extent of double night fishing, how many double night shots have occurred or when they were most likely to occur. It was originally envisaged that a double night fishing event could be defined as either three shots (day or night) or two night shots within a calendar day. There was no evidence from the logbook database however of fishers reporting more than two shots or two night shots within a calendar day. It was therefore not possible to identify double night shots in the logbooks using a definition based on number of shots on a calendar day. The most appropriate method for distinguishing double night from standard shots was to develop a definition using the time of set and time of haul, however the logbook does not require fishers to record this information. Fishers only needed to record the 'shot type' (day or night) and 'date of month' (calendar day).

While the current structure of the logbook does not preclude a fisher from recording two night shots on the same calendar day it is made improbable because at midnight (or between night shots) it becomes a new calendar day. For example, a fisher could set their pots at 3pm then haul them at 11pm on the 1 January and then re-set them at 1am and re-haul them at 7am on the 2nd January. While this is undeniably a double night fishing event and both shots could be classified as night shots under the definition, they will be recorded across two separate calendar days. It is not possible to determine whether a fisher reset them on the same night as in the example above on 1/2 January or whether they set them early on the following night of the 2/3 January.

This problem is further complicated by the dramatic seasonality changes in Tasmania, which could mean a shot classified as night in winter could be day in summer due to the large differential in the amount of daylight between seasons. For example, a fisher sets their pots at 3pm and then hauls them at 11pm on 1 July before re-setting them at 1am and re-hauling them at 10am on 2 July. Both shots are night shots, but if the date was 1 December, both shots would be day shots. This makes it difficult to create a definition based on the type of shot. Two further issues with the structure of the logbook was the ambiguity in the current definition of 'date of month' or calendar day and reliance on fishers estimating the amount of day and night time across a long soak time to determine the correct 'shot type'.

The current definition of 'date of month' in the logbook gave no guidance on whether a fisher who set their pots at 9pm on 1 January and hauled them at 3am on 2 January should record this fishing event as taking place on the day of the set or haul. This ambiguity and resulting lack of consistency among fishers further complicates the classification of double night fishing events.

The number of shots across each trip from the depth logger was compared to the logbook to assess the level of reporting. The level of under-reporting was low in the logbook (< 1 shot per trip), indicating that the total number of shots are appropriately recorded by fishers. Importantly this indicates that the reporting of double night fishing is not leading to biases in the estimates of CPUE. The configuration of the reporting often followed the logbook instructions, which allow two shots of 50 pots to be recorded as a single shot of 100 pots, a method of recording which still correctly captures the amount of catch and of effort.

Out of a total of 425 shots that could be matched from the depth logger to the logbook, 84% of fishers correctly recorded the shot type. When just examining the correct classification of double night shots there was an accuracy rate of 69% across 39 fishing shots. There was a misclassification of shot type more frequently for double night than standard shots

- *Alternative methods of investigating double night fishing*

The depth loggers recorded a total of 84 fishing trips in the TSRLF, which included 1,424 shots, of which 246 were double night shots. Out of the 13 fishers who participated (volunteered because they identified as double night fishers) only three undertook double night fishing on greater than 20% of their total days fished (Figure 4.9a). This was a clear indication that double night fishing was not as widespread as initially thought, or at least not during 2010/11. There were a total of six observer trips on vessels undertaking double night fishing. Of these, double night fishing occurred on more than 40% of the fishing days on only four trips (Figure 4.9b), however it should be noted that three out of those four trips were on the same vessel.

- *Record the size structure and composition of night time shots*

There was a minor difference in the size of lobsters caught in double night compared to standard shots (Figure 4.10a). Lobsters from double night shots were longer by 2mm (mean carapace length, mm), however there was up to a 30mm difference in the size of lobsters caught between December and August (Figure 4.10b). Fishing month had a much larger effect on the size of the lobster caught than fishing type (Figure 4.10b). The initial concern that double night fishing targeted lots of undersized lobsters and resulted in increased handling and release of lobsters was not supported by this research.

**Figure 4.9:** Percentage of fishing days where a double night fishing event was completed for (a) all depth logger shots by fisher and; (b) each observer trip. Black bars denote days with a double night fishing event and grey bars denote days without a double night fishing event.

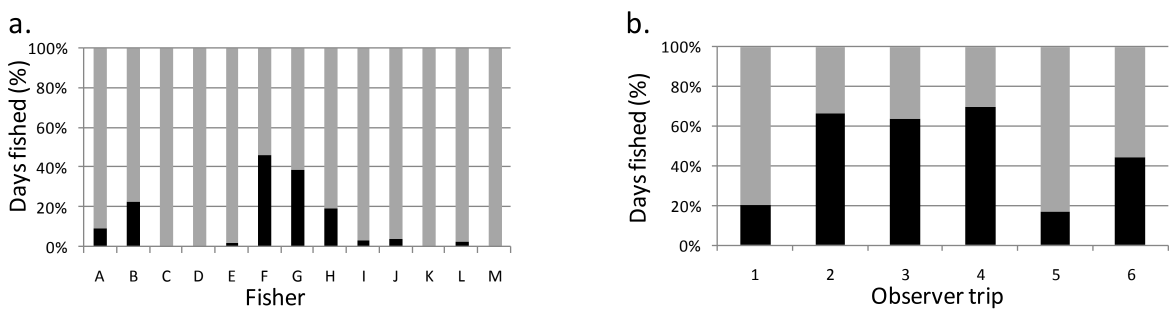
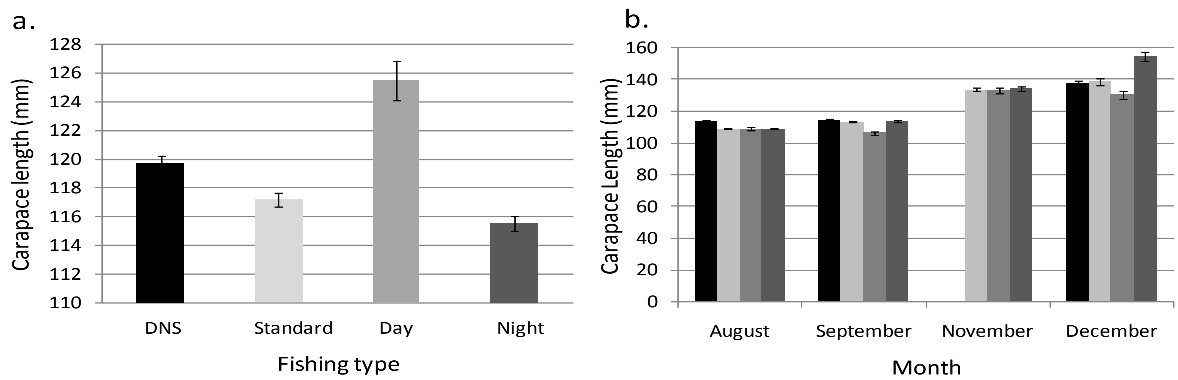
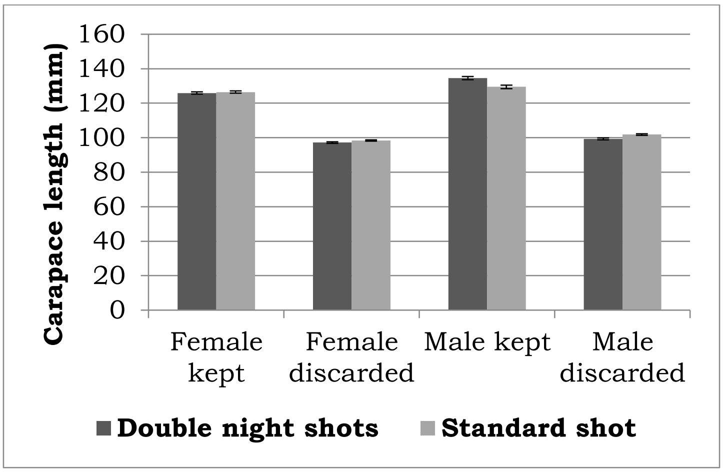



**Figure 4.10:** Carapace length (mean ± SE) of lobsters landed by different fishing types for (a) all observer trips and; (b) each month.



The size of discarded lobsters was the same for double night fishing as it was for standard fishing. At the outset of this project there was a concern that fishing through the night led to the increased capture, handling and discard of smaller lobsters, particularly females. There was no indication that double night fishing was biased towards the capture and discarding of smaller lobsters (Figure 4.11).

**Figure 4.11:** Size (mean CL ± SE) of discarded and kept lobsters measured on observer trips.




By-catch species diversity and abundance was the same regardless of fishing type (Figure 4.12), however lobster mortality in pots caused by octopi was lower for double night shots (Figure 4.13). Many fishers reported that they use double night fishing to reduce the number of lobster mortalities caused by octopi in their pots.

**Figure 4.12:** Bycatch (mean ± SE) from double night and standard shots measured on observer trips displaying the average (a) species diversity and (b) species abundance

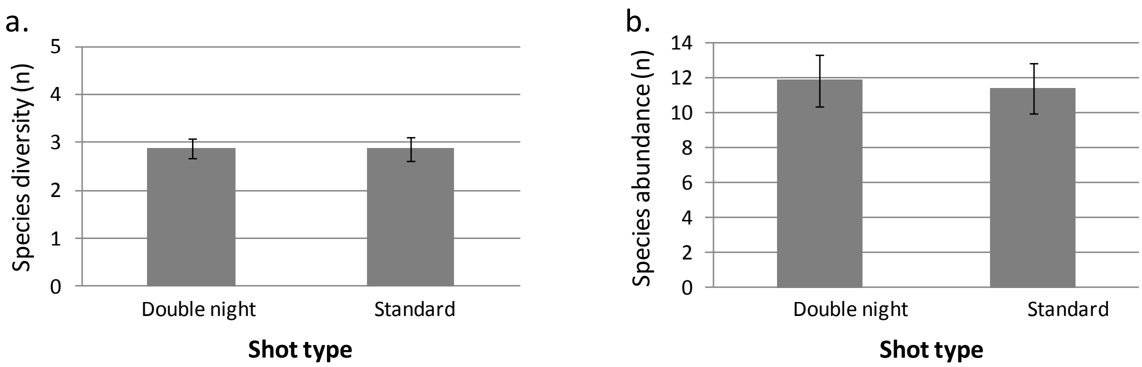
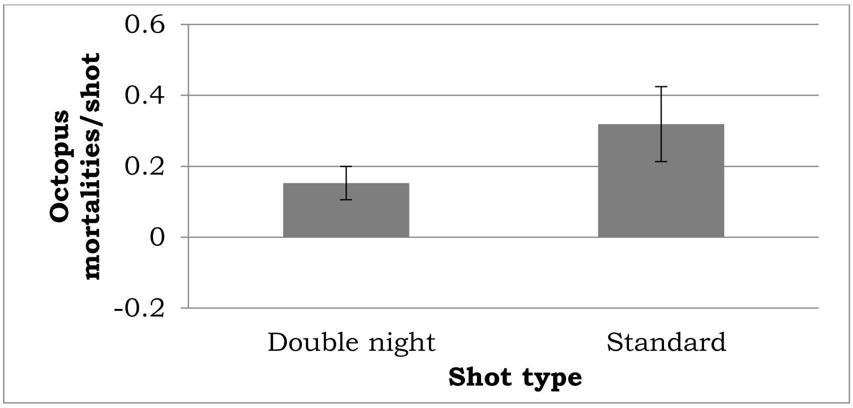



**Figure 4.13:** Number of lobsters killed by octopi within the pots (mean/pot ± SE) from double night and standard shots measured on observer trips



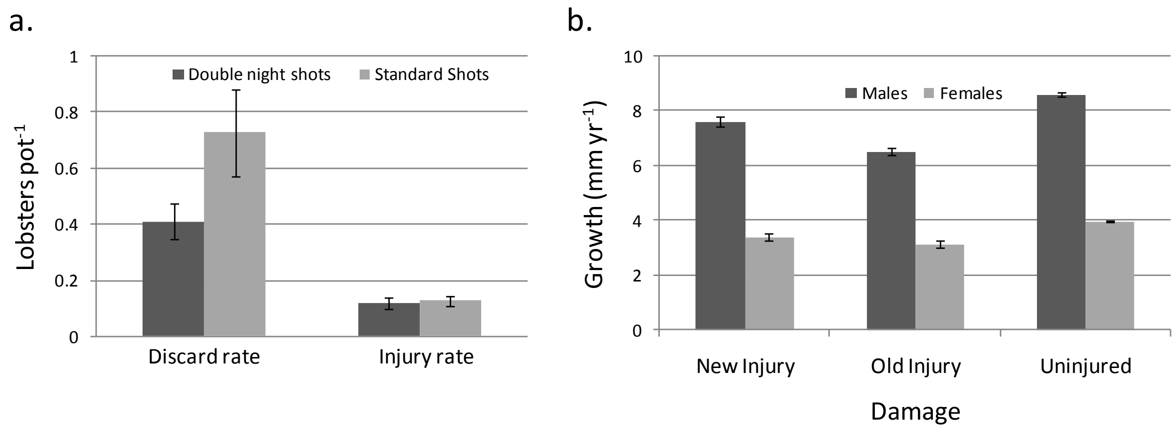

- *Assess whether capture increases limb loss and loss of limbs influences growth*

The rate of injury and discards between double night and standard fishing trips was compared using data from observer trips. The injury rate for both types of shots was similar and occurred in less than 0.2 lobsters per pot ($F_{1,98}$=0.075, p=0.78). The discard rate was lower for double night than for standard fishing trips ($F_{1,98}$=4.46, p=<0.05, Figure 4.14a).

Long-term tagging data from CRAYBASE was used to assess the impact of injuries on the growth of rock lobsters. There were a total of 27,160 lobsters in the analysis. Of the 15,079 male lobsters, 1,487 had an old injury, 924 suffered a new injury and 2,277 had either type of injury. Of the 12,081 female lobsters, 924 had an old injury, 849 suffered a new injury and 1,670 had either type of injury. Injuries were limb or antennae loss.

Growth rate was reduced in both male and female lobsters that were injured through fisher handling and capture (males, $F_{1,15063} = 22.64$, $p < 0.001$, females $F_{1,12065} = 24.59$, $p < 0.001$, Fig. 14b). These results suggest some impact on the annual growth of lobsters from injuries caused by fishing, but as double night fishing did not increase the amount of damage to lobsters, then it is no more likely to reduce growth rates through injury and discards than standard fishing.

**Figure 4.14:** (a) Rate of injury and discard of lobsters (mean ± SE) per pot and; (b) Annual growth rate of injured and uninjured lobsters from double night and standard shots measured on observer trips



### *4.4.3 Assess the costs effectiveness of double night fishing*

Double night fishing resulted in no detectable change in catch rate and a slight increase in the number of shots per day and consequently the number of shots per trip. These changes were sufficiently small that even wide-scale adoption of double night fishing would not substantially change the temporal or spatial composition of the Tasmanian southern rock lobster catch. The main exception to this (which has not been examined in this study) was if fishers change their fishing grounds in order to undertake double night shots.

Due to the limited effect on the dynamics of the rock lobster fishery, a study of the effect of double night fishing using the Tasmanian bio-economic rock lobster model was not carried out. This study would have shown limited/no effect.

On average, fishers who double night fished carried out 0.16 additional shots per day (1.65 instead of 1.49). Consequently the daily catch rate for double night fishers was 11% higher. This clearly had positive economic implications for fishers as the same catch could be caught in fewer fishing days. This is considered in Table 4.1. The costs per potlift and vessel (Table 4.1) are taken from the South Australian 2009/10 survey and are therefore more recent than surveys from Tasmania. Fishing operations in South Australia clearly differ from Tasmanian operations but this provides a general guide.

**Table 4.1:** Costs of lobster fishing split by variable and fixed costs

| | Variable cost / Potlift | Fixed cost / vessel | Fleet fixed cost |
|---|---|---|---|
| Labour as fixed cost | AUD $8.07 | AUD $224,007 | AUD $51,521,610 |
| Labour as variable cost | AUD $19.54 | AUD $94,115 | AUD $21,646,450 |

The first row considers the situation where labour is treated as a fixed cost, the second row where labour is treated as a variable cost. This distinction is important as it is unclear whether double night fishing will incur additional labour costs (i.e. it should be treated as a variable cost) or if fishers will work harder (in which case it should be treated as a fixed cost). For each vessel that begins double night fishing (to the extent that vessels in this study double night fished) a fleet wide increase in profitability of between AUD $24,640 (11% of $224,007) and AUD $10,353 (11% of $94,115) would be obtained (depending on the additional labour costs required for double night fishing). This gain is obtained as the vessel could take a greater catch in fewer days, and consequently for every nine vessels that take up double night fishing, the fishing fleet could be reduced in number by one vessel, thereby saving the fixed costs attributed to that vessel. Similarly, the maximum gain obtainable across the fleet (if all vessels commenced double night fishing) was between AUD $2.38 million and AUD $5.67 million. These values are maximum values and are unlikely to be fully realised in practice as vessels are unlikely to switch to double night fishing practices for every single trip.

### *4.4.4 Develop management strategy evaluations based on the outcomes of the project*

As there was no evidence that the fishing practice called double night fishing was widespread in the TSRLF or was responsible for significant increases in catch rates, there was little value in a management strategy evaluation.

There was also no evidence that double night fishing influenced catch rates or biomass, so the annual stock assessment model would be adequate in recording any changes in the fishery. It was recommended that monitoring of the practice of double night fishing continued, to assess whether in the future it was responsible for any increase in effort or catch rate that would result in a decline in inshore biomass. To this end, the log books would need to be changed to allow for the adequate recording of two shots in a single night.

At the outset of this project there was a call to ban the practice of double night fishing. To respond directly to this the following list of options (from most to least prohibitive) for legislation have been identified in the case that double night fishing was to be banned.

1. Prohibit two (2) Night Shots during the same Night whereby the *majority* of soak time for the two (2) shots have occurred during the Night
   *(Note this means that the 1st set can occur during the Day and the 2nd haul can occur during the Day but the majority of soak time for both shots must have occurred during the Night)*
2. Prohibit two (2) Shots occur during the same Night whereby both shots have been set and hauled *within* the Night period
3. Prohibit the *setting* of pots during the Night for a second ($2^{nd}$) time
4. Prohibit the setting and pulling of pots *between 9/10pm and 4am*
5. Prohibit Night Fishing/Double Night Fishing practices *in specified areas* (spatial management approach).
6. Establish a *Legal Minimum Soak Time* (e.g. pots must be soaked for 7 hours or more).

If research on changing fishing practices in the TSRLF were considered a priority then it was recommended that the requirements in the logbook for fishers to record 'shot type' and 'date of month' are removed and fishers instead record the time and date of first pot set and time and date of first pot hauled in two separate columns. This would remove the errors surrounding estimates of day and night hours a pot is underwater and the ambiguity in the recording of 'date of month' as the time of set or haul. 'Shot type' can be later determined using sunrise/sunset times and total soak hours. It was also recommended that the logbook no longer allows fishers to combine shots across a given calendar day by simply reporting double the number of pots. This prohibits the matching of other sources of data such as observer records with logbook records and in some cases the two shots could be different 'shot types' (day or night) which is a misrepresentation. It also prevents researchers in the future from examining CPUE based on shot rather than pot. These amendments would enable an accurate assessment of the extent of double night fishing in the TSRLF without depth logger or observer data.

## 4.5 Conclusion

Double night fishing is not the primary cause of declines in the inshore stocks of southern rock lobster. While it was not possible to directly assess the extent of the declines by further dividing the stock assessment model above and below 30 m (objective 1), it was possible to determine that catch rates have been decreasing in both deep and shallow water at similar rates throughout most of the state. Fishers were concerned that an increase in multiple night shots was masking real trends in catch rate data. To address this concern an analysis of catch rates restricted to day shots only was conducted. This analysis showed that overall catch rates declined by 13% state-wide, and catch rates for day shots declined by 19% state-wide.

Double night fishing effort was adequately recorded in the logbooks and therefore captured in the current stock assessment and estimates of CPUE (objective 2). If research on changing fishing practices in the SRL fishery was considered a priority then it was recommended that the requirements in the logbook for fishers to record 'shot type' and 'date of month' are removed and fishers instead record the time and date of first pot set and time and date of first pot hauled in two separate columns. Only 23% (3 out of 13) of fishers who identified as double night fishers undertook double night fishing on greater than 20% of their total days fished, suggesting that of the fishers sampled, double night fishing was not a substantial part of their fishing practice in the time period sampled. Of those that did conduct double night fishing trips, effort (number of shots per day) was slightly higher. There was no difference however in CPUE by shot. The size and number of discarded lobster and the rate of injuries were the same for double night and standard fishing shots. The average size of lobsters was slightly larger for double night shots although this size difference was much smaller than the monthly variation in sizes. Growth rate was reduced in both male and female lobsters that were injured through fishing handling and capture but as double night fishing did not increase the amount of damage to lobsters then it was no more likely to reduce growth rates through injury and discards than standard fishing. There were no differences in by-catch composition between double night and standard shots. Lobster mortality due to octopus predation in pots was reduced with shorter soak time in double night fishing, and efficiency of fishing was increased.

Double night fishing was a cost-effective practice as it increased the efficiency of the fishery (objective 3). Under a TAC, increasing effort and reducing the costs of fishing had positive outcomes for the fishery, with an estimated increased in profitability per boat undertaking double night fishing of between AUD $10,000 and AUD $25,000 per year.

There was not a management strategy evaluation (objective 4) as at current levels of double night fishing the annual stock assessment model should be adequate to record any changes in the fishery. It was recommended that the practice of double night fishing continues to be monitored in the future.

# Chapter 5: Fishing for revenue: how leasing quota can be hazardous to your health

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## 5.1 Abstract

Fisheries management decisions have the potential to influence the safety of fishers by affecting how and when they fish. This implies a responsibility of government agencies to consider how fishers may behave under different policies and regulations in order to reduce the incidence of undesirable operational health and safety outcomes. In the Tasmanian southern rock lobster fishery, Australia, the expansion of the quota lease market under individual transferable quota (ITQ) management coincided with a rise in the number of commercial fishing fatalities, with five between 2008 and 2012. A discrete choice model of daily participation was fitted to compare whether physical risk tolerance varied between fishers who owned the majority of their quota units (quota owners) and those who mainly leased (lease quota fishers). In general, fishers were averse to physical risk (wave height), however this was offset by increases in expected revenue. Lease quota fishers were more responsive to changes in expected revenue than quota owners, which contributed to risk tolerance levels that were significantly higher than quota owners in some areas. This pattern in behaviour appeared to be related to the cost of leasing quota. Although ITQs have often been considered to reduce the incentive for fishers to operate in hazardous weather conditions, this assumes fishing by quota owners. This analysis indicated that this doesn't hold true for lease quota fishers in an ITQ system, where in some instances there remains an economic incentive to fish in conditions with high levels of physical risk.

## 5.2 Introduction

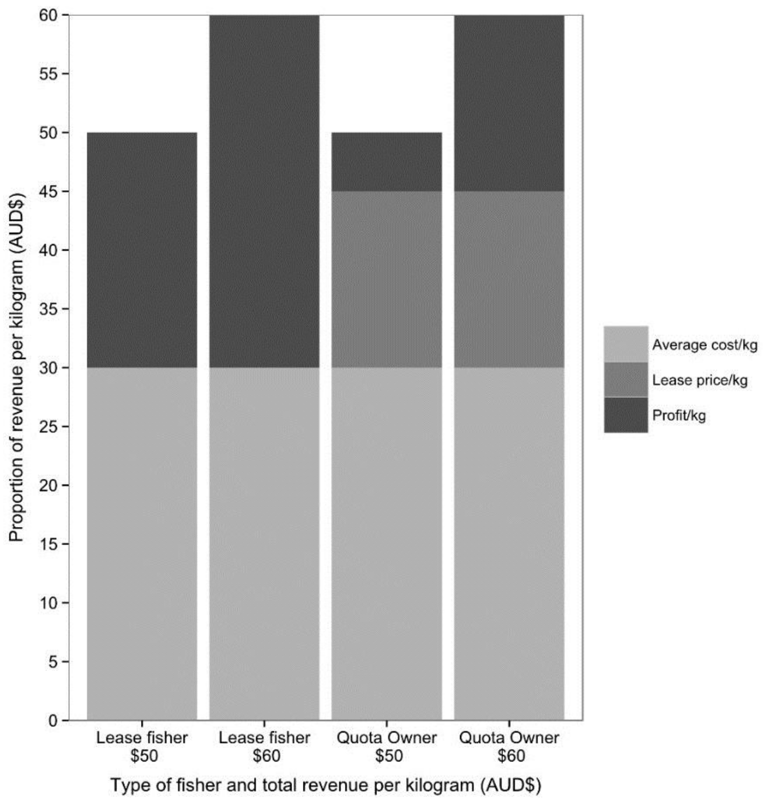
Successful fisheries management requires an understanding of fisher decision-making to ensure the desired behavioural response to institutional or regulatory change (Smith and Wilen, 2005; Hilborn, 2007; Fulton et al., 2011). In many cases, the institution of management measures and policies have altered the incentives and consequent behaviour of fishers in ways unanticipated by their designers (Fulton et al., 2011). This was observed in fisheries where fishing inputs were restricted in an attempt to prevent the total allowable catch (TAC) from being exceeded (Grafton et al., 2000; Hilborn et al., 2005a; Hilborn, 2007). These input restrictions created incentives for fishers to increase their fishing power and therefore undermined the objective of the management rule (Branch et al., 2006; Grafton et al., 2006). Greater individual fishing power can increase overall harvest costs, lower the net economic returns from the fishery and force regulators to implement further controls and shorten the fishing season to prevent TAC overruns. Temporally compressed fishing seasons caused by seasonal closures reduce the price for fish through market saturation, exacerbate gear conflict (i.e. tangled gear), increase the amount of lost gear and force fishers to operate in hazardous weather conditions, reducing safety at sea (National Research Council, 1999; Leal, 2005; Branch et al., 2006).

Individual transferable quota (ITQ) management has been considered an improvement on traditional input control management because it aims to align fisher incentives and thus behaviour with desired fishery outcomes (Grafton, 1996; Grafton et al., 2006). By providing individual fishers, enterprises or vessels with a guaranteed fixed proportion or share of the TAC as quota units, incentives are created for: (i) quota owners to maximise their profits by both harvesting their fixed quota units (or catch) at minimum cost and modifying their fishing behaviour to increase revenue and; (ii) inefficient owners to sell their quota units to more efficient owners and leave the fishery, thereby reducing capitalisation and stimulating fleet rationalisation (Herrmann, 2000; Branch et al., 2006; Grafton et al., 2006). For example, the introduction of ITQs in the Tasmanian southern rock lobster fishery, led to a shift in spatial fishing preferences towards more inshore areas, where lobsters had a higher market price due to their colour composition (Chandrapavan et al., 2009). ITQs also facilitate relaxation and even removal of input controls such as seasonal closures, which can: (i) reduce competitive fishing and associated gear loss; (ii) increase price through improved handling and reduced market saturation and; (iii) improve safety at sea as hazardous weather conditions can be avoided. Ownership of the quota units has also been hypothesised to create a stewardship incentive to conserve the resource and conduct fishing in a manner that protects future stock. This incentive exists because the value of the ITQ allocation is directly proportional to the health of the fishery (National Research Council, 1999). In a comprehensive review of the environmental, economic and social performance of 15 fisheries in the U.S. and Canada following the introduction of ITQ management, Grimm et al (2012) highlighted improvements in economic efficiency, per-vessel revenue, season length, sea safety and the probability of not exceeding the TAC.

These theoretical advantages of ITQ management implicitly assume that fishing is undertaken by those who own the majority of their quota units (i.e. quota owners). In many ITQ fisheries, there is an increasing disconnect between those that own the quota and those that actually fish the quota, with many quota owners preferring to lease out their quota to gain income from their quota asset (Connor and Alden, 2001; Pinkerton and Edwards, 2009). For example, around 60% of the quota in the mid-Atlantic (U.S.) surf clam (*Spisula solidissima*) and ocean quahog (*Artica islandica*) fishery was leased out by quota owners instead of directly fished ten years after the introduction of ITQs (Brandt, 2005). ITQs were introduced in the early 1990s in the British Columbia halibut (*Hippoglossus stenolepis*) fishery and by 2006, 79% of the quota was leased out by quota owners and half of the vessels operating relied on leased quota for the majority of their catch (Pinkerton and Edwards, 2009). Similarly, after ten years of ITQ management in the Tasmanian southern rock lobster (*Jasus edwardsii*) fishery, 37% of the quota was leased out by quota owners, with the number of lease dependent fishers (fishers who only lease quota in) growing over the same period (van Putten and Gardner, 2010).

With lease quota fishing now representing the majority of the fishing effort in many ITQ fisheries it is important to understand how the behaviour of those who lease the majority of their quota units (i.e. lease quota fishers) may vary from that of quota owners. Lease quota fishers are not guided by the same incentive structure generated by ITQ management that theoretically regulates the behaviour of quota owners (Bradshaw, 2004a; Gibbs, 2009). This is because their revenue is not constrained by the quota they own – they are able to obtain effectively unlimited additional quota through the lease market. Further, their profitability is based on the margin between the quota lease price and market price and do not receive any benefit from improvement in the resource rent (which flows to quota owners). Having to pay to lease quota units can create greater incentives for lease quota fishers to respond to short-term changes in expected revenues than quota owners. For example, if the average revenue per kilogram of fish increased by AUD $10, from AUD $50 to AUD $60, with the cost of fishing estimated at AUD $30/kg, the overall profit of a quota owner would increase by 50% but for a lease quota fishers it would increase by 300%, when factoring in a lease price of AUD $15/kg (Figure 5.1). Similarly, with a lease price of AUD $21/kg and revenue of AUD $50 per potlift, a quota owner would only have to set 2,000 pots to make AUD $100,000 (not taking into account individual fixed and variable costs). Conversely, a lease quota fisher (who owned none of their quota units) would have to set 4,596 pots to achieve the same result, which is over 100% more. Therefore, there may be an incentive for lease quota fishers to target higher volume and valued catch relative to quota owners, resulting in them fishing many more days at sea and having less flexibility in deciding when to fish.

**Figure 5.1:** Variations in the profitability of a lease quota fisher and quota owner when the revenue per kilogram of fish increases



The fishing incentives and behaviour of quota owners and lease quota fishers is particularly important when considering regulatory changes that have ramifications for the operational health and safety of fishers (Smith and Wilen, 2005). Fishing is a dangerous occupation with high rates of fatalities and injuries due to the nature of the working conditions and unpredictability of the environment (Mayhew, 2003; Windle et al., 2008; Roberts, 2010; Brooks, 2011). Most empirical evidence on the risk behaviour of fishers suggests that they are generally risk averse (Sutinen, 1979; Mistiaen and Strand, 2000; Nguyen and Leung, 2009), particularly to physical risk caused by weather (Smith and Wilen, 2005; Kahui and Alexander, 2008). Risk aversion or the decision to fish may vary, however, depending on the interactions of factors such as the current management system, expected revenue, skipper experience, vessel size and financial security (Brooks, 2007). For example, in a study of fishing grounds off the north-eastern United States between 1981 and 2000 Jin and Thunberg (2005) found a slow decline in accident rates through time, which could have been associated with the introduction of national safety regulations and outreach programs to promote safety at sea. They also found that increased revenue led to greater number of fishers choosing to fish, while conversely, increased wind speed reduced the number of fishers choosing to go to sea (Jin and Thunberg, 2005).

While ITQ management is often associated with reductions in fishing practices that are hazardous and have the potential to cause harm (Brooks, 2005; Hughes and Woodley, 2007; Woodley et al., 2009), a literature review on physical risk in fisheries by Windle (2008) found mixed results, which were dependent on the concentration of quota ownership in the fishery. Likewise, the expected safety benefits of ITQ management may be reduced for lease quota fishers, who in targeting higher volume and valued catch, to cover fixed debt costs and increase daily profits, may choose to fish more often in hazardous weather conditions.

The Tasmanian southern rock lobster (TSRL) fishery in Australia was used as a case study to examine the effect of ITQs on the physical risk tolerance of lease quota fishers and quota owners. ITQ management was introduced to this fishery in 1998, after which followed two contrasting periods of stock abundance (Hamon et al., 2009; Emery et al., 2014), incorporating a phase of high profitability and catch rates in the early-to-mid-2000s, followed by a phase of low recruitment and depletion of legal sized stock, reduced catch rates and a non-binding (i.e. non-constraining) TAC in the late-2000s. Following the introduction of the ITQ system in 1998 there were no recorded commercial fishing fatalities until 2008. Since 2008, there have been five commercial fishing fatalities while at-sea from a fleet of approximately 225 vessels, with four out of the five fatalities involving fishers who leased in the majority of quota units they held. The expansion of the quota lease market in the fishery over the last decade altered the composition of the fleet, with the proportion of catch taken by lease quota fishers rising (van Putten and Gardner, 2010), particularly between 2008 and 2010, when the lease price declined due to a non-binding TAC (Emery et al., 2014). The expansion of the quota lease market coupled with the rise in the number of commercial fishing fatalities meant that the TSRL fishery was a useful case-study to analyse variations in the physical risk tolerance and behaviour of lease quota fishers and quota owners.

In developing a discrete choice model of fisher participation to examine the risk tolerance of lease quota fishers and quota owners, this study assumed that the decision to fish on a given day, in a particular area, was based on the interaction between significant wave height, length of vessel, home port of vessel, expected revenue, expected revenue variability and the proportion of quota units a fisher owned (initial allocation) to held (initial allocation plus leased in or out quota units) at the end of the fishing season. It was found that in general, fishers were averse to physical risk when choosing to fish, however this was offset by increases in expected revenue. This relationship with revenue differed significantly between quota owners and lease quota fishers in all areas. Lease quota fishers responded more positively to increases in expected revenue than quota owners, which State-wide and in the area off King Island led to physical risk tolerances that were significantly higher than quota owners.  This may be due to the added costs of leasing quota and operating at a diminished daily profit margin between the lease and market price, which created a greater economic incentive for them to fish compared with quota owners. The assumption that ITQs will improve overall sea safety, may not be as applicable to those fisheries that are dominated by fishers who lease in the majority of their quota units, as they may be more motivated in some instances by an economic incentive to fish in hazardous weather conditions. This finding highlights the importance of using models to understand the risk tolerance of fishers, particularly as fisheries transform under ITQ management. It will also assist regulators to understand the potential consequences of legislative decisions on the operational health and safety of fishers.

## 5.3 Methods

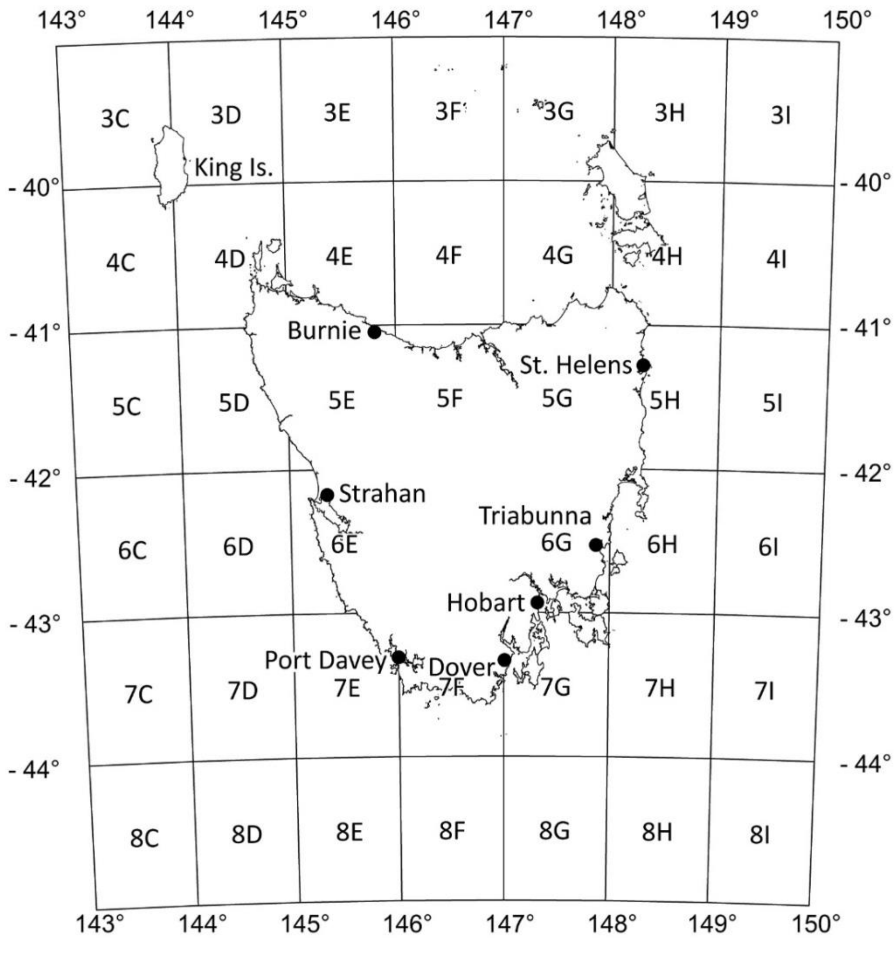
Fishers often make decisions on where and when to fish, what gear to use and/or species to target, on a short-term basis (Eggert and Martinsson, 2004). Much of this can be attributed to the influence of weather and expected utility (Mistiaen and Strand, 2000; Brooks, 2007). Therefore, it was hypothesised that the decision to fish on a particular day was based on the size of a fisher's vessel, the expected revenue, physical and financial risk. Underlying behavioural incentives are not necessarily homogenous (Mistiaen and Strand, 2000; Smith and Wilen, 2005) so fishers were compared based on the proportion of quota owned to held at the end of the fishing season.

