Bio-economic analysis of the response of a fishery to changes in access regulation: the case of Individual Transferable Quotas in the Tasmanian rock lobster fishery

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Analyse bio-économique de la réponse d'une pêcherie à un changement de régulation de l'accès: le cas des quotas individuels transférables dans la pêcherie de langouste en Tasmanie

Thèse soutenue le (date à préciser)
devant le jury composé de :

Prénom NOM jury 1
Titre, Etablissement / *qualité*

Prénom NOM jury 2
Titre, Etablissement / *qualité*

Prénom NOM jury 3
Titre, Etablissement / *qualité*

Prénom NOM jury 4
Titre, Etablissement / *qualité*

Etc...
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By

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Submitted in fulfilment of the requirements for the Degree of

Doctor of Philosophy in Quantitative Marine Science
(A joint CSIRO and UTAS PhD program in quantitative marine science)

Institute of Marine and Antartic studies

University of Tasmania
in co-tutelle with
L'université De Bretagne Occidentale

March, 2011

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I   Introduction

1 Background

The latest report from the Food and Agriculture Organization of the United Nations (2009) states that the proportions of overexploited, depleted and recovering marine fisheries remain high at 19%, 8% and 1% respectively. Fisheries management using traditional conservation measures has largely failed to maintain fish stocks at sustainable levels. Numerous examples of stock depletion and fisheries collapse are found in the literature despite a range of attempts to manage fisheries (Hilborn et al., 2003, Caddy and Agnew, 2004). Although the amount of over exploited or depleted stocks seems to have stabilized (FAO, 2009), some scientists have made alarmist predictions concerning the future of worldwide fisheries, forecasting the total collapse of fisheries by 2048 (Worm et al., 2006).

It has long been argued that the problem underlying the failure of fisheries management is "too many boats chasing too few fish" (Berkes, 1985, Hilborn, 2007). This results from the open access nature of the resource (Gordon, 1954, Hardin, 1968). The negative externalities created by each fisher on the rest of the fleet incite fishers to be the first to catch the fish and feed the "race for fish". Marine fish are common pool resources, and unlike other natural resources, their allocation to individual owners cannot be done a priori. In principle, the absence of access regulation means that fish can be caught by whoever wants to fish. In open access fisheries, fishers have incentives to enter the fishery until it is economically unprofitable to do so, when the rent has been dissipated (Gordon, 1954). The fishing fleet becomes too large compared to the production potential of the fish stock and the overcapacity leads to competition between harvesters. Management measures decreasing the race for fish exist and can be used to complement conservation measures, by restricting access to fisheries. This has spurred the development of management relying on access regulation worldwide is an attempt to tackle the difficulties arising from the open access nature of the resources. Thébaud et al. (2006a) analysed the advantages and limitations of alternative policy approaches to the problem of access regulation in fisheries, and explain how the use of administrative or economic (incentive based) tools such as taxes and individual fishing authorizations (transferable or not) can reduce the race for fish.

A widely proposed and increasingly adopted management option is based on individual transferable fishing rights (Christy, 1973, Moloney and Pearse, 1979, Wilen, 2006). Different fishing rights can be implemented, based on effort or catch (see Boncoeur et al., 2006 for the

typology of fisheries management tools). Costello et al. (2008) suggested that the development of the use of catch shares worldwide would curb the collapse of fisheries predicted by Worm et al. (2006). Catch shares are defined as allocations of catch rights to individuals or collectives, usually as percentages of a total allowable catch (TAC). When catch rights are allocated to individuals and can be traded, they are called individual transferable quotas, ITQs. The introduction of ITQs started about three decades ago (Chu, 2009). Within the Organisation for Economic Co-operation and Development (OECD, 2006) sixteen countries had implemented individual quotas to manage part of or all their fisheries by 2006. In 2007, at least seven nations used ITQs as a major fisheries management system including Iceland, New Zealand, Australia, Canada, Chile, Greenland, the Netherlands, Russia and Morocco (Arnason, 2007). Other countries also manage their fisheries using ITQs with variable degrees of tradability, including several European Union members, the USA, Mexico and Namibia (Arnason, 2007, MRAG et al., 2009).

2 Fisheries management with individual transferable quotas

Combined with an appropriately set total allowable catch (TAC), the predicted outcomes of ITQs include a higher economic efficiency of fisheries and, indirectly, sustainable stocks. The later outcome is expected to result from the fact that, although the TAC alone controls the total catch and the stock sustainability, ITQs are believed to increase the stewardship and the compliance of participants (Anderson, 1995). However, the main expected outcome of ITQs is increased economic efficiency, as was argued by Christy (1973) in his seminal work. For a given TAC, fisheries profitability can increase by increasing the value of the product and decreasing the costs of fishing. In many fisheries in a state of overcapacity, a direct way of reducing fishing cost is to reduce the number of vessels in the fishing fleet (so-called rationalization) and adjust the capacity to a lower level. This can be facilitated by the transferability of fishing rights. Less efficient fishers can sell their quota to more efficient fishers and exit the fishery, with "windfall gains" as the fishing rights are often given for free to the first generation of fishers (Brandt, 2007).

In addition to decreasing their costs, fishers in an ITQ system can increase their revenue from fishing by changing their fishing behaviour to land more valuable fish categories and increase the value of their landings. Multiple strategies have been used by fishers to increase their

revenue within the constraints of their quota allocation. One of the most famous example is the British Columbia halibut fishery (Casey et al., 1995), in which under "derby fishery conditions", the fishing season had shrunk to two days per year and most of the fish was frozen. Once ITQs were introduced, fishers were allocated a share of the TAC and did not need to race for fish anymore. Subsequently, fishing occurred all year long ensuring a continuing supply of fresh fish fetching a higher price. In other fisheries, fishers have switched to less damaging gears (Dewees, 1989), shifted their fishing effort to months when beach-prices are higher (Annala, 1996) and increased the value of products by onboard processing (Annala, 1996).

Despite the largely positive outcomes expected of the ITQ management system in terms of economic efficiency, some of its economic and social outcomes have raised criticism (Copes, 1986, McCay, 1995, Pinkerton and Edwards, 2009). Although the transferability of fishing rights has positive effects as it leads to the reduction of excess capacity of fleets, the aggregation of fishing rights in the hand of a few owners observed in some ITQs fisheries has been considered to have negative economic effects. In particular, the consequence of quota accumulation is the change in market power with a small group controlling the market for fishing rights, which can lead to market inefficiencies (Anderson, 2008). In addition, equity and wealth distribution issues have been regarded as the main drawbacks of the management system. Equity concerns have focused on the risk of eviction of smaller fishing firms, with bigger or wealthier companies only having the capital to expand their fishing allocation (Bernal et al., 1999). Moreover local economies can be impacted if the fishing rights are transferred to other regions (Campbell et al., 2000, Arnason, 1993). In most cases, rules have been enforced to avoid or limit consolidation, by restricting the proportion of total allowable catches owned or used by an individual or a company.

Three decades after the first introduction of ITQs in the Netherlands for plaice and sole and in Iceland for herring (Chu, 2009), the interest of the scientific community and managers is still growing. It has now been recognized that ITQs are not a panacea and that the implementation of the system requires careful consideration of the potential social effects. Despite the increasing interest for ITQs, very few studies have focused on the behaviour of the fishing fleet under ITQs. Bio-economic models have been applied to investigate the optimal distribution of quota between fishing fleets under the assumptions that fishers would not change their fishing activity (Guyader, 2002, Andersen and Bogetoft, 2007, Armstrong and Sumaila, 2001, Kulmala et al., 2007). However, one of the main expected effects of ITQs is

that fishers will change their fishing practices to increase their profitability. Despite the growing recognition of fisher's behaviour being the main factor of uncertainty in fishery management outcomes (Fulton et al., 2011, Hilborn, 2007, Wilen, 1979), models of individual behaviour have rarely been considered in ITQ fisheries. The development of effort allocation and quota trading models in ITQ systems has increased in recent years (see Little et al., 2009 for an applied quota market, and Poos et al., 2010 for an example of fishers behaviour in an ITQ fishery) but there are only a few, very recent examples justifying the exploration of such models in the current thesis.

3   Thesis objectives

This thesis addresses this gap in knowledge and analyses the response of individual fishers to the introduction of ITQs. The research has two main objectives. The first one is to compare the theoretical predictions on the incentives created by ITQs to real data on fisher behaviour. The empirical information, both qualitative and quantitative, available on a case study fishery is used to assess the drivers of behavioural responses, and the ensuing changes in fishing activities. The second objective is to create a bio-economic model including fishing effort allocation and quota trading, and capturing the incentives identified in the analysis of the case study. A fleet dynamics component is added to an existing biological operating model. Fishing and quota leasing decisions are modelled at the individual level to capture the short-term micro-economic behaviour of actors in the fishery. The model is then used to discuss the potential effects of management and external perturbation scenarios. The attention is particularly focused on the examination of alternative quota trading limitations and their impacts on economic outcomes of the ITQ system and on testing future scenarios of likely perturbations and to examine the adaptive response of the fishery to climate change and economic disturbances. The Tasmanian rock lobster fishery is used as a case study for this thesis.

4   The Tasmanian rock lobster fishery

The Tasmania rock lobster fishery is the second most important wild fishery of Tasmania behind the abalone fishery in terms of landed value (ABARE, 2008) but it is the most

important fishery in terms of employment (Gardner et al., 2004). The value of the commercial catch at first sale was estimated at AUD$60 millions in 2006-07 (ABARE, 2008), while the direct employment in the fishing and processing sector was estimated at 1350 full-time equivalent persons in 2002 (Haddon and Gardner, 2009). In addition, about 20000 recreational licences, nearly 4% of the total population in Tasmania, were issued in 2006/07 (Lyle, 2008). Given the economic and social importance of the fishery, its sustainable management has been important to the Tasmanian population. The Tasmanian Department of Primary Industries, Park, Water and Environment (DPIPWE) is responsible for the management of the fishery, including the collection of catch and effort data, quota auditing and compliance. In addition to daily catch and effort data recorded by fishers, DPIPWE also collects monthly beach prices reported by processors, quota exchanges (temporary and permanent) between quota owners and characteristics of fishing vessels, fishers and quota owners. Besides the data regularly monitored, a socio-economic survey was undertaken immediately before (Williamson et al., 1998) and after the introduction of quota (Frusher et al., 2003) and an economic survey was undertaken in 2007 (Gardner and Van Putten, 2008). The amount and quality of the data available made the Tasmanian rock lobster fishery a good case for this study.

Southern rock lobster, *Jasus edwardsii*, is harvested around Tasmania, south-eastern Australia (see map figure I-1). Although managed as a single stock, Tasmanian rock lobsters display characteristics specific to their area of settlement. Rock lobsters are highly sedentary after the larval stage (Gardner et al., 2003) so the environmental pressures driving the growth and the shell colour produce a spatially heterogeneous population. Lobsters in the North of Tasmania are larger due to faster growth in warmer water compared to the cold southern waters (Gardner et al., 2006). Moreover, lobster colour depends on the depth where lobsters live. Lobsters caught in shallow waters are bright red while deeper water lobsters are "whitish" (Chandrapavan et al., 2009). Since the late 90's, around 75% of the Tasmanian rock lobster are exported live to China (Bradshaw, 2004). Lobsters fetch different prices on the Chinese market depending on their size, driven by the south-north gradient (Processor, *pers. comm.*), and colour, determined by a shallow-deep gradient (Chandrapavan et al., 2009). The beach prices offered to Tasmanian rock lobster fishers reflect the Chinese demand. The red lobsters are more valuable than whitish lobsters and fetch from $2 to $6 more per kg on average (Chandrapavan et al., 2009). Small to medium size lobsters that can be either served for one,

two or four people are the most valuable, often fetching between \$5 to \$10 more per kg than lobsters larger than 2kg.
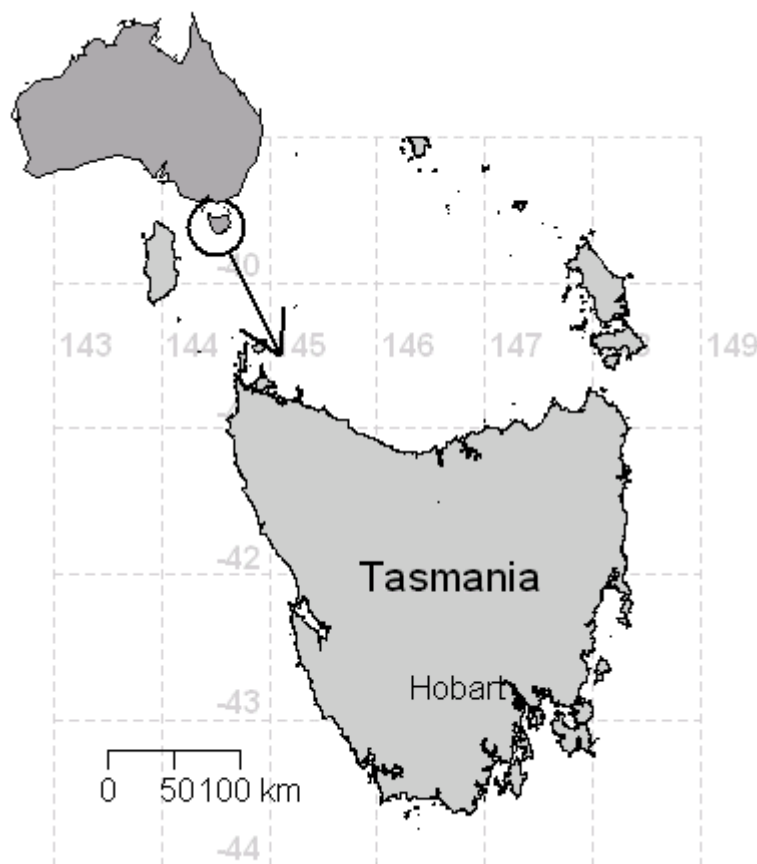
Figure I-1 Geographical position of Tasmania.

The Tasmanian rock lobster industry is a "price taker" (Harrison, 2004) as prices are exogenous to the fishery, mainly depending on the Chinese market and the exchange rate between the Australian dollar (AUD\$) and the Chinese renminbi (RMB)[1]. In addition to spatial gradients, seasonal patterns also impact the economic performances of fishers. Catch rates and beach prices display opposite seasonal patterns, in summer catch rates are high while the beach price is low whereas winter catch rates are low and beach prices are high. The lobster catch-rates are driven by the life cycle of lobsters, regulation and the physical environment (see box 1).

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[1] The formation of ex-vessel prices for the Tasmanian rock lobster has been studied as part of a project in an econometric course and is not reported in this thesis HAMON, K. G. (2008) Analysis of the price of Tasmanian rock lobster 1993-2006. University of Tasmania.

Box 1: Seasonal variation of rock lobster catch rates

Catch rates represent the catch per unit of effort (CPUE). For the Tasmanian rock lobster fishery, this is the number of legal size lobsters caught per individual trap lift. They depend on the available biomass but also of a set of factors affecting the catchability of lobsters. The available biomass is the biomass legally exploitable (e.g. above the legal size limits when the fishery is open for harvesting). In the Tasmanian rock lobster fishery, growth and regulations change the size of the available biomass seasonally. Rock lobsters grow by discontinuous growth called moulting. Lobster growth consists of the replacement of their protective shell by a larger shell as fast as possible in order to shorten the time when they are vulnerable (Frusher, 1997). Lobsters hide in a shelter during the moulting process and do not feed at this time. They only leave their refuge when the new shell is hard enough to offer protection from predators and then forage actively to compensate for the lower food intake during moult. Moulting is supposed to occur synchronously for lobsters of similar size in the same region. Male lobsters moult from August to November in southern Tasmania and a little later in northern Tasmania. Female lobster moult in April and May after which mature females carry eggs. A seasonal closure on harvesting female lobsters protects them during the reproduction period (May to September).

The combination of a minimum legal size resulting in knife-edge retention and discontinuous growth causes the entry of a large portion of undersize lobsters into the legal size biomass in November. Inversely, in winter (May to September) the female fraction of the stock is removed from the available biomass as all female lobsters captured must be immediately returned to the sea. In addition, Ziegler et al. (2002a) showed that the catchability varies seasonally and probably with water temperature with low catchability during cold water temperatures in winter.

Rock lobster has been exploited in Tasmania since the first settlers colonized the island in 1804 (Winstanley, 1973). First, they harvested lobsters with small boats and ring nets in shallow waters. Baited fishing traps were first introduced by Victorian fishers (coming from the mainland Australian state, Victoria, north of Tasmania) around 1880 but were considered "destructive" and banned in 1902. The use of traps was legalized in Tasmanian waters in1926 and trap licences were introduced. With fishing traps becoming more popular, the fishery changed. Larger vessels went fishing on deeper reefs identified by trials or soundings. Today,

baited traps are the only gear used by commercial fishers. Trap dimensions are regulated and escape gaps for juveniles are compulsory in all fishing traps (Anon, 2006). In the 1990's, the rock lobster fleet was composed of more than 300 vessels ranging from 6 to 45m in length. The majority of the vessels were made of timber but newer vessels began to be made of steel to fish in rougher areas. Commercial fishers are unevenly distributed along the coast of Tasmania. The main part of the fleet is based in the south-eastern part of Tasmania and on the East coast where most of the Tasmanian population is located due to the milder climate and access to infrastructure. The rest of the fleet comes from, by decreasing number of vessels, the north coast, the Bass Straight Islands (King Island and Flinders Island), the west coast and other Australian states (Williamson et al., 1998). While commercial fishers cover the state's waters to catch rock lobster, recreational fishers concentrate on areas close to populated areas, by diving for rock lobsters or using traps or ring nets (Lyle et al., 2005).

In the late 1980's, declining catch rates led to growing concerns in the industry. Despite the numerous management measures based on input controls already enforced, fishing effort was higher than the effort estimated to sustainably harvest the resource and needed to be reduced (Anon, 1993). Two management options were suggested and debated within the industry. The first advised the reduction of the number of traps in the fishery by about 30%. The second option recommended the introduction of a total allowable catch and its allocation through ITQs (Ford, 2001a). Although, most in the industry recognized the need to reduce catch and effort in the fishery, a consensus on the method was hard to reach (Ford and Nicol, 2001). Eventually, a majority of the industry voted for the ITQ option and in 1996 the Government established a committee to oversee the implementation of output controls and the merit of retaining some of the existing input controls and technical measures already implemented in the fishery (see figure I-2 on history of the rock lobster management). The Government supported the introduction of ITQs because it also provided a mechanism to restructure the industry and allowed fishers who decided to leave to do so with a reasonable return (Ford and Nicol, 2001). ITQs were implemented in March 1998.

technical conservation measures: species and gear-related				input restrictions: licences			lead-up to quota mgt		output control: catch-related
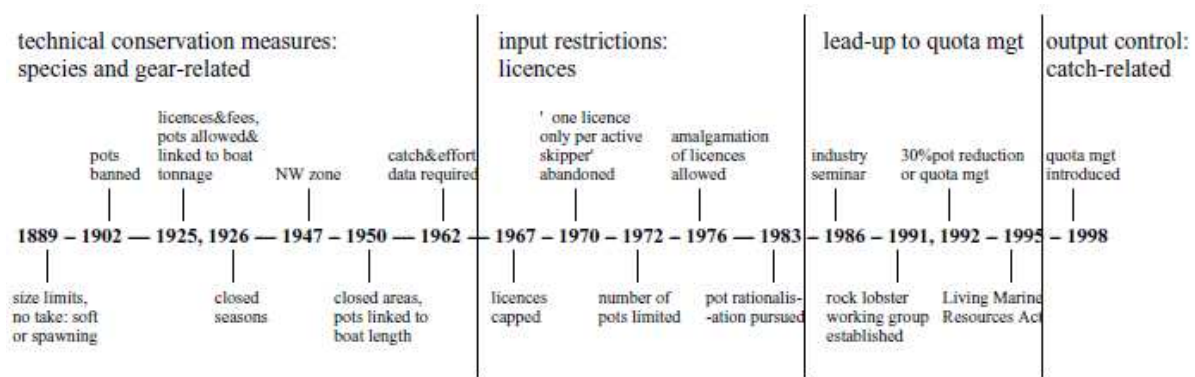
Figure I-2 Timeline of management measures in the Tasmanian rock lobster fishery. (adapted from Bradshaw, 2004).

5 Structure of the thesis

This study investigates the outcomes of the introduction of ITQs in the Tasmanian rock lobster fishery 10 years after their introduction and the behavioural responses of the industry. In chapter 2, the observed impacts of ITQs on the fishery are compared to the theoretical expected effects of ITQs drawn from the literature. The response of the fishing fleet in terms of rationalization and change of fishing practices to target more valuable products are investigated. Moreover, the extent to which quota was accumulated by quota owners is quantified.

Chapter 3 focuses on individual responses. The micro behaviour of fishers is studied to test whether the changes in fishing practices identified in chapter 2 result from a change of individual behaviour or from the departure of fishers traditionally operating the less profitable fishing activities. Fishing activities are identified and characterized at both short-term (the location choices at the trip level are called "métiers") and annual scales ("fishing strategies"). The analysis shows how the activity of individual fishers has changed since the introduction of ITQs.

The second approach developed in this thesis uses modelling and computer simulation. Chapter 4 describes a fleet dynamic model developed for this study. The fleet dynamic model is designed as an agent based model of short term behaviour. Quota owners select fishing activities among the métiers defined in chapter 3 and lease in or lease out quota to match their catch expectation to their quota entitlement. The fleet dynamics is integrated into the existing biological operating model (Punt and Kennedy, 1997). The dynamics of the fishing fleet is affected by the lobster dynamics which is itself affected by the response of the fleet in a

"feedback" loop at the monthly level. Thus, choices of quota owners/fishers impact, and are impacted by, the lobster stock. The model is then used to investigate the potential effects that different quota trade limitations would have had on the fishery, as compared to the observed changes following the introduction of ITQs.

Using the bio-economic model developed in chapter 4, chapter 5 explores the possible future of the fishery taking into account environmental and economic perturbations. The future of the fishery is highly uncertain as impacts of climate change on the Tasmanian rock lobster population have already been identified (Pecl et al., 2009). The potential response of the fishery to climate change impacts and to change on the lobster market are examined, and the importance of including dynamic responses of fishing firms, in terms of fishing activity and quota trading is assessed in this evaluation.

Finally, chapter 6 summarizes the results obtained in the study. The findings are put in the broader perspectives of ITQ management and future research avenues flowing from the results presented in this thesis are identified.

II A retrospective analysis of the effects of adopting individual transferable quotas in the Tasmanian red rock lobster, *Jasus edwardsii*, fishery.

Abstract:

Individual transferable quotas (ITQ) were implemented in the Tasmanian red rock lobster fishery in 1998 and ten years later we assessed the impacts on the fishery. Particular attention was devoted to investigating the performances of the fishery with regard to three features identified as major impacts in the literature: rationalization of the fishing fleet, change in fishing strategy in order to maximise the fisher's profit and concentration of fishing rights and activity. On average, the fishery reacted as expected and reached its objective in terms of reconstruction of the biomass, but the overall assessment in terms of resulting profitability is not very conclusive. There is no evidence of decrease of the profitability over the period of the study but the fishery is more reactive to external factors on its export market in China than to changes in its own structure.

1   Introduction

The state of worldwide fisheries is alarming with half of global fish stocks reported as fully exploited and a further quarter as either overexploited or depleted (FAO, 2007), reducing the long-term economic benefits derived from fishing (Clark, 2006, Hilborn, 2007). There is growing international consensus on the central role of the "race for fish" in the development of excess harvesting. The common-pool status of marine fish stocks leads to the existence of reciprocal negative externalities between fishing operators (Hardin, 1968). These externalities entail a divergence between individually and socially optimal choices, and the development of excess fishing capacity. Fishers tend to invest in more powerful and efficient fishing gear and techniques in order to stay in the race, leading to economic inefficiency, conflicts and social disruption, and in many cases to the depletion of fish stocks beyond safe biological limits (Thébaud et al., 2006a).

These difficulties are not new and have led to the development of fisheries management policies which can be broadly classified, according to their purpose, in two complementary sets of regulations (Troadec and Boncoeur, 2003): (i) measures aimed at the resource conservation, and (ii) measures aimed at regulating the access to resources. To a large extent, fisheries management worldwide has rested exclusively on the first category of measures, at least initially. Although such regulations have proved indispensable, their effectiveness has been limited by the fact that they do not tackle the economic and institutional roots of excess capacity. Economic difficulties and conflicts have thus continued to develop, and resources are degraded despite the existence of conservation measures. In addition, the tense social climate resulting from excess capacity situations has often led to pressure being put on decision-makers to water-down conservation objectives themselves. Hence, many fisheries which have been conventionally managed for decades continue to show poor performances (Hilborn et al., 2003).

As stressed in the latest report on the status of worldwide fisheries published by the Food and Agriculture Organization of the United Nations (FAO, 2007), there is growing recognition that the allocation of access rights to fisheries and fish resources is at the heart of sustainable fisheries management. Boncoeur et al. (2006) proposed a set of tools to regulate the individual access to fish stocks, including the use of incentive-based approaches resting on the definition of individual fishing rights (Grafton, 1996, Clark, 2006, Hilborn, 2007). In particular,

implementing individual transferable quotas (ITQ) has been proposed as a regulation measure which can produce the incentives required for fishers to harvest fish stocks sustainably (Arnason, 1990). Moloney and Pearse (1979) explain that fishers are expected to maximize profits within ITQ constraints, usually defined as shares of a given total allowable catch (TAC). The transferability of fishing rights would lead the most efficient fishers to buy additional quota shares from the least profitable fishing firms, thus reducing fishing capacity and improving the economic efficiency of fleets (Clark, 2006, Copes, 1986, McCay, 1995).

Such a rationalization process may take several years depending on alternative opportunities for vessels and crews (Campbell et al., 2000, Grafton, 1996) and on the degree of transferability of quotas (Dewees, 1998), but it is expected to improve the overall profitability of fisheries, and to reduce conflicts due to excess capacity. Increased profitability can also result from improvement in the market value of fish landed. A better market value and hence a higher ex-vessel price received by fisher for their catch can be achieved in different ways, e.g. fish quality improvement by i) the use of less damaging fishing gears (as expected for the Baltic Sea herring fishery in Kulmala et al., 2007), ii) on-board processing, and iii) the value of the catch can also be increased through price, if fishing occurs in seasons with high prices or if fishers can target fish categories fetching higher prices, see Annala (1996) for examples of fisheries implementing on-board processing and changing fishing seasons to fit the market.

A number of potential problems arising from the implementation of ITQ schemes have also been highlighted; see Copes (1986) for a comprehensive list of drawbacks of ITQ systems. Some of these difficulties relate to output-based controls. In particular, given individual catch constraints, fishers may choose to discard the less valuable fish caught, in order to save their quota for more valuable fish (so-called high-grading), thus leading to increased catches and fishing mortality for given levels of landings. If undetected by catch monitoring systems, high-grading may lead to "data fouling", which in turns leads to less reliable stock assessments and setting of TAC at unsustainable levels (Copes, 1986). Other difficulties relate to the social implications of the changes in fisheries entailed by the adoption of ITQs, both in terms of reductions in employment (Copes, 1986, McCay, 1995), and concentration of quota ownership. The latter have often led to the adoption of measures aimed at limiting the aggregation of quota shares (Dewees, 1998). A key question which has also been largely debated in various contexts concerns the initial allocation of quota shares; see Arnasson (2002) for an overview of the different allocation systems worldwide.

The fishery investigated in this paper is the Tasmanian red rock lobster fishery (Australia). The fishing fleet is composed of more than 200 vessels targeting rock lobster (*Jasus edwardsii*) in the State coastal waters (figure II-1) during the official fishing year from March to February with a seasonal closure in October to protect males during moulting and a ban on retaining female during the reproduction period from May to September. Lobsters returned to the water after capture are considered to survive the fishing process. The fishery currently generates a gross revenue of about AUD 60 million at first sale (ABARE, 2008). The employment related to the rock lobster industry in Tasmania was estimated at 1350 jobs in the early 2000s (Haddon and Gardner, 2008). The TAC of 1523 tonnes in 2008, is caught with baited traps. Most rock lobster caught in Tasmania is exported overseas (approximately 74% according to Bradshaw, 2004) especially to the live Chinese market where the fishery is a 'price-taker', sensitive to Chinese prices. To match the Chinese market prices, processors practice split prices in the fishery with rock lobster categories depending essentially of two factors, size and colour. Those two factors are closely linked to the spatial distribution of effort based on two dimensions, the depth fished and the latitude. Red lobsters are caught in shallow waters (less than 40m depth) whereas lobsters caught in deeper waters are 'strawberry' to whitish in colour. The growth rate of lobster is highly variable spatially with a positive growth gradient from the southern to the northern regions of the state (Punt et al., 1997). The difference in growth results in a size gradient with small lobsters in the south and bigger lobsters in the north. Due to the difference in growth rates eight areas are modelled and assessed separately despite a statewide management (fig 1). Winter prices are also higher due to a decline of international supply of southern rock lobster (mostly Australia and New Zealand, Annala, 1996).

Tasmanian rock lobster has been exploited for more than two hundred years and was first managed in 1889 with the "Fisheries Act" following a decline in lobster abundance (Winstanley, 1973). Until 1967, only technical conservation measures were implemented, including gear restrictions, minimum landing size, seasonal closure, and a ban on the harvesting of egg-bearing females. The sustainability of the stock remained questionable under those measures which did not prevent a continuous increase of fishing effort. In an attempt to curb this effort, input restrictions were implemented from the late 1960s onwards, which capped the number of fishing licences and the number of traps used (Bradshaw, 2004). Despite these input controls, catch and catch rates continued to decline in the fishery to a historically low level in 1994, and in 1996 the fishing industry voted in favour of an ITQ

management system for the Tasmanian rock lobster fishery, after several years of debate involving the industry, scientists and managers. The ITQ system was implemented in 1998 and the initial allocation was a particularly sensitive and strongly debated issue (see Ford and Nicol, 2001 for details). The final allocation was primarily based on trap ownership, with a minor share of the quota allocation based on catch history in such a way that, during the first three years of the ITQ implementation, catch history accounted for 9%, 5% and 2% of the TAC. Individual catch history was set as the sum of the best three years from the period November 1988 to October 1997 (Ford and Nicol, 2001). The 10 507 quota units are currently worth 145 kg each. To limit aggregation of fishing rights, a 200 quota unit limit per quota owner was implemented (Anon, 2006).
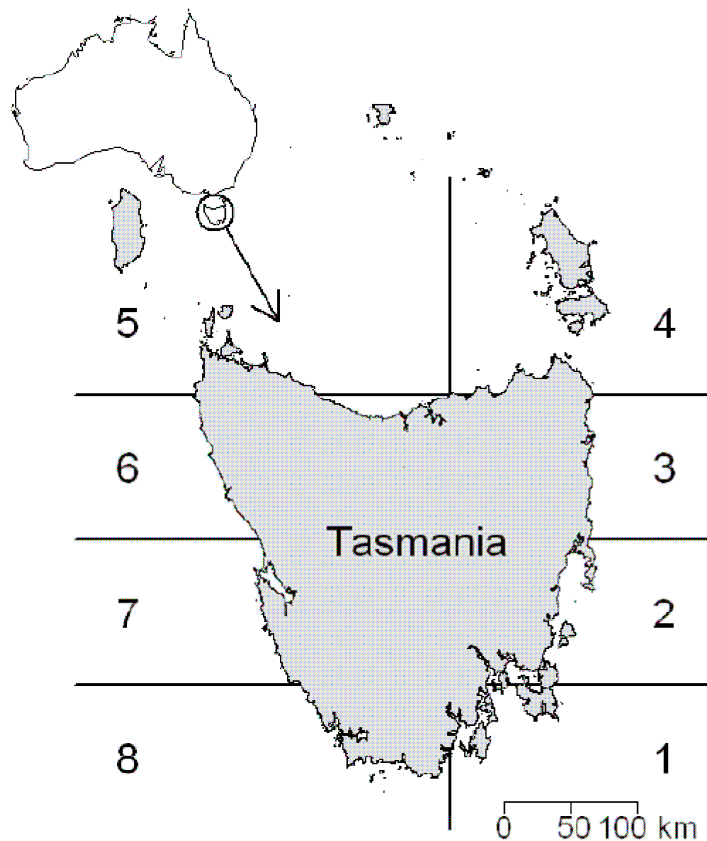
Figure II-1 Location of the Tasmanian rock lobster fishery and the assessment areas

Based on a literature review, we identified the key effects expected from the implementation of ITQs in a fishery displaying excess capacity, against which to confront the experience of

the Tasmanian rock lobster fishery. We classified these expected effects in three broad categories:

- *Fleet rationalization*: following introduction of ITQs, less efficient vessels are expected to leave the fishery, leading to a decrease in overall costs of harvesting and to an increase in the economic efficiency of the fleet. Associated social consequences relate in particular to potential reductions in employment in the fishery (for examples of rationalization Annala, 1996, Arnason, 1996, Arnason, 2002, Arnason, 2005, Grafton, 1996);

- *Changes in harvesting strategies*: these relate to the fact that fishers will seek to get the best value out of their individual allocation, and may entail high-grading, and selection of areas, zones and fish targeted in order to land catches at the highest possible prices (Annala, 1996, Arnason, 2002, Campbell et al., 2000);

- *Concentration of landings and quota ownership*: it has been observed in various contexts where ITQs have been adopted, and is seen as a major social effect of such systems (Annala, 1979, Brandt, 2005, Eythorsson, 1996).

The objective of this paper is to examine the impacts of the adoption of ITQs in the Tasmanian fishery for rock lobster (*Jasus edwardsii*) that have operated since 1998. Despite a growing number of papers describing the effect of ITQs all over the world, fairly few studies have analysed the retrospective economic impacts of the introduction of ITQs. Apart from the analysis of the halibut fishery in British Columbia by Casey et al. (1995), we are not aware of any similar analysis of the economic effects of ITQs in a fishery. We present a retrospective analysis of the effects of the adoption of ITQs, referring to the main expected effects of ITQ systems as they have been proposed and discussed in the literature: i) the rationalization of the fleet, ii) the change in fishing strategy and iii) the concentration of activity and quota ownership. Descriptive statistics for key variables were produced, as well as simple indices calculated to measure changes in the status of the fishing fleet. Variables considered include vessel numbers and characteristics, fishing effort, landings and sale prices.

2 Materials and methods

2.1 Data

2.1.1 Vessel data

Information on fishing vessels was compiled from several databases. First, vessel characteristics since 2000 were collected from the database of the Department of Primary Industries, Park, Water and Environment (DPIPWE), which manages Tasmanian natural resources. These characteristics include length, tonnage, construction type and the home port of the vessels. The second source of data was Marine and Safety Tasmania (MAST), a statutory authority responsible for the operational safety of recreational and commercial vessels of Tasmania. The MAST database included information on length, gross tonnage, construction year and horsepower for 2007. Information on vessel characteristics was used for 1997 and beyond.

2.1.2 Catch-and-effort data

The catch and-effort data analysed in this paper were extracted from the DPIPWE database, which consists of compulsory logbook data recorded daily by fishers since 1993. In addition to catch–and-effort data, various spatial and technical details concerning fishing trips are recorded in the database. The catch- and-effort time series were completed with monthly aggregated historical data available for the period 1970-1992.

2.1.3 Price data

The monthly ex-vessel price of rock lobster was derived from processor records, also collected by DPIPWE. Individual processors must inform the Department of the average monthly price at which they bought rock lobster from fishers and of the amount of lobster bought per month. The monthly price of rock lobster was thus calculated as the average price paid by individual processors weighted by the quantities of red rock lobster bought. Nominal prices (i.e. non-deflated) were used for the price analysis, while the Australian consumer price index was used to deflate the total value of the fishery using 2006 as reference year (source: Reserve Bank of Australia (http://www.rba.gov.au).

2.2 Retrospective analysis

The retrospective analysis was carried out with the aim to assess the changes observed in the fishery with respect to the three broad categories of effects, namely, rationalization of the fleet, change in fishing strategies and concentration of activity and fishing rights. Analyses are based on the compilation of the different data sets describing the evolution of the status of the fishery over the last decade following implementation of the scheme.

2.2.1 Analysis of the fleet

The evolution of the fleet in terms of total number and composition was assessed through simple analysis of vessel characteristics. Length and tonnage were the only characteristics included in the analysis because of the quality of the coverage of the data, respectively 100 and 95% of vessels covered.

2.2.2 Changes in fishing strategies

Several factors affect the profit of the fishery: the operating costs, the fixed costs and the revenue generated from fishing. While fishers can hardly influence their fixed costs, they can seek profit maximization by decreasing their operating costs, depending on costs per unit of effort and effort, and increasing the revenue from fishing, which mostly depends on the price they received for their landings, given that the amount of rock lobster landed is fixed by their quota shares. Unfortunately, data were not available for costs which could not be included in the analysis of the evolution of fishing strategies. However, we did examine extensive time series and evolution of revenue through catch and price. Changes in fishing strategy were expected to occur with fishers seeking to maximize the return from their quota allocation due to the existence of market categories fetching different prices (Frusher et al., 2003, Bradshaw, 2004). The market categories of a rock lobster depend on several factors including (i) physical condition, (ii) colour and (iii) weight resulting in "split" prices, with "premium" lobsters with a rigid shell (i.e. not soft due to recent moulting), completely red in colour and weighing between 0.8 and 2 kg, receiving up to AUD 10 more per kg (C. Gardner, pers comm.). These characteristics are affected by spatial and temporal parameters, i.e. latitude, depth and season. To investigate potential changes in effort allocation related to premium prices, we compared the proportion of effort in the high-prices categories (premium size, shallow waters and

winter) for periods of 5 years before (1993-1997) and after (2002-2006) introduction of the ITQ system.

Specific attention was devoted to rock lobster ex-vessel price, with the aim to assess whether sale prices for rock lobster had improved after the introduction of ITQs. The analysis was carried out using the Hodrick-Prescott (Hodrick and Prescott, 1997) filter. This is used to identify long-term trends in time series by decomposing a time series y_t as the sum of a trend component τ_t and a cyclical component c_t: $y_t = \tau_t + c_t$. The filter finds the τ_t that minimizes the following expression over the time series of length T:

$$\min_{\tau_t} \left(\sum_{t=1}^{T}(y_t - \tau_t)^2 + \lambda \sum_{t=2}^{T-1}[(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})]^2 \right)$$

Two terms are identified in this expression. The first term constrains the cyclical component and the second constrains the trend component. The parameter λ influences the strength of the penalty on the trend component. The lower the time step between observations, the higher λ is in order to smoothen out the series. The data analysed in this paper are available at a monthly time step; the value for the λ parameter used in the analysis is that recommended by Hodrick and Prescott (1997) for monthly data, i.e. 14 400.

2.2.3 Evolution of activity and ownership concentration

The evolution of concentrations of activity and fishing rights in the fishery was explored through methods commonly used in economics to measure inequity of wealth distribution, the Lorenz curve and the Gini index (Lorenz, 1905, Gini, 1921).

3 Results: the effects of adopting ITQs on the fishery

The introduction of ITQs in 1998 involved the setting of a TAC which had not previously been implemented. The initial TAC was set at 1500 t, which was lower than the pre-ITQ catch. In 2002, the TAC was raised to 1523 t (Haddon and Gardner, 2008).

Prior to the introduction of ITQs, total effort and catch increased mainly as a result of fishers building catch history, while discussions went on regarding the implementation of the scheme. This is supported by the reduction of effort in the summer (November to February) of

1997, five months prior to the introduction of the quota management scheme, which was not taken into account in the definition of catch history.

Fishing effort continued to decrease after the introduction of quotas, in the absence of further regulations on the input side (figure II-2). Following adoption of the TAC, and the capping of catch at a constant level, the stock has been rebuilding. This has contributed to an increase in average catch rates (figure II-2), as in 2006/2007 fishers used 20% less trap-lifts to catch the TAC than in 1998/1999 (Haddon and Gardner, 2008).
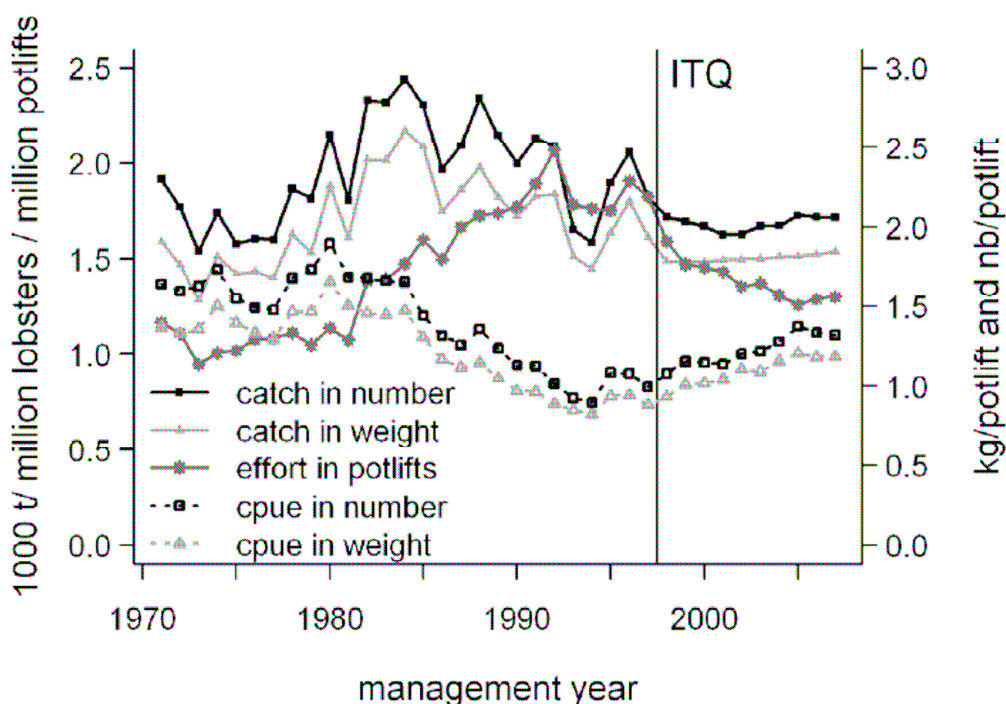
Figure II-2 Annual trend in effort, catch and catch rates in Tasmanian red rock lobster fishery.

3.1 Changes in the fishing fleet

3.1.1 Rationalization of the fleet

As expected, the size of the fishing fleet was reduced by 25%, from 325 to 242 vessels, in the first three years of quota-based management (table II-1). It then stabilized around 240 vessels until 2004 before a further decline, with the latest estimate of the fleet size being 214 vessels in 2006. The number of traps used by fishers is regulated and the amount of traps allowed

onboard varies from 15 to 50, depending on the size and gross tonnage of the vessel (Anon, 2006).

Table II-1 Number of fishing vessels per length class

Length class	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
≤10m	39	28	18	12	10	10	10	9	8	6
10 - 18 m	271	244	225	217	214	208	207	202	199	193
> 18 m	15	15	12	13	15	17	17	21	18	15
total	325	287	255	242	239	235	234	232	225	214

3.1.2   Characteristics of the vessels

The size composition of the fleet did change over the years, as expected. Most vessels measure between 10 and 18 m in length (table II-1), with the number of vessels in this fleet segment rising from 83% of the total fleet in 1997 to 90% in 2000. Most of the vessels less than 10-m long left the fishery in the first three years of quota: from the 39 vessels catching rock lobster in 1997 only a third remained in 2000. The number of the bigger vessels (>18 m) in the fleet remained the same, with 15 vessels in 2006 as in 1997 and even increased up to 21 in 2004. The evolution of the structure of the fleet can also be considered in terms of contribution of size classes to the capacity of the fleet (gross tonnage), which was reduced more strongly for the small vessels as shown in table II-2.While most of the fleet's capacity has been composed of vessels between 10 and 18 m and remained consistent at around 80% of the fleet capacity, the proportion of capacity for bigger vessels has varied, from 13% of fleet's total tonnage in 1997 to 20% in 2004 and 16% in 2006 (table II-2).

Table II-2 Contribution of length class to the total physical capacity of the fleet as percentage of gross tonnage

Length class	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
≤ 10 m	3	3	2	2	1	1	1	1	1	1
10 - 18 m	84	81	85	84	83	83	83	79	82	83
> 18 m	13	16	13	14	16	16	16	20	17	16

This evolution of the size distribution of vessels could be related to the development of winter fishing for the Asian market in the early 1990s, which led to the construction of bigger vessels, more suitable for rougher winter and west coast seas. It is also likely that the carrying

limit of traps on board influenced this distribution. Indeed, only vessels longer than 18 m and bigger than 30 t are allowed to carry the maximum of 50 traps.

3.2   Changes in fishing strategy

3.2.1   Seasonal distribution of fishing activity

Like all crustaceans, red rock lobsters exhibit discontinuous growth in size by periodic moulting. During the first stages of moulting, when the carapace is extremely soft, lobsters remain in dens and do not feed. The combined stress of moulting and fasting lowers the condition of the rock lobsters. The end of the moulting period in November was historically the beginning of the fishing season: once the exoskeleton begins to harden, rock lobsters are highly catchable as they attempt to replenish their food reserves. However, those rock lobsters are in poor physical condition, and processors are often reluctant to purchase them because of the large mortality rates suffered during shipment to the Asian market. Softer lobsters are thus normally retailed on the domestic market at lower prices.

The proportion of fishing effort allocated to the winter season increased after the introduction of ITQs from a median value of 39 to 46% of effort allocated to winter months (figure II-3). Fishers' response to the new regulation was extremely fast, and it may have been facilitated by the change which occurred in the regulatory dates of the management year. Managers decided to set the official fishing season from March to February and opened fishing in September (but kept the seasonal closure in October for the moult), instead of the traditional fishing season from November to August to encourage fishing in winter (April to September) when prices are high. Indeed, keeping quota for winter would have been risky, as catch rates are lower and weather conditions can prevent fishers from going out to sea. With the current fishing season starting in March, fishers can plan their fishing calendar without fear of having a portion of their quota uncaught at the end of the season. The variability of the seasonal fishing allocation is relatively high due to the fact that fishers are opportunistic and can change their fishing plans depending on weather conditions or if winter prices are not as high as expected (this happened during the severe acute respiratory syndrome (SARS) outbreak. Despite a high variability in the proportion of winter allocation, it should be noted that there is no overlap of the error bars between the before and after periods (figure II-3).

3.2.2   Fishing depth

The colour of rock lobster depends on the depth of its habitat. In shallow waters (less than 40 m) the rock lobster is uniformly bright red. In depths greater than 40 m, rock lobsters become paler and their appearance is speckled. Following introduction of individual quotas, the proportion of fishing effort in shallow waters tended to increase, most probably due to a targeting of these premium rock lobsters (figure II-3); before 1998, around 70% of trap-lifts were made in shallow waters and this proportion increased to 80% in the 2002-2006 period. This change in effort allocation to shallow waters also allowed reduction in steaming time, and therefore fuel costs.
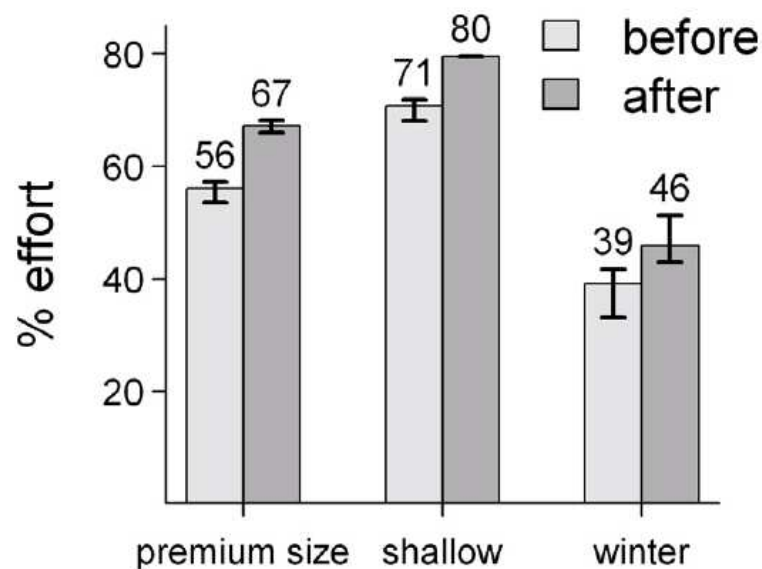
Figure II-3 Proportion of effort resulting in catch of red rock lobster of premium depth, season and size. The height noted above the bars represents the median, and the whiskers the min and max non-outlier values. Before and after periods are respectively 1993-1997 and 2002- 2006.

3.2.3   Lobster size

The fishing strategy regarding the size of targeted rock lobsters was calculated as the average lobster size per trip (total weight of lobster caught divided by their number). Before 1998, the proportion of trips with average lobster size in the premium size range (0.8 to 2 kg) was slightly above 55%, while the proportion of trips with premium average size has grown to

around 67% of total effort since 1998 (figure II-3). Three factors might have led to the increase of average size of lobsters, (i) a lack of smaller lobsters in the north of the state, where fishers and scientists have observed a decline in lobster recruits in the past few years (Haddon and Gardner, 2008); (ii) animals left in the water growing further, increasing the proportion of big lobsters in the water resulting from the rebuilding of the stock, and (iii) fishers targeting specific sizes. It is likely that all these factors combined are partly responsible for the increase in premium size in the landings. However, no trend could be identified in the average size of lobster in each management area (figure II-1), suggesting that the targeting of specific size classes is probably the main factor affecting average size in landings.

Contrary to expectations, there was no clear evidence that high-grading has increased in the rock lobster fishery after the introduction of individual quotas, and discards have been assumed to have remained constant over the period. This was checked against the new data system whereby fishers record the number of lobsters put back in the water, and very little discard was recorded. The only high-grading that occurs is the discarding of big lobsters (more than 2 kg) because the beach price of those lobster is much lower than for any other size category, and this only occurred since 2004, when the cost of leasing quota increased over AUD 20 per kg. However, discarding has never been an issue in this fishery because lobsters are released alive in the water causing no or very little mortality. Fishers can also target particular sizes by setting their pots at different latitudes (there is a south-north positive growth gradient in the Tasmanian rock lobster population).

3.2.4   Consequences on ex-vessel prices and gross returns

Most Tasmanian rock lobster is exported to the Asian live lobster market (Bradshaw, 2004). The beach price of rock lobster is therefore highly influenced by the Chinese market and exchange rates. The trend line computed with the Hodrick-Prescott filter applied to the nominal ex-vessel prices (figure II-4) shows an increase in lobster price in the early 1990s corresponding to the development of exports of live Tasmanian rock lobster to Asian markets. The decline observed in 2003 is due to the SARS episode in Asia which affected tourism and, as a result, decreased the demand for high-value food products on Asian markets (Hacourt, 2003).
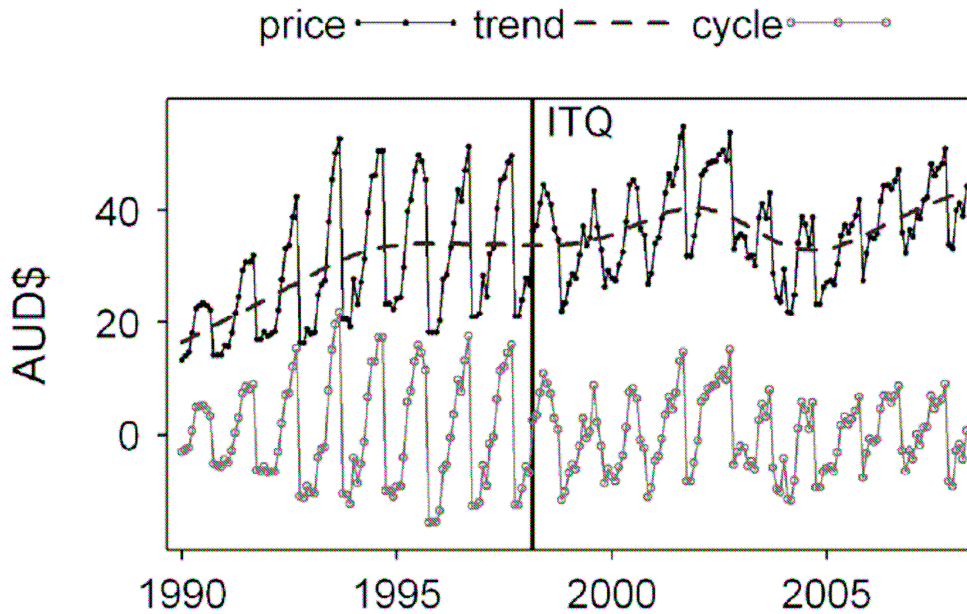
Figure II-4 Hodrick-Prescott filter of monthly ex-vessel prices of Tasmanian red rock lobster.

Because of this incident, it is difficult to clearly identify at the scale of the study period the long-term effect of ITQs on beach price for lobster, which could be expected from the changes in the composition of landings. However, in the first few years following the introduction of ITQs, the trend price increased from around AUD 34 per kg (1995-1997) to more than AUD 40 per kg in 2002 in nominal (non-deflated) terms. The exchange rate with Hong-Kong is certainly the most important factor influencing the average ex-vessel prices, even though there is some inconsistency at the end of the time series (figure II-5). The price trend followed the exchange rate as a mirror image, except for the few years after the SARS crisis (2005-2007); during these years, lobster price continued growing despite an increasing exchange rate (figure II-5).

The seasonal redistribution of effort explains the strong change observed in the intra-annual price variability for lobster, shown by the cyclical pattern (figure II-6). The variability of ex-vessel prices (i.e. the difference between the annual maximum and minimum price) decreased from around AUD 30 before 1998 to less than AUD 20 after 1998. Overall, and excluding the SARS episode, winter prices are not as high as before the introduction of ITQs, and summer prices are not as low either and the intra-annual price variability has been significantly reduced (figure II-6). Higher summer prices are probably related to a decrease in soft-shell landings in November.
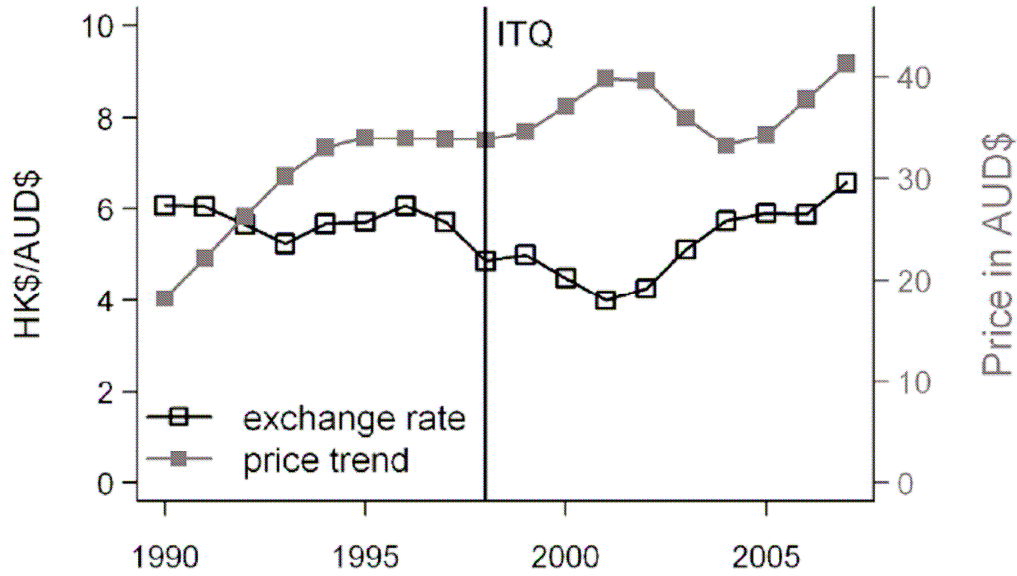
Figure II-5 Exchange rate and Hodrick Prescott price trend.
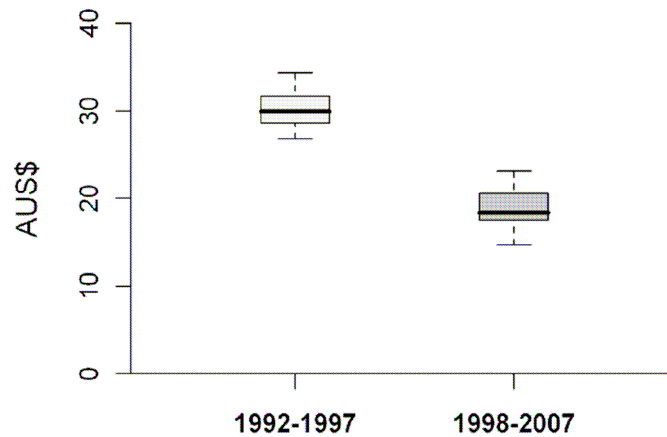
Figure II-6 Variability of price cycle.

The consequences of the price variation in terms of the total value of rock lobster catch can be estimated on the basis of the product of the monthly catch and the average monthly beach price (figure II-7). To analyse the evolution of the value of lobster catch, we consider deflated prices and correct gross value by the Australian consumer price index (CPI) relative to 2006 ($CPI_{2006} = 1$). The TAC, set in 1998, was below the pre-ITQ catch and resulted in a decline in the total value of the fishery in 1998 and 1999. The large increase in nominal value of the catch in the following years (2000-2002) is a result of an advantageous exchange rate (figure II-5). The drop observed for the following years derived from the decrease in the price of lobster due to SARS as the quantity landed did not change. However, the last increase in total

value (2005-2006 on figure II-7) cannot be explained by the exchange rate (figure II-5), as the increasing exchange rate would have had the opposite effect. The individual quality of rock lobsters is most likely to be the cause of the large increase in gross value product for the period 2005-2006. The deflated gross value of the fishery in 2006 is around the same level as at the introduction of ITQ in 1998 despite the SARS accident (figure II-7).
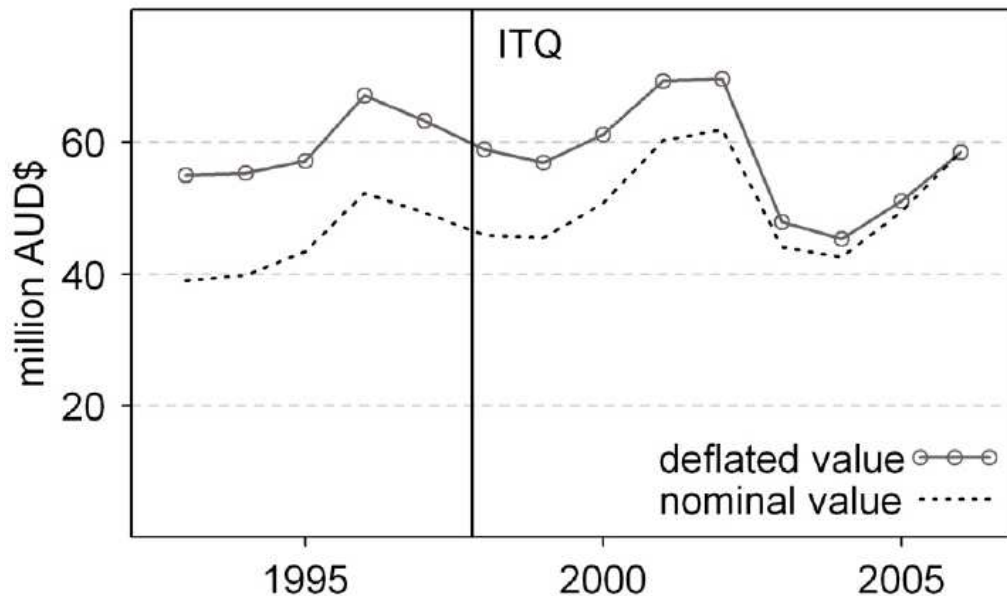
Figure II-7 Evolution of the total nominal and deflated value of Tasmanian red rock lobster catch.

3.3   Concentration of rights and activity.

Concentration of quota was not regarded as a potential issue in the Tasmanian rock lobster fishery because the aggregation limit per quota owner was set relatively low (2% of the TAC, Anon, 2006). This is confirmed when looking at the concentration profile of ownership (

figure II-8a). As expected from the theory, the distribution of quota shares in the fishery was less equitable in 2006 than the initial allocation in 1998 but the Gini index, which is commonly used as a measure of the inequity of distribution (Gini, 1921), remained at a fairly low level (0.36 in 2006). The extremely low level of the Gini index at initial allocation (0.20) proves that the extensive debate prior to implementation of the management scheme led to an equitable repartition of fishing rights amongst industry participants. It should be noted than

the number of owners is almost the same in 2006 as in 1998 (respectively 292 and 291) and that the number of quota owners remained stable over the period.

The concentration of activity, however, has not changed. Despite a major decrease of the number of vessels in the fishery, the catch (and therefore the TAC) has been distributed evenly amongst the remaining operators and the distribution of activity has been maintained at a relatively constant level (Figure II-8b); this was also assessed by looking at the evolution of Gini indices. Catch distribution exhibit low Gini index (around 0.35), suggesting a rather homogeneous distribution of catch in the fishery. No change can be identified in the evolution of the index, the concentration of catches having apparently remained stable as the overlapping curves on Figure II-8b suggest. We could have expected a distribution of effort 'flatter' after 1998 as the less active vessels were expected to have left the fishery but it seems that there were still fishers with low catches operating in the Tasmanian rock lobster fishery in 2006.
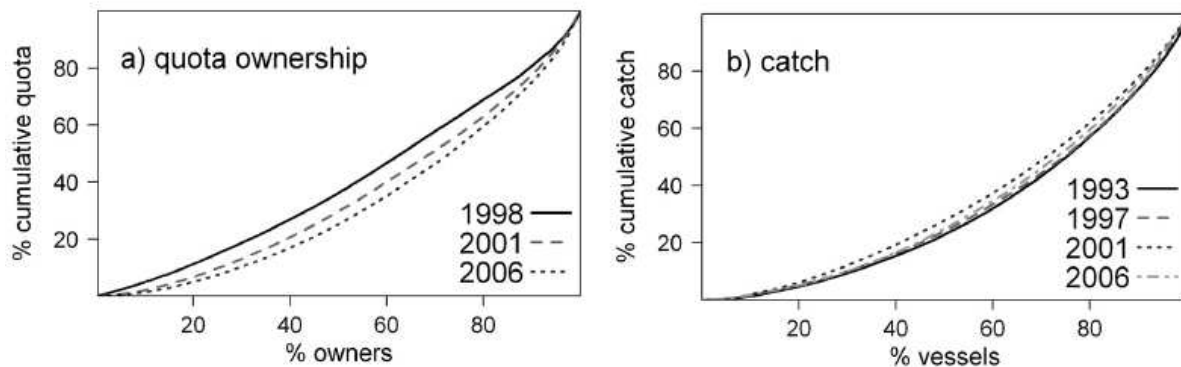
Figure II-8 Concentration profiles of (a) quota ownership and (b) catch by vessel.

4   Discussion – Conclusion

The studies and debates over ITQs are still dividing scientists, and the management system once presented as the ideal management tool for sustainable fisheries is now considered as a very efficient scheme under certain given conditions. Grafton and McIlgorm (2009) defined a formal framework for ex-ante evaluation of a fishery before introduction of ITQs, based on five criteria to ensure that the conditions for a successful ITQ system were satisfied.

The Tasmanian rock lobster fishery would have passed the five criteria they proposed. Firstly, the gross value of production (GVP) was twenty times higher than the AUD 2 million threshold they chose which could support the additional costs related to management. Secondly, the rock lobster fishery is a single-species fishery with very little by-catch, satisfying the targeting ability required. Thirdly, the number of vessels in the fishery was relatively small (just over 340 in 1993) but high enough to allow competition in quota trading. Fourthly, there is the ability to get premium products through seasonal and spatial redistribution of effort as discussed extensively in this paper and, finally, the variability of the stock recruitment relationship is rather low relative to harvest-effort relationship (Haddon and Gardner, 2008). As a result, the Tasmanian rock lobster fishery would have been considered a very good candidate for ITQs as are most fisheries with high-value products (McIlgorm and Tsamenyl, 2000).

ITQ was introduced in the Tasmanian rock lobster fishery as an attempt to limit the pressure on the stock and stop the decline in biomass. According to the 2008 fishery assessment report (Haddon and Gardner, 2008), the management system has been successful, with exploitable biomass doubling since historical low record in 1994. The expected impacts on the fishery identified in the literature were largely observed in the Tasmanian rock lobster fishery, and fishers mostly behaved as anticipated by the managers. The decrease of the fleet capacity and of fishing effort relieved the pressure on the stock, which rebuilt over the period. The decrease of effort should be related to operating costs and, even though the time series of costs was not available, the decrease of fishing effort by 30% between 1997 and 2006 can be compared to the 28% increase of CPI over the same period, which can be taken as a proxy for operating costs. The number of vessels operating in the fishery decreased dramatically by 25% during the first three years of quota and further until the current size, slightly over 200 vessels, i.e. 60% of the initial fleet. The fishing vessels were mostly made out of timber and sold as leisure sailing boats because most valuable fisheries around Tasmania had been locked down with a similar limited-entry scheme by the time ITQs were implemented for rock lobster (Frusher et al., 2003). The total fixed costs of the fishery are positively related with the size of the fishing fleet. Although mostly smaller vessels left the fishery, it can be assumed that, given the large amount of vessels leaving, at worse the total fixed costs of the fishery remained stable and they might even have decreased slightly.

The overall assessment of the fishery in terms of profit is not very conclusive. The total profit of the fishery is likely to have remained stable over the period when taking the inflation into

account, but owner-operators are probably better off because fewer of them are sharing this profit. As Frusher et al. (2003) observed by interviewing fishers in the industry, the situation of leasers is more complex because the profit is then shared between the owner of the quota share and the fisher through leasing price. Fishers have adapted their fishing behaviour to maximize the return per kg of rock lobster. The analysis of the data confirms what Frusher et al. (2003) had identified as emerging behaviours through interviews. Fishers chose to reallocate their effort, both spatially and temporally, towards more valuable lobsters for export to Asia. This new fishing strategy has had a direct effect on the gross value of the fishery which, despite the SARS accident, has been growing against the exchange rate for last few years of the period studied.

While the Tasmanian rock lobster industry is satisfied by the ITQ system (Treloggen, Tasmanian Rock Lobster Fishermen's Association's executive officer, pers. comm.), the change in fisher's behaviour brought about by the ITQ system has focused attention on the need for improved spatial management of the fishery to ensure productivity from optimal harvest regions.

The implementation of an ITQ system has had an overall positive impact in the Tasmanian rock lobster fishery. However, given how well it satisfied the required conditions stated in Grafton and McIlgorm (2009), the results can be disappointing. The global trend in fisheries management still focuses towards right-based management which is currently being intensively discussed in the European Union as future common policy. The lessons learned from the Tasmanian case study show that, even if the fishery behaves in an expected way, unexpected external perturbations can greatly impact the performances of such a system.

III Response of the Tasmanian rock lobster fishing fleet to the introduction of individual transferable quota.

Abstract:

The effects of individual transferable quotas (ITQs) have been widely studied in fisheries. However, little has been done on identifying the impacts of ITQs on individual fishers. In this study, we investigate the response of the Tasmanian rock lobster fishing fleet to the introduction of ITQs in 1998 in term of structural changes and in terms of fishing behaviour. We use vessel characteristics to examine the evolution of the fishing fleet and describe the profiles of vessels leaving, staying or entering the fishery. We define a typology of fishing activities at the trip and annual levels, and use this to investigate individual fishing strategies and their evolution since the implementation of ITQs.

The movement of vessels was primarily related to their physical characteristics and their region of origin. Vessels holding the maximum number of traps entered the fishery while smaller, old, wooden vessels left. The responses also varied regionally with vessels based in regions further from the major fishing grounds leaving the fishery. The change in temporal and spatial fishing patterns at the fleet level resulted from two distinct effects. Fishers changed their fishing practices and fished more in winter and shallow waters to obtain higher prices per kilogram of lobster. However, very little change could be seen in the large scale spatial distribution of individual effort of fishers, as fishers remained strongly dependent on their traditional fishing areas, closer to their home-port.

1   Introduction

The Tasmanian rock lobster fishery has been managed with individual transferable quotas (ITQs) since 1998 when they were chosen after years of debate because, unlike alternative management measures, they were expected to lead to the rationalization of the fishing fleet while an appropriate total allowable catch (TAC) would rebuild the lobster stock (Ford, 2001b). The theory on which ITQs are based predicts the departure of the least efficient fishers by selling or leasing their quota to more efficient fishers, resulting in the rationalization of the fishing fleet (Campbell et al., 2000). In addition, the fishers staying in the fishery would shift their effort towards more valuable products, as the allocation of catch quotas removed the "race to fish" and provided greater certainty for individual fishers. The value of a unit of fish could be increased by fishing when prices are high (e.g. winter fishing for rock lobster in New Zealand, Annala, 1996), or targeting market categories with higher value and commercialising the product in more valuable forms (e.g. fresh halibut in British Columbia, Casey et al., 1995, live fish in New Zealand, Annala, 1996, and herring for human consumption in Norway, Kulmala et al., 2007). Ten years after the introduction of ITQs in the Tasmanian rock lobster fishery, the overall impacts have been assessed and compared with the expected effects (chapter 2, Hamon et al., 2009) and the Tasmanian rock lobster fishery was found to behaved largely as expected. The fleet size decreased by about 25% within the first three years of the new management system, the effort towards lobster market categories and seasons with higher beach price increased, and minor concentration of quota ownership was observed due to strict limitation on quota aggregation.

The aggregated effects of ITQs on fisheries have been widely studied worldwide (Arnason, 1996, Annala, 1996, Campbell et al., 2000), but despite a growing recognition of fishers behaviour being the main source of uncertainty in fisheries (Wilen, 1979, Fulton et al., 2011, Hilborn, 2007), little work has been done to study the changes induced by ITQs on a finer scale, looking at the individual changes in fishing fleets.

In this study, we investigate the response of a fleet to the introduction of ITQs at the vessel level, using the Tasmanian rock lobster fishery as a case study. The southern rock lobster (*Jasus edwardsii*) is exploited in the coastal waters off Tasmania, Australia (figure III-1). Except for a seasonal closure in October to protect males during moulting, the fishery operates throughout the year and most lobsters are shipped alive to the Chinese market (Haddon and Gardner, 2008). Although the fishery targets a single species, southern rock

lobster, it presents complex spatial and temporal patterns due to heterogeneity of the stock and commercial fishing fleet. The Tasmanian rock lobster population is spatially structured in terms of i) individual size, from small lobsters in the South to larger lobsters in the North, ii) population density, with higher densities in deeper waters in the South and West, and iii) shell colour, with shallow water lobsters being bright red while lobsters caught in deeper water are "strawberry" or whitish (Bradshaw et al., 2000). The size and colour of lobsters are highly influential in determining the price fishers obtain in the Chinese market (Chandrapavan et al., 2009). White coloured lobsters do not reach prices as high as red coloured lobsters because culturally in China, the colour red is associated with luck, happiness and prosperity. In addition to spatial discrepancies, the availability and quality of lobsters varies highly between seasons within a year. A peak in catch rates is observed after the male moult in November (Austral spring). This is due to the entry of previously undersized lobsters to the exploitable biomass through growth, but also because lobsters do not eat during the moulting process and are therefore attracted to bait after moulting, and subsequently, highly catchable in traps. In contrast, winter fishing (May to September) displays lower catch rates because the catch of females is prohibited during this period as they incubate eggs and catchability declines with water temperature (Ziegler et al., 2002a, Ziegler et al., 2002b). The fishing fleet also displays spatial patterns. The western part of the state has very little infrastructure and most fishers come from their home ports in the south-east, east and north of Tasmania. The East coast, with better weather conditions and more resident fishers, has lower catch rates while the West coast, subject to rougher weather conditions and longer steaming time has higher catch rates.

After the introduction of ITQs in the Tasmanian rock lobster fishery, fishing was directed toward higher value lobsters and to seasons with higher beach price (chapter 2, Hamon et al., 2009). The combination of these two changes created altered fishing strategies observed at the fishery level. Individual change of fishing strategies and exit of fishers have been observed in other fisheries during the transition between input/output control management to fishing right based management and were linked to the economic efficiency gains of such fisheries (Brandt, 2007). A socio-economic study conducted in 1997, the year before the introduction of ITQs, suggested that the Tasmanian rock lobster industry would change under the introduction of ITQs (Williamson et al., 1998). The fleet would adapt to become more economically efficient as big vessels would be traded for vessels with lower operating costs and fishers would invest in vessels allowed to hold the maximum number of traps. The initial allocation of quota was related to the number of traps a fisher was allowed to use, depending

on the size of the vessel rather than on the historical catch. Fishers with high catches felt disadvantaged and the socio-economic survey predicted that those fishers would have to target more high-valued product or increase their debt by purchasing or leasing more quota.
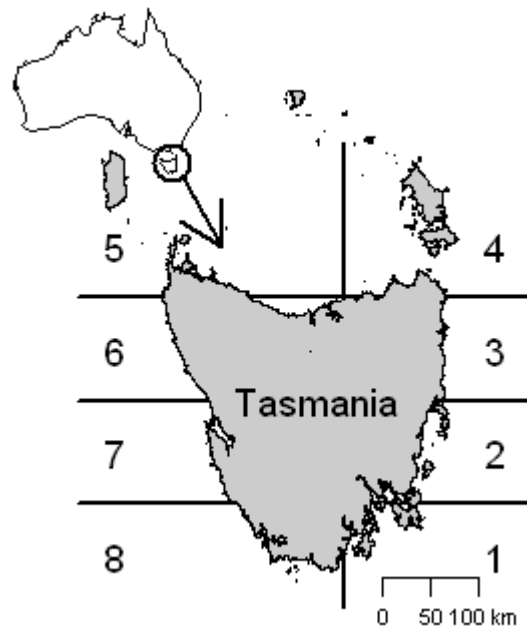
Figure III-1 Location of the assessment areas in the Tasmanian rock lobster fishery.

In this analysis, the evolution of the fishery is investigated through log-book data and other official data containing vessel characteristics and individual fishing activity to answer two questions: what type of fishers stayed in the fishery and how did the fishers that remained in the fishery modify their activity in response to the introduction of ITQs? This study relates to Brandt's (2007) as it examines the response of a fishery to the introduction of ITQs in terms of vessel exit and change in efficiency of the remaining fishers. In addition, the current study investigates the characteristics of selection of exiting and staying fishers and explores how fishers that stayed have changed their fishing behaviour to achieve greater profitability. The first part of this study examines the fishing fleet in order to identify the profile of vessels that stayed or left the fishery. The second part of the study is devoted to the definition and description of a typology of fishing activities in the Tasmanian rock lobster fishery at the trip and annual levels. The last part considers how fishers changed their fishing activities and verifies the extent to which changes in fishing patterns observed at the fleet level were due to

spatial and temporal changes in individual fishing strategies of the fishers who stayed, or to the exit of fishers traditionally operating in less profitable fishing strategies.

2   Material and Methods

2.1   Data

The Tasmanian rock lobster catch and effort data analysed in this paper were extracted from the Tasmanian Department of Primary Industries, Parks, Water and Environment (DPIPWE) database, which consists of compulsory logbook data recorded daily by fishers since 1993. In order to identify fisher choices of fishing location, fishing activity is examined at the "trip" level. Trips used in this study are defined as the monthly aggregation of fishing operations (1 trip = fishing operations of 1 month) for each vessel because of the lack of information on the duration of fishing trips.

In addition to catch and effort data, spatial and technical details concerning fishing shots and vessel characteristics are recorded in the database. In this study, a fishing shot corresponds to the setting and hauling of a number of traps at once (usually, all the traps onboard the vessel). The depth, spatial location by quarter degree block and number of lobster caught are recorded for each shot. The total catch weight is estimated for each trip or unloading. The weight is then divided by the number of lobsters caught during the trip to estimate average weight. Vessel characteristics include length, tonnage, construction material, age of the vessel and home port. Unfortunately, it appeared that the home port information defined in the database is partly inaccurate because it is not updated if the fisher changes home-port or when the vessel is sold and used in another port. Since the spatial allocation of fishing is highly dependent on the origin of fishers, "home regions" have been defined and fishing and unloading data have been used to identify the base region of Tasmanian rock lobster vessels for the 1993-2008 period (see details of the region definition in appendix A). The definition of home regions for vessels from King Island, Flinders Island and vessels coming from other Australian States is difficult because fishers from interstate keep their vessels in King or Flinders Islands during the fishing season (Williamson et al., 1998). For the purpose of this analysis, vessels from King Island, Flinders Island and interstate have been grouped in the "other states and Northern Islands" region.

Data on quota and vessel ownership is also collected by DPIPWE. Unfortunately, the data available did not allow the characterization of individual owners nor the exploration of the dynamics of the fleet at the owner level because quota and vessel owners can be companies to which no personal information is attached in the database, and the name of the company can be modified without changing the quota owner (e.g. several companies changed from individual ownership to family trust after the introduction of ITQs). Quota owners could be linked to vessels annually over the 1998-2008 period but could not be followed over time due to change in company names. Owners were characterized based on their quota holding and the amount fished by their vessel annually (van Putten and Gardner, 2010), as

1. *investors*: leasing all their quota to other fishers,

2. *income supplementors*: fishing only part of their quota and leasing the rest out,

3. *quota redistributors*: leasing quota in and out,

4. *lease dependent fishers*: fishing all their quota plus some additional quota leased from other owners, and

5. *independent fishers*: fishing exactly their quota and not involved in the quota market.

2.2   Definition and description of fishing activity

Numerical analyses have been used to describe the complexity of fisheries in terms of fishing practises and their effects on fish stocks (Murawski et al., 1983, Bertignac, 1992, Rogers and Pikitch, 1992, Lewy and Vinther, 1994). Ordination and classification techniques have been used to define groups of fishing practices with similar characteristics, either combined (Pelletier and Ferraris, 2000) or separately (e.g. classification: Murawski et al., 1983, and ordination: Biseau and Gondeaux, 1988). Groups defined by fishing operations have been called various names, including the term "métier" which will be used in this study (Biseau and Gondeaux, 1988). A method combining ordination and classification was adapted from Pelletier and Ferraris (2000) by separating Tasmanian waters into a number of fishing areas and combining the management areas (figure 1) with depths deeper or shallower than 70 meters. This resulted in defining 16 fishing grounds. The stock characteristics across the fishing grounds covered size, abundance and colour combinations in that size varied from north to south, abundance varied from west-east and lobster colour varied from deep to shallow. A principal component analysis (PCA) was carried out on a normalised matrix describing the proportion of effort in each fishing ground (columns) per trip (rows).

Classification was performed after the PCA as it is difficult to interpret factorial analysis of 16 variables. Classification techniques aim to group individuals into clusters that are both well separated and as homogeneous as possible with respect to the observed variables. The grouping of trips with similar geographical distribution was achieved with a hierarchical agglomerative cluster (HAC) on the 15 first PCA factorials (out of the 16). Ward's minimum variance method (Ward, 1963) was used on Euclidean distances to group clusters. To the authors knowledge, there is no optimal way of choosing the appropriate number of clusters. In this analysis, the proportion of variance explained was used to determine the number of clusters retained (Legendre and Legendre, 1998). The number of groups was chosen as the number for which the increase of variance explained plateaued (Ulrich and Andersen, 2004). Due to computational limits, the typology was performed on a sample of 7293 trips corresponding to three years of data spread over the period of study: 1994, 1997 and 2000. The clusters were then examined to ensure that none contained less than 1% of trips. Clusters with similar fishing grounds were pooled to form a single métier. Finally, all the 34219 trips undertaken by the Tasmanian rock lobster fleet over the period 1993-2008 were allocated to métiers by a set of simple rules based on the main fishing zone during the trip. The allocation rules for each métier are defined in table VII-3 in appendix B. The results of this analysis gave a classification of all fishing trips into different métiers defined by the allocation of fishing effort to the 16 fishing grounds during each trip.

In a similar way, annual fishing patterns were analysed and vessels who operated in the same areas within a year were grouped. The classification and description of fishing activity at the annual level were based on the same analytical methods, using all 4239 observations defined as vessel-years with full information on their activity in the Tasmanian rock lobster fishery. The resulting groups of vessels practicing similar activities throughout the year will be called "fishing strategies" in this study (Fall et al., 2006). Fishing strategies were defined as the combination of métiers that operated during a fishing season. A normalized PCA was performed on the matrix defined as the percentage of activity in each métier (columns) per fishing-season (year) and per vessel (the vessel-year observations as rows). A "no fishing" métier was added to the métiers identified in the first step of the analysis to account for the time spent not fishing for rock lobster during the fishing season. Seasonal closures of the fishery were excluded from the analysis.

The resulting métiers and fishing strategies were characterized with a set of indicators. Métiers were described by spatial and seasonal distribution of effort, the intensity of the

fishing activity and the variability in the resulting catch. The spatial component of a métier was described by the main fishing grounds. The seasonality of métiers was compared to the average seasonality of fishing to identify "above average" occurrences. Fishing intensity was investigated through the number of days spent fishing per month. The resulting catch for each métier was characterized by the average lobster size, and by the average catch rates in each métier.

Annual fishing strategies were characterized with an index describing the flexibility of vessels in changing métiers within a year, the proportion of time active in the fishery per year, and the seasonality of the activity. The diversification of vessel activity in different métiers was expected to be relatively high because métiers were defined as fishing locations using the same fishing gears, so no investment was required to change métiers. A seasonality index based on Ulrich and Andersen (2004) was used to assess the distribution of activity throughout the year. It was computed as the maximum number of consecutive months dedicated to one métier within a year. A high seasonality index (around 6 or 7) for a vessel indicates that one main métier is favoured throughout the year while a lower index, around 3 or 4, reflects a higher seasonal pattern in the chosen métiers and an index close to 1 reveals a high variation in the activity and probably a more opportunistic behaviour.

The time evolution of métiers and fishing strategies were examined with linear models. For each métier, the proportion of trips allocated to the métier was calculated as the ratio of the number of trips in the métiers over the total number of trips that year and the null hypothesis "no temporal trend" was tested with classical linear regression models. The same method was used for fishing strategies with the annual proportion of active vessels operating following a strategy, calculated as the ratio of the number of vessels following the strategy over the total number of active vessels that year. Proportions were preferred to absolute numbers because the total effort input and the number of vessels active in the fishery decreased over the period of study (chapter 2, Hamon et al., 2009).

2.3 Dynamics of the fleet

Two perspectives of the fishery dynamics were investigated: the evolution of the entire fishing fleet, and the evolution of fishing activity of the vessels that have remained active in the fishery since the introduction of quota. The vessels operating in the Tasmanian rock

lobster fishery have been divided into three groups, the "exit vessels" that were present in the fishery before 1997 and exited after 1997, the "new-comers", entering the fishery since 1997 and the "stay vessels" that have been active in the fishery since before 1997 and were still active after 2006 (with a possibility for temporary interruptions of activity). The new-comers include vessels entering the year before the first year of ITQs as it is believed that people anticipated the implementation of ITQs in March 1998 and bought licences and fishing vessels before the price increased (Williamson et al., 1998). Each vessel group was characterized by the physical attributes (i.e. length, tonnage, material and age) and fishing characteristics (e.g. strategy, fishing efficiency). The average fishing efficiency of a vessel was calculated as the average individual deviations of catch-rates compared to the average catch rates in the fishery using a closed-form estimation method (Haddon, 2001).

The shift of vessels between strategies from year to year was investigated as the percentage of vessels following a strategy *k* in year *y* that followed strategy *k'* in year *y + 1* similar to the index of stability in Ulrich and Andersen (2004). The average proportions of vessels changing strategy over the period were used as indicators of the transitions in fishing activity. Changes in fishing activity were also investigated in terms of fishing seasonality as winter lobster prices are higher than summer prices (Austral winter being defined as April to September). The concentration of fishing was explored through the evolution of catches by individual vessels. Additionally, the "stay vessels" were investigated in 2005-2007 through a number of characteristics (catch, evolution of catch over 10 years, region of origin, quota units owned and quota ownership type) using multiple correspondence analysis (MCA, see Venables and Ripley, 2002 for the plot of MCA). All the analyses were performed using R statistical packages (R Team, 2009).

3 Results

3.1 Evolution of the Tasmanian rock lobster fishing fleet

Although vessels have entered and exited the fishery every year over the 1993-2008 period, the number of vessels in the Tasmanian rock lobster fleet dropped by 25% in the first 3 years after introduction of the quota management system (see figure III-2). The number of entrants and exit vessels generally balanced each other before ITQ probably reflecting either investment in new vessels or fishers retiring and selling or leasing their licence to new fishers.

Since ITQ introduction, the departure of vessels has regularly been greater than entries, leading to a reduction of the fleet size although the annual TACs were set at a level comparable to catch in the mid 1990's (see chapter 2). The rationalisation of the fleet has not been uniformly distributed around the state (figure III-3). Eight years after the introduction of ITQs, the South-East region has remained the area with the most fishers and the number of active vessels only declined slightly (from 95 to 88 vessels). The north coast and west coast of Tasmania had a smaller fleet but they also remained relatively constant over the period. In contrast, the East Coast used to be the home-region of a large part of the fleet in 1995-1997 (74 vessels) of which 56% only remained active by the mid 2000's. This can probably be explained by the demographic structure of the population in the area. The East coast is the residence of an older population and the retirement of aging fishers might explain the decline in the local fleet (Williamson et al., 1998). The "other states and Northern Islands" region displays the largest decrease in the number of vessels. Most vessels in this group have owners from interstate so the strong decline in this part of the fleet may be due to higher travel costs making fishing less profitable.
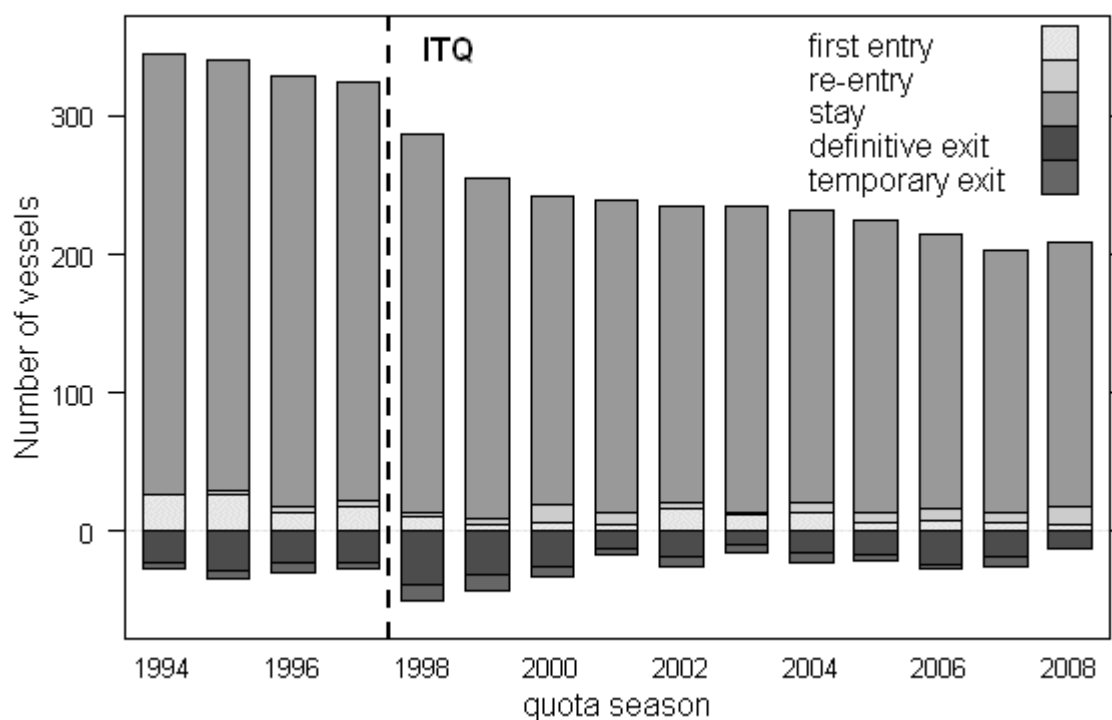
Figure III-2 Annual vessels movements in and out of the Tasmanian rock lobster fishery.(1994-2008). Re-entry and temporary exit correspond to a suspension of rock lobster fishing for at least one year. The category "exit vessels" corresponds to the sum of "definitive exits" between 1997 and 2006. "New-comers" are vessels that first appeared "first entry" in the fishery between 1997 and 2008; "stay vessels" are vessels which were in the fishery before 1997 and were still active in 2007 and/or 2008.

Inter-annual variations of the fleet size are also due to temporary suspension of rock lobster fishing. The number of vessels interrupting their fishing activity for at least a year increased after 1998 (figure III-2). Several factors can explain this increase. First, the transferability of quota entails higher flexibility. If fishers need to interrupt their activity for personal reasons, they can do so and maintain an income by leasing their quota. Second, quota owners who also own a vessel, regularly compare the price of quota against the lobster beach price and decide to either lease their quota or fish it. Last, the regulation requires every fisher to hold (own or lease) a minimum of 15 quota units at the beginning of the season to be allowed to go fishing. Lessees who own little quota may have difficulties obtaining 15 quota units and may be forced to skip a season. Overall, 166 vessels fishing before 1997 definitively left the fishery over the 1997-2006 period (exit vessels), 113 vessels entered the fishery for the first time between 1997 and 2008 (new-comers) and 150 vessels have remained active throughout the period (stay vessels, with some temporary exits). An additional 96 vessels were not included in the analysis because they left the fishery before 1996, and their exit is assumed unrelated to the introduction of ITQs.
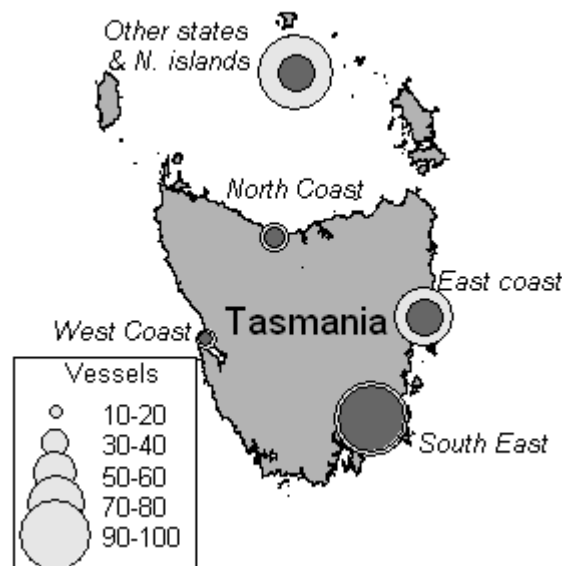
Figure III-3 Number of vessels by region before and after the introduction of ITQs.
Number of vessels before introduction of ITQ estimated as average 1995-97 (light grey circles) and after ITQs as average 2005-07 (dark grey circles).

Movements of vessels have modified the average characteristics of the rock lobster fishing fleet. Most small vessels have exited the fishery, while larger vessels, both in length and gross tonnage, have entered (see figure III-4). More than half the vessels entering the fishery have a capacity of at least 30 tons and have therefore the right to carry the maximum number of traps on-board (50 traps according to fisheries rules, Anon, 2006). While most vessels leaving the fishery were made of timber, this material was only used for 20% of new vessels. The major construction materials of the entering fleet were steel and fibreglass, attesting to the modernization of the fishing fleet with lighter materials that are also cheaper to purchase and maintain. The fluxes of vessels in and out of the fishery have also rejuvenated the fishing fleet with at least 20% of new vessels younger than 10 years at the date of entry, attesting to a positive investment in the fishery.
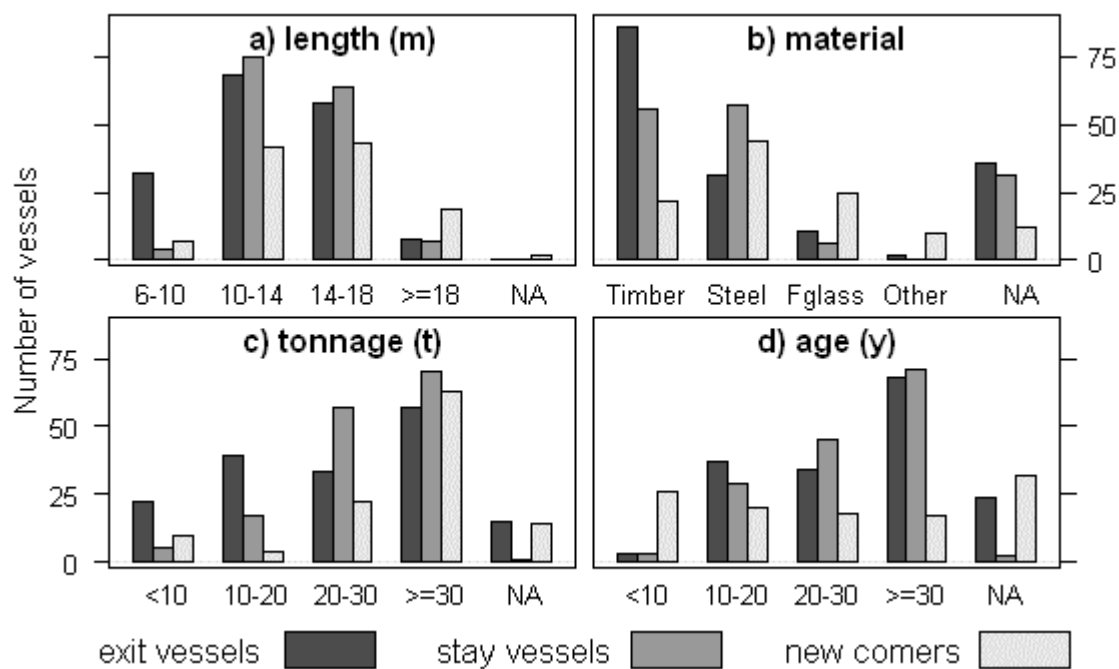
Figure III-4 Characterisation of vessels leaving, staying and entering the fishery.

Exit vessels are vessels that left the fishery after 1997, stay vessels remained in the fishery since 1996 until 2007 and new comers are the vessels that entered the fishery after 1997. Characteristics include (a) vessel length in meters, (b) vessel construction material (timber, steel, fibreglass and others), (c) gross tonnage in tons and (d) vessel age in years. The age of vessels shown here are the age of the vessel at the last year of activity prior to leaving, the age at the first year of activity for the new comers and the average age over the period 1996–2008 for vessels remaining. NA represents the percentage of non available data.

Fishing efficiency coefficients are the individual deviations of catch rates compared to the average catch rates. Because average catch rates are weighted by catch in the calculation of fishing efficiency, the weight associated with very efficient fishers who catch more lobsters is higher than the weight of less efficient fishers and the median of individual efficiencies is lower than 1 (0.8 here). While some of the fishing efficiency patterns are expected, such as 95 fishers leaving the fishery being less efficient than the average fisher (fishing efficiency lower than 0.8, see figure III-5), analysis at the vessel level only allows for a limited interpretation on the movements of fishers. A quarter of "exit vessels" (or 45 vessels) are in the category "very efficient" but some are likely to be fishers who invested in new vessels and would then also be found in the very efficient "new-comers" category. By comparing the number of exit vessels and new-comers for each efficiency level, a net exit of vessels is observed for the extreme categories: very efficient and least efficient fishers. The departure of about 20 of the most efficient vessels can be surprising but fishing efficiency also reflects the experience of fishers and, fishers retiring after decades of fishing for rock lobster are possibly some of the most efficient in the fishery. Twenty-six vessels (20% of the stay vessels) with very low efficiency stayed active in the fishery. The majority of vessels remaining in the fishery have a fishing efficiency around the average fishing efficiency with only 33 "stay vessels" being in the 25% most efficient fishers observed over 1996-2008. The new-comers are evenly spread in all fishing efficiency categories. The occurrence of new vessels in the two highest efficient categories can probably be explained by investment of the most efficient fishers in new vessels. Another possible explanation relates to the physical characteristics of new vessels. More resistant to rougher weather, with a higher accessibility to less exploited fishing grounds and with newer technology, the new vessels are probably more efficient at tracking lobsters. The least efficient new comers are probably new, less experienced fishers buying into the fishery after quota introduction.
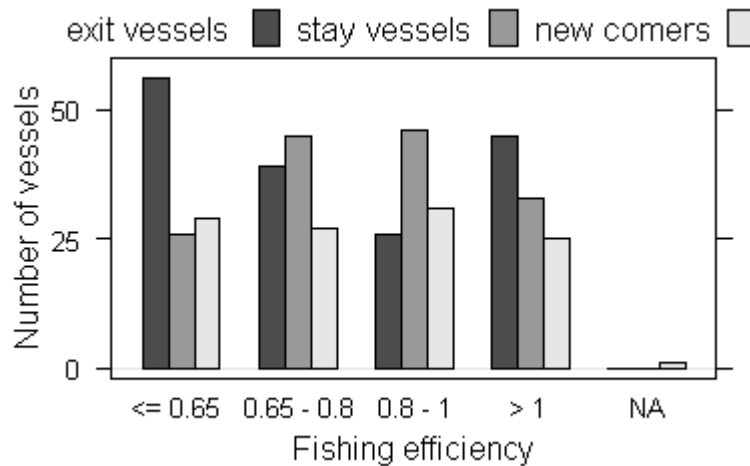
Figure III-5 Distribution of vessels by fishing efficiency levels for exit vessels, stay vessels and new comers. The observations are divided in four levels following the 25%, 50%, 75% and 100% quartiles: the least efficient fishers (fishing efficiency lower than 0.65), the medium low fishers (efficiency between 0.65 and 0.8), the medium high fishers (efficiency between 0.8 and 1) and the very efficient fishers (efficiency higher than 1).

To summarize, the Tasmanian rock lobster fishing fleet decreased since the introduction of ITQs. The exit of vessels from the fishery led to a strong decline in local rock lobster fleets from the "other States" and Northern islands with higher travelling costs and from the East coast probably due to retirement. The reduction of the fleet happened at the expense of smaller wooden vessels with investment in larger, younger vessels made of steel or fibreglass. The rationale behind using larger vessels is to meet the required regulated size to carry the maximum number of traps onboard and thus increase the catch per day. In addition, larger vessels can operate in rougher weather increasing the possibility of fishing during winter when beach prices are high and the new lighter material decreases fishing and maintenance costs. Despite expecting that the most efficient fishers would remain in the fishery while the least efficient would leave (Anderson, 1986), the picture observed in the Tasmanian rock lobster fishery is more complex. Only a third of the vessels leaving the fishery were less efficient, some of the best fishers also left the fishery. The exit of some of the most efficient fishers can be explained by the aging profile of the fishery (Frusher et al., 2003). Older fishers either retired from the fishery and sold their quota or became investors, leasing their quota to active fishers.

3.2   Description of fishing activities

3.2.1   Métiers

The classification of fishing trips for the three selected years 1994, 1997 and 2000, resulted in the identification of 36 clusters of fishing trips characterised by the location profiles (16 fishing grounds) explaining 93% of the variance. These groups were then pooled into 13 métiers with similar dominant fishing grounds insuring that no cluster contained less than 1% of trips. The importance of each fishing métier in term of number of trips over the period 1993-2008 varies from 345 (or 1%) for métier NW deep to more than 6000 trips (18%) for métier SW shallow (see table III-1). The métiers cover all the areas in Tasmanian waters, each métier focusing on one fishing ground or two when some of the fishing occurs in deep water (table III-1). The first nine métiers cover shallow waters (less than 70 m deep) all around Tasmania. In addition, four métiers target deeper water lobsters on the West coast of Tasmania, focusing on deep water fishing in the North-West (métiers 10 and 11) or combining shallow and deep waters of south western areas (métiers 12 and 13). No deep water fishing was identified on the East coast. Shallow water métiers have been preferentially chosen by fishers throughout the period of study. Over the 1993-2008 period, at least a thousand trips have been undertaken in each shallow water métier (up to 6103 trips for métier SW shallow) while deeper métiers have been operated less frequently (from 345 trips for NW deep métier up to 871 for WNW deep métier).

The métiers in shallow waters target primarily red, high value, lobsters while métiers in deeper water target the less valuable white lobsters but with higher catch-rates. The north-south geographical partition shows that métiers are distributed along the coast covering the full range of latitudes and lobster sizes, from the northern areas targeting the larger lobsters (average lobster size during a trip between 0.8 kg and 1.5 kg for métiers 1, 2, 4, 10 and 11) to the southern areas with smaller lobsters (average lobster size less than 0.8 kg for métiers 7, 8, 9 and 13). Métiers in mid-range latitudes (3, 5, 6 and 12) target intermediate sizes.

The métiers devoted to fishing in shallow waters off the East and South coasts (métiers 2, 4, 6, 8 and 9) seem to be favoured during winter months compared to the métiers on the West coast (shallow, métiers 1, 3, 5, 7; and deep, métiers 10 to 13). This seasonal partition is expected because most of fisher's home ports are on the East coast and fishers tend to fish closer to home during winter, partly due to rougher weather conditions in winter which is exacerbated on the West coast where fishing can become hazardous.

Table III-1 Characteristics of the rock lobster métiers.