### *5.3.1 Data*

Two separate datasets were used to analyse changes in fisher decision-making: fishery catch and effort data and weather data from around Tasmania, Australia. Fishery data containing information on rock lobster vessels (i.e. vessel length, gross registered tonnage [GRT], home port), quota holdings, beach price and catch and effort are compiled in several databases, which are maintained by the Tasmanian Government's Department of Primary Industries, Parks, Water and Environment (DPIPWE). Catch and effort data was derived from the compulsory rock lobster logbook, which provided information on the spatial and temporal details of fishing, as well as catch (kg), number of lobster caught and number of potlifts. Beach price data was derived from processor records, which provided the monthly amount and price of rock lobster purchased from fishers. All price data was adjusted to account for inflation (i.e. deflated) using the Australian consumer price index (http://www.rba.gov.au/calculator/). The amount of quota owned in each year was derived by subtracting quota units leased in and/or adding quota units leased out from quota held at the end of the fishing season.

Significant wave height (m), defined as equal to the average of the highest one-third of the waves, as measured from the trough to the crest (NOAA, 2011), was considered the single most important weather variable affecting safety in this study, as demonstrated in Canadian fisheries (Wu et al., 2005). Daily significant wave height data (m) for coastal Tasmania in the period 1 March 2001 to 28 February 2011 was compiled from the National Oceanic and Atmospheric Administration (NOAA) WAVEWATCH III (NWW3) regional model for wave data (Tolman, 2002). Weather conditions were contrasted on the spatial scale of one-degree blocks (e.g. 3C in Figure 5.2) around Tasmania.

**Figure 5.2:** Map of the Tasmanian southern rock lobster fishery, Australia, with one degree squares (e.g. 3C) used for compulsory logging of the location of daily effort



### *5.3.2 Model development*

A discrete choice model of daily participation was fitted to assess the physical risk tolerance of fishers under an ITQ management system. A fisher's decision whether to go fishing on each day was related to the average significant wave height (m), length of vessel (m), home port of vessel, expected revenue (AUD $ per potlift), expected revenue variability (AUD $ per potlift) and the proportion of quota units a fisher owned to held at the end of each quota year (%). This was modelled using a binomial general linear model (GLM) with a logit link function. This model was applied to data spanning ten fishing seasons between 1 March 2001 and 28 February 2011.

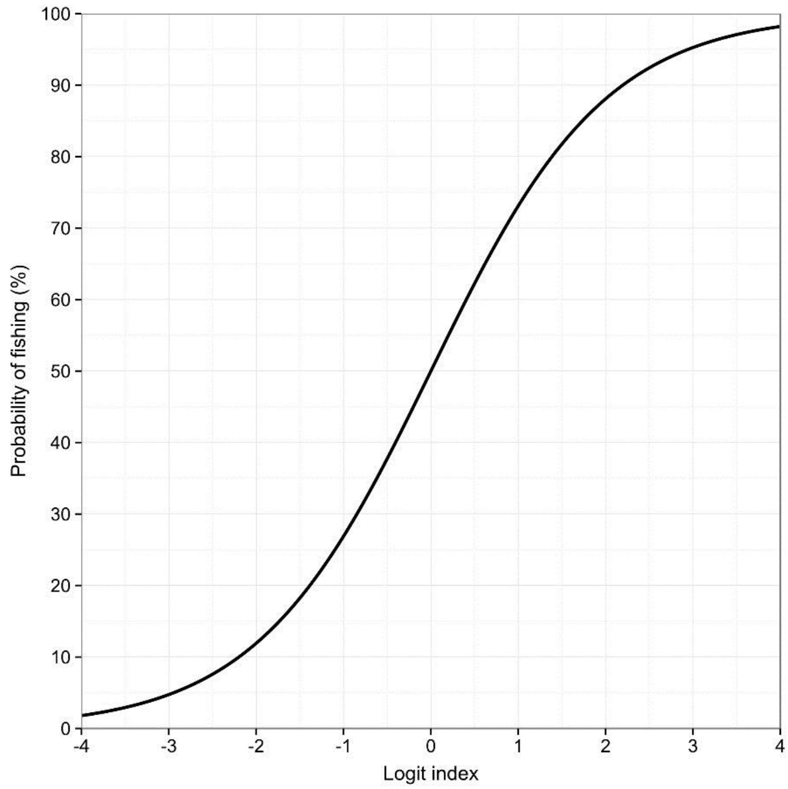
Individual logbook data was used to identify the location where a fisher chose to fish or could have fished each day. As the analysis was undertaken on a one degree spatial scale and there was not a large transfer of vessels between ports, rules were used to determine the location that a fisher could have chosen to fish on the days between fishing trips or during trips that were not reported in the logbook (i.e. where they did not set or haul any pots). These rules were conditional on the location of the previous and succeeding fishing event (i.e. where they last and then next set and hauled their pots). Days during fishery closures, and periods of time incorporating the Christmas break and at the end of the quota year (late February) where a fisher may have caught their entire available quota were excluded from analysis. If the number of days between fishing events exceeded 21 (i.e. 3 weeks) it was assumed the fisher was otherwise occupied (e.g. on holidays or participating in another fishery) and these days were also excluded from analysis. If the location of the previous fishing event was greater than two fishing blocks away from the location of the succeeding fishing event (e.g. 3C to 6E), then it was considered no longer viable to estimate a fisher's location and the intervening days were also excluded from the analysis. For the periods during and/or between fishing events where none of the above exceptions were triggered, fishing location was assigned based on the area of the previous fishing event and the area of the succeeding fishing event. If these were the same (e.g. both 3E), then it was assumed a fisher could have fished the same location (3E) in the intervening period. If the fishing location of the previous fishing event (e.g. 3E) was not the same as succeeding fishing event (e.g. 4D) then it was assumed that the fisher could have fished in either location (3E and 4D) with equal probability during the intervening days.

The binomial GLM was developed to analyse fishing behaviour using R (version 2.13.0) (R Core Team, 2013). Explanatory variables included: (i) significant wave height (m) (ordinal variable); (ii) expected revenue (AUD $ per potlift), expected revenue variability (AUD $ per potlift), vessel length (m) and the proportion of quota owned to held at the end of each quota year (%) (continuous variables) and; (iii) vessel, day, month, quota year, home port of vessel and block (location) (categorical variables). Non-significant variable interactions were removed from the model as indicated in Table 1. It was assumed that fishers would respond positively to expected revenue under the assumption that they either share information or are knowledgeable about the historical CPUE at particular locations/time periods and/or current beach price for lobster. Expected revenue was derived by multiplying the monthly mean State-wide beach price by a prior five-day rolling average of catch-per-unit-effort (CPUE) for a given day in each block fished. This period was chosen after preliminary testing five and three-day rolling averages and observing similar results. Mean CPUE was calculated by dividing the total lobster catch in each block by the total number of potlifts. Monthly mean beach price was determined by calculating the average price paid weighted by the quantities bought by processors. It was considered more appropriate to use monthly rather than daily mean beach price because it was unlikely a fisher would be able to accurately predict the beach price for the day they returned in advance. Fishers' decisions to go fishing were predicted to respond negatively to financial risk caused by variability in expected revenue and expected revenue variability was calculated based on the same assumptions and methods for expected revenue, using the standard errors of CPUE and beach price as a measure of financial risk. Determining the proportion of quota owned to held for each fisher was calculated by simply dividing the amount of quota owned (initial allocation), to held (initial allocation plus leased in or out quota units) at the end of the fishing season. Significant wave height (m) was rounded to the nearest whole number and then grouped into five categories (≤1 m, 2 m, 3 m, 4 m and ≥5 m). Waves that were greater or equal to 5 m were considered "hazardous" for fishers.

As the TSRL fishery has distinct modes of fishing around the State as well as geographical and biological variations that influence wave height and revenue per potlift, the State-wide model was sub-divided into three specific geographical areas for comparison. These included: the east coast and Hobart (blocks 5H, 6H, 6G and 7G), King Island (blocks 3C, 3D, 4C, 4D) and the south-west coast (blocks 5D, 6E, 7E, 7F) (Figure 5.2). The east coast and Hobart area is characterised by a multitude of ports and safe anchorages. Wave height was the lowest of all areas studied but fairly constant through time, averaging (mean ± standard deviation) 1.84 ± 0.76 m in summer and 2.18 ± 1.07 m in winter. Due to its accessibility, historical effort was relatively constant through time (418,513 ± 19,264 potlifts) but average revenue per potlift was the lowest (AUD $35.53 ± 20.02) of all areas studied and has been declining since 2007. The east coast and Hobart area also had the smallest average vessel length (13.2 ± 2.4 m) and GRT (27.2 ± 13.3) of all areas, which reflected its geography and the nature of fishing trips, which ranged from day to week long trips (see supporting information for detailed figures). King Island is located off the north-west coast of Tasmania with wave heights that remained constant through time, averaging 2.36 ± 0.82 m in summer and 3.07 ± 1.22 m in winter. Historical effort was relatively low (249,568 ± 39,579 potlifts) over the period due to the smaller number of vessels based in this area, which also meant that the revenue per potlift was the highest (AUD $53.76 ± 20.77) of all areas. While King Island vessels usually make short day trips, average vessel length (14.8 ± 2.4m) and GRT (35.3 ± 11.9) was comparable to those vessels based on the south-west coast (see Appendix for detailed figures). The south-west coast is characterised by long stretches of exposed, uninhabited coastline with wave heights that were the highest of all areas studied, averaging 2.98 ± 1.36 m in summer and 3.91 ± 1.4 m in winter. The five fatalities in the rock lobster fishery since 2008 all occurred along the south-west coast of Tasmania, which is indicative of its hazardous nature. Despite its ruggedness, historical effort in this region was high (532,148 ± 81,260 potlifts) over the time period studied as well as average revenue (AUD $52.99 ± 23.77) but it has declined since 2006. Some vessels fishing this area travel from the east coast and Hobart area to conduct one-two week fishing trips, so the average length (14.5 ± 2.7 m) and GRT (34.9 ± 16.5) of vessels was higher than the State-wide average over the time period studied (see Appendix for detailed figures).

It is important to note that the discrete choice model has a non-linear response function (logit), which must be understood to interpret the results. Therefore, Figure 5.3 displays a logit index plot, which allows the reader to judge the potential variation in decision-making by adding together coefficients from the model(s) to obtain a logit index and then deduce the probability of fishing. For example, if the logit index is -1 the probability of going fishing is 27%. Similarly, if a factor increases the logit index by one the maximum increase in fishing probability is 23%. This maximum increase is attained if the logit index was zero beforehand but could be negligible if it was already high or low.

**Figure 5.3:** Logit index plot displaying the probability (%) of fishing for a given logit index



## 5.4 Results

The overall effect of wave height was a significant factor in the decision to fish of all fishers in the TSRL fishery (Likelihood Ratio Test [LRT] $p<0.001$ for all areas). Increasing wave height reduced the number of fishers choosing to fish on a given day in all areas, consistent with the expected widespread aversion to physical risk (Table 5.1, Figure 5.4). For example, when expected revenue and revenue variability were AUD $35 and AUD $10 per potlift respectively and significant wave height was 1 m, the model predicted that there was a 60% (59-62%, 95% CI) probability that a quota owner using a 15 m vessel in December 2008 would chose to fish along the east coast and Hobart (7G), compared to only 45% (42-47%, 95% CI), when significant wave height was ≥5 m. Geographical variation in physical risk tolerance was also evident as fewer fishers off the south-west coast chose to fish in more hazardous wave heights (i.e. ≥5 m) (Figure 5.5b). In contrast along the east coast and Hobart (Figure 5.6b) and off King Island (Figure 5.7b), there was a higher tolerance to physical risk displayed by all fishers.

While increasing significant wave height acted as a disincentive for fishers to choose to fish, this was offset by a higher expected revenue (LRT $p<0.001$ for all areas). Expected revenue had a significant influence on a fisher's decision to fish at hazardous wave heights, in all areas (Table 5.1, $p<0.001$), except the south-west coast (Table 5.1, $p=0.67$). For example, when significant wave heights were ≥5 m and expected revenue and revenue variability were AUD $35 and AUD $10 per potlift respectively, the model predicted that there was a 45% (42-47%, 95% CI) probability that a quota owner using a 15 m vessel in December 2008 would chose to fish along the east coast and Hobart (7G), compared to 72% (69-77%, 95% CI), when expected revenue increased to AUD $70 per potlift.

The influence that changes in expected revenue had on a fisher's decision to fish, varied with the level of quota ownership. When the interaction between quota ownership and expected revenue was removed and the model rerun and compared, there was a significant difference in all areas (LRT $p<0.001$). In other words, the lower the proportion of quota owned to held by a fisher, the more influence changes in expected revenue had on their decision to fish. This effect was also significantly influenced by wave height in all areas (LRT $p<0.001$ for State-wide and King Island; $p<0.05$ for East coast and Hobart), except off the south-west coast ($p=0.18$). This led to lease quota fishers both State-wide and off King Island being more tolerant of hazardous wave heights than quota owners in all areas but particularly, State-wide (Figure 5.4) and off King Island (Figure 5.7). For example, when significant wave heights were ≥5 m and expected revenue and revenue variability were AUD $70 and AUD $10 per potlift respectively, the model predicted that there was a 68% (64-73%, 95% CI) probability that a quota owner using a 15 m vessel in December 2008 would chose to fish off King Island (3C), compared to a 81% (75-85%, 95% CI) probability a lease quota fisher would chose to fish. While lease quota fishers were still more likely to choose to fish at hazardous wave heights than quota owners off the east and south-west coasts when expected revenue was high, the difference was not as marked (Figures 5.5 and 5.6). For example, when significant wave heights were ≥5 m and expected revenue and revenue variability were AUD $70 and AUD $10 per potlift respectively, the model predicted that there was a 72% (69-77%, 95% CI) probability that a quota owner using a 15 m vessel in December 2008

**Table 5.1:** Discrete daily choice model comparing the decision to fish among significant explanatory variables

| | State-wide | | | King Island | | | South-West Coast | | | East Coast | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficient | Standard Error | P value | Coefficient | Standard Error | P value | Coefficient | Standard Error | P value | Coefficient | Standard Error | P value |
| Intercept | 1.564 | 0.0474 | **<0.0001*** | 2.1024 | 0.1677 | **<0.0001*** | 0.0566 | 0.1762 | 0.7479 | 1.273 | 0.0712 | **<0.0001*** |
| % Quota Owned/Held | -0.1391 | 0.0197 | **<0.0001*** | 0.1585 | 0.1151 | 0.1686 | 0.124 | 0.0165 | **<0.0001*** | -0.2078 | 0.0361 | **<0.0001*** |
| Length | -0.0103 | 0.0018 | **<0.0001*** | -0.0361 | 0.0047 | **<0.0001*** | 0.0122 | 0.0025 | **<0.0001*** | -0.0206 | 0.0032 | **<0.0001*** |
| Wave height 2m | -0.362 | 0.0298 | **<0.0001*** | -0.3492 | 0.1407 | 0.0131 | -0.0965 | 0.1685 | 0.5667 | -0.3599 | 0.0462 | **<0.0001*** |
| Wave height 3m | -0.6688 | 0.0333 | **<0.0001*** | -0.8469 | 0.1434 | **<0.0001*** | -0.4138 | 0.1677 | 0.0136* | -0.6127 | 0.0528 | **<0.0001*** |
| Wave height 4m | -1.007 | 0.0395 | **<0.0001*** | -1.6317 | 0.1576 | **<0.0001*** | -0.7386 | 0.1685 | **<0.0001*** | -0.9195 | 0.0754 | **<0.0001*** |
| Wave height >5m | -1.463 | 0.0483 | **<0.0001*** | -2.2274 | 0.243 | **<0.0001*** | -1.2948 | 0.1709 | **<0.0001*** | -1.316 | 0.0865 | **<0.0001*** |
| Variability | -0.0454 | 0.0005 | **<0.0001*** | -0.0637 | 0.0014 | **<0.0001*** | -0.033 | 0.0006 | **<0.0001*** | -0.0827 | 0.0016 | **<0.0001*** |
| Revenue | 0.0139 | 0.0005 | **<0.0001*** | 0.0193 | 0.0023 | **<0.0001*** | 0.0204 | 0.0025 | **<0.0001*** | 0.0194 | 0.0011 | **<0.0001*** |
| % Quota Owned/Held: Wave height 2m | 0.0702 | 0.0184 | **0.0001*** | -0.0093 | 0.1215 | 0.9388 | | | | 0.0458 | 0.0343 | 0.1814 |
| % Quota Owned/Held: Wave height 3m | 0.134 | 0.021 | **<0.0001*** | -0.0312 | 0.1236 | 0.8008 | | | | 0.1276 | 0.0365 | **0.0005*** |
| % Quota Owned/Held: Wave height 4m | 0.1871 | 0.027 | **<0.0001*** | 0.0492 | 0.1337 | 0.7127 | | | | 0.1374 | 0.0502 | **0.0062*** |
| % Quota Owned/Held: Wave height >5m | 0.1659 | 0.0333 | **<0.0001*** | 0.2099 | 0.2469 | 0.3952 | | | | 0.181 | 0.0505 | **0.0003*** |
| Wave height 2m: Revenue | 0.0026 | 0.0006 | **<0.0001*** | 0.0032 | 0.0024 | 0.1921 | -0.0052 | 0.0025 | **0.0358*** | 0.0037 | 0.0011 | **0.0008*** |
| Wave height 3m: Revenue | 0.0023 | 0.0006 | **0.0004*** | 0.005 | 0.0025 | 0.0487 | -0.0057 | 0.0025 | **0.0204*** | 0.006 | 0.0013 | **<0.0001*** |
| Wave height 4m: Revenue | 0.0031 | 0.0008 | **0.0001*** | 0.0134 | 0.003 | **<0.0001*** | -0.0063 | 0.0025 | **0.0109*** | 0.0127 | 0.0022 | **<0.0001*** |
| Wave height >5m: Revenue | 0.0076 | 0.0011 | **<0.0001*** | 0.0176 | 0.0053 | **0.0009*** | -0.0011 | 0.0026 | 0.674 | 0.017 | 0.0026 | **<0.0001*** |
| % Quota Owned/Held: Revenue | -0.0001 | 0.0002 | 0.7398 | -0.004 | 0.0021 | 0.0636 | -0.0024 | 0.0003 | **<0.0001*** | 0.001 | 0.0007 | 0.1196 |
| % Quota Owned/Held: Length | 0.0043 | 0.0009 | **<0.0001*** | | | | | | | 0.0056 | 0.0015 | **0.0002*** |
| % Quota Owned/Held: Wave height 2m:Revenue | -0.0007 | 0.0003 | **0.0257*** | -0.0001 | 0.0023 | 0.9633 | | | | -0.0005 | 0.0008 | 0.5435 |
| % Quota Owned/Held: Wave height 3m:Revenue | -0.0016 | 0.0004 | **<0.0001*** | -0.0009 | 0.0024 | 0.7141 | | | | -0.002 | 0.0009 | **0.0236*** |
| % Quota Owned/Held: Wave height 4m:Revenue | -0.0029 | 0.0006 | **<0.0001*** | -0.0056 | 0.0029 | 0.0515 | | | | -0.0018 | 0.0013 | 0.1891 |
| % Quota Owned/Held: Wave height >5m:Revenue | -0.0026 | 0.0008 | **0.0014*** | -0.0117 | 0.0058 | **0.0439*** | | | | -0.0029 | 0.0014 | **0.0317*** |

| | | | | |
|---|---|---|---|---|
| Observations | 371711 | 68252 | 125347 | 129561 |
| AIC | 440024 | 70905 | 155019 | 156126 |
| Dependent variable: Decision to fish | | | | |
| Insignificant variables were removed from the model | | | | |
| Other significant variables not displayed: Quota year, home port of vessel, month and block (area) | | | | |

**Figure 5.4:** The contribution to the logit index for the decision to fish State-wide based on average expected revenue (AUD $) per potlift for average significant wave heights of 2 m (a) and 5 m (b) with an average expected revenue variability of AUD $10

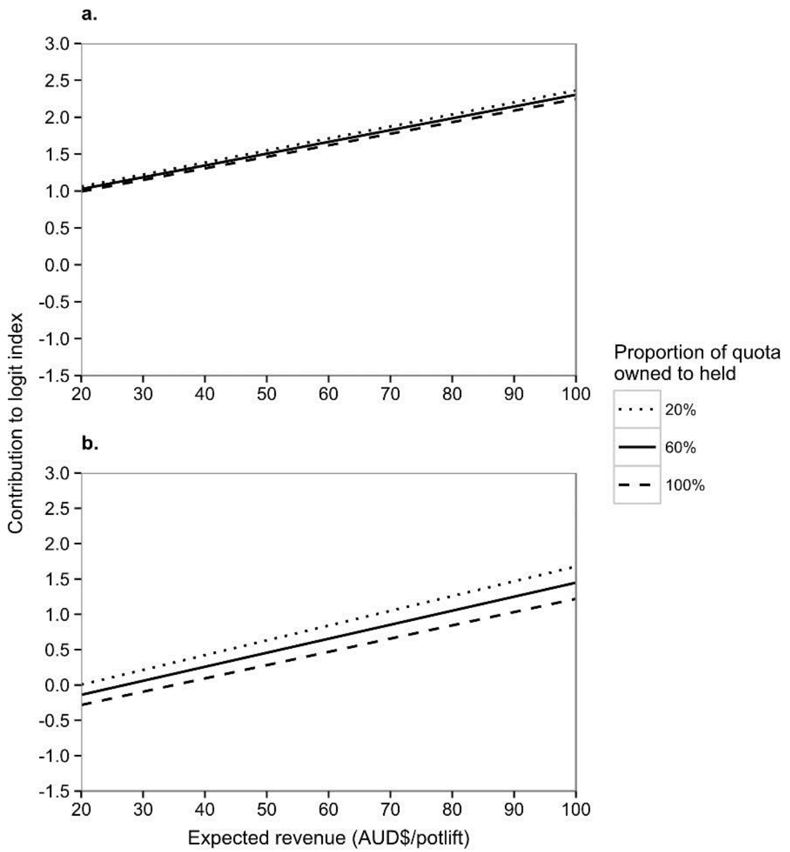



**Figure 5.5:** The contribution to the logit index for the decision to fish along the south-west coast based on average expected revenue (AUD $) per potlift for average significant wave heights of 2 m (a) and 5 m (b) with an average expected revenue variability of AUD $10

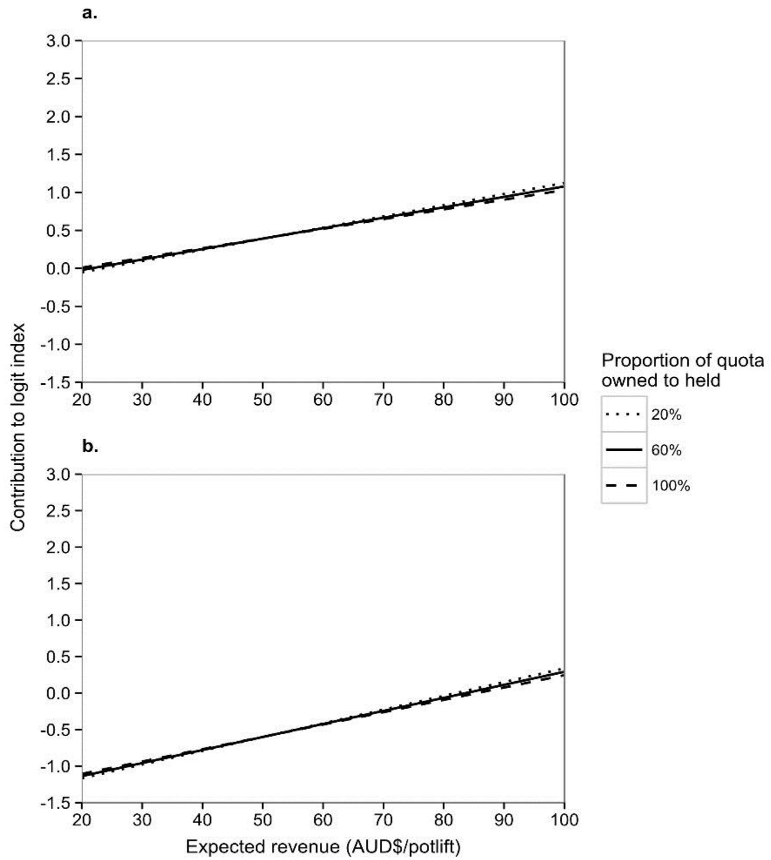


**Figure 5.6:** The contribution to the logit index for the decision to fish along the east coast and Hobart based on average expected revenue (AUD $) per potlift for average significant wave heights of 2 m (a) and 5 m (b) with an average expected revenue variability of AUD $10

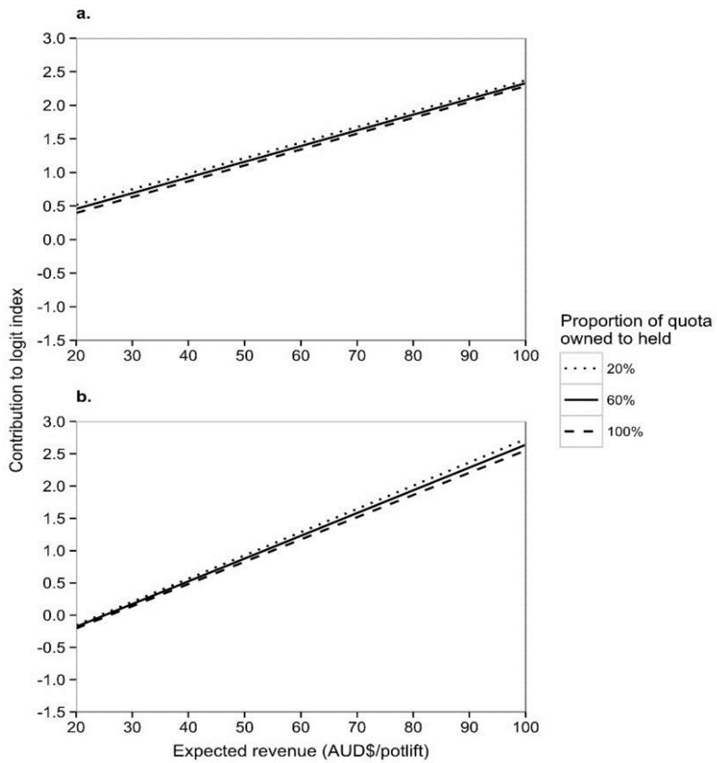
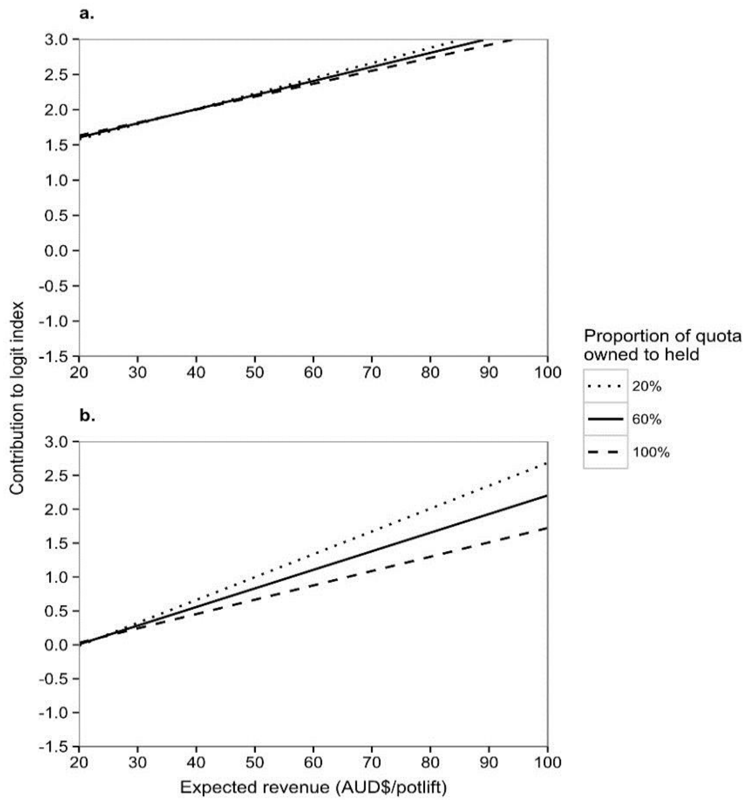



**Figure 5.7:** The contribution to the logit index for the decision to fish off King Island based on average expected revenue (AUD $) per potlift for average significant wave heights of 2 m (a) and 5 m (b) with an average expected revenue variability of AUD $10



would chose to fish along the east coast and Hobart (7G), compared to a 74% (70-78%, 95% CI) probability a lease quota fisher would chose to fish.

To assess whether the amount of quota owned by a fisher influenced the size (i.e. length) of their fishing vessel, a secondary GLM was developed for each area of the TSRL fishery. Those fishers who owned smaller amounts of quota (i.e. lease fishers), used significantly smaller sized vessels while fishing in all areas ($p<0.001$) (Table 5.2). For example, the model predicted that a fisher owning only one quota unit would fish using a 13 m vessel compared to a 17 m vessel for a fisher owning 100 quota units, along the east coast and Hobart (Figure 5.8). Geographical variation among the vessel sizes of lease quota fishers was also evident with those along the east coast and Hobart predicted to use smaller vessels than their equivalents at King Island (Figure 5.8).

**Figure 5.8:** Predicted size of vessel (length) based on the amount of quota units owned by a fisher in the TSRL fishery.

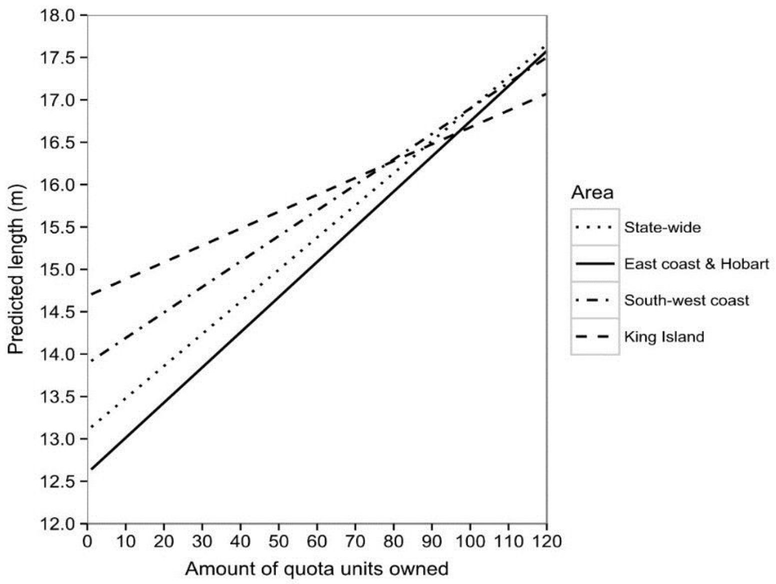


**Table 5.2:** General linear model comparing vessel size to quota owned and the proportion of quota owned to held by fishers in the TSRL fishery

| | State-wide | | | King Island | | | South-West Coast | | | East Coast | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficient | Standard Error | P value | Coefficient | Standard Error | P value | Coefficient | Standard Error | P value | Coefficient | Standard Error | P value |
| Intercept | 13.1004 | 0.1391 | **<0.0001*** | 14.6854 | 0.2593 | **<0.0001*** | 13.8891 | 0.178 | **<0.0001*** | 12.5976 | 0.1564 | **<0.0001*** |
| No. Quota Owned | 0.0379 | 0.0035 | **<0.0001*** | 0.0199 | 0.0057 | **0.0005*** | 0.0301 | 0.0044 | **<0.0001*** | 0.0415 | 0.0042 | **<0.0001*** |
| % Quota Owned/Held | -0.0992 | 0.0252 | **<0.0001*** | -0.1795 | 0.0438 | **<0.0001*** | -0.0878 | 0.041 | **0.0327*** | -0.0433 | 0.0284 | 0.127 |
| Observations | | 1767 | | | 571 | | | 1114 | | | 1139 | |
| AIC | | 8643 | | | 2778 | | | 5540 | | | 5375 | |
| Dependent variable: Length | | | | | | | | | | | | |

## 5.5 Discussion

Fisheries management regulations and policies can both directly and/or indirectly enhance or reduce the level of physical risk to fishers (Windle et al., 2008). For example, the imposition of competitive TAC management historically created a "race to fish" among fishers, which in turn increased the prevalence of hazardous fishing practices and reduced their operational health and safety (National Research Council, 1999; Branch et al., 2006). ITQ management is often associated with reductions in hazardous fishing practices through increased season lengths and incentives to reduce costs (National Research Council, 1999; Hughes and Woodley, 2007; Woodley et al., 2009; Grimm et al., 2012). This assumes however that fishing is being undertaken by quota owners, whose behaviour is theoretically regulated by the incentive structure generated under ITQ management (Bradshaw, 2004a; Gibbs, 2009). This study showed that fishers were generally averse to physical risk, but this was offset by increases in expected revenue. Furthermore, the influence that expected revenue had on a fisher's decision to fish was variable based on the proportion of quota units owned. The lower the proportion of quota owned to held by a fisher, the more influence changes in expected revenue had on their decision to fish. This effect resulted in lease quota fishers being more tolerant of hazardous wave heights than quota owners in all areas but particularly, State-wide and off King Island. The nature of fishing at King Island may explain why the divergence in physical risk tolerance was greater than in other areas examined, as trips in this area usually comprise short day trips. Consequently, the results may indicate that lease quota fishers are only willing to tolerate greater levels of physical risk than quota owners if the trips are brief and there is an ability to expediently return to port. Concurrently, the absence of a significant divergence in fisher behaviour on the south-west coast could be simply due to its hazardous nature and the need to commit to one-two week trip in advance, meaning that both expected revenue and physical risk could change significantly during the length of a trip. Given that lease fishers use smaller vessels in the TSRL fishery, which reduces their operational capacity to withstand hazardous weather conditions, their ability to quickly retreat from deteriorating weather conditions back to the safety of port may be a critical factor in their overall decision-making.

The divergence observed in the behaviour of quota owners and lease quota fishers in the TSRL fishery when expected revenue and physical risk were both high, particularly State-wide and off King Island was either due to misperceptions or misinformation regarding the underlying physical risk and/or expected revenue (Smith and Wilen, 2005) or direct differences in their decision-making. When deciding whether to fish, an individual is motivated by an interplay of short-term drivers such as expected revenue, business structure and long-term drivers, such as their wealth, implicit discount rate, (which reflects their perception of uncertainty in the fishery) and overall risk tolerance (Brooks, 2007; Fulton et al., 2011). Given that there are no conditions in the lease agreements that would regulate the behaviour of lease quota fishers, significant within-season drivers for explaining the divergence in physical risk tolerance of fishers observed in this study were likely to be: (i) the costs of leasing quota and (ii) variations in business structure.

### *5.5.1 The costs of leasing quota*

Quota lease prices should reflect the current resource rent generation in the fishery (Eythorsson, 1996). In many ITQ fisheries, quota lease prices have increased through time due in-part to capital adjustments (Lindner et al., 1992), greater efficiency (Eythorsson, 1996) and reduced inter-annual variability among ecological indicators (Essington, 2010). For example, the quota lease price increased by 45% between 1999 and 2007 in the TSRL fishery and by 49% between 1993 and 2008 in the British Columbia (BC) halibut fishery. From the annual value of their landed catch, lease quota fishers have to recover the costs of leasing quota in addition to other variable (e.g. fuel) and fixed costs (vessel) of fishing. When the lease price is compared as a proportion of the ex-vessel value (i.e. catch value) of the fish in these fisheries (from 40% in 2001 to 64% in 2005 in the TSRL fishery and from 53% in 1993 to 78% in 2008 in the BC Halibut fishery), it is apparent that lease quota fishers face an intensifying "cost-price squeeze between what [they] must pay to lease the quota and what [they] are paid for [their] catch" (Pinkerton and Edwards, 2009). The cost of leasing quota can act as barrier to entry into fisheries (van Putten and Gardner, 2010), create debt-service obligations (Bromley, 2005) and reduce the commercial viability of fishing operations (Davidson, 2010).

High costs of quota leasing result from high demand and a limited supply of quota units (Eythorsson, 1996). For example, in the TSRL fishery, lease quota fishers can only operate above normal economic profit in the long-term if they can procure large portions of the available quota, which increases competition in the market and the cost of leasing quota (van Putten and Gardner, 2010). In Iceland, a severe reduction in the TAC for Atlantic cod (*Gadus morhua*), led to a high demand and competition for quota as fishers tried to remain operational and cover their bycatch of cod while fishing for other species (Eythorsson, 1996). In addition to competing against their counterparts, lease quota fishers must compete in the market against quota owners who in principle, can afford higher lease price prices by virtue of being initially allocated quota units. These quota owners often cross-subsidise within their business and are able to bid up the lease price by virtue of the income generated through the quota units they own (Pinkerton and Edwards, 2009). Under these circumstances the lease price of quota reflects only the quota owners perception of the market value of current resource rent generation, not lease quota fishers (Pinkerton and Edwards, 2009), further undermining their ability to compete in the market and remain viable.

ITQ management also increases the bargaining power of quota owners due to the wealth that the ITQ allocation represents and the necessity of quota units as a prerequisite to fish (Terry, 1993). If large aggregations of quota become concentrated among a small number of owners or vertically integrated companies, the market value of quota may become distorted. This occurred in the lease market for snapper (*Pagrus auratus*) in New Zealand, where quota owners with significant allocations had the power to affect the lease prices they paid and received (Batstone and Sharp, 2000). Similarly, in Iceland, small operators became dependent on large vertically integrated companies for leased quota, resulting in contract fishing and a pattern of tenancy and commercial exploitation developing as lease quota fishers delivered fish to the company's processors for landed prices well below what could be sold at auction, reducing their overall income (Eythorsson, 1996). Leasing quota from vertically integrated companies, or choosing to fish another person’s quota units can also encourage the continuation of hazardous fishing practices if fishers lack control over on-the-water decision-making (e.g. when to fish), due to contractual arrangements/pressures (Windle et al., 2008). While it was not possible to identify those vessels in this study that may be skippered by someone fishing another person's quota, it is anecdotally reported in the TSRL fishery.

While not affected by issues of quota concentration, due to a cap on maximum ownership of around 1.9% of the TAC, the lease market in the TSRL fishery is effective in creating competition amongst lease quota fishers and generating a "cost-price squeeze". This is evident in the lease payments made to quota owners, which appear to capture all the resource rent, as well as in the income of lease quota fishers, which are typically low and below their next best source of employment (van Putten and Gardner, 2010; van Putten et al., 2011). This can lead to the behaviour observed in the TSRL fishery where lease quota fishers, in operating at a lower profit margin, choose to fish during times of hazardous wave heights to maximise the landed value of their product and offset the increased costs of leasing quota. Similar behaviour has also been anecdotally noted in the BC halibut fishery (Davidson, 2010). It could also have led to fishers in the TSRL fishery using smaller (and potentially older) vessels in order to offset leasing costs, which can further increase their risk exposure when choosing to fish at hazardous wave heights.

### *5.5.2 Variations in business structure*

The TSRL fishery is trending towards a fishery dominated by a reduced number of highly active lease quota fishers who are supplied by a growing and broad number of investors, most of whom were previously active quota owners (van Putten and Gardner, 2010; van Putten et al., 2011). The behavioural differences observed between lease quota fishers and quota owners in this study are due, in part, to their diverse business structures. In order to achieve long-term viability in the TSRL fishery, lease quota fishers need to increase the scale of their operations and catch large quantities of fish (van Putten and Gardner, 2010). This has increased competition in the market and contributed to a "cost-price squeeze", which may result in lease quota fishers fishing with smaller (and older) vessels, taking on large amounts of debt or act as a barrier to economic viability and lead to their exit from the industry. This has also meant that their business structures are orientated towards catching large quantities of fish, spending many more days at sea (van Putten and Gardner, 2010) and responding positively to changes in expected revenue to offset their reduced payoff margins created through leasing quota. Conversely, quota owners in being reluctant to enter the lease market, have a finite catch available and in usually having paid off their debts have a business structure favouring a lower fishing effort that is motivated less by changes in expected revenue. A similar experience was evident among small-scale fishers in Norway where those with lower levels of debts had a lower fishing intensity than their counterparts with higher debts (Maurstad, 2000).

In the TSRL fishery the inherent exposure of lease quota fishers to physical risk is therefore higher than for quota owners, despite their natural aversion because: (i) they expend more effort to catch greater quantities of fish (van Putten and Gardner, 2010) and; (ii) use smaller vessels to take their catch. Fishing more days at sea increases the likelihood of fisher fatigue, stress and encountering stochastic weather events while working from smaller vessels increases the risk of injury and fatalities due to reduced working space and operational capacity of the vessel to withstand hazardous weather conditions (Mayhew, 2003). These factors are both intensified by the nature of potting, which is considered one of the most hazardous forms of fishing (Thomas et al., 2001; Woodley et al., 2009; Roberts, 2010). This is because while working on an unstable, shifting platform, fishers must operate machinery (i.e. crab pot launchers or lobster pot winches) and avoid getting caught in ropes/chains and other pots scattered around the deck. Fisheries that use pots usually transport them stacked on top of one another and the process of transferring them into and out of the sea can be treacherous, particularly in rough conditions (Thomas et al., 2001).

### *5.5.3 Issues for consideration*

The reduced profit margin caused by leasing quota in the TSRL fishery has created a business structure orientated towards fishing more days at sea, catching larger quantities of fish using smaller vessels and targeting times of higher expected revenue, often with less regard to the physical risk caused by hazardous weather conditions. This is in contrast to the expectation that ITQ management lowers fishing intensity and improves safety at sea through the removal of "race to fish" incentives (National Research Council, 1999; Grimm et al., 2012). This is because the incentive structure generated by ITQ management, theoretically regulating the behaviour of quota owners, does not apply to lease quota fishers (Bradshaw, 2004a; Gibbs, 2009). This divergence in behaviour among fisher groups in the TSRL fishery is not novel and is in fact a feature of the neoclassical corporate ownership structure created under ITQ management. This structure leads to a separation between ownership and control of wealth (Smith, 1776), where quota owners (principals) contract out or rent to lease quota fishers (agents) to fish on their behalf, as depicted by Gibbs (2008). Because lease quota fishers have different incentives to quota owners (caused by the costs of leasing), their underlying business structures and hence behaviour will deviate from that of quota owners.

These findings highlight the usefulness of behavioural models for examining fisher decision-making and risk tolerance. Further analysis is required to determine whether the behaviour observed in the TSRL fishery is representative of other ITQ fisheries. Future work to strengthen the robustness of this model would be first, to examine the historical fishing behaviour of all fishers in the TSRL fishery individually and then incorporate this knowledge of fishing actions into the model. This would have the advantage of increasing the precision and accuracy of approximating the location of fishers during periods of time between fishing shots for which there was no data, rather than estimating their location based on their previous and succeeding fishing event. Alternatively, a survey of fishing spatial and temporal preferences could be conducted with rock lobster fishers to compare model-predicted preferences to those advised by fishers. Second, to incorporate information on the amount of experience (i.e. years fished) and wealth of individual fishers into the model, which may explain some of the variation observed and provide greater clarity to the findings.

## 5.6 Conclusion

Understanding how humans respond to physical risk has important implications for policy-makers designing fishery policies and associated regulations that may, or are intended to, influence behaviour (Holland, 2008). If the risk tolerance levels of fishers and their effect on individual decision-making are not considered, unexpected and sometimes undesirable outcomes may occur, such as reductions in the operational health and safety of fishers (Smith and Wilen, 2005). Historically, there has been little attempt to correlate the implementation and/or alteration of fisheries management regulations and/or policies with operational health and safety outcomes (Windle et al., 2008). This shouldn't be ignored by government agencies advocating forms of ITQ management in an attempt to improve operational health and safety outcomes given the divergence observed in the risk tolerance and behaviour of lease quota fishers and quota owners in the TSRL fishery. Government agencies should take greater responsibility for regulation and/or policies that may affect fisher incentives and behaviour by ensuring systematic reviews are undertaken prior to their implementation to assess the potential consequences for the operational health and safety of fishers. As highlighted in the literature, fishing is a dangerous occupation with some of the highest fatal accident rates of all occupations (Mayhew, 2003; Roberts, 2010; Brooks, 2011). The incentive to take greater risks and engage in hazardous fishing practices in order to increase revenue is not in the interest of governments, emergency response/search and rescue authorities and/or local fishing communities.

The rise in the fatality rate observed in the TSRL fishery was associated with a significant expansion of the quota lease market. In order to improve operational health and safety outcomes for fishers in ITQ fisheries, governments need to look closely at preventing large-lease dependent fisheries from developing in the first instance. This could be achieved through restrictions on the transferability of quota units to active fishers and through the use of and owner-on-board provisions (e.g. requiring the skipper to own the quota), such as those adopted in the Alaskan halibut and sablefish fisheries (Pinkerton and Edwards, 2009). While these sort of provisions may impose efficiency costs (Costello et al., 2010), it is no doubt worth the prevention of further loss of life at sea.

## 5.7 Appendix

**Figure 5A.1:** Average significant wave height (m) in Tasmanian coastal waters by season (a) and through time (b)

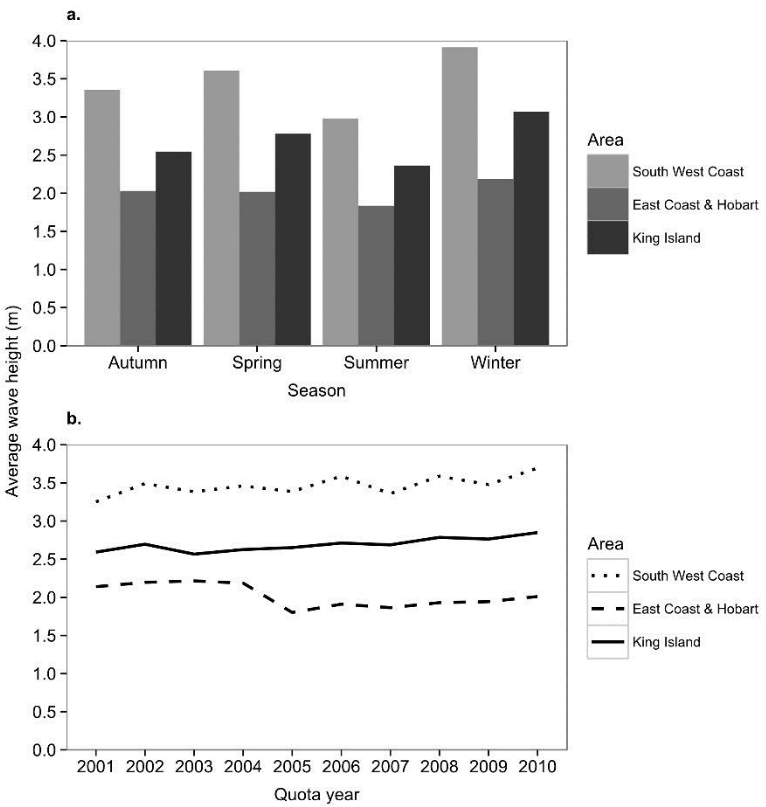



**Figure 5A.2:** Total catch (kgs) (a) and total number of potlifts ('000s) through time (b) in the Tasmanian southern rock lobster fishery

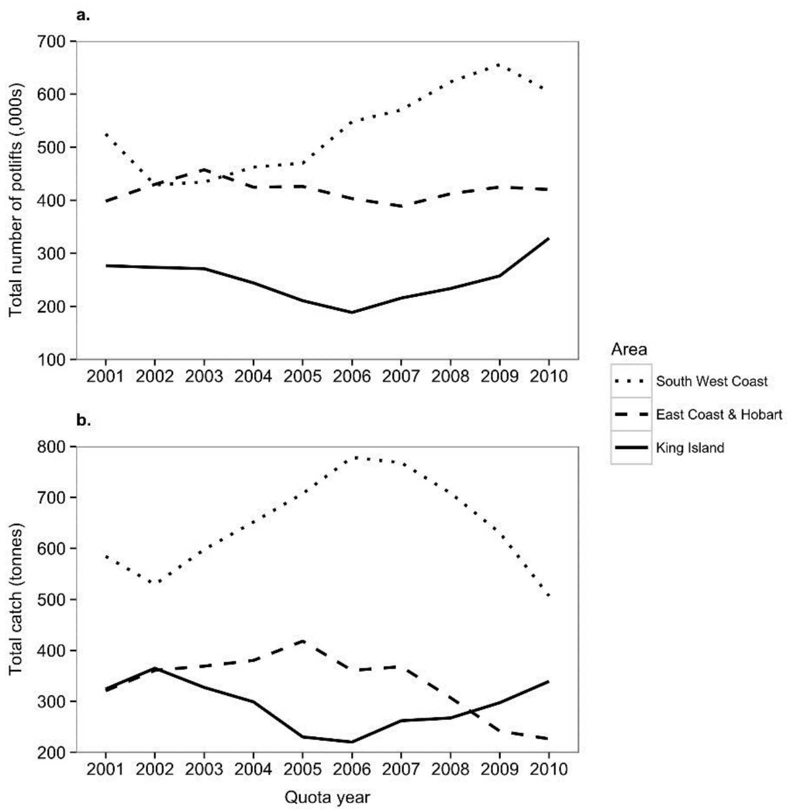


**Figure 5A.3:** Average expected revenue (AUD $) per potlift in the Tasmanian southern rock lobster fishery by season (a) and through time (b).)

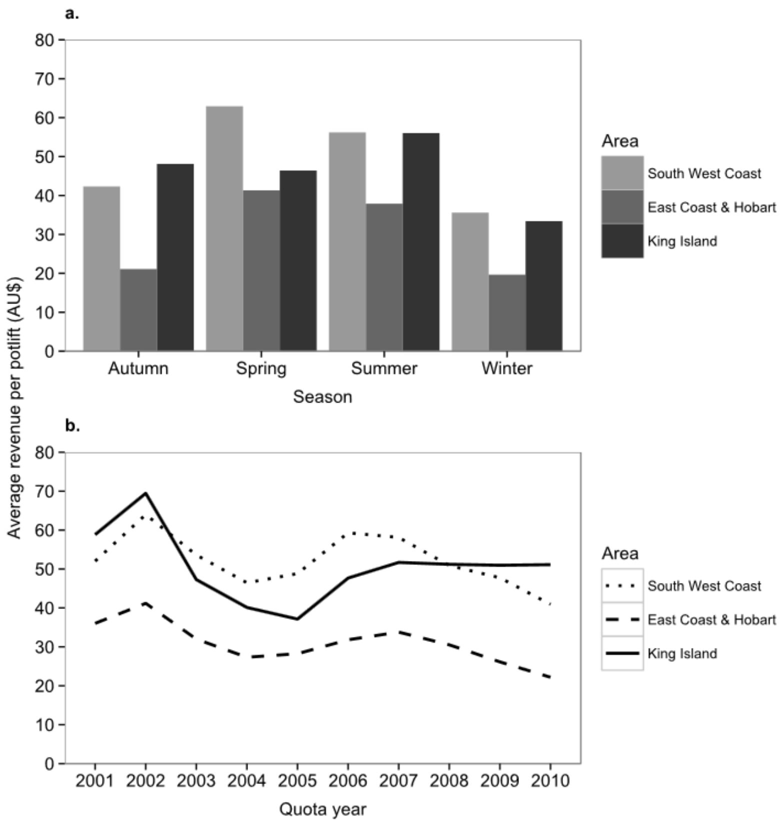
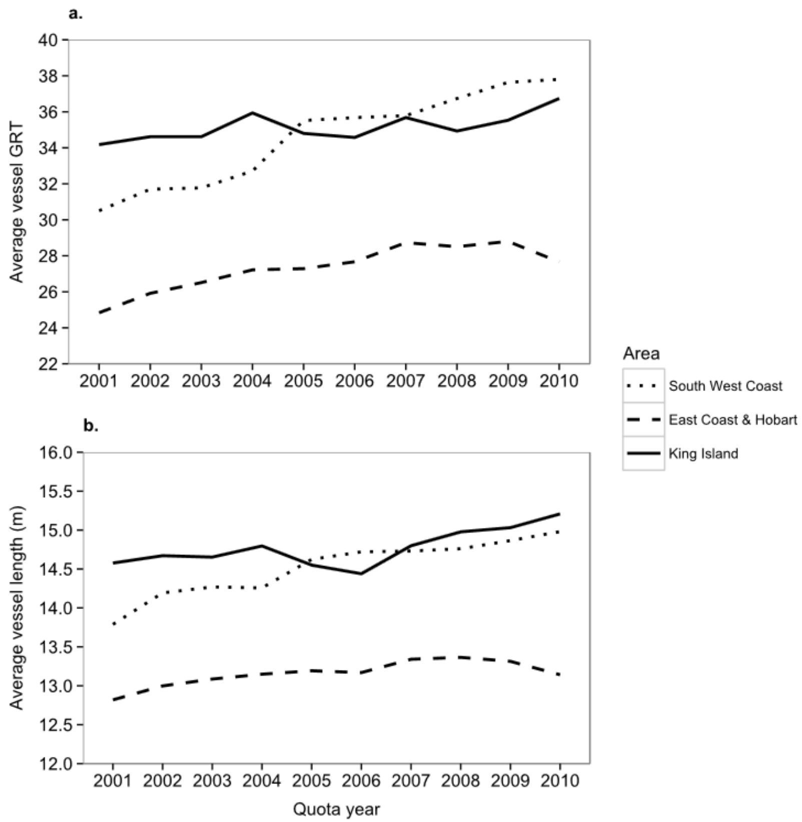



**Figure 5A.4:** Average gross registered tonnage (a) and average length (m) of vessel through time (b) in the Tasmanian southern rock lobster fishery.



# Chapter 6: An experimental analysis of assignment problems and economic rent dissipation in quota managed fisheries

This chapter is *under review* with Ocean and Coastal Management as:

Emery, T.J., Tisdell, J., Hartmann, K., Green, B.S., Gardner, C., and Leon, R. An experimental analysis of assignment problems and economic rent dissipation in quota managed fisheries

## 6.1 Abstract

If the spatial and temporal distribution of fishery resources is not homogenous it creates an assignment problem for fishers. While the adoption of individual (or transferable) quota management in many commercial fisheries has resolved issues of over-appropriation, assignment problems may remain due to the spatial and temporal complexity of fisheries resources, which creates heterogeneity in the economic value of catches. This leads to competition between fishers for the most valuable portions of the stock, which potentially results in dissipation of economic rent. In order to solve an assignment problem, either the quota units must be fully delineated in time or space, or fishers need to agree to coordinate their effort. The ability of two groups of fishers (lease quota fishers and quota owners) to coordinate to solve an assignment problem was investigated using a series of economic experiments. It was found that participants were more likely to cooperate and make socially optimal decisions to prevent rent dissipation when they could communicate amongst themselves and were in an experimental group containing solely quota owners. Furthermore, groups containing both lease quota fishers and quota owners were less likely to cooperate suggesting lease quota fishers were less likely to adopt a socially-optimal strategy for preventing rent dissipation due to: (i) inequality in wealth; (ii) insecurity of tenure; and (iii) asymmetric information exchange. As both types of fishers were aware of these disparities, it appeared to negatively affect the ability of the heterogeneous groups to establish trust and a sense of identity. While quota owners were initially receptive to cooperation, once no reciprocity was observed, they also chose to defect, leading to a downward spiral of rent dissipation. Although these laboratory experiments are greatly simplified compared

to actual quota managed fisheries, they nonetheless provide a prediction and insight into the difficulties heterogeneous fishers have in solving assignment problems under quota management.

## 6.2 Introduction

Fisheries have historically been a common-pool resource, in which appropriation of the resource by one fisher creates an external cost on others and it is difficult to exclude (limit) the access rights of potential (existing) fishers (Schmitt et al., 2000; Maldonado and Moreno-Sanchez, 2009). In such open-access environments fishers face a collective-action (prisoner's) dilemma, in which there is an economic incentive to appropriate more of the resource and ignore the external costs of appropriation imposed on others, provided that expected returns exceed costs (Hackett et al., 1994; Grafton, 1996). This behaviour is rational because a fisher receives all of the returns from appropriating more of the resource, but it is collectively disastrous, because the costs of their actions are shared amongst all fishers (Gordon, 1954; Hardin, 1968).

Understanding the decision-making of harvesters is critical in reducing unexpected and undesirable outcomes of policy implementation and improving overall management of resources such as fisheries (Cárdenas and Ostrom, 2004; Fulton et al., 2011). Economic experiments provide a means of examining human behaviour, alternate policy directives and/or institutional settings under controlled conditions by comparing direct observations with predicted outcomes (Tisdell et al., 2004; Knapp and Murphy, 2010; Reeson et al., 2011). For example, economic experiments have been used to recreate the "tragedy of the [unmanaged] commons"

(Hardin, 1968; Hardin, 1998) in order to investigate the externalities that drive harvesters to over-appropriate the resource. This has been achieved through: (i) prohibiting communication and therefore agreements between participants; (ii) providing participants with complete, symmetric information about the payoffs associated with their appropriation decisions (Maldonado and Moreno-Sanchez, 2009) and (iii) relaxing regulations governing the resource. Under this scenario, non-cooperative game theory predicts that participants will over-appropriate the resource because they will only take into account their own net benefits and assume others will do likewise (Cárdenas and Ostrom, 2004). This private, efficient level of appropriation is called the Nash equilibrium strategy (Nash, 1950). Conversely, a superior payoff for all participants could be achieved through universal reductions in appropriation to the extent that no participant could achieve a higher payoff, without making another have a lower payoff (termed the Pareto-optimal solution) (Ostrom et al., 1994). Researchers predict however, that this will not occur while there remains a more individually rewarding alternative option (Reeson et al., 2011).

Evidence from resource economic experiments illustrate that some individuals make appropriation decisions that depart from the Nash equilibrium strategy reflecting motivations such as altruism, equality and/or reciprocity (Moreno-Sanchez and Maldonado, 2009) or an inherent concern for the environment (Cárdenas et al., 2013). The introduction of communication among participants further enhances the capacity for groups to cooperate and make decisions that are more socially efficient than predicted by the Nash equilibrium strategy (Ostrom et al., 1994; Sally, 1995; Cárdenas, 2000; Tisdell et al., 2004). The supposition is that communication can allow participants to: (a) detect what decisions others in the group are likely to make; (ii) devise a group strategy and make promises or commitments; (iii) develop a process of moralisation among the group and; (iv) create and reinforce a sense of group identity (Messick and Brewer, 1983; Kollock, 1998). These processes can establish and enhance reciprocity, individual reputations and trust to solve a variety of collective-action dilemma problems (Ostrom, 2006). Communication, however does not always improve efficiency. It depends on the rule structure of permitted communication, the form of communication used (i.e. face to face or computer-exchange), as well as the complexity of the social dilemma setting (Hackett et al., 1994; Rocco and Warglien, 1995). Similarly, the framing or context of the collective action dilemma, scrutiny of participant's actions and associated absence of anonymity and/or selection of participants can also affect the level of efficiency (Levitt and List, 2007).

While economic experiments have shown that communication can reduce over-appropriation and improve social efficiency in static situations, for harvesters of fisheries resources the situation is more complex. Fishers must contend with the complex and changing population dynamics of the resource, making it difficult for them to determine whether declines in yield are due to over-appropriation or environmental factors (Schlager, 1994). Furthermore, it is challenging to determine the exact size of the stock, the amount that should be harvested and what effect an individual's catch has on others (Walters and Pearse, 1996). Consequently, many governments have preferred to introduce forms of quasi-private property allocations in an attempt to resolve appropriation problems. Historical evidence confirms that allocating shares of a total allowable catch (TAC) for a given fish stock to fishers as individual quota units (IQs or ITQs when transferable) has reduced over-appropriation of the resource and increased economic efficiency (Grafton et al., 2000; Costello et al., 2010). This is because fishers no longer have an incentive to maximise catch, but rather to minimise costs because their gross revenue is fixed by their quota-holdings in the absence of leasing (Grafton, 1996).

ITQs have been introduced in over 121 different fisheries across at least 22 countries (Chu, 2009; Deacon, 2012) and have been largely effective in reducing appropriation problems through regulations that set: (i) a suitable level of resource appropriation (i.e. TAC); (ii) the methods for appropriating the resource (i.e. permitted fishing gear); and (iii) how output is allocated (i.e. IQs or ITQs). However, many assignment problems remain largely unresolved. Assignment problems arise when the resource is heterogeneous in economic value through time and/or space (Ostrom et al., 1994). Many fisheries are characterised by economic heterogeneity arising from “patchy” stock distributions, spatial/temporal productivity differences or spatial variations in profitability based on the proximity of fishing grounds to ports and market facilities (Cancino et al., 2007). If the quota management system does not impose restrictive spatial and temporal conditions on harvests or there is no centralised authority coordinating effort, fishers will compete for the most valuable portions of the stock (Costello and Deacon, 2007; Deacon and Costello, 2007; Deacon, 2012). In engaging in a competition to appropriate the most valuable portions of the stock, fishers will dissipate part of the fishery’s economic rent through production externalities, such as congestion on fishing grounds (Boyce, 1992; Fell, 2009). One example occurred in the New Zealand southern scallop fishery, where in racing to fish higher valued portions of the stock early in the season, fishers applied an excessive amount of effort that dissipated part of the fishery's economic rent (Bisack and Sutinen, 2006).

Heterogeneity among harvesters can compound assignment problems because it makes the task of agreeing to and sustaining efficient appropriation strategies for preventing rent dissipation more challenging. According to Hackett et al. (1994) and Ostrom (2006) any strategy for averting rent dissipation may produce variable earnings among harvesters, leading to some benefiting more than others. Furthermore, their incentives and/or discount rate (which harvesters apply to future income) may vary. Some harvesters may be motivated by short-term profits, while others may be more interested in long-term asset value and associated preservation of the resource it is dependent upon (Fulton et al., 2011).

Heterogeneity among harvesters has become particularly apparent in fisheries under quota management that allow temporary transferability of quota units within season (e.g. ITQs with leasing). This is because fishers who were bestowed quota units in the initial allocation (quota owners) have historically preferred to retain their quota units after they retire from the fishery and lease them out to gain income from their quota asset (Connor and Alden, 2001). This has given rise to a growing number of fishers who lease quota units (lease quota fishers) (Pinkerton and Edwards, 2009; van Putten and Gardner, 2010). The decision-making and incentives are likely to diverge between the two types of fishers because lease quota fishers are required to bid competitively to lease annual quota and have to recover their leasing costs in addition to other fixed and variable costs of fishing from the landed value of their catch (Pinkerton and Edwards, 2009; Parslow, 2010). Thus increased costs place lease quota fishers under greater financial stress than quota owners. Some economic experiments have illustrated how unequal distributions in wealth or heterogeneity among harvesters can reduce their capacity to coordinate (Hackett et al., 1994; Cárdenas, 2003). They postulate that this is may be due to heterogeneity hindering key triggers of cooperation and collective action, such as reciprocity and trust or building a greater sense of group identity (Kramer and Brewer, 1984; Cárdenas, 2003).

In a seminal paper Cárdenas et al. (2013) conducted a repeated fishery game with ecological complexity in the form of path-dependency of previous use that led to varying payoffs based on the state of resource in any one round. They found that groups regularly over-extracted and depleted the resource and, in the absence of communication, were unable to sustain a reduced level of effort that would enable the resource to recover. They interpreted this to mean that reducing group effort to a level that would have allowed the stock to recover was more expensive in terms of foregone income than the group continuing to allocate high levels of effort. This study modified their design and incorporated the complexity and heterogeneity of the environmental and harvesting systems inherent within fisheries into a series of framed laboratory experiments, with the aim to examine whether a heterogeneous group of fishers could effectively coordinate to reduce rent dissipation, whilst fishing a dynamic resource.

Based on the experimental work conducted by Hackett et al. (1994), Cárdenas and Ostrom (2004) and Cárdenas et al. (2013), it was hypothesised that:

- groups of harvesters who were unable to communicate would fail to resolve the assignment problem and over-extract the dynamic resource, leading to rent dissipation;

- the introduction of communication would improve the ability of groups to coordinate their harvesting to prevent over-extraction of the resource and rent dissipation; and

- heterogeneity among harvesters would moderate cooperation to prevent over-extraction of the resource and promotion of stock recovery.

## 6.3 Methods

### *6.3.1 Experimental Design*

Research questions were tested using a modified version of the experimental design developed by Cárdenas et al. (2013), which was first outlined in Castillo et al. (2011) for fisheries resources and also used by Prediger et al. (2011) for grazing resources in semi-arid rangelands. This protocol was adopted because it reflected the spatial variability (patchiness) of fishing grounds and inter-temporal dynamics of fish stocks, featuring path-dependency of previous use and non-linearity of payoffs. This protocol was altered in this study to first, incorporate harvester heterogeneity, as many quota management systems have two distinct types of fishers (lease quota fishers and quota owners) and second, incentivise rotational fishing, so that areas that were overfished (i.e. depleted) had a higher probability of shifting back to an abundant state. While it would have advantageous to incorporate other ecological, economic or social features of the fishery (e.g. changing market price) in the experimental design, a balance was sought. This was because greater experimental complexity would result in longer experimental session times and a higher probability that participants miscomprehend experimental procedures. Varying other ecological, economic and social features of the fishery are dimensions for future research.

In each experimental session, participants were randomly allocated the role of either a quota owner or lease quota fisher, with the numbers of each dependent on the type of fishery (Table 1). Three different types of fisheries were examined: (i) a lease-dominated fishery; (ii) an owner-dominated fishery; and (iii) an owner-controlled fishery. All fisheries operated under quota management and had a cap on the number of participants fishing each round (6) (i.e. limited entry), the total number of quota units available in the fishery (12) (i.e. TAC), and the number of quota units available to each participant (2) (i.e. quota holding cap). All experimental sessions consisted of 12 rounds and the composition of the group and role of individuals as either a quota owner or lease quota fisher remained unchanged throughout each session, with participants unaware of the actual number of rounds in advance. A 3 x 2 factorial design was used, examining the effect of communication (non-communication and communication factors) across three different types of fisheries (lease-dominated, owner-dominated and owner-controlled factors) (Table 6.1). Three independent sessions (replicates) of each treatment were conducted for a total of 18 experimental sessions. The Appendix contains an example of the instructions and associated quiz provided to participants.

The treatments examining the lease-dominated and owner-dominated fisheries in each round consisted of two stages: a discriminative price, closed call market for quota packages and a fishing decision. The treatments examining the quota-controlled fishery consisted of only one stage: a fishing decision.

**Table 6.1:** Experimental design

| | *Factor* | *Communication* | | *Definition* |
|---|---|---|---|---|
| | | *Communication* | *Non-communication* | |
| *Type of fishery* | *Lease-dominated* | 3 sessions | 3 sessions | 6 lease quota fishers<br>2 quota owners |
| | *Owner-dominated* | 3 sessions | 3 sessions | 3 lease quota fishers<br>4 quota owners |
| | *Owner-controlled* | 3 sessions | 3 sessions | 6 quota owners |

In the first stage, lease quota fishers were given 60 seconds to submit a bid in a discriminative price, closed call market in order to acquire a quota package containing two units from an external regulatory authority. A competitive market for quota packages was created by setting the demand (i.e. number of bidders) greater than the supply (i.e. number of packages available). In the lease-dominated fishery, the highest four out of the six bidders acquired quota units and in the owner-dominated fishery, the highest two out of three bidders acquired quota units each round. The successful acquisition of a quota package through the tender system allowed a lease quota fisher to make a fishing decision in that round, with the price of their bid subtracted from the payoff attained from their fishing decision. Failure to acquire a quota package meant that a lease quota fisher was excluded from making a fishing decision in that same round and their payoff for that round was 20 experimental dollars. Lease quota fishers only knew whether their bid was successful or not and were not provided with any information on the bids submitted by other participants, as per a typical quota lease market. Participants were not allowed to communicate with each other during the discriminative price, closed call market.

The presence of a quota lease market in this experiment meant that lease quota fishers, in contrast to quota owners who were bestowed a quota package each round from the authority and whose profit was only affected by the state of the resource, had: (i) reduced security of tenure through access to quota; (ii) diminished wealth by having to pay to acquire a quota package; and (iii) profitability determined by the margin between the price paid to lease quota and the revenue accrued from fishing.

In the second stage, participants who had a quota package were given 60 seconds in the non-communication treatment or 120 seconds in the communication treatment to make a fishing decision. The first part of this decision involved determining whether to expend quota units in one or two areas (area *a* and area *b*). The second part involved deciding how many quota units to expend in each area (zero, one or two). Individual decisions were made privately and individually (i.e. they were not known to the rest of the group during or after the session) with only the aggregate group effort in each area presented to participants at the end of each round. A total of six participants made a fishing decision in each round with a maximum aggregate group effort of 12 units. In the communication treatment, only participants who were allocated a quota package or acquired a quota package through the tender were allowed to communicate with each other online through the experimental software (which was analogous to instant messenger). Lease quota fishers who were not successful in attaining a quota package were not allowed to observe or participate in the group discussion.

A decision table (Table 6.2) was used by participants to calculate their payoff based on the resource state (abundant or depleted) at the start of the round and their individual fishing decision. The payoff that a participant received was dependent on: (i) which area(s) they chose to expend their quota units, (reflecting the spatial variability of fishing grounds) and; (ii) the stock status of those area(s), which was determined by fishing effort in previous rounds, (reflecting the inter-temporal dynamics of the fish stock). For example, if the aggregate group effort in an area that was in an abundant state exceeded the maximum carrying capacity of six units in round *s,* that area (resource) would change to a depleted state in round *s+1*. Conversely, if the aggregate group effort during round *s* was less than or equal to six quota units, the resource would remain in an abundant state in round *s+1*. An area could recover from a depleted state if the aggregate group effort was three or less units for two consecutive rounds. This meant that there were six possible ecological states in any one round, as per the design of Prediger et al. (2011):

- AA: both areas are in an abundant state

- $AD_1$: one area is in an abundant state; the other area is in a depleted state but has already recovered one round

- $AD_2$: one area is in an abundant state; the other area is in a depleted state and needs two rounds to recover

- $D_1D_1$: both areas are in a depleted state but have already recovered one round

- $D_1D_2$: one area is in a depleted state and needs two rounds to recover and the other area has already recovered one round

**Table 6.2:** Decision table with payoffs in experimental dollars based on the area, resource state and amount of quota units expended by an individual. Empty values denote the quota expenditure combinations that are not possible as each individual can expend only a maximum of two quota units.

| | | | ***Area A*** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | ***Abundant*** | | | ***Depleted*** | | |
| | | *Units* | *0* | *1* | *2* | *0* | *1* | *2* |
| ***Area B*** | ***Abundant*** | *0* | $ 20.00 | $ 107.00 | $ 200.00 | $ 20.00 | $27.00 | $50.00 |
| | | *1* | $ 53.00 | $ 160.00 | | $ 53.00 | $80.00 | |
| | | *2* | $ 100.00 | | | $100.00 | | |
| | ***Depleted*** | *0* | $ 20.00 | $ 107.00 | $ 200.00 | $ 20.00 | $ 27.00 | 50.00 |
| | | *1* | $ 40.00 | $ 147.00 | | $ 40.00 | $ 67.00 | |
| | | *2* | $75.00 | | | $ 75.00 | | |

When the stock was in an abundant state, quota units allocated to area *a* provided a higher payoff than area *b* (Table 6.2). When the stock was in a depleted state however, area *b* had a higher payoff as it was more resilient. Consequently, it was predicted that in round one, all participants would allocate their two quota units to area *a* and the stock would be depleted at the end of the round. In round two, all participants would then choose to allocate their two quota units to area *b*, which remained abundant, resulting in both areas *a* and *b* being in a depleted state ($D_1D_2$) at the commencement of round three. In that situation allocating two quota units to area *b* resulted in the highest payoff, so all players would continue to allocate their two quota units to area *b* for as long as area *a* was in a depleted state. In periods 4, 7 and 10, area *a* would recover to an abundant state and participants would again allocate their two quota units to this area as it yielded the highest payoff. Therefore the stable individual payoff-maximising strategy, given the expected behaviour of the other players (Nash equilibrium strategy), would lead to a rotation system where area *a* would become abundant every third round (from the second round). Conversely, the social optimal strategy was for all participants to synchronise their fishing effort and allocate one quota unit to both area *a* and *b* in order to maximise the long-term payoff to the group. Participants therefore faced both a coordination dilemma in choosing where to allocate their quota units and a collective-action dilemma in there being a dominant strategy to defect (i.e. maximise individual payoff).