Trips represents the number of trips undertaken in the métier between 1993 and 2008. The main location corresponds to the assessment areas split by depth less or greater than 70m. Season represent higher than average occurrence in months. CPUE is the average kg/traplift. Fishing days is the average number of days spent fishing during a month. The Trend is calculated on the proportion of trips spent in the métier per year. In parenthesis are indicated [1]percentage, [2] the trends and significance of trends at 5% level indicated by star *

	Metier name	Trips	Main location[1]	Season	Lobster size[1]	CPUE[2]	Fishing days[2]	Trend
1	**NW shallow**	5899	area 5 <70m (93)	High Mar-May	0.8-1.5kg (85)	1.0 (0.02*)	17 (-0.21*)	-0.18
2	**NE shallow**	4601	area 4 <70m (90)	High Jun-Aug	0.8-1.5kg (84)	0.9 (0.02*)	17 (-0.31*)	-0.05
3	**WNW shallow**	2515	area 6 <70m (89)	High Jan-May	0.8-1.5kg (63) & < 0.8kg (36)	1.1 (0.02*)	13 (-0.18*)	-0.05
4	**ENE shallow**	2839	area 3 <70m (90)	High Jun-Aug	0.8-1.5kg (76)	0.6 (0.03*)	19 (-0.09*)	-0.23*
5	**WSW shallow**	2033	area 7 <70m (85)	High Nov-May	< 0.8kg (56) & 0.8-1.5kg (44)	1.3 (0.04*)	11 (-0.08*)	0.05
6	**ESE shallow**	3280	area 2 <70m (90)	High Jun-Aug & Nov-Dec	< 0.8kg (51) & 0.8-1.5kg (48)	0.7 (0.03*)	17 (-0.19*)	0.12
7	**SW shallow**	6103	area 8 <70m (90)	High Nov-Feb	< 0.8kg (73)	1.0 (0.03*)	13 (-0.17*)	0.2*
8	**SE shallow**	3523	area 1 <70m (89)	High Jun-Jul & Nov-Dec	< 0.8kg (70)	0.7 (0.02*)	15 (-0.26*)	0.4*
9	**S shallow**	1091	areas 8 <70m (50), 1 <70m (42)	High Jun-Jul	< 0.8kg (75)	0.8 (0.02*)	16 (-0.18*)	0.18*
10	**NW deep**	345	area 5 >=70m (77)	High Feb-May	0.8-1.5kg (74)	1.7 (0)	14 (-0.41*)	-0.09*
11	**WNW deep**	871	area 6 >=70m (67)	High Jan-May	0.8-1.5kg (71)	1.8 (0.05*)	13 (-0.28*)	-0.16*
12	**WSW deep**	554	area 7 >=70m (40), <70m (32)	High Dec-May	< 0.8kg (59) & 0.8-1.5kg (40)	1.2 (0.02*)	13 (-0.16*)	-0.12*
13	**SW deep**	565	area 8 >=70m (53), <70m (36)	High Sep-Feb	< 0.8kg (82)	1.3 (0.03*)	12 (-0.06)	-0.09*

The time spent fishing each month decreased for all métiers with the number of fishing days decreasing by 0.06 to 0.41 days per trip each year (i.e. métiers SW deep and NW deep respectively). While the TAC remains stable between 1500 t/yr (1998-2000) and 1523t/yr (2001-2008), the decline in the number of days fishing is a result of the increase in catch rates and the increase in trap-lifts per day per vessel due to the use of larger vessels with more traps onboard (see figure III-6).
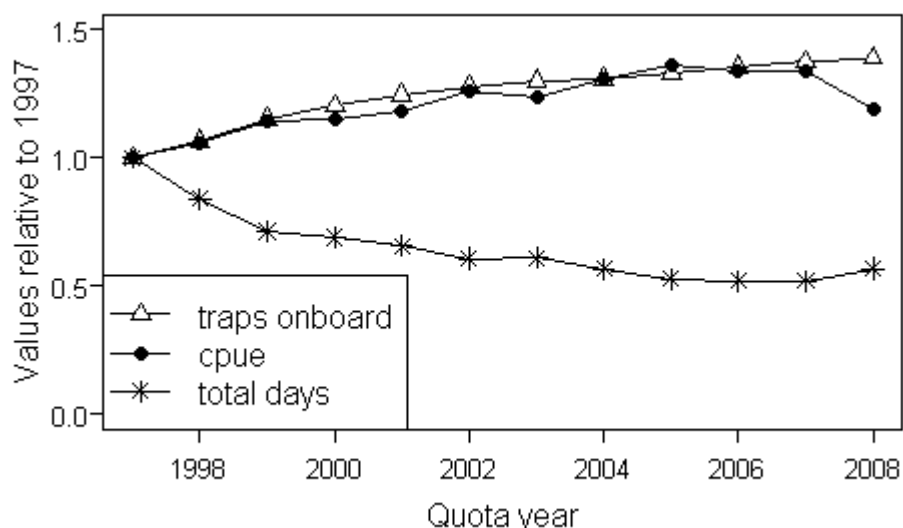
Figure III-6 Relative evolution of fishing indicators.

Traps onboard are approximated by the average number of traps used per shot, CPUE (non standardised catch rates in kg/traplift) and annual fishing days for the fleet.

The distribution of trips to métiers changed throughout the time period examined. All métiers that operated in western deep waters (10 to 13) and the shallow waters of the North (1 to 4) showed declines in the proportion of trips taken by year, although the trend is not significant for métiers NW shallow, NE shallow and WNW shallow (table III-1). The decrease in the northern deep and shallow waters is balanced by the positive trends for all the shallow water métiers in the southern half of the state (significant for métier SW shallow, SE shallow and S shallow). Before introduction of quota, fishers did not have secure catch shares and the "race for fish" probably led fishers to develop strategies maximizing catches, even if this was at lower prices. With the individual quotas, fishers have been allocated secure catch shares and have had the opportunity to develop strategies aimed at targeting specific lobster market categories and seasons with higher prices, as well as reducing the costs per kilogram harvested, which are higher for deep water fishing

The decrease in deep water fishing is probably due to the lower price received for white coloured lobsters that constitute the deep water catch (Chandrapavan et al., 2009). Prior to quota introduction, high catch-rates in deep water balanced the lower beach price fetched by whiter lobsters and the fishing costs associated with fishing further at sea. With the introduction of ITQs and the rebuilding of the lobster stock, catch rates increased all around Tasmania and the decision of fishers to fish closer inshore was driven by a combination of

factors including higher beach prices, lower travelling costs and increasing catch rates in those shallow areas.

The decline in the proportion of trips in the North of the state is related to the change in the structure of the fleet and to fishers favouring fishing grounds closer to their home region (see figure III-7). The selection of fishing métiers is highly related to their home-region. From 1993 to 2008, a small proportion of fishers operated out of the direct vicinity of their region of origin. Among the vessels fishing far from their home port, fishers from northern parts of Tasmania and interstate have been the most mobile, regularly fishing in the South and South West (figure III-7). Métiers NW shallow, NE shallow and ENE shallow have mainly been operated by vessels from "Other states and Northern Islands" and from the "East coast", which are the two regions with the largest decline in number of vessels. Inversely, the métiers with positive trends in proportion of trips (métiers SW shallow, SE shallow and S shallow) are operated by vessels from the South East where the number of vessels remained constant (see figures III-3 and III-7).
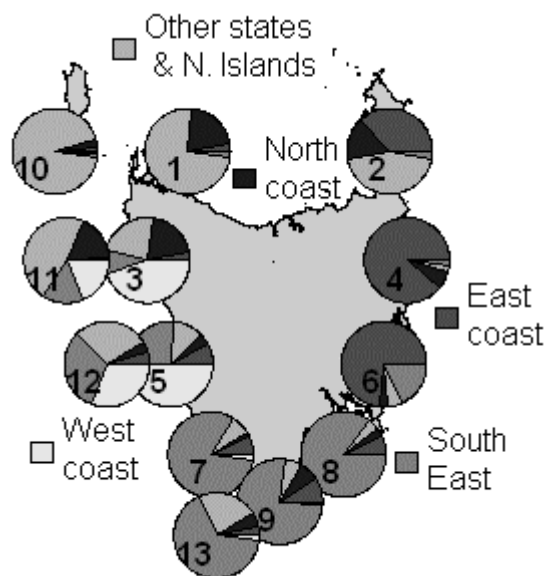
Figure III-7 Average distribution of the 1993-2008 rock lobster fishing trips by vessel's region of origin. The grey shades represent the different regions of origins for each métier numbered from 1 to 13 in table III-1.

3.2.2   Annual strategies

Rock lobster fishing occurs all around Tasmania (see location of métiers figure III-7), most of the fishing activity happens in shallow waters targeting red lobsters but fishers have also ventured to deeper waters on the West coast. Fishing in the different métiers results in different lobster in terms of colour with bright red lobsters in shallow water and in terms of sizes, from larger lobsters in the North to smaller lobsters in the South (table III-1). This is an important feature of the Tasmanian rock lobster fishery, since ITQs fishers have had incentives to increase their profit per kg of lobster as their total catch is fixed. Fishers can increase the value of their catch by fishing in seasons when the price is higher but also by targeting lobster categories more valued on the Chinese market. The colour of lobsters is selected through the depth of the fishing grounds (Chandrapavan et al., 2009) and the size by varying the latitude where fishing occurs (Gardner et al., 2006). Fishers can also decrease their fishing costs by fishing closer to their home port and in areas where catch rates are higher. Although there are no restrictions to rock lobster fishers operating throughout Tasmanian waters, Tasmanian rock lobster fishers are attached to specific fishing grounds within a trip and are consistent in their choice of métiers within a fishing season (table III-2).

The annual combinations of métiers are grouped into annual strategies using a cluster analysis which identified 14 groups explaining 68% of the variance in the data. The size of the different fishing strategies varies from 82 observations or "vessel-years" (i.e. 1.9% of the total number of observations for fishing strategy 4) to 627 vessel-years (i.e. 14.8% for fishing strategy 14) over the 1993-2008 fishing period. Each strategy is characterised by a single or set of dominant métiers from the range of métiers defined previously. Nine strategies are mainly composed of métiers operated in shallow water (strategies 2, 3, 5, 6, 8, 9, 11, 12 and 13 in table III-2), four associate a mix of both shallow and deep water métiers off the West coast (strategies 1, 4, 7 and 10) and the last strategy was characterised by a low number of rock lobster fishing trips per year (strategy 14). Except for the south-western shallow strategies (8 and 13) in which fishers operate several métiers, the strategies directed toward shallow water display a high métier fidelity, each focusing on a single rock lobster métier.

All strategies include at least a month without fishing in addition to the seasonal closures. The number of months active in the fishery is slightly higher for shallow strategies (from 8.2 to 9.7 trips per year) compared to the strategies involving deeper fishing (from 7.2 to 8.3 trips per year). Comparatively, in the strategy called "low RL fishing", fishers are active in the

Tasmanian rock lobsters (RL) fishery only four months during a year. The average number of months active per year does not follow a clear trend for most strategies but strategies "SW mix" and "NW shallow" where an increase in the number of trips undertaken per year can be observed (respectively 0.1 and 0.03 additional month per year).

Table III-2 Characteristics of the final fishing strategies.

"Obs" represents the number of 'vessel-year' practising the fishing strategy during the 1993-2008 fishing years, "Main métiers" is the dominant métiers operated in a strategy, "Trips/year" is the average number of months of activity per year, "CPUE" the catch rate in kg/traplift and "Seasonality" represents the seasonality index i.e. the number of consecutive months practicing the same métier. In parenthesis are indicated [1]average number of trips in métier per year, [2]the trend of the variable (* indicates a significant trend at the 5% level) .

	Fishing strategies	Obs	Main metiers[1]	Trips/year[2]	CPUE[2]	Seasonality[2]	Trend
1	**NW mix**	137	NW shallow (4), inact (2.7), NW deep (1.9)	7.8 (-0.04)	1.4 (0.04*)	4.7 (0.01)	-0.26*
2	**NW shallow**	457	NW shallow (8.4)	9.7 (0.03*)	1.0 (0.03*)	6.8 (0.12*)	-0.06
3	**NE shallow**	478	NE shallow (7.3), inact (1.7)	9.0 (0.01)	0.9 (0.03*)	5.4 (-0.05)	-0.15
4	**WNW deep**	82	WNW deep (4.1), inact (2.2), WNW shallow (1.1)	8.3 (-0.03)	2.0 (0.09*)	3.0 (-0.05)	-0.11*
5	**WNW shallow**	250	WNW shallow (7), inact (1.6)	9.0 (0.04)	1.1 (0.02*)	5.7 (0.07)	-0.13*
6	**ENE**	264	ENE shallow (7.7), inact (1.1)	9.4 (0.02)	0.6 (0.02*)	5.7 (-0.01)	-0.30*
7	**W mix**	155	inact (2.5), WSW deep (2.3), SW shallow (1.6)	8.0 (0.05)	1.3 (0.04*)	3.6 (-0.05)	-0.25*
8	**WSW shallow**	231	WSW shallow (5.9), inact (2.1), SW shallow (1.1)	8.5 (0.02)	1.3 (0.04*)	4.7 (-0.05)	0.02
9	**ESE**	392	ESE shallow (6.4), inact (2.4)	8.3 (-0.01)	0.8 (0.02*)	4.6 (-0.1*)	0.15
10	**SW mix**	196	inact (3.4), SW shallow (2.3), SW deep (2.1)	7.2 (0.1*)	1.2 (0.04*)	4.0 (-0.06*)	-0.25*
11	**SW shallow**	325	SW shallow (7.8), inact (1.8)	8.8 (-0.02)	1.0 (0.03*)	5.6 (-0.13*)	0.05
12	**SE**	351	SE shallow (6.7), inact (2.5)	8.2 (0.02)	0.7 (0.02*)	5.4 (-0.07*)	0.31*
13	**S shallow**	294	SW shallow (4.4), S shallow (2.1), inact (1.5), SE shallow (1.4)	9.2 (0.02)	0.9 (0.03*)	3.3 (-0.01)	0.40*
14	**Low RL fishing**	627	inact (6.5), NW shallow (1.3)	4.2 (-0.01)	1.1 (0.03*)	5.9 (0.04)	0.59*

As expected, the seasonal component of the annual strategies is inversely related to the number of métiers practiced in the strategy. The more métiers practiced in a strategy, the lower the seasonality index (number of consecutive months in the same métier). The lowest seasonal indices are observed for the "WNW deep", "S shallow" and "W mix" strategies and the highest for the "NW shallow" and "low RL fishing" strategies. Fishers operate in their

main métier for a minimum of three to four months and up to more than five months consecutively for half the strategies. The seasonality index is a measure of the flexibility of changing métier from month to month. Although the relatively high seasonal indices denote that fishers are strongly attached to a small subset of métiers that they operate for periods of a few months, four annual strategies (9-12) show a significant decreasing trend of seasonality indicating that they have been changing métier more often. Alternatively the strategy "NW shallow" with the highest specialization has its seasonality index increase over the period of study.

No relationship could be identified between the catch rates in the strategy (CPUE) and the diversity of métiers or the seasonality. Catch rates are primarily determined by the fishing location and the season. The East Coast is easily accessible to most fishers and has been traditionally fished more intensively than the west coast and especially the deeper areas of the west coast that are less accessible due to challenging weather conditions for part of the year. As a result, strategies focusing on the eastern areas (strategies 3, 6, 9 and 12) display lower catch-rates (i.e. less than 1kg/traplift) than strategies operated in the west. Weather conditions are harder on the west coast, limiting the time fishing in winter, when catch rates are lower due to the ban on females and lower catchability. Catch rates in the strategies that primarily fish in the west in summer are driven by the high summer catch rates.

The evolution of annual strategies from 1993-2008 follows similar trends as observed at the métier level, i.e. decrease of the proportion of deep water fishing in the north of the State while the proportion of fishing in the southern shallow water increased. A significant reduction of the proportion of active vessels is observed in annual strategies oriented towards deep fishing grounds on the West coast (strategies "NW mix", "WNW deep", "W mix" and "SW mix") and towards shallow areas in the North (strategies "WNW shallow" and "ENE"). The decline in those strategies varies from 0.11% to 0.30% less vessels per year (table III-2). In addition, the other two northern strategies ("NW shallow" and "NE shallow") display non significant negative trends. Only the five strategies targeting southern and shallow waters ("WSW shallow", "ESE", "SW shallow", "SE" and "S shallow") had positive trends although only the "SE" and "S shallow" were significant. The "low RL fishing" strategy displays the record high trend with 0.59% more vessels choosing a reduced activity every year.

3.3   Evolution of the fishing activity

3.3.1   Spatial

Since the introduction of ITQs, the effort in the fishery has decreased from about 1.7 million trap-lifts per year in the mid 90's down to 1.3 million trap-lifts in the mid 2000s (chapter 2, Hamon et al., 2009). However the decrease in effort has not been distributed homogenously around Tasmania. The proportion of fishing effort decreased in the North and deep Western areas balanced by an increase in the shallow Southern areas.

The inter-annual shifts of vessel strategies demonstrate that fishers seem dedicated to their traditional fishing strategy with high percentages of fishers being observed in the same strategy the next year (on the bolded diagonal table III-3). This is particularly true for shallow strategies with 64 to 76% of fishers operating the same strategy from year to year, except "SW shallow" and "S shallow" which have only 55 and 41% of loyal fishers but fishers remained in close areas. On average, the "deep strategies" display a lower rate of devoted fishers with respectively 35, 50, 32 and 30% of fishers keeping the "NW mix", "WNW deep", "W mix" and "SW mix" as their strategy for two consecutive years. Although the "low RL fishing" is the strategy with the most vessels and the highest increase rate (table III-2), only 29% of fishers stay in the strategy from one year to the next.

The increasing and decreasing trends observed for strategies (table III-2) are due to the rearrangement of vessels to other strategies. First, fishers who had originally fished in a mix of shallow and deep métiers relied more on the shallow métier they practiced for a greater portion of their catch as fishing stocks rebuilt. Second, possibly due to recovering stocks, higher catch rates and quota limitation, fishers decreased their activity in terms of months active and ended up in the "low rock lobster fishing" strategy. For all deep or mix strategies, a shift of fishers to the shallow counterparts is observed. An average of 21% of fishers fishing in the "NW mix" strategy fished in the "NW shallow" strategy the following year, likewise fishers have switched from strategies "WNW deep", "W mix" and "SW mix" to "WNW shallow", "WSW shallow", and "S shallow" at a respective rate of 9, 14 and 13% per year (table III-3; figure III-8b). In addition, in five of the six strategies with significant negative trends, more than 10% of the vessels engaged in the "low RL fishing" strategy the following year (figure III-8c). Finally, the strategies with decreasing trends attracted less fishers from other strategies over time, the negative signs in table III-3 indicate decreasing flows towards northern and deep strategies. Interestingly, only a low percentage of vessels left the fishery

(temporarily or definitively) that were engaged in a major activity. Most of the vessels that exited the fishery were in the "low RL fishing" strategy during the previous year.

Table III-3 Average percentage of annual vessel shifts between fishing strategies.

Shifts are indicated from year y (in rows) to year y+1 (in columns) over the period 1993-2008. Values on the diagonal represent the percentage of vessels staying in the same strategy from year to year. Minus (-) and plus (+) signs indicate significantly declining and increasing trends, although the coefficients of the trends are not specified. Percentages higher than 10% are bolded.

Year y+1 / Year y	NW mix-	NW shall	NE shall	WNW deep-	WNW shall-	ENE-	W mix-	WSW shall	ESE	SW mix-	SW shall	SE+	S shall+	Low RL fishing+	temp. exit	definit. exit
NW mix-	**35**	**21**	3	3	1		7			2-		1		**19**	3	5
NW shallow	6-	**69+**	2-		2	1	1-		1		1		2	**12**		3
NE shallow	1	2-	**76**			4					1		2+	8	1	5
WNW deep-	9	1		**50**	9		8			6				**14+**	1	3-
WNW shallow-		3	1	1-	**67**		2	4	2	2	1	1	1	8		5
ENE-			6			**71**		1	4				1	**10**	2	5
W mix-	3	2-		6	4	1	**32**	**14**		**11**	3		6	**11**	2	5
WSW shallow	1	2			4	2	5	**64**		1-	6	1	2	5	2	6
ESE		1	2		1	1			**75**		1	3	4	5	1	6
SW mix-	3	2	1	1	2		8	3		**30**	9	2	**13**	**12**	3-	4-
SW shallow							2-	4	2	4	**55**	1	**15**	8	1	5
SE+		1	1			1	1		4	1	2	**70**	6+	5	2	8
S shallow+		4	3		1	1	3-	1	4	4	**15**	**12**	**41**	7	1	4
Low RL fishing+	3	8	5	2	1	3	2	1	2	3	4	2+	3	**29**	7	**24-**
re-entry	1	1	1		4	1	6	9	4	8	2	9	5	**43+**		
first entry	2-	4	3	1-	4	2	2	4	7	7	1	9+	1	**54**		

Among the increasing strategies (with a plus sign in superscript next to the strategy names in table III-3), strategy "SE" is the only one with more than half the vessels staying in the strategy from year to year. In addition to 70% of the vessels continuing in the strategy every year, vessels operating in the closest strategy "S shallow" switched to "SE" (12% of the vessels, see table III-3 and figure III-8b) and 9% of the entrants (first entry and re-entry) chose the "SE" strategy (table III-3). Despite a lower rate of vessels staying in the strategy "S shallow" and vessels entering or re-entering the strategy, the strategy "S shallow" increased over the period due to the shift of vessels from South West strategies ("SW mix" and "SW shallow" see table III-3 and figure III-8b).

The "low RL fishing" strategy seems to hold an intermediate position in the fishery. It is the first step towards exiting the fishery definitely (24% per year in average, decreasing) or temporarily (7%) and it seems to be the preferred strategy of entry or re-entry in the fishery with more than half (54%) the first timers choosing to start with this strategy and 43% of the vessels re-entering each year use this strategy. This intermediate position can partly be explained by the vessel registration process, if a vessel is changed in the middle of a fishing season, the activity allocated to the vessel for the year is low and therefore the vessel ends up in the "low RL fishing" strategy. Thus the figure will also reflect fisher's upgrading or changing their vessels. Although, less than a third of the vessels in the "low RL fishing" strategy remain in the strategy the following year, the strategy has gained vessels over the years through entry of vessels in the fishery and also major shifts from other strategies (figure III-8c). A variety of factors can have caused the increase of the "low RL fishing" strategy. With secure rock lobster fishing rights and increasing catch rates, some fishers have spent less time fishing for lobster and have been involved in other professional activities, like fishing for scallop or giant crab. Quota owners who are not fully retired may fish part of their quota to assess the state of the fishery first hand and lease the rest of the quota to other fishers.
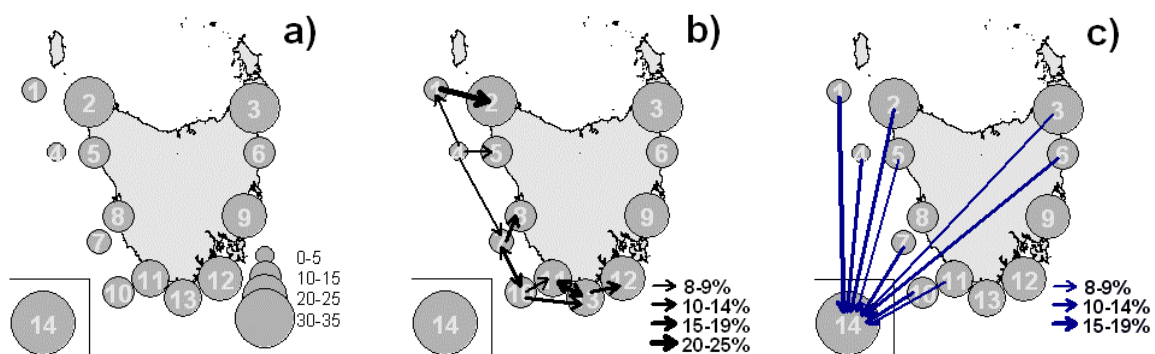
Figure III-8 Approximate geographical position of strategies and movement of vessels.
Strategies are numbered in bubbles as on table 2, 1- NW mix, 2- NW shallow, 3- NE shallow, 4- WNW deep, 5- WNW shallow, 6- ENE, 7- W mix, 8-WSW shallow, 9-ESE, 10- SW mix, 11- SW shallow, 12- SE, 13- S shallow and 14- low RL fishing. The average number of vessels in the strategy per year are indicated by the size of the bubbles on panel a), inter-annual shifts to active strategies are indicated with arrows on panel b) and inter-annual shifts toward "low RL fishing" strategy are indicated on panel c).

3.3.2 Seasonal

The seasonal allocation of fishing effort for rock lobster has changed since quota introduction with an increase of winter fishing (chapter 2, Hamon et al., 2009). In 1995-1997, the majority of the fishing fleet (about 80%) spent between 30 and 50% of their fishing effort in winter months when beach prices are higher (see figure III-9). Ten years later vessels fished more during winter, half the fleet sets more traps in winter than in summer (compared to 16% before ITQs), while only 40% of the fishing fleet kept the previous seasonal pattern (30-50% of effort in winter). The increase in winter fishing is mainly the result of fishers redirecting part of their fishing effort to winter. The "exit vessels" fished as much in winter as the "stay vessels" prior to ITQs.
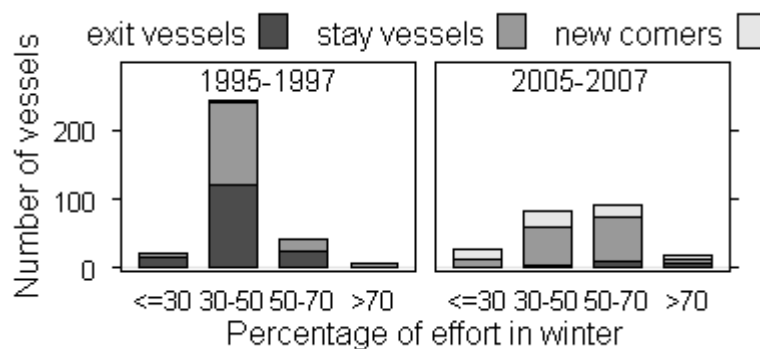
Figure III-9 Average number of vessels by proportion of effort allocated to winter before and after ITQs. Number of vessels by categories: exit vessels, stay vessels and new comers before (left) and after (right) implementation of ITQs. Exit vessels are vessels exiting after 1997, Stay vessels are vessels staying in the fishery over the 1997-2007 period and new comers are vessels that have entered since 1997 .

3.3.3 Catch aggregation

Williamson et al. (1998) predicted that the effects of introducing ITQs in the Tasmanian rock lobster fishery would be different for "big" and "small" catchers. Over the first 10 years of the quota management system, the catch profile has changed with less "small" catchers (less than 5t per year) and more "big" catchers (more than 10t a year, see figure III-10). The change in the catch profile is due to the exit of small catchers (107 vessels or 65% of exit vessels fished at most 5 tons of lobsters per year prior to quota introduction). Between 1995-1997 and 2005-2007, vessels remaining in the fishery have intensified their catch as almost a quarter of those vessels fish more than 10 tons a year in 2005-2007 (against 9% 10 years earlier).
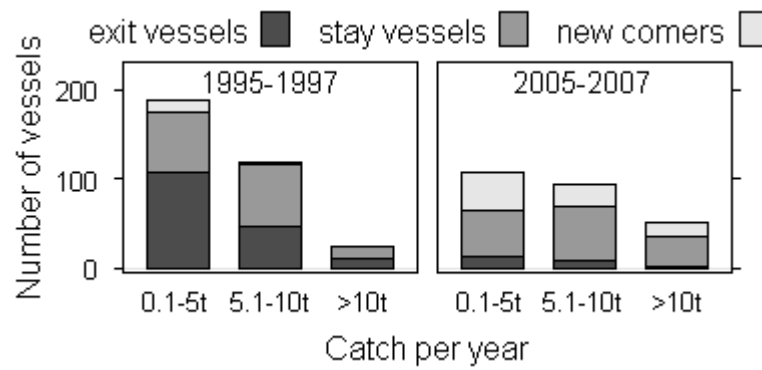
Figure III-10 Average number of vessels by catch intensity before and after ITQs.
Vessels catching less than 5t, 5 to 10t or more than 10t per year before(left a) and after (right) the introduction of quota by category.

The characteristics of the fishers that stayed in the fishery over the 1996-2008 period were investigated using multiple correspondence analysis (MCA) with five factors and the individual fishers are plotted on figure III-11 each panel corresponding to the projection of one of the five factors used for the MCA and individuals are coloured according to their value. More than half of the vessels that remained active over the 1996-2008 period increased their catch (figure III-12) resulting in a fleet with most vessels fishing more than five tons a year (figure III-10). Those who decreased their catch mainly fished at most five tons a year in 2005-2007 (figure III-11-a and -b).
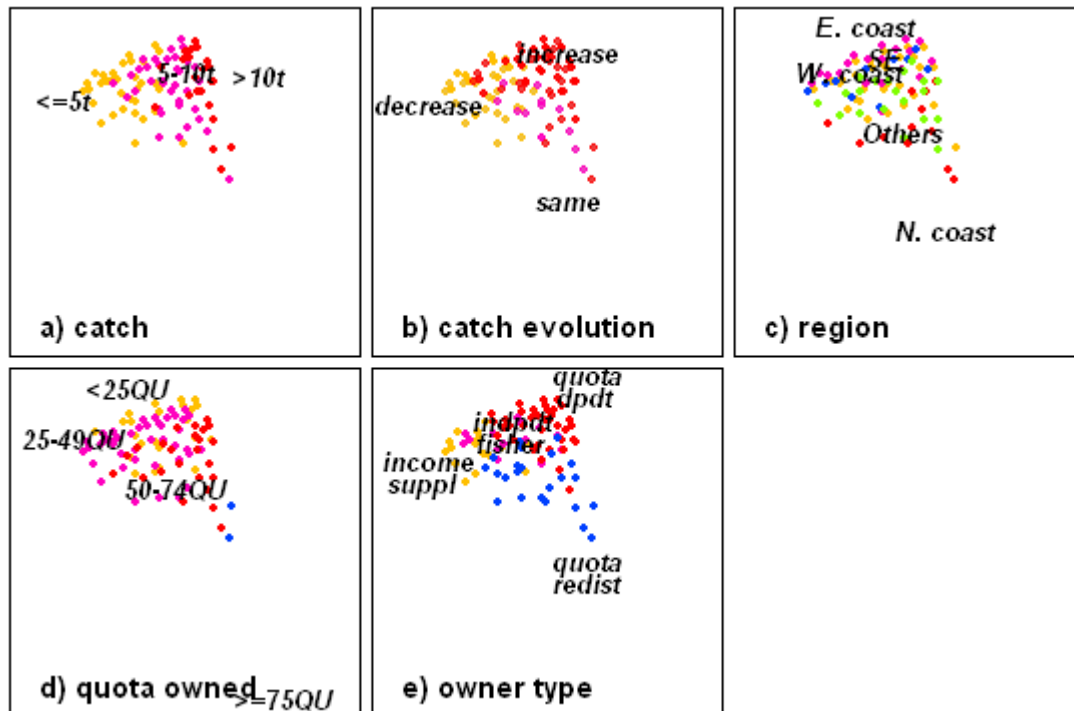
Figure III-11 Multiple correspondence analysis plot of the stay vessels.

The dots represent vessels and the colours represent states of the qualitative variables. a) annual catch in 2005-2007 (<=5t, 5-10t, >10t), b) the evolution of individual catch between 1995-1997 and 2005-2007, c) the region of origin of the vessels in 2005-2007, d) the number of quota units (QU) owned (less than 25QU, 25-49QU, 50-74QU, 75QU and more), and e) the type of owner as defined in methods (income supplementor, independent fisher, quota redistributor and quota dependent fisher). The positions of the categories are defined by the multiple correspondence analysis.

The catch intensity should be related to the type of quota ownership observed in 2005-2007 (figure III-11e). Almost half the fishers who stayed in the fishery were quota lease dependent fishers in 2005-2007 (figure III-12), the rest of the fishers staying were evenly divided into independent fisher, income supplementor and quota redistributor categories. Only fishers actively leasing quota in (quota redistributors and lease dependent fishers) fished more than 10 tons a year in 2005-2007 and mainly increased their individual catch since the introduction of ITQs possibly making up for the lower marginal profit of catch leased quota (figure III-11-a, -b and –e). Lease dependent fishers and quota redistributors differed by the amount of quota they owned and their region of origin. Quota redistributors owned more units (figure III-11-d) and while the lease dependent fishers came mainly from the South, East and West of Tasmania, quota redistributors came from the North coast and the other States and Northern Islands, i.e. the regions furthest from the small lobsters in the South of Tasmania (figure III-

11-c). Quota redistributors may compensate the distance to the best fishing grounds by higher flexibility in their fishing plan (hence lease quota in and out). Fishers became income supplementors by decreasing their catch over the period and leasing the surplus out. In 2005-2007 they owned between 25 and 49 quota units (figure III-11-d), probably their initial allocation, but fished less than 5t of lobster per year (less than 34 quota units). Some quota owners have remained out of the lease quota market, independent fishers have increased and decreased their catch over the period, possibly to match their quota allocation. Independent fishers catch less than quota lease dependent fishers and quota redistributors suggesting that the consolidation of their quota holding has been limited.
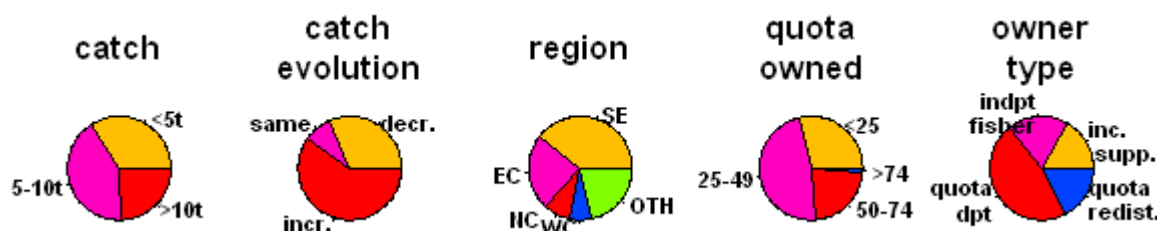
Figure III-12 Characteristics of the fishers remaining in the fishery.
Characteristics include the average annual catch in 2005-2007, the evolution of the catch between 1995-1997 and 2005-2007, their region of origin (SE: South East, EC: East coast, NC: North coast, WC: West coast and OTH: Other States and Northern islands), the average quota units owned over 2005-2007 and the type of quota ownership.

Over the 1993-2008 period, fishing practices have changed in the rock lobster fishery. Fishing decreased in the North and deep areas off the West coast while higher proportions of fishers operate in the shallow waters in the South of Tasmania and spent less time at sea. Even if spatial shifts of activity from deep to shallower strategies have been observed, fishers have remained attached to their traditional fishing grounds. Thus, the decrease of effort in the Northern strategies was mainly driven by the departure of vessels operating in those strategies. Fishers have been more flexible regarding the time of fishing and they increased their catch during the high price season in winter despite lower catch rates. Although the number of fishers has decreased and the concentration of catch in the hands of fewer vessels has been observed, more than a third of the vessels remaining active between 1995-1997 and 2005-2007 decreased their catch over the period despite increasing catch rates. The industry spread in two directions, the vessels decreasing their activity to fishing less than 5t a year in

2005-2007 and the vessels that increased their catch up to 5 to 10 tons a year, the latter group depending on quota lease to cover their catch. The fishery is divided in two major groups, the investors and income supplementors drawing an income from leasing quota on one side and the lease dependent fishers and quota redistributors leasing quota to fish on the other side. In between, the number of independent fishers declined over time, fishers either becoming income supplementor or lease dependent fishers (van Putten and Gardner, 2010).

4   Discussion and Conclusion

The Tasmanian rock lobster fishery has undergone substantial changes since the introduction of individual transferable quotas in 1998. This study investigates the changes observed in the fishery over 16 years between 1993-2008 looking at two causes: structural modification of the fleet (exit of fishers) and individual adaptation to the new management system. After ITQs were introduced, vessels left the fishery and newer, larger and more modern vessels entered. The analysis is based on vessels as vessel owners could not be followed over time. The 113 vessels that entered the fishery, including vessels replacing some of the exiting vessels, can be seen as a measure of the health of the fishery and the dynamic investment following the introduction of quota. Fishers from interstate, the Northern Islands and from the East coast were the most impacted and accounted for the majority of vessels that exited the fishery. In contrast, the local fleets from other regions were maintained at their pre-ITQ level. The likely explanation for fishers from other States leaving the fishery is the high costs induced by the travelling from their home port to fishing grounds to catch a limited quota. Prior to ITQs, the travel costs were balanced by high catches but the implementation of individual quotas limited their catch and quota leasing costs decreased their marginal profit on catch over their quota allocation. The East coast decline was probably also caused by the demographic structure of the local population (Williamson et al., 1998). Older fishers seized the opportunity of retiring with a "golden handshake" (Bradshaw, 2004). The resulting fishing fleet is thus not only composed of the most technically efficient fishers, some fishers remained in the fishery despite low fishing efficiency while some of the efficient fishers left. In addition not every fisher increased their catch, some decreased their fishing activity while supplementing their income by leasing their extra quota.

Fishers remaining in the fishery adapted their fishing behaviour to the new regulation system in order to increase their marginal profit (chapter 2, Hamon et al., 2009). If the seasonal distribution of catch has been individually modified to benefit from the higher winter prices, fishers kept fishing in the areas they traditionally harvested. Although, they fished more inshore where lobsters are bright red and fetch higher prices, closer to their home port to save on fuel costs, fishers did not explore new areas to target a different range of sizes. The size of lobsters is determined by the latitude of the fishing grounds, the departure of fishers from the North of Tasmania and interstate released the fishing pressure in the North of the Island where big less valuable lobsters are caught. It is unclear if the price difference between sizes caused the departure of vessels from the Northern part of the State. It is interesting to see that although fishers have changed their fishing pattern to target more valuable lobsters (in winter and shallow water) they stayed in areas they already knew. Rock lobsters are found on rocky reefs and the knowledge of the distribution of lobsters on these reefs obtained from years of fishing experience cannot be found on maps or with electronic devices. The consistency of fishers in terms of spatial allocation of effort testify to the importance of local knowledge in the rock lobster fishing activity.

This study investigates the individual adaptation of fishers to the introduction of ITQs. Ten years after the introduction of ITQs, the Tasmanian rock lobster fleet as a whole had behaved largely as expected although there was variability between individuals. The patterns observed at the fleet level can be due to two causes both observed in Tasmania: less profitable fishers left the fishery resulting in the fleet becoming more profitable on average, and remaining fishers modified their fishing strategies toward more valuable activities (Brandt, 2007). While fishers have remained attached to fishing areas and regions, they fished more in winter and in shallower water, increasing the value of their landings and decreasing their fishing costs. The decline in Northern areas was primarily due to the exit of a part of the fleet that traditionally travelled from interstate to fish in these areas.

Scientists and managers seek better understanding of the decisions taken by the fishers, such as their participation in a fishery and the choice of their spatial and temporal distribution of effort and how those decisions vary with external perturbations such as management measures or change in ex-vessel prices. Econometric models of exit behaviour are useful tools for managers to predict the evolution of a fishery especially in the anticipation of the implementation of ITQs (Thébaud et al., 2006b, Brandt, 2007). However, basing the exit decisions solely on economic factors seems to be a strong assumption as, in the long term,

individual characteristics like age can affect the decision to remain active in a fishery. Moreover, it appears from the current study that the exit of the fishery is a progressive decision and fishers decrease their fishing activity before leaving the fishery. In addition to a better understanding of vessels movements in and out of the fishery driven by economic considerations and individual characteristics, the current study set the base to understand fishing allocation by defining a discrete set of fishing alternatives (or métiers) from which fishers choose every month. Biseau and Gondeaux (1988) defined the description of métiers as the first step of bio-economic modelling of fisheries. The métiers defined here will be used to feed a micro-economic fishers behaviour model of fishing allocation and to investigate the factors affecting their choices.

IV Simulation of the effects of quota trading limitation in an ITQ fishery using an agent based model of fishing allocation and quota trading

In preparation for *Land economics*:

Abstract:

Individual transferable quotas (ITQs) have been used in several countries worldwide to regulate access to marine fisheries. While ITQs can improve the economic efficiency of fisheries, in practice they are not a panacea and distribution and equity issues have been raised in many cases. To overcome those issues, ITQ systems have sometimes been designed with a set of regulations limiting the trade and capping ownership of quota units. In this study, we use an agent-based modelling approach to simulate the effects of introducing ITQs in the Tasmanian rock lobster fishery. Individual agent decisions regarding spatial and temporal fishing distribution are modelled at a monthly level taking into consideration the profitability they derive from fishing rock lobster. A quota trading model is integrated into the fisher decision making process allowing fishers the choice of leasing quota units in or out depending on economic performance and their catch expectations. The model is then used to investigate the consequences of setting a limit on quota trading. Results are presented on how the different harvesting patterns induced by a cap on trade and concentration of quota effect the socio-economic performance of the fishery and the biological resource.

Allowing quota trade has been important in reducing capacity in the fishery. Simulations suggest that non tradeable individual quotas would not have led to the observed reduction in the active fleet. The model was also used to simulate the trajectory of quota leasing prices over the first decade of the ITQ system, and to assess the sensitivity of quota price to external drivers such as the market crisis observed in the early 2000s.

1   Introduction

Individual transferable quotas (ITQs) have been used for regulating access to marine fish resources in developed countries for the past three decades (Chu, 2009). Although seen as a successful management tool to improve the economic efficiency of fisheries, the social consequences have been regarded as an issue (Copes, 1986, McCay, 1995, Bradshaw, 2004, Bromley, 2009, Pinkerton and Edwards, 2009). The theory behind ITQs states that more efficient fishers will have incentives to buy/ lease in the quota of less efficient fishers, hence reducing the overall costs of fishing and subsequently making the fishery more efficient (Anderson, 1986). However, the increase in efficiency may come at the cost of concentration in quota ownership. The aggregation of quota shares in the hands of fewer operators and a shift towards investor owned rather than owner-operator fishery are the potentially negative social effects of ITQs. According to Anderson (2008), accumulation of quota can lead to two negative consequences. The first is that monopolistic behaviour can result if all quota is held by a single company which has the control of the quota leasing price and thus the market. The second negative consequence is in terms of equity. In particular, artisanal or small scale fishers often lack the cash flow needed to expand their allocation and the market for quotas only profits the big companies (Bernal et al., 1999). Moreover the transferability of quotas and the possibility of concentrating quota shares can have an effect on local economies and employment if quota is transferred to different regions (Campbell et al., 2000, Arnason, 1993).

In practice, rules can and have been adopted in an attempt to avoid or at least reduce such effects. Trade of quota is often constrained to avoid concentration of shares in the hands of speculative investors. In Iceland, a fisher who is not willing to fish at least 25% of her allocation for two consecutive years would forfeit her permanent holding (Arnason, 1996). New Zealand, the only country using individual transferable quota as the default management tool for its fisheries, has restricted the holding of quota shares to New Zealand residents and to companies where the board has at most 25% of foreign voting power (Boyd and Dewees, 1992). In addition, all countries have limits on how much quota a single operator can hold. The limits range from up to 35% for deep sea species in New Zealand or 50% of the amount of quota auctioned in Chile (Bernal et al., 1999, Dewees, 1998), to lower limits, such as 10% of total quota for rock lobster in New Zealand (Dewees, 1998), or no trading at all, which was implemented for the first two years in the halibut fishery in British Columbia (Dewees, 1998).

Iceland has also restricted exchanges of quota between different regions even if in practice most trades were allowed between regions (Arnason, 1993). Such tight aggregation limits however affect economic efficiency of the fishery (Anderson, 2008) because limiting quota trading and aggregation can be inefficient if firms cannot reach their optimal size (Asche et al., 2008) or if the capital investment to harvest the species is high (e.g. deep sea species in New Zealand; Batstone and Sharp, 1999).

Rock lobster has been harvested commercially by local communities for over two centuries in Tasmania, South Eastern Australia (see map figure IV-1 and Winstanley, 1973 for the history of the fishery). The fishery had been managed through input controls for about a century when in the late 1980's, concerns were raised regarding decreased catch rates and the sustainability of the rock lobster fishery. Limits on the number of fishing traps per vessel, a seasonal closure for moult and minimum legal size were all insufficient to cap the growing effort in the fishery. After several years of debating on how to reverse the declining trends in biomass, a quota management system was adopted and individual transferable quotas were introduced in the fishery in March 1998 and added to the pre-existing management measures (Ford and Nicol, 2001). As in other fisheries, rules were implemented regarding limits on ownership and exchange of quota. Equivalent to an initial total allowable catch (TAC) of 1 500t, the 10 507 quota units were each worth 143kg and quota owners were limited to 120 quota units per license or 200 quota units in total. Hence the aggregation limit was lower than 2% of TAC and despite the possibility of nominating family members as beneficial owners, as a way around the limit, evidence for concentration of quota has been minimal, although some concentration of quota ownership has occurred over the 1998-2006 period (chapter 2, Hamon et al., 2009). A common measure of wealth distribution, the Gini index (Gini, 1921) has been seen in the Tasmanian fishery below values observed in other fisheries meaning the quota is more evenly distributed among participants. For example, values over 0.7 have been observed for the Icelandic cod fishery (Pálsson and Helgason, 1995) whereas the Gini index of quota ownership was only 0.36 in the Tasmanian rock lobster fishery in 2006 (chapter 2, Hamon et al., 2009). The introduction of ITQs has had some significant impacts on the fishery, leading to changes in the harvesting strategies of fishing operators towards increased value of landings, with a modification in the spatial and temporal distribution of fishing effort, as well as a reduction in the overall capacity of the fleet (see chapter 2 and 3).
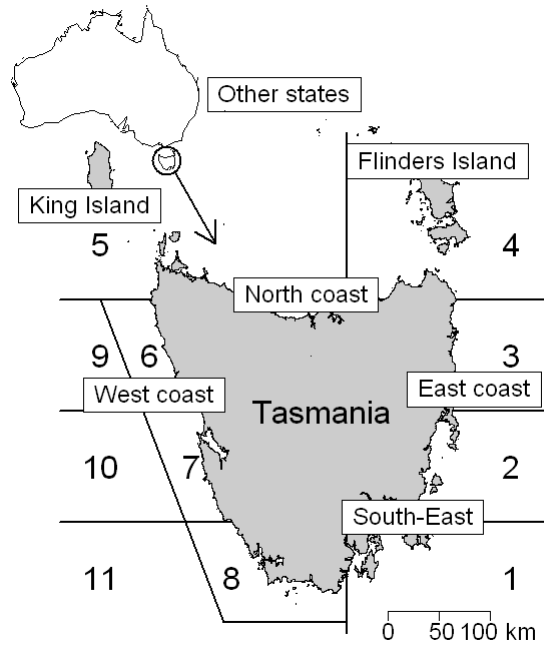
Figure IV-1 Map of Tasmania with the eleven assessment areas.

In this chapter, we examine the dynamic response of fishing operators to the introduction of an ITQ system in this fishery, using a bio-economic simulation model which includes an explicit representation of the choices fishers face as to where and when they fish, which in turn depends on the returns they obtain from fishing, and on quota trading. Individual responses to management perturbations will differ due to the heterogeneity of fishers in terms of their port of origin, cost structure and quota ownership. In this study, we consider results on the ways in which scenarios related to trading limitations implemented to prevent quota concentration influence the individual behaviour of fishers/quota-owners, and the ensuing biological and economic consequences at the scale of the fishery.

2   Model

The Tasmanian rock lobster fishery has been assessed annually since 1997 using statistical catch-at-length models to assess the state of the fishery and forecast its future (Punt and Kennedy, 1997, Frusher, 1997). The projection model of the Tasmanian rock lobster stock dynamics used for these assessments is described in Punt and Kennedy (1997) and Hobday *et al.* (2005). The biological projection model runs a fleet dynamic module at each period, with periods of one or three months (three month periods occurring during the Austral winter, from

May to October). The fleet dynamics model, coded as a FORTRAN 77 procedure, works as a function called from the biological operating model, taking stock information as input and feeding back the percentage of TAC caught for the period in each area.

The allocation of fishing effort of the Tasmanian rock lobster fleet is modelled using an agent-based approach (Uchmanski and Grimm, 1996). Every agent in the model is a quota-owner (fishers must hold at least one quota unit on a rock lobster fishing licence, van Putten et al., 2011). Agents have a geographic location (home port), an initial quota allocation (the same allocation at the beginning of every fishing season), individual fishing efficiency and a vessel with specific characteristics drawn from real data. Agents make decisions on whether, where and how much to fish under their fishing right allocation constraint.

At the beginning of the quota season (beginning of year on figure IV-2), each agent computes an annual fishing plan defined as the choice of a fishing activity for every month based on expectations on economic performances of the different activities. For every month, fishers can choose between fishing in a predefined activity or not fishing. The "non-fishing" option is chosen by agents without vessels, without quota or without a profitable fishing option.

Quota trading is optional in the model, if quota trading is allowed, agents lease quota in and out in an attempt to maximise their profits, otherwise they proceed directly to the next step. Based

Figure IV-2 Structure and components of the Tasmanian rock lobster fleet dynamics model. Dark grey components run for each vessel individually, whereas light grey modules run for the all fleet simultaneously.

on the quota price, every owner decides to lease in quota to catch more during profitable months (within the legal limit of quota usage) or to lease out part of or all their quota.

Finally the model captures the fishing dynamics. All agents fish simultaneously. The fleet dynamics model is run at the month level. For time-steps longer than a month (three month steps in winter), catches are removed from a local copy of the exploitable biomass at the end of each month and the fleet dynamic model is run three times. Once the fleet dynamics has run for the period, the catch split by area (proportion of the TAC caught during the period in each area) is computed and exported to the biological projection model.

At the beginning of each month, agents update their expectations on catch-rates, total catch, costs and revenue for all the remaining months of the quota season. They base their new expectations on the latest information on the fishery and on their knowledge on seasonal patterns of catch-rates and prices. They then update the allocation of their quota to remaining months to maximise their profit, go to the quota lease market if trading is allowed and finally go fishing in the areas they have allocated effort to.

2.1   Rock lobster dynamics

The biological projection model forecasts possible futures of the fishery based on assumptions regarding future growth and larval settlement. In the present study, this projection model was modified to integrate greater details regarding the human dimension of the fishery in an additional fleet dynamics procedure. Here, we briefly review the comprehensive biological processes included in the model, and describe the modifications implemented. The rock lobster population is structured using 5mm size-classes. Biological processes are allocated to specific "periods" or time steps within the assessment model. During each period, lobsters die due to natural and fishing mortality, while migration, growth and lobster settlement at the end of the larval stage only occur during specific periods. Although the lobster population is considered to be a single genetic stock around Tasmania, the growth gradient in Tasmanian waters along with the limited movement of lobsters requires the resource to be divided into eight stock assessment areas when modelling the population. In addition to these stock assessment areas, three of these areas have been divided into shallow and deep water to account for the difference of lobster colour depending on the depth at which it is caught (areas 9, 10 and 11 on figure IV-1), which influences sale prices.

2.2 Fleet dynamics

2.2.1 Fishing plan

At the beginning of the year, agents define a fishing plan for the year composed of their monthly fishing activities or "métiers". Métiers are defined as fishing for rock lobster in specific locations (see the map figure IV-1 for the areas and chapter 3, for the definition and description of the métiers practiced in the Tasmanian rock lobster fishery). In addition to the 12 métiers describing spatially explicit rock lobster fishing activities, agents can also choose not to fish for rock lobster. The initial fishing plan corresponds to what agents could do if they were profit maximisers and not constrained by quota. The effort per month is then set a priori the maximum number of days fishing in the métier chosen, the month and for vessels of the same size as the vessel. Based on their fishing plan, agents calculate the monthly catch they will try to attain by leasing quota, their initial demand for quota being the difference between their total expected catch and their quota holding. In effect, most agents will have to scale their fishing plan down and reduce their fishing effort during the year due to their quota constraint.

Modelling the choice by agents among alternative fishing activities or métiers can be based on several alternative approaches (see van Putten et al., in Prep). In this study, choices are assumed to be based on the relative profitability of alternative activities, following the assumption that this is the main driving factor explaining effort allocation in this fishery (Hilborn and Kennedy, 1992). The choice of métier is stochastic with the probability of an agent, v, choosing a métier, met, increasing with the associated marginal profit, $\hat{\Pi}^{kg}_{v,met,m,y}$ expected during month m of year y (expected value indicated by the hat sign ^). The expected marginal profit is calculated as the difference between expected revenues per day, $\hat{R}^{day}_{v,met,m,y}$, and expected operating costs per day divided by the expected catch for the day, $\hat{H}^{day}_{v,met,m,y}$ (equation IV.1). Operating costs include fuel costs, $\hat{C}^{fuel}_{v,met,m,y}$, labour costs, $\hat{C}^{labour}_{v,met,m,y}$, and other fishing costs, $\hat{C}^{other}_{v,met,m,y}$.

$$\hat{\Pi}^{kg}_{v,met,m,y} = \frac{\hat{R}^{exp}_{v,met,m,y} - (\hat{C}^{fuel}_{v,met,m,y} + \hat{C}^{labour}_{v,met,m,y} + \hat{C}^{other}_{v,met,m,y})}{\hat{H}^{day}_{v,met,m,y}} \qquad \text{IV.1}$$

The expected revenue, $\hat{R}_{v,met,m,y}^{day}$, is the sum of product of the expected lobster price, $\hat{P}_{cat,m,y}^{lobster}$, and the expected catch per market category, cat, $\hat{H}_{v,cat,met,m,y}^{day}$ (equation IV.2).

$$\hat{R}_{v,met,m,y}^{day} = \sum_{cat} \hat{H}_{v,cat,met,m,y}^{day} \hat{P}_{cat,m,y}^{lobster} \qquad \text{IV.2}$$

Where the sum of the expected catch per market category corresponds to the expected catch per day (equation IV.3).

$$\hat{H}_{v,met,m,y}^{day} = \sum_{cat} \hat{H}_{v,cat,met,m,y}^{day} \qquad \text{IV.3}$$

Lobsters fetch different prices depending on their market category based on size and colour, with plate-sized red lobsters being the most valuable. Because of the absence of price monitoring per market category, lobster prices by category are defined relative to a reference category, ref, and the season-specific difference between the reference price and the price per category, $\gamma_{cat,m}$ (called the "split price") is kept constant over the years (see section 3.5, model calibration, for the calculation of the price split and the reference price). Ex-vessel lobster prices have also a seasonal pattern with higher prices expected in winter and lower prices in summer (chapter 2, Hamon et al., 2009). Agents expectations of lobster price per category for each month until the end of the year, $\hat{P}_{cat,m,y}^{lobster}$, are based on the price pattern observed for the previous year for a reference category, ref, $P_{ref,m,y-1}^{lobster} \big/ P_{ref,cur,y-1}^{lobster}$, the price offered in the current month, cur, for the reference category, $P_{ref,cur,y}^{lobster}$, and the split price for the category, $\gamma_{cat,m}$ (equation IV.4).

$$\hat{P}_{cat,m,y}^{lobster} = \frac{P_{ref,m,y-1}^{lobster} P_{ref,cur,y}^{lobster}}{P_{ref,cur,y-1}^{lobster}} + \gamma_{cat,m} \qquad \forall m > cur \qquad \text{IV.4}$$

Daily expected catches per lobster category, $\hat{H}_{v,cat,met,m,y}^{day}$, are related to the number of traps on-board of vessels, $T_{v,m,y}$, the number of shots per day, S_m, and the expected catch-rates per traplift, $\hat{U}_{v,cat,met,m,y}^{traplift}$ (equation IV.5).

$$\hat{H}_{v,cat,met,m,y}^{day} = T_{v,m,y} \cdot S_m \cdot \hat{U}_{v,cat,met,m,y}^{traplift} \qquad \text{IV.5}$$

The number of quota units held by an agent (owned or leased in) defines the number of traps onboard a vessel, $T_{v,m,y}$, within the limits of number of traps allowed for the vessel (defined

by the regulation in Anon, 2006). The number of times fishers can set their traps per day , S_m, depends on the fishing period: in summer days are longer and two shots are possible while in winter a single shot per day is assumed.

Similar to lobster prices, catch-rates also display a seasonal pattern due to the biology of lobsters and the regulatory framework. Catch-rates increase after moult in November because of a part of the undersized stock growing to legal size. However, there is a ban on the catch of female lobsters during Austral winter (May to October) so only the male component of the stock is available during these months. Expected catch-rates for an agent, $\hat{U}^{traplift}_{v,cat,met,m,y}$, are calculated by lobster category for each month until the end of the year using normalised catch-rates of the previous month for each métier, $U^{norm}_{cat,met,cur-1,y}$, the seasonal pattern from the previous year $U^{norm}_{cat,met,m,y-1}/U^{norm}_{cat,met,cur-1,y-1}$ and the knowledge of the relative fishing efficiency of the vessel, q^{Eff}_v (equation IV.6).

$$\hat{U}^{traplift}_{v,cat,met,m,y} = q^{Eff}_v \frac{U^{norm}_{cat,met,cur-1,y} U^{norm}_{cat,met,m,y-1}}{U^{norm}_{cat,met,cur-1,y-1}} \qquad \text{IV.6}$$

Normalised catch-rates in a métier, $U^{norm}_{cat,met,m,y}$ correspond to the catch per traplift of a fisher with an efficiency of one (average efficiency observed in the fishery). It is assumed that agents have perfect information on other agent's catch-rates and fishing efficiency and that they know exactly how to rate themselves against the rest of the fishery through their efficiency coefficient. The initialisation of catch rate expectations in the model is described in appendix C.

Only operating costs related to rock lobster fishing are taken into account in the calculation of marginal profit, i.e. costs for fishing in other fisheries are excluded. In addition, since the model is used to predict short-term behaviour, fixed costs are ignored. Expected fuel costs per day $\hat{C}^{fuel}_{v,met,m,y}$ are calculated as the product of the current fuel price, $P^{fuel}_{cur,y}$ and the fuel usage per day $\varphi_{v,met,m}$ (equation IV.7).

$$\hat{C}^{fuel}_{v,met,m,y} = P^{fuel}_{cur,y} \cdot \varphi_{v,met,m} \qquad \text{IV.7}$$

The fuel usage per day depends on the size of the vessel and the distance, $D_{v,met,m}$ between the home port of the vessel and the métier specific fishing grounds (equation IV.8 and parameter values in table VII-4 appendix E.1).

$$\varphi_{v,met,m} = \delta_v \left(a \cdot D_{v,met,m} + b \right) \qquad \text{IV.8}$$

In the model the daily labour costs, $\hat{C}^{labour}_{v,met,m,y}$ are the sum of the crew's wage, $S^{crew}_{v,y}$ for each of the n^{crew}_v members (the number of crew is function of the vessel size, see table VII-5 appendix E.1) and the skipper wage, $S^{skipper}_{v,y}$ (equation IV.9).

$$\hat{C}^{labour}_{v,met,m,y} = n^{crew}_v s^{crew}_{v,y} + s^{skipper}_{v,y} \qquad \text{IV.9}$$

Although a share system is used in the Tasmanian rock lobster fishery, fixed wages were adopted in this version of the model, with their level assumed to be at the opportunity cost of working in the fishery. In reality, it appears that the cost of leasing quota is at least partly shared between crews and quota owners in the fishery. In a model assuming that quota owners seek to maximise their profits, if labour costs are simulated using a share system with no minimum wage, quota prices will tend to reduce, the "rest to be shared" (revenue minus leasing costs) and wages will fall below the opportunity cost of employment in the fishery (see Guyader and Thebaud, 2001, for the effect of cost sharing). The crew wage and skipper wage are thus fixed at the level of their estimated opportunity costs, considering an average employment time of 170 days at sea, with a 4% increase per year (see figure VII-2 appendix E.1).

The other fishing costs $C^{other}_{v,met,m,y}$ per day include bait, food, ice and equipment costs (equation IV.10; details of the calculation of equipment and ice costs in equations VII.11 and VII.12 appendix E.1 and values for those other costs in table VII-4 appendix E.1). The monthly expected value for those costs, $\hat{C}^{other}_{v,met,m,y}$, is taken as the average costs over the active months for the previous year, $\overline{C}^{other}_{v,y-1}$ (assumed to be independent on the month or métier, equation IV.11).

$$C^{other}_{v,met,m,y} = P^{bait} S_m T_{v,m,y} + P^{food} (n^{crew}_v + 1) + C^{ice}_{v,y} + C^{equip}_{v,y} \qquad \text{IV.10}$$

$$\hat{C}^{other}_{v,met,m,y} = \overline{C}^{other}_{v,y-1} \qquad \text{IV.11}$$

Tasmanian rock lobster fishers tend to keep fishing on their traditional fishing grounds (chapter 3). In order to capture this inertia in the model, we assume that the probability of allocating effort to a métier is penalised by a factor ω (ω between 0 and 1) if the agent did not operate in the métier the previous month or the same month the previous year (equation IV.12).

$$\Pi^{pen}_{v,met,m,y} = \begin{cases} \hat{\Pi}^{kg}_{v,met,m,y} & \text{if } met \in \{met_{v,m-1,y}, met_{v,m,y-1}\} \\ \omega \cdot \hat{\Pi}^{kg}_{v,met,m,y} & \text{otherwise} \end{cases} \qquad \text{IV.12}$$

This penalty captures the existence of a variety of drivers which may influence decisions to change fishing areas, including aversion to risk, knowledge of specific fishing grounds and imperfect information of what others have achieved in other regions. Sensitivity analysis on the level of this penalty showed that, in the model, agents would need an expected profit at least 40% higher to that expected from their current (not shown) choices to be led to change métier. To capture this, a penalty ω of 0.6 is applied to expected profits in métiers other than the previous métiers.

For each agent, each month, the expected marginal profits for all métiers are rescaled by removing the minimum marginal profit, in order to spread the marginal profit expectancies and to give less weight to métiers with lower profits (equation IV.13).

$$\Pi^{trans}_{v,m,met} = \Pi^{pen}_{v,met,m,y} - \min_{met}(\Pi^{pen}_{v,met,m,y}) \qquad \text{IV.13}$$

Based on this calculation of marginal profit, agents choose a fishing métier for each month at the beginning of each fishing season with the probability for each métier to be chosen proportional to the normalized value of expected profit, $\Pi^{trans}_{v,m,met}$ (equation IV.14). If agents do not expect a positive marginal profit for any métier in a month, they choose the métier "no fishing" for the month.

$$Prob_{v,m}(met) = \frac{\Pi^{trans}_{v,m,met}}{\sum\limits_{met} \Pi^{trans}_{v,m,met}} \qquad \text{IV.14}$$

Every agent calculates expectations of profit for every month-metier pairs based on personal, seasonal and metier characteristics. The marginal profit expectations are then used to select a metier for each month of the fishing season defining an annual fishing plan for each agent. The maximum expected rent per month (short term profit minus leasing costs) has also been

tested as a selection factor but sensitivity analysis (results not shown) was performed and the percentage of correct predictions was higher using marginal profit. For each month of the initial fishing plan, the number of fishing days is set to $E_{v,met,m}^{max}$, the maximum number of days spent fishing for rock lobster in the métier chosen (taken as the 95th percentile of the number of days observed in the métier, *met*, month, *m*, and vessels of the same size as the vessel *v*, see figure VII appendix E.2). The maximum number of days spent fishing in a métier varies according to the vessel size and the month. Some métiers on the west coast of Tasmania are exposed to rough weather and are therefore less practicable than the ones in the sheltered East coast.

2.2.2 Monthly quota allocation

In a fishery managed with individual quotas, assuming compliance with quota restrictions, fishers will be constrained by their quota allocation and may need to reduce their fishing effort if they do not have enough quota to cover their entire expected catch. However, the reduction of fishing effort will not be distributed homogeneously throughout the year as some months are more profitable than others. Given the profit maximisation assumption underlying the model, quota owners are assumed to use their quota in the most profitable way and allocate their quota holding to months based on their monthly expectations on profit per kg.

In assigning monthly allocation of quota, expected marginal profits are discounted at a monthly rate, r. A discount rate of 2.5% per month was identified through sensitivity analysis as the rate achieving the best prediction of seasonal allocation of effort (equation 15).

$$\hat{\Pi}_{v,met,m,y}^{disc} = \frac{\hat{\Pi}_{v,met,m,y}^{kg}}{(1+r)^{m-cur}} \qquad \text{IV.15}$$

Agents assign quota, $Q_{v,m,y}^{alloc}$, in priority to the month with the highest expected discounted marginal profit, $\hat{\Pi}_{v,met,m,y}^{disc}$, and once the expected catch for the month is covered by quota, they allocate quota to the month with the second highest marginal profit, and so on. The quota allocation to months stops when the agent has allocated all his quota or the fishing plan is full, whichever comes first. At the beginning of each month, agents re-assess their monthly allocation of quota based on the quota they have left and the updated expectations of marginal

profit in the remaining months. Finally, if there is no quota assigned to the current month after quota trading, the métier is changed into "no fishing" and the effort is set to zero.

2.2.3 Quota trade

When quota is transferable, agents lease quota in or out to attempting to match their fishing plans every month. If quota is not tradable, agents skip this step and directly proceed to fish (see figure 3). Agents will attempt to acquire additional quota if their expected discounted marginal profit $\hat{\Pi}^{disc}_{v,met,m,y}$, is higher than the expected quota price, $P^{quota}_{m,y}$ for months for which the quota they allocated, $Q^{alloc}_{v,m,y}$, is lower than their expected catch, $\hat{H}^{month}_{v,met,m,y}$ (the months satisfying these conditions make the set M, see top condition in equation IV.16). Individual quota demands are calculated as the quota needed by the agent to cover the expected catch of all months with a higher profitability than the expected price of quota, within the quota aggregation limit, Q^{lim} (equation IV.16).

$$
Demand_v = \begin{cases} \displaystyle\sum_{m \in M} (\hat{H}^{month}_{v,met,m,y} - Q^{alloc}_{v,m,y}) & M = \{m : m \geq cur \,\&\, \hat{\Pi}^{disc}_{v,met,m,y} > P^{quota}_{m,y}\} \\[2em] \displaystyle Q^{lim} - \sum_{m=1}^{cur-1} H^{month}_{v,met,m,y} - \sum_{m=cur}^{12} Q^{alloc}_{v,m,y} & \text{if } \sum_{m \in M} (\hat{H}^{month}_{v,met,m,y} - Q^{alloc}_{v,m,y}) > Q^{lim} \end{cases} \qquad \text{IV.16}
$$

Alternatively, agents can also decide to lease out quota they have allocated to months with a discounted marginal profit lower than the expected quota price. Agents are assumed to be profit maximisers and will lease out all the remaining quota, Q^{left}_v, in excess of the quantity needed to cover the expected catch of the months with discounted marginal profits, $\hat{\Pi}^{disc}_{v,met,m,y}$, higher than the price of quota, $P^{quota}_{m,y}$ (months in M', equation IV.17).

$$
Supply_v = Q^{left}_v - \sum_{m \in M'} Q^{alloc}_{v,met,m,y} \qquad M' = \{m : m \geq cur \,\&\, \hat{\Pi}^{disc}_{v,met,m,y} < P^{quota}_{m,y}\} \qquad \text{IV.17}
$$

The quota price is set as the price maximising the exchange of quota. The quota price could not be simply calculated by optimisation because demand and supply are discontinuous functions of the quota price (the functions will decrease/increase by steps when all the expected catch of a month is removed/added from the demand/supply so the functions cannot be derived). Instead quota price, $P^{quota}_{m,y}$, was calculated as the price maximizing the exchanges using the iterative bisection method (Press et al., 1992) with a lower bound, P^{min}, set to

AUD\$0 and a higher bound, P^{max}, set to AUD\$100 (as quota price was never observed above AUD\$25/kg). The initial quota price in this process is set as the last observed quota price. For each iteration of the bisection method, individual demands and supplies are calculated as described in equations IV.16 and IV.17, and are then summed over all agents and compared. In case of mismatch between the total demand and supply the quota price is changed and demand and supply are recalculated. If the demand is higher (lower) than the supply, the quota price is set to the average of the quota price used to calculate the demand and supply and the upper (lower) bound. The lower (upper) bound is then changed to the quota price resulting from the previous iteration. Using the bisection method (equations IV.18 toIV.19), the quota price converges quickly where a solution exists. Due to the discontinuity of the demand and supply, there may be cases where it does not (there is no price for which demand equals supply exactly); in such cases, iterations stop when the difference between quota prices of two consecutive iterations is lower than \$0.01 or when the mismatch between supply and demand is lower than 100kg (equation IV.20). The price is then set as the last quota price calculated.

$$P_0 = P^{quota}_{m-1} \qquad\qquad\qquad \text{IV.18}$$

$$\forall i > 0, P_i = \begin{cases} \dfrac{P_{i-1} + P^{min}}{2} & \text{if } \sum_v Demand_v < \sum_v Supply_v \\[2mm] \dfrac{P_{i-1} + P^{max}}{2} & \text{if } \sum_v Demand_v > \sum_v Supply_v \end{cases} \qquad \text{IV.19}$$

$$P^{quota}_{m,y} = P_i \quad, P_i - P_{i-1} < 0.01 \text{ or } \left| \sum_v Demand_v - \sum_v Supply_v \right| < 100kg \qquad \text{IV.20}$$

The quota leased in on the market is then allocated to the most profitable months first as in 2.2.2 or in case of quota leased out, removed from the fishing plan from the less profitable months first.

2.2.4 Fishing

Agents in the model go fishing with expectations on catch-rates, $\hat{U}_{v,cat,met,m,y}$, and the amount of quota they want to use, $Q^{alloc}_{v,m,y}$. The number of days they expect to spend fishing the quota allocation for the month, $\hat{E}_{v,m,y}$, is related to the number of traps they have on-board, $T_{v,m,y}$, the number of shots they can make per day, S_m, and the expected catch-rates per traplift, $\hat{U}_{v,cat,met,m,y}$ (equation IV.21).

$$\hat{E}_{v,m,y} = \begin{cases} \dfrac{Q_{v,m,y}^{alloc}}{S_m T_{v,m,y} \hat{U}_{v,m,y}} & \text{if } \leq E_{v,met,m}^{max} \\ E_{v,met,m}^{max} & \text{else} \end{cases} \qquad \text{IV.21}$$

The effort in trap-lifts devoted to each fishing area, $\hat{L}_{v,a,m,y}$, is then calculated as the product of the proportion of effort in the area $\alpha_{a,met,m,reg}$, based on the métier and the region of origin of the agent (see figure VII-5 appendix E.2), the expected number of days fishing, $\hat{E}_{v,m,y}$, and the number of trap-lifts per day, $S_m T_{v,m,y}$ (equation IV.22).

$$\hat{L}_{v,a,m,y} = \alpha_{a,met,m,reg} \hat{E}_{v,m,y} S_m T_{v,m,y} \qquad \text{IV.22}$$

Fishing occurs once a month, for all agents at the same time. Agents have expectations on their fishing effort and resulting catch in each area. The catch of each agent is computed in weight for each lobster size-class l, in each area a as the product of effort, $\hat{L}_{v,a,m,y}$, vessel efficiency, q_v^{Eff}, catchability, $q_{a,m}$, and exploitable (legal-sized) biomass, $\overline{B}_{a,m,y,l}^{exploit}$ in the middle of the month m, after half the catch is removed (equation IV.23, see appendix D for the calculation of $\overline{B}_{a,m,y,l}^{exploit}$).

$$H_{v,a,m,y,l} = q_v^{Eff} q_{a,m} L_{v,a,m,y} \overline{B}_{a,m,y,l}^{exploit} \qquad \text{IV.23}$$

If catch is higher than the exploitable biomass in an area, commercial effort of all agents is decreased in the area and reallocated to the other areas visited proportionally to the effort planned by the agent in those areas.

The monthly level of fishing effort is decided based on expected catch-rates. However, catch-rates experienced by the agent may be higher or lower than expected and agents need to adapt their behaviour. With catch-rates higher than expected, agents will fish for the number of days planned and their catch will exceed the quota they had assigned for the month provided that they hold enough quota. In the case of catch rates lower than expected, agents will try to catch the quota they allocated to the month by increasing their effort within the limit of the maximum number of fishing days.

3   Model calibration

3.1   Agents definition and characterisation

Agents are defined in the model as the quota owners at the beginning of the first quota season, in March 1998. Quota owners were linked to their 1998 vessel through the licence and unloading databases of DPIPWE (Department of Primary Industries, Parks, Water and Environment). If no vessel could be linked to a quota owner in 1998, 1997 licence data were used to link the entitlement to a vessel. Overall, 290 owner-vessel couples and 12 owners without vessels were defined for a total of 302 agents.

Agents were then characterised with a set of indicators. First, agents were allocated their real quota shares as observed in 1998. Individual allocations ranged from 10 to 100 quota units with most of the agents owning between 20 and 50 quota units (see figure VII-7 in appendix E.4). The twelve agents without boats held a total of 291 quota units or approximately 2% of the TAC.

In addition, agents with a vessel were characterised in terms of their fishing activity. The length of the vessel and the region of origin were extracted from data available from MAST (marine and safety Tasmania) and DPIPWE (figure VII-8 appendix E.5). Key features of fishing operations were defined based on the size of the vessel, including the number of crew members and the maximum number of traps (see tables VII-5 and VII-8 appendix E)

Each fishing vessel was also assigned a fishing efficiency coefficient, since for the same effort, some fishers were observed to catch more lobsters than others. The fisher efficiency coefficient was calculated as the individual deviation from the average catchability using a closed-form estimation method (Haddon, 2001). Although higher efficiency is likely to come from superior knowledge of the fishing grounds and therefore vary temporally and spatially for each fisher, a constant coefficient in space and time, q_v^{Eff}, was used per fisher (see equation IV.24).

$$q_v^{Eff} = e^{\frac{1}{n}\sum_{a,m,y} \log\left(\frac{H_{v,a,m,y}}{q_{a,m} \cdot E_{v,a,m,y} \cdot B_{a,m,y}^{exploit}}\right)}$$

IV.24

Where the individual catch, $H_{v,a,m,y}$, and effort, $E_{v,a,m,y}$, by month and area are observations extracted from log-books and the catchability, $q_{a,m}$, and the exploitable biomass, $B_{a,m,y}^{exploit}$, are

estimates from the stock assessment model. The fishing efficiency profile of the fleet is shown in figure VII-9 (appendix E.5).

3.2   Fishing activity

Every month, agents engage in a métier. Each métier has a month specific spatial distribution of effort, $\alpha_{a,met,m,reg}$, varying with the region of origin of the vessel but constant over the years. The distribution of effort to the areas is calculated as the proportion of trap-lifts in each area for a métier based on log-book data (see figure VII-5 in appendix E.2).

The number of fishing days for a métier during a month for a vessel of a certain size is constrained to a maximum, $E_{v,met,m}^{max}$, because technical and regulatory factors, such as weather/sea condition and seasonal closures, limit the maximum number of days that can be spent fishing for rock lobster each month in a métier. The maximum number of fishing days in a month in a métier for a vessel is thus set in the model as the 95th percentile of the number of fishing days observed in the month in the métier by a vessel of similar size for the period 1993-2008 (see figure VII-6 in appendix E.2).

3.3   Management data

TACs have been set annually since the introduction of ITQs. The historical commercial TACs have been used in the model while estimates of the total recreational catch are used as recreational TAC (see table VII-7 in appendix E.3). The distribution of recreational catch to months and areas used in the model is the same as the one used in the stock assessment model. In addition, to recreational and commercial removals of lobsters, the model also assumes a non-compliance effect with illegal catches estimated to be 2% of commercial catches in all months, all areas, but illegal catch is not accounted in fishers economic performances.

3.4   Biological parameters

Growth by area, lobster movement, natural mortality, size and sex selectivity are set at the values used for projections in the fishery assessment (Gardner and Ziegler, 2010). The

catchability by month and by area, the recruitment by area and by year and the initial status of the lobster stock (as of 1997) included in the model are derived from the assessment model (ran in 2009).

3.5   Economic data

Economic data includes variable costs and lobster prices. Fuel prices, $P_{m,y}^{fuel}$, illustrated in figure VII-3 in appendix E.1, are derived from historical fuel price data. The cost data collected in an economic survey in 2007 are used for the other short term costs of fishing and held constant for all years (Gardner and Van Putten, 2008). They include estimates of bait cost per traplift, food costs per day and per person, ice cost per trip, gear replacement and clothes costs per year, estimates of fuel consumption depending on the distance and the size of the vessel and estimates opportunity cost of crew and skipper for calculation of wages (see table VII-4 and figure VII-2 in appendix E.1).

Only the average beach price per month is recorded by DPIPWE, so beach price by lobster market category had to be estimated. Chandrapavan et al (2009) have identified price differences for lobsters depending on the shell-colour, white-strawberry lobsters in waters deeper than 40m fetching lower prices than red lobsters from shallow water. In addition, disaggregated price data for 2009 from a processor have been used to identify four lobster size categories and price differences between a reference market category and the other market categories ("split prices"). Due to the lack of additional information, season-specific split prices per category, size and colour, $\gamma_{cat,m}$, are held constant from year to year (table VII-6 in appendix E.1). Using the catch distribution per market size class estimated by the stock assessment model and the depth of fishing as a proxy for colour, the proportion of landing by market category allowed me to approximate a time series of lobster price per month for the reference category, $P_{ref,m,y}^{lobster}$, over the 1998-2008 period (see figure VII-4 in appendix E.1). The reference price and the split prices are used in the model to calculate prices by market category (equation IV.4).

4   Quota trading scenarios

In the current study, the model was used to simulate the effect of different trade limitations on the fishery. Based on concentration limits found in other fisheries (from no trade initially allowed in British Columbia, Dewees, 1998, to high level of aggregation in the deep water fisheries of New Zealand, Annala, 1996) and on the current management of the fishery studied, four scenarios were investigated regarding the extent to which quota aggregation is limited in the fishery. As the model includes only the short-term drivers of fishing activity, the quota trading modelled in this study is exclusively temporary quota trades or leases. The model was used to examine the effect of limiting quota usage rather than quota holding, by addressing four scenarios:

1. A quota management system is simulated without transferability of individual fishing rights. This scenario is the most extreme in terms of preserving a strictly equitable allocation of catch shares across fishers. Since only active fishers can own quota, rationalization of the fleet is prevented because each quota owner can only fish their initially allocated quota.

2. Quota transferability is implemented but quota owners are limited to using 120 quota units. This corresponds to the actual management measures implemented in the fishery for owners possessing a single license. The number of licenses available in the fishery being limited (Bradshaw, 2004), in practice very few fish more than 120 units and fewer own more than 120 units (van Putten and Gardner, 2010);

3. Quota transferability is implemented but with limits of owning, holding or using a maximum of 200 quota units per year for any agent. This limit became the official aggregation limit per licence in March 2010 (Anon, 2010a) ;

4. Quota transferability is implemented but with unlimited trading and use of quota by individual fishers, which has been suggested would maximize economic efficiency in a fishery, as only the most efficient fishers are expected to remain active (Anderson, 2008).

For each scenario, 100 replicates are run, and selected model outputs are examined in the following section. The effects of quota trade limitation on the fishery are investigated through several indicators. First, the dynamics of quota trading are assessed through lease price and trade volume. In an ITQ managed fishery, quota price is considered one of the most important

indicators (Arnason, 1990, Batstone and Sharp, 2003). In theory, if the market for quota is perfect (perfect information and access to all the participants), the quota price represents the assessment of the fishery from an investor's point of view (similarly to market shares) and higher quota prices indicate that the fishery is considered worth investing in.

Second, the social impacts of the different trade limitations are analysed through the number of active vessels and distribution of catch among agents. One of the main expected effects of allowing transferability of fishing quota is to increase the rate at which the fishing fleet will be reduced in a the fishery with over-capacity, as was the case for the Tasmanian rock lobster fishery at the time of introduction of ITQs (Ford and Nicol, 2001). In this fishery, the number of active vessels has decreased by 25% in the first three years after the introduction of ITQs in 1998 (chapter 2, Hamon et al., 2009). The departure of fishers led to the fishery being increasingly operated by lease dependent fishers (chapter 3) while quota is mostly held by investors (van Putten and Gardner, 2010).

Third, the economic performances of the fishery are considered at different level, at the level of individuals and for the whole fishery. The economic efficiency of the fishery is expected to be highest when quota are tradable without limits (Anderson, 2008).

Finally, the impacts of the different trading limitations on the rock lobster stock are evaluated through exploitable biomass. Tasmanian rock lobsters are sedentary crustaceans displaying very little movement after their settlement on reefs but they display substantial spatial variability in their growth rates (Gardner et al., 2003, Gardner et al., 2006). As such the stock is assessed by areas to investigate local exploitation (Gardner and Ziegler, 2010). The simulation results are compared to results from the stock assessment model which represents the best available information on the rock lobster population.

5   Simulation results

5.1   Economic and social effects

5.1.1   Quota trading

The annual quota price was computed as the average monthly price weighted by the volume exchanged per month. From 1999 to 2002, the price of quota increases steadily (figure IV-3), while the volumes of quota traded on the market increase until 2001 (figure IV-4). This is followed by a period during which prices decline for two years before increasing again until

2006. The decrease in quota price observed in 2003-2004 is due to the impacts of the severe acute respiratory syndrome (SARS) on the market for rock lobster. SARS hit Asia in 2003 and damaged tourism in the region, entailing a drop in lobster demand in China, the main market for Tasmanian rock lobster (Hacourt, 2003). The beach price for lobster decreased during the SARS episode (figure VII-4 in appendix E.1), as a contraction in the quota market was observed, which the model captures well. Indeed, quota price is highly correlated to beach price in the model (r = 0.92; p < 0.001).
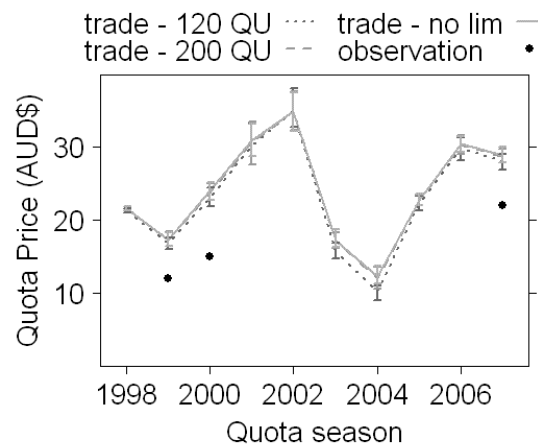
Figure IV-3 Average simulated quota price per year.
Quota prices are estimated for the scenarios with trade over the period 1998-2007 compared to anecdotal knowledge of the quota price in the fishery (black dots) found in Frusher et al. (2003) and van Putten and Gardner (2010). Error-bars show the dispersion of simulated results.

In the model, fishers update their expectations and trade quota every month to match their expected catch for the rest of the year. The resulting simulated market is likely to display more active trading compared to historical data. For example, all years the total volume of quota units exchanged in the model is higher than the real volume of exchanges observed in the fishery, with larger differences observed in the initial years following introduction of ITQs (figure IV-4).The higher the quota aggregation limit, the more quota units are exchanged. At the end of the simulation period, for the 120 QU limit scenario (corresponding to the actual limit implemented in the fishery) the number of quota units exchanged each year is still 1.7 times higher than the real number of exchanges. The simulated volume of quota exchanged annually, when there is no limit on aggregation, is close to or above the total number of units

in the fishery and on average two to three times the number of units actually exchanged in the fishery.
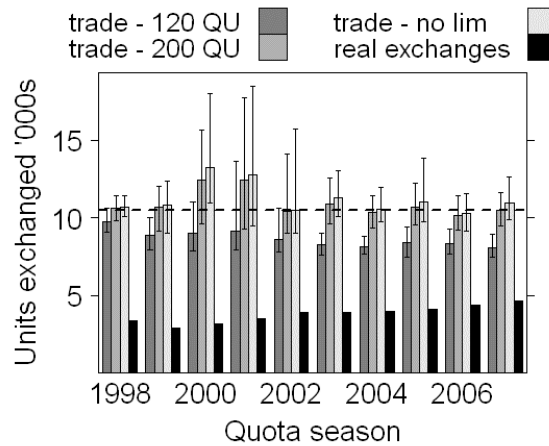
Figure IV-4 Average quantity of quota exchanged per year.

Simulation results (grey bars) are compared to observed exchanges (black bars). Error-bars show the dispersion of simulated results and the horizontal line indicates the total number of quota units in the fishery (10507).

Simulated agents account for risk by discounting the expected marginal profit for future months, and continue leasing quota in or out until it is economically unprofitable for them to do so. If they expect their marginal profit (or discounted marginal profit for the months after the current month) to be higher than the market quota price, they will lease quota in. In reality, fishers probably also take some of their fixed costs into account causing the price they are ready to pay for quota to be lower than simulated (simulated price is 30 to 50% higher than observed prices, figure IV-3). The quantity exchanged (figure IV-4) has little impact on the price of quota (figure IV-3), predicted at the same level for the three scenarios with trade in the range of scenarios examined. Agents are fully flexible, have full access to all the actors in the market and continue fishing within the limits of each scenario as long as it is profitable to do so, causing simulated exchanges to be much higher than the actual amount of quota trade.

5.1.2   Fleet evolution

The high simulated quota transfers (figure IV-4) indicate that the number of active vessels in the model was reduced to a greater degree than what actually occurred (figure IV-5). The

simulation results also display phases where the active fleet increases in size (e.g. during the SARS episode in 2003) because even if agents become inactive for a period of time, they can re-enter the fishery when circumstances provide for profitable fishing possibilities.
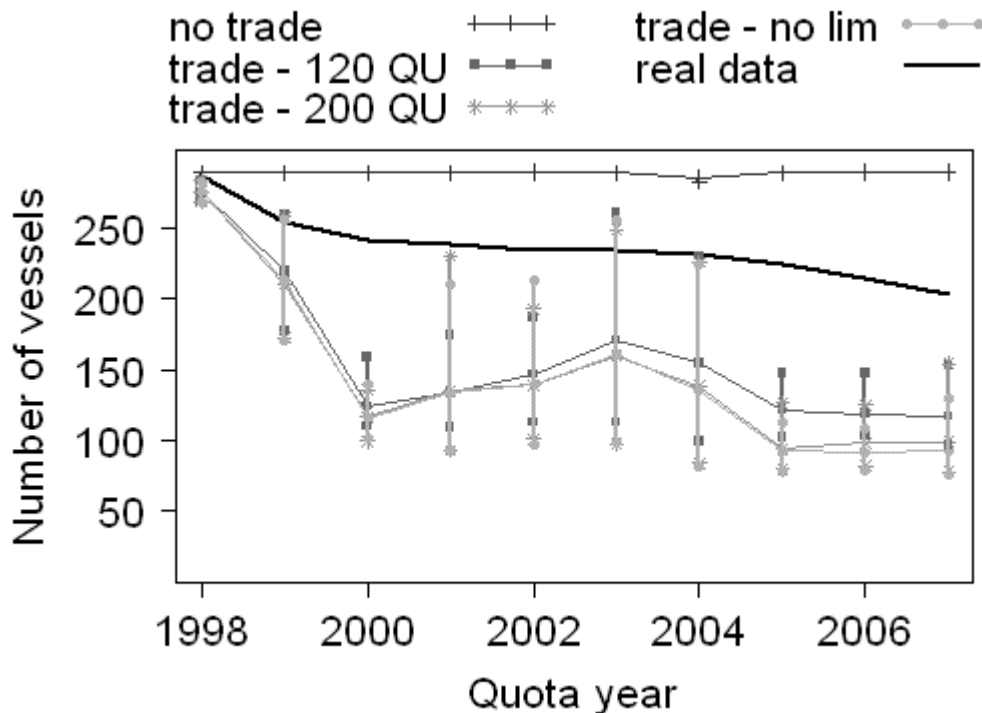
Figure IV-5 Number of vessels active in the fishery per year.

Active fleet predicted by simulations compared to observed number of vessels. The vertical bars represent the 90% dispersion of results.

The flow of agents in and out of the active fishing fleet depends on the trade limit scenario, causing different patterns of quota usage. Figure IV-6 illustrates the evolution of catch distribution in relation with the amount of quota owned between the implementation of quota (1998) and the end of the simulation period ten years later. The "no trade" scenario is composed of agents who do not own vessels and can not fish (concentration of points vertically at zero quota units fished, figure IV-6 a) and agents fishing exactly their allocation (on the diagonal). The division of agents in two groups can be seen both in 1998 (panel a) and 2007 (panel e) as trade is not allowed and agents are constrained by their quota allocation. In the scenarios where trade occurs, the fleet is composed of a range of agents from investors, fishing zero units, fishers leasing some of their quota out (left of diagonal) to fishers who need to lease quota to cover their catch (right of the diagonal, panels b, c, d, f, g and h figure

IV-6). While the distribution of agents is continuous in those three categories in 1998, at the end of the simulation period (2007), the fleet is separated in two groups: the investors, on the zero quota unit fished vertical line and the fishers depending on quota lease on the right of the diagonal.
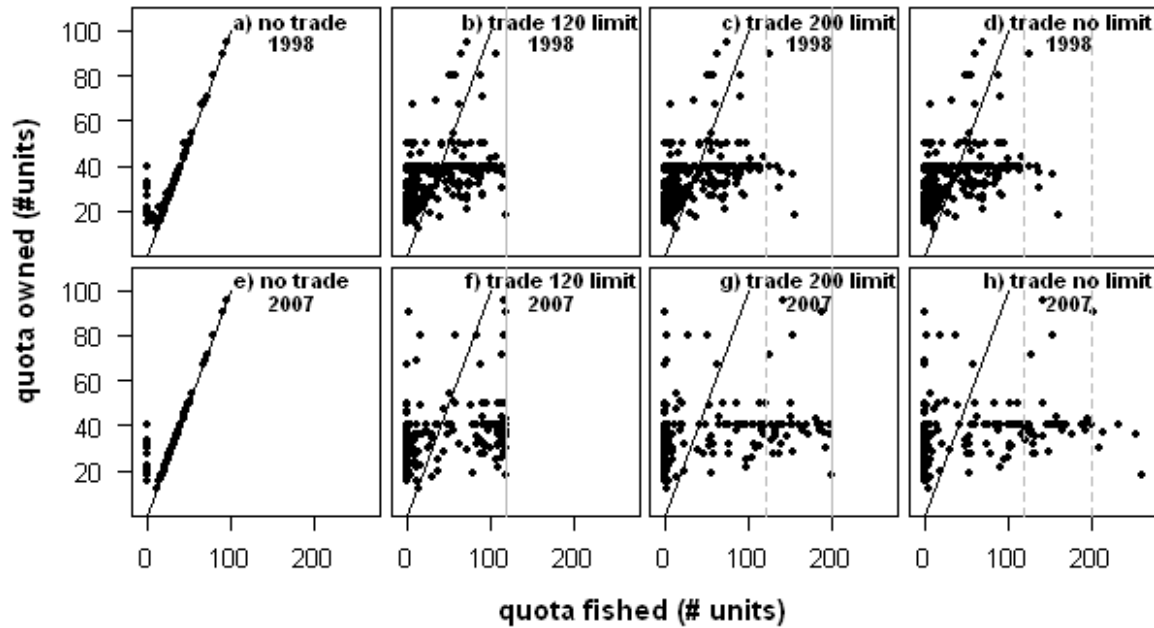
Figure IV-6 Average distribution of fishers with regards to the quota owned and quota fished. Results are shown for 1998 (top) and 2007 (bottom). The diagonal line indicates the limit where fishers fish their own allocation, on the left of the line they lease out, on the right they lease in. The grey vertical lines correspond to the 120 quota units and 200 quota units aggregation limits.

Considering the 120 quota unit limit scenario, figure IV-7 illustrates the simulated changes in the fishing activity of agents, grouped in terms of their initial quota allocation. Quota was allocated on the basis of the number traps per licence and 40 traps was the maximum allowed on a vessel prior to quota introduction (when it increased to 50), so most fishers were allocated 40 quota units or less as initial allocation, explaining the horizontal lines at 40 units on the figure IV-6. The proportion of investors in each group increases for all groups, while the proportion of fishers with a limited to medium fishing activity (less than 100 QU) decreases (figure IV-7). In contrast, the proportion of highly active fishers increases, particularly in the groups owning larger quota shares, which would indicate a shift to larger scale fishing operations.
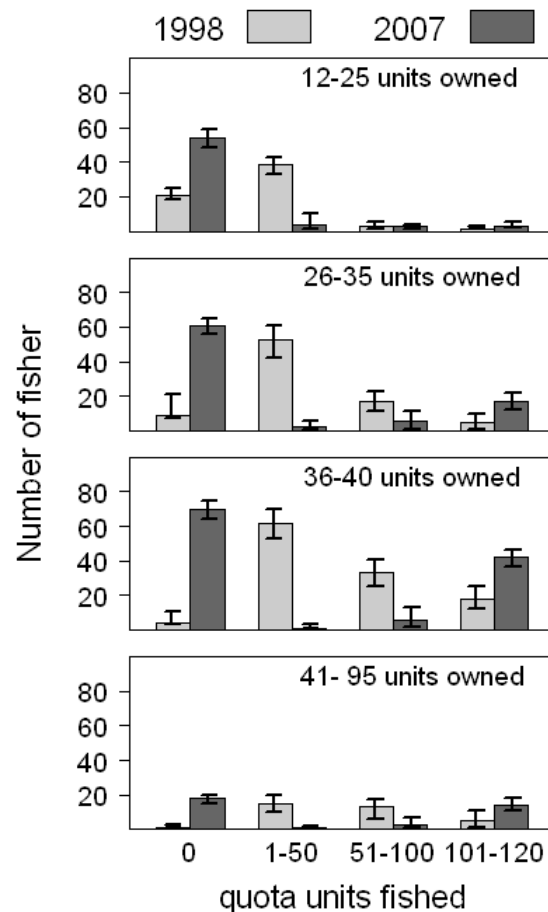
Figure IV-7 Distribution of fishers according to their catch and quota owned for the 120 QU scenario. Comparison of the number of fishers in in 1998 and 2007

Another notable result seen in figure IV-6 is the final size of fishing operations. On average, about 40 vessels would increase their fishing operation beyond the 120 quota units if allowed (limit at 200 quota units or no limit), but only seven vessels would fish more than 200 quota units if allowed. This indicates that the 120 quota unit limit is constraining the fishing activity while the 200 quota unit limit would not constrain many fishers assuming all the current technical regulations enforced and a fleet composition based on that of 1998.

5.1.3   Economic performances

The profitability of agents is examined through the annual short-term individual rent (profit minus lease costs), excluding fixed costs (see figure IV-8). Agents have been divided in two categories depending on whether they fished, "owner-operators", or not, "investors". Owner-operators have an average annual rent between $100,000 and $ 200,000 per year, lower if

trade is prohibited. The number of owner operators, however, is smaller in the case of trade scenarios (about half the 1998 fleet), so on average, owner-operators catch more than in the "no trade" scenario where agents are limited by their initial allocation. As a result, for most years, the average rent of owner-operator per kg of lobster caught is probably lower with trade than without, due to the payment of quota leasing costs. In a transferable quota system, fishing not only pays the skipper, crew and firm owner as in traditional fisheries, the quota owner also gets a share through quota leasing. The variability of owner-operators' rent increases with the degree of transferability of quota. Under the scenario with no aggregation limit, some owner-operators make twice as much as the average, but some, who probably leased in more quota than they could fish have low rents. Greater flexibility in trade appears to come with greater risk to fishers who plan their fishing season at the beginning of the year and lease in the quota they think they will need. In case of degraded economic conditions fishers may loose money along the year by leasing quota at too high a price at the beginning of the year.
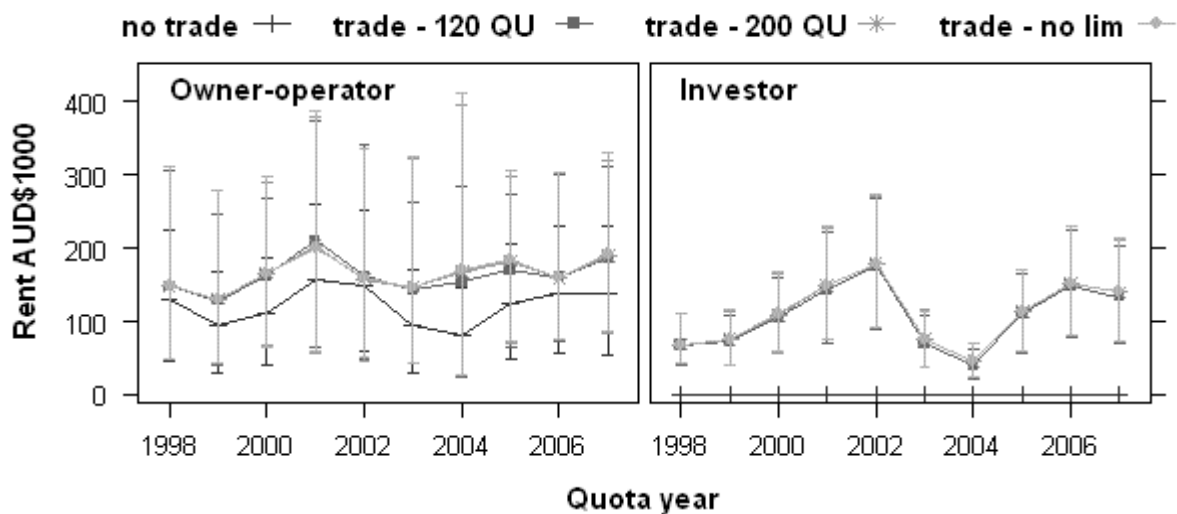
Figure IV-8 Average annual rent for agents.

Rent are estimated for owner-operators (left) and investors (right) bars indicate 90% confidence interval.

The rent difference between the "no trade" scenario and the three scenarios with trade is obviously more important for investors as their rent is directly proportional to the quota price and their quota holding (and investors cannot lease their quota out in the "no-trade" case equivalent to a quota price of zero). The intra annual variability of investor rent depends mainly on the amount of units they own. The inter-annual variability follows the trend of

quota price as on figure IV-3, explaining the reason why average annual rent of investors decreased during the SARS episode. The revenue of owner-operators declined during the SARS episode because beach prices declined, which led to low quota price, thus mainly affecting the rent of owner-operators in the "no trade" scenario. For the scenarios with trade, most of the lobster price declined was incurred by investors.

On average, the simulation results suggest that the rent per kg (total rent of quota owners in the fishery divided by total catch) is 10 to 15% higher if trade occurs (figure IV-9). This confirms the theoretical basis of the model that the fishery is more economically efficient if quota is transferable. The difference in efficiency is mainly due to lower fishing costs as quota is transferred to the more efficient agents (figure IV-9). The average beach price is the same for all scenarios, confirming that even if quota is not tradable, individual agents will seek the highest return for their allocation by modifying their fishing strategy (as seen for the fishers staying in the fishery, chapter 3).
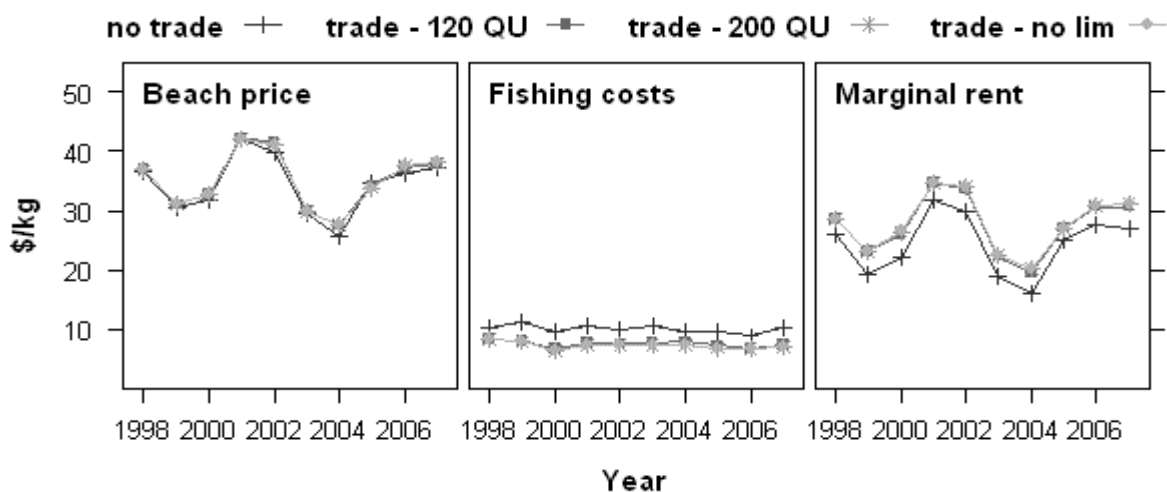
Figure IV-9 Prediction of economic indicators.
Average simulated beach price, fishing cost pre kg, and marginal rent in the fishery for the four scenarios.

5.2   Effect on the lobster stock

The historical simulated exploitable biomass is consistent with the stock assessment biomass in all areas (figure IV-10). The "step down" observed in areas 6 and 9 is due to high amounts

of effort devoted to those two areas the first two years of simulation (figure VII-10 in appendix F). The catch rates in those two areas are higher than in the rest of the fishing areas (Gardner and Ziegler, 2010), therefore high catch rate expectations lead many agents to choose the métiers operating in those two areas and to a massive shift of effort from area 1 to 5 and area 8 to areas 6 and 9 for that initial year. Although the simulated effort returns to observed levels in areas 6 and 9 from the second year of simulation (figure VII-10 in appendix F), high fishing effort keeps the pressure on the local population and the deficit of biomass is carried on throughout the simulations. In reality, various reasons such as the weather or the accessibility to the good fishing grounds probably limit the fishing effort in areas 6 and 9.