### *6.3.2 Experimental Procedure*

All the experiments were carried out in the University's experimental computer laboratory between August 2012 and August 2013 using custom-designed software. At the beginning of each session, participants were randomly assigned to a computer and asked to read through a set of instructions before attempting a multiple-choice quiz to test their understanding of the instructions. Once they had answered all the questions correctly they could participate in the experiment. Researchers were on hand to supervise and assist at all times. Participants were not allowed to communicate throughout the course of the experiment except through the experimental software as appropriate. Most experimental sessions lasted between 60 and 90 minutes (including the time taken for the instructions and quiz), with participants receiving earnings between $US10 (which was the minimum show up fee) and $US50 (average $US35). Participants were confidentially paid their earnings in cash at the end of each experimental session.

### *6.3.3 Experimental analysis*

Student subjects were recruited from across the university campus through advertising billboards and a designated website, before being randomly selected to participate in individual sessions using a database of student volunteers who had registered to take part in experiments.

While the use of volunteer students is common in laboratory experiments, some authors believe results from these experiments are not representative of the general population due to divergent social preferences (Levitt and List, 2007; Loomis, 2011). Therefore it is contended that student samples provide a biased estimation of social preferences for the analysis of economic outcomes (Falk et al., 2013). Recent empirical evidence however, has shown that volunteer students display similar behavioural patterns to non-students, with no systematic overestimation of social preferences, meaning that students are appropriate subjects on which to examine human behaviour in contemplation of public policy design (Exadaktylos et al., 2013; Falk et al., 2013; Janssen et al., 2011). It is also important to note that the intention of this experiment was not to measure actual levels of socially optimal behaviour but investigate what factors (e.g. policy instruments) may affect those relative levels (Kraak, 2011). The idea being that policy instruments instituted in a lab environment would influence human behaviour at a basic biological and psychological level representative of the field environment (Kraak, 2011).

### *6.3.4 Experimental analysis*

The experimental economic data was analysed with a population average (marginal) model using a generalised estimating equation (GEE) approach in R (version 3.0.0) (R Core Team, 2013). The GEE approach was developed by Liang and Zeger (Liang and Zeger, 1986) and Zeger and Liang (Zeger and Liang, 1986) and was used because the data was in longitudinal form with multiple observations from the same player through time (i.e. length of the experiment). Consequently, the decisions of players may have been correlated, as their decision in round $s+1$ could be highly associated with their decision in round $s$, which would violate the assumption of independence made by traditional regression procedures. A GEE approach allowed an analysis of changes in the population mean, which was the average probability of making a Nash decision across all players, given changes in covariates, while accounting for within-player non-independence of observations when deriving the variability estimates of these coefficients (Hubbard et al., 2010). GEE is a satisfactory approach to the analysis of longitudinal data when the dataset consists of short, complete sequences of measurements (i.e. the decisions of six players) observed across a common time period (i.e. twelve rounds) on many subjects (126 players) and a conservative selection in the choice of working correlation matrix is applied (Diggle et al., 2002). In fact, while efficiency of estimates can be improved by correctly specifying the working correlation matrix, the GEE approach remains consistent as well as providing correct standard errors even if the nested correlation structure is incorrectly specified or not precisely defined (Lalonde et al., 2013; Tze and Small, 2007; Freedman, 2006; Liang and Zeger, 1986).

There were three steps to fitting the model in this study using a GEE approach (Zuur et al., 2009). The first step involved specifying a regression model with $K$ coefficients for the mean and no interactions:

$$E[Y_{is}] = p_{is} = e^{\alpha + \sum_{k=1}^{K} \beta_{isk} X_{isk}}$$

Where $\alpha$ is the intercept, $\beta$ is the coefficients vector, $X$ is the covariates matrix and $Y_{is}$ is 1 if a Nash decision is made in round $s$ by player $i$ and 0 if a non-Nash decision is made. Therefore $Y_{is}$ is binomially distributed with probability $p_{is}$. Given the response variable was binary, the link transformation function was logit, so the covariates were transformed by the log of the odds ratio (the ratio of a response of "1" in the data to a response of "0"). Covariates included *treatment*, *fishery, session* and *state of the resource* as categorical variables and *cumulative income* and *experience* (i.e. number of rounds played) as continuous and discrete control variables respectively. An interaction term *treatment x fishery* was included to determine whether players in a particular fishery with or without communication were more likely to make a Nash decision. The clustering variable was *player* with a total of 126 unique players across the 18 experimental sessions with a maximum of 12 (possibly) correlated responses. Wald chi-square tests informed the removal of non-significant variables such as *fishery type* (i.e. lease fisher or quota owner) from the final model.

The second step involved specifying the mean-variance relationship of the observed data so the regression coefficients could be properly interpreted:

$$var(Y_{is}) = p_{is} \times (1 - p_{is})$$

A binomial distribution was chosen because the response variable was in binary form (i.e. yes or no).

The third step involved specifying a working correlation structure which was believed to be present among responses within players ($i$) between the rounds $s$ and $t$:

$$cor(Y_{is}, Y_{it}) = \rho^{|s-t|}$$

An auto-regressive (AR-1) correlation structure was chosen because the data was in temporal form (clustered over time) and had the lowest Pan's quasi-likelihood under the independence model information criterion (QIC) score (Pan, 2001) following testing.

## 6.4 Results

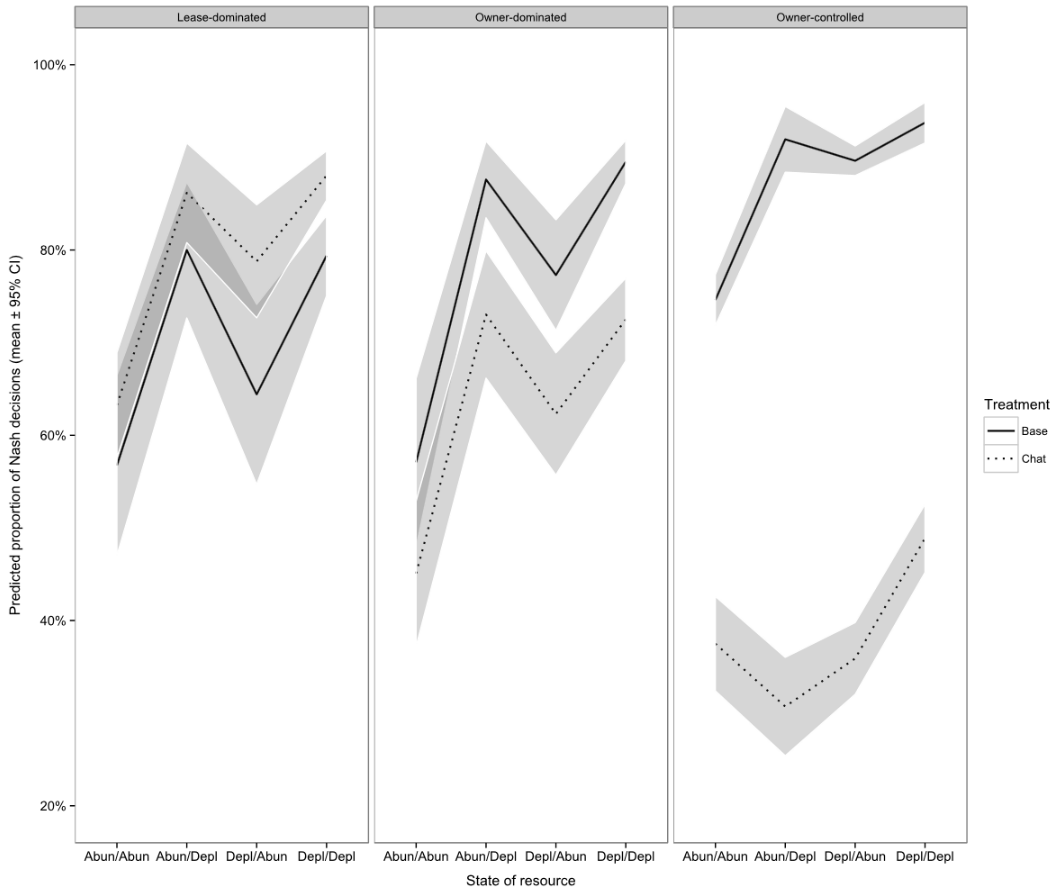
### *6.4.1 Assignment problems*

In the absence of communication, participants in all three fisheries made decisions that were close to their Nash equilibrium strategy for a given resource state (Figure 6.1), leading to a cyclical pattern of congestion, spatial depletion and rent dissipation. There was no significant difference in the mean decision of all players in choosing Nash between the lease-dominated and owner-dominated fisheries ($p=0.85$) but players in the owner-controlled fishery were significantly more likely to make Nash decisions than those in the lease-dominated fishery ($p<0.02$) (Figure 6.1, Table 6.3). For example, when both areas were in an abundant state (AA) at the start of round one, the socially optimal strategy was to place one quota unit in each area, which would have prevented rent dissipation and resulted in the maximum group payoff. As hypothesised however, participants in the non-communication treatment allocated most of their quota units to area *a*. In the lease-dominated fishery the mean quota units (±SE) allocated to area *a* when the resource was abundant in both areas was 1.67 ± 0.08 per participant. This was even higher for the owner-dominated fishery at 1.83 ± 0.09 per participant and the owner-controlled fishery at 2.00 ± 0.00 per participant. When the resource state was abundant in both areas, the model predicted (95% CI) a player would choose Nash in the lease-dominated fishery 57% (48-66%) of the time, which was similar to the owner-dominated fishery at 57% (48-66%), but lower than the owner-controlled fishery at 75% (72-77%).

If the resource at the end of round one was in state $AD_2$, the socially optimal scenario was for three participants to allocate one unit to each area and the other three participants to only fish one unit in area *b*. As predicted however, participants allocated most of their quota units to area *b*, thereby depleting both resources by the start of round three. For example, in the lease-dominated fishery, the mean quota units allocated to area *b* when the resource was depleted in area *a* and abundant in area *b* ($AD_2$) was 1.78 ± 0.08 per participant. This was even higher for the owner-dominated fishery at 1.83 ± 0.09 per participant but similar to the owner-controlled fishery at 1.78 ± 0.13, albeit with more variability. When the resource state was abundant in area *b* and depleted in area *a*, the model predicted (95% CI) a player would choose Nash in the lease-dominated fishery 64% (55-74%) of the time, which was lower than both the owner-dominated fishery at 77% (71-83%), and the owner-controlled fishery at 90% (88-91%).

In round three, both areas were usually in a depleted state ($D_1D_2$) with varying recovery times. In this case, the socially optimal solution was for three participants to fish one unit only in area *a* and the other three to fish one unit only in area *b*. As area *b* was more resilient to depletion than area *a,* and had a higher payoff, participants predictably allocated the majority of their quota units to area *b*. For example, in the lease-dominated and owner-dominated fisheries the mean quota units allocated per participant to area *b* were similar: 1.74 ± 0.04 and 1.77 ± 0.05 respectively, but were higher for the owner-controlled fishery at 1.87 ± 0.04. When the resource state was depleted in both areas, the model predicted (95% CI) that a player would choose Nash in the lease-dominated fishery 79% (75-84%) of the time, which was lower than both the owner-dominated fishery at 90% (87-92%), and the owner-controlled fishery at 94% (88-91%). When both areas were in a depleted state, participants across all fisheries were more likely to choose Nash than in any other resource state.

**Figure 6.1:** Comparing the predicted probability of making a Nash decision across non-communication and communication treatments for each fishery in each resource state.




Once area *a* became abundant again ($AD_2$), the socially-optimal solution was for three participants to allocate one quota unit to each area and then three to allocate only one unit to area *a* and maintain both areas in an abundant state. What followed, however, was a cyclical pattern of depletion where all participants would allocate the majority of their quota units to area *a*, depleting it again before allocating their quota units to area *b* for two rounds while they waited for area *a* to recover. Consequently, area *a* never remained in an abundant state and area *b* never recovered from a depleted state. For example, in the lease-dominated fishery the mean quota units allocated to area *a* when the resource was abundant in area *a* and depleted in area *b* was 1.82 ± 0.04 per participant. This was even higher for the owner-dominated fishery at 1.92 ± 0.04 per participant but similar again to the owner-controlled fishery at 1.83 ± 0.07 per participant. When the resource state was abundant in area *a* and depleted in area *b*, in the model predicted (95% CI) that a player would choose Nash in the lease-dominated fishery 80% (73-87%) of the time, which was lower than both the owner-dominated fishery at 88% (83-92%), and the owner-controlled fishery at 92% (88-96%).

### *6.4.2 The effect of communication on decision-making*

The introduction of communication allowed participants to discuss fishing strategies among the group prior to making a final decision. They could attempt to establish an agreed plan for coordinating their fishing effort and improve their returns through cooperation (Ostrom, 1990).

**Table 6.3:** Generalised estimating equation regression for the probability of making a Nash decision

| | Coefficient | Standard Error | Wald | P value |
|---|---|---|---|---|
| Intercept | -7.6627 | 1.1151 | 47.22 | **<0.0001*** |
| Treatment: Communication | 0.4236 | 0.4823 | 0.77 | 0.3798 |
| Session II | 0.6139 | 0.3181 | 3.72 | 0.0537 |
| Session III | -0.1317 | 0.2726 | 0.23 | 0.6289 |
| Fishery: Owner Controlled | 1.2804 | 0.5302 | 5.83 | **0.0157*** |
| Fishery: Owner Dominated | 0.1063 | 0.5524 | 0.04 | 0.8474 |
| State of Resource: Abun/Depl | 0.9566 | 0.2544 | 14.14 | **0.0002** |
| State of Resource: Depl/Abun | 1.1431 | 0.2849 | 16.10 | **<0.0001*** |
| State of Resource: Depl/Depl | 1.8362 | 0.3263 | 31.67 | **<0.0001*** |
| Experience | -0.9227 | 0.1423 | 42.07 | **<0.0001*** |
| Cumulative Income | 0.6345 | 0.0856 | 54.89 | **<0.0001*** |
| Treatment: Communication*Fishery: Owner Controlled | -2.8039 | 0.6583 | 18.14 | **<0.0001*** |
| Treatment: Communication*Fishery: Owner Dominated | -0.7159 | 0.6857 | 1.09 | 0.2965 |

*Correlation structure: AR-1*

*Distribution: Binomial*

*Estimated correlation parameters: (estimate: 0.05, standard error: 1.825)*

*Number of clusters: 126*

*Maximum cluster size: 12*

While the socially-optimal strategy to resolve the assignment problem and prevent rent dissipation was relatively simple in theory, participants found cooperation difficult, with no group across any fishery able to maintain the resource abundant in both areas for all 12 rounds of the experiment. Cooperation was particularly difficult in the lease-dominated fishery, where the introduction of communication had no significant effect (p=0.38) on reducing rent dissipation from the non-communication treatment (Figure 6.1, Table 6.3). When the resource was abundant in both areas, the mean decision (±SE) in area *a* remained high, above the socially-optimal level at 1.56 ± 0.12. Similarly, when the resource was depleted in both areas, the mean decision in area *b* was 1.86 ± 0.04. The model predictions for the probability of making a Nash decision in the lease-dominated fishery with communication were on average higher than the non-communication treatment. When the resource state was abundant in both areas, the model predicted (95% CI) that a player would choose Nash 63% (58-69%) of the time compared to 88% (85-91%) of the time when the resource state was depleted in both areas.

The introduction of communication in the owner-dominated fishery marginally improved the coordination of the participants, but had no significant effect ($p=0.48$) on reducing rent dissipation from the non-communication treatment (Figure 6.1, Table 6.3). Furthermore the probability of participants making a Nash decision was not significantly different from the lease-dominated fishery with communication ($p=0.30$). Participants generally were not able to solve the collective-action dilemma, remaining trapped in the same cyclical pattern of resource depletion that occurred without communication. When the resource was abundant in both areas, the mean decision in area *a* remained high, above the socially-optimal level at 1.44 ± 0.12. Similarly, when the resource was depleted in both areas, the mean decision in area *b* was 1.67 ± 0.06. The model predictions for the probability of making a Nash decision in the owner-dominated fishery with communication were lower than both the non-communication treatment and lease-dominated fishery with communication. When the resource state was abundant in both areas, the model predicted (95% CI) that a player would choose Nash 45% (37-53%) of the time compared to 72% (68-77%) of the time when the resource state was depleted in both areas.

The advent of communication improved cooperation among participants in the owner-controlled fishery with a significant reduction ($p<0.001$) in rent dissipation from the non-communication treatment (Figure 6.1, Table 6.3). Furthermore the probability of participants making a Nash decision was significantly reduced compared to both the lease-dominated fishery ($p<0.001$) and owner-dominated fishery ($p<0.001$) with communication. While the groups did not keep both areas abundant for the entire 12 rounds of the experiment, they did attempt to solve the collective-action dilemma by refraining from over-allocating quota units to more profitable areas, which characterised other fisheries in the communication treatment. When the resource state was abundant in both areas, the mean decision in area *a* was $1.21 \pm 0.04$, which was lower than the non-communication treatment and both the other two fisheries with communication. When the resource was depleted in both areas however, groups continued to struggle to cooperate with the mean decision in area *b*, $1.64 \pm 0.08$. The model predictions for the probability of making a Nash decision in the owner-controlled fishery with communication were the lowest of all treatments. When the resource state was abundant in both areas, the model predicted (95% CI) that a player would choose Nash 38% (32-43%) of the time compared to 49% (45-53%) of the time when the resource state was depleted in both areas.

The communication logs illustrate participants were aware that the socially-optimal strategy to prevent rent dissipation was for everyone to allocate one quota unit to each area for the entire experiment. For example, in the lease-dominated fishery one participate stated *"ATTENTION guys: Please choose (1, 1) throughout this* *experiment to maximise our profit! Thanks".* Another participant similarly stated *"Why not just put 1 on A and 1 on B? All 12 rounds will get 160"*. The logs also highlight that participants were aware the lack of group coordination was reducing their overall payoff. For example in the lease-dominated fishery, one participant advised *"we made $8 less because of no cooperation"* while a participant in the owner-dominated fishery said *"we could all have been $14 richer, but that is the real world, everyone for themselves"*.

As it only took one participant in the experiment to renege from the socially-optimal strategy to deplete the resource, group cooperation could easily collapse. Participants who were quota owners in the lease-dominated and owner-dominated fisheries also believed that the presence of lease quota fishers (who could be different participants each round due to the bidding process) would not necessarily agree to any group strategy and were the defecting players each time. For example, in the lease-dominated fishery one participant stated *"Who messed up?"* and another answered *"Probably the guy who had to bid for the quota"*. Similarly in the owner-dominated fishery, another participant stated in response to non-cooperation that *"Maybe the one person who needed to bid did not buy that"*. The presence and perceived lack of reciprocity from lease quota fishers due to them having to bid for a quota package was therefore a deterrent in the group managing to cooperate in these two fisheries through coordinating their fishing effort.

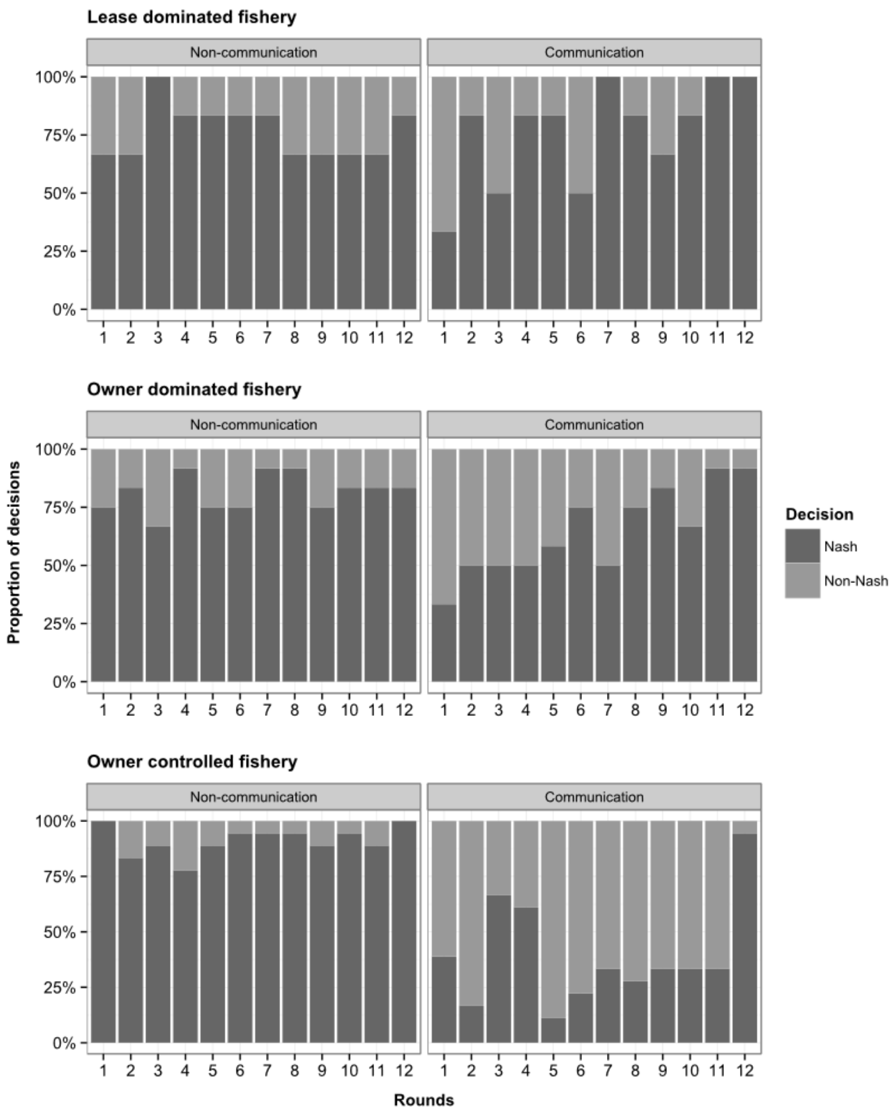
The hypothesis that the presence of lease quota fishers restricted the ability of participants to cooperate to reduce the extent of the assignment problem, despite communication, was reinforced by the results of the owner-controlled fishery, which was socially-optimally superior in preventing rent dissipation to both other fisheries and had no lease quota fishers making a decision each round.

### *6.4.3 The decision-making of lease quota fishers and quota owners*

There was no significant difference in the fishing decisions of quota owners and lease quota fishers and following a Wald chi-square test the covariate was removed from the final model. Nonetheless, other significant covariates provided some indication that the decisions of quota owners may have been more socially-optimal than lease quota fishers. For example, participants with more experience (i.e. rounds played) were significantly less likely ($p<0.0001$) to make a Nash decision relative to someone with less experience in the same round (Table 6.3). As quota owners were allowed to make a fishing decision each round, they were more likely to be experienced than their lease quota fisher counterparts. Additionally, participants with a higher real “cash” income (as opposed to experimental income) were significantly more likely ($p<0.0001$) to make a Nash decision than those with lower real “cash” income in the same round (Table 6.3). Quota owners on average (±SE) had a lower real “cash” income during and at the end of the experiment (AUD \$31.67 ± 0.69) relative to lease quota fishers (AUD \$32.28 ± 1.32).

There was also evidence that the decisions of quota owners were affected by the presence of lease quota fishers (Figure 6.2). In fisheries with lease quota fishers present, the proportion of Nash decisions made by quota owners increased through time (i.e. rounds). In the first round the majority of quota owners made socially-optimal decisions, which conveyed their desire to cooperate in both types of fisheries. Within a few rounds however, the majority had reverted to making Nash decisions, possibly due to other participates failing to reciprocate their socially-optimal decisions (Figure 6.2). This contrasted with the owner-controlled fishery where the proportion of Nash decisions made by quota owners fluctuated in the first few rounds before remaining relatively stable for the middle part of the experiments (i.e. rounds 6-11), where it appeared participants were more successful in cooperating by coordinating their appropriation decisions (Figure 6.2).

**Figure 6.2:** Comparing the proportion of Nash and non-Nash decisions made by quota owners through time (i.e. rounds) in each type of fishery.



## 6.5 Discussion

Assignment problems may remain in IQ or ITQ (quota managed) fisheries when the quota unit value of the stock is economically heterogeneous in time and space and the timing or place of harvest of these quota units is not regulated (Deacon and Costello, 2007; Ostrom et al., 1994). Through the introduction of stock complexities such as spatial variability in economic value and inter-temporal dynamics of the stock (i.e. path-dependency of previous use), this study showed that, as expected, fishers preferred to expend all their quota units in the most individually profitable areas through time and space. This was despite having the knowledge that the cumulative harvest in these areas could directly impact on the economic profit of the entire fleet through local stock depletion. Without communication, aggregate economic rent was far beneath that which could have been attainable due to non-optimal spatial allocation of quota units, irrespective of the type of fishery. While there were occasional attempts by quota owners in the lease-dominated and owner-dominated fisheries to cooperate by constraining harvesting in particular areas and coordinate their fishing effort, these attempts were later abandoned apparently due to a lack of reciprocity, leading to decisions reflective of the Nash equilibrium strategy. A similar result was also observed by Cárdenas et al. (2013) in their field experiments where participants failed to solve the collective-action dilemma and refrain from over appropriating the resource in the early rounds, resulting in rapid stock decline. Participants were also unable to coordinate their fishing effort in the absence of communication to recover the stock back to an abundant state. While there were individual attempts to reduce effort, these were insufficient to meet the required low levels of effort across the group. Similar behaviour among a particular group of resource users was also observed by Prediger et al. (2011), where they had difficulty in maintaining grazing areas in an abundant state within the early rounds and subsequent issues in coordinating to reduce grazing intensity in depleted areas to promote recovery.

The behaviour of the participants in this study was also consistent with observations in many fisheries where the introduction of quota management has led to a shift in spatial allocation of quota units in an attempt to maximise individual profit. With many fisheries characterised by spatial and temporal variability in quota unit value, this has led to in-season production externalities such as congestion and stock depletion that dissipate part of the fishery's profit (Boyce, 1992). For example, the introduction of quota management in the Tasmanian southern rock lobster fishery (TSRLF) led to a shift in spatial allocation of fishing effort. Fishers preferred to catch their quota units in inshore areas where lobsters had a higher market price due to their colouration, despite offshore areas having higher catch rates (Green et al., 2012). Similar spatial contraction of catch and effort into inshore areas was also evident in the South Australian southern rock lobster fishery following the introduction of quota management. Despite higher catch rates in offshore areas, approximately 80% of the TAC was caught in inshore areas, leading to significant declines in catch rates and localised depletion (Linnane and Crosthwaite, 2009). Bio-economic models have also been used to estimate the foregone profits caused by in-season production externalities. In the New Zealand southern scallop fishery for instance, losses were estimated between 10-20% per firm due to temporal variability in quota unit value, which led to excessive quota being caught by fishers early in the season. Similarly in the Maine lobster fishery, Holland (Holland, 2011) estimated losses under the quota management structure of up to 30% due in-part to temporal variability in quota unit value, which led to excessive catches by fishers in summer and autumn relative to other seasons.

The introduction of communication in this study provided an opportunity for participants to coordinate their actions. While participants were able to regularly agree on a strategy for coordinating effort to reduce rent dissipation, some continued to renege in the pursuit of greater individual returns. In other words, groups were unable to coordinate despite the ability to communicate. Consistent with the results of Cárdenas et al. (2013), if participants were unable to coordinate in the first round, it had an enduring effect on their ability to cooperate throughout the duration of the experiment. This was due to the path dependency of previous use, which shifted overexploited areas to a depleted state in the following round, making it even more difficult for participants to cooperate because they had to reduce and coordinate the amount of quota units they expended as a group in areas that were depleted; and potentially difficult for participants to continue to trust others in the group after they had reneged on a previous agreement to cooperate. Furthermore, when both areas were depleted, the socially-optimal scenario required: (i) turn-taking between all six participants; and (ii) acceptance of a low return compared to that earned when the resource was abundant in both areas.

Communication may also have had a disparate effect on the decision-making of participants within different types of fisheries, despite similar ecological complexities. This was due to the heterogeneity of the participants. Both the lease-dominated and owner-dominated fisheries, containing lease quota fishers and quota owners, were less successful in attempting to cooperate to reduce rent dissipation than the owner-controlled fishery, containing solely quota owners. The difficulty in reaching and sustaining an agreement to achieve coordination can be exacerbated when groups are heterogeneous, because any agreement may financially benefit one group more than another (Hackett et al., 1994; Ostrom, 2006). Lease quota fishers may have seen themselves as disproportionately affected in adopting a socially-optimal strategy to prevent rent dissipation under the experimental conditions due to: (i) inequality in wealth; (ii) insecurity of tenure and; (iii) asymmetric information exchange.

Differences in wealth can impair the effectiveness of communication in solving collective-action dilemmas by making it harder for groups to implement and sustain mechanisms that increase social efficiency (Cárdenas et al., 2000; Cárdenas, 2003). While the payment function in the present study ensured that participants were not disadvantaged (in terms of real “cash” income) in the experiments, lease quota fishers operated at a perceived reduced payoff margin (in terms of experimental income) between the lease price and payoff from their fishing decision. For example, the mean purchase price of a quota package when the resource was abundant in area *a* was 49 ± 1% of the maximum payoff attainable (i.e. Nash equilibrium strategy) and when depleted in both areas was 62 ± 1%. Lease quota fishers therefore faced a "cost-price squeeze between what [they] must pay to lease the quota and what [they] are paid for [their] catch" (Pinkerton and Edwards, 2009). Consequently, they would have had to make a greater sacrifice to their payoff than quota owners in choosing any strategy that wasn’t the Nash equilibrium strategy.

Lease quota fishers faced an insecurity of tenure that did not exist for quota owners because they might not have been able to make a fishing decision each round. Consequently, lease quota fishers would have less incentive to make a socially-optimal decision because there was uncertainty about whether they would experience resultant future losses or gains in profitability (Sumaila, 2010; Parslow, 2010). If a lease quota fisher made a socially-optimal decision in one round and then failed to acquire quota in the following round, their potential loss from not playing the Nash equilibrium strategy in the preceding round would be compounded, particularly if the other lease quota fisher who acquired quota at their expense chose not to cooperate with the same socially-optimal group strategy. This design may not have been reflective of the true leasing environment in many quota managed fisheries, as there would be barriers to transiency and lease quota fishers may not choose to invest without security of employment, however it still reflects the underlying insecurity that all lease quota fishers face relative to quota owners in acquiring quota units, whether this be monthly, annually or across multiple years.

Preventing some participants communicating and making decisions each round in this experiment (as different participants may have been successful in the tender for a quota package) created a level of asymmetric information exchange, which impaired the ability of participants to cooperate (Schmitt et al., 2000). This was done because it was reflective of the historical management structure in many quota-managed fisheries where authorities engage only with quota owners in decision-making. With many quota fisheries categorised by an increasing number of lease quota fishers (Pinkerton and Edwards, 2009; van Putten and Gardner, 2010), asymmetric information exchange can lead to misinformation and confusion between fishers over regulations and/or policy, eroding overall trust. For lease quota fishers in this experiment, not necessarily participating in every group discussion meant that they had incomplete information on the social identity of the group and any strategic plan to reduce rent dissipation. Concurrently, quota owners had to reaffirm any plan for reducing rent dissipation with a different group of lease quota fishers each round, creating uncertainty about how they may strategically respond and/or follow agreements previously made by their counterparts. Consequently, trying to establish any form of group identity and maintain cohesion would have been particularly difficult with this reduced ability to create a history of effective group decision-making.

While the inequality in wealth, insecurity of tenure and asymmetric information exchange clearly influenced the decision-making of lease quota fishers, it was not possible to determine the main driver influencing observed lease quota fisher behaviour within the current experimental design. Further research separating the drivers would be beneficial, for instance by examining insecurity of tenure among homogenous participants or by allowing heterogeneous groups to have symmetric information and comparing the results.

According to Cárdenas and Ostrom (2004) the information that participants obtain on the composition of their experimental group, influences their decision of whether to cooperate to achieve a socially-optimal outcome. In this study, the communication logs indicated that quota owners anticipated the likelihood of lease quota fishers deviating from agreements due to reasons such as their reduced payoff margin, which in the initial rounds, was a barrier to trust and prevented cooperation on a strategy for preventing rent dissipation. Therefore, the first one or two rounds of the experiment were crucial for participants in establishing trust and reciprocity. When allowed to communicate, quota owners were willing to cooperate in fisheries with lease quota fishers early in the experiment. However this willingness deteriorated through time, probably because they observed participants defecting, leading to a “crowding out” effect of cooperative behaviour (Cárdenas and Ostrom, 2004). This initial willingness of quota owners to cooperate is consistent with the persona that Gintis (2000) described as *homo reciprocans*. These types of participants come to strategic interactions with a propensity to cooperate, respond to cooperative behaviour by maintaining or increasing cooperation but respond to non-cooperative behaviour by retaliating against the offenders. In the absence of a structure for punishing offenders, as in this experiment, *homo reciprocans* responds to defection by defection, leading to downward spiral of non-cooperation (Andreoni, 1995; Gintis, 2000).

Communication between groups of harvesters under quota management is less likely to be effective in resolving assignment problems caused by stock complexity and heterogeneous harvesting. This is because any alternative strategy to the Nash equilibrium will produce differential earnings across groups of harvesters (Hackett et al., 1994; Ostrom, 2006). In this experiment, lease quota fishers may have seen themselves as disproportionately affected in adopting a socially-optimal strategy for reducing rent dissipation due to: (i) inequality in wealth; (ii) insecurity of tenure; and (iii) asymmetric information exchange. As quota owners were aware of these differences it would have affected the ability of the group to initially establish trust and a sense of group identity. When it was observed that other participants were defecting from the group strategy, quota owners responded like *homo reciprocans* and chose also to defect, leading to a "crowding out" effect of cooperative behaviour and downward spiral of continued rent dissipation.

## 6.6 Conclusion

Experimental economic research has shown that the introduction of communication can improve the capacity of participants to solve a variety of social dilemmas (Ostrom, 2006). For the most part however, these experiments have remained simplified, linear designs with only one dimension of interdependence (Cárdenas et al., 2013). While these have contributed to a wealth of information about trust, reciprocity and cooperation in general, there is a need to incorporate additional social, ecological and economic dimensions that are representative of the system being studied (Schnier, 2009; Cárdenas et al., 2013). Natural resources are often structurally complex, with economic yields that are spatially and temporally variable. The availability of the resource is influenced by the spatial structure and productivity of the stock and the amount that has been removed in the past (Sanchirico and Wilen, 1999). Similarly, harvesters are not homogenous, varying in characteristics such as sociocultural background, wealth, business structure and expertise, which may affect their decision-making (Varughese and Ostrom, 2001).

By including ecological complexities and harvester heterogeneity into economic experiment(s) of various quota managed fisheries, this study has contributed to the body of knowledge by gaining a greater understanding of individual fisher decision-making and what institutions or governance structures may be used to manage an assignment problem, in the absence of fully spatially and temporally delineated quotas. The results of this study suggest that the institution of quota management and the ability to communicate cannot prevent rent dissipation caused by spatial and temporal heterogeneity in the productivity of the stock, particularly when groups of fishers are heterogeneous, which is a growing trend in many quota-managed fisheries as quota owners prefer to lease out their quota to gain income from their asset (Connor and Alden, 2001). Consequently, it is important that the potential for rent dissipation be further studied in individual quota-managed fisheries and understood to determine what further institutions or management structures might be established to regulate fishing catch and effort in a way that can solve spatial and temporal heterogeneity in the productivity of the stock. Although the findings of this laboratory experiment are simplified compared to actual quota managed fisheries and require external validation in the field they nonetheless provide prediction and insight into the difficulties heterogonous fishers may face in solving assignment problems under quota management.

# 6.7 Appendix

## *6.7.1 Example of experimental instructions*

**About this Experiment**

If you follow the instructions and make sound decisions based on the information you are provided with, you may earn money that will be paid to you in cash at the end of the session.

What to do:

1. *Read through the instructions carefully.*
2. *After reading the instructions, you will be taken to a short quiz that will test your comprehension of the instructions.*
3. *Correctly answering ALL of the quiz questions will give you a unique password that you can use to login to the experiment.*

**Overview of this experiment**

This experiment is concerned with the way people make decisions, which impacts on their payoff into the future. You are one of two types of fishermen who need quota to fish in either one or two areas. One group own quota and only have to decide where they wish to fish. The other group have to buy quota in a tender system before they can fish.