Over the simulation period, predicted effort is on average lower than observed in areas 4 and 5 leading to higher local biomass. Two causes can explain this. First, the fishers typically fishing in the northern areas come from other Australian States or from the northern regions of Tasmania (see chapter 3) and most of those fishers display a lower fishing efficiency (see figure VII-9 in appendix E.5). While those fishers exited the fishery more efficient fishers caught the northern lobsters using less effort. In addition, lobsters in area 4 and 5 are larger and do not fetch as high a price as in southern areas. Given that the model runs under the assumption that all lobsters caught are retained, agents would not target northern areas and large lobsters as much as southern areas (see catch by area figure VII-11 in appendix F). The lower simulated catch in the north leads to increasing biomass in the two areas up to 1.5 to twice as much biomass than estimated by the assessment model (figure IV-10).
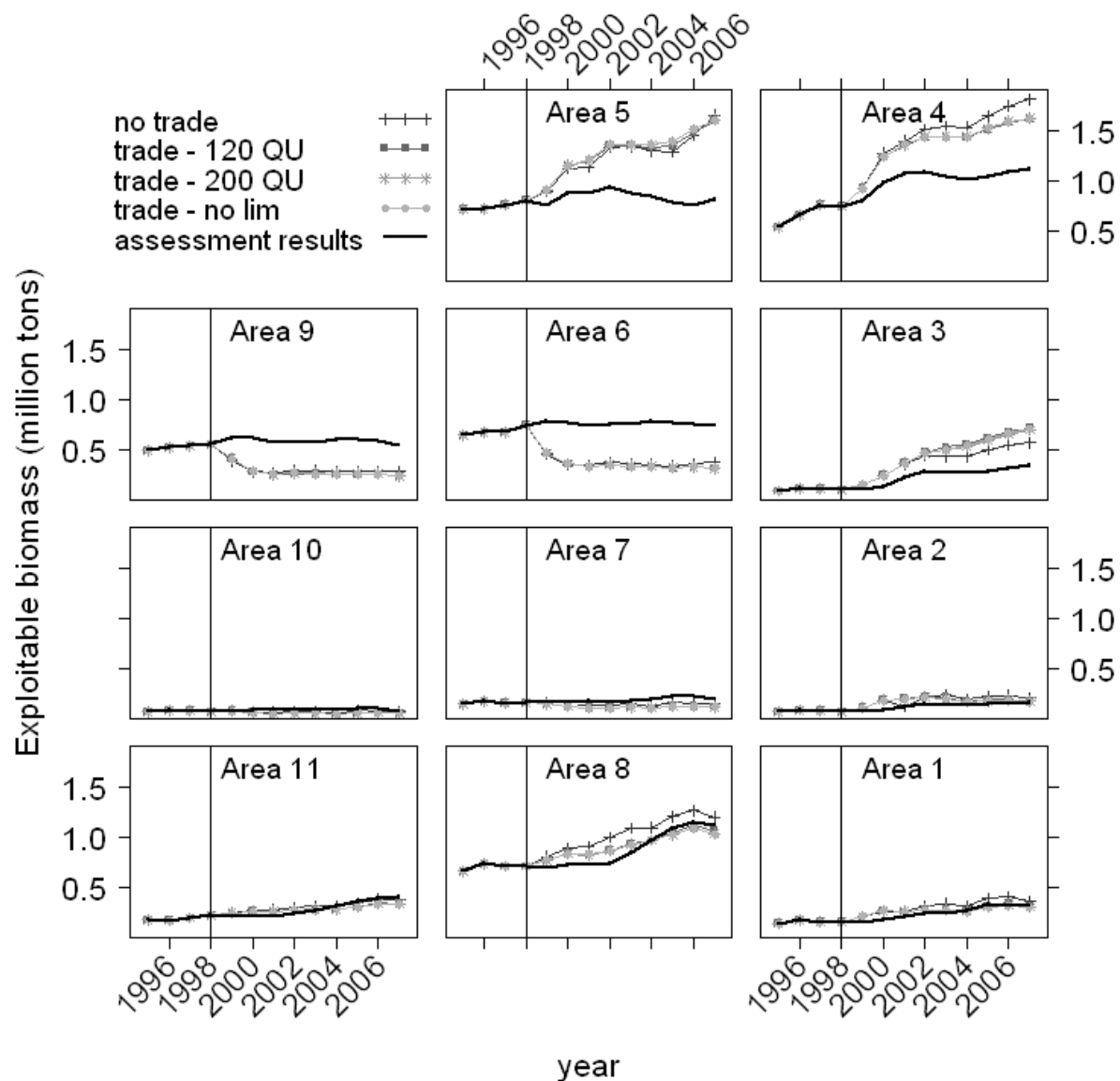
Figure IV-10 Exploitable biomass at the beginning of each year per area.

The results for the simulated scenarios are compared to the real biomass from stock assessment. Average exploitable biomass expressed in million tons calculated over 100 simulations for the scenarios. The vertical line indicates the beginning of the simulations in 1998.

Overall, the difference in trade allowance has little influence on the catch distribution and the resulting biomass except that in absence of trade ("no trade" scenario) less efficient fishers continue to fish their quota, increasing the effort in the fishery.

6   Discussion

Modelling and simulations are useful tools, increasingly used by scientists and managers to explore "what if" situations and understand the drivers of fishers behaviour. The effects of trade limitation on the fishery are discussed through i) the structure of the fishery in terms of active vessels and the involvement of quota owners in fishing activities and ii) through the resulting economic efficiency of the fishery. In addition, the ability of the model to predict fishers behaviour under the maximizing profit assumption, is evaluated and potential improvements of the model are suggested.

The model is used to compare different management scenarios regarding the limitations of temporary quota trade. A scenario in which agents are allocated quota but are not allowed to trade is compared to three other scenarios where quota owners can adjust their quota holding by leasing quota in and out within the limit set for the scenario. For two of those scenarios, exchanges are constrained so that no agents can fish more than 120 and 200 quota units per year respectively. In the last scenario, exchanges are unrestricted and fishers can fish as much as they want, provided they lease the quota covering their catch. All the fishers of the initial fleet (1998 fleet) still have a positive short term profit from rock lobster fishing and can continue fishing in 2007 (see the "no trade" case). However, when given the option to trade, some agents stop their fishing activities and become investors, leasing their quota out to fishers with higher marginal profit. The less restrictive the quota aggregation limit, the more quota transfers occur. Allowing the transferability of quota leads to the expected decline in the number of active vessels in the fishing fleet and an increase in the profitability of the fishery.

In reality, there are reasons for fishers leasing decisions that are not captured by the marginal profit equation used in the model. For example, the model assumes every agent to have a perfect knowledge of the fishery, and while some of the information is freely and easily available to all, (e.g. beach price or fuel price), other information like area-specific catch-rates or quota price are probably only shared locally. This may have been particularly true of the initial years after the introduction of ITQs, and during the time required for the market for quotas to establish itself. In particular, the model assumes that all agents trade simultaneously at a price maximizing the total volume of trade. However van Putten et al. (2011) have shown that the quota market was probably initially composed of many sub-markets, only developing into a statewide market after a few years.

Other motivations limiting quota trade and keeping participation in the fishery high are related to the agents' opportunity cost of fishing. Simulated agents can fish almost the entire year (except for technical and regulatory reasons limiting the number of days fishing in some métiers), as there is no limit on the number of days they can spend at sea per year. In reality, fishers will have families and other obligations which constrain the number of days they spend at sea. Conversely, some fishers enjoy fishing as an activity and would keep some quota even though they could get more money by leasing it out. Owner-operators might also want to keep fishing for a limited number of days per year to assess the state of the fishery and have first-hand information on catch rates. None of the above drivers are considered in the model, leading to a rapid decrease of the active fishing fleet, the number of inactive quota owners, and leasing of quota to more efficient fishers, boosting the quota market and driving the price of quota higher. At the end of the simulation period, if quota is transferable the quota-owners can be divided into two main groups: the investors and the owner operators who lease quota, a trend actually observed in the fishery (van Putten and Gardner, 2010).

In the model, the overcapacity reduction happens by selection of the most efficient fishers. As a result, the fishing effort needed to catch a given TAC is lower, reducing the fishing costs in the fishery. The cutback of fishing costs has two consequences, it increases the overall profitability of the fishery and it increases the marginal profit of fishers, driving the price of quota higher. The predicted rent of the fishery is higher when quota is tradable as agents with higher marginal profit lease additional quota and fish as much as possible. Despite the limitation of quota use, the competition between the most profitable agents drives the quota price up, to the benefit of the non-fishing quota owners, the investors. It should be noted that with a fleet that is highly reactive and completely flexible, the model predicts that an external shock such as the one provoked by SARS on beach price, would mainly be supported by investors as the quota price would drop following the individual marginal profits.

The model presented in this study is purely profit driven, agents are assumed to be profit maximisers and indeed results suggest that Tasmanian rock lobster fishers are for the main part economic agents taking rational decision for their fishing business. Simulations on the first ten years of quota management allowed us to compare the model predictions with what occurred in the fishery. The ability of the model to reproduce the reality is explored through the difference between the 120 quota units limit scenario and the actual assessment data. The spatial distribution of catch and effort in the fishery is well captured by the model, suggesting that effort allocation decisions are mostly based on economic considerations. The differences

observed in the northern areas can be explained by the size structure of the landings in the region where lobsters are larger and thus, fetch a lower beach price. Using a selectivity allowing the discard of larger lobsters could increase the attractiveness of these areas to the observed levels.

If the spatial distribution of fishing is well captured in the model, quota trading is overestimated with 1.7 times more quota units leased than in reality. Agents are assumed to keep fishing as long as it is profitable to do so, therefore efficient fishers continue fishing and aggregate quota resulting in a smaller active fleet. The distance between what agents would do, and observations of what fishers have done indicates that other drivers influence fishers choice in terms of how much time they spend fishing that are not captured in the cost and earning approach to economic performance. Fishers have reasons to limit the time spent at sea that are not constrained by the measure of short-term profit used in the study. Fishers also have reasons to stay active in the fishery despite what would be considered rational (e.g. to have first hand information on the catch rates). A random utility model (RUM) could be used to explore additional factors influencing agents choices in term of how much they fish. Alternatively, if additional data are not available, an "inertia" variable is usually used in fleet dynamics models to capture those drivers.

The simulated price of quota follows very closely the beach price of lobster, this means that the simulated costs are low compared to what has been estimated in the literature (Ford and Nicol (2001) suggested that fishing costs amounted for 65% to 76% of the total value landed prior to the introduction of ITQs). The introduction of ITQs is assumed to select the most economically efficient fishers, lowering the overall costs of fishing. In the model, fishing costs fall from about 45% of the revenue in 1998 down to about 22% of revenue in 2002 for the scenarios "trade – 120 QU", "trade – 200 QU" and "trade – no lim". Given that fishing costs remain higher in the "no trade" scenario (about 35% of value landed), the decrease of fishing costs can be related to quota transfers. However, the diminution of fishing costs is probably overestimated in the model for two reasons. First, the simulations predict that the most efficient fishers of the 1998 fleet remain in the fishery while the fishing fleet changed after the introduction of ITQs and some of the most efficient fishers left at the introduction of ITQs (see chapter 3). Second, the model predicts that efficient agents concentrate most of the catch lowering the average fishing costs. Again, using models with non-economic drivers to predict the level of fishing for each individual fisher could improve the predictions and would be expected to drive fishing costs higher.

7   Conclusion

The aim of this study was to develop and use a model to investigate the effects of changing the quota trading limitation in a fishery under ITQs. The agent-based model captures the short-term behaviour of the Tasmanian rock lobster fleet combining individual effort allocation and quota trading. The fleet dynamics model developed for this study assumes that quota owners are economic agents whose goal is to maximize the profit they draw from the fishery. Although fleet dynamics models at the fleet or vessel group level successfully captured the spatial dynamics of fishing allocation (Poos and Rijnsdorp, 2007), an individual-based approach has been used in this study to capture the dynamics of quota trading.

The simulation results suggest that the reduction of overcapacity would not have occurred, were the individual quotas not transferable. The three scenarios allowing quota lease give similar results although the number of vessels predicted to remain active in the fishery is higher for the case of 120 quota unit limitations and the profitability lower. The differences predicted in terms of number of active vessels and quota exchanged between the 200 quota units limit and the no aggregation limit scenarios are very limited. Indeed, of the total fleet, about 12% of vessels would fish more than 120 units when allowed whereas only about 1% would fish more than 200 quota units. This suggests that unlike the 120 units limit, the 200 quota units limit would not restrict the fishing activity with other current regulations applied (e.g. the cap on traps onboard). The limit on quota holding has been efficient in preventing the concentration of quota into the hand of investors unlike what has been observed in other fisheries (Hamon et al., 2009), but the results of our study suggest that limiting the use of quota to 120 units per license may have constrained fishing activity below optimum levels. Although the real fishery has not been as reactive as the simulated fishery, and the recent pressure from the industry resulting in an increase of the limitation up to 200 quota units per license tends to confirm the findings (Anon, 2010a).

The fleet is composed of agents with individual characteristics and a quota allocation based on real data. Expectations of catch-rates in the different métiers are initially drawn from log-book data and updated by fishers on a monthly basis based on their "previous experience" in the model. The fleet dynamic model is integrated with the biological model of the fishery developed for the southern rock lobster fisheries (Punt and Kennedy, 1997, Hobday et al., 2005) using a feedback loop between the lobster stock and the fishing fleet at the period level (one to three months).The dimension at which biological processes are simulated is fixed by

the biological model and some assumptions have been made to obtain suitable data to initialise the fleet dynamics (see description and discussion of initialisation in appendix C). The high expected catchabilities in some Western areas creates instability at the beginning of the simulation period and the model predicts a shift of effort towards the western areas due to high catch rates expectations. Despite this initialisation driven shift, the profit-driven behavioural model of fishing allocation and quota trade reproduces the reality well in terms of spatial effort allocation, catch and effect on the biological stock. The results suggest that fishing effort distribution is primarily driven by economic considerations. Apart from the shift of catches from northern areas to deep water off the west coast, simulation results in all the other areas are remarkably close to what was actually observed over the study period.

The model simulations suggest that if quota owners had been purely profit driven, the fleet would have decreased more than the observed rationalization. The simulated fishery is much more reactive than what has been observed. The assumption that decisions are based on profit expectations appears valid for the spatial allocation of fishing, but the difference between the sizes of the simulated and real fleet suggest that other factors drive fishers decisions to keep fishing or not. Fishers in King Island have traditionally complemented their fishing activity with a farming activity (Williamson et al., 1998). The double activity may explain why those fishers kept fishing part of the year. Additionally, many fishers would have retired from fishing during the 10 years period (due to the aging profile of the fishing population, see Frusher et al., 2003). Data on those factors were not available or the coverage was insufficient to be used for the whole fleet and further research is needed to identify the macro economic drivers of quota trading.

Reliable economic data is notoriously hard to access and when it is available it is often too aggregated to be used in economic studies. For this study, landings and beach prices should have ideally been disaggregated by market category, quota lease price recorded since the introduction of quota and variable and fixed costs of fishing monitored regularly (instead of a single economic survey). In addition, an exhaustive study of the economic situation of the fishery prior to the introduction of ITQs would provide a baseline to evaluate the evolution of the fishery. The use and need of biological data to assess the state of a fishery is long recognised by managers, when it comes to economic data however, the need becomes less obvious. Confidentiality issues are often cited as a difficulty to obtain such data but in the Tasmanian rock lobster fishery, managers were not aware of the scientific value of economic indicators and collection of economic data was not envisaged.

Modelling fisher's behaviour is a challenging task but it seems that assuming that fishers take rational decisions based on profit expectations is a good starting point. To capture the quota trading and the evolution of the fishing fleet, additional information on the opportunity costs of fishing and personal characteristics would be needed. A maximum number of days at sea per year could be implemented in the model to limit artificially the individual activity but a more interesting way to capture the drivers of quota trading decisions would be to use discrete choice models such as random utility models to investigate the effect of fishers age, weather conditions and additional factors believed to have an impact on the fishers activity. The model predicted a response from the fishery to the external economic shock of SARS in 2003-2004. The simulations suggested that the drop in beach price leading to a diminution of fishers profits was mainly absorbed by non-fishing agents (investors). Although this did not happen in the fishery, as fishers and investors did not expected the crisis to last, the simulation results indicate that quota price is sensitive to perturbations modifying the profitability of the fishery and that change in quota price impacts greater on investors than on fishers. The model will be used to investigate the response of the fishery to such perturbations affecting catch rates such as climate change (Pecl et al., 2009) in chapter 5.

V   Adaptive behaviour of fishers to external perturbation : Simulation of the Tasmanian rock lobster fishery

Abstract:

Fisher's behaviour is increasingly integrated in models used to predict the spatial and temporal allocation of fishing fleet. In this chapter, the responses of three models of fleet behaviour to external perturbations are investigated. The models vary in complexity from a simple model with constant allocation of catch in time and space, to a model assuming linear projection of the spatial distribution of catch depending on regional biomasses and to an agent based model where every fisher chooses their allocation of fishing effort based on economic consideration and interact with the other quota owners on quota trading market. Environmental and economic perturbations are applied on the fishery. The simulations show that accounting for the dynamics of the fleet is necessary when long-term disturbances are expected. The environmental disturbance was captured both by the model using linear projections function of biomass and the agent-based model. In addition, the agent based model responded to economic perturbations and allowed the investigation of additional socio-economic aspects of the fishery.

1   Introduction

The management of fisheries is complex. As no direct measurements of the size of the exploited stocks are available, scientists use a set of mathematical tools to estimate the stock state and calculate the proportion that can sustainably be harvested (see Haddon, 2001 for details). Forecasting possible futures for a fishery, must take into account this complexity, to adequately support the selection of management measures by including external ecological and economic perturbations which may affect the dynamics of the fishery, and the response of fishers. Integrating explicitly the human dimension in fisheries advice through fleet dynamic models has been advocated by scientists for over two decades (Hilborn, 1985, Branch et al., 2006). Mostly, these models are used to try and anticipate the behavioural response of fishers to the introduction of new management measures (Poos et al., 2010), but they can also be useful to predict the effect of other perturbations on fisheries (Soulie and Thebaud, 2006).

Individual transferable quotas (ITQ) were introduced in the Tasmanian rock lobster fishery in 1998 following concerns for the sustainability of the resource (Ford, 2001b). Since the introduction, the stock has rebuilt, catch rates have increased and the overall economic performance of the fishery has improved (chapter 2 and Hamon et al., 2009). Several factors contributed to the recovery of the fishery including several years of good recruitment combined with the establishment of a total allowable catch (TAC) set at a sustainable level. However, since 2008 catch rates have been declining because of poor recruitment around the island (Gardner and Ziegler, 2010, Linnane et al., 2010) and a management plan has been advised and partially adopted for the next few years, which includes cuts in the TAC. Climate change has been identified as the probable cause of the decline in recruitment but the long term effects of climate change and the future of the fishery remain uncertain (Pecl et al., 2009).

In addition to environmental pressures, the Tasmanian rock lobster fishery is also subjected to economic constraints. Most of Tasmanian rock lobster is exported live to China and the industry relies entirely on this sole customer to buy their lobster (Bradshaw, 2004). In 2003, the severe acute respiratory syndrome (SARS) outbreak in Asia caused the lobster price to drop suddenly in Tasmania, only to recover months later. Since the SARS episode, fishers are aware they should diversify their sale and find alternative markets like Europe or North

America but China has been the best buyer and Tasmanian processors persist on mainly shipping lobsters live to China (fisher, *pers. comm.*).

Pecl et al. (2009) studied the potential effects of climate change on the Tasmanian rock lobster fishery and identified certain limitations to their study. In particular, they suggested that the response of the fishing industry to the modification of the structure of the stock should be investigated by including fisher behaviour in a bio-economic model. The current study addresses this gap of knowledge and aims at understanding better the response of fishers to perturbations such as those which could arise from climate change. The current study uses simulations to investigate scenarios of external perturbations on the biology of the stock and on the lobster market using three different fleet dynamic models varying in complexity. We compare the projection results of previous modelling attempts with a new agent-based model of fisher behaviour developed in chapter 4.

2   Models

The model presented in this study is based on a model developed for the southern rock lobster, *Jasus edwardsii*, fisheries (Punt and Kennedy, 1997, Punt et al., 1997, Hobday and Punt, 2001, Punt et al., 2006, Hobday and Punt, 2009). The model is now used for projecting the stock assessment into the future (Gardner and Ziegler, 2010) and runs for periods shorter than a year, with ecological processes and human activities modifying fishing stock at each period. The effect of the commercial fishing fleet on the rock lobster stock is modeled through fleet dynamics models that are integrated into the biological projection model at each time step. The pre-existing fleet dynamics model is used in two forms in the current study, one form includes a constant spatio-temporal distribution of catch (static) and the other allows for movement of the fleet to follow the biomass (see Pecl et al., 2009 for details). In addition to the pre-existing model, an agent based model of fishing allocation and quota trading has been developed for this study (see chapter 4).

2.1   Dynamics of the Tasmanian rock lobster population

For the Tasmanian rock lobster fishery, biology is modelled at the period level corresponding to time steps of one to three months. Three month periods are used in Austral winter when

less data are available (figure V-1). At each period, the size-structured stock is modified in each of the 11 fishing areas composing the Tasmanian fishing zone (see chapter 4 for the fishing areas). While natural and fishing mortalities affect the stock during each period, other biological processes including movement of lobsters between areas, growth and settlement, only happen during specific periods (figure V-2).
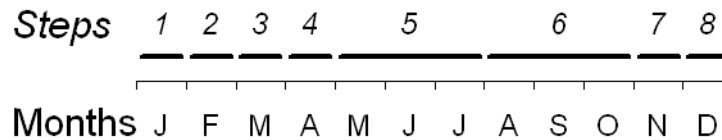
Figure V-1 Definition of the periods for which the model runs.
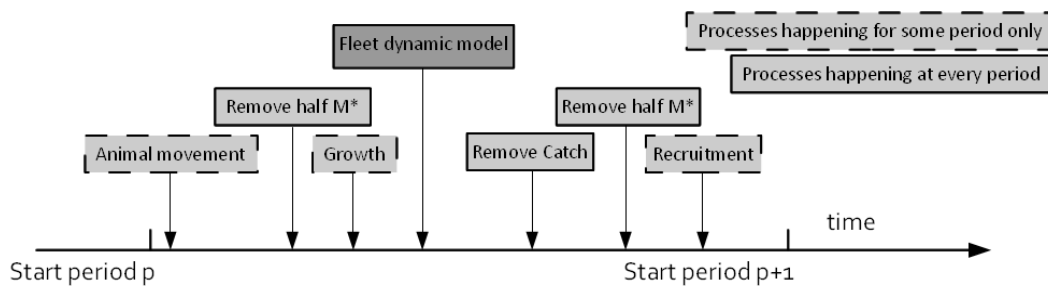
Figure V-2 Sequence of events happening to the rock lobster stock.
Events occur in each area, some at each period other for specific periods only. M* is the period specific natural mortality.

Natural mortality is commonly difficult to estimate. In this model, the total natural mortality is set constant to 0.1 for all sizes and was estimated using tag-recapture data (Punt and Kennedy, 1997). The natural mortality is then distributed evenly throughout the year in proportion to the length of the period. The fishing mortality per area and period depends on the fishing allocation of recreational, commercial and illegal catches. Recreational fishing is regulated by a total allowable recreational catch (TARC). The TARC is set to 170 tonnes per year if the total allowable catch (commercial and recreational catch) is less than 1700 tonnes. If the TAC is higher than 1700 tonnes the TARC is set to 10% of the TAC (Anon, 2006). In practice, the TARC is not enforced even though the TACC was reduced in recent years. The latest estimates derived from surveys placed the recreational catch at 135 tonnes during the 2006-2007 fishing season and the seven preceding seasons (Lyle, 2008). In the model,

recreational catch, by period and area, is defined as a fixed proportion of a total recreational catch set at 150 tonnes a year. The allocation of commercial catch is defined as a percentage of the TACC per area and period calculated by a fleet dynamics model (see next section for the fleet dynamic models used). Given the lack of information on illegal fishing, an arbitrary value of 2% of commercial catch in each area and period is applied.

Selectivity and vulnerability are used in the model to determine how the catches are distributed over sizes and sexes of lobsters. Traditionally, selectivity relates to gear selection depending mainly on animal size. In Tasmania, rock lobster fishers use traps with escapement gaps for juveniles. Fishers must adhere to the minimum legal size of 105mm carapace length for females and 110mm for males (Anon, 2006). The gear selectivity used in the Tasmanian rock lobster model is represented by a truncated logistic function (figure V-3) and despite the use of different gears in the recreational fishery, (i.e. diving, ring nets and traps) the same selectivity is applied to recreational commercial and illegal catches because of a lack of information. Vulnerability is defined as the relative availability of female compared to male lobsters. Males are vulnerable throughout the fishing season while there is a ban on female catch from May to October. Additionally, a large number of females are already carrying eggs in April and these females must be returned to the sea (Anon, 2006) so vulnerability is set at 0.5 for females during April. Catchability is period and area specific but constant from year to year and is derived by the stock assessment model (Gardner and Ziegler, 2010, Ziegler et al., 2003).
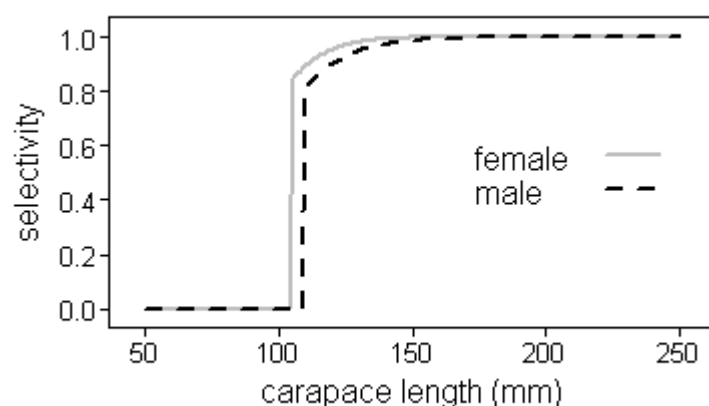
Figure V-3 Selectivity of rock lobster fishing traps in the Tasmanian fishery for males and females.

Southern rock lobster is essentially a rocky reef dweller and seldom ventures onto sandy bottoms (Winstanley, 1973). Gardner et al. (2003) showed that no long-distance movement has been detected in Tasmania for *Jasus edwardsii*. Rock lobsters show a high site-fidelity although tag recapture data have shown minor inshore-offshore movements between areas 6-9, 7-10 and 8-11. These are estimated as a proportion of lobsters of one area moving to another at the beginning of each year.

There is no stock-recruitment relationship available for the southern rock lobster stocks but the estimated recruitment is the combination of an average recruitment and an annual deviation that can depend on external factors (Linnane et al., 2010). Growth of lobsters is modelled using transition matrices between 5mm size classes (Punt et al., 1997, McGarvey and Feenstra, 2001). As both settlement and growth rates are believed to be affected by climate change in Tasmanian waters, temperature-dependent growth rates and settlement were implemented in the model (Pecl et al., 2009).

2.2   Fleet dynamic models

The fleet dynamics component of the model defines the spatio-temporal distribution of lobster catch. The three fleet dynamic models used in this study vary in terms of model complexity and range from a constant model (FD0) to a linear model function of the local biomass (FD1, used in Pecl et al., 2009) and to a model explicitly representing individual fishers and quota owners using the agent based modelling approach (FD2, defined in chapter 4 and table V-1).

Table V-1 Brief description of the fleet dynamic models.

Model	Description	Modelling approach	Catch allocation based on	Type
FD0	Static model	Constant catch distribution	• Historical catch distribution pattern	Deterministic
FD1	Simple dynamic model	Linear regression	• Historical catch distribution pattern • Local exploitable biomass	Deterministic
FD2	Complex dynamic model	Agent based model of effort allocation and quota trading	• Economic data (costs, ex-vessel price) • Individual characteristics (vessel size, quota holding, fishing efficiency) • Catch-rates previously achieved	Stochastic

More complex models require more data for calibration, more time to develop and to run but the loss in simplicity is balanced by the additional information obtained in the simulations and the possibility to investigate more complex scenarios. Model FD0 assumes the fishing fleet keeps the same fishing pattern from one year to the next in proportion to the TACC in year y, regardless of ecological and economic perturbations (equation V.1). This relies on a strong assumption that the fleet remains unchanged and the individuals demonstrate the same behaviour across years. The constant proportions, $\alpha_{a,p}$, are calculated as the average catch distribution by area/period between 1997 and 2006.

$$H_{a,p,y} = \alpha_{a,p} TACC_y \qquad \text{V.1}$$

The fishing effort per period and per area, $E_{a,p,y}$, used to calculate fishing costs is calculated from the catch and the exploitable biomass $B_{a,p,y}^{exploit}$ in area a at the start of period p of year y by assuming constant period and area specific catchabilities $q_{a,p}$ (equation V.2).

$$E_{a,p,y} = \frac{H_{a,p,y}}{q_{a,p} B_{a,p,y}^{exploit}} \qquad \text{V.2}$$

Model FD1 is slightly more complex (equation V.3, adapted from Pecl et al., 2009). Although the seasonal distribution of the catch is fixed with a constant share of TACC caught per period, λ_p, the spatial allocation within a period, $P_{a,p,y}$, is a function of constants and of the exploitable biomass $B_{a,p,y}^{exploit}$ (equations V.4 and V.5, from Pecl et al., 2009).

$$H_{a,p,y} = \lambda_p P_{a,p,y} TACC_y \qquad \text{V.3}$$

$$P_{a,p,y} = Y_{a,p,y} \Big/ \sum_{a' \in A} Y_{a',p,y} \qquad \text{V.4}$$

where $Y_{a,p,y}$ is given by:

$$\ln Y_{a,p,y} = \delta_{a,p} + \beta_{a,p} B_{a,p,y}^{exploit} \qquad \text{V.5}$$

FD1 assumes that fishers are only driven by expected catch rates through perfect knowledge of the levels of biomass. The effort needed to capture the catch is calculated in the same way as for FD0 (equation V.2). In simulation runs with FD1, the fishery is expected to respond to perturbations affecting the fishing stock but not to changes in the economic conditions under which the fleet operates.

Finally, FD2 integrates the key set of factors which drive the fisher decision process. The choices of fishing allocation and quota trading are based on expected marginal profit (chapter 4). Expected marginal profit for each vessel and month depend on vessel specific costs and fishing efficiency, catch rates and cost of fishing per area and price of lobster. Therefore, in addition to ecological perturbations detected through catch rates, economic changes (e.g. in fishing costs, in the demand and price by lobster category, in the beach price seasonality) will also trigger responses from the fishery in the FD2 model.

2.3   Data and model calibration

2.3.1   Data

Similar to chapter 4, agents in model FD2 are defined as the quota owners at the beginning of the first quota season of the simulation period, in March 2007 (quota seasons are from March to February of the following year). Quota owners were linked to a vessel through the licence and unloading databases of DPIPWE (Department of Primary Industries, Parks, Water and Environment). Overall, 216 owner-operators and 76 investors (quota owners without vessels) were defined for a total of 292 agents. Agents were allocated their actual quota shares as observed in 2007. Individual allocations ranged from 1 to 172 quota units with most of the agents owning between 10 and 50 quota units (about 70% of owners). The 76 agents without boats held a total of 2203 quota units or approximately 20% of the TAC. In addition, agents with a vessel were described with additional characteristics (see chapter 4 for the list of characteristics included in the model and chapter 3 for the evolution of those characteristics between 1998 and 2007). The biological parameters for rock lobster stock dynamics used in the current study were the same as in chapter 4 except that the initial status of the stock was taken as of 2006.

Economic data include variable costs and lobster prices. Fuel prices, illustrated in figure 4, are derived from historical fuel price data at the month level since 2006 (www.fuelwatch.wa.gov.au/) and the future projected prices (dashed line on figure V-4) were extracted from the northern prawn fishery regional assessment group report (Anon., 2010). The projected prices represent the best estimates of the average future behaviour of the system excluding all variability. Other costs were extracted from Gardner and van Putten (2008) and most are held constant for all years except for labour cost for an annual increase is assumed, as explained in chapter 4. These include fishing costs, labour costs and gear maintenance

costs (see appendix E.1). In the FD2 model, costs are dependent on both the choice of fishing location and time and on the fisher operating (in relation with vessel size and port of origin). In the models FD0 and FD1, the fleet is not explicitly described so cost estimates are less precise and are only used to output economic indicators. Period- and area-specific costs per traplift are defined and multiplied by an annual trend factor (fishing costs per traplift estimated for Pecl et al., 2009). In order to obtain comparable model outputs, the cost per traplift by area and period used in the models FD0 and FD1 is multiplied by an annual trend (equation V.6).

$$C_{a,p,y}^{traplift} = T_y^{cost} C_{a,p,2007}^{traplift}$$

V.6

The cost multiplier, T_y^{cost}, is defined as the combination of projected costs with the relative importance of each determined from Ford and Nicols (2001). Fuel costs account for 5% of fishing costs and labour for 65%, the rest of fishing costs (30% including gear maintenance, bait, food, ice) are assumed constant over the simulation period . The cost factor representing the annual trend in costs, T_y^{cost}, is calculated as follow:

$$T_y^{cost} = 0.30 + 0.05 T_y^{fuel} + 0.65 T_y^{labour}$$

Where T_y^{fuel} and T_y^{labour} represent annual fuel price (as on figure 4) and opportunity costs of fishing (with a 4% increase per year, see chapter 4 for estimates of labour costs) relative to 2007.

Beach prices are defined per month and lobster categories (by size and colour – see chapter 4). The price for each category is defined relative to a reference category. Different scenarios for the projection of prices are considered (see section 2.4). The month specific split prices for each category are kept constant, which reflects the assumption that the structure of demand by size and colour remains unchanged over time, as landing prices for rock lobster are demand driven (see chapter 4).
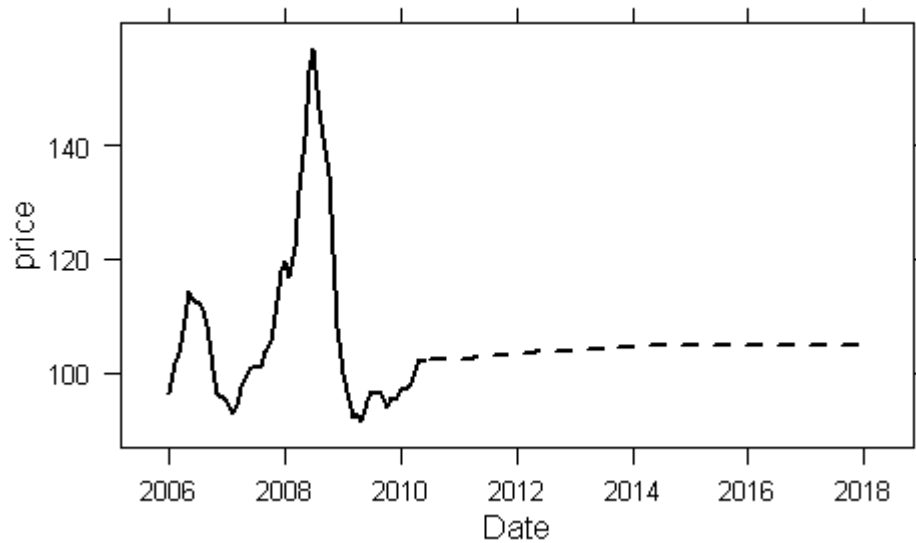
Figure V-4 Fuel prices at the month level.

Prices are expressed in cents/L (based on fuel price scenario in Anon., 2010).

2.3.2   Management plan

Since ITQ were introduced in 1998, a TAC is set every year. A committee composed of scientists, managers, fishers and processors give their advice to the ministry based on a scientific assessment of the fishery. Due to declines in catch rates since 2008, management actions have been demanded by the fishing industry. A management plan is being considered including the reduction of the commercial TAC but no change in the recreational catch allowance (Anon, 2010b). The currently agreed management plan consists of drastic cuts in the commercial TAC over a 4 year period from 2008 to 2012 (see figure V-5 for the TACC). The TACCs after 2010 have not been voted at the time of writing this thesis (Anon, 2010b). The other technical measures enforced by regulation include a maximum number of traps onboard vessels, strict trap design, seasonal closure in October and ban on females from May to September (Anon, 2006). In addition, following demand from the industry, the quota holding and use limit has been increased from 120 to 200 quota units per licence in the 2010/11 fishing season (Anon, 2010a).
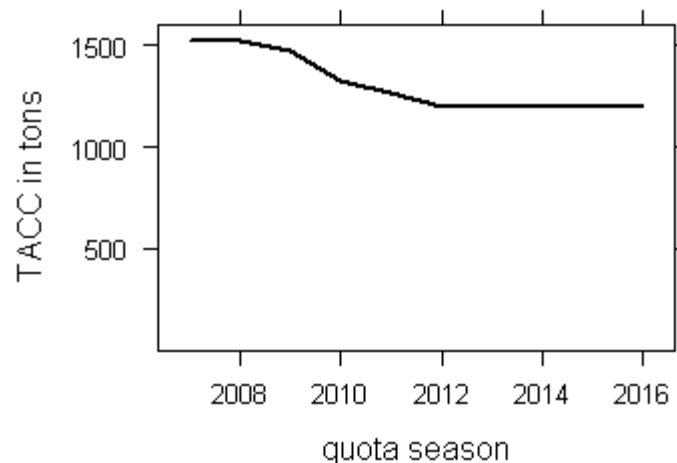
Figure V-5 Projected commercial TAC between 2007 and 2016.
The values after 2010 have not been officially approved.

2.4   Scenarios

Three fleet dynamic models are used to investigate scenarios of exogenous perturbations. The Tasmanian rock lobster fishery is subjected to many constraints on which stakeholders have no influence. In particular, environmental perturbations have recently led to lower recruitment in the fishery (Linnane et al., 2010). Although the exact causes of reduced recruitment episodes is unclear, the change in regional currents induced by global climate change is the probable cause (Pecl et al., 2009). Climate change (manifested by water temperature) is likely to affect the settlement of juveniles and the growth rates of settled lobsters. The settlement of juvenile lobsters would be negatively impacted by an increase in sea temperature whereas growth rates would increase with water temperature. However, the recruitment predictions are based on extrapolations beyond the range of available data, which is fairly restricted, and the prediction of recruitment based on future temperatures beyond the range observed in Tasmania may not be accurate. The future of the fishery is therefore investigated according to 2 scenarios (see table V-2) :

- C1 - Climate change effect: increase of growth rates, decrease of recruitment (the most likely)

- C2 - No effect of climate change (using the average recruitment of 2007-2009)

The area specific temperatures used for projections are based on the Intergovernmental Panel on Climate Change (IPCC) emission scenarios A1B, with downscaled data from a suite of

nine global climate models accessed using a CSIRO tool OzClim for Oceans (as in Pecl et al., 2009).

The Tasmanian rock lobster fishery is a price taker and beach prices are driven by the Chinese market and the exchange rate (Hamon, 2008). Over the past two decades the beach price of rock lobster has changed dramatically in Tasmania, mainly influenced by the development of exports to the Chinese market (chapter 2, Hamon et al., 2009). The Tasmanian rock lobster price varies both inter-annually and seasonally. These two sources of price variation are captured in the definition of scenarios. The historical inter-annual trend and seasonal pattern of lobster price are investigated using the Hodrick-Prescott filter (Hodrick and Prescott, 1997 as used in chapter 2). To extend the Hodrick-Prescott inter-annual trend two scenarios are explored, an increasing trend at the same rate of the last eight months of data (about $2 per year, dotted line figure V-6) and a constant price at the level of the last available data point (in April 2010, dashed line on figure V-6).
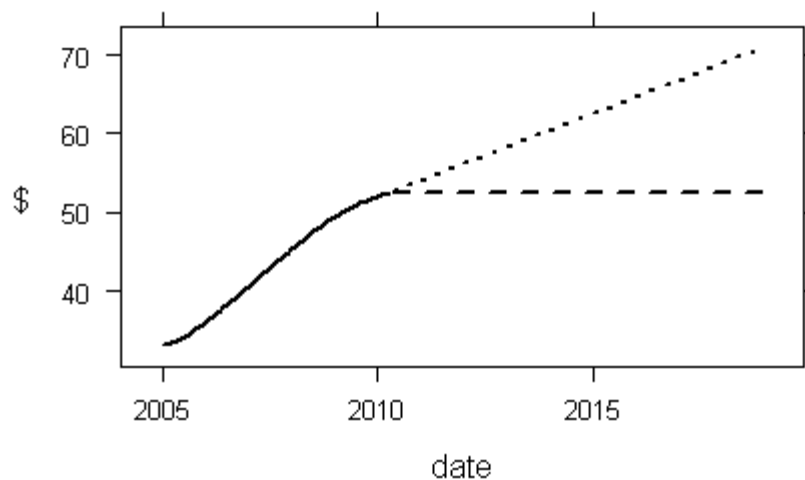
Figure V-6 Predicted price trends for rock lobster for the period 2010-2017.
The full line is the observed historical trend estimated by Hodrick-Prescott filter, the dashed line is the constant trend at the level of 2010 and the dotted line considers an increase trend equal to the rate observed for the last 8 months of the Hodrick-Prescott trend on historical data.

The seasonal price pattern was extracted as the cycle of the Hodrick-Prescott filter. Traditionally, the price is higher in winter and decreases in the Austral summer (November to March see full line figure V-7). However, since the 2008-2009 fishing season, the decline in summer has been reduced. This is supposedly due to the decline in the Western Australian

(WA) rock lobster fishery. For years, the WA rock lobster fishery dominated the Australian production of rock lobster with about 65% of Australian rock lobsters (ABARE, 2008). The decline in the WA fishery led to a change in seasonal pattern, where price for southern rock lobster did not drop as much as expected in summer November – March (dashed line figure V-7).
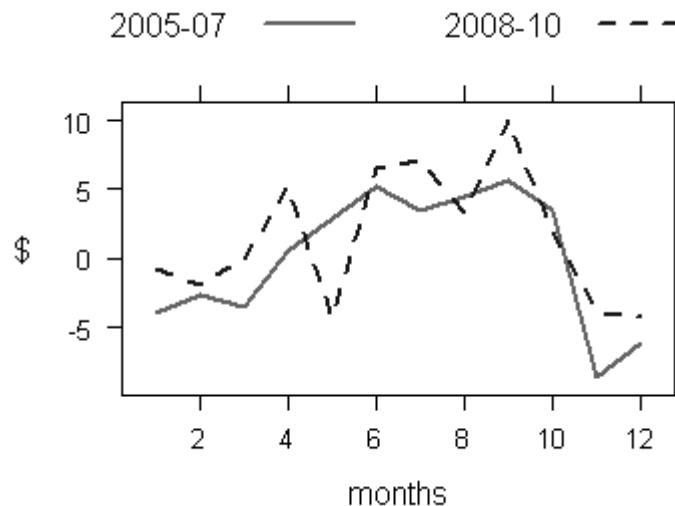
Figure V-7 Seasonality estimates for the lobster beach price.
The seasonality is estimated as the average cycle component of the Hodrick Prescott filter. The solid line corresponds to the 2005-2007 period and dashed line to the 2008-2010 period.

The four price scenarios envisaged combine assumptions on the inter-annual trend and on the seasonal pattern of beach prices:

• P1 - using the 2008-2010 seasonal pattern of price with the increasing trend (this is the most likely scenario).

• P2 - Historical seasonal pattern (2005-2007) + increasing trend

• P3 - 2008-2010 seasonal pattern, constant trend

• P4 - 2005-2007 seasonal pattern, constant trend.

The three available fleet dynamic models are used to assess the five scenarios presented in table V-2 over a 10 years period (2007-2016) using 50 replicates of each run. The period of simulation may seem short to evaluate the evolution of the fishery with regard to long term changes such as climate change but the agent based model focuses on the short term behavioural response of the fishing fleet and predictions about the economics of the fishery

(e.g. input and output prices, production function, exchange rates) become quite difficult beyond 10 years.

Table V-2 Scenarios description.

Climate change scenarios: C1= effect of temperature on recruitment and growth rates, C2= no effect of temperature; Beach price: P1=increasing trend & 2008-10 seasonality, P2= increasing trend & 2005-07 seasonality, P3= no trend & 2008-10 seasonality, P4= no trend & 2005-2007 seasonality.

	Climate Change		Beach Price			
	C1	C2	P1	P2	P3	P4
Scenario 1	X		X			
Scenario 2		X	X			
Scenario 3	X			X		
Scenario 4	X				X	
Scenario 5	X					X

2.5   Evaluation of the fishery performances

The sustainability of the fishery is assessed annually through a set of variables that compared performances measures against trigger points (Gardner and Ziegler, 2010). Indicators of the stock status include the regional and statewide legal size biomass, and egg production, and indicators of the commercial and recreational sectors of the fishery include regional and overall commercial catch rates, size of the fleet and total commercial catch. Even though the Tasmanian rock lobster fishery harvests a single stock, the use of trigger points by area is justified by the low level of movement between areas and the different growth rates depending on latitude (Gardner et al., 2003, Gardner et al., 2006). Initially, the trigger points were defined as the worst state ever observed for the biomass, egg production and catch rates, 220 active vessels for the minimum size of the fleet (about 2/3 of the original fleet), commercial catch of 95% of the TACC (insuring for a restrictive TACC) and the recreational catch of 10% of the TACC (Frusher, 1997). However, the latest fishery assessment report presents a new set of reference points defined as the lowest values observed for the variables of interest since the quota management system was introduced in 1998 (Gardner and Ziegler, 2010). In the current study, only the values of legal size biomass, egg production (estimated by the biomass of mature females) and catch rates were kept for the evaluation (see tableV-3).

In addition to the official trigger points, economic indicators were determined from the model outputs. Fishery revenue was calculated as the total value landed (sum of product of the catch by month and fishing category times the beach price for that category and that month). The costs of fishing include only variable costs (labour, fuel, gear maintenance) such that the fishery profit estimated by the model is the annual short-term profit.

Table V-3 Fishery performance indicators.

Trigger points are adapted from Gardner and Ziegler (2010).

Indicator	Trigger point	Reference year = lowest since 1998
Regional legal size biomass	Minimum exploitable biomass by area since 1998	1998 for areas 1-4, 9-10; 1999 for 7-8; 2000 for 11; 2001 for 6; 2006 for 5
Statewide legal size biomass	Minimum of total exploitable biomass since 1998	1998
Regional egg production	Minimum spawning biomass by area since 1998	1998 for areas 1-4,11; 1999 for 8; 2001 for 7,10; 2006 for 5-6, 9
Statewide egg production	Minimum of total spawning biomass since 1998	1998
Regional catch rates	Minimum catch rates by area since 1998	1998 for areas 2-5, 9; 1999 for 1; 2000 for 7-8, 11; 2001 for 10; 2006 for 6
Statewide catch rates	Minimum of total catch rates since 1998	1998

3   Results

3.1   Climate change

The response of the fishing fleet to the different environmental conditions in Scenarios 1 and 2 is investigated with the three fleet dynamics models: FD0 which assumes the fishing fleet has a constant distribution of catch (not effort) per area and period, FD1 which assumes the fishing fleet follows the biomass and adapts the spatial allocation of catch accordingly, and FD2 which captures the fishing fleet response to the environmental changes by adjusting its fishing effort in time and space. The spatial allocation of fishing effort shows that the fleets respond differently to environmental pressures (figure V-8) which can be explain by the exploitable biomass by area (figure V-9) but also and mainly by the assumptions driving the fleet dynamics models. For models FD0 and FD1 fishers allocate catch to areas and then input the effort needed to obtain the catch (figure V-10) while in FD2 fishers choose their fishing

effort and the resulting catch depends on the biomass and on how much effort is applied by other fishers.

Fishing effort is distributed differently among areas according to the fleet dynamics model used (figure V-8). The FD0 fleet allocates a lot more effort in northern areas and less in the south compared to the FD1 or FD2 fleets. The effort of FD0 and FD1 fleets can be compared because the catchability is the same for both models while the effort is usually lower with FD2 as only the most efficient agents remain active in the fleet improving the average catchability of the FD2 fleet. The different models capture the observations to varying degrees in the different areas (i.e. the black dots on figure V-8 are closer to the model predictions of different models in different areas). FD1 predictions are the closest to what happened in 2007 and 2008 in the north (areas 4 and 5), on the East coast (areas 2 and 3) and in deep water (area 9) whereas FD2 predictions are closer on the West coast (areas 6 and 7). All models perform equally poorly in areas 1 and 8 in the south and equally well in areas 10 and 11 (deep south-western areas). This probably means that there are spatially heterogeneous constraints that are not explicitly captured in the models, FD1 and FD2, which influence the extent to which fleets respond. The overestimations of effort in area 9 by FD2 model seem to result from a shift of effort from areas 1, 2, 3, 4, 5 and 8. The over-prediction of regional effort in model FD2 could be due to real-life constraints not included in the model (e.g. weather constraint and sea condition), while the under-predictions of effort in the areas close to shore can be due to the exit of less efficient fishers who used to catch close to their home port. With the less efficient agents becoming non-active, the remaining agents needed less effort to catch the same amount of lobster on the East coast (areas 2 and 3 on figure 8 for effort and 10 for catch).
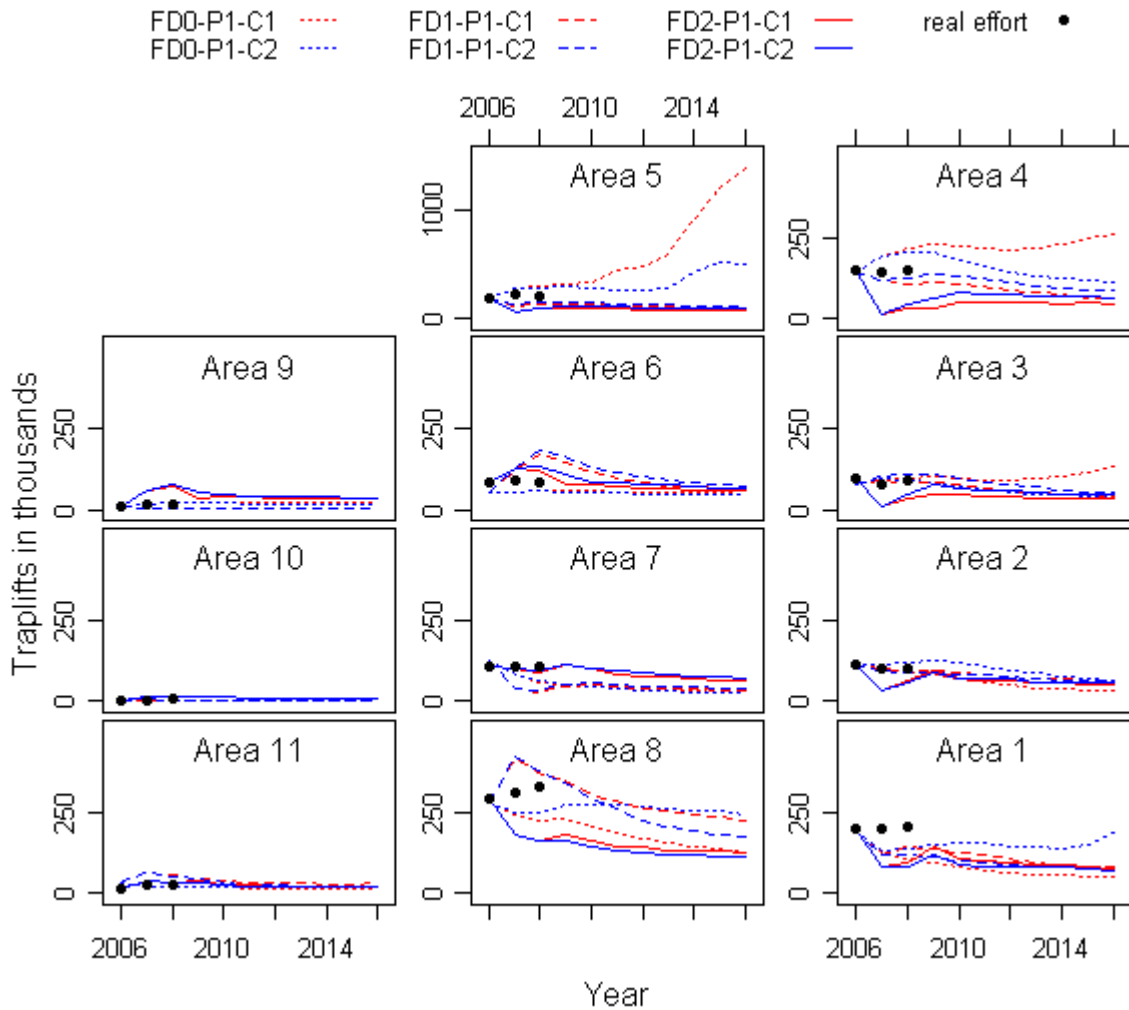
Figure V-8 Average simulated effort per year per area.

Effort in trap-lifts for the three fleet dynamics models with (red lines) or without (blue lines) climate change for the period 2007-2016. Black dots represent the latest observations. It should be noted that the y-axis scale is different for area 5 (0 to 1500) compared to the other areas (0 to 500).

The models predict different reactions of the fleet to climate change (C1, red lines). The dynamic models (FD1 and FD2) predict more fishing in the south and less in the north when climate change impacts the stock (C1) while the FD0 model predicts the opposite pattern. The climate change scenario (C1) is based on the assumption that the warming of sea water temperature will entail an increase of the growth rate of lobsters but reduce the settlement of post-larvae and therefore the recruitment of lobsters in the fishery (Pecl et al., 2009) whereas scenario C2 assumes that the growth rates and recruitment will remain consistent with historical levels. Climate change does not have the same effect on each region. The contrasting effects of climate change on biomass between the north and the south is observed

in the simulation results (figure V-9). Regardless of the fleet dynamics model used, the biomass is higher with climate change in the south and lower in the north. In the northern warmer waters of Tasmania (areas 4 and 5), the growth rate of lobster has always been higher than in the south where water is colder (Gardner et al., 2006). In the north, the lower settlement of juvenile lobsters is already observed by fishers, whereas the increase in growth rate has resulted in increased profitability from increased catch rates in southern regions. (areas 1, 8 and 11) as an increased proportion of the large undersized biomass attains legal size (Gardner and Ziegler, 2010).
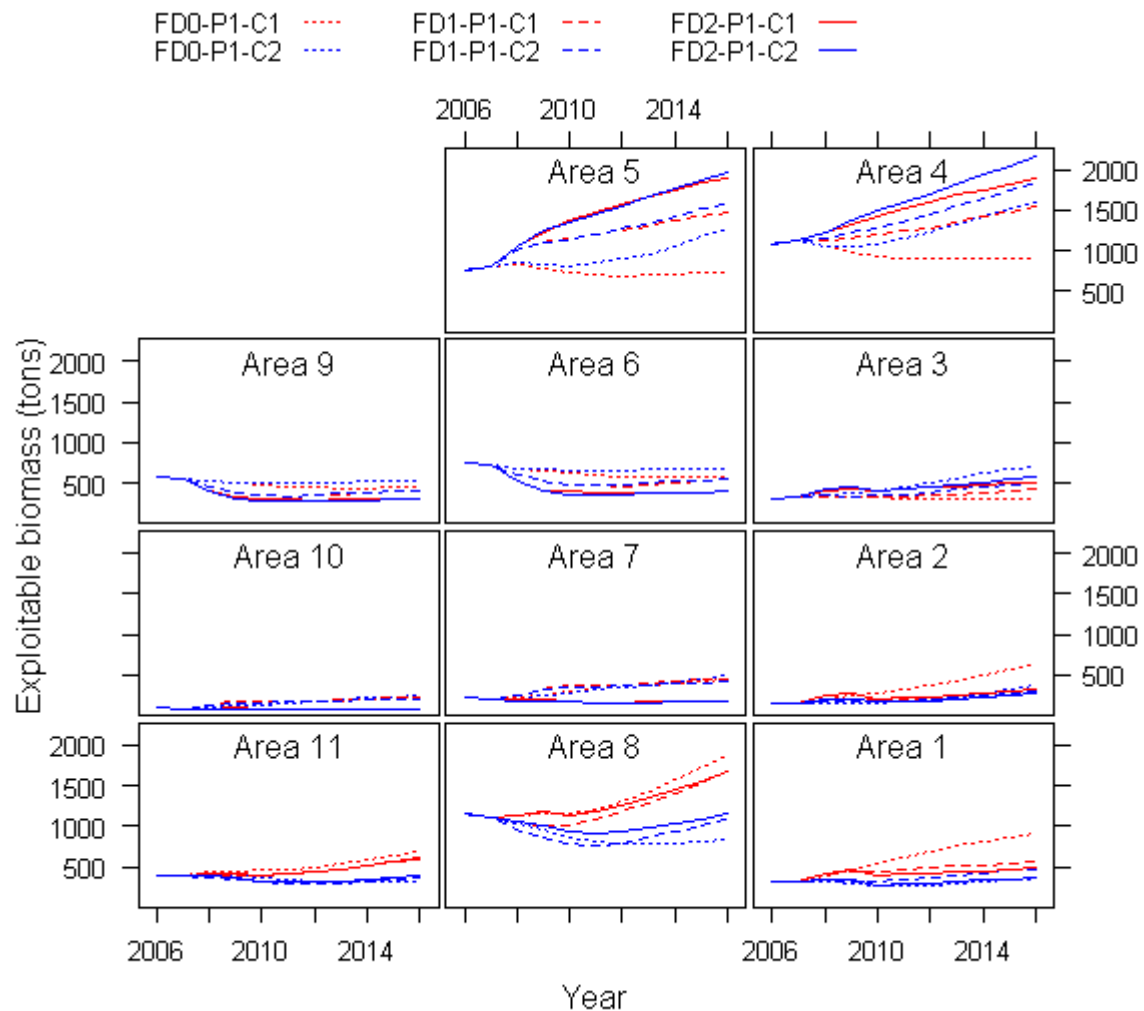
Figure V-9 Average exploitable biomass per year per area.

Exploitable biomass estimated as of the 1st January of each year for the three fleet dynamics models with (red lines) or without climate change (blue lines) for the period 2007-2016.

Although the effect of climate change on the local biomass is consistent for all the fleet dynamic models (higher biomass in the south, lower in the north), the differences observed between the models come from the different degrees that fleets adapt to their changing environment by modifying their fishing practices. The distance between the C1 and C2 biomass is greater when the fleet does not adapt (FD0) compared to when the fishing fleet adapts its spatial allocation to follow the biomass (FD1 and FD2). By adapting its fishing allocation the fleet reduces the effects of climate change on local biomass. It should be noted that the lack of new recruits due to climate change would eventually negatively affect the biomass in the south of the state when the pool of undersized rock lobsters is exhausted but the period of study is too short for this to occur (Pecl et al., 2009).

While, by definition, the non-adaptive fleet of the FD0 model keeps fishing the same proportion of catch per area as during the 1997-2006 period, fishing fleets in models FD1 and FD2 react to the differential changes in biomass and adapt their catch allocation accordingly (figure V-10). Under the climate change scenarios (C1), following the increase in exploitable biomass due to faster growth in the south, fishing effort intensifies in southern areas with models FD1 and FD2, particularly in areas 1 and 8. Inversely, in the north of the state, where growth rates have traditionally been higher, the lack of recruitment results in lower exploitation rates in the dynamic fleet versions of the model. The lower catches in area 5 with the climate change effect) compared to no climate change scenario do not come from lower biomass in the area (the biomass for C1 and C2 scenarios are superimposed for both FD1 and FD2 models, figure V-9) but rather from the attractiveness of southern areas that have increased biomass with climate change. The FD2 model, which includes the ability for fleets to respond to the size structure of catches, predicts lower catches than the FD1 model in areas 4 and 5 with and without climate change. This can be justified by the structure of the lobster population in these areas. The increase in growth rate means that the lobsters found in the north reach larger sizes faster and, combined with a decline in recruitment, result in fewer small lobsters in the landings. Given that the price of large lobsters is much lower than the price of smaller lobsters (about AUD$10 less per kg), the average price per kg of lobster caught would tend to be lower in the north, driving fleets away under FD2.
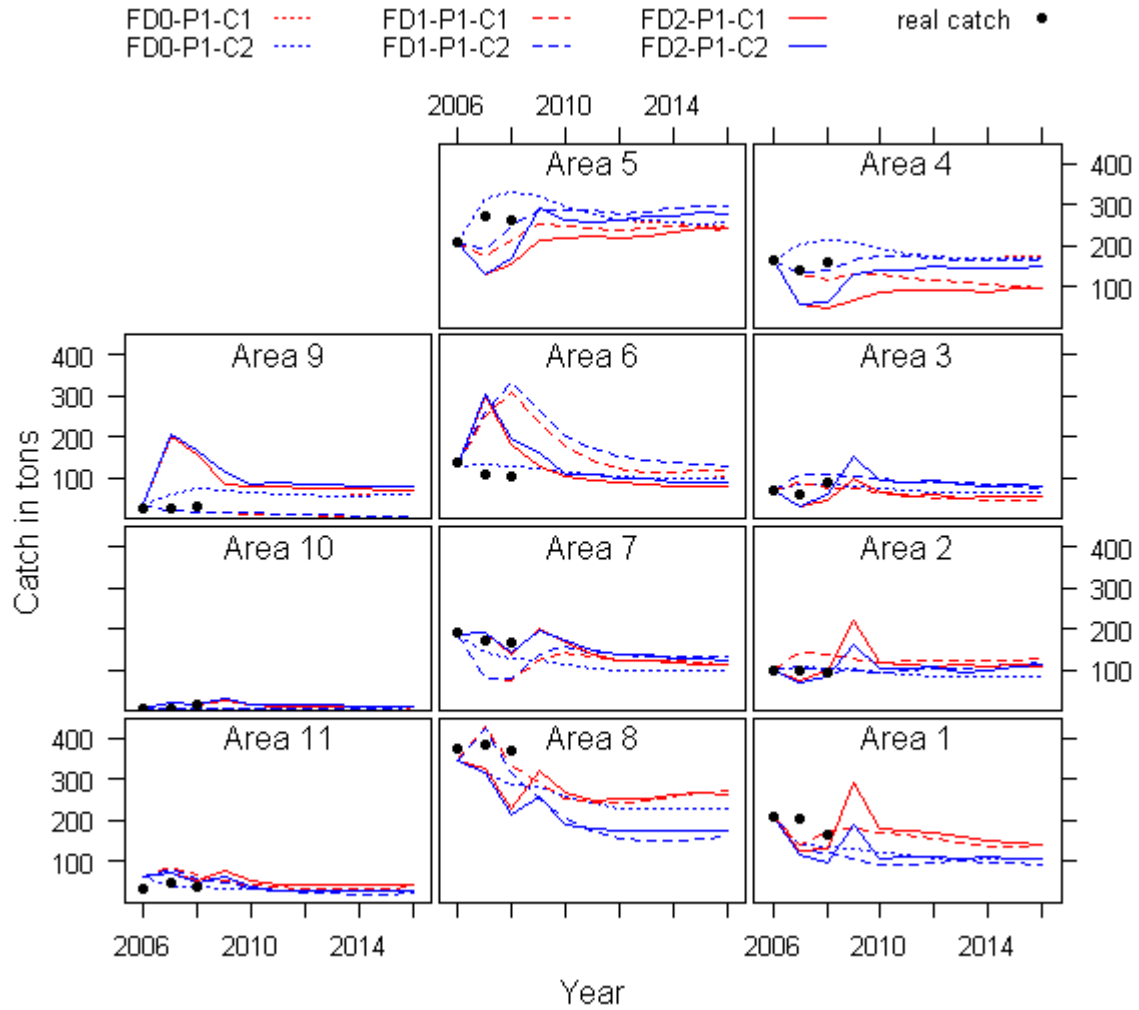
Figure V-10 Average simulated catch per year per area.

Catch is expressed as tons of lobsters for the three fleet dynamics models with (red lines) or without climate change (blue lines) for the period 2007-2016. Black dots represent the latest observations.

The catches of FD1 and FD2 fleets converge towards the end of the simulation period for most areas (figure V-9). Only area 9 (deep water on the West coast) shows notable differences of catch between model FD1 and FD2. This comes from the low effect of local biomass on catch proportion in model FD1 (low β in equation V.5). The FD1 fleet does not respond to changes in biomass in area 9 and the level of catch remains close to the value observed (figure V-9). In contrast, the FD2 fleet is highly attracted to area 9 due to relatively high expected catch rates (also observed in the fishery see Gardner and Ziegler, 2010). Real-life factors such as dangerous weather probably keep the fleet from catching more in the area. Such a factor would be captured by FD1 in the estimation of the constant term $\delta_{a,p}$ (equation V.5). The similarity between fishing allocations of fleets FD1 and FD2 is expected because climate

change directly affects the biomass (driving FD1 fleet) and subsequently catch rates (driving FD2 fleet through marginal profit). However, it should be noted that the fishing effort of the FD0 fleet remains also similar to the other models in the south, suggesting that the positive effects of climate change on the southern biomass were probably already observed in the period of calibration of FD0 (1997-2006). The lack of recruits in the north was probably not yet felt in the calibration period as the catch in the north remained high, driving the fishing effort of the FD0 fleet up to an unrealistic level in area 5 (figure V-8).

3.2   Impact of changes in the market for rock lobster

The lobster market disturbances in scenarios 3, 4 and 5 investigated in this section relate to the evolution of the lobster price both seasonally and annually, but do not include any change in the demand for size or colour categories, i.e. the price difference between categories remain constant. The catch distribution by area for the models FD0 and FD1 is not affected by the different price scenarios as fishing fleets do not respond to economic stimuli in those models. Changes in the spatial distribution of catch and effort for FD2 are also limited as price differences between market categories are assumed to remain constant over the years in the simulation so the relative attractiveness of one area compared to another remains unchanged. However, the change in price seasonality influences the seasonality of catch. With higher prices in winter (P2 and P4 scenarios), the proportion of lobsters caught in winter is expected to be higher than for the scenarios with a less obvious price seasonality (P1 and P3). This is only observed if the price increases annually (P2, figure V-11), while the proportion of catch in winter decreases from 2007 to 2016 for all other scenarios.

While in 2007, the differences in catch proportion between the price P2 scenario and the others are not significant or the difference in proportion is low (table V-4). However, the differences between the P2 price scenario and the others are significant in 2016 and on average over the simulation period. In 2016, agents catch 5 to 7% lobsters more in winter if the price seasonal variability is high and the inter-annual trend increases (P2) compared to all the other scenarios. It seems that if the price remains constant over years (P4) higher winter prices do not compensate for the lower winter catch rates (from May to September all female lobsters captured must be returned to the water unharmed) and increasing costs of fishing, resulting in declines in winter effort and catch.
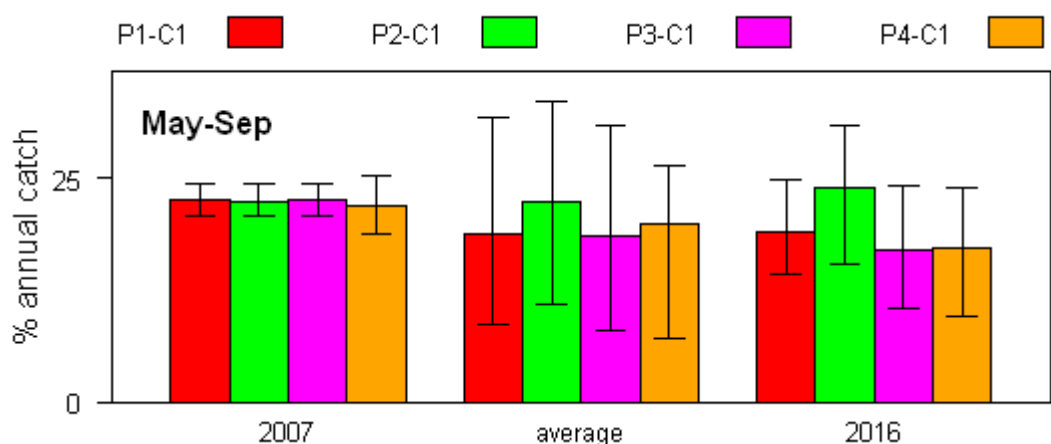
Figure V-11 Proportion of catch in winter.

Catch expressed as the percentage of annual catch during the female ban (winter) for each price scenario with model FD2 for the first year of simulation (2007), the average over the period ("average") and the last year of simulation (2016). P1 and P3 are prices with the recent seasonality (lower variation in seasonal price) and P2 and P4 reflect a much higher price in winter. P1 and P2 scenarios assume an increasing inter-annual trend while the inter-annual trend is constant in P3 and P4. The error bars represent the 90% confidence intervals.

Table V-4 Comparison of winter catch proportion between scenarios.

Difference in proportion of winter catch between the price scenario P2 (scenario 3) and the other lobster price scenarios (scenarios 1, 4 and 5) for the 50 simulations.

Model tested (H_0)	2007 coeff	P value	Average coeff	P value	2016 coeff	P value
P1-P2 = 0	0.04	0.18	-3.71	< 0.001	-4.97	< 0.001
P3-P2 = 0	-0.03	0.41	-2.41	< 0.001	-6.87	< 0.001
P4-P2 = 0	-0.63	< 0.001	-2.64	< 0.001	-6.69	< 0.001

3.3 Performance of the fishery under perturbations

The environmental pressures applied on the fishery and the way the fleet responds to those perturbations affect the viability of the fishery. The overall performance of the simulated fishery in terms of sustainability is assessed relative to the reference points defined in table 3. In this section the state of the Tasmanian lobster stock is examined at the end of the simulation period in 2016 on the performance of the exploitable and spawning stock biomass for all assessment areas (figures V-12 and V-13). In addition to ecological considerations,

economic and social indicators are also explored to assess the viability of the fishery (figures V-15 and V-16).

With climate change, southern areas are predicted to increase in exploitable biomass. For models that enable the fleet to be dynamic, this increase in biomass redirects effort from northern regions (areas 4 and 5) resulting in the final area specific biomass estimates in 2016 being closer to the trigger points in the south (areas 1, 2 and 8) compared to the static model where the fleet cannot re-distribute itself (figure V-12). The redirection of effort from northern to southern regions releases pressure on northern population (areas 4 and 5) which results in the predicted biomass moving from below the trigger point (model FD0) to being above the trigger point (models FD1 and FD2).
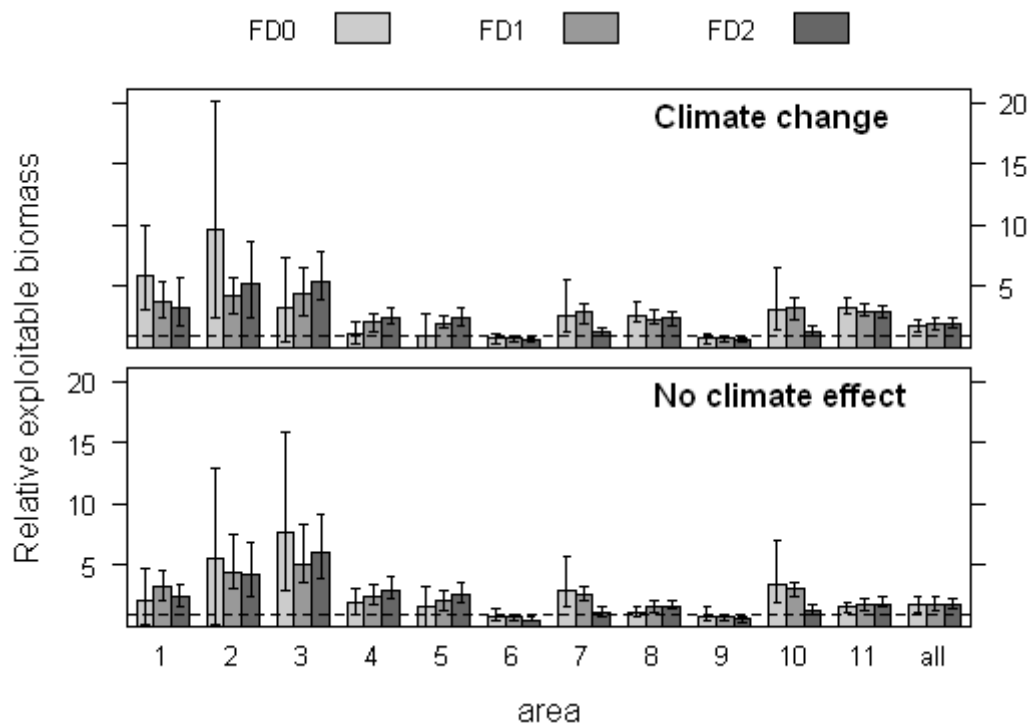
Figure V-12 Relative exploitable biomass by area with and without climate change.
Biomass is estimated by area and statewide ("all") in 2016 relative to the reference points defined in table V-3. Values are obtained by simulation models FD0, FD1 and FD2, with climate change (C1, upper panel) and without climate change (C2, lower panel) with price scenario P1. Error bars represent the interval of confidence of predicted values. The dashed horizontal line represents the reference point (relative exploitable biomass = 1).

Climate change effects the conservation of the spawning stock biomass (SSB), and lowers the local and statewide performances of the fishery if the fleet is dynamic (FD1 and FD2, upper

panel figure V-13). In all areas except for areas 3, 4 and 5 in the north, there is a risk of the SSB falling below the respective regional trigger point (figure V-13). If the fleet is considered static (FD0), the opposite pattern is predicted, southern areas display higher SSB than with a dynamic fleet but the northern areas show lower levels of SSB close to or below the trigger points (i.e. areas 3 to 5). In the case where climate change does not effect the growth and recruitment (lower panel figure V-13), higher SSB are predicted for most areas regardless of the fleet responsiveness. The decline of SSB in the southern areas can easily be explained by the use of statewide regulation on minimum landing size. Indeed, females in the south were indirectly protected by the minimum size limit used in the fishery as most of the southern female lobsters never reached the minimum legal size and thus the exploitable component of the stock (Gardner et al., 2006). The faster growth rates expected with climate change push part of the southern females over the size limit, making them vulnerable to fishing. In contrast, the spawning stock has always been part of the exploitable biomass in the north (females mature close to the legal size), therefore the decline of the exploitable biomass observed in the north with the static fleet is also seen for the SSB.

Overall, the predictions for the fishery from the model are promising (figure V-14). The chances of statewide ("total") exploitable biomass and spawning stock biomass (SSB) remaining above the reference level are higher than 80% (figure V-14). The catch per unit of effort (CPUE) is also estimated to remain high except in the case where the fleet is assumed to be static (FD0, dotted lines figure V-14). However, performance of the fishery at a local level are on average lower than the statewide performances. In particular, high catches in area 6 and 9 at the beginning of the simulation period resulted in lower biomass in those areas. The probability that the regional exploitable biomass in 2016 remains higher than the reference local biomass is about 75% for all scenarios, and is only marginally lower than at the beginning of the simulation period in 2007 (figure V-14).

The performance of the fishery regarding the maintenance of a reproductive female population looks more pessimistic than for the exploitable biomass. Climate change leads to the growth of southern females above the legal size limit, making them vulnerable to fishing, especially when the fleet is dynamic and increases fishing pressure in the south.
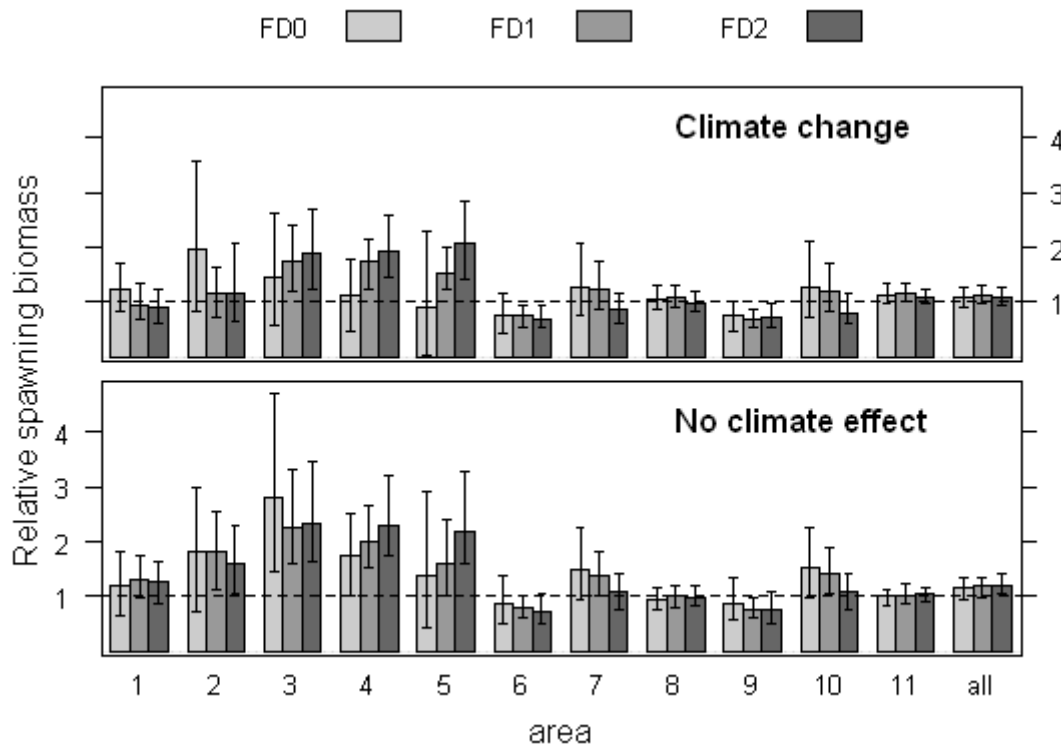
Figure V-13 Average spawning biomass by area with and without climate change.
Spawning biomass is estimated by area and statewide ("all") in 2016 relative to the reference point defined in table V-3. Values are obtained by simulations using models FD0, FD1 and FD2, with climate change (C1, upper panel) and without climate change (C2, lower panel). Error bars represent the interval of confidence of predicted values. The dashed horizontal line represents the reference point (relative spawning biomass = 1).

In the model, the catch rates obtained by the fishing fleet depend mainly on the exploitable biomass. Lower catch rates are obtained by the fishing fleet insensitive to biomass fluctuations (FD0 on figure V-14). Despite the declining biomass in those northern areas (figure V-9), the fishing fleet keeps on catching an important share of the TAC in the north of the state (figure V-10), mobilizing unrealistically high fishing effort (figure V-8). Dynamic fleets manage to maintain their catch rates at the same level as in 2007 by moving from areas of lower catch rates to areas of higher catch rates (figure V-14). It should be noted that the biological performances of the fishery are not influenced at all by the different price scenarios when FD0 or FD1 are used and the effect of alternative beach price scenarios on the lobster stock remains limited even with FD2, as the price variation does not effect the relative attractiveness of some lobster categories that could be targeted by shifting catches geographically.
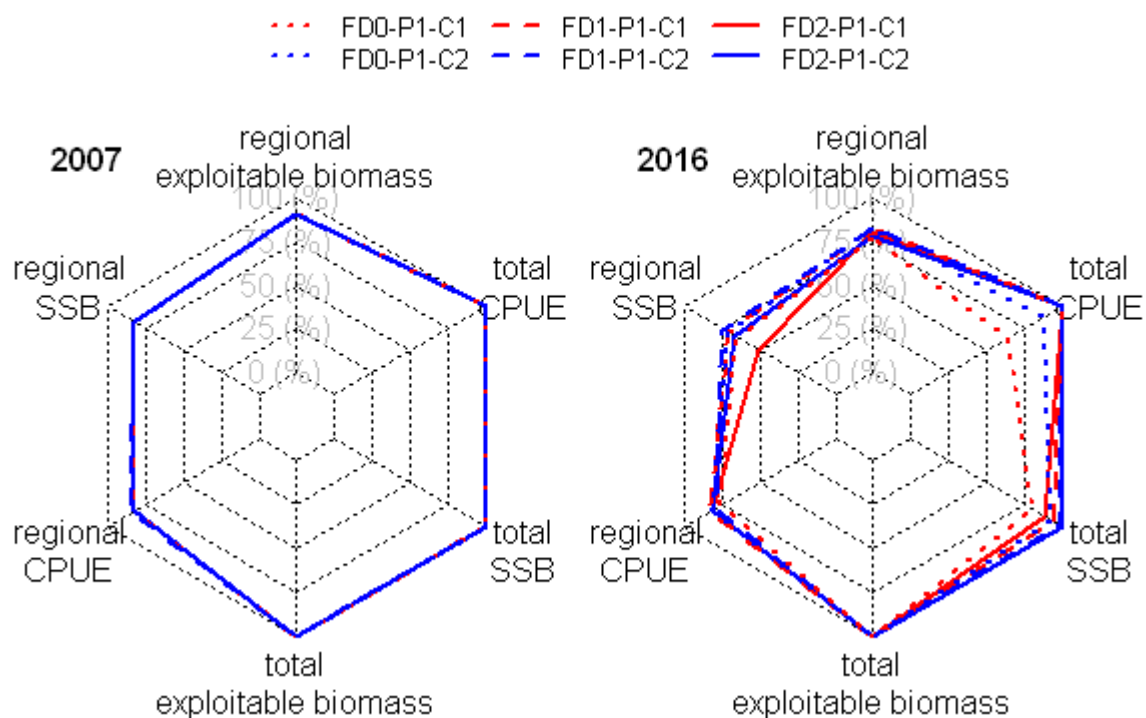
Figure V-14 Summary of the performances of the fishery in 2007 and 2016.
Results are presented for the three fleet dynamics models. The performance indicators are expressed as the percentage of the 50 simulation runs above the trigger points. Only the climate change scenarios are presented here (C1-red: climate change effect, C2-blue: historical recruitment and growth).

The fishery is managed with conservation objectives and with an objective of maintaining an active professional fishing fleet. Although the lobster stock is likely to be less productive in the future if the trend in low recruitment resumes, regardless of the fleet dynamic model used, the projections of the fishing stock for 2016 show that, with the current management plan, the exploitable biomass available statewide would remain higher than observed in 1998. The economic viability of the fishery is determined through costs and earnings (figure V-15). While the revenue from fishing shows little variability between models and within runs of a scenario, the fishing costs are considerably higher for a static fleet. The effort needed to catch the historical proportion (FD0) in the northern declining areas drives the fishing costs to extreme values potentially resulting in negative short term profit for the fishery (negative error bars in figure V-15). Under such a scenario, there is a considerable risk that the commercial fishery would cease to exist. The fishing costs are expected to be considerably lower and maybe underestimated in FD2 as only the most efficient agents remain active in the fishery, leasing the quota from less efficient fishers.
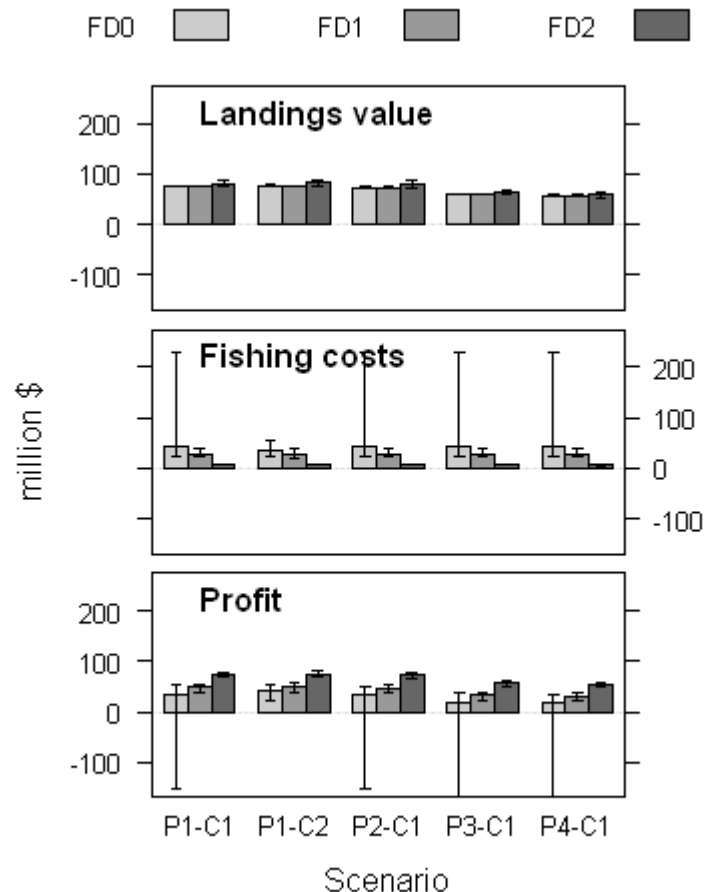
Figure V-15 Average of economic indicators on the fishery in 2016.

Economic indicators are calculated for all models (grey shades) and all scenarios (x-axis). Vertical bars represent confidence intervals.

Although the different scenarios on beach price trends investigated in this study do not affect fishers behaviour and subsequently the sustainability of the stock, they strongly affect the economic diagnostics of the fishery. In the scenarios with constant trends (P3 and P4), the fishery would be significantly less profitable than under the assumption of an inter-annual increasing trend of lobster price (an increase in lobster price is the most likely scenario). This highlights the importance of these assumptions when testing the economic viability of the fishery.

The viability of the fishery is also explored through the number of vessels active in the fishing fleet (figure V-16). Only the agent based model (FD2) allows investigation of the effect of perturbations on the size of the fleet, the size of the fleet in the other models is kept at the current level and presented for comparison purposes only. The size of the simulated fleet is much lower than the current fleet and probably underestimated indicating that real-life factors

not captured in the economic model affect the behaviour of fishers (see discussion on this in chapter 4). The size of the fleet does not vary significantly between scenarios but the differences between average fleet size seem related to the profit of the fishery. The model predicts a larger fleet when the expected profit of the fishery is higher.
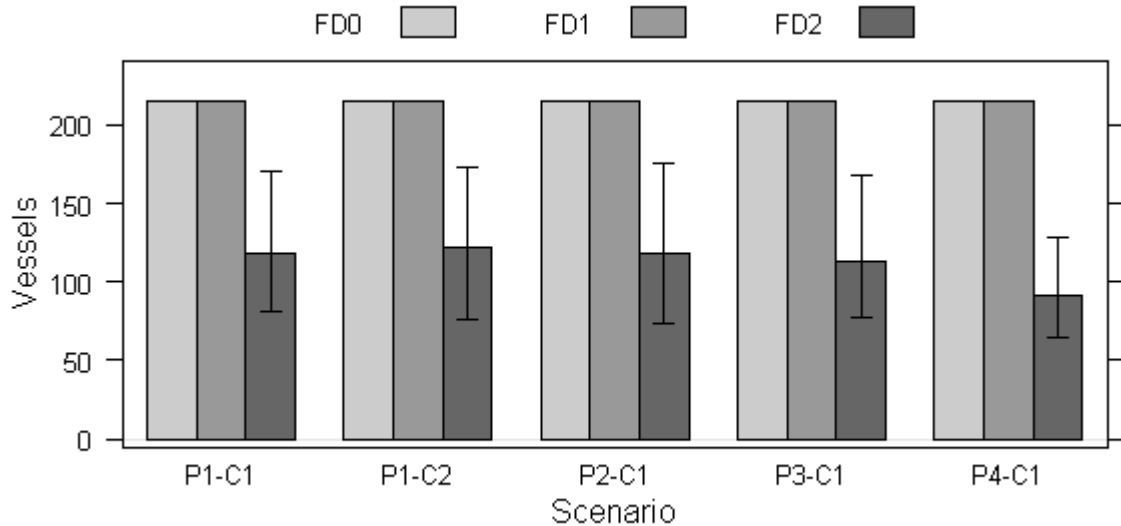
Figure V-16 Average number of vessels in the fishery in 2016.
Number of active vessels in the fishery are compiled for the FD2 model and all scenarios (x-axis). For models FD0 and FD1, the number of vessels is assumed constant at the 2007 level.Vertical bars represent confidence intervals.

The variability of predictions using the FD0 model is consistently higher than the variability of biomass and economic predictions using more realistic models with dynamic fleets (see exploitable biomass, figure V-12; SSB, figure V13- and economic indicators, figure V-15). With a static fleet, exogenous perturbations directly affect the fishery; while the response of dynamic fleets attenuate the effect of these perturbations. Although the effect of the uncertainty on the input parameters should be investigated by sensitivity analysis, it seems that the complex fleet dynamics model including stochastic elements (FD2) does not necessarily increase the uncertainty on results as fishers adapt their behaviour to counteract the negative effects of external perturbations. This is very important when studying the economics of the fishery, as variability in profits is a key driver of firm's decisions on investment and production.

As in other fisheries, spatial management of the Tasmanian rock lobster fishery has been suggested but fishers wish that their quota continues to give them access to the whole fishery and to freely move around Tasmania, rather than be contained to particular areas. This study shows that spatial management would be detrimental to the fishery under climate change perturbation.

4   Discussion

The current study examines the effect of external perturbations on a fishery system and how the likely change in fisher's behavior in response to such perturbations may affect the bio-economic performances of the fishery. Three fleet dynamics models are investigated. The simplest model (FD0) relies on a static allocation of catch by area and by period based on the historical catch distribution during the 1997-2006 period. The other two models are dynamic, FD1 integrates the effect of the local biomass in the distribution of catch to areas within a period but catch per fishing period is estimated constant over the years and both the period and area allocation of catch are calibrated on the 1997-2006 log-book data. The third fleet dynamics model used in the study (FD2) is based on the agent based modeling approach. FD2 allows for decisions by individual fishers on whether, when and where to fish on a monthly basis based on profitability considerations (chapter 4).

Unrealistic outcomes were obtained when no fleet dynamic component was incorporated in the model leading to three times as much effort needed to catch the same TACC as with dynamic fleets. Importantly, the dynamics of the fleet counter-acts the effects of perturbations resulting in the reduction in biomass being more evenly distributed across regions. As fishers are not constrained spatially in Tasmania, management decisions need to account for adaptation by fishers. The results also show that a simple fleet dynamics model integrating a biomass effect in the spatial allocation of catch (FD1) will successfully predict the reaction of the fishing fleet to changes in the fish stock.

However, model FD1 does not account for economic factors in the choice of fishing grounds and although catch rates are used to calculate profit, other factors also contribute to the profitability of fishing activity and should be taken into account when predicting fisher's behaviour. For instance, the composition of the catch can influence fishers choice if some categories are more valuable than others. This is the case in Tasmania.

High-grading has been taking place in the north of the state where fishers put the larger lobsters back in the water to save their quota for smaller lobsters that are more valuable. The negative impacts of climate change are felt faster in the north of the state as the lack of recruitment and faster growth rates of lobsters change the size structure of the catch with less small, high value lobsters (Gardner and Ziegler, 2010). Subsequently the returns in those areas are lower than what would be expected by looking simply at catch rates and an average beach price and fishers are likely to respond by moving away from these areas, to fish in more profitable areas. Although the size structure of the catch is taken into account in the FD2 model, the unique, constant selectivity used in the model may actually underestimate the catch predictions for the northern areas. The model assumes that all the catch is retained. As a consequence, the simulated FD2 fleet avoids the areas with large lower valued lobsters. To overcome this problem, the possibility for fishers to high-grade could be included in the model. With this possibility, fishers would potentially remain in the northern areas more than is predicted with the current FD2 model, although the costs associated with high-grading may still act as a partial deterrent to fish in these areas.

The effects of climate change on the fishing stock and the response of the fishing fleet agree with the findings of Pecl et al. (2009). The different beach price scenarios show less contrasted results. Tasmanian rock lobster fishers have adapted their catch to the seasonal distribution of prices after the introduction of ITQs and increased their share of catch in winter to profit from the higher prices on the Chinese market (chapter 2, Hamon et al., 2009). So a change in price seasonality was expected to impact the seasonal allocation of catch with winter catch expected to be higher in winter when prices are assumed higher (scenarios P2 and P4). However, higher winter catch were only observed for the P2 scenario. This could once again be due to the composition of the catch. Historically, exploitable biomass in the south-east was mainly composed of males as females grew slower and most of them did not reach the legal size (Gardner et al., 2006). With an exclusively male fish stock, the ban on female catches did not effect the catch rates in winter (although the colder water did, Ziegler et al., 2004). However, under the climate change scenarios southern lobsters grow faster and females which previously remained under the legal size limit become part of the exploitable biomass (Gardner et al., 2006). Thus, the lower winter catch-rates decrease even further during the ban on female lobsters, but higher winter beach prices may not be enough to compensate the lower catch rates, especially if the beach prices remain at the same inter-annual level (scenario P4).

Overall, the three fleet dynamic models give similar ecological diagnostics of the fishery but the model that captures fleet response to perturbation leads to a more regionally homogenous diagnosis. In addition to environmental considerations, the conservation of an active and economically efficient commercial fishery is also a major objective. To assess the wealth of the fishery, economic indicators have been calculated with available economic information. The amount of economic data needed for calibration of the FD2 fleet dynamics model may be deterring but the same information is needed to calculate cost estimates for FD1 models and in the latter case additional hypothesis are required to calculate average costs per traplift for the fleet (i.e. hypothesis on the composition of the fleet and the assumption that the fleet is kept constant). Ultimately, it is on the economic diagnosis of the fishery that disparities appear between fleet dynamic models. The FD2 model gave the most optimistic prognosis for the future of the fishery, while the FD0 model essentially predicts the end of rock lobster commercial fishing activity in Tasmania if the climate-change driven trends in recruitment and growth rates persist. Static models of fishing fleet (FD0) are only useful for a fishery without long-term perturbation, assuming a dynamic response of the fishery allows to test for ecological impact of perturbation as well as to changes in the fishery, both in term of reallocation of fishing effort (FD1 and FD2) and in terms of economic performances (FD2).

5   Conclusion

Climate change will certainly play a major role in defining the future of the Tasmanian rock lobster fishery. The findings of the current study confirms the prediction of Pecl *et al.* (2009), namely the short term effect of climate change will be the increase of biomass through faster growth in the south of the state and a commensurate shift of fishing effort towards the south to harvest the increased biomass. The situation in the north will be less fortunate as the lack of recruitment will rapidly result in the decline of local biomass. As projections in this study have only been exploring the fishery until 2016, the positive effect of higher growth rates outweigh the drop in recruitment and the overall performances of the fishery are still reasonably good at the end of the simulation period.

Two seasonal patterns and two annual trends of beach prices were examined in the study. A higher seasonal variation of lobster price led the fleet to fish more in winter when prices are higher but only if prices are high enough (increasing inter-annual trend). If the lobster prices

remain constant over years, the higher seasonality of prices do not impact the seasonal allocation of fishing and the simulated fleet favours summer fishing when catch rates are higher. In addition to increases in rock lobster prices, decreases should also be explored as rapid decreases have been experienced by the fishery – such as by SARS in 2003 and with market regulation in 2010 (ABC, 2010).

The use of comprehensive fleet dynamic models offers many advantages. The scenario testing possibilities increase enormously with complexity and the diagnostics of the state of the fishery can include more important aspects such as economic viability. In the agent based model used in the study, fishers' behaviour follows simple economic rules that try to maximize the return they can obtain from their quota allocation, either by fishing it where and when it is most profitable or by leasing it to other fishers. As shown in this study, this behaviour has important consequences on the spatial distribution of fishing effort, and on the economic performance of the fleet. Although the simulated fleet is probably adapting faster than in reality, the model is a useful and novel approach to forecast the repercussions of external perturbation on the fishery after the reaction of the fleet is taken into account.

VI   General discussion

This chapter first provides a brief summary of the findings presented in the thesis. Second, the results obtained are discussed in details in the context of the Tasmanian rock lobster fishery. The modelling approach and the main assumptions are discussed in the next section, highlighting the challenges encountered while modelling fishers' behaviour. Suggestions regarding improvements to the modelling of ITQ systems are then presented. Finally, the chapter concludes on the use of ITQs as management tools and how simulation work prior to the implementation of ITQs can support decisions on the design of such management systems.

1   Summary of findings

This thesis focused on the behavioural response of fishers to the introduction of individual transferable quotas in fisheries. The research was based on the study of the Tasmanian fishery for rock lobster, *Jasus edwardsii,* where ITQs were introduced in 1998. The response of fishers to the implementation of ITQs was investigated in four chapters. Chapter 2 showed that the overall effects of ITQs on the fishery conformed to the expectations found in the literature, i.e. rebuilding of the fishing stock, reduction of fleet overcapacity, increase in economic efficiency and some concentration of quotas, although the latter has been fairly limited. In chapter 3, I demonstrated that the changes induced by ITQs observed at the fishery level were the results of two combined factors, the structural modification of the fishing fleet and a change in individual behaviours of the fleet that remained active. Then a bio-economic model of the dynamics of the fishing fleet was developed combining fishing effort allocation and quota trading to capture the decision process of fishers and quota owners in this ITQ managed fishery (presented in chapter 4). The model was used to evaluate the effects of a change of quota trading limitations on the fishery (chapter 4) and to predict the future of the fishery, taking into account possible effects of climate change, and scenarios regarding the rock lobster market, driven by exports to China (chapter 5). The model performed well for fishing effort allocation but tended to overestimate the dynamics of quota trading and the exit of fishers from the active fleet. The fleet dynamics model proved particularly useful to project the future of the fishery with perturbation scenarios as it was able to account for the response of fishers to those perturbations.

2   ITQs in the Tasmanian rock lobster fishery

This thesis examined the Tasmanian rock lobster fishery ten years after the introduction of ITQs to assess the response of fishers to their implementation. With all the recommended conditions favourable to a successful implementation of ITQs, the Tasmanian rock lobster fishery was a good case study to investigate the response of fishers to this management measure. Prior to the introduction of ITQs, the details of the quota management system in the Tasmanian rock lobster fishery were discussed by the stakeholders with ecological, economic and social objectives in mind (Ford and Nicol, 2001). To maintain the lobster stock at a sustainable level (ecological objective), a TAC was implemented about 10% lower than the catch from previous years (Bradshaw, 2004) and was added to pre-existing technical measures such as minimum landing size, gear restrictions and seasonal closures. Economic and social objectives were also discussed prior to the introduction of ITQs in the fishery with two main concerns in mind: the equitable allocation of quota amongst fishers and to minimise the risk of the concentration of quota into fewer owners. The initial allocation of quota was the most debated aspect of the introduction of ITQs and the reason why part of the industry opposed ITQs. An agreed initial allocation was based on trap ownership which was the basis for prior access rights in the fishery (Ford and Nicol, 2001). To prevent the concentration of quota, limitations were set on ownership and use of quota at 120 quota units per licence or 200 quota units per person, i.e. less than 2% of the 10 507 quota units of the fishery (Anon, 2006).

The case study used in this thesis presents all the characteristics of the successful implementation of individual transferable quotas (Grafton and McIlgorm, 2009). The Tasmanian rock lobster fishery is a valuable fishery with a value at first sale estimated at AUD$60 millions in 2006-07 (ABARE, 2008), targeting a single species, *Jasus edwardsii,* for which the relatively small number of fishers (325 vessels in 1997) can obtain higher ex-vessel price from catching at different times and places. The conclusions drawn in the current study may not be directly transposable to other fisheries as different results could be found in fisheries with profiles less favourable to ITQs such as a multispecies fishery where other issues like high-grading and discarding should be considered.

ITQs were introduced because of the worrying state of the lobster stock in Tasmania in the early 90's, which rebuilt rapidly resulting in increased catch rates after their introduction (Haddon and Gardner, 2008). This recovery was due to a positive recruitment peak that

flowed through the fishery in the first years after quota introduction and to the cap set by the TAC. Setting adequate, restrictive TACs is essential to successful quota management system. Although the ecological effect of ITQs is positive in most cases, some fisheries such as Greenland halibut and New Zealand orange roughy, have been less successful than the Tasmanian rock lobster fishery and have shown decline in biomass after the introduction of ITQs, possibly due to inappropriate TACs, the lack of control or disregarded ecosystem issues (Chu, 2009).

After the introduction of ITQs the economic efficiency of the fishery has increased as a result of the reduced capacity of the fleet, improved catch rates, and of more fishing effort directed toward higher priced lobsters (chapter 2). The reduction in overcapacity was fairly rapid, 25% of the 325 vessels present in 1997 had left by 2001 (although it is lower than the exit rate of vessels in the mid-Atlantic surf-clam fishery where 56% of the fleet left within the first 4 years of quota management, Brandt, 2007). The changes in fishing strategies observed at the scale of the fishery resulted from the combination of a structural change of the fishing fleet and a modification of the behaviour of fishers staying in the fishery (chapter 3). Fishers traditionally operating in the northern areas where lobsters are larger and fetch a lower price left the fishery while the fleet in the South of Tasmania, close to the most profitable fishing grounds remained stable. In addition, the fishers remaining in the fishery intensified their effort in winter when rock lobster prices on the Chinese market are high, and targeted higher value red lobsters in shallow water.

Although the economic efficiency of the Tasmanian rock lobster fishery has improved since the introduction of ITQs, model simulations based on the available data and on assumptions relating to the behaviour of fishing operators suggest that the TAC could have been caught by even less vessels. Based on the 1997-98 fishing fleet and considering quota owners and fishers as profit maximisers with opportunity cost of fishing equal to the average salary in other industries, the fleet dynamic model described in chapter 4 predicts a fishing fleet of less than 150 active vessels in 2007 (against 215 active vessels observed) and a quota lease price more than AUD$5 higher per kilo than observed. This characterization of the simulated fishing fleet as being more economically efficient than the real fleet over the study period probably reflects the existence of various constraints and sources of inertia which impact on the decisions of fishing operators in reality, and which are not captured in the behavioural assumptions of the model.

The ITQ regime has induced some quota aggregation by owners (see chapter 2) but the limitation of quota ownership has prevented scenarios which occurred in New Zealand where the fishing industry is vertically integrated and big processor firms hold most of the quota (Batstone and Sharp, 1999). According to Tasmanian rock lobster processors, the aggregation limit is too low to be profitable for processors to gain market power on the rock lobster market (van Putten et al., 2011). Although limited concentration of quota has been observed, more quota is held by quota owners not fishing themselves (investors or former fishers), resulting in an increased amount that is leased (van Putten and Gardner, 2010). Simulations indicated that the limit of catch concentration implemented in 1998 (120 units) constrained the economic efficiency of some fishing firms, but the limit implemented in 2010 (200 units) would not have much effect on the size of fishing operations (chapter 4). The cap on the number of fishing traps used by fishers to catch their quota (limited at 50 fishing traps for the largest vessels) could however be restricting the size of fishing operators and make the limit on quota use redundant.