There are a total of eight participants in the experiment. There are two participants in the experiment who automatically receive a quota package (containing two quota units) each round. They do not have to bid for quota. You are one of six participants who have to bid for a quota package (containing two quota units) in a tender in order to acquire fishing quota and thus make a fishing decision each round. Only four quota packages are available each round to the highest bidders, meaning the two lowest bidders miss out and so cannot make a fishing decision each round.

Participants with quota can choose to fish in one or both of two areas. The number of quota units fished in each area determines the state of the area ('abundant' or 'depleted') and subsequent payoff in the following round(s). There are only six participants out of the total of eight who make a fishing decision each round.

In each round:

- You bid for quota by submitting an offer (bid price) to a tender.
- If your bid is successful you will receive a quota package containing two quota units and will be able to make a fishing decision. If you are not successful in the tender you will not receive a quota package and not be able to make a fishing decision.
- Depending on the total group decision in each area the stock will either be "depleted" or "abundant" at the end of each round.
- Your payment depends on bidding successfully for a quota package and if successful, the bid price for the quota package, your fishing decision and the state of the resource at the start of the round.
- You are allowed to communicate with other players during the course of the experiment using the chat software.
- There will be a number of rounds.

**Experimental Rules**

You are being paid to participate in this experiment. Failure to comply with these rules will result in the forfeiture of earnings from this session and you will not be allowed to participate in future sessions.

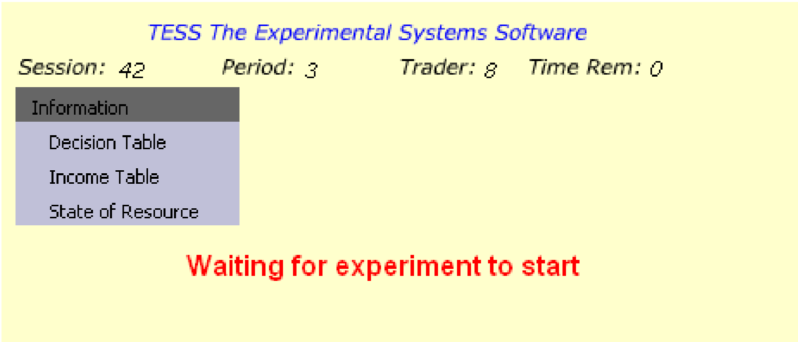
- Talking is not permitted during the experiment: You can ONLY communicate with other players using the chat software.
- You must not identify yourself when communicating using the chat software. When communicating you must conform to the University's code of conduct. In particular you must communicate in a manner that *is free from harassment and discrimination.*
- Only the experiment windows are permitted to be open during the experiment: You are not permitted to operate other software such as email or internet during the experiment
- You may ask questions of the instructor during the experiment

Instructors can answer questions about procedures but cannot provide you with advice about decisions or trading. You must make decisions and develop strategies by yourself.

**At the Start**

Once you have successfully completed the quiz, you will be taken to the login screen where you will enter your Player Number (provided to you by the instructor) and Password (obtained when you successfully complete the quiz).


Once you have entered your Player Number and Password you will see the main experiment screen, as follows:




By clicking on the "information" tab you can access information about your choices. You can choose from the following menu selections:

**Decision Table:** These tables provide you with:

- Information on the payment you will receive based on your fishing decision;
- The maximum number of people fishing and maximum amount of group quota units in the fishery each round and;
- The maximum number of group quota units that can be allocated to an area in each round for it to remain in an "abundant" state or move from a "depleted" to "abundant" state over two consecutive rounds.

**Income Table:** This table provides you with information on your payment for each round which is based on:

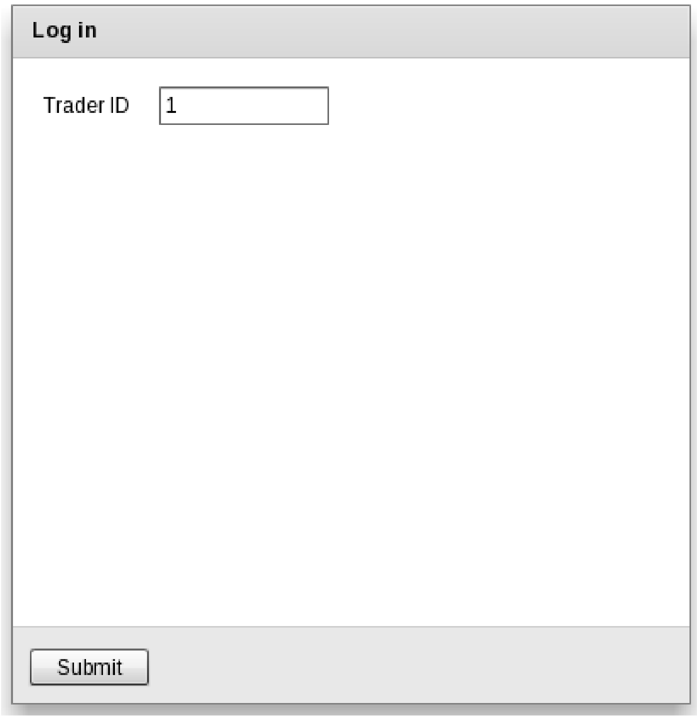
- Whether you were successful in bidding for a quota package and if successful, the bid price paid for a quota package;
- The state of the resource at the start of the round and;

- Your fishing decision.

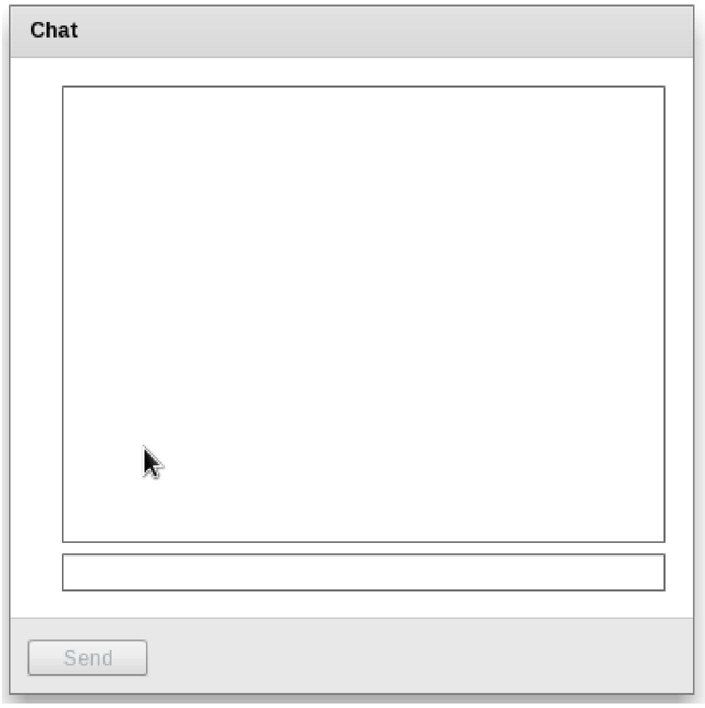
**State of the Resource:** These figures provide you with information on the amount of group quota units allocated to each of the two areas in each round.

**Chat Panel**

Once you have successfully completed the quiz, you will also be able to access the chat system for the experiment through this log-in screen. Enter your Player Number (provided to you by the instructor) and click the Submit button.



Once you have entered your player number you will see the chat window as follows:




In order to send a message, click on the text bar at the bottom of the window and type your message. Then click the Send button.

During the experiment, you will ONLY be able to communicate with other participants who have a quota package in the current round using this chat window. If you do not have a quota package you will not be able to communicate with other participants in that round.

Please note that you will only be able to chat with other participants during the decision period and NOT during the quota bidding period. If you have a quota package in the current round you will be notified by the administrator (Player 9) when the chat window is open for communication through the message "Start chat" appearing in your chat window and when the chat window is closed for communication by the message "End chat" appearing. It is only during this period that you will be able to communicate with other participants.

Your message is prefaced with your Player Number, as shown above. Message history is shown in the chat window.

IMPORTANT NOTE: during the experiment your chat must confirm with the University Codes of Conduct. You cannot give any indication of your identity.

**Decision Table**

Clicking on the “DECISION TABLE” information tab in the main experiment screen will show you two tables (see screenshot below).

The first (top) table shows you the maximum number of individual quota units (2) you can own, the number of participants (6) who are allowed to make a fishing decision each round, the maximum number of group quota units (12) in the fishery, the maximum number of group quota units (6) that can be allocated to an area in order for it to stay in an "abundant" state in the next round and the maximum number of group quota units (3) that can allocated for two consecutive rounds to return an area that is "depleted" to "abundant" in the next round. The second (bottom) table shows you the payments that you could receive as a result of your fishing decision in each round and the resource state at the start of the round. The payments are measured in experimental dollars. Each experimental dollar is worth AUD$0.041.

Each round you will have to successfully bid for a quota package in order to make a fishing decision. If successful, you will be allocated a quota package containing two quota units, which you may use to make a fishing decision each round. You may choose to fish zero, one or two quota units in either Area A or Area B. Your payment in a particular round will be based on where you choose to fish your quota units, the state of the resource ("abundant" or "depleted") at the start of the round and the quota bid price paid.

| General information on the fishery | |
|---|---|
| Maximum amount of individual quota units you can own | 2 quota units |
| Maximum number of people fishing in the fishery each round | 6 people |
| Maximum number of group quota units in the fishery | 12 quota units |
| Maximum number of group quota units that can be allocated to either area (A or B) for it to remain'abundant' next round | 6 quota units |
| Maximum number of group quota units that can be allocated to either area (A or B) for it to return to 'abundant' if in 'depleted' state | 3 quota units for 2 consecutive rounds |

| Payoff based on your quota unit decision | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Area A | | | | | |
| | | | Abundant | | | Depleted | | |
| | | Units | 0 | 1 | 2 | 0 | 1 | 2 |
| Area B | Abundant | 0 | $20.00 | $107.00 | $200.00 | $20.00 | $27.00 | $50.00 |
| | | 1 | $53.00 | $160.00 | | $53.00 | $80.00 | |
| | | 2 | $100.00 | | | $100.00 | | |
| | Depleted | 0 | $20.00 | $107.00 | $200.00 | $20.00 | $27.00 | $50.00 |
| | | 1 | $40.00 | $147.00 | | $40.00 | $67.00 | |
| | | 2 | $75.00 | | | $75.00 | | |

**EXAMPLES ONLY:**

Example 1:

If a player chooses to allocate one quota unit in Area A and one quota unit in Area B when the resource state is "abundant" at the start of the round, they will earn 160.00 experimental dollars.

Example 2:

If a player chooses to allocate two quota units in Area A when the resource state is "depleted" at the start of the round they will earn 50.00 experimental dollars.

Example 3:

If a player chooses to allocate zero quota units to both areas they will earn 20.00 experimental dollars regardless of the resource state at the start of the round.

**Income Table**

Clicking on the “INCOME TABLE” information tab in the main experiment screen will show you for each round, whether you were successful in bidding for a quota package, the quota bid price paid, where you allocated your individual quota units, where the rest of the group (including you) allocated their quota units, the resource state at the start and end of the round, the income you received from your decision (“decision income”) minus the quota bid price paid (“round income”) and rolling player income (“total income”) (see screenshot below). The payments, which are reflected in the “decision income” and "round income" column(s), are measured in experimental dollars. Each experimental dollar is worth AUD $0.041 and this is reflected in the "player income" column.

YOUR TOTAL INCOME: $10

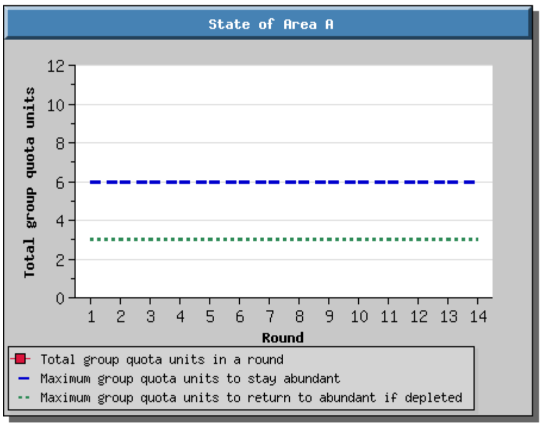
| Income Table | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Round | Quota bid success | Quota bid price | Resource state (start) | | Your decision | | Group decision | | Resource state (end) | | Decision income | Round income | Player income |
| | | | A | B | A | B | A | B | A | B | | | |

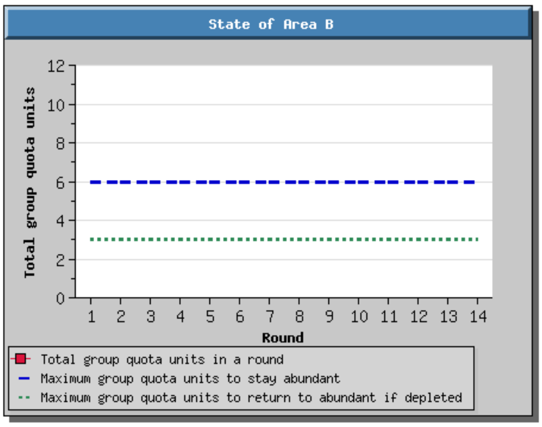
**State of Resource**

Clicking on the “STATE OF RESOURCE” information tab in the main experiment screen will show you two figures (see screenshot below), which graphically display the total group units (including yours) allocated to each area (A and B) in each round. The blue dashed line on both figures represents the maximum number of group quota units (six), which can be allocated to either area (A or B) in a round for it to remain "abundant" in the next round.

Remember, if the total number of quota in either site exceeds the maximum, the site is depleted in the following round(s). The payoff decreases if the site is in a depleted sate as shown in the income table.

The green dotted line represents the maximum number of group units (three), which can be allocated to either area (A or B) if in a "depleted" state for two consecutive rounds to return to an "abundant" state. The experiment session starts round one with both areas in an “abundant” state.




**EXAMPLES ONLY:**

Example 1:

If in round one, the total group effort in Area A is seven, the resource will move from an "abundant" to "depleted" state in round two.

Example 2:

If in round one, the total group effort in Area A is four and in Area B is eight, the resource in Area A will remain "abundant" and the resource in Area B will move from an "abundant" to "depleted" state in round two.

Example 3:

If in round four, the resource in Area B is in a "depleted" state and in round three four quota units were allocated to Area B, the resource will remain in a "depleted" state in round five even if no greater than three units are allocated by the group to Area B.

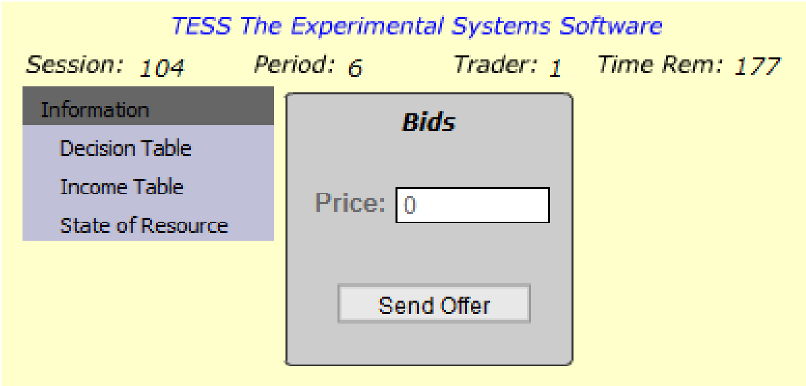
Example 4:

If in round four, the resource in Area B is in a "depleted" state and in round three only three quota units were allocated to Area B, the resource will move to an "abundant" state in round five if no greater than three units are allocated by the group to Area B.

**Procedure**

**Step 1 – Bidding round for quota**

Before the start of each round a tender will be held for quota packages and a bidding box (see screenshot below) will appear on your screen. There are only four quota packages available each round for six potential bidders, so only the four highest priced bidders will be successful at the tender and allocated a quota package. If you are one of the two participants whose bid is not successful, you will not be allocated a quota package, will not be able to use the chat software to communicate with other participants and be unable to make a fishing decision in that round.

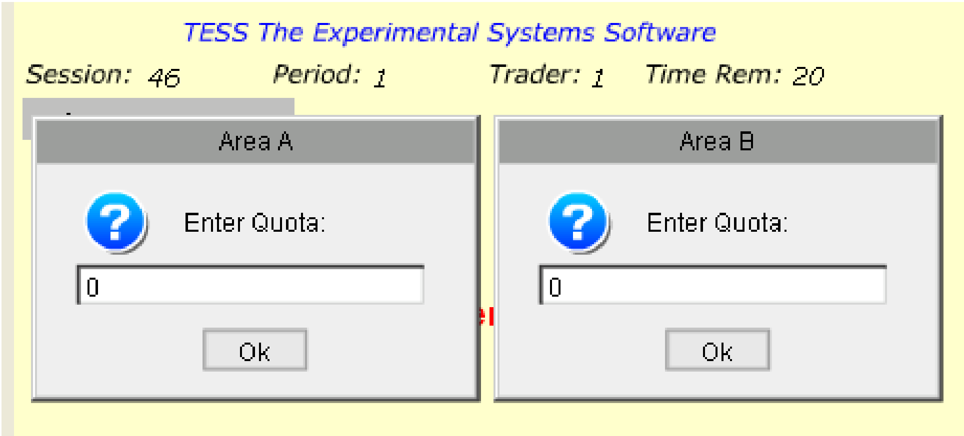



You will not be allowed to bid more than once each round…so think carefully! You will have 60 seconds to make a bid.

At the end of each round the quota bid price paid by the four successful bidders will be deducted from their decision income in experimental dollars. The minimum you are allowed to bid is 1.00 experimental dollar and you are not allowed to bid more than the maximum amount you could earn given the current resource state ('abundant' or depleted') in that round.

**Step 2 – Making a decision**

For each round in the experiment where you were successful at the tender and allocated a quota package, you will be asked to enter a decision (see screenshot below). In order to make a decision, you must enter an appropriate value in both decision boxes. To fish one unit only, enter a value of "1" in the decision box of either Area A or B and "0" in the other decision box. To fish one unit in each of Area A and B, enter a value of "1" in both decision boxes. To fish two units in one area, simply enter "2" in the decision box of either Area A or B and "0" in the other decision box. To fish zero units enter a value of "0" in both decision boxes.
You will not be allowed to fish more than two quota units in a round and you will only be allowed to enter your decision once each round…so think carefully! You will have 120 seconds to make a decision. \




**Step 3 – Review decisions and income earnings**

On the conclusion of the decision period, your income table will be updated with a summary of your fishing decision, the fishing decision of the group (which includes you), the state of the resource at the end of the round and your round income (minus the quota bid price paid).

**Step 4 - Repeat of Steps 1-3**

A number of rounds will be conducted. Decisions are only valid in the current round. The decision table will be the same in each round.

**Step 5 – Conclusion of experiment**

IMPORTANT: At the conclusion of the experiment you will be paid in cash the sum of the income you earned each round in addition to the turn up fee of AUD $10.

**Before you start the quiz**

You are being paid to participate in this experiment. Failure to comply with these rules will result in the forfeiture of earnings from this session and you will not be allowed to participate in future sessions.

1. Talking is not permitted during the experiment: You can ONLY communicate with other players using the chat software.

2. You must not identify yourself when communicating using the chat software. When communicating you must conform to the University's code of conduct. In particular you must communicate in a manner that *is free from harassment and discrimination.*
3. Only the experiment windows are permitted to be open during the experiment: You are not permitted to operate other software such as email or internet during the experiment
4. You may ask questions of the instructor during the experiment

Instructors can answer questions about procedures but cannot provide you with advice about decisions or trading. You must make decisions and develop strategies by yourself.

Now that you have read the instructions – please click on the quiz located on your desktop.

### *6.7.2 Example of experimental quiz*

**Question 1** *What is the correct value(s) to enter in the decision boxes to fish two units in Area A in a round?*

**A.** "2" in Area A decision box

**B.** "2" in Area A decision box and "0" in Area B decision box

**C.** "0" in Area A decision box and "2" in Area B decision box

**Your answer:**

**Question 2** *What is the correct value(s) to enter in the decision boxes to fish zero units in a round?*

**A.** "0" in Area A decision box and "0" in Area B decision box

**B.** "0" in Area A decision box

**C.** Leave both decision boxes blank

**Your answer:**

**Question 3** *What is the maximum number of group quota units in the fishery?*

**A.** 2

**B.** 6

**C.** 12

**Your answer:**

**Question 4** *What is the maximum number of people who can fish each round?*

**A.** 2

**B.** 6

**C.** 12

**Your answer:**

**Question 5** *If I enter "1" in the Area A decision box and "0" in the Area B decision box and both areas are in an "abundant" state, which of the following is true?*

**A.** I have decided to fish one quota unit in Area A and I will receive 27.00 experimental dollars

**B.** I have decided to fish one quota unit in Area A and I will receive 107.00 experimental dollars

**C.** I have decided to fish one quota unit in Area B and I will receive 53.00 experimental dollars

**Your answer:**

**Question 6** *Which of the following is true?*

**A.** If I enter "2" in the Area A decision box and "0" in the Area B decision box and the resource is "depleted" in both areas I will receive a payment of 200 experimental dollars

**B.** If I enter "1" in both Area A and Area B decision boxes and the resource is "abundant" in both areas I will receive a payment of 67.00 experimental dollars

**C.** If I enter "1" in both Area A and Area B decision boxes and the resource in Area A is "abundant" and in Area B is "depleted" I will receive a payment of 147.00 experimental dollars

**Your answer:**

**Question 7** *If everyone else decides to fish one quota unit in both Areas A and B and you decide to fish two quota units in Area A and zero quota units in Area B, which of the following is true?*

**A.** The resource in Area A will be depleted and the resource in Area B will be abundant next round

**B.** The resource in Area A and Area B will be abundant next round

**C.** The resource in Area B will be depleted and the resource in Area A will be abundant next round

**Your answer:**

**Question 8**

*If you bid $75 experimental dollars for a quota package when the resource is "depleted" in both areas (A and B) which of the following is true?*

**A.** You will earn zero experimental dollars from your decision to fish two quota units in Area B

**B.** You will earn 75.00 experimental dollars from your decision to fish two quota units in Area B

**C.** You will earn 50.00 experimental dollars from your decision to fish two quota units in Area A

**Your answer:**

**Question 9**

*What is the maximum number of group quota units that can be allocated to any area to keep it in an "abundant" state in the next round?*

**A.** 3

**B.** 6

**C.** 12

**Your answer:**

**Question 10**

*How many consecutive rounds does it take for an area that is in a "depleted" state to return to an "abundant" state if three or less group quota units are fished?*

**A.** 1

**B.** 2

**C.** 3

**Your answer:**

**Question 11**

*If Area B is in a "depleted" state at the start of round five after being "abundant" in round four, what is the maximum number of group quota units that can be allocated in order to move it to an "abundant" state in round six?*

**A.** 6

**B.** 3

**C.** Area B can't move to an "abundant" state in the next round

**Your answer:**

**Question 12** *Which of the following is true?*

**A.** My profit each round is based on my fishing decision

**B.** My profit each round is based on my fishing decision and state of the resource

**C.** My profit each round is based on my fishing decision, state of the resource and quota bid price

**Your answer:**

**Question 13** *Finish this sentence - During the experiment I...*

**A.** Can talk to any of the other participants using the chat software

**B.** Can talk to any of the other participants who have quota, using the chat software, in a way consistent with University Codes of Conduct

**C.** Can talk to any of the other participants using the chat software, in a way consistent with University Codes of Conduct

**Your answer:**

**Question 14** *When am I allowed to use the chat software?*

**A.** During the decision period and quota bidding period if I have a quota package

**B.** During the decision period only

**C.** During the decision period only if I have a quota package

**Your answer:**

# Chapter 7: Experimental analysis of the use of temporal closures and fishery cooperatives to reduce economic rent dissipation caused by assignment problems

This chapter is *under review* with Fisheries Research as:

Emery, T.J., Tisdell, J., Hartmann, K., Green, B.S., Gardner, C and Leon, R. Experimental analysis of the use of temporal closures and fishery cooperatives to reduce economic rent dissipation caused by assignment problems

## 7.1 Abstract

Assignment problems in quota managed fisheries are caused by spatial and temporal heterogeneity in the productivity of the stock. If the quota management system is not fully delineated then fishers will compete with each other and overexploit parts of the fishery where or when the quota unit value is highest, leading to economic rent dissipation. This study took an experimental economic approach to assess the effectiveness of temporal closures and income-sharing fishery cooperatives in resolving assignment problems across three different fisheries with varying levels of fisher heterogeneity (i.e. numbers of quota owners and lease quota fishers) and the ability of fishers to communicate. This study found that while most fisheries were successful in reducing economic rent dissipation under the temporal closure management structure relative to their baseline(s), fisheries characterised by a greater number of lease quota fishers and larger sized groups were less effective. This was due to the differential values that lease quota fishers place on the resource relative to quota owners as a result of having insecurity of tenure and diminished wealth in having to bid for a quota package and pay for it using their revenue from fishing. Furthermore, trust and a sense of group identify was more difficult to elicit in fisheries with both quota owners and lease quota fishers because of asymmetric information exchange. Conversely, income-sharing fishery cooperatives were equally successful across all three fisheries in reducing assignment problems relative to their baseline(s). This was because income-sharing reduced the incentive to over-appropriate the resource, particularly among heterogeneous groups. While these experiments are clearly simplified versions of the field environment, they still provide prediction and insight into resolving assignment problems under quota management.

## 7.2 Introduction

It is challenge for fishery managers to design and implement management institutions that both prevent over-appropriation of the resource and moderate assignment problems. Over-appropriation of the resource by fishers occurs in the absence of individual constraints on harvesting, as they receive all of the economic benefits (increased revenue) from taking more of the resource, while the economic costs of their actions (reduced yield) are shared amongst all fishers (Ostrom et al., 1994; Branch et al., 2006). Assignment problems are caused by fishers competing spatially and temporally for the most valuable portions of a heterogeneous stock in the absence of effort coordination or spatial and temporal restrictions on harvests, leading to economic rent dissipation (Costello and Deacon, 2007; Deacon and Costello, 2007).

Fisheries managers have historically failed to account for fisher behaviour and decision-making when designing management regulations (Hilborn et al., 2004a; Fulton et al., 2011), even though appropriation problems were identified many years ago by Gordon (1954), Scott (1955) and later popularised by Hardin (1968). This has led to stock depletion in many international fisheries (National Research Council, 1999). Output control management, including forms of catch shares such as individual transferable quotas (ITQs), were an attempt to account for appropriation problems in management decision-making. Allocating fishers a guaranteed share of the resource in the form of catch shares theoretically promotes efficiency by removing the incentive for fishers to apply excessive capital and labour in order to maximise catch, replacing it with an incentive to reduce costs and change their fishing behaviour in order to maximise profit (Branch et al., 2006;

Branch, 2009; Costello et al., 2010). Where catch shares are tradeable as ITQs, a fisher's gross revenue becomes fixed (not accounting for any leasing of quota units) and there is an incentive for less efficient owners to sell their quota units to more efficient owners, further reducing overcapacity (Copes, 1986; Grafton, 1996; Branch et al., 2006). Output controls have been largely successful in reducing the probability of over-appropriation by controlling annual catches so that the fishery moves towards target reference points (Essington, 2010; Melnychuk et al., 2012).

While the resolution of appropriation externalities has progressed through the use of output controls in over 121 different fisheries, in at least 22 countries (Chu, 2009; Deacon, 2012), they have not been able to resolve all the negative externalities of fishing and the complex problems of fisheries management (Degnbol et al., 2006; Grafton et al., 2006). For example, ITQs do not resolve assignment problems caused by spatial and temporal heterogeneity in the dynamics of the stock. Incentives remain for fishers to compete with each other and overexploit the most productive areas at the most opportune time (Copes, 1986; Deacon, 2012; Wilen et al., 2012). In the absence of effort coordination or spatial and temporal restrictions on harvests, fishers will not take account of these dynamics, leading to economic rent dissipation (Costello and Deacon, 2007; Deacon and Costello, 2007). This occurred following the introduction of ITQs in the Australian southern rock lobster fisheries, where there was a contraction of effort to inshore areas to target higher valued lobsters (due to colour composition) despite higher catch rates offshore (Hobday and Punt, 2006; Chandrapavan et al., 2009; Linnane and Crosthwaite, 2009). This type of behaviour can reduce the yield of the entire fishery through over-exploitation (or serial depletion) of one part of the population (i.e.

inshore) and under-exploitation of other parts (i.e. offshore) (Holland, 2004). Furthermore, if fishing costs increase proportionally with declining exploitable biomass, individual harvest can reduce the current stock density and increase the harvest costs of all fishers in the future (Deacon, 2012; Wilen et al., 2012). For example, suboptimal allocation of fishing effort in the New Zealand southern scallop fishery at the start of the season led to increased costs of fishing, due to lower stock densities later in the season and dissipation of economic rent (Bisack and Sutinen, 2006). Sub-optimal allocation of fishing effort can also lead to direct competition between fishers, resulting in rent dissipation through gear interference and reduced product quality (Clark, 1980; Holland, 2004; Wilen et al., 2012).

If fishers are heterogeneous in financial wealth or security in the fishery, it will impact on their willingness to initially cooperate and sustain agreements to reduce assignment problems (Hackett et al., 1994). This is because regulations or collective agreements to improve cooperation may adversely affect some fishers more than others (Johnson and Libecap, 1982; Kanbur, 1992; Hackett et al., 1994). In many quota-managed fisheries with free transferability of quota units, there are now two distinct types of fishers, those that catch predominately quota units that they own (i.e. quota owners) and those that mainly catch leased quota units (i.e. lease quota fishers). The behaviour and decision-making of both types of fishers is likely to diverge due to different financial constraints. Lease quota fishers face high upfront capital investment costs to enter the fishery and reduced financial security in having to lease in quota units and recover those costs, in addition to other fixed and variable costs of fishing, from the landed value of their catch (Pinkerton and Edwards, 2009; Parslow, 2010). Lease quota fishers theoretically have less incentive than quota owners to reduce fishing effort in the short term (Maurstad, 2000) due to the need to maintain short-term financial returns (Emery et al., in press; Van Putten et al., in press). In other words, the values that lease quota fishers and quota owners put on the natural resource is likely to vary. In the absence of an external regulatory mechanism or equitable output sharing rule this could lead to a collapse in cooperation and reversion to non-cooperative outcomes (Kanbur, 1992).

Management measures that optimise the spatial and temporal deployment of effort across the entire fishing fleet would reduce assignment problems and economic rent dissipation in ITQ fisheries where fishers are heterogeneous (Deacon et al., 2013). This could be achieved through either: (i) fully delineating the ITQ allocation spatially and temporally (Costello and Deacon, 2007; Deacon and Costello, 2007); (ii) some form of centralised coordination of effort or collective action through informal agreements among fishers or fishing cooperatives (Deacon and Costello, 2007; Deacon, 2012); or (iii) the use of spatial and temporal closures and/or gear restrictions (Holland, 2004). For many fisheries the cost of spatially and temporally delineating the ITQ allocation and reallocating quota units to fishers is prohibitive and logistically difficult. Once instituted, ITQs typically become a highly valuable and traded commodity, so reallocating quota units spatially and temporally is likely to have various financial and legal repercussions for the management agency in addition to being logistically complex (Copes, 1986; Copes and Charles, 2004). Evidence from various international fisheries suggests that well-defined, legitimised and resourceful fishing cooperatives or groups of harvesters are a successful way of dealing with assignment problems and reducing rent dissipation. The main pathways are through exchanging information about the resource, coordinating the location and timing of harvest, pooling income and/or consolidating effort among their most efficient fishers (Wilson et al., 2007; Deacon, 2012; Deacon et al., 2013). Behavioural experiments have also shown that output sharing among groups within common pool resource environments can reduce incentives to over-appropriate the resource (Schott et al., 2007; Buckley, 2009; Heintzelman et al., 2009). Conversely, area-based management, such as temporal or spatial closures, are relatively straightforward to implement and can reduce localised depletion though spatial reallocation of fishing effort. However they can reduce fisher efficiency (Hannesson, 1998) and the short-term security of their ITQ allocation, which can be counterproductive to the objectives of the ITQ management system (Emery et al., 2012). The adaptive behaviour of fishers may also override potential gains in protection (Eikeset et al., 2011) if fishers redistribute their effort to other vulnerable areas (Hilborn et al., 2004b). Furthermore, behavioural experiments suggest that in some circumstances, external regulatory control can “crowd out” cooperative behaviour and moral obligations, despite the fact that the regulatory institutions are designed to induce more efficient choices (Ostmann, 1998; Cárdenas et al., 2000; Reeson and Tisdell, 2008).

Economic experiments are a well-established tool for examining the behavioural response and decision-making of human subjects in a controlled environment (Tisdell et al., 2004; Reeson et al., 2011; Exadaktylos et al., 2013). In this context experimental economics provided a way of assessing the effectiveness of management institutions or cooperative action in resolving assignment problems among a heterogeneous group of fishers. Historically, the response of fishers to management measures has rarely been considered by fisheries managers but remains an important requirement for preventing unexpected and undesirable outcomes from decision-making (Fulton et al., 2011). Experimental economics has the potential to improve the design of fisheries management measures and reduce the uncertainty of management outcomes by predicting how incentives and institutions affect fisher decisions and outcomes (Cárdenas et al., 2013). Such economic experiments have already identified communication as an important tool for engendering socially-optimal outcomes through collective action (Ostrom et al., 1992; Anderies et al., 2011) and external regulation, larger group sizes and heterogeneity among participants as inhibitors to reaching socially-optimal outcomes (Hackett et al., 1994; Sally, 1995; Cárdenas et al., 2000; Ostrom, 2001).

This study used experimental economics to examine what institutions or management measures may create incentives for a heterogeneous group of fishers to resolve assignment problems and prevent economic rent dissipation. The experimental design was based on Cárdenas et al. (2013) and incorporated ecological dynamics in order to make it representative of the marine environment (List, 2006) including: (i) spatial variability in stock productivity and non-linearity of payoffs and; (ii) path dependency of previous use (i.e. group decision in round *s* impacts individual payoffs in round *s* +1). Harvester heterogeneity was also included in the experimental design as there are two distinct groups of fishers (quota owners and lease quota fishers) in most quota-managed fisheries (Connor and Alden, 2001; Pinkerton and Edwards, 2009). The effectiveness of three management institutions: (i) quota management; (ii) quota management with a temporal closure; and (iii) quota management with a fishery cooperative; were examined across three different types of fisheries: (i) lease-dominated fishery; (ii) owner-dominated fishery and; (iii) owner-controlled fishery; to analyse their effectiveness and the propensity of the group(s) to cooperate to prevent economic rent dissipation. Based on the experimental work conducted by Hackett et al. (1994), Cárdenas (2000), Schott et al. (2007) and Cárdenas et al. (2013), it was hypothesised that:

- heterogeneity among harvesters would reduce cooperation that would otherwise prevent over-extraction of the resource and promote of stock recovery;

- the introduction of temporal closures or external regulation with communication would not improve upon traditional quota management; and

- the introduction of fishery cooperatives or output sharing with communication would reduce incentives to over-extract the resource and would improve upon traditional quota management.

## 7.3 Methods

### *7.3.1 Experimental design*

The experimental design was similar to that used in the previous chapter (Chapter 6) and was intended to represent the key ecological and social features of a developed fishery under quota management. It was based on a modified version of the protocol developed by Cárdenas et al. (2013) for fisheries resources. This design incorporated the key ecological dynamics of the resource, including path-dependency of previous use and non-linearity of payoffs due to spatial heterogeneity. In other words, current appropriation decisions influenced the future productivity and hence profitability of the resource, and the spatial productivity and/or resilience of the resource was variable. This experiment also incorporated harvester heterogeneity by varying the capacity of some participants to make decisions each round, their subsequent payoffs from decisions and information they received about the experimental group. While it would have advantageous to incorporate other ecological, economic or social features of the fishery (e.g. changing market price) in the experimental design, a balance was sought. This was because greater experimental complexity would result in longer experimental session times and a higher probability that participants miscomprehend experimental procedures.