The future of the fishery is highly uncertain as it is largely driven by external factors. After a rapid recovery observed in the first ten years of quota management, the rock lobster stock has declined in the late 2000's (Gardner and Ziegler, 2010). A lack of recruitment seems to be linked to a regional trend of poor settlement of post-larvae (Linnane et al., 2010). Climate change is the likely cause of changes in oceanic currents leading to the lower settlements (Pecl et al., 2009). The lack of settlement and subsequently recruitment is already affecting the northern areas where lobsters grow faster. In contrast, the southern exploitable biomass benefits from climate change. The higher sea temperatures are considered to have improved the growth of lobsters causing the large undersized lobster population present in the South of the state to grow faster to the legal fishing size. The sudden growth of undersized lobsters to legal size would result in the increase of the legal size biomass in the southern areas in the short term (chapter 5). However, if poor settlements persist, the exploitable biomass will also decline in the South (Pecl et al., 2009). In addition to climate change, the invasive sea urchin, *Centrostephanus*, is altering the rock lobster environment on the East coast of Tasmania leading to an environment that is unfavourable to lobsters. (Ling et al., 2009).

Besides environmental perturbations, the economic situation of the fishery is also uncertain as it largely depends on a single client, which is the Chinese market. Disruption of the market as during the SARS outbreak in the early 2000s can strongly affect the economic viability of the fishery (Hacourt, 2003). In chapter 5, the scenarios investigated assumed that the price of

lobster would probably increase or remain at the same level as in early 2010, but in late November 2010 China decided to temporarily ban all Australian rock lobster causing a crash of rock lobster beach price in Tasmania. Given this recent event, it appears that the predictions presented in this study could actually be optimistic and overestimate the future profit of the fishery under the range of scenarios considered. Additional price scenarios could be tested regarding the overall trend in beach prices, the seasonality of demand or the change in demand (and price) of specific market categories. Economic perturbations of the fishery could also come from a change in the cost structure of rock lobster fishing operations, which is also largely driven by external forces. For example, labour costs for deckhand are believed to be related to the salary offered in the mining industry of Western Australia (S. Frusher, *pers. comm.*), so changes in the mining sector could drive labour costs in the fishery higher or lower. Finally, the choice of fishing location is highly related to fishers' fuel costs. The price of fuel has shown high variability since the early 2000s. This variability should be taken into account in future simulations of alternative management strategies.

3 Modelling behaviour in an ITQ fishery

Tradable quota facilitate the reduction of overcapacity in fisheries as most economically efficient fishers are expected to buy out less efficient fishers (Anderson, 1986). Quota trading occurs because quota owners have different expectations about the profitability of fishing. In a model with temporary transfers only (i.e. leasing), fishers expecting the highest profit per kg will lease quota from the less economically efficient fishers. To capture the dynamics of quota trading in the current study, individual agents are described explicitly and the dynamics of the fishing fleet are modelled with an agent based approach (Uchmanski and Grimm, 1996). The agent based modelling approach described in chapter 4 takes into account individual characteristics for quota trading as well as for fishing allocation decisions. The choices on where, when and even whether to fish depend on the expected economic profitability of each option. In a fishery where there is considerable contrast in the geographic location, the size of vessels and the efficiency of the fleet, individual economic performances are different and agent based modelling captures the heterogeneity of choice situations.

With individual quota limiting the catch of each fisher, it is assumed that fishers will try to maximize their marginal profit and choose the fishing option with the highest profit per kg.

Short term rent (i.e. short-term profit minus quota leasing costs) has also been tested as a driver of fishing decisions but as expected, the predictions of monthly choice of fishing activity matched the reality better when fishers tried to maximise their marginal profit (chapter 4). Fishing allocation is reasonably well described by a fleet-level linear model depending on the local biomass (chapter 5). However, such a model ignores the influence of price parameters which may play a crucial role in explaining the response of fishing fleets to changes in the environment in which they operate. Although biomass or catch rates have been used to predict fishing effort allocation, direct estimations of profit or revenue have usually been favoured to explain economic decisions (Smith, 2002, Vermard et al., 2008, Marchal et al., 2009a, Prellezo et al., 2009). The agent based model developed in this study allows the explicit description of the quota owners' decision process based on economic performances, and allows for scenario testing including economic perturbations. However, the computation power required to run agent based simulations is higher and specific data are needed, especially information relating to the individual characteristics of operators.

In the model, the flow of information is assumed to be perfect: every agent has instantaneously access to all the data such as catch rates per area or quota price. Subsequently, the response of agents to the information they receive is rational and immediate. In reality, information sharing is probably more limited, which could drive certain "investors" to maintain a minimal fishing activity to assess the state of the fishery themselves. While developing, the quota market seemed partitioned in sub-markets, and fishers probably did not have access to all the quota, but rather traded the quota held by people they knew (van Putten et al., 2011). As a consequence of these information limitations, and of other technical constraints, there is inertia in the real system that is not captured by the fleet dynamics model. This explains the difference between the predictions of the economic model and reality. To include this inertia effect in the model, the deviation between pure profit maximisers and real quota owners should be measured, and factors explaining the inertia, such as delayed information or risk averse behaviour, should be researched.

One of the greatest challenges identified during this study is the lack of adequate data to effectively integrate the economic dimension in a fleet dynamics model. While catch and effort data have been collected by each fisher at the daily level and by quarter degree block, cost and earning data are scarce in the Tasmanian rock lobster fishery. The only estimates of costs available for this study were collected in 2007 on a sample of 14 active fishers (Gardner and Van Putten, 2008). The lack of more precise economic data makes it difficult to estimate

costs at the individual level and to highlight the contrasts between fishers, which are the drivers of quota trading dynamics. In addition, a time series of more precise economic data would have been useful to investigate if fishers' decision processes changed with the introduction of ITQs. Finally, the evolution of the economic performances of the fishery since the introduction of ITQs can not be examined due to the lack of an economic baseline information before the introduction of ITQs. Without a routine collection of economic data, managers cannot assess the economic viability of a fishery against their economic objectives. The results of this thesis show that fishers behaviour is reasonably captured under the assumption of profit maximization behaviour. However, it is unclear if the difference observed between model predictions and reality are due to non-economic factors that should be included in the modelling of individual decision-making processes (see Fulton et al., 2011, and van Putten et al., In Press for the discussion of drivers of economic behaviour) or simply due to the absence of good economic data at the appropriate scale.

4   Perspectives for future research

The model developed for this thesis only takes into account short term behaviour and can therefore only be used for short term projections. The Tasmanian rock lobster fishing fleet has changed a lot in ten years and changes keep occurring. Long term economic decisions such as investment and disinvestment in quota and vessels and entry/exit of fishers should be included for any projection over 5 years. In addition, the decision processes already included in the model (fishing allocation and short-term quota trading) assume that agents are profit maximisers and only account for economic performances in predicting choices. In other fisheries, additional factors such as risk or individual characteristics including normative and social factors (Hatcher et al., 2000), have been integrated into the decision making process (van Putten et al., In Press) and discrete choice models such as random utility models (RUM) have been used and have successfully captured the effect of those additional factors (Vermard et al., 2008, Wilen et al., 2002). Such an approach to decision making could be implemented in the Tasmanian rock lobster model.

Information sharing is assumed to be perfect in the model, as regards both the quota market and the catch rates. In reality knowledge is limited and probably shared through social networks. ITQ advocates seem to assume that quota markets will be perfect, particularly in

terms of information (Arnason, 1990, Batstone and Sharp, 2003). However, van Putten *et al.* (2011) showed that the Tasmanian quota market was subdivided in smaller markets in the first few years of quota management. Different quota market structures could be investigated to test the effects of non-perfect quota markets. Subsets of quota owners trading within each group could be identified with network analysis and treated as independent markets in the model. This has already been implemented but not yet tested in the model I developped. Each agent would only be part of one market at a time and the quota price on a market would only depend on the local demand, supply and willingness to pay of members of that sub-component. Alternatively, network approaches could be used to model information flows between fishers.

Finally, high-grading should be taken into account. Although discarding is not believed to induce mortality as lobsters are returned live to the water, high-grading has implications for the economic performances of the fishery. For now, the biological model assumes the retention of all legal size lobsters caught by fishers. However, there is evidence that fishers discard larger lobsters as they fetch a lower price. In a projection model driven by marginal profit, the retention of those large lobsters will entail a lower attractiveness of the areas where they are found, explaining that simulated agents avoid the northern areas. A simple fix to this problem would be to have the possibility to choose between different retention options varying with the size/price of lobsters.

The improved model could be used for management advice. While commercial fishers have been reducing their catch in recent years (Gardner and Ziegler, 2010), the recreational fishery remains practically unrestricted. The number of recreational fishers has never been so high, keeping the pressure on the lobster stock close to populated regions (Lyle, 2008). Using the model to separate and investigate the effects of recreational and commercial fisheries could be helpful in the discussion of future management plans. In addition, our findings suggest that the cap on traps may be limiting the economic efficiency of Tasmanian rock lobster fishers who could increase their effort in winter months at reduced costs by using more traps. The model could also be used to test a range of trap limitation scenarios as a management decision support tool.

5   On the use of ITQs to manage fisheries

ITQs have been relatively successful at restoring a viable Tasmanian rock lobster fishery. Despite the difficulties encountered by the fishery leading to the reduction of the commercial TAC in recent years, the general feeling among the industry participants met during the preparation of this thesis was that there might not be a commercial rock lobster fishery left in Tasmania were ITQs not implemented in 1998. The success of ITQs in this fishery seems to be largely due to the discussions leading to the implementation of individual quotas which involved all the industry, and during which time was taken to debate contentious details such as the initial allocation of the quota shares and the limitation on quota concentration (Ford and Nicol, 2001).

This research was co-funded by the French marine research institute, IFREMER. The purpose was to investigate a case study with enough data to test the modelling of fisher behaviour in an ITQ system, and provide background knowledge and information on this, in the context of the current debate on the new European Common Fishery Policy (CFP). Issues have been identified in the European fisheries and several management options are investigated as a way to curb the current difficulties encountered in European fisheries (Anon, 2009). It is clear that the European Commission is currently evaluating ways to implement ITQs at a larger scale in the European Union (EU). In fact, the Netherlands and Denmark are already using ITQs to manage some of their fisheries.

"Our aim should be a system that helps to formalise these economic values as individual fishing rights, so facilitating greater transparency, legal certainty, security, and ultimately greater economic efficiency for fishermen, which will also mean minimising the costs to the rest of society." (Anon, 2007)

Although there is a strong push towards ITQs in several Northern European countries, the European Commission recognizes that ITQs are not a *panacea* and that implementing this access regulation scheme is a delicate matter, calling for some discussion prior to implementation. Several issues have been identified as key topics for coming discussions (Marchal et al., 2009b, Anon, 2007). Among those topics, some are political such as the principle of "relative stability" between EU countries which consists in keeping a constant

share of total catch shares at country level. This and other topics could be investigated through bio-economic models like the one presented in this thesis, focusing on quota concentration issues and alternative limitations of quota holding (chapter 4). In addition, scenarios on initial allocation and who can hold quota can also be envisaged through modelling. Finally, the issue of ITQ-related discarding or high-grading in mixed fisheries has also been investigated (Branch and Hilborn, 2008) and modelled (Poos et al., 2010, Little et al., 2009). The type of model presented in this study, combining effort allocation and quota trading, should be used to investigate the biological, economic and social consequences of the details of implementing ITQs.

VII Addendum

1   Appendices

A   Correction of regions of origin

Over the period 1993-2008, 116 of the 525 vessels operating in the Tasmanian rock lobster fishery had contradicting information on home port between the two available databases, MAST and DPIPWE, a further 152 vessels were only present in one of the database and 18 vessels were missing in both databases. Moreover, when present, data on home-ports was potentially inaccurate because of a lack of updating vessel information throughout the vessel's life. It is expected that location of origin would be a major factor influencing fisher's choice regarding their spatial fishing allocation via fuel costs. Therefore, the correction of fisher's geographical origin was undertaken.

The method used to allocate a home region to a vessel for a given year is described in figure VII-13. Seven regions were defined, "SE" South-East (area 1 on figure III-1), "EC" East coast (areas 2 and 3), "NC" North coast, "WC" West coast (areas 6 and 7), "FI" Flinders Island (North-East of Tasmania), "KI" vessels from King Island (North-West of Tasmania) and "OTH" with vessels from other Australian states (figure III-1). King Island and Flinders Island were separated from the North coast because as islands the possible alternative activities open to fishers are different from Tasmania's main land and this can influence their fishing decisions. The sorting method is used on every vessel separately identifying region of origin for all years active in the fishery. The first step is to identify periods with homogenous distribution of effort between the different assessment areas. The similarity over a period was tested by looking at the correlation between consecutive years. If two consecutive years had a correlation coefficient lower than 25% then a break in the time series was identified. Sequences of years between breaks define 'consistent periods'. It is assumed that the home region is the same within a consistent period, breaks (and possibly change of region) can be due to the vessel being sold to another fisher or the fisher moving home town. The second step is to identify home-region within the consistent periods. The two types of data with a spatial dimension that could be used to check and define region of origin of a vessel are the logbooks with the spatial description of fishing effort and the quota docket information which records unloadings since 1998.

Winter fishing is used first because it is usually more localised than during summer. Fishers tend to fish closer to their home and to the coast during winter due to rough weather and shorter days. When a vessel has fished in winter since 1998, unloading sites are used as a proxy to home region. Individual ports are all assigned to a "region" depending on their locations. If at least 75 % of the winter unloading occurred in a region then the vessel is assumed to be from that region for that given year. If the region of origin of a vessel is identified for some years within a 'consistent period', the same region is assigned to the years for which a region could not be identified.
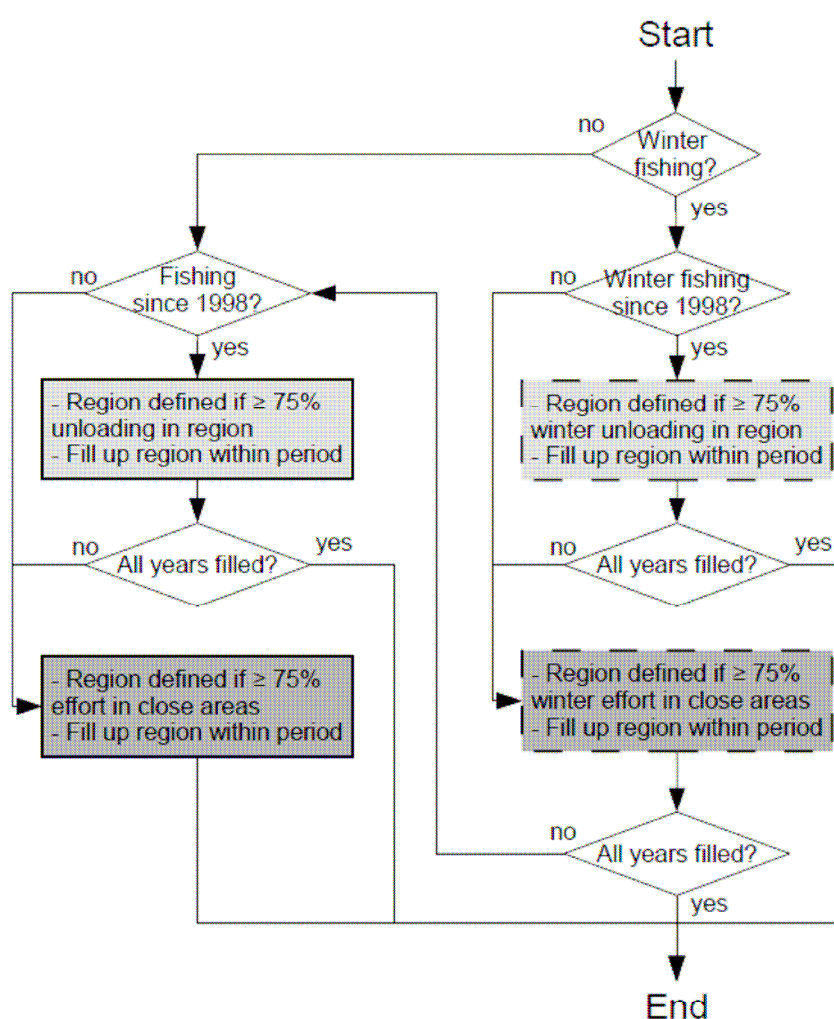
Figure VII-1 Flow chart of the allocation of home region for a vessel.

The definition of home regions is based on the available data, unloading (light grey box) since 1998 or effort (dark gray box) and winter data (dashed line box) or annual data (full line box)

In a second time, the main location of catch is used as a proxy for region of origin for the periods without region assigned. For East coast, South-East and West coast, the relationship between fishing areas and home regions is straightforward. The four other regions (North coast, King Island, Flinders Island and other states) share fishing grounds in areas 4 and 5, so a finer special scale, the quarter degree fishing blocks, is used to identify the home region. If at least 75% of the effort is put in areas (or blocks) neighbouring a region for a year then the region is assigned as the vessel home region for the year. The home-region was assigned to the whole period when identified as the region for a year within a 'consistent period'.

Of the 4256 vessel-year in the databases, 603 do not fish during winter (defined as the period June to August) representing approximately 14% of the vessel-year. In case of no fishing in winter unloading data and fishing effort allocation are used at the annual level to determine the region of origin. The newly defined home-regions are analysed against the previous definition of regions of origin available from official databases. Table VII-1 shows on the last row, the distribution of the predicted home-regions for the period, with each observation corresponding to a "vessel-year" (i.e. each year spent by a vessel in the fishery is an observation). First, the very low number of vessel-years without region should be noticed, from 296 vessel-years with missing information on home region down to only 15. Information on fishers home-region is important for the analysis of fishing activity and also to assess how different part of the fishery responded to the change of management. Second, the repartition of observations in each region is consistent with the original data. The matching level of the predictions with the data contained in official databases (bolded diagonal) is coherent with the fact that the official data was correct at an undefined point in time but likely to have changed. Third, the allocation of vessel-year to regions does not match the official data as well in the North of the state. Areas 4 and 5 on figure III-1 are in the immediate vicinity of four of the defined regions: North coast, King Island in area 5, Flinders Island in area 4 and the other Australian states North of the fishing areas. On table VII-1, too many vessel-years are allocated to King Island and Flinders Island whereas the North coast and other states vessels are probably underestimated.

Table VII-1 Proportion of matching prediction of home regions.

Predicted regions (columns) are compared to the official location of vessels (rows)

	West Coast	South East	East Coast	North Coast	King Island	Flinders Island	Other states	Non allocated	Num obs
West Coast	**54**	1	2	4	1	0	0	0	228
South East	10	**79**	10	16	18	14	5	0	1474
East Coast	2	4	**73**	7	9	7	3	20	871
North Coast	8	7	6	**61**	7	26	32	27	645
King Island	1	2	1	0	**42**	4	0	7	341
Flinders Island	0	0	1	0	2	**33**	6	0	115
Other states	6	2	1	3	15	9	**50**	7	286
Non allocated	18	5	7	9	6	7	4	**40**	296
Num obs.	309	1408	933	467	681	258	185	15	4256

It should be noted that the inter-annual shifts between regions are low. On average for each region, more than 80% of the vessels remain in the same region from one fishing season to the next denoting a geographical stability of vessels and by extension of fishers (table VII-2). No migration pattern of fishing vessels from a region to another can be identified as such. Vessels have left all regions, but in some regions the departure was partly compensated by entries (East coast, North coast and King Island). Entries in the fishery have been particularly important in the South East of Tasmania which is not surprising given that the . state-capital, Hobart, is located in this area. The proportion of vessels that left the fishery can seem really high but given that we work at the vessel level (and not the fisher) when a fisher replaces his fishing vessel by a vessel that was not previously operating in the fishery, the old vessel appears as "definitive exit" and the new vessel as a "first entry".

Table VII-2 Average annual vessel shifts between home regions between 1993 and 2006 in the Tasmanian rock lobster fishery expressed in percentage per year.

	West Coast	South East	East Coast	North Coast	King Island	Flinders Island	Other states	temporary exit	definitive exit
West Coast	81	3	3	2	1			1	9
South East	1	85	1	1				2	9
East Coast		2	87	1	1			2	7
North Coast		3	2	83	1			3	7
King Island		2			89			2	7
Flinders Island		1				85		2	10
Other states		2		1	1		89	4	4
re-entry	7	56	10	11	9		4		
first entry	9	36	17	13	14	5	7		

B Allocation rules of trips to métiers

Table VII-3 Allocation rules of fishing trips to metiers for all rock lobster trips during 1993-2008 period.

Effort is expressed as trap-lifts

Métier	Allocation rule
NW shallow	≥70% effort in area 5 less than 70 m deep
NE shallow	≥50% effort in area 4
WNW shallow	≥70% effort in area 6 less than 70 m deep
ENE shallow	≥60% effort in area 3
WSW shallow	≥70% effort in area 7 less than 70 m deep
ESE shallow	≥50% effort in area 2
SW shallow	>70% effort in area 8 less than 70 m deep
SE shallow	≥70% effort in area 1
S shallow	≥70% effort in areas 1 and 8 less than 70 m deep but <70% effort in area 1 and <70% effort in area 8 less than 70 m deep
NW deep	≥40% effort in area 5 more than 70 m deep
WNW deep	≥30% effort in area 6 more than 70 m deep
WSW deep	≥10% effort in area 7 more than 70 m deep
SW deep	≥30% effort in area 8 more than 70 m deep

C   Initialisation of the fleet dynamics model

To initialise the model, some data needed to be computed for 1997, the year before the simulations started. Among the data, month- and métier- catch rates by market category is used to calculate catch rate expectations and average monthly fishing costs other than fuel, labour and quota leasing costs are used to compute the fishing costs expectations. In addition quota price is used to initialise quota trading.

To initialise the month- and métier-specific catch-rates by market category for the year before the first year of simulation, log-book data and outputs from the stock assessment model are used. Catch-rates by area and month are initialised using 1997 log-book data. To obtain métier-specific catch rates, $U_{met,m,y}^{traplift}$, the catch rates by area, $\bar{U}_{a,m,y}^{traplift}$, are averaged weighted by the average distribution of effort to areas, $\bar{\alpha}_{a,met,m}$, for each métier (equation VII.1).

$$U_{met,m,y}^{traplift} = \bar{\alpha}_{a,met,m}\bar{U}_{a,m,y}^{traplift} \qquad \text{VII.1}$$

The catch rates are then disaggregated to lobster categories. Market categories are approximated by two variables: the colour (red in shallow water or white in deep water) and the size class (less than 0.8 kg, 0.8 to 1.5 kg, 1.5 to 2 kg and more than 2 kg). The depth at which lobsters are caught is used as a proxy for the colour (using a 40m limit available in logbook records, Chandrapavan et al., 2009) and the proportions of lobster in each size category by area and by period are derived from the outputs of the stock assessment model. The approximation of the distribution by size category is based on the assumption that the size selectivity is the same for every fisher and homogenous within an area. The fishing efficiency of those harvesting lobsters in those month-métiers (q_v^{Eff} defined in equation IV.24) is extracted and used to normalise the 1997 catch rates for a fishing efficiency of 1 (equation VII.2). The efficiency per month and métier is the average over the fishers weighted by the catch in the month-métier.

$$U_{cat,met,m,y}^{norm} = \frac{\sum_v q_v^{Eff} H_{v,met,m,y}^{month}}{\sum_v H_{v,met,m,y}^{month}} U_{cat,met,m,y}^{traplift} \qquad \text{VII.2}$$

Expectations of monthly fishing costs excluding fuel, labour and quota leasing costs, $\hat{C}_{v,met,m,y}^{other}$, are calculated per vessel for 1998 as the sum of the bait, food, clothes, gears and ice

costs for the year before (1997), divided by the number of months the vessel was active in the fishery.

Last, quota price the previous year is input has a initial value for the bisection method on the quota market. The simulations starting the first year quota was introduced, the initial price of quota is set to zero.

D Calculation of commercial catch

Because agents all fish simultaneously, catch by size class would be overestimated if the catch was calculated using the biomass at the beginning of the period. Instead, commercial catch is computed in each area using the biomass after half the catch is removed including the commercial, $H_{a,m,y,l}^{COMM} = \sum_v H_{v,a,m,y,l}$, illegal, $H_{a,m,y,l}^{ILL}$, and recreational, $H_{a,m,y,l}^{REC}$ catch (equation VII.3).

$$\overline{B}_{a,m,y,l}^{exploit} = B_{a,m,y,l}^{exploit} - \frac{H_{a,m,y,l}^{COMM} + H_{a,m,y,l}^{ILL} + H_{a,m,y,l}^{REC}}{2} \qquad \text{VII.3}$$

The recreational catch, $H_{a,m,y,l}^{REC}$, is set as a fixed proportion of a total allowable recreational catch TARC (see appendix E.3). However, the commercial catch depends on the exploitable biomass (as in equation VII.4) and the illegal catch is defined as a fixed proportion β_m of the commercial catch by period and by area. The commercial catch and exploitable biomass in the middle of the period can be computed by iteration (equations VII.4 to VII.8).

$$(H_{a,m,y,l}^{COMM})_k = F_{a,m,y} \cdot (\overline{B}_{a,m,y,l}^{exploit})_k \quad \forall k > 0 \qquad \text{VII.4}$$

where the total commercial exploitation rate, $F_{a,m,y}$, is calculated as

$$F_{a,m,y} = \sum_v q_v^{Eff} q_{a,m} L_{v,a,m,y} \qquad \text{VII.5}$$

and $(\overline{B}_{a,m,y,l}^{exploit})_1 = B_{a,m,y,l}^{exploit}$

$$(\overline{B}_{a,m,y,l}^{exploit})_{k+1} = B_{a,m,y,l}^{exploit} - \frac{(1+\beta_m)(H_{a,m,y,l}^{COMM})_k + H_{a,m,y,l}^{REC}}{2} \qquad \text{VII.6}$$

By substitution of $(H^{COMM}_{a,m,y,l})_k$ by its expression (equation VII.4) in equation VII.6:

$$(\bar{B}^{exploit}_{a,m,y,l})_{k+1} = B^{exploit}_{a,m,y,l} - \frac{(1+\beta_m)F_{a,m,y} \cdot (\bar{B}^{exploit}_{a,m,y,l})_k + H^{REC}_{a,m,y,l}}{2} \qquad \text{VII.7}$$

By iteration:

$$(\bar{B}^{exploit}_{a,m,y,l})_{k+1} = B^{exploit}_{a,m,y,l} - \left(\frac{(1+\beta_m)F_{a,m,y} \cdot B^{exploit}_{a,m,y,l} + H^{REC}_{a,m,y,l}}{2} \right) \cdot \sum_{i=0}^{k} \left(\frac{-(1+\beta_m)F_{a,m,y}}{2} \right)^k \qquad \text{VII.8}$$

Using Taylor's series (equation VII.9) and given that $(1+\beta_m)F_{a,m,y}$ represents the exploitation rate of commercial and illegal catch, it must be smaller than 1:

$$\forall |x| < 1 \quad \sum_{n=0}^{\infty} x^n \sim \frac{1}{1-x} \qquad \text{VII.9}$$

Thus, equation VII.8, converges to:

$$\bar{B}^{exploit}_{a,m,y,l} = (\bar{B}^{exploit}_{a,m,y,l})_\infty = B^{exploit}_{a,m,y,l} - \frac{B^{exploit}_{a,m,y,l}(1+\beta_m)F_{a,m,y} + H^{REC}_{a,m,y,l}}{2 + (1+\beta_m)F_{a,m,y}} \qquad \text{VII.10}$$

E   Data and model calibration

E.1   Economics data

The economics data used in this study are mainly derived from interviews with fishers of the Tasmanian rock lobster fishery in 2007 (Gardner and Van Putten, 2008). The survey included mainly estimates of costs (see table VII-4). Most fishing costs are linearly correlated with effort but some of the operating costs are only available at the annual level or the trip level. Gear costs, $C^{gear}_{v,y}$, are a combination of trap replacement costs and other annual fishing costs, namely rope and clothes costs (equation VII.11) divided by the number of days spent fishing per year, $E_{v,y}$. Ice costs are defined at the trip level (equation VII.12). The length of a trip, E^{trip}_v, depends on the vessel size (see table VII-5).

$$C^{gear}_{v,y} = \frac{\lambda \cdot P^{trap} \cdot T_{v,y} + P^{rope} + P^{clothes}}{E_{v,y}} \qquad \text{VII.11}$$

$$C_{v,y}^{ice} = \frac{P^{ice}}{E_v^{trip}} \qquad \text{VII.12}$$

Table VII-4 Costs variables kept constant over the period.

Cost estimates are based on a survey completed in 2007 (Gardner and Van Putten, 2008).

Parameter	Symbol	Value
Fuel usage – size multiplier- vessels <10m	δ_v	1
Fuel usage – size multiplier- vessels 10-18m	δ_v	1.5
Fuel usage – size multiplier- vessels ≥18 m	δ_v	2
Fuel usage – Distance multiplier	a	10
Fuel usage - constant	b	40
Bait cost per trap-lifts	P^{bait}	1$
Food cost per day, per person	P^{food}	50$
Replacement cost per trap	P^{trap}	180$
Percentage of traps replaced per year	λ	25%
Rope costs per year	P^{rope}	350$
Clothes cost per year	$P^{clothes}$	800$
Ice cost per trip	P^{ice}	1$

Table VII-5 Number of full time crew on board of vessels and duration of fishing trips according to vessel length.

Vessel length	Number of full time crew (n_v^{crew})	Duration of a fishing trip in days (E_v^{trip})
6 - 10 m	0.5	1
10 – 18 m	1	5
> 18 m	2	10

Labour costs defined in equation IV.9 depend on the number of crew members onboard of vessels (table VII-5) and on the opportunity costs of crew and skipper (figure VII-2). Although in the fishery most quota owners are skippers and may not consider their wages as costs, it is assumed here that every skipper is hired on the same salary, including owner-operators.
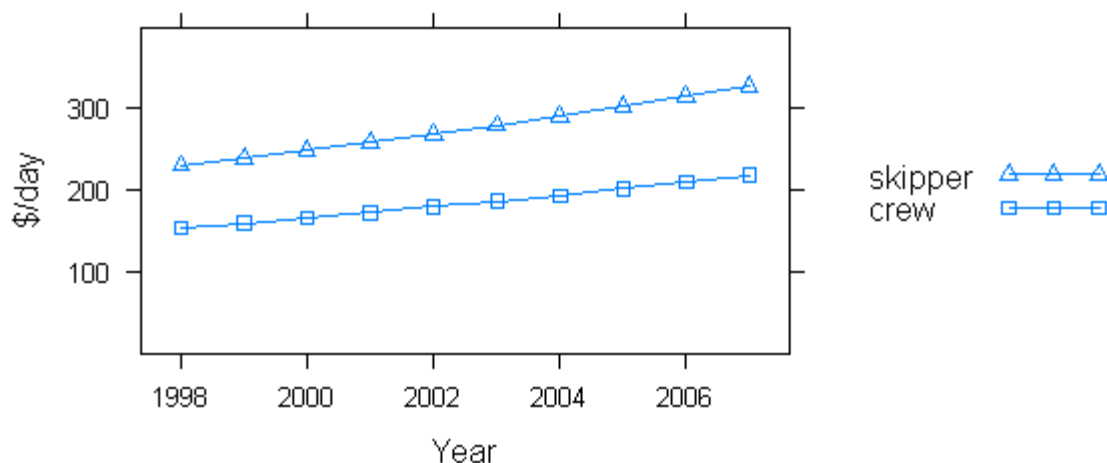
Figure VII-2 Daily opportunity cost of crew $S_{v,y}^{crew}$ and skipper $S_{v,y}^{skipper}$ 1998-2007

In addition to the cost data extracted from the survey including fuel use, fuel prices per month are needed to calculate fuel costs. The historical time series of fuel cost is extracted at the month level since 2001 (www.fuelwatch.wa.gov.au/) and average annual fuel price between 1997 and 2000 (www.abare.gov.au).
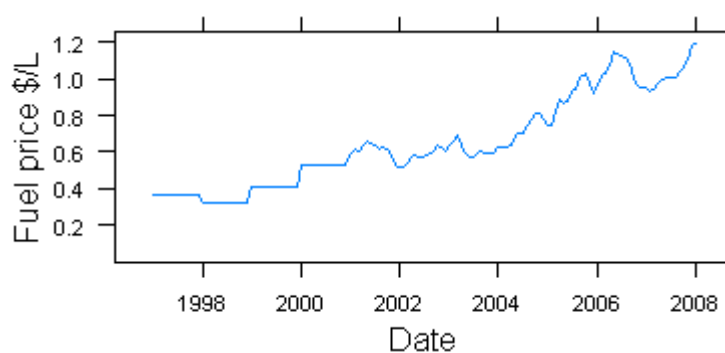
Figure VII-3 Fuel price, $P_{m,y}^{fuel}$, by month over the 1997-2008 period

The revenue from fishing is calculated as the sum of product of catch and beach price by lobster category. The beach price in the fishery is only recorded as the average lobster price per month by each processor without any reference to market categories. To integrate the price difference for different size and colour, a split price was calculated for each lobster category. Due to the lack of information on the composition of landings in terms of those market categories, the splits are calculated on 2009 data from one processor and assumed

season specific but constant over years (table VII-6). The price by category is calculated as the sum of the beach price for the reference lobster category (red, 0.8 to 1.5 kg, figure VII-4) and the split price.

Table VII-6 Split prices, $\gamma_{cat,m}$, between lobster market categories and the reference category (red lobster, 0.8-1.5 kg) by season.

	Summer		Winter	
	Red	White	Red	White
[0.6 - 0.8 kg[	-0.9$	-6.9$	0$	-2.4$
[0.8 - 1.5 kg[	0$	-6.0$	0$	-2.4$
[1.5 – 2 kg[	-5.7$	-12.1$	-1.1$	-3.4$
≥ 2 kg	-10.3$	-15.4$	-12.5$	-14.3$
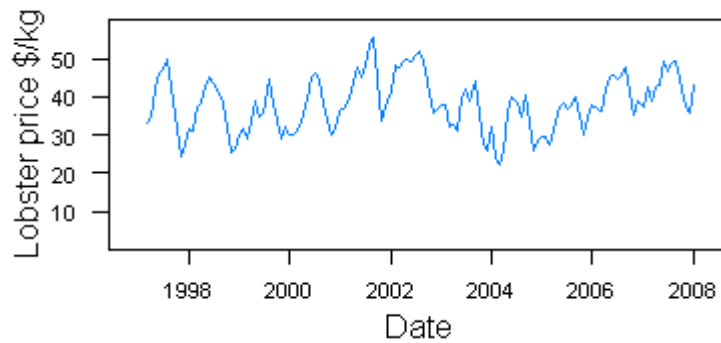
Figure VII-4 Lobster price for the reference market category, $P^{lobster}_{ref,m,y}$, for the 1997-2008 period.

E.2   Métiers characteristics

The distribution of effort to fishing areas is intrinsic to the definition of métiers (see chapter 3 for the definition of métiers). However, according to the season and the region of origin, the spatial effort allocation can vary slightly (figure VII-5). Fishers tend to fish closer to shore in winter (hence lower effort proportion in deeper areas) and when going to fishing areas far from their home port, it is not unusual for fishers to set a few traps in the areas they cross. Additionally to spatial heterogeneity, the maximum time spent fishing in a metier varies according to the season and the size of the vessel (figure VII-6). Indeed, rough weather prevents fishers to access some areas in winter, especially for the smaller vessels.
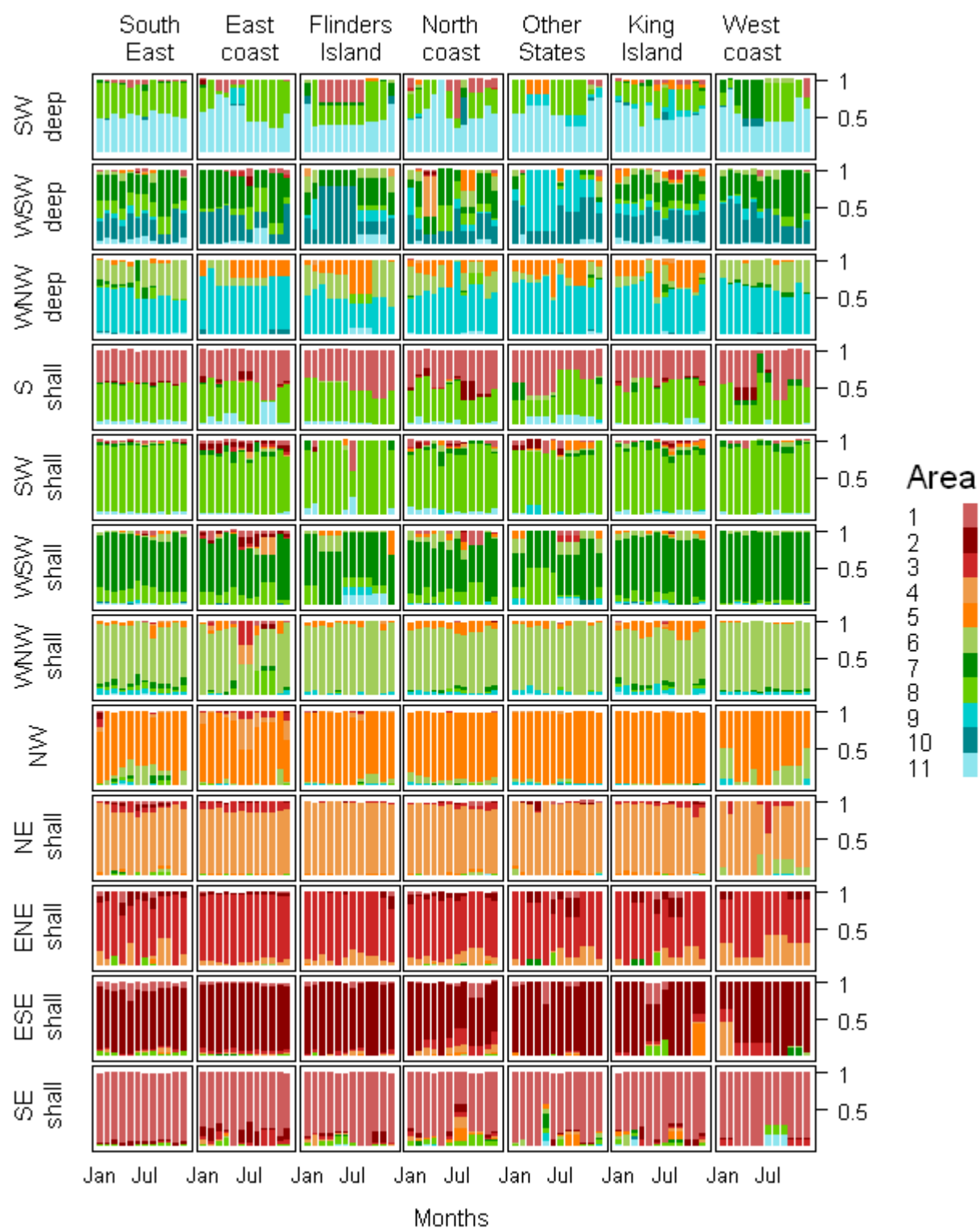
Figure VII-5 Distribution of effort by area for each métier for the different regions of origin, $\alpha_{a,met,m,reg}$.

Each panel corresponds to the month specific (x-axis) proportion of effort in each area (y-axis, sum of effort proportion in a métier, a month is equal to 1) of one métier (name of the métiers on the left of the figure) and one region (on top of the figure) .
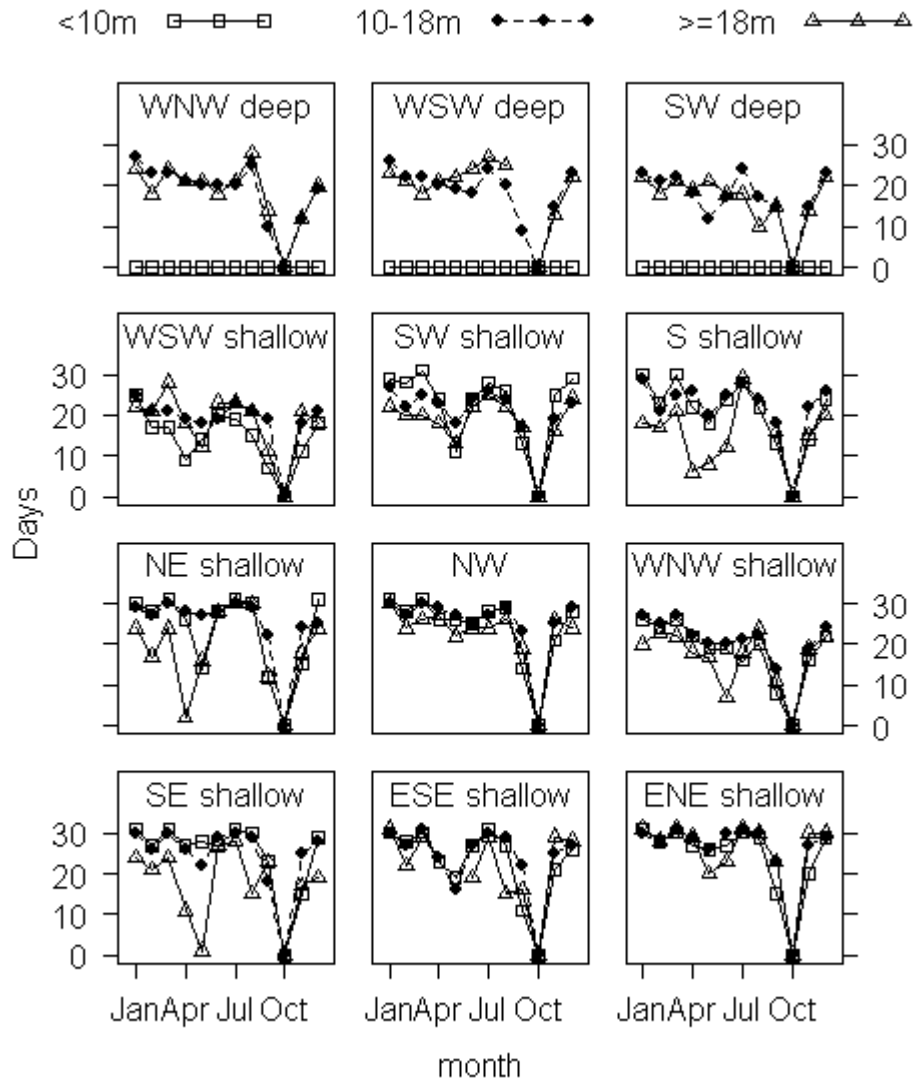
Figure VII-6 95th percentile of the number of fishing days, per month for each métier based on vessel size. $E_{v,met,m}^{max}$ **, observed during 1993-2008.**

E.3 Management

The management of the rock lobster fishery includes TAC on both commercial and recreational fisheries. The commercial TAC is strongly controlled and monitored and the values in table VII-7 correspond to the historical TACC. In contrast, the recreational TAC is not enforced in practice. The recreational TAC used here correspond to estimates of recreational catch used in the fishery assessment projections (Gardner and Ziegler, 2010), higher than the estimates from survey on recreational fisheries (Lyle, 2008).

Table VII-7 Commercial and recreational TAC for the Tasmanian rock lobster fishery 1998-2007.

Fishery	Period	TAC
Recreational	1998-2007	150 t
Commercial	1998-2001	1500 t
	2001-2007	1523 t

E.4   Quota allocation

Quota units were allocated to Tasmanian rock lobster licence owners based on the number of traps attached to the licence (the number of traps has been limited to 10507 since 1983, Bradshaw, 2004). The number of traps allowed on board of a vessel was limited to 40 prior to the introduction of ITQs, explaining why the majority of owners held 40 quota units or less in 1998. Owners with more than 40 units (figure VII-7) were the owners of multiple fishing licences that they used to lease out before the introduction of ITQs but in 1998, they recalled their licences and aggregated the quota units so that they could continue to fish large volume, forcing their lessees out of the fishery (Bradshaw, 2004).
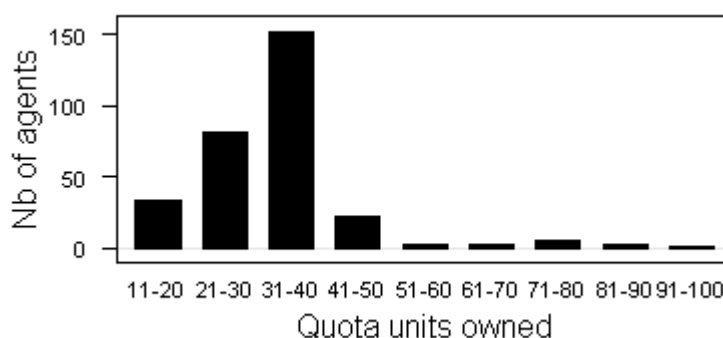
Figure VII-7 Number of quota owners according to number of quota units held for the 1998 fleet.

E.5   Vessels

Tasmanian rock lobster vessels come from all around the island and some from other Australian states (figure VII-8). The region of origin of vessels was extracted from official databases (DPIPWE and MAST) and was corrected using unloading and spatial catch information (appendix A). The most populated areas have traditionally concentrated the largest number of vessels (South-East and East coast), although the fishery profile has changed after the introduction of ITQs (chapter 3). The size of vessels has also evolved, but in 1998, most vessels in the fishery were of average size (figure VII-8). Fishers have invested in

larger vessels because the number of fishing traps allowed onboard of vessels is limited by regulation (table VII-8). The largest vessels can carry up to 50 traps. Using more traps has been a way of reducing the fishing costs (as with the introduction of quota every economic indicators became relative to the kg of lobsters caught).
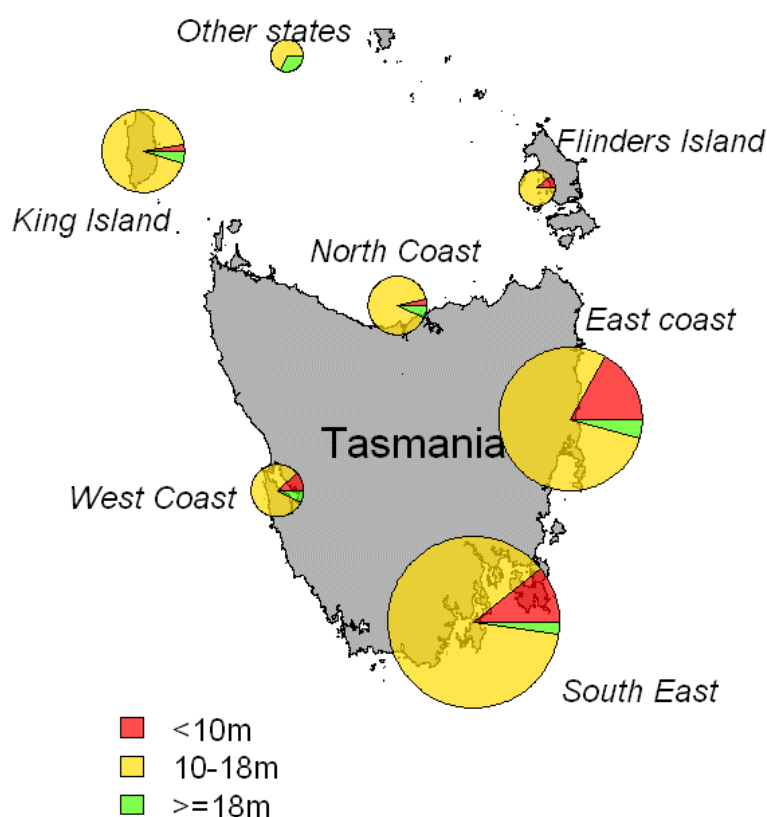
Figure VII-8 Distribution of the 1998 fleet by region and by vessel size, the size of the pie charts is proportional to the number of vessel from each region.

Table VII-8 Number of rock lobster traps according to length of vessel (Anon, 2006)

Length of vessel	Maximum no. of rock lobster traps
< 6 m	0
[6 – 7 m[	19
[7 – 8 m[	21
[8 – 9 m[	23
[9 – 10 m[	25
[10 – 10.5 m[	28
[10.5 – 14 m[	34
[14 – 15 m[	36
[15 – 16 m[	38
[16 – 17 m[	41
[17 – 18 m[	46
≥ 18 m	50

The fishing efficiency of vessels is an important factor in the selection of future participants of the fishery. It is expected that only the most efficient fishers remains active while the others lease their quota. The efficient fishers are not homogeneously distributed to regions (figure VII-9). Fishers from the South-East and the East coast seem to have higher fishing efficiencies than fishers from King Island, Flinders Island and the West coast.
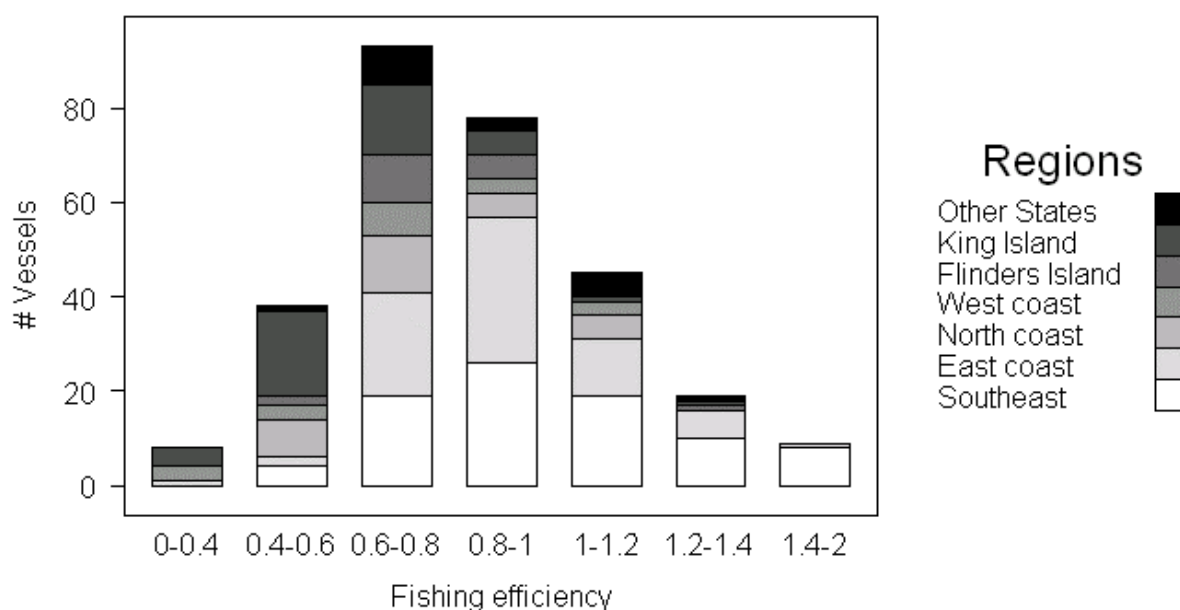
Figure VII-9 Distribution of the 1998 fleet according to their fishing efficiency, q_v^{Eff}, by region.