The capacity of a heterogeneous group of fishers to prevent rent dissipation while fishing a dynamic resource was assessed across three different type of fisheries: *lease-dominated*, *owner-dominated* and *owner-controlled*, with each having a varying number of participants playing the role of either a quota owner or lease quota fisher (Table 7.1). All fisheries operated under quota management, with a cap on the number of participants fishing each round (6) (i.e. limited entry), the total number of quota units available in the fishery (12) (i.e. TAC), and the number of quota units available to each participant (2) (i.e. quota holding cap). These types of fisheries were then compared across three different management structures: *fishery baseline, temporal closure* and *fishery cooperative* (Table 7.1) to assess whether they could influence the ability of groups in different fisheries to prevent rent dissipation. A total of 12 rounds were held in each experimental session, signifying the number of months in a calendar year and communication was allowed between participants in each treatment. Participants were not aware of the number of rounds in advance and their role (quota owner or lease quota fisher) remained unchanged throughout each session, along with the overall composition of the group. Three independent sessions (replicates) of each treatment combination were conducted for a total of 27 experimental sessions (Table 7.1). The supplementary material contains an example of the instructions and associated quiz provided to participants.

**Table 7.1:** Experimental design

| | *Factor* | *Management structure* | | | *Definition* |
|---|---|---|---|---|---|
| | | *Baseline* | *Closure* | *Cooperative* | |
| *Type of fishery* | *Lease-dominated* | 3 sessions | 3 sessions | 3 sessions | 6 lease quota fishers<br>2 quota owners |
| | *Owner-dominated* | 3 sessions | 3 sessions | 3 sessions | 3 lease quota fishers<br>4 quota owners |
| | *Owner-controlled* | 3 sessions | 3 sessions | 3 sessions | 6 quota owners |

In the experimental sessions of the lease-dominated and owner-dominated fisheries, participants were randomly allocated the role of either a quota owner or lease quota fisher, while in the owner-controlled fishery all participants were allocated the role of a quota owner. In the lease-dominated and owner-dominated fisheries, each round of the experiment consisted of two stages: (i) a market for leasing quota packages and; (ii) a fishing decision. In the owner-controlled fishery only a fishing decision was made each round.

In the first stage of the experiment, all lease quota fishers had 60 seconds to competitively bid amongst themselves in a discriminative price, closed call market to lease a quota package containing two quota units. Competition was created by setting the number of available quota packages less than the number of bidders. For example, in the lease-dominated fishery there were a total of eight participants, six lease quota fishers and two quota owners. As both quota owners automatically received quota packages each round this meant that there were only four quota packages available for lease. In the owner-dominated fishery there were a total of seven participants, three lease quota fishers and four quota owners. This meant that there were only two quota packages available for lease. Lease quota fishers were allowed to bid up to the maximum they could earn in any given round. At the end of the 60 seconds all bids were collated and successful bidders were allocated a quota package. This allowed them to make a fishing decision in the second stage. All lease quota fishers who were successful in leasing a quota package had their bid price subtracted from their fishing decision payoff in the second stage. Lease quota fishers who failed to acquire a quota package were unable to make a fishing decision in the second stage and were not allowed to observe or participate in any group discussion. This meant that as opposed to quota owners, lease quota fishers had: (i) an insecurity of tenure, in potentially not being able to fish each round; (ii) a reduced payoff margin, in having to subtract their successful bid price from their fishing decision payoff and; (iii) asymmetric information, in not necessarily being able to observe or participate in group discussion each round.

In the second stage of the experiment, all participants with a quota package had 120 seconds to decide where to fish and how many quota units (0, 1 or 2) to allocate to either one or two fishing sites (areas *a* and *b*). Participants used a payoff table (Table 7.2) to inform their decision, with resulting payoffs dependent on: (i) the amount of quota units allocated to a particular area; (ii) the area fished (*a* or *b*) and; (iii) the state of the resource in that area (i.e. abundant or depleted). While fishing two quota units obviously provided a higher payoff than fishing just one unit, area *a* provided a higher payoff when in an abundant state than area *b* (Table 7.2). When both areas were in a depleted state however, area *b* was more resilient and provided a higher payoff (Table 7.2). This reflected the non-linearity of payoffs, which occurs where fishing grounds are spatially heterogeneous in economic yield. At the start of each experimental session the state of the resource was abundant in both areas. However when the aggregate group allocation of quota units (i.e. the sum of all six participants allocation decisions) in an area (*a* or *b*) exceeded six in round *s*, the state of the resource shifted from abundant to depleted in round $s$+1. In other words, the depleted state of the resource in the next round was caused by over-allocation of quota units during the current round. Once an area shifted to a depleted state, it could only recover back to an abundant state if the aggregate group allocation of quota units was less than four for two consecutive rounds. This reflected the path-dependency of previous use, where spatially-selective fishing can inhibit payoffs through localised depletion and recovery may require a significant reduction in fishing pressure for a period of time. Participants made their decisions privately and confidentially, and were not aware of the individual fishing decisions of others, only the group aggregate in each area at the end of each round.

There were six possible ecological states in any one round of the experiment (based on Prediger et al. (2011)):

- AA: both areas are in an abundant state

- $AD_1$: one area is in an abundant state; the other area is in a depleted state but has already recovered one round

- $AD_2$: one area is in an abundant state; the other area is in a depleted state and needs two rounds to recover
- $D_1D_1$: both areas are in a depleted state but have already recovered one round

- $D_1D_2$: one area is in a depleted state and needs two rounds to recover and the other area has already recovered one round

If all participants in the experimental group chose to follow their Nash equilibrium strategies (Nash, 1950) and seek to maximise their individual payoff, assuming that others would do likewise, then this would result in a payoff of 1,425 experimental dollars for a quota owner. Conversely, if all participants made socially-optimal decisions and chose to fish one unit in each area (*a* and *b*) for the entire experiment, the payoff for a quota owner would be 1,920 experimental dollars.

**Table 7.2:** Decision table with payoffs in experimental dollars based on the area, resource state and amount of quota units expended by an individual. Empty values denote the quota expenditure combinations that are not possible as each individual can expend only a maximum of two quota units.

| | | | ***Area A*** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | ***Abundant*** | | | ***Depleted*** | | |
| | | *Units* | *0* | *1* | *2* | *0* | *1* | *2* |
| ***Area B*** | ***Abundant*** | *0* | $ 20.00 | $ 107.00 | $ 200.00 | $ 20.00 | $27.00 | $50.00 |
| | | *1* | $ 53.00 | $ 160.00 | | $ 53.00 | $80.00 | |
| | | *2* | $ 100.00 | | | $100.00 | | |
| | ***Depleted*** | *0* | $ 20.00 | $ 107.00 | $ 200.00 | $ 20.00 | $ 27.00 | 50.00 |
| | | *1* | $ 40.00 | $ 147.00 | | $ 40.00 | $ 67.00 | |
| | | *2* | $75.00 | | | $ 75.00 | | |

The introduction of two alternative management structures allowed comparisons to be made to the fishery baseline. These were a temporal closure and a fishery cooperative. This was to examine whether these intuitions could improve the ability of heterogeneous groups to coordinate and choose socially optimal decisions for preventing economic rent dissipation.

The only change in the temporal closure structure relative to the baseline structure was that whenever an area (*a* or b) was in a depleted state, it was closed to all fishing. Participants were not allowed to allocate any quota units to that area until it had recovered back to an abundant state. This was intended to represent a fisheries management agency intervening and implementing a temporal closure to protect the depleted stock from further fishing pressure. The temporal closure introduced an additional cost to non-cooperation as groups who were not able to prevent areas from shifting to a depleted state would have a reduced payoff relative to the baseline treatment(s). For example, if all participants continued to follow their Nash equilibrium strategies then the income of a quota owner would be 1,200 experimental dollars, which was 225 less than in the baseline structure.

The only change in the fishery cooperative structure relative to the baseline structure was that all participants were placed in a cooperative and the payoffs from their individual fishing decisions pooled and shared equally among all participants. This was meant to imitate fishery cooperatives in countries such as Japan, where members share income from fishing to reduce congestion and improve productivity (Carpenter and Seki, 2011). Theoretically, sharing income introduces a disincentive for participants to choose their Nash equilibrium strategy as the benefit will not necessarily be individually attained and the cost will be shared among all members.

### *7.3.2 Experimental participants*

Student subjects were recruited from across the university campus through advertising billboards and a designated website, before being randomly selected to participate in individual experimental sessions.

While the use of volunteer students is common in laboratory experiments, some authors believe results from these experiments are not representative of the general population due to divergent social preferences (Levitt and List, 2007; Loomis, 2011). Consequently, student samples provide a biased estimation of social preferences for the analysis of economic outcomes (Falk et al., 2013). Recent empirical evidence has shown, however that volunteer students display similar behavioural patterns to non-students, so there is no systematic overestimation of social preferences and students are appropriate subjects on which to examine human behaviour in contemplation of public policy design (Exadaktylos et al., 2013; Falk et al., 2013; Janssen et al., 2011). It is also important to note that the intention of this experiment was not to measure actual levels of socially optimal behaviour but investigate what factors (e.g. policy instruments) may affect those relative levels (Kraak, 2011). The idea being that policy instruments instituted in a lab environment would influence human behaviour at a basic biological and psychological level representative of the field environment (Kraak, 2011).

### *7.3.3 Experimental procedure*

All experiments were carried out in the University's experimental laboratory between August 2012 and August 2013 using custom-designed computer software. Student subjects were recruited from across the university campus through advertising billboards and a designated website, before being randomly selected to participate in individual experimental sessions. At the commencement of each experimental session, participants were asked to read through a set of instructions before undertaking a multiple-choice quiz to test their understanding of the experiment. Once all participants had successfully completed the quiz they could access the experimental interface. Researchers were available to answer any questions and provide assistance at all times. During the experiment, participants were not allowed to communicate except through using the experimental software, which was analogous to instant messenger. Experiments on average lasted one and half hours and participants were paid cash in private at the conclusion of the experiment according to income earned from their decisions, in addition to an attendance stipend of AUD $9. On average, participants earned a sum of AUD $32 for participating in an experimental session.

### *7.3.4 Experimental analysis*

The fishing decisions of participants were compared across management structures, fishery types and resource state(s). In order to measure the level of cooperation among groups, the proportion (%) of rounds spent in each resource state (i.e. abundant-abundant) was examined across the fishery baseline, closure and cooperative management structures. The proportion (%) of Nash to non-Nash decisions in each resource state was also examined across all three management structures to assess the effectiveness of groups coordinating to reduce economic rent dissipation. While Nash decisions reflected individual payoff-maximising behaviour, non-Nash decisions reflected more cooperative behaviour, but not necessarily the socially-optimal decision.

All experimental data was analysed with a population average (marginal) model using a generalised estimating equation (GEE) approach in R (version 3.0.0) (R Core Team, 2013) as used in the previous chapter (Chapter 6) and reproduced here. The GEE approach developed by Liang and Zeger (1986) and Zeger and Liang (1986) is appropriate when data is in longitudinal form with multiple observations from the same player through time (i.e. length of the experiment). Consequently, the decisions of players may have been correlated, as their decision in round $s+1$ could be highly associated with their decision in round $s$, which would violate the assumption of independence made by traditional regression procedures. A GEE approach allowed an analysis of changes in the population mean, which was the average probability of making a Nash decision across all players, given changes in covariates, while accounting for within-player non-independence of observations when deriving the variability estimates of these coefficients (Hubbard et al., 2010). GEE is a satisfactory approach to the analysis of longitudinal data when the dataset consists of short, complete sequences of measurements (the decisions of six players) observed across a common time period (i.e. twelve rounds) on many subjects (188 players) and a conservative selection in the choice of working correlation matrix is applied (Diggle et al., 2002). In fact, while efficiency of estimates can be improved by correctly specifying the working correlation matrix, the GEE approach remains consistent as well as providing correct standard errors even if the nested correlation structure is incorrectly specified or not precisely defined (Liang and Zeger, 1986; Freedman, 2006; Tze and Small, 2007; Lalonde et al., 2013).

There were three steps to fitting the model in this study using a GEE approach (Zuur et al., 2009). The first step involved specifying a regression model with $K$ coefficients for the mean and no interactions:

$$E[Y_{is}] = p_{is} = e^{\alpha + \sum_{k=1}^{K} \beta_{isk} X_{isk}}$$

Where $\alpha$ is the intercept, $\beta$ is the coefficients vector, $X$ is the covariates matrix and $Y_{is}$ is 1 if a Nash decision is made in round $s$ by player $i$ and 0 if a non-Nash decision is made. Therefore $Y_{is}$ is binomially distributed with probability $p_{is}$. Given the response variable was binary, the link transformation function was logit, so the covariates were transformed by the log of the odds ratio (the ratio of a response of

"1" in the data to a response of "0"). Covariates included *management structure*, *fishery* and *state of the resource* as categorical variables and *cumulative income* as a continuous control variable. An interaction term *treatment x fishery* was included to determine whether players in a particular fishery with fishing closures or fishing cooperatives were more likely to make a Nash decision than the baseline. The clustering variable was *player* with a total of 188 unique players across the 27 experimental sessions with a maximum of 12 (possibly) correlated responses. Wald chi-square tests informed the removal of non-significant variables such as *fishery type* (i.e. lease fisher or quota owner) and *experience* (i.e. number of rounds played) from the final model.

The second step involved specifying the mean-variance relationship of the observed data so the regression coefficients could be properly interpreted:

$$var(Y_{is}) = p_{is} \times (1 - p_{is})$$

A binomial distribution was chosen because the response variable was in binary form (i.e. yes or no).

The third step involved specifying a working correlation structure which was believed to be present among responses within players ($i$) between the rounds $s$ and $t$:

$$cor(Y_{is}, Y_{it}) = \rho^{|s-t|}$$

An auto-regressive (AR-1) correlation structure was chosen because the data was in temporal form (clustered over time) and had the lowest Pan's quasi-likelihood under the independence model information criterion (QIC) score (Pan, 2001) following testing.

## 7.4 Results

### *7.4.1 The effectiveness of temporal closures*

The introduction of temporal closures were successful in reducing economic rent dissipation in the lease dominated fishery and owner-controlled fishery relative to their baseline(s) (Table 7.3). This was evident through a significant difference in the mean decision of all players in making socially-optimal decisions between the temporal closure and baseline in the lease-dominated fishery ($p < 0.001$) and owner-controlled fishery ($p < 0.001$) but not in the owner-dominated fishery ($p = 0.2$).

The introduction of temporal closures increased the propensity for groups to cooperate and keep the resource abundant in both areas by making socially-optimal decisions, particularly in the fisheries with lease quota fishers. For example, when the resource was abundant in both areas in the baseline, participants in the lease and owner-dominated fisheries made non-Nash decisions 44% and 56% of the time respectively (Figure 7.1). This improved to 83% and 94% respectively through the introduction of temporal closures, an increase of 39% and 38%. Similarly in the owner-controlled fishery, participants made non-Nash decisions 78% under the baseline, increasing to 96% through the introduction of temporal closures, an increase of 18% (Figure 7.1). When the resource shifted to depleted/abundant however, the difference was not as marked, with an increase of 25% and 6% from the baseline in the lease and owner-dominated fisheries respectively and a decrease of 11% from the baseline in the owner-controlled fishery. In other words, a failure to initially refrain from choosing Nash when the resource was abundant in both areas led to a greater proportion of participants making Nash decisions when the resource was depleted in either area later in the experiment, particularly in the owner-dominated and owner-controlled fisheries (Figure 7.1). When comparing the effect of temporal closures across different fisheries there was no significant difference found in the probability of participants making socially-optimal decisions between the lease-dominated fishery and owner-dominated fishery($p = 0.09$) but participants in the owner-controlled fishery were significantly more likely ($p < 0.03$) than those in the lease-dominated fishery to make socially-optimal decisions.

When examining the proportion of rounds spent in an abundant/abundant state, it was evident that the introduction of temporal closures improved the propensity for groups to remain more often in this socially-optimal resource state (Figure 7.2). For example, in the owner-dominated and owner-controlled fisheries, groups were able to maintain the resource in an abundant/abundant state for 64% and 69% of all rounds respectively, following the introduction of temporal closures, compared to just 8% and 39% under their respective fishery baseline(s) (Figure 7.2). In the lease-dominated fishery however, there was only a marginal improvement from the baseline, with groups only able to maintain the resource in an abundant/abundant state 14% of all rounds, compared to just 8% in the baseline.

**Table 7.3:** Generalised estimating equation regression for the probability of making a Nash decision

| | Coefficient | Standard Error | Wald | P value |
|---|---|---|---|---|
| Intercept | -2.0720 | 0.4794 | 18.68 | **<0.0001*** |
| Management Structure: Closure Communication | -2.9352 | 0.4243 | 47.85 | **<0.0001*** |
| Management Structure: Coop Communication | -5.0008 | 0.4968 | 101.33 | **<0.0001*** |
| Fishery: Owner Controlled | -2.2443 | 0.4342 | 26.72 | **<0.0001*** |
| Fishery: Owner Dominated | -1.0924 | 0.4750 | 5.29 | **0.0215** |
| State of Resource: Abun/Depl | 1.6037 | 0.2946 | 29.63 | **<0.0001*** |
| State of Resource: Depl/Abun | 2.1551 | 0.2660 | 65.66 | **<0.0001*** |
| State of Resource: Depl/Depl | 1.638 | 0.2695 | 18.64 | **<0.0001*** |
| Cumulative Income | 0.1385 | 0.0122 | 129.04 | **<0.0001*** |
| Management Structure: Closure Communication*Fishery: Owner Controlled | 1.2748 | 0.5976 | 4.55 | **0.0329** |
| Management Structure: Coop Communication*Fishery: Owner Controlled | 1.8631 | 0.6582 | 8.01 | **0.0046** |
| Management Structure: Closure Communication*Fishery: Owner Dominated | 0.2858 | 0.6809 | 0.18 | 0.6746 |
| Management Structure: Coop Communication*Fishery: Owner Dominated | 1.4532 | 0.6318 | 5.29 | **0.0215** |

*Correlation structure: AR-1*

*Distribution: Binomial*

*Estimated correlation parameters: (estimate: 0.215, standard error: 0.061)*

*Number of clusters: 188*

*Maximum cluster size: 12*

**Figure 7.1:** Proportion of Nash and non-Nash decisions across different treatments by resource state

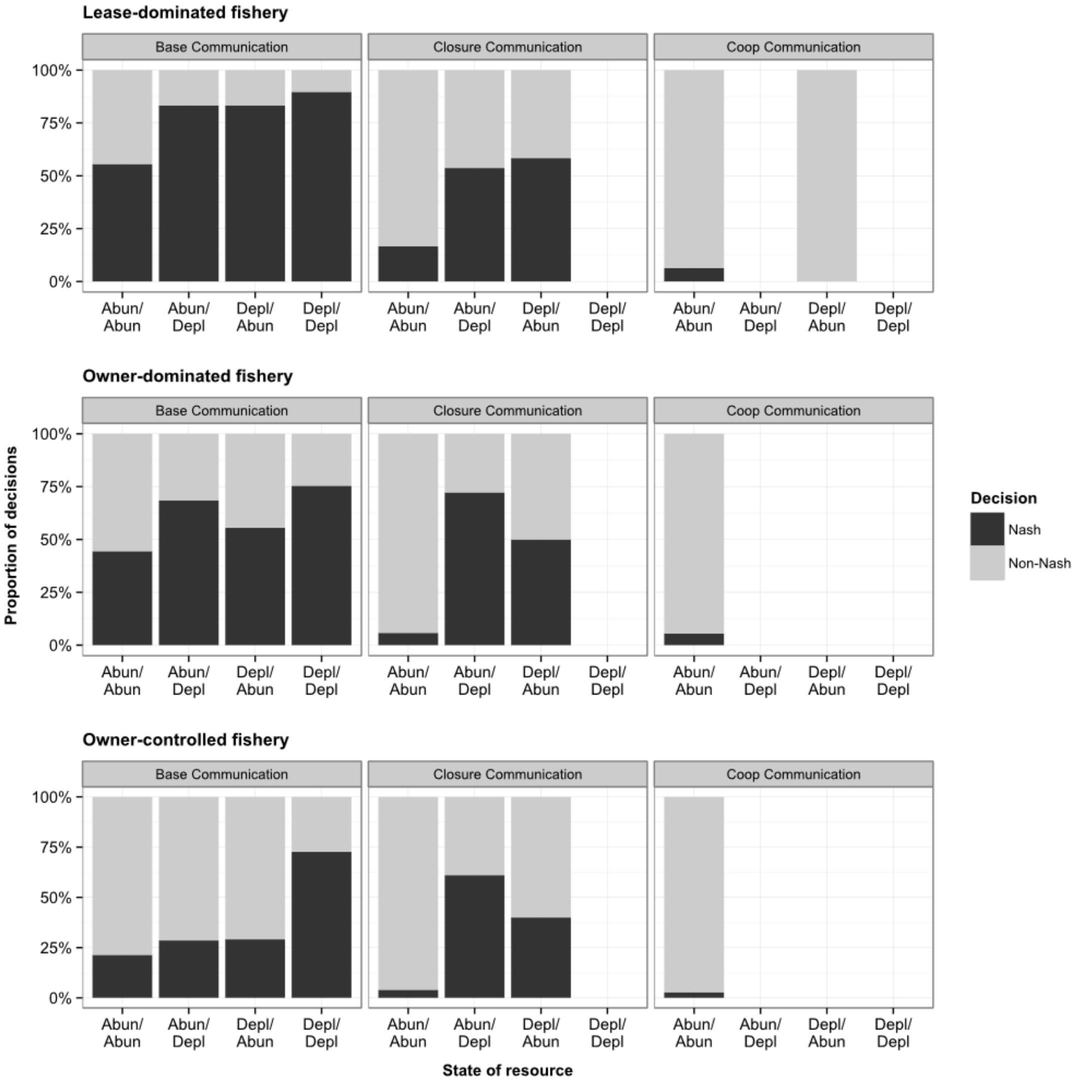
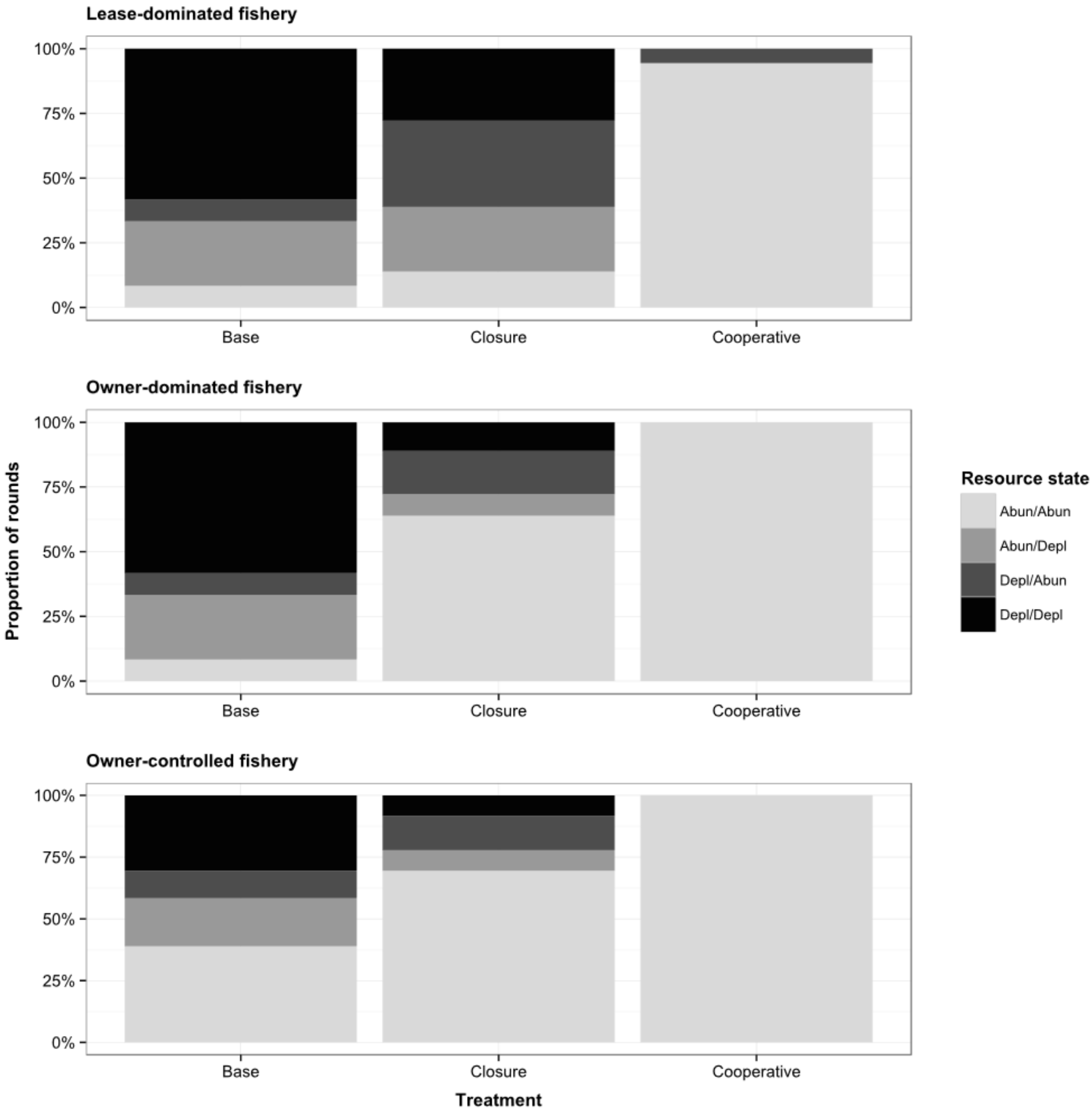


**Figure 7.2:** Proportion of rounds groups spent in a particular resource state across different treatments




### 7.4.2 The effectiveness of fishery cooperatives

The introduction of income-sharing fishery cooperatives was highly successful in providing a mechanism for groups to cooperate to reduce economic rent dissipation (Table 7.3). This was evident through a significant increase in the propensity for players in the lease-dominated fishery ($p < 0.001$), owner-dominated fishery ($p <$

0.02) and owner-controlled fishery ($p < 0.001$) to make socially-optimal decisions relative to their baseline(s). The introduction of income-sharing fishery cooperatives, however was only significantly more successful from the temporal closure structure ($p < 0.001$) in the lease-dominated fishery. This suggests that the introduction of fishery cooperatives provided effective incentives for fishers to resolve assignment problems, particularly when the fishery was lease-dominated.

These results were also reflected in the propensity for players to make socially-optimal decisions across all rounds. For example, when the resource was abundant in both areas in the lease-dominated fishery, participants made non-Nash decisions 94% of the time, an increase of 11% and 50% from the temporal closure and baseline respectively (Figure 7.1). Similarly, in the owner-dominated and owner-controlled fisheries, participants made non-Nash decisions 94% and 97% of the time respectively, however this didn't represent any significant change in decision-making from the temporal closure(s) (Figure 7.1). When comparing the effect of fishery cooperatives across different fisheries, there was no significant difference found in the probability of participants making socially-optimal decisions, suggesting they were all equally successful in reducing economic rent dissipation.

The introduction of fishery cooperatives resulted in groups remaining in an abundant/abundant state for most of the experiment. For example, in the owner-dominated and owner-controlled fisheries, groups were able to maintain the resource in an abundant/abundant state for 100% of the time, which was an improvement from the temporal closure treatment of 36% and 31% respectively

(Figure 7.2). In the lease-dominated fishery, groups were able to maintain the resource in an abundant/abundant state for 94% of the time, which was an improvement of 80% from the closure treatment (Figure 7.2).

Cooperation was most improved through the introduction of fishery cooperatives in the lease-dominated fishery. In the owner-dominated and controlled fisheries, participants were slightly more successful in cooperating to prevent economic rent dissipation through the introduction of fishery cooperatives compared to the institution of temporal closures.

## 7.5 Discussion

Quota management alone cannot fully address all of the complexities of fisheries management (Degnbol et al., 2006) because it is impractical to specify allocation shares over every aspect of the fishery environment (Grafton et al., 2006). Consequently, externalities such as assignment problems exist, where spatial or temporal variations in productivity across fishing grounds create disparity in the revenue obtained from an individual quota unit (Copes, 1986; Boyce, 1992). Fishers then race each other to those areas, or at those times, where and when the revenue obtained from fishing is highest, leading to economic rent dissipation through increased costs of fishing, localised stock depletion and congestion of fishing grounds (Holland, 2004; Costello and Deacon, 2007; Wilen et al., 2012). This study identified that both temporal closures and income-sharing fishery cooperatives can reduce economic rent dissipation caused by assignment problems relative to traditional quota management. With the exception of the income-sharing fishery cooperative(s) however, these improvements were moderated by the presence of a greater number of lease quota fishers making decisions and larger group sizes.

Heterogeneity among groups of harvesters can impede cooperation, due to the differential values that they place on the resource and the subsequent distributional conflict associated with alternative sharing rules (Johnson and Libecap, 1982; Kanbur, 1992; Hackett et al., 1994). In a previous study, heterogeneity among groups of quota owners and lease quota fishers was shown to limit the benefits of communication in reducing economic rent dissipation caused by assignment problems (Chapter 6). This was because relative to quota owners, lease quota fishers had: (i) inequality in wealth, in having to subtract their costs of purchasing a quota package from their revenue from fishing; (ii) insecurity of tenure, in having to bid competitively each round in order to acquire a quota package and; (iii) asymmetric information exchange, in not being able to participate in group discussion during rounds where they didn't acquire a quota package.

As the enforcement of temporal closures in areas that were depleted would not resolve the inherent problem of distributional conflict caused by group heterogeneity, it was hypothesised that there would be no improvement from the baseline structure(s). However, the disincentive of potential reduced revenue through not being able to necessarily make a fishing decision at times when both areas were closed, resulted in significant reductions in economic rent dissipation from the baseline(s) in all fisheries. Consequently, external regulation had a positive effect on incentivising groups to coordinate as predicted under standard economic theory and this was greatly assisted by the ability of groups to communicate (Emery, unpublished data).

While the introduction of temporal closures altered the incentives of participants and improved group coordination, the inherent problem of distributional conflict caused by group heterogeneity remained unresolved and continued to impede coordination in the lease-dominated fishery, relative to the other two fisheries. For example, participants in the owner-controlled fishery were significantly more likely to make socially-optimal decisions relative to their lease-dominated fishery counterparts. While all groups were unable to maintain the resource abundant in both areas for the entire experiment, participants in the lease-dominated fishery spent a much greater proportion of their time in a suboptimal resource state. This was because the foremost effect of temporal closures was to shift fishing effort to other areas and promote stock recovery, not alter underlying behavioural incentives that cause fishers to over-appropriate the resource (Hilborn et al., 2004b). Fishers are often extremely effective at adapting in order to minimise losses, leading to effort displacement that may have undesirable impacts on the productivity of areas that remain open (Hilborn et al., 2004b; Abbott and Haynie, 2012). For example, Abbott and Haynie (2012) showed how large spatial closures in the U.S. Eastern Bering Sea designed to protect red king crab, led to large increases in halibut bycatch, due to displaced effort and adaptations in fisher behaviour. Similarly, Holland (2000) showed that ecological benefits may be offset by the redistribution of fishing effort to unprotected areas and alternative species by simulating a hypothetical fishery closure in the northwest Atlantic. In this study, the benefits of temporal closures may have been inflated, because the variable and fixed costs of fishing were assumed to be equal across all fishers (not including leasing) and there was only one area available to fish following the institution of a temporal closure. In reality, most commercial fisheries would have multiple fishing grounds with varying productivity. The closure of one area could have disproportionate impacts on fishers who are “area specialists” (fish only that area) compared to “movement specialists” (fish multiple areas) (Branch et al., 2006), theoretically reducing the probability of cooperation. Furthermore, it is unlikely that an entire commercial fishery would be closed for a period of time as simulated in the experiment, which would presumably create a greater incentive to coordinate than what would occur in reality.

Group size may also have been a factor reducing the effectiveness of the lease-dominated fishery in reducing economic rent dissipation under the temporal closure structure. This is because as group size increases there is a greater probability of some participants adopting a Nash equilibrium strategy and there are higher transaction costs associated with internal agreements among participants to coordinate (Ostrom, 2001). In this experiment the ability to establish trust was seriously impeded because the same lease quota fishers were not necessarily able to participate in every group discussion. This reflected the historical management structure in many quota-managed fisheries where authorities engage only with quota owners in decision-making. With many ITQ fisheries categorised by an increasing number of lease quota fishers (Pinkerton and Edwards, 2009; van Putten and Gardner, 2010), asymmetric information exchange can lead to misinformation and confusion between fishers over regulations and/or policy, eroding overall trust (see Chapter 6). In the lease-dominated fishery there were 15 different possible combinations of participants communicating in any one round compared to just five different combinations in the owner-dominated fishery and zero in the owner-controlled fishery. This would have made it difficult for groups in the lease-dominated fishery to establish any form of identity and maintain a cooperative outcome given their reduced ability to create a history of effective group decision-making (see Chapter 6).

While the temporal closure strategy failed to address the underlying issue of distributional conflict caused by group heterogeneity, the introduction of income-sharing fishery cooperatives altered fishing behaviour, through creating a disincentive for participants to choose their Nash equilibrium strategy. As the income from all participants was pooled at the end of the round and divided equally, the benefits that a single participant received from playing their Nash equilibrium strategy was significantly reduced if others didn't also choose likewise. For example, when both areas were abundant, a participant could make 200 experimental dollars from choosing their Nash equilibrium strategy. Under the fishery cooperative structure however, they would only receive 167 experimental dollars, assuming others chose the socially optimal strategy. With communication, participants refrained from choosing their Nash equilibrium strategy across all three fisheries. One possible explanation is that they believed others would choose the socially-optimal strategy and so choose likewise. This resulted in all three fisheries being equally effective in reducing economic rent dissipation for most, if not all of the experiment(s).

Experimental evidence has similarly indicated that by creating an incentive to "free-ride" on the efforts of others, output sharing among appropriately sized groups can offset the incentive to over-appropriate the resource, when or where the value is highest (Schott et al., 2007; Heintzelman et al., 2009). While not directly comparable to this study due to an absence of individual fishing costs, the "free ride" outcome nevertheless highlights the benefits of income-sharing in resolving assignment problems. Field examples of income-sharing among fishery cooperatives also highlight its effectiveness in rectifying assignment problems. For example, Carpenter and Seki (2011) showed that pooling of income among Japanese artisanal shrimp fishers created an incentive to reduce over-appropriation and congestion through coordinating fishing effort. This led to greater catches and higher incomes among fishers who pooled income compared to non-poolers. The effectiveness of fishery cooperatives in reducing economic rent dissipation caused by assignment problems is not limited however to solely those that share income. There are also many historical examples of self-organisation among fishers and fishing cooperatives to deal with assignment problems through a bottom-up approach. For example, well-functioning cooperatives in the Bering Sea pollock and Alaskan Chignik sockeye salmon fisheries increased profitability of members by coordinating harvests among the most efficient fishers, sharing information on fish stocks and sharing inputs in order to reduce fishing costs (Deacon, 2012). In the Pacific halibut fishery between 1933 – 1941 and 1957 – 1976, heterogeneous fishing cooperatives from the U.S. and Canada were able to implement a "lay-up system", which prevented fishers from going back to sea for a set number of days following the conclusion of a trip (Pinkerton, 2013). Compliance among fishers was high because they were responsible for enforcing regulations and it was effective in reducing fishing pressure, overcapitalisation and assignment problems (Pinkerton, 2013). Similarly, in the Gulf of Maine lobster fishery since the 1930s, territorial harbour gangs functioning as fishery cooperatives have been effective in introducing and enforcing a series of rules to conserve the lobster stock and reduce assignment problems. (Acheson and Gardner, 2014; Acheson and Gardner, 2010). The effectiveness of the gangs in developing a conservation ethic and agreed rules was primarily due to the small size and homogenous nature of the industry (Acheson and Gardner, 2014; Acheson and Gardner, 2010). With the exception of the Gulf of Maine lobster fishery, in all of these examples however, some fishers remained outside the cooperatives, a choice that was not presented to participants in this experiment in order to simplify the design. Consequently, if participants were given the choice about whether to join a fishery cooperative the results may have been different. For example, the lay-up system in the British Columbia halibut fishery collapsed in the 1970s following an increase in the number of new entrants and an inability to enforce rules on non-members (Pinkerton, 2013). This led to members dropping out of the cooperative due to their inability to compete financially with non-members.

Income sharing fishery cooperatives were able to offset the incentive of participants to over-appropriate the resource when and where it was most profitable, by creating a disincentive for participants to choose the Nash equilibrium strategy if they doubt others would do the same. While temporal closures were surprisingly almost as effective in reducing assignment problems in the owner-dominated and owner-controlled fisheries, greater heterogeneity and possibly larger group sizes resulted in the lease-dominated fishery being significantly less effective. This was due to the same group of participants not necessarily being able to discuss fishing strategies each round, resulting in asymmetric information exchange and difficulties in establishing a group identity and eliciting trust. Lease quota fishers relative to quota owners also had to cope with wealth inequality and insecurity of tenure in having to bid for a quota package and pay for it using their revenue from fishing. Given that many quota fisheries are increasingly characterised by lease quota fishers (Pinkerton and Edwards, 2009; van Putten and Gardner, 2010), this experimental approach has illustrated the benefits of income-sharing fishery cooperatives in reducing the distributional conflict caused by heterogeneity, which restricts participants from agreeing to and maintaining a social-optimal strategy for resolving assignment problems.

## 7.6 Conclusion

Quota management is unlikely to resolve assignment problems given that the benefit of correcting the problem by fully delineating quota units is often less than the operational and logistical cost of doing so (Copes, 1986; Copes and Charles, 2004; DPIPWE, 2009). Consequently, there is need to determine which cross-disciplinary management measures may be most effective in resolving assignment problems. By incorporating fisher heterogeneity and ecological dynamics such as path-dependency of previous use and non-linearity of payoffs into this experimental design it was identified that temporal closures can overcome assignment problems among smaller sized and homogenous groups of fishers. They do not resolve however, the issue of the distributional conflict caused by heterogeneity among fishers, which reduces the propensity for groups to agree to and maintain a strategy for preventing economic rent dissipation. In this experimental setting, the introduction of fishery cooperatives was able to resolve this issue through enforcing income-sharing among all participates, which reduced their incentive to choose their Nash equilibrium strategies. While the results require external validation in the field due to their simplified nature, they still provide prediction and insight into possible ways of resolving assignment problems under quota management.

# Chapter 8: General Discussion

## 8.1 A thesis overview

The specific aim of this thesis was to assess the effectiveness of individual transferable quota (ITQ) systems of management in meeting economic, ecological and social objective(s) through quantitatively analysing changing fishing practices and behaviour of fishers in the Tasmanian southern rock lobster (TSRL) fishery to inform management decision-making. I addressed this aim firstly, in Chapter two, through examining the ability of ITQ systems to meet ecosystem based fisheries management (EBFM) outcomes by analysing the prevalence of input controls (e.g. gear restrictions) in both domestic and international fisheries that were certified as sustainable. Because all ecosystem components (i.e. non-target, threatened, endangered and protected (TEP) species, habitats) were not included in the ITQ systems of most assessed fisheries, fishers did not have any incentive to modify their behaviour to avoid negative interactions with them, as it wouldn't directly affect their asset value or ability to successfully catch target species. Consequently, these ITQ fisheries continued to use input controls to meet EBFM targets, particularly those with less selective fishing methods, such as trawl and gillnet. I argued that input controls continued to be used because they were transparent, relatively straightforward to introduce and any modification of the ITQ system(s) would be logistically and financially prohibitive. I ventured that the use of input controls under ITQ management eroded the security (property right) characteristic of the ITQ (see, Ridgeway and Schmidt, 2010) through loss of access and increasing inefficiency, which had the potential to misalign industry incentives and behaviour with societal objectives for sustainability. In other words, ITQ systems won't necessarily be able to resolve all EBFM outcomes, particularly in those fisheries with less selective fishing methods or even targeting multiple species.

Consequently, building increased flexibility and adaptability into future ITQ systems is important, as well as meticulously defining all objectives and understanding trade-offs prior to implementation.

In Chapter three, I analysed changes in fishing practices in the TSRL fishery between 2001 and 2010. Between 2008 and 2010, the TSRL fishery had a non-binding (i.e. non-constraining) total allowable catch (TAC). This increased fisher uncertainty and discount rates, while concurrently reducing confidence in the ITQ management system and state of the stock, leading to modifications in behaviour and decision-making. Observed changes in behaviour included a concentration of fishing effort temporally between November and February when the quota unit value was highest, an increase in fishing to revenue, reduced quota investment and a reactivation of latent effort, which led to increases in fishing fleet inefficiency. I ventured that the fishery effectively operated as a regulated limited-entry fishery during those years, highlighting that the effectiveness of an ITQ system relied not just on ensuring effective governance (Hanna, 1999) and appropriate monitoring, control and surveillance (Parslow, 2010) but a binding TAC set by the managing authority. This is the first study to my knowledge that used an actual fishery case study to demonstrate how open-access inefficiencies can reappear under ITQs if the TAC is non-binding. Following on from assertions made in chapter two about the importance of upholding the security of the ITQ right, this chapter provided a clear example of how behaviour and incentives can actually transform following reductions in security of the ITQ right.

In the wake of analysing overarching modifications in fisher behaviour and decision-making under a non-binding TAC, I shifted in chapter four to examining whether a specific change in fishing practices termed “double night fishing” could cause localised depletion in the TSRL fishery. While I was unable to assess the full extent of the practice due to the current format of the logbook, I was able to show that among volunteer fishers who “supposedly” undertook double night fishing, the practice was surprisingly uncommon. While double night fishing trips on average, had three more shots per trip than standard fishing trips, there was no detectable differences in trip length, bycatch composition, size selection or catch per unit effort (CPUE) between double night and standard shots. I therefore asserted that double night fishing was unlikely to be causing localised depletion of the stock but without broader participation of the fishing fleet and clearer recording of shot times in the logbook, that it was difficult to determine whether the true extent of the activity had been captured. This result underlined the importance of ITQ fisheries having access to fine-scale spatial and temporal data in order to inform real-time management decision-making. The absence of information on time of set and haul in the logbook prevented a precise assessment of the fleet-wide extent and impact of double night fishing. Advantageously in 2014, the management authority is now amending the logbook and implementing some of the changes recommended by the work.

In my last three chapters (five to seven) I shifted away from analysing fishery-wide behaviour to directly comparing the behaviour of different groups of fishers under ITQ management. In many ITQ fisheries there is a growing disconnect between those that own quota units (quota owners) and those that fish those same quota units (lease quota fishers). Importantly, I wanted to compare whether the behaviour and decision-making of lease quota fishers was different from quota owners and whether divergence could inhibit some of the theoretical advantages of ITQ management. While much has been written on the subject of differing incentives between quota owners and lease quota fishers (e.g. Gibbs, 2009; Pinkerton and Edwards, 2009; Parslow, 2010; Pinkerton and Edwards, 2010) their behaviour under ITQ management has not been quantitatively compared. In chapter five, I examined whether the ITQ system in the TSRL fishery equally reduced the physical risk tolerance of both types of fishers and their propensity to engage in hazardous fishing practices (e.g. fishing at high wave heights). Using a discrete choice model of fisher participation I found that fishers in general, were averse to physical risk but this was offset by increases in expected revenue. In other words, fishers were more likely to take risks if there was a financial incentive. Lease quota fishers however, were more responsive to changes in expected revenue, which led to significantly higher risk tolerances in some areas than quota owners. I advocated that this observed difference in fishing incentives was due to lease quota fishers having to cover their costs of leasing quota (in addition to other fixed and variable costs of fishing) from their landed catch revenue. In many ITQ fisheries the lease price as a proportion of the ex-vessel value of the catch is exorbitant, so lease fishers face a "cost-price squeeze between what [they] must pay to lease the quota and what [they] are paid for [their] catch" (Pinkerton and Edwards, 2009). This result highlighted the importance of understanding behavioural differences between quota owners and lease quota fishers, particularly as the theoretical advantages of ITQs implicitly assume that those fishing are quota owners; which in many ITQ fisheries is simply no longer true (Connor and Alden, 2001; van Putten and Gardner, 2010). Given the increasing propensity for ITQ fisheries to be dominated by lease quota fishers I believe it is important that decision-makers carefully assess the trade-offs in allowing free transferability of quota units and whether this meets associated economic and social objectives of the fishery.

After quantitatively modelling the behaviour of lease quota fishers and quota owners in chapter five I took an experimental economic approach in chapters six and seven to examine under laboratory conditions, the propensity of both types of fishers to coordinate to resolve assignment problems caused by heterogeneity in the economic value of catches across space and time. Previous research has highlighted that if the ITQ system does not impose overly restrictive spatial and temporal conditions on harvesting or there is no centralised authority coordinating effort, fishers will compete for the most valuable portions of a heterogeneous stock, which will dissipate part of the fishery's economic rent through production externalities (Costello and Deacon, 2007; Deacon and Costello, 2007). In chapter six, I examined whether groups of varying numbers of lease quota fishers and quota owners could coordinate through the use of communication to reduce economic rent dissipation. While previous experimental research has underlined the success of communication in allowing groups to coordinate (Ostrom et al., 1992; Sally, 1995; Ostrom, 2006), my research indicated that the advent of communication was unsuccessful in improving group coordination among heterogeneous fishers. I speculated that this was due to the differential value that lease quota fishers place on the resource relative to quota owners, due to having: (i) inequality in wealth; (ii) insecurity of tenure; and (iii) asymmetric information exchange, which meant they were less likely to adopt a socially-optimal strategy for preventing rent dissipation. Homogenous groups of quota owners were more successful in preventing rent dissipation, suggesting that the presence of lease fishers negatively affected the ability of heterogeneous groups to establish trust and a sense of identity. Given these results, I then examined in chapter seven whether the introduction of fishery closures or income-sharing through a fishery cooperative with communication, could assist the same groups to reduce economic rent dissipation. Previous field research has emphasised the success of fishery cooperatives in coordinating harvests, sharing information and fishing inputs in order to reduce externalities and increase profitability (Deacon, 2012; Deacon et al., 2013). I found that with the exception of the groups dominated by lease quota fishers, all other groups were successful in reducing rent dissipation under both fishery closure and cooperative treatment(s) relative to their baseline(s). The groups dominated by lease quota fishers however, were only successful in coordinating to reduce economic rent dissipation when required to share income through the fishery cooperative. This was because the income-sharing offset the incentive to over-appropriate the resource if participants doubt that other would do the same, as the benefit would not be individually attained the and the cost shared among the entire group. While the results of both chapters require external validation in the field, I believe they reiterate the importance of recognising and understanding the differing incentives and behaviours of lease quota fishers and quota owners, which is likely to affect some of the theoretical advantages of ITQ systems. They also highlight the benefits of well-functioning fishery cooperatives, which allow fishers under ITQ management to increase profitability by reducing assignment problems that cause economic rent dissipation.

ITQs have been highly successful in meeting a variety of fishery economic and ecological objectives for target species, however their inability to address a number of socio-ecological objectives has highlighted the need for a multi-disciplinary approach to management (Degnbol et al., 2006; Olson, 2011). ITQs are logistically complex and financially costly to implement, not to mention difficult to amend once instituted. ITQs do not necessarily remove the need for further input controls to manage all ecosystem components as required under an EBFM policy framework, require increased capacity in data collection and monitoring, control and surveillance and don't necessarily support collective economic rationality among industry to reduce assignment problems and maximise economic rent. Consequently, it is important that fisheries managers and all other relevant stakeholders appropriately consider the initial design and development of any ITQ system in meeting its target objectives. Assessment of the evolution of ITQ systems and the historical behaviour and decision-making of different types of fishers under this form of management, can inform current fisheries managers and stakeholders in designing ITQ systems. The aim of this thesis was to assess the costs and benefits of ITQ management in the TSRL fishery and highlight the importance of assessing post-implementation behavioural changes and decision-making among different types of fishers. While this type of research remains in its infancy, there are growing calls for further research and its consideration in management decision-making (Fulton et al., 2011; Thébaud et al., 2012). Through my research I was able to emphasise the importance of: (i) carefully considering economic, ecological and social objectives of ITQ management prior to implementation, to ensure appropriate contemplation of trade-offs; (ii) quantitatively analysing whether ITQ systems do indeed achieve objectives through greater consideration of fisher behaviour and; (iii) understanding the divergence in the incentives of lease quota fishers and quota owners in many ITQ fisheries caused by the free transferability of quota units and whether this affects the ability of ITQ systems to achieve objectives. Further research into assessing the impact of ITQ management in established fisheries will allow future decision-makers to appropriately consider the costs and benefits of this form of management and if preferred, base their design and implementation on best-practice.

# Appendix A. Handled with care: minimal impacts of appendage damage on the growth and productivity of the southern rock lobster (*Jasus edwardsii*)

This chapter is *under review* with Fisheries Research as:

Emery, T.J., Hartmann, K., Green, B.S., Gardner, C and Tisdell, J. Handled with care: minimal impacts of appendage damage on the growth and productivity of the southern rock lobster (*Jasus edwardsii*).

## A.1 Abstract

The capture, handling and release of invertebrates such as lobsters during commercial fishing operations can lead to physiological changes such as reduced growth and impaired reproduction. In particular, damage to appendages can reduce the exploitable biomass available to fishers as moulting lobsters expend energy resources re-growing limbs at the expense of increasing in size. To assess the effect of injuries on the growth of male and female lobsters smaller than the legal minimum size (undersize), a Bayesian hierarchical approach was taken to fit the parameters of the von Bertalanffy growth equation to mark-recapture observer data from southern stock assessment areas (SSAAs) of the Tasmanian southern rock lobster (TSRL) fishery in Australia. While the effect of handling damage on the growth of undersize females could not be distinguished from zero because of small growth increments, the impact on males was marked, with damage to antennae or legs estimated to have a similar proportional impact on growth of 7% (0-16%, 95% CI) and 7% (0-14%, 95% CI) respectively. Damage to both antennae and legs had a greater estimated proportional impact on growth of 40% (24-57%, 95% CI). Despite the substantial reductions in predicted growth caused by the loss of antennae and/or legs, fewer than 6% of undersize male lobsters had these types of injuries. With an estimated 4.22 ± 0.4 (mean ± 95% CI) million lobsters discarded annually between 2001 and 2010 from SSAAs, annual lost productivity and revenue from slower growth was predicted to be 1.6 tonnes and AUD $72,905 respectively in the TSRL fishery. The overall impact of damage on male lobsters was less than 1% of the total allowable catch and revenue for the TSRL fishery in 2010. Mortality among damaged lobsters was estimated at 3.9% from SSAAs for a total productivity

loss of 22.1 tonnes in the TSRL fishery. These results highlight the effectiveness of the fishing method, sorting procedures, as well as management measures (escape gaps) and the biology of the species in reducing excessive amounts of handling damage in the TSRL fishery. Gradual improvements in gear design and increased awareness and education of fishers could reduce the effect of handling damage and make minor improvements to fishery productivity and profitability.

## A.2 Introduction

Crustacean growth is discontinuous and measured across a series of moults where the hardened exoskeleton is shed and a larger one forms. The rate of growth is a function of both the change in size at moult (moult increment) and the frequency of moults (moult period) (Davis and Dodrill, 1980; Davis, 1981). These both vary due to intrinsic factors such as size, sex and the onset of sexual maturity (Wahle and Fogarty, 2006; Chandrapavan et al., 2010) and extrinsic factors such as water temperature (Chittleborough, 1975; Annala, 1991; Green et al., in review), food availability/diet (Chittleborough, 1975; Joll and Phillips, 1984; McGarvey et al., 1999), density of lobsters (Booth and Kittaka, 2000) and damage (Chittleborough, 1975; Davis, 1981).

The incidence of physical damage (i.e. broken appendages) in the natural environment is consistently high in crustaceans, ranging from 19-32% in Decapods to 36-50% in Amphipods (Lindsay, 2010). Physical damage can reduce the moult increment (Chittleborough, 1975; Davis, 1981; Brown and Caputi, 1985; Brouwer et al., 2006) and decrease (Chittleborough, 1975; Brouwer et al., 2006) or increase (Davis and Dodrill, 1980; Davis, 1981; Hunt and Lyons, 1986) the moult period.

Reductions in the moult increment occur because energy reserves are redistributed towards regenerating lost limbs at the expense of increasing in size (Davis and Dodrill, 1980; Davis, 1981; Dubula et al., 2005). The size increase at moult declines with the extent of regeneration required and has been termed the “regenerative load” (Skinner, 1985; Juanes and Smith, 1995). Reductions in growth can impact on the ecological interactions of crustaceans as body size is ultimately linked to fecundity, foraging efficiency, mating success, predator avoidance and defensive capability (Juanes and Smith, 1995; Parsons and Eggleston, 2005).

Physical damage may occur through inter-specific competition among conspecifics in their natural environment and the capture, handling and release of undersized crustaceans during commercial fishing operations. Direct handling by commercial fishers or agonistic behaviour among conspecifics awaiting sorting can induce autonomy, which is a typical response of crustaceans to avoid predation or injury where appendages such as the legs are reflexively shed at the fracture plane in the exoskeleton (Uhlmann et al., 2009). It can also lead to appendage fractures that are not distal to the fracture plane. The latter form of damage is known to increase wounding, blood loss and mortality (Juanes and Smith, 1995; Uhlmann et al., 2009). Fishing for crustaceans usually involves setting baited pots/traps on the seabed, which after varied soak times are hauled to the surface before the catch is sorted and undersize animals discarded. As many crustacean fisheries have minimum size limits to protect a portion of the spawning stock, attempts have been made to reduce the unintended capture of undersize animals by improving the selectivity of various gear configurations (Uhlmann et al., 2009). For example, the introduction of escape gaps in the pots used in many lobster fisheries (Krouse and Thomas, 1975; Krouse, 1978; Schoeman et al., 2002a; Schoeman et al., 2002b).

Although the introduction of escape gaps have significantly reduced the discarding of undersize lobsters (Phillips et al., 2008), their complex shell morphology prevents the defined selection of a particular size class in pots, with large numbers still caught and discarded (Brown and Caputi, 1985).

Damage to appendages, whether through autonomy or fractures lead to reductions in somatic growth rates (Davis and Dodrill, 1980; Davis, 1981; Dubula et al., 2005), with even minor losses (one or two appendages) causing significant declines in growth (Davis, 1981). In various fisheries, reductions in growth have resulted in: (i) animals remaining undersize for longer periods of time and being exposed to multiple capture and handling events as well as additional natural mortality; (ii) animals entering the fishery at smaller sizes thereby reducing harvestable yield and; (iii) reductions in the size at maturity, which may concurrently reduce the fecundity of animals due to correlations with body size (Davis, 1981; Brown and Caputi, 1985). This can reduce fisheries productivity, with consequences for sustainable management as the growth rate is inherently linked to the level of exploitable biomass in the fishery through its influence on population productivity (Hunt and Lyons, 1986; Bergh and Johnston, 1992; Schoeman et al., 2002b).

Successful fisheries management requires an understanding of the occurrence and effect of physical damage on the growth of crustaceans. Many of the studies assessing the rate and impact of physical damage on crustacean growth have come from captive animals that are caged, tank-held or tethered, analysed over short periods of time (e.g. Parsons and Eggleston, 2005; Brouwer et al., 2006). Frisch and Hobbs (2011) argue that captive animals in controlled settings may not be representative of the wild population because they behave, grow and survive differently due to variations in food supply and predation risk. Moreover, the effect of physical damage on the growth increment may be over-or-underestimated as consequences may be long-term or take considerable time to manifest, or be different when an animal has to forage, maintain a home range and avoid predation. Many studies also group together different types of limb loss (i.e. antennae, walking legs, chelipeds) and collectively term them “appendage damage”. Damage to more specialised limbs however, may require greater energy investment or have larger ecological implications (Juanes and Smith, 1995). For example, damage to a few walking legs in crustaceans is theoretically less costly to overall fitness than the loss of the first pereopod or cheliped, which is used in defence against predators (Davenport et al., 1992; Roth and Kitchell, 2005), inter-and-intra-specific competition (Smith, 1992; Parsons and Eggleston, 2005), capture, manipulation and subdual of prey (Lawton, 1989; Keller and Hazlett, 1996) and in mating (Smith, 1992; Juanes and Smith, 1995; Mariappan et al., 2000). While the impact on growth may be more pronounced when a specialised limb is damaged, this may not necessarily be the case across all crustacean species (Kouba et al., 2011). It is therefore important to conduct long-term studies using data from wild-caught populations to evaluate the effects of different types of injuries on the growth of individual species.

This study used a 20 year tag-recapture dataset to assess the effect of different types of limb loss (i.e. antenna, walking leg or both) from commercial fishing operations on the growth increment of both males and female southern rock lobsters (*Jasus edwardsii*) distributed around southern Tasmania, Australia. While it is known that released southern rock lobsters survive the handling process (Hamon et al., 2009) and that escape gaps effectively reduce the capture of undersize lobsters (Krouse, 1978), there is no information available on the effect of handling damage on released lobsters around Tasmania and what impact this may have on the productivity of the stock through reductions in the growth increment. Given the prevalence of injury in crustacean populations (Lindsay, 2010), the ecological importance of the species (Juanes and Smith, 1995) and the potential productivity and revenue costs for the species and fishery respectively, analysis of the long-term effects of different types of damage on the growth of the southern rock lobster in its natural environment will support its effective management.

## A.3 Methods

### *A.3.1 Study species: southern rock lobster (Jasus edwardsii)*

Residing primarily on rocky reef habitat at depths of 1 – 200 m, the southern rock lobster range extends the length of southern Australia and New Zealand (Booth, 2006). In south-eastern Australia, the stock supports important commercial and recreational fisheries in South Australia, Victoria and Tasmania with an estimated total catch of 3,500-4,000 tonnes and a gross commercial value of around AUD $200 million (Knight and Tsolos, 2009; Linnane et al., 2010a). These fisheries all use gear consisting of baited rectangular or round pots with compulsory escape gaps that are either set during the day and hauled in the late evening and/or set overnight and hauled at first light. In Tasmania, there are more than 225 vessels that target southern rock lobster during the official fishing season from March to February. Input controls in the fishery include a minimum size limit of 110 mm and 105 mm carapace length (CL) for male and female lobsters respectively and maximum pot sizes of 1.25 m high and 7.5 m wide, with either one escape gap of 57 mm high and 400 mm wide or two escape gaps of 57 mm high and 200 mm wide, required to reduce juvenile catch (Anonymous, 2011). There is also a seasonal fishery closure to protect male moulting lobsters from October to November and compulsory discarding of female lobsters from May to November to protect the moult and egg production cycle (Anonymous, 2011).

Despite significant regional differences in spatial biology (Gardner et al., 2006), there is limited spatial aspects to management across the range in Australia with five separate zones for individual transferable quotas (ITQs) and only two size limit regimes. Spatial variation poses an ongoing management challenge within the Tasmanian jurisdiction (McGarvey et al., 1999; Chandrapavan et al., 2010) because the growth rates and size at sexual maturity of southern rock lobster vary substantially from north to south of Tasmania (Punt et al., 1997). These spatial variations in demographic traits result in more lobsters being released through the course of normal fishing operations in the south of the State because growth is slower in this region. Thus the effect of damage on the growth increment of southern rock lobster is of greatest concern in this region of the fishery.

### *A.3.2 Modelling data and assumptions*

To investigate the effect of damage on the annual moult increment of undersize southern rock lobster, tag-recapture data from commercial fishing operations over the period 1992 to 2012 was collated from a dataset administered by the Institute for Marine and Antarctic Studies, University of Tasmania. This dataset contained comprehensive information on lobster size, sex, maturity and location, among other biological characteristics, allowing a direct assessment of the change in size of lobsters over the time elapsed between tagging and recapture, based on sex and location. Tag-recapture data has been routinely collected in the fishery since the early 1990s, providing numerous records of lobsters with multiple recaptures. Only the first recapture was used in the analysis to estimate the effect of damage on the annual moult increment because multiple recaptures can bias growth estimates (Wahle and Fogarty, 2006). Similarly, because accurate rates of injury may be obscured by rapid regeneration if the time between capture and recapture is lengthy (Lindsay, 2010), all records where the lobster was at large for more than four years were removed from the analysis. As there was limited tag-recapture information from the northern areas of the state and regional variation in the biology of the stock between the north and south (Punt et al., 1997), only tag-recapture information from southern stock assessment areas (SSAAs 1, 2, 7 and 8), below 42 degrees South were used in the analysis (Figure A.1). Additionally, as the study was focused on the effect of new damage on the growth of lobsters released back into the sea through normal fishing operations only undersize lobsters were used in the analysis. It was also assumed that there was no substantial difference in the handling of lobsters by scientists on board research trips and fishers on commercial trips as similar gear and methods of extracting lobsters would be employed, so data from both were included in the analysis. This meant that there were a total of 12,740 tagging records (6,255 female, 6,485 male) used to analyse the effects of damage on the growth of southern rock lobsters. Most of these lobsters were tagged in the spring and summer seasons (Figure A.2).

**Figure A.1:** The boundaries of the eight stock assessment areas in the Tasmanian southern rock lobster fishery

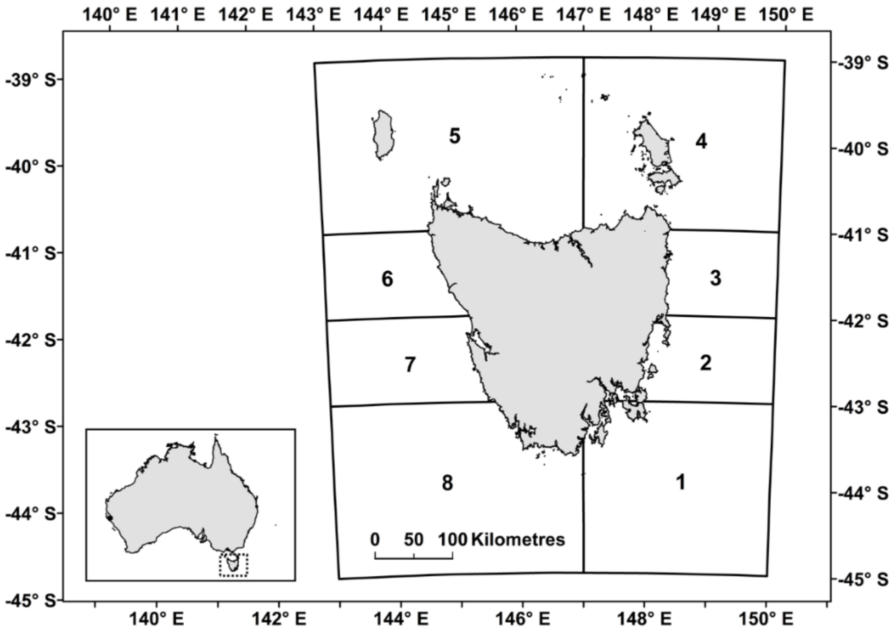
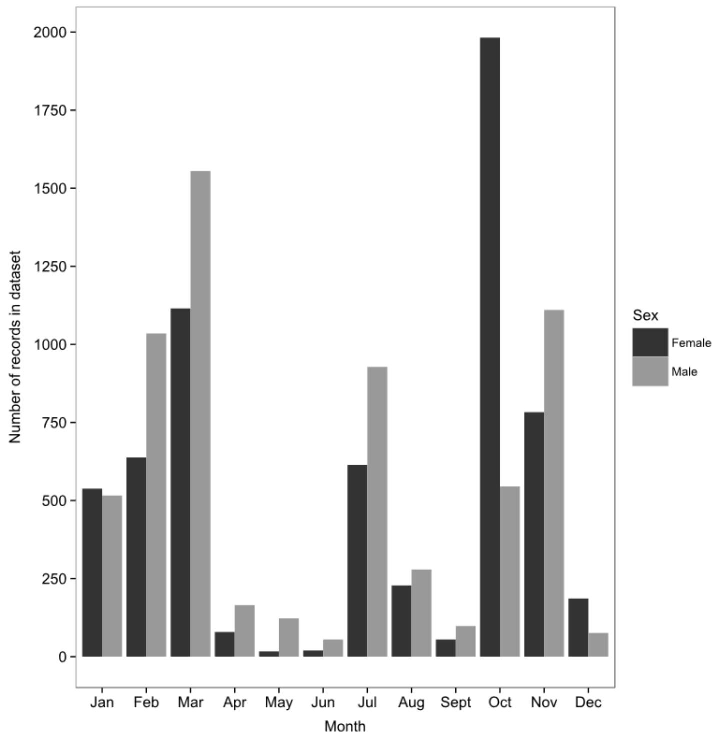



**Figure A.2:** Seasonal distribution of tagging records for undersize male and female lobsters in the Tasmanian southern rock lobster fishery



During data collation, the number of days elapsed between initial capture and recapture were used to estimate the number of moults. Based on previous analyses of tag-recapture data from this region, it was assumed that both sexes of lobsters only moulted once annually, presumably in females between the months of March and May and males between August and October (Ziegler et al., 2002b; Green and Gardner, 2009; Chandrapavan et al., 2010; Gardner and Mills, 2013). Consequently, the total number of days elapsed between captures was divided by 365 and rounded down to determine how many moults occurred during the intervening years, before an additional moult probability was added to this number based on the time of year the lobster was initially captured and recaptured. A male or female lobster that was captured after 31 October and 31 May respectively, in any given year, was assumed with 100% probability to already have moulted that year. For the days preceding those dates, a descending scale of probability was used for each sex to estimate the likelihood of moulting. Table A.1 summarises the moult probability at different times of the year for each sex. Lobsters that were assumed to have not moulted in the intervening period between capture and recapture were removed from the analysis. Average annual growth was calculated as the carapace length (mm) at recapture minus the carapace length (mm) at capture, divided by the estimated number of moults.

Undersize lobsters were divided into separate categories based on their sex (male or female) and type of damage. There were three types of damage recorded by at-sea observers in the Tasmanian southern rock lobster (TSRL) fishery: (i) “old damage”, which occurred prior to capture and was identified in the field by a dark melanisation at the site of injury (ii) “new damage”, which occurred during capture and was identified in the field by a new loss without melanisation at the site of injury and; (iii) "regenerated damage", which was recognised in the field by a noticeable smaller or thinner appendage re-growing at the site of an old injury (Melville-Smith and De Lestang, 2007). For the purposes of this analysis new damage was divided into four categories: (i) "no damage", (ii) "leg injuries", (iii) "antenna injuries" and, (iv) "leg and antenna injuries" and collectively termed "appendage damage". Injuries to the telson, pleopod and uropod were excluded due to a lack of representative data across both sexes and size classes. Additionally there was insufficient data to separate lobsters which had multiple injuries within the same damage category (e.g. three damaged legs) from lobsters which had a single injury within the one damage category (e.g. one damaged leg). While the frequency of all types of damage was analysed using descriptive statistics only new damage categories were included in the model and it was assumed that tagging of lobsters does not affect growth (Green and Gardner, 2009).

**Table A.1:** Moulting probability of both male and female lobsters based on the time of year

| Males | | Females | |
|---|---|---|---|
| Days | Probability of having moulted that year | Days | Probability of having moulted that year |
| 1 January – 30 April | 0% | 1 January – 31 January | 30% |
| 1 May – 31 May | 10% | 1 February – 28 February | 50% |
| 1 June – 30 June | 30% | 1 March – 31 March | 70% |
| 1 July – 31 July | 50% | 1 April – 30 April | 80% |
| 1 August – 31 August | 70% | 1 May – 31 May | 90% |
| 1 September – 30 September | 80% | 1 June – 31 December | 100% |
| 1 October – 31 October | 90% | | |
| 1 November – 31 December | 100% | | |

### *A.3.3 Model formulation*

The von Bertalanffy growth model (VBGM) has been shown to model growth effectively when applied to mark-recapture data (Chen et al., 1992). The VBGM however, assumes continuous growth, which is not true for crustaceans whose growth is a function of a discontinuous moult cycle. While there is concern in applying the VBGM to crustaceans (Stewart and Kennelly, 2000; Phillips, 2006), it has been successfully used for describing the growth in moulting species (Phillips et al., 1977; Caddy, 2003) and in the present study allowed for a direct comparison of the effect of damage on the growth increment of lobsters across sexes. The typical VBGM is given by:

$$\frac{dl}{dt} = K_s(L_{\infty,s} - l)$$

Where $l$ is the the length, $L_{\infty,s}$ is the asymptotic average length for lobsters of sex $s$ and $K_s$ is the growth rate. Thus the rate of growth is directly proportional to the growth rate and the difference between the lobster's current size and its maximum size.

As lobster growth is punctuated, time was defined as the number of moults that had occurred. This was determined from the dataset as outlined previously. Lobster damage was assumed to impact the growth rate hence:

$$K_s = \acute{K}_s(1 - d_{i,s})$$

Where $\acute{K}_s$ is the growth rate for undamaged lobsters and $d_{i,s}$ is the proportional reduction in growth of lobsters of sex $s$ due to the $i$th damage category. The standard VBGM parameters $L_{\infty,s}$ and $\acute{K}_s$ and the damage specific parameters were estimated for both undersize male (≤110mm) and female (≤105mm) lobsters from the SSAAs and the proportional impact of appendage damage on annual growth increment estimated for each category of new damage.

A Bayesian hierarchical approach was used to estimate the standard sex specific VBGM parameters $L_{\infty,s}$ and $\acute{K}_s$ and the damage specific parameters, $d_{i,s}$ (Essington et al., 2001; Pilling et al., 2002; Siegfried and Sansó, 2006) using the freely available program JAGS (Plummer, 2003). The data input to the model consisted of the growth rate, sex and damage category of each recaptured lobster. Two models (sex-specific) were run in JAGS with two chains per model. For each chain, the first one million iterations were discarded (burn-in period) before generating a further one million iterations. Convergence in the Bayesian model(s) was evaluated through visual inspection of auto-correlation to ensure independence of values within each chain, a Heidelberger and Welch (1983) test to assess the adequacy of the burn-in period and a Geweke (1992) test to evaluate the stationarity of the mean.

### *A.3.4 Calculation of the discard rate and annual productivity loss from damage*

The southern rock lobster stock assessment model (modified from Punt and Kennedy, 1997) was used to estimate the number of lobsters in each 5 mm size class from 60 mm to 105 mm (females) and 110 mm (males), in the SSAAs in 2012 (Figure A.1). An estimate of the number of lobsters discarded in each size class was determined by dividing the total number of discards in the SSAAs by the proportion of lobsters in each size class. The total number of lobsters discarded in the SSAAs was calculated by multiplying the average number discarded per potlift from historical at-sea observer records between 2001 and 2010 by the average annual number of potlifts in each stock assessment area from logbook data, incorporating data between 2001 and 2010.

All undersize male lobsters from 60 to 110 mm carapace length were divided into 5 mm size classes and the probability of an individual lobster being in one of the damage categories determined from the tag-recapture dataset. The model's estimate of the impact of different types of new damage on the annual growth increment of undersize males was then multiplied by the probability of being in one of the corresponding damage categories to calculate the proportional impact on growth for each damage category. This was then summed across all damage categories for each size class to get the total proportional impact of new damage on the annual growth increment.

The $L\infty$ and $K$ growth parameters from the Bayesian model were then multiplied by the median size for each 5mm size class (i.e. 62.5 mm for size class 60-65 mm) to estimate expected annual growth (mm). To convert this to weight (kgs), parameters were taken from the southern rock lobster stock assessment model to estimate an individual lobster's expected weight, before and after moulting and calculate the difference (kgs) for each size class. The lost growth (kgs) from damage was then estimated for each size class by multiplying the expected annual growth (kgs) by the number discarded and total proportional impact of new damage on the annual growth increment. This was then summed across all size classes to determine the total lost growth (kgs) or productivity in the TSRL fishery.

While there are a number of biases associated with using tag-recapture data to estimate post-release mortality a crude estimate was attained by determining the proportion of lobsters damaged versus undamaged at the initial tag and release than again at the time of recapture. Change in this proportion provided an indication of differential post-release mortality due to damage. The estimate of post-release mortality for damaged lobsters was then multiplied by the proportion who were injured and expected growth to determine the total lost growth (kgs) or productivity in the TSRL fishery.

## A.4 Results

### *A.4.1 Fishing effort and undersize lobsters*

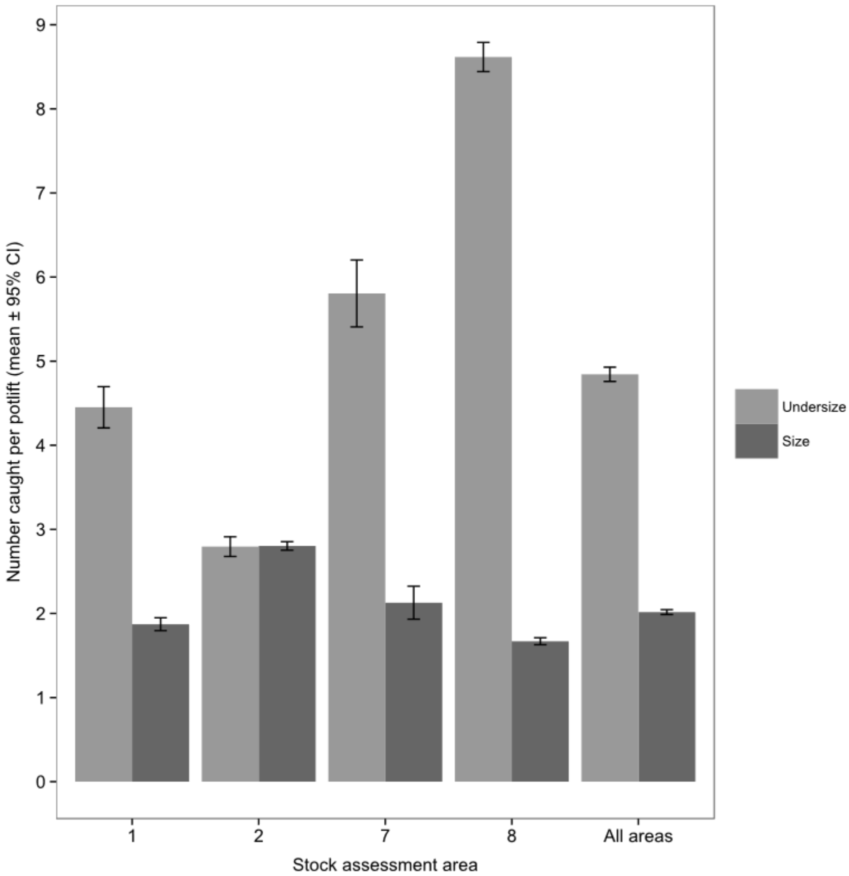
Average (mean ± 95% confidence interval [CI]) annual fishing effort (number of potlifts) in the TSRL fishery between 2001 and 2010 was 1.38 ± 0.07 million potlifts with SSAA 8 recording the highest average annual fishing effort of all SSAAs at 0.32 ± 0.04 million potlifts (Table A.2). The average annual effort of all SSAAs over the decade was 0.73 ± 0.05 million potlifts.

With an average 4.84 ± 0.08 undersize lobsters discarded per potlift over the decade (Figure A.3 and Table A.2) it was estimated that an average 6.68 ± 0.4 million lobsters were discarded annually in the TSRL fishery between 2001 and 2010 (Table A.2). SSAA 8 had the highest number of undersize lobsters discarded per potlift at 8.62 ± 0.17 over the decade with an estimated 2.74 ± 0.4 million lobsters discarded annually over this time frame (Table A.2). The average annual number of undersize lobsters discarded per potlift of all SSAAs over the decade was 5.77 ± 0.10 with an estimated 4.22 ± 0.4 million lobsters discarded annually.

**Table A.2:** Average (mean ± 95% CI) number of potlifts and discards between 2001 and 2010 for both southern stock assessment areas and all stock assessment areas in the Tasmanian southern rock lobster fishery

| ***Area*** | ***1*** | ***2*** | ***7*** | ***8*** | ***All stock assessment areas*** |
|---|---|---|---|---|---|
| *Mean potlifts/year* | 185,942 ± 13,857 | 126,158 ± 10,486 | 101,881 ± 15,895 | 317,890 ± 36,744 | 1,379,919 ± 67,259 |
| *Mean potlifts/day* | 594 | 415 | 423 | 1024 | 584 |
| *Mean discard rate* | 70% | 50% | 73% | 84% | 71% |
| *Mean no. lobsters discarded per potlift* | 4.45 ± 0.24 | 2.79 ± 0.12 | 5.80 ± 0.40 | 8.62 ± 0.17 | 4.84 ± 0.08 |
| *Mean no. lobsters discarded annually* | 827,696 ± 110,694 | 352,608 ± 45,320 | 591,425 ± 139,123 | 2,739,060 ± 378,209 | 6,684,122 ± 448,325 |

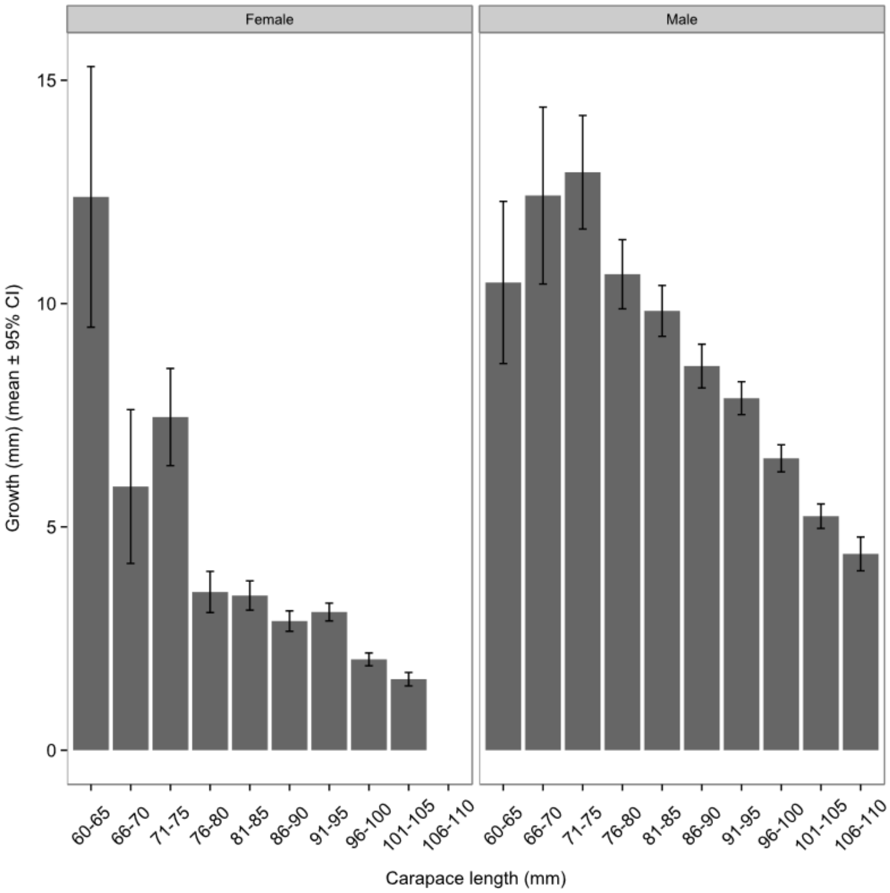
**Figure A.3:** Average (mean ± 95% CI) number of undersize and size lobsters caught per potlift between 2001 and 2010 both southern stock assessment areas and all stock assessment areas in the Tasmanian southern rock lobster fishery



## *A.4.1 Growth rate of undersize lobsters*

Average growth rates of undamaged male and female lobsters from SSAAs were highly variable among initial size classes of 60-75mm carapace length (CL) but declined steadily in both sexes with increasing size (Figure A.4). Female growth rates were similar to male growth rates at 60-65mm CL but by 66-70mm CL were less than half, which was presumably an indication of the advent of sexual maturity and redistribution of energy reserves. Female growth rates after 75mm CL were around 40% of male growth rates.

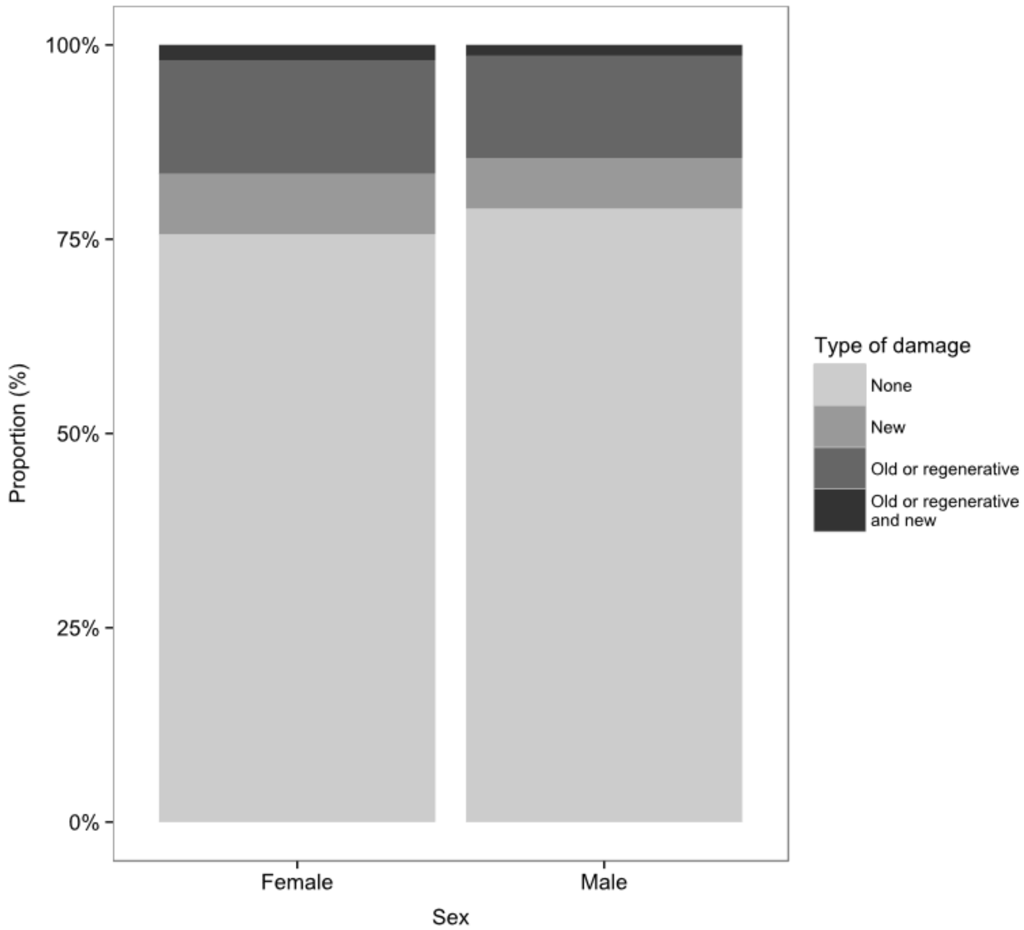
**Figure A.4:** Average (mean ± 95% CI) growth rate (mm) of undersize male and female lobsters by size class in the southern stock assessment areas of the Tasmanian southern rock lobster fishery



## *A.4.3 Proportion of lobsters with damage*

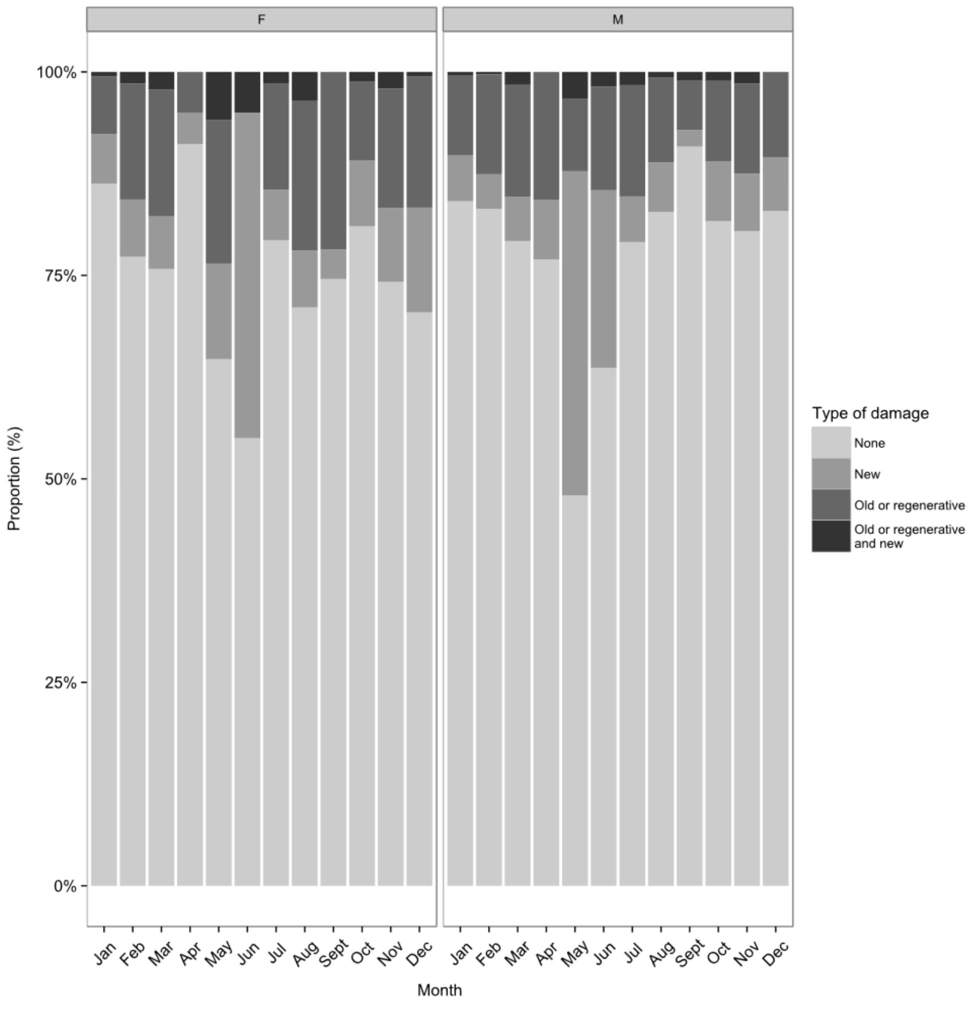
The majority of undersize lobsters (79% males and 76% females) captured during fishing operations in the SSAAs of the TSRL fishery had no observable damage (Figure A.5). New damage (i.e. occurred during capture) was only observed in 6% of males and 8% females whereas old or regenerative damage (i.e. occurred prior to capture) was more prevalent, including 13% of males and 15% of females. Lobsters with both forms of damage were rare, including just 1% of males and 2% of females.

**Figure A.5:** Proportion of undersize male and female lobsters in each damage category in the southern stock assessment areas of the Tasmanian southern rock lobster fishery



With the exception of the months of May and June, (which had a small number of tagging records; see Figure A.2) seasonal variation in new damage was minor (Figure A.6). In summer the proportion of undersize female lobsters with new damage ranged from 6-13% and in males from 4-7%. In spring it ranged from 4-9% in females and from 2-7% in males. In autumn it ranged from 4-6% in females and from 5-7% in males. Lastly, in winter it ranged from 6-7% in both females and males.

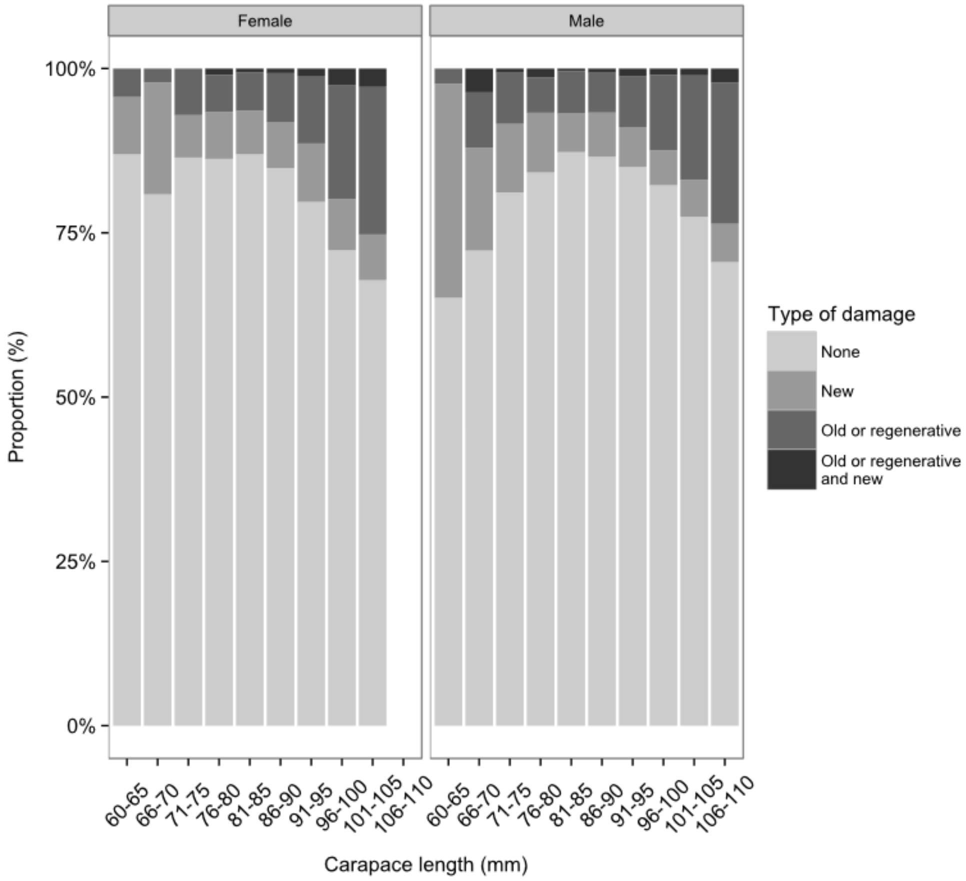
**Figure A.6:** Proportion of undersize male and female lobsters in each damage category in the southern stock assessment areas of the Tasmanian southern rock lobster fishery



When the damage categories were examined across size classes (i.e. carapace length) (Figure A.7) it was evident that the proportion of undersize females with new damage remained fairly constant around 7-8%, with the exception of size class 66-70 mm CL where it was 17%. The proportion of undersize males with new damage however was much greater in lower size classes, around 32% at 60-65 mm CL but decreased to around 6% by 81-85 mm CL before remaining stable as the lobster continued to grow. As expected, the proportion of lobsters with old or regenerative damage in both sexes increased as lobsters grew larger to the point where 22% of all females and 21% of all male lobsters had this form of damage by size classes 101-105 mm CL and 106-110 mm CL respectively.

Among those lobsters with solely new damage, leg injuries were the most common, with 53% of males and females with this form of damage across all size classes. Antenna injuries comprised 39% and 38% of all forms of new damage for male and female lobsters respectively, leaving 8% and 9% with both forms of new damage. There was more variation between the sexes among those lobsters with solely old damage, with leg injuries the most common again, with 74% and 69% of male and female lobsters with this form of damage. While there were proportional more lobsters with old leg injuries relative to new leg injuries there were less with antenna injuries, with only 17% of males and 23% of females with this form of damage. This left 9% of males and 8% of females with both forms of old damage.

**Figure A.7:** Proportion of undersize male and female lobsters in each damage category by size class in southern stock assessment areas of the Tasmanian southern rock lobster fishery




## *A.4.4 The effect of damage on fishery productivity*

The impact of new damage on the growth of undersize females from SSAAs was small enough that it wasn't possible to distinguish it from zero. This was despite convergence diagnostics indicating that the chains had converged to the stationary distribution. In contrast, the impact of new damage on the growth of undersize males from SSAAs was marked, with damage to antenna, legs as well as both legs and antenna leading to substantial proportional reductions in their annual growth increment (Figure A.8). Damage to solely an antenna or leg was estimated to have a similar proportional impact on growth of 7% (0-16%, 95% CI) and 7% (0-14%, 95% CI) respectively. Damage to both an antenna and leg had a greater estimated proportional impact on growth of 40% (24-57%, 95% CI).

The proportional impact of new damage on the growth of undersize male lobsters in SSAAs varied by size class. Smaller lobsters were more adversely affected due to the greater proportion of them in this damage category (Table A.3). While there were more lobsters discarded at larger size classes, the greater proportion of these had old damage, so the overall impact on growth from new damage was less. When basing the proportion of male lobsters discarded in each size class and damage category on the average number discarded annually between 2001 and 2010 it was apparent that the overall annual lost growth (i.e. productivity) to the fishery was around 1.6 tonnes (1.4 - 1.9 tonnes, 95% CI) from SSAAs (Table A.3). The equivalent loss to fishery revenue using an average of the processor price of rock lobster was AUD $72,905 ($62,023 - $83,788, 95% CI) after taking into account inflation (i.e. deflated) using the Australian consumer price index [http://www.rba.gov.au/calculator/ (last accessed 14 December)] standardised to 2010.

The difference between the proportion of captured and then recaptured lobsters, with and without damage was 3.9%. This was used as an approximation of the post-release mortality, which when applied to the number damaged and discarded in each size class (2001 to 2010 average) led to a total productivity loss of around 5.2 tonnes for male lobsters and 16.9 tonnes for female lobsters, for a total of 22.1 tonnes from SSAAs.

**Figure A.8:** Proportional impact of different forms of new damage on the annual growth increment of undersize male lobsters from southern stock assessment areas of the Tasmanian southern rock lobster fishery.

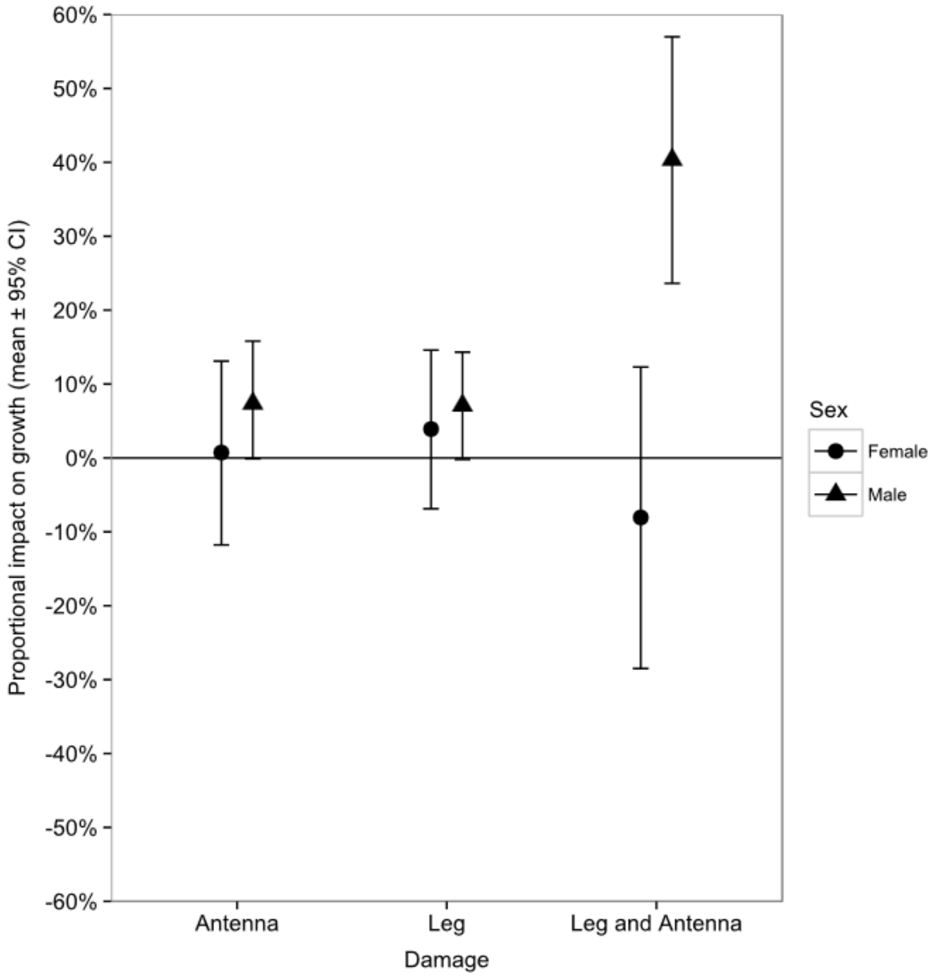


**Table A.3:** Predicted impact of new damage and mortality on fishery productivity for undersize male and female lobsters from southern stock assessment areas of the Tasmanian southern rock lobster fishery based on the proportion discarded and expected lost growth in length and weights (kgs) across each size class.

| ***Sex*** | ***Size class*** | ***N. caught*** | ***N. discarded*** | ***Damage impact*** | ***Expected growth (mm)*** | ***Expected growth (kg)*** | ***Lost growth to damage (kgs)*** | ***Damaged lobster mortality (kgs)*** | ***Total productivity loss (kgs)*** |
|---|---|---|---|---|---|---|---|---|---|
| ***Male*** | 60-65 | 170,362 | 43,794 | 0.0427 | 12.0191 | 0.0813 | 152.13 | 67.54 | 219.54 |
| | 65-70 | 617,009 | 158,613 | 0.0258 | 11.1661 | 0.0865 | 354.30 | 246.93 | 601.23 |
| | 70-75 | 687,121 | 176,636 | 0.0096 | 10.3130 | 0.0908 | 154.74 | 233.45 | 388.19 |
| | 75-80 | 347,537 | 89,340 | 0.0131 | 9.4600 | 0.0940 | 110.17 | 122.13 | 232.30 |
| | 80-85 | 553,106 | 142,186 | 0.0071 | 8.6069 | 0.0958 | 96.88 | 189.81 | 286.69 |
| | 85-90 | 424,306 | 109,075 | 0.0084 | 7.7539 | 0.0962 | 87.92 | 184.79 | 272.71 |
| | 90-95 | 590,520 | 151,803 | 0.0096 | 6.9008 | 0.0949 | 138.86 | 341.13 | 479.99 |
| | 95-100 | 781,009 | 200,772 | 0.0073 | 6.0478 | 0.0918 | 135.38 | 629.75 | 765.13 |
| | 100-105 | 936,533 | 240,752 | 0.0075 | 5.1947 | 0.0866 | 157.03 | 1120.32 | 1277.35 |
| | 105-110 | 1,144,667 | 294,256 | 0.0102 | 4.3417 | 0.0792 | 237.38 | 2074.31 | 2311.69 |
| | **Total** | | | | | | **1624.79** | **5210.16** | **6834.82** |
| ***Female*** | 60-65 | 924,201 | 237,582 | | 6.0636 | 0.0389 | n/a | 149.88 | 149.88 |
| | 65-70 | 611,915 | 157,303 | | 5.5473 | 0.0413 | n/a | 772.76 | 772.76 |
| | 70-75 | 861,942 | 221,577 | | 5.0310 | 0.0431 | n/a | 256.03 | 256.03 |
| | 75-80 | 1,444,586 | 371,356 | | 4.5146 | 0.0441 | n/a | 2906.26 | 2906.26 |
| | 80-85 | 1,621,107 | 416,734 | | 3.9983 | 0.0442 | n/a | 594.87 | 594.87 |
| | 85-90 | 1,578,282 | 405,725 | | 3.4820 | 0.0432 | n/a | 4662.27 | 4662.27 |
| | 90-95 | 1,464,759 | 376,542 | | 2.9656 | 0.0411 | n/a | 750.61 | 750.61 |
| | 95-100 | 1,397,789 | 359,326 | | 2.4493 | 0.0377 | n/a | 5635.72 | 5635.72 |
| | 100-105 | 1,390,365 | 357,417 | | 1.9330 | 0.0329 | n/a | 1170.40 | 1170.40 |
| | **Total** | | | | | | n/a | **16898.80** | **16898.80** |

## A.5 Discussion

The capture, handling and release of undersize crustaceans as part of commercial fishing operations can cause appendage damage, which may impede their growth and effect the long-term productivity and revenue from the fisheries they support (Davis, 1981; Brown and Caputi, 1986). In the TSRL fishery, an estimated 4.22 ± 0.4 million undersize lobsters were discarded annually in the SSAAs between 2001 and 2010, with 6% of males and 8% of females displaying forms of new damage (i.e. antennae, legs) across the tagging dataset. Damage to antennae or legs during fishing operations reduced the annual growth increment of undersize male lobsters by a similar average of 7%, while the annual growth increment of undersize male lobsters with both forms of damage was reduced by an average of 40%. Similar effects of damage on the moult increment have been observed in other crustacean fisheries (Davis and Dodrill, 1980; Brown and Caputi, 1985; Hunt and Lyons, 1986; Brouwer et al., 2006) and again highlight the long-term costs of multiple injuries (Brown and Caputi, 1985; Brouwer et al., 2006). Given the number of undersize male lobsters discarded with types of new damage and its predicted impact on their growth, average annual productivity and resulting revenue losses were estimated at 1.6 tonnes and $72,906 respectively in the TSRL fishery. This is a direct measurable cost from lost growth but there can also be indirect costs of handling damage (Davis, 1981). For example, injured *Panulirus argus* entered a fishery in Florida 33 weeks later than uninjured lobsters, allowing natural mortality to occur over a significantly longer period of time, leading to associated reductions in the productivity of the stock (Davis, 1981). Crustaceans are also frequently marketed alive and graded based on size, colour and damage (Hamon et al., 2009; Stoner, 2012). Therefore handling damage can indirectly effect revenue through reducing their visual appeal and consequent market price. This is particularly the case for lobster fisheries in Australia, where the majority of the catch is exported live overseas and professional graders score for condition and the likelihood of survival based upon vitality indices (Paterson et al., 2005). Notwithstanding these indirect effects, the direct cost from lost growth of males in the SSAAs of the fishery was minor, representing less than 1% of both the TAC and revenue of the fishery in 2010.

There may be further impacts on fishery productivity however if handling damage increased the post-release mortality of lobsters. Based on this study the post-release mortality of injured lobsters was estimated at 3.9%, which was the difference between the recapture rate of injured lobsters and uninjured lobsters. While post-release mortality of tagged and released undamaged *Jasus edwardsii* in other local studies was low (Mills et al., 2005; Green and Gardner, 2009), damage to specialised appendages, such as antennae or legs, may reduce overall survivorship due to their importance in performing a variety of physiological functions (Kouba et al., 2011). For example, antennae are important in mediating social interactions with conspecifics (Rutherford et al., 1996), gaining tactile information on the topography of their local environment (Phillips and Macmillan, 1987; Koch et al., 2006) and in locating food and conspecifics (Giri and Dunham, 1999). Legs also perform important functions in terms of locomotion (Fielder, 1965; Pond, 1975), sensing and foraging for food (Lavalli and Factor, 1995; Frisch and Hobbs, 2011), as well as reproduction and egg-laying (Andrews, 1906). Consequently, in addition to growth impairments, damaged lobsters may also suffer from an increased risk of predation and incidence of disease, as well as a reduced foraging efficiency and mating success (Juanes and Smith, 1995; Brouwer et al., 2006; Freeman and MacDiarmid, 2009; Raby et al., 2013), particularly when lobsters are discarded over new or unsuitable habitats or exposed to air for long periods of time (Brown and Caputi, 1983; Evans et al., 1994; Koch et al., 2006). The impact may be also be cumulative if the lobster is recaptured multiple times (Bergmann and Moore, 2001b). As one such example of these impacts, Parsons and Eggleston (2005) found that injured *Panulirus argus*, were more likely to be preyed upon than their uninjured counterparts, because injuries reduced the defensive capability of lobsters, attracted the attention of predators through chemosensory cues and reduced the attractiveness for uninjured lobsters to shelter with injured conspecifics, reducing the benefits of group defence. Predators are also often opportunistic and have been known to congregate near fishing grounds to prey on escaped or discarded animals (Ryer, 2002; Raby et al., 2013). For example, *Panulirus cygnus* who were exposed to air for longer periods were more likely to be preyed upon by octopus following their release than their unexposed counterparts (Brown and Caputi, 1983). While the physiological impairments caused by handling damage have been shown to have a critical effect on the survivorship of lobsters (Figiel and Miller, 1995; Bergmann and Moore, 2001b; Bergmann and Moore, 2001a) the type of injury and the extent of damage remains a poor predictor of ultimate survival (Ridgway et al., 2006; Stoner, 2012). Consequently, further species-specific experiments are required to appropriately evaluate the impact of post-release mortality on the productivity and profitability of the TSRL fishery and the figure of 22.1 tonnes should only be used a rough estimate.

While there was no discernable effect of new damage on the growth of undersize female lobsters in the TSRL fishery, females were more likely than males to be damaged during fishing operations. Females were also handled and released more often than male lobsters due to the fishing season remaining open throughout their main moult period from March to May. This resulted in estimated productivity losses for female lobsters, caused by post-release mortality that were three times higher than for male lobsters. The absence of an effect of damage on the growth of female lobsters in the dataset was therefore interesting and may have been due to the biology of the species in the assessment area. In the SSAAs, female growth is known to occur in smaller increments than in the northern areas of fishery due to temperature effects (Green et al., in review). The advent of sexual maturity around 60-65mm CL in SSAAs (Gardner et al., 2006; Chandrapavan et al., 2010), which is the size at which lobsters are first allowed to be tagged, is also known to reduce the moult increment. Consequently, the absence of an effect of damage on growth of undersize females may not have been due to differences in gender but diminished precision in measuring lobster growth in the field and distinguishing moulting events when increments were small and variable.

While this study did not discern any impact of damage on the growth increment of females the impact on males was marked, with associated reductions in the productivity of the stock and revenue from the fishery. However, the overall proportion of lobsters (both male and female) with new damage and the overall effect that new damage had on the productivity and profitability of the fishery was less than predicted. This may have been due to the resilience of crustaceans relative to other taxa to the effects of capture, handling and release due to their physiological attributes including: a durable exoskeleton, air breathing capabilities and an ability to autotomize appendages (Broadhurst and Uhlmann, 2007; Stoner, 2012). For example, Uhlmann et al. (2009) showed that the mortality and stress of discarded blue swimmer crabs was higher when appendages were fractured as opposed to autotomized, due to the associated blood loss caused by unsealed wounds. Similar effects of autonomy have also been observed for other crustaceans (Bergmann and Moore, 2001b; Patterson et al., 2007). Alternatively, it may have been an indication of the benign nature of potting, the success of escape gap management measures and/or the nature of on-board processing and sorting of catches in the TSRL fishery. For example, it has been highlighted that pot-captured lobsters have lower incidences of damage relative to trawl-captured lobsters (Smith and Howell, 1988; Potter et al., 1991) or hand-captured lobsters (Powrie and Tempero, 2009; Leland et al., 2012), as the capture of lobsters by the latter two methods applies a higher level of physical force. Escape gaps, as legislated in the TSRL fishery, have also been shown to reduce the capture and consequent handling of undersize lobsters in many fisheries (Krouse, 1978; Brown, 1982; Brown and Caputi, 1986) and given that most TSRL fishers sort their catch directly from pots during hauling operations (Gary Carlos pers. comm), the prevalence of stress and damage caused by conspecifics and exposure is less than when catch is sorted at the end of hauling operations (Anonymous, 1981; Brown and Caputi, 1986; Brown and Dibden, 1987). Finally, the estimated 6.68 ± 0.4 million lobsters discarded in the fishery is low relative to other commercial lobster fisheries such as the *Jasus lalandii* fishery in South Africa where an estimated 34 million lobsters were discarded annually in 2004 (Brouwer et al., 2006) and in the *Panulirus cygnus* fishery in Western Australia where an estimated 16 - 20 million undersize lobsters were discarded annually in 1983 (Brown and Caputi, 1983).

These biological factors and fishery handling and management measures could have contributed to a reduced number of undersize lobsters in the TSRL fishery being damaged through capture, handling and release. When interpreting the results however, it is important to note that there is an inherent bias associated with the recapture of individual lobsters, particularly those that are injured, that may have influenced the results. First, it is well established in the TSRL fishery that the catchability of lobsters in pots is influenced by the size of lobster, with both smaller-sized male and female lobsters frequently underrepresented in pots and the sex of the lobster, with medium and larger females under-represented in pots compared to males of a similar size (Ziegler et al., 2002a; Ziegler et al., 2002b). Second, injured lobsters are not as frequently recaptured as uninjured lobsters. For example in a study undertaken by Potter et al. (1991) the recapture rate of undamaged sand crabs (*Portunus pelagicus*) was twice that of damaged crabs due to improved survival. Similarly, Brown and Caputi (1983) found that the recapture rate of damaged, displaced or exposed lobsters was 11.4% less than those non-affected lobsters, due to improved survival. Consequently, the proportion of damaged undersize male and female lobsters may have been underestimated in this study, a point similarly discussed by Brouwer et al. (2006). Further field experiments examining the recapture rate of both injured and uninjured *Jasus edwardsii* would be required to appropriately assess whether this was also the case in the TSRL fishery. It is also important to note that the dataset only examined the effects of new damage caused by commercial fishing operations and not recreational fishers. Recreational fishers, particularly in the dive sector, have the propensity to cause greater damage to lobsters due to having less experience in their proper handling as well as using hand collection, which increases the extent and scale of damage (Powrie and Tempero, 2009; Leland et al., 2012). Recreational fishers also fish inshore waters where growth increments are higher that the effects of damage may be more pronounced, particularly in faster-growing males. Further work could directly compare the effects of hand collection and potting on damage in the recreational rock lobster fishery.

Nevertheless, in the commercial sector it seems that the combination of fishing method, management measures and biology of the species are effective mechanisms in reducing excessive amounts of handling damage in the TSRL fishery. The susceptibility of lobsters in general to handling damage could be further reduced through: (i) greater publicity and education being provided to fishers on the effects of damage on fishery productivity, in addition to the need for them to rapidly sort pots while hauling gear, using appropriate handling techniques and; (ii) the use of grid sorters to further reduce undersize catch and to prevent handling of lobsters in pots.

# Appendix B: References

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# Appendix C: Published papers

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