F   Simulated catch and effort by area

In the model, fishers take decisions on where to allocate their fishing effort based on expected profitability (figure VII-10). The effort is then translated into catch as a function of the exploitable biomass, the fisher's fishing efficiency and the effort of other fishers in the area. The selection of the most efficient fishers can explain that although, effort in Northern areas is lower than the real effort fishers put in the fishery, predicted catch in those areas remain close to observed catch (figure VII-11). High expected catch rates in areas 6 and 9 (Gardner and Ziegler, 2010) leads to predict a massive effort allocation to those areas in the first two years of simulation while the predicted effort comes back to observed levels afterward.
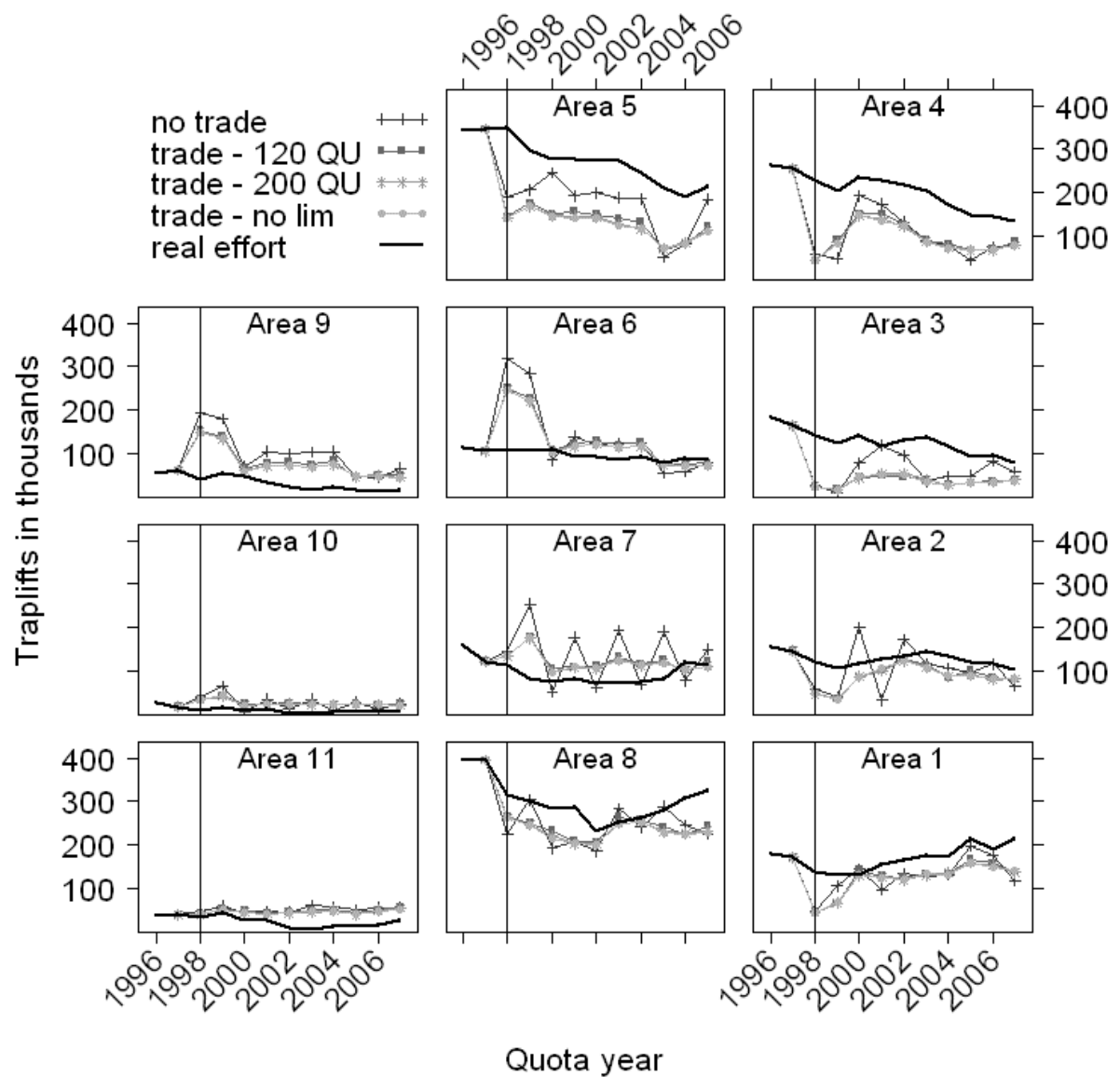
Figure VII-10 Effort per year and per area for the simulated scenarios compared to the real effort from log book data. Average effort in trap-lifts calculated over 100 simulations for the scenarios. The vertical line indicates the beginning of the simulations in 1998.
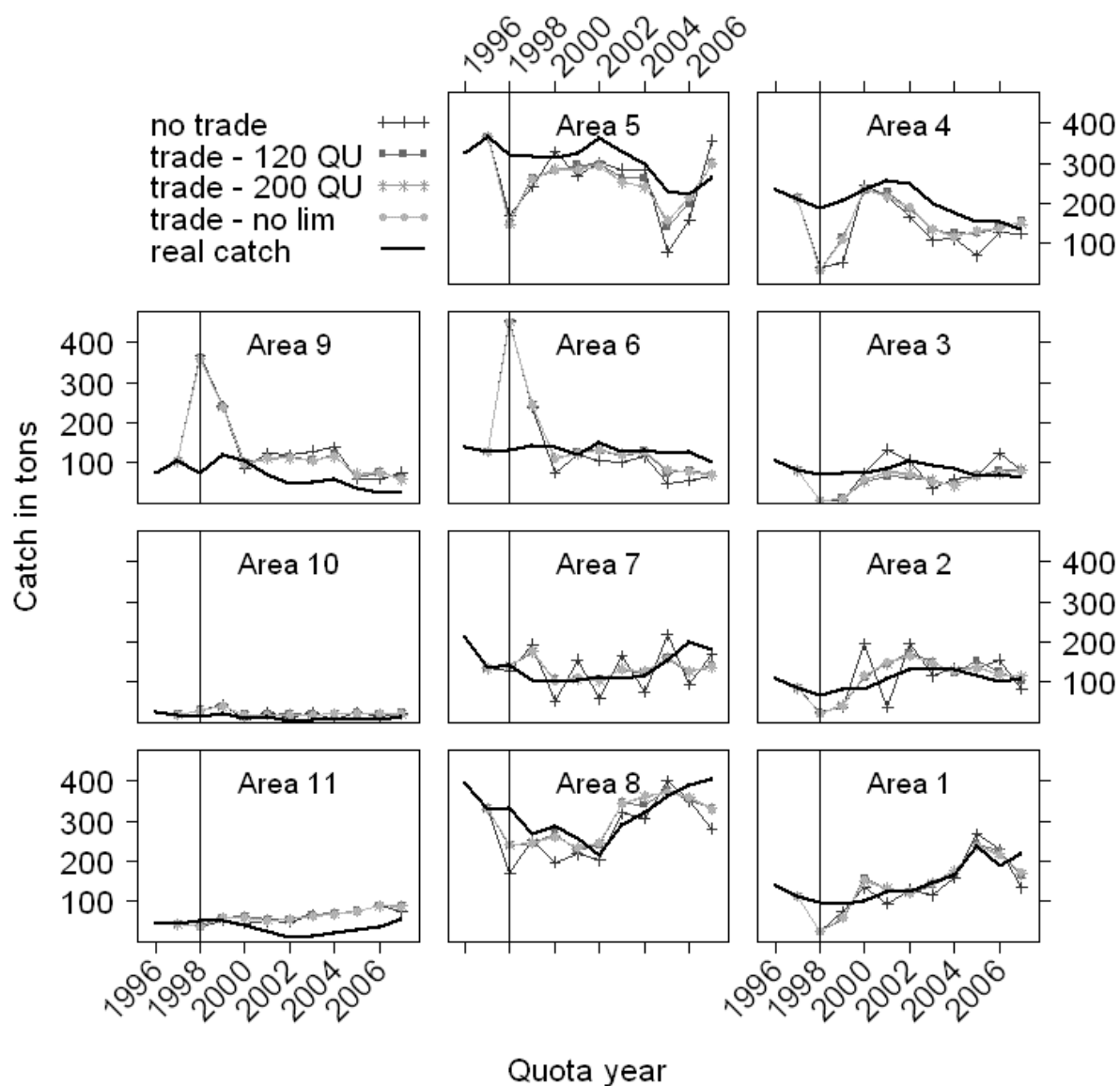
Figure VII-11 Catch per year and per area for the simulated scenarios compared to the real catch from log book data. Average catch in tons calculated over 100 simulations for the scenarios. The vertical line indicates the beginning of the simulations in 1998.

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3   Summary

In the past three decades, there has been a move towards rights-based management of access to marine fisheries, especially individual transferable quotas (ITQs). Although it is generally agreed that ITQs improve the economic efficiency of fisheries, few empirical studies examined how stakeholders respond to the incentives set in an ITQ fishery[0], determining the actual economic, social and ecological outcomes of such a management system. This thesis addresses the question of how fishers and quota owners make decisions regarding their fishing activities in the context of an ITQ system.

The study focuses on the Tasmanian rock lobster fishery. In 1998, ITQs were introduced in the fishery in an attempt to decrease fishing effort, while the total allowed catch (TAC) would restore the stock at a sustainable level. The thesis investigates the dynamics of the fishery as it evolved during the decade after introduction of ITQs. The study is based on an empirical analysis of the changes that occurred in the fleet and its activity, and on a bio-economic simulation model. To understand the complex dynamics of the fishery, fishing activity of the fleet was categorised as metiers that account for the spatial and seasonal heterogeneity of biological characteristics, infrastructure and weather encountered in the fishery.   These metiers were used to inform an agent based model of fishing behaviour. The model combines individual decisions on allocation of fishing effort with a quota trading market where quota owners can lease in/out quota according to their expected economic performances.

Empirical analysis shows that ITQs reduced the overcapacity in the fishery and that the TAC allowed the stock to rebuild. The impacts of ITQs on the fishery were the results of both structural changes of the fishing fleet and of the change of fishers behaviour. Fishers responded to the management change by modifying their fishing strategies in space and time to increase profit. In addition, the ownership of the fishing rights changed toward a higher proportion of quota owned by non-fishers, although concentration of quota has been limited in the fishery.

The bio-economic model was used to investigate the key drivers that underpin fishing and quota-trading decisions by the fishers and profit-maximising decision process predicted well the observed fishing behaviour. The limitation of quota aggregation is believed to have facilitate the reduction of excess capacity of the fleet but could constrain economic efficiency of fishing firms. The model was also used to assess the future of the fishery and test scenarios

on the potential impacts of changes in the economic and ecological environment in which the fishery operates. Although the future of the fishery remain uncertain, integrating dynamic fishing behaviour in projection models reduce the uncertainty and the use of economic drivers to simulate decision process allows to explore a wide range of scenarios regarding economic predictions and their outcomes including social and economic considerations.

4 Résumé long[2]

4.1 Introduction

4.1.1 Contexte

La gestion des ressources halieutiques est complexe car elle prend en compte des objectifs écologiques, économiques et sociaux. Dans ses évaluations les plus récentes (en 2008), la FAO (organisation des Nations Unis pour l'alimentation et l'agriculture) faisait état de 20% des stocks halieutiques mondiaux en surexploitation ou en voie d'extinction. La gestion des pêches par des mesures traditionnelles de conservation n'a pas réussi à maintenir les stocks de poissons à des niveaux durables. Des exemples d'épuisement des stocks et d'effondrement de pêcheries se trouvent dans la littérature, malgré les mesures de gestion pour préserver ces pêcheries (Hilborn et al., 2003, Caddy et Agnew, 2004). Bien que le nombre de stocks surexploités ou épuisés semble s'être stabilisé (FAO, 2009), certains scientifiques ont fait des prédictions alarmistes concernant l'avenir de la pêche mondiale, en prévoyant notamment l'effondrement mondial des pêches d'ici 2048 (Worm et al., 2006).

Depuis de nombreuses années, les scientifiques ont identifié le problème sous-jacent l'échec de la gestion des pêches comme «trop de pêcheurs pour pas assez de poissons» (Berkes, 1985, Hilborn, 2007). Ceci résulte de la nature d'accès libre des ressources halieutiques (Gordon, 1954, Hardin, 1968). Les externalités négatives créées par chaque pêcheur sur le reste de la flottille incitent les pêcheurs à être les premiers à capturer le poisson et alimentent la "course au poisson». Les poissons sont des ressources communes, et contrairement à d'autres ressources naturelles, le partage entre propriétaires individuels ne peut se faire a priori. En principe, l'absence de réglementation de l'accès signifie que les poissons peuvent être pris par quiconque veut pêcher. Dans les pêcheries en accès libre, les pêcheurs sont incités à entrer dans la pêcherie jusqu'à ce qu'il ne soit plus économiquement rentable de le faire, lorsque le profit d'exploitation est dissipé (Gordon, 1954). Les flottilles de pêche deviennent trop grande par rapport au potentiel de production des stocks de poissons et la surcapacité de la flottille conduit à une concurrence entre les pêcheurs. Les mesures de gestion diminuant la course au poisson existent et peuvent être utilisées pour compléter les mesures de conservation, en limitant l'accès à la pêche. L'utilisation de mesures de régulation de l'accès aux pêcheries

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[2] Conformément à l'accord de co-tutelle liant l'Université de Tasmanie et l'Université de Bretagne Occidentale, la thèse a été rédigée en anglais avec l'ajout de ce résumé long en français.

s'est développée dans le monde entier pour tenter de surmonter les difficultés résultant du libre accès aux ressources. Thébaud et al. (2006a) ont analysé les avantages et les limites des différentes approches de réglementation de l'accès aux pêcheries, et expliquent comment l'utilisation d'outils administratifs ou économiques tels que les taxes et les autorisations de pêche individuelles (transférables ou non) peut réduire la course au poisson.

Des mesures de gestion largement proposées et de plus en plus adoptées se basent sur des droits de pêche individuels et transférables (Christy, 1973, Moloney et Pearse, 1979, Wilen, 2006). Des droits de pêche de différente nature peuvent être mis en œuvre, basés sur l'effort ou les captures (voir Boncoeur et al., 2006 pour la typologie des outils de gestion de la pêche). Costello et al. (2008) ont suggéré que le développement d'autorisations individuelles de capture à travers le monde permettrait de freiner l'effondrement de la pêche prévue par Worm et al. (2006). Les autorisations individuelles de captures sont définies comme des allocations de droits de capture à des particuliers ou collectifs, généralement sous forme de pourcentages d'un total admissible de captures (TAC). Lorsque les droits de capture sont attribués à des individus et peuvent être échangés, ils sont appelés quotas individuels transférables, QIT. L'introduction de QIT a commencé depuis plus de trente ans (Chu, 2009). Dès 2006, seize pays de l'organisation de coopération et de développement économiques (OCDE) avaient mis en place des quotas individuels pour gérer tout ou partie de leurs pêcheries (OCDE, 2006). En 2007, au moins sept pays utilisaient des QIT comme leur principal système de gestion des pêches, y compris l'Islande, la Nouvelle-Zélande, l'Australie, le Canada, le Chili, le Groenland, les Pays-Bas, la Russie et le Maroc (Arnason, 2007). D'autres pays gèrent également leurs pêcheries à l'aide de QIT avec des règles d'échange variables, parmi ces pays on retrouve plusieurs membres de l'Union européenne, les États-Unis, le Mexique et la Namibie (Arnason, 2007, MRAG et al., 2009).

4.1.2 La gestion des pêches avec les quotas individuels transférables

En théorie, associés à des TACs appropriés, les QITs ont pour effets une plus grande efficacité économique de la pêcherie et, indirectement, l'exploitation des stocks à des niveaux soutenables. Le deuxième résultat est dû au fait que, même si seul le TAC contrôle les captures totales, les QIT sont censés donner un sentiment de propriété et de responsabilité aux participants entraînant un meilleur respect des règles (Anderson, 1995). Toutefois, le principal résultat attendu des QIT est d'accroître l'efficacité économique, comme l'a annoncé Christy (1973). Pour un TAC donné, la rentabilité d'une pêcherie peut être améliorée en augmentant

la valeur des débarquements ou en diminuant les coûts de pêche. Dans de nombreuses pêcheries en surcapacité, un moyen direct de diminuer les coûts de pêche est de réduire le nombre de navires dans la flottille (rationalisation). La rationalisation d'une pêcherie peut être facilitée par le transfert des droits de pêche. Les pêcheurs les moins économiquement efficaces peuvent vendre leurs quotas aux pêcheurs plus rentables et quitter la pêcherie, avec les gains de la vente de leur quota (Brandt, 2007).

En plus de diminuer leurs coûts, les pêcheurs peuvent augmenter leur revenu en changeant leur stratégie de pêche et en débarquant des catégories de poissons avec des prix plus élevés, augmentant ainsi la valeur des débarquements. Plusieurs stratégies ont été adoptées par les pêcheurs pour améliorer leurs revenus tout en tenant compte des contraintes imposées par leur quota. L'un des exemples les plus célèbres est la pêche au flétan en Colombie-Britannique (Casey et al., 1995), dans laquelle les pêcheurs atteignaient leur quota annuel en deux jours par an et la plupart des poissons étaient vendus congelés. Une fois que les QIT ont été mis en place, les pêcheurs se sont vus attribuer une part du TAC et n'ont plus eu besoin de rivaliser entre eux pour capturer leur quota. Ainsi la pêche s'est étalée sur toute l'année assurant un approvisionnement continu de poisson frais à un prix plus élevé. Dans d'autres pêcheries, les pêcheurs sont passés à des engins de pêches plus sélectifs (Dewees, 1989), ont transféré leur effort de pêche pendant les saisons où les prix sont plus élevés (Annala, 1996) et ont augmenté la valeur des produits débarqués par la transformation du poisson à bord (Annala, 1996).

Malgré des prédictions largement positives en termes d'efficacité économique, certains impacts des QIT aux niveaux économique et social ont soulevé des critiques (Copes, 1986, McCay, 1995, Pinkerton et Edwards, 2009). Bien que la transférabilité des droits de pêche ait des effets positifs car elle conduit à la réduction de la capacité excédentaire de la flottille, l'agrégation des droits de pêche par quelques propriétaires a été observée dans certaines pêcheries sous QIT et est considérée comme ayant des effets économiques négatifs. En particulier, la conséquence de l'accumulation de quotas entraîne un déséquilibre du marché pouvant conduire à l'inefficacité du marché (Anderson, 2008). En outre, les questions d'équité et de distribution des richesses ont été considérés comme les principaux inconvénients du système de gestion. Les préoccupations d'équité sont centrées sur le risque d'éviction des plus petites entreprises de pêche, où seules les firmes les plus grandes ou les plus riches ont accès au capital nécessaire pour acheter plus de quota (Bernal et al., 1999). De plus, l'économie locale des communautés de pêcheurs peut être affectée si le quota est

transféré à d'autres régions (Campbell et al., 2000, Arnason, 1993). Dans la plupart des cas, des règles ont été appliquées pour éviter ou limiter la concentration de quota, en limitant la proportion du TAC qu'une personne ou une entreprise peut posséder ou utiliser.

Trente ans après l'introduction des premiers QIT aux Pays-Bas pour la plie et la sole et en Islande pour le hareng (Chu, 2009), l'intérêt de la communauté scientifique et des gestionnaires ne cesse de croître. Il est maintenant reconnu que les QIT ne sont pas une panacée et que la mise en œuvre du système nécessite un examen attentif des possible effets sociaux. Malgré l'intérêt croissant pour les QIT, très peu d'études ont porté sur le comportement des flottilles de pêche dans le cadre de pêcheries sous QIT. Des modèles bio-économiques ont été utilisés pour analyser la répartition optimale des quotas entre les flottes de pêche sous les hypothèses que les pêcheurs ne changeraient pas leur activité de pêche (Guyader, 2002, Andersen et Bogetoft 2007, Armstrong et Sumaila, 2001, Kulmala et al. 2007). Toutefois, l'un des principaux effets attendus de QIT est que les pêcheurs vont changer leurs pratiques de pêche pour améliorer leur rentabilité. Malgré une prise en compte croissante du comportement des pêcheurs comme le principal facteur d'incertitude dans les résultats de la gestion de la pêche (Fulton et al., 2011, Hilborn, 2007, Wilen, 1979), des modèles de comportements individuels ont rarement été appliqués aux pêcheries sous QIT. Le développement de modèles d'allocation d'effort et de marchés de quotas dans les systèmes de QIT a augmenté ces dernières années (voir Little et al., 2009 pour l'application d'un marché de quotas, et Poos et al., 2010 pour un exemple de modèle de comportement des pêcheurs dans une pêcherie sous QIT), il n'existe cependant que quelques exemples, tous très récents, justifiant l'exploration de ce type de modèle dans cette thèse.

4.1.3   Objectifs de la thèse

Les objectifs de cette thèse visent à contribuer à l'amélioration des connaissances sur la réponse des pêcheurs à l'introduction de QIT. La recherche a deux objectifs principaux. Le premier consiste à comparer les prédictions théoriques sur les incitations créées par QIT à des données réelles sur le comportement des pêcheurs. Les données empiriques, à la fois qualitatives et quantitatives, sur un cas d'étude sont utilisées pour identifier et évaluer les facteurs influençant les réponses des pêcheurs, et analyser les changements dans les activités de pêche. Le deuxième objectif est de créer un modèle bio-économique, incluant allocation de

l'effort de pêche et marché de quotas, afin de capturer les motivations identifiées dans l'analyse du cas d'étude. Un module de dynamique de flottille est ajouté à un modèle biologique existant. Les décisions de pêche et d'échange de quotas sont modélisées au niveau individuel pour capturer le comportement micro-économique à court terme des acteurs de la pêcherie. Le modèle est ensuite utilisé pour discuter des effets potentiels de mesures de gestion et pour simuler des scénarios de perturbations externes. Une attention particulière est apportée à i) l'examen de différentes règles limitant l'échange de quotas et de leurs impacts sur les performances économiques de la pêcherie et à ii) la simulation de scénarios de perturbations et l'examen de la réponse de la pêcherie aux changements climatiques et à des perturbations économiques. La pêcherie de langouste en Tasmanie est utilisée comme cas d'étude.

4.1.4   La pecherie Tasmanienne de langouste

La pêcherie de langoustes est la deuxième plus importante pêcherie de Tasmanie en valeur derrière la pêcherie d'ormeaux (ABARE, 2008) mais c'est la pêcherie la plus importante en terme d'emplois (Gardner et al., 2004). La valeur des débarquements a été estimée à 60 millions AUD $ en 2006-07 (ABARE, 2008), tandis que les emplois directs dans le secteur de la pêche et des entreprises de transformation ont été estimés à 1350 personnes équivalent temps plein en 2002 (Haddon et Gardner , 2009). En outre, environ 20000 permis de pêche récréative, ont été délivrés en 2006/07 soit près de 4% de la population Tasmanienne, (Lyle, 2008). Compte tenu de l'importance économique et sociale de la pêcherie, sa gestion durable a été importante pour la population de Tasmanie. Le ministère des industries primaires, des parcs, de l'eau et de l'environnement (DPIPWE) est responsable de la gestion de la pêche, incluant la collecte des données de capture et d'effort, du contrôle des quotas. En plus, de données de capture et d'effort par jour fournies par les pêcheurs, DPIPWE recueille également les prix moyens payés par les mareyeurs, les échanges de quotas (temporaires et permanents) entre les propriétaires de quotas, des caractéristiques des navires de pêche, et des informations sur les pêcheurs et les propriétaires de quota. En plus des données collectées régulièrement, des enquête socio-économiques ont été effectuées juste avant (Williamson et al., 1998) et après l'introduction de quotas (Frusher et al., 2003) et une enquête économique a eu lieu en 2007 (Gardner et Van Putten, 2008). La quantité et la qualité des données disponibles faisait de la pêcherie Tasmanie de langouste un bon cas d'étude.

La langouste, Jasus edwardsii, est exploitée en Tasmanie, au sud-est de l'Australie. Bien que géré comme un seul stock, la langouste Tasmanienne présente des caractéristiques liées aux zones d'habitat. Les langoustes sont sédentaires après le stade larvaire (Gardner et al., 2003) alors, les pressions environnementales influencent la croissance et la couleur de la carapace produisant une population spatialement hétérogène. Dans le Nord de la Tasmanie, les langoustes sont plus grandes car la croissance est plus rapide dans l'eau chaude que dans les eaux froides du Sud (Gardner et al., 2006). De plus, la couleur des langoustes dépend de la profondeur où elles vivent. Les langoustes capturées dans les eaux peu profondes sont rouge vif tandis que les langoustes d'eau profonde sont «blanchâtres» (Chandrapavan et al., 2009). Depuis la fin des années 90, environ 75% des langoustes Tasmaniennes sont exportées vivantes vers la Chine (Bradshaw, 2004). Sur le marché chinois, le prix des langoustes varie en fonction de leur taille, déterminée par le gradient nord-sud (mareyeur, comm. pers.), et de leur couleur, déterminée par le gradient de profondeur (Chandrapavan et al., 2009). Les prix offerts aux pêcheurs tiennent compte de la demande chinoise. Les langoustes rouges sont plus chères que les langoustes blanchâtre, entre 2 $ à 6 $ de plus par kg en moyenne (Chandrapavan et al., 2009). Les petites et moyennes langoustes pouvant être servies pour une, deux ou quatre personnes sont les plus chères, atteignant souvent de 5 $ à 10 $ de plus par kg que les langoustes de plus de 2 kg.

Les prix de la langouste en Tasmanie sont exogènes à la pêcherie (Harrison, 2004), principalement fonction du marché chinois et du taux de change entre le dollar australien (AUD $) et le renminbi chinois (RMB). En plus de gradients spatiaux, des variations saisonnières impactent également les performances économiques des pêcheurs. Les taux de capture et les prix de langoustes présentent des cycles saisonniers inversés, les captures par unité d'effort (CPUE) sont élevées en été alors que le prix de la langouste est faible, tandis qu'en hiver, les CPUE sont faibles et les prix sont élevés. Les CPUE dépendent du cycle de vie des langoustes, de la réglementation et de l'environnement physique

La langouste a été exploitée en Tasmanie depuis que les premiers colons ont colonisé l'île en 1804 (Winstanley, 1973). A la fin des années 1980, les pêcheurs ont commencé à s'inquiéter de la baisse des CPUE. Malgré les nombreuses mesures de gestion déjà en place, l'effort de pêche était plus élevé que l'effort durable et devait diminuer (Anon, 1993). Apres plusieurs années de débat, l'introduction des QIT a été votée en 1996. Les QIT ont été mis en place en mars 1998 et ajoutés aux mesures de gestion déjà existantes.

4.2   Chapitre 2

Dans le chapitre 2, j'ai étudié les performances de la pêcherie 10 ans après l'introduction des QITs. D'après les exemples trouvés dans la littérature, les QITs impactent les pêcheries de plusieurs façons. Les effets attendus de la mise en place des QITs dans la pêcherie Tasmanienne comprennent une amélioration de l'état du stock de langouste, une réduction de la flottille, des changements dans les stratégies de pêche afin de maximiser le profit des pêcheurs et concentration des droits et de l'activité de pêche. Les données disponibles d'effort, de capture et de prix ont été utilisées pour comparer les effets attendus avec ce qu'il s'est vraiment passé dans la pêcherie.

En moyenne, la pêcherie a réagi conformément aux prévisions. Tout d'abord, la mise en place d'un TAC dans la pêcherie Tasmanienne de langoustes a eu un effet positif sur le stock en limitant les captures. Un pic de recrutement, juste après l'implémentation des QITs, a permis d'atteindre les objectifs en terme de reconstruction de la biomasse de langouste Tasmanienne. De plus, la pêcherie a réagi au changement de système de gestion, la flottille a été réduite de 25% dans les trois premières années et la flottille restante a changé ses pratiques de pêche pour cibler les langoustes atteignant les prix les plus élevés sur le marché Chinois. Pour sélectionner les catégories de langouste les mieux valorisées, la flottille a adapté l'allocation spatial et temporelle de son effort de pêche c'est à dire que la proportion d'effort de pêche en hiver, quand les prix sont les plus hauts a augmenté et les tailles et couleurs les mieux valorisées sur le marché Chinois ont augmenté dans les débarquements. Si la transférabilité des quotas individuels a permis la réduction de la sur-capacité en diminuant le nombre de navires actifs dans la pêcherie, elle a aussi conduit à une légère concentration des quotas. L'agrégation de quota a été limitée grâce à la mise en place d'une limite stricte sur la quantité maximale de quota possédé par personne.

Le bilan global en terme de rentabilité de la pêcherie reste cependant mitigé. Il n'y a pas de signe de diminution de la profitabilité au cours de la période étudiée mais la pêcherie est plus réactive aux stimulus externes sur son marché d'exportation, la Chine, qu'aux changements survenus dans sa propre structure. Cette sensibilité au marché Chinois a pu être observée pendant l'épidémie de SARS en 2003 où les prix des produits alimentaires dits de luxe comme la langouste se sont effondrés, mettant en évidence la vulnérabilité de la pêcherie Tasmanienne au marché Chinois.

4.3   Chapitre 3

Dans le chapitre 3, les effets observés à l'échelle de la flottille sont étudiés plus en détails. Les impacts des QITs identifiés dans le chapitre 2 sont caractérisés selon qu'ils sont dus à des changements structurels de la flottille ou des changements de comportements des pêcheurs. Les caractéristiques des navires sont utilisées pour examiner l'évolution de la flottille de pêche et décrire les profils des navires sortis, entrés ou restants dans la pêcherie. Les méthodes statistiques d'ordination et de classification sont utilisées pour définir une typologie des activités de pêche à l'échelle de la marée et à l'échelle annuelle. Les activités par marées sont définies comme un choix de zone de pêche par mois, chaque choix identifié dans la typologie est appelé métier. L'activité de pêche d'un navire à l'échelle annuelle est caractérisée par la combinaison des métiers choisis dans l'année, les combinaisons de métiers par an définissent des « stratégies ». Les stratégies sont ensuite utilisées pour étudier les changements de comportements de pêche des individus après la mise en place des QITs.

Les entrées et sorties des navires dans la flottilles sont principalement liées à leurs caractéristiques physiques et leur région d'origine. Des navires pouvant utiliser le nombre maximal de casiers sont entrés dans la pêcherie tandis que les petits bateaux en bois les plus anciens sont sortis de la pêcherie. Les réponses ont également variées selon les régions, les navires basés dans les régions les plus éloignées des meilleures zones de pêche (i.e. venant du Nord de la Tasmanie ou d'autres Etats Australiens) ont quitté la pêcherie. De même, la flottille de la côte Est de la Tasmanie a été réduite à cause des départs en retraite des pêcheurs les plus âgés.

Le changements spatio-temporels des pratiques de pêche observés au niveau de la flottille sont le résultat de deux effets distincts. Les pêcheurs qui sont restés dans la pêcherie ont augmenté la pêche en hiver et dans les eaux peu profondes pour obtenir des prix plus élevés par kilogramme de langouste. Cependant, très peu de changements ont été observés dans la distribution spatiale de l'effort de pêche des individus, les pêcheurs restant fortement dépendants de leurs zones de pêche traditionnelles, plus près de leur port d'attache. Les changements de zones de pêche observés à l'échelle de la flottille sont eux dus au départ des pêcheurs du Nord et de l'Est de la Tasmanie.

Les pêcheurs restés actifs dans la pêcherie de langouste Tasmanienne ont en moyenne augmenté leurs captures et ont donc besoin de louer le quota des investisseurs et anciens pêcheurs pour couvrir leurs débarquements.

4.4 Chapitre 4

Dans le chapitre 4, j'ai développé un modèle de simulation de dynamiques des flottilles intégrant les décisions d'allocation d'effort de pêche et de location de quota à un modèle biologique décrivant les dynamiques du stock de langouste Tasmanienne. Le modèle est basé sur l'approche de modélisation « individu-centré » pour simuler les effets de l'introduction des QIT dans la pêcherie de langouste de Tasmanie. Les décisions individuelles concernant la distribution spatiale et temporelle des pêcheurs sont modélisées à un pas de temps mensuel en tenant compte de la rentabilité qu'ils tirent de la pêche de langoustes. Pour chaque mois, les agents simulés dans le modèle peuvent choisir de pêcher dans un des métiers définis dans le chapitre 3 ou de ne pas pêcher. Le modèle de location de quotas est intégré dans le processus de prise de décision des pêcheurs afin de permettre aux pêcheurs de louer des unités de quota supplémentaires ou d'offrir leur propre quota en location en fonction de leurs prévisions de performance économique et de capture. Le modèle est utilisé pour étudier l'impact de différentes limites d'utilisation du quota. Quatre scénarios ont été envisagés, i) la location de quota est interdite et les agents ne peuvent pêcher que le quota qu'ils possèdent, ii) les agents peuvent utiliser un maximum de 120 unités de quota par an (règle jusqu'en 2009), iii) les agents peuvent utiliser jusqu'à 200 unités de quota par an (règle depuis 2010) et iv) les agents peuvent pêcher autant de langoustes qu'ils veulent tant qu'ils louent le quota dont ils ont besoin pour couvrir leurs débarquements. La pêcherie est simulée entre 1998 et 2007, soit les dix premières années de QITs.

Les résultats de simulation montrent que permettre la location de quotas a été important pour réduire la taille de la flottille dans la pêcherie que l'interdiction de transfert de quota n'aurait pas conduit à la diminution de capacité observée dans la flottille. Le modèle a également été utilisé pour simuler la trajectoire des prix de location de quotas durant la première décennie du régime de QIT, et d'évaluer la sensibilité du prix du quota à des forces extérieures telles que la crise du marché Chinois observée dans le début des années 2000.

Le modèle capture relativement bien la distribution spatio-temporelle de l'effort de pêche mais tend à surestimer la capacité d'adaptation de la flottille et prédit une plus grande réduction du nombre de navires dans la flottille comparé à ce qui a été observé en réalité. Ce résultat suggère que des facteurs supplémentaires, non liés à la rentabilité des activités de pêche, influencent la décision des pêcheurs de participer ou non à la pêcherie.

4.5   Chapitre 5

Le modèle est ensuite utilisé pour prédire l'avenir de la pêcherie dans le chapitre 5. La pêcherie de langouste Tasmanienne subit des contraintes extérieures qui affectent sa rentabilité et sa viabilité sur le long terme. Ces pressions sont à la fois environnementales et économiques. Les eaux Tasmaniennes se réchauffent à cause de dérèglements climatiques qui ont entraîné des changements dans les courants océaniques du Sud de l'Australie. L'augmentation de la température de l'eau semble favoriser une croissance plus rapide des langoustes mais les changements de courants semblent être à l'origine de la baisse de l'établissement de langoustes en phase larvaire sur les côtes Tasmaniennes entraînant une diminution de la population de langoustes. De plus, la pêcherie de langoustes Tasmanienne est toujours vulnérable à des possibles perturbations sur le marché Chinois, son seul marché d'exportation et principal client.

Trois modèles de comportement de flottilles ont été utilisés pour évaluer les impacts de pressions extérieures. Les modèles varient en complexité d'un modèle simple d'allocation des captures constante dans le temps et l'espace, à un modèle individu-centré où tous les pêcheurs choisissent la répartition de leur effort de pêche en se basant sur des considérations économiques et interagissent avec d'autres propriétaires de quotas sur le marché de location de quotas, en passant par un modèle supposant une projection linéaire de la distribution spatiale des captures en fonction de la biomasse locale. Les trois modèles de comportement de la flottille sont soumis à des perturbations environnementales et économiques. Les scénarios environnementaux assument que i) le changement climatique a bien un impact sur la croissance et l'établissement des larves en Tasmanie ou ii) qu'il n'y a pas d'impacts climatique et que la croissance et l'établissement de larves resteront proches des niveaux historiques. Les scénarios économiques intègrent des hypothèses sur la tendance générale des prix de langoustes (croissante ou constante) et sur la variabilité saisonnière du prix des langoustes (saisonnalité historique ou saisonnalité observée récemment où le prix ne baisse pas autant en été). Les simulations montrent qu'il est nécessaire de prendre en compte la capacité d'adaptation de la flottille lorsque la pêcherie est soumise à des perturbations à long terme. Si les perturbations environnementales sont capturées à la fois par le modèle utilisant des projections linéaires fonction de la biomasse et le modèle multi-agents, seul le modèle individu-centré est capable d'intégrer des perturbations économiques dans les décisions des pêcheurs et permet en outre d'examiner les aspects socio-économiques de la pêcherie.

4.6   Discussion générale

4.6.1   QIT dans la pêcherie de langouste Tasmanienne

Cette thèse a examiné la pêcherie de langoustes en Tasmanie dix ans après l'introduction de QIT pour évaluer la réponse des pêcheurs à leur mise en place. Avec toutes les conditions recommandées favorable à une mise en œuvre réussie de QIT, la pêcherie de langoustes Tasmanienne a été un bon cas d'étude pour comprendre la réponse des pêcheurs à cette mesure de gestion. Avant l'introduction des QIT, les détails du nouveau système de gestion ont été discutés avec les acteurs de la pêcherie avec des objectifs écologiques, économiques et sociaux (Ford et Nicol, 2001). Pour maintenir le stock de langoustes à un niveau durable (objectif écologique), un TAC a été choisi environ 10% plus bas que les captures des années précédentes (Bradshaw, 2004) et a été ajouté aux mesures de conservation pré-existantes telles que la taille minimale de débarquement, restrictions sur les engins pêches et les fermetures saisonnières. Des objectifs économiques et sociaux ont également été pris en compte avant l'introduction de QIT dans la pêcherie avec deux principales préoccupations: la répartition équitable des quotas entre les pêcheurs et le risque de concentration des quotas par quelques propriétaires. L'allocation initiale des quotas a été l'aspect le plus controversé de l'introduction de QIT et la raison pour laquelle une partie de l'industrie s'est opposée aux QIT. L'allocation initial de quota fut finalement basée sur la propriété de casiers (Ford et Nicol, 2001). Pour éviter la concentration de quotas, des limites ont été établies sur la propriété et l'utilisation du quota à 120 unités de quota par licence ou 200 unités de quota par personne, soit moins de 2% des 10 507 unités de quota que compte la pêcherie (Anon, 2006).

Le cas d'étude utilisé dans cette thèse présente toutes les caractéristiques pour un mise en place réussie de quotas individuels transférables (Grafton et McIlgorm, 2009). La pêcherie de langoustes Tasmanienne est une pêcherie importante avec une valeur des débarquements estimée à 60 millions de dollars AUD en 2006-07 (ABARE, 2008), ciblant une seule espèce, Jasus edwardsii, pour laquelle le nombre relativement faible de pêcheurs (325 navires en 1997) peut obtenir un prix de débarquement plus élevé en ciblant des saisons et zones de pêche spécifiques. Ainsi, les conclusions tirées de la présente étude ne sont pas toutes directement transposables à d'autres pêcheries et des résultats différents pourraient être obtenus dans des pêcheries avec des profils moins favorables aux QIT comme une pêcherie multispécifique où d'autres questions comme les rejets doivent être pris en considération.

Les QIT ont été mis en place en raison de l'état préoccupant du stock de langouste en Tasmanie au début des années 90. Apres l'introduction des QITs, le stock de langouste s'est rétablit rapidement entraînant une augmentation des CPUE (Haddon et Gardner, 2008). Cette reconstruction de la biomasse est due à un pic de recrutement dans les premières années après l'introduction de quotas et au TAC. Choisi à un niveau adéquat et restrictif, le TAC est essentiel au succès des système de gestion par quotas. Bien que l'effet écologique des QIT est positive dans la plupart des cas, certaines pêcheries comme le flétan du Groenland et l'hoplostète orange de Nouvelle-Zélande, ont eu moins de succès que la pêche de langoustes de Tasmanie et ont décliné après l'introduction de QIT, probablement en raison d'un TAC trop élevé, le manque de contrôle ou des fonctionnement d'écosystèmes mal compris (Chu, 2009).

Après l'introduction des QITs, l'efficacité économique de la pêcherie Tasmanienne de langouste a augmenté en raison de la réduction de la capacité de la flottille, des CPUE plus élevées, et de l'effort de pêche ciblant des catégories de langoustes atteignant un prix plus élevé (chapitre 2). La réduction de la surcapacité a été assez rapide, 25% des 325 navires présents en 1997 avait quitté la pêcherie en 2001 (bien qu'il soit inférieur au taux de sortie des navires dans la pêcherie de palourdes Atlantique où 56% de la flottille est partie dans les 4 premières années de la gestion par QIT, Brandt, 2007). Les changements dans les stratégies de pêche observés à l'échelle de la pêcherie résultent de la combinaison d'un changement structurel de la flottille de pêche et de la modification du comportement individuel des pêcheurs qui sont restés (chapitre 3). Les pêcheurs opérant traditionnellement dans les régions septentrionales où les langoustes sont plus grandes et atteignent un prix inférieur ont quitté la pêcherie tandis que la flottille du sud de la Tasmanie, à proximité des zones de pêche les plus rentables est restée stable. De plus, les pêcheurs ont intensifié leurs efforts en hiver lorsque les prix de langouste sur le marché chinois sont élevés, et ciblée des langoustes rouges de plus grande valeur trouvées dans les eaux peu profondes.

Bien que l'efficacité économique de la pêcherie de langouste Tasmanienne s'est améliorée depuis l'introduction des QIT, des simulations basées sur les données disponibles et sur des hypothèses relatives au comportement des pêcheurs suggèrent que le TAC pourrait être capturé par un plus petit nombre de navires et que le prix de location du quota devrait être plus élevé. Le fait que la flottille simulée est économiquement plus efficace que la flottille réelle reflète probablement l'existence de diverses contraintes et de sources d'inertie qui

influencent les décisions des pêcheurs dans la réalité, et qui ne sont pas capturées dans le modèle.

Le régime de QIT a conduit à l'agrégation de quotas par certains propriétaires (voir chapitre 2), mais les règles strictes limitant la concentration de quotas ont permis d'éviter les scénarios qui vus en Nouvelle-Zélande où les entreprises de pêche sont verticalement intégrées et quelques mareyeurs possèdent le plus gros du quota (Batstone et Sharp, 1999). Bien que peu de concentration de quota a été observée, de plus en plus de quota est détenu par des propriétaires ne pêchant pas eux-mêmes (les investisseurs ou les anciens pêcheurs), résultant en une plus grande quantité de quota louée (van Putten et Gardner, 2010). Les simulations indiquent que la limite de concentration de quota mis en œuvre en 1998 (120 unités) restreint l'efficacité économique de certaines entreprises de pêche, mais la limite de mise en œuvre en 2010 (200 unités) ne limiterait la taille des opérations de pêche (chapitre 4). La limite sur le nombre de casiers de pêche utilisés par les pêcheurs (limité à 50 casiers pour les plus grands navires) pourraient toutefois restreindre la taille des entreprises de pêche et rendre la limite sur l'utilisation des quotas redondante.

L'avenir de la pêcherie de langouste en Tasmanie est très incertaine car elle est largement déterminée par des facteurs externes. Après une reprise rapide observée dans les dix premières années de la gestion des quotas, le stock de langouste a diminué vers la fin des années 2000 (Gardner et Ziegler, 2010). Un déficit de recrutement de langoustes dans la pêcherie semble être lié à une tendance régionale (Linnane et al., 2010). Le changement climatique est probablement la cause de changements dans les courants océaniques entraînant des colonisations plus faibles par les larves de langoustes (Pecl et al., 2009). L'absence de recrutement affecte déjà les régions du nord où les langoustes se développent plus rapidement. En revanche, la biomasse exploitable a augmenté dans le sud dù au changement climatique. Les températures plus élevées ont amélioré la croissance des langoustes causant la croissance de la grande population de langoustes sous-tailles présente dans le sud. La croissance soudaine de langoustes à la taille légale entraîne, à court terme, la hausse de la biomasse de taille légale dans les régions méridionales (chapitre 5). Toutefois, si les faibles recrutement persistent, la biomasse exploitable diminuera également dans le Sud (Pecl et al., 2009). En plus du changement climatique, l'oursin, Centrostephanus, a envahi la côte Est de la Tasmanie détruisant l'habitat des langoustes. (Ling et al., 2009).

Outre les perturbations de l'environnement, la situation économique de la pêche est également incertaine car elle dépend en grande partie sur un seul client, qui est le marché chinois. Des perturbation du marché peuvent fortement affecter la viabilité économique de la pêcherie, comme lors de l'épidémie de SRAS dans le début des années 2000 (Hacourt, 2003). Dans le chapitre 5, les scénarios étudiés suppose que le prix du langouste va probablement augmenter ou rester au même niveau qu'en début de 2010, mais à la fin de Novembre 2010 la Chine a décidé d'interdire temporairement toutes les langoustes d'Australie causant une baisse soudaine des prix de la langouste en Tasmanie. Compte tenu de ce récent événement, il semble que les prévisions présentées dans cette étude pourrait en fait être optimiste et surestimer les profits futurs de la pêcherie. Des scénarios supplémentaires pourraient être testés quant à la tendance générale des prix de langouste, de la saisonnalité de la demande ou de l'évolution de la demande par catégorie de marché. La pêcherie pourrait également être perturbée par un changement dans la structure des coûts de pêche, qui sont aussi en grande liés à des facteurs extérieurs. Par exemple, le choix du lieu de pêche est fortement lié aux frais de carburant des pêcheurs. Le prix du carburant a montré une forte variabilité depuis le début des années 2000. Cette variabilité devrait être prise en compte dans les futures simulations.

4.6.2   Modélisation des comportements dans une pêcherie sous QITs

Les quotas transférables permettent la réduction de la surcapacité dans les pêcheries où les pêcheurs les plus économiquement efficaces devrait racheter le quota de pêcheurs moins efficaces (Anderson, 1986). L'échange de quotas se produit parce que les propriétaires de quotas ont des prévisions différentes quant à leur rentabilité en tant que pêcheurs. Dans un modèle avec des transferts temporaires seulement (location), les pêcheurs s'attendant au plus haut profit par kg louent le quota des pêcheurs économiquement moins efficace. Pour saisir la dynamique des échanges de quotas, les agents individuels sont décrits de façon explicite et la dynamique de la flotte de pêche est modélisée avec une approche individu-centré (Uchmanski et Grimm, 1996). La modélisation individu-centré décrite dans le chapitre 4 tient compte des caractéristiques individuelles des agents pour les échanges de quotas ainsi que pour les décisions d'allocation de l'effort de pêche. Le choix de où pêcher, de quand pêcher et même de pêcher ou non dépendent de la rentabilité économique attendue pour chaque option. Dans une pêcherie où la flottille est contrastée en terme d'origine géographique, de taille des navires et d'efficacité des pêcheurs, les performances économiques sont différentes pour chaque individu et la modélisation individu-centrée capture cette hétérogénéité.

Avec des quotas individuels limitant les prises de chaque pêcheur, les pêcheurs sont censés maximiser leur profit marginal et choisir l'activité de pêche avec le plus haut profit par kg.. Si l'allocation de l'effort de pêche est assez bien décrite par un modèle linéaire fonction de la biomasse locale (chapitre 5), un tel modèle ne tient pas compte de l'influence de facteurs économiques qui peuvent jouer un rôle crucial dans l'explication de la réponse des flottilles de pêche aux changements de l'environnement dans lequel elles opèrent. Bien que la biomasse ait été utilisée dans d'autres pêcheries pour prédire la répartition de l'effort de pêche, les estimations directes de profits ou de revenus ont été généralement préférés pour expliquer des décisions économiques (Smith, 2002, Vermard et al., 2008, Marchal et al., 2009a, Prellezo et al., 2009). Le modèle individu-centré développé dans cette étude permet la description explicite du processus de décision des propriétaires de quotas basé sur les performances économiques, et permet de tester des scénarios incluant les perturbations économiques de la pêcherie. Cependant, la puissance de calcul nécessaire pour effectuer des simulations individu-centrées est plus élevée et des données spécifiques sont nécessaires, en particulier des informations relatives aux caractéristiques individuelles des opérateurs.

Dans le modèle, le flux d'information est supposé parfait: chaque agent a instantanément accès à toutes les données telles que les CPUE ou le prix du quota. Par conséquent, la réponse des agents à l'information qu'ils reçoivent est rationnelle et immédiate. En réalité, le partage de l'information est probablement plus limité, ce qui pourrait conduire certains "investisseurs" à maintenir une activité de pêche pour évaluer l'état de la pêcherie eux-mêmes. Au début de sa mise en place, le marché des quotas semblait partitionné en sous-marchés, et les pêcheurs n'avaient probablement pas accès à tous les quotas, mais plutôt échangaient leur quota avec des personnes qu'ils connaissaient (van Putten et al., 2011). En conséquence de ces limitations de l'information, et d'autres contraintes techniques, il existe une inertie dans le système réel qui n'est pas capturée par le modèle. Ceci explique la différence entre les prédictions du modèle économique et la réalité. Pour inclure cette effet d'inertie dans le modèle, l'écart de comportement entre des maximisateurs de profit et les propriétaires de quotas réels doit être mesuré, et des facteurs expliquant l'inertie, tels que un délai dans la transmission de l'information ou l'aversion au risque, devraient être étudiés.

Un des plus grands défis identifiés au cours de ce projet est le manque de données adéquates pour intégrer efficacement la dimension économique dans un modèle de dynamiques de flottille. Bien que les données de capture et d'effort soient collectées par les pêcheurs chaque jour, les données de coûts et de revenus sont rares dans la pêcherie de langouste de Tasmanie.

Les seules estimations des coûts disponibles pour cette étude ont été recueillies en 2007 sur un échantillon de 14 pêcheurs actifs (Gardner et Van Putten, 2008). L'absence de données économiques plus précises rend difficile l'estimation de coûts au niveau individuel et la mise en évidence des contrastes entre les pêcheurs, qui sont les moteurs des échange de quotas. En outre, une série chronologique des données plus précises sur l'économie aurait été utile pour étudier si le processus de décision des pêcheurs a changé avec l'introduction des QIT. Enfin, l'évolution des performances économiques de la pêche depuis l'introduction des QIT ne peut pas être examinée en raison de l'absence de données économiques avant l'introduction des QIT. Sans une collecte systématique de données économiques, les décideurs ne peuvent pas évaluer la viabilité économique d'une pêcherie par rapport à leurs objectifs économiques. Les résultats de cette thèse montrent que le comportement des pêcheurs est raisonnablement proche d'un comportement de maximisation du profit. Toutefois, il est difficile de savoir si la différence observée entre les prédictions du modèle et la réalité sont dus à des facteurs non-économiques qui devraient être inclus dans la modélisation des différents processus de décision (voir Fulton et al., 2011, et van Putten et al. In Press pour la discussion des facteurs de comportement économique) ou tout simplement en raison de l'absence de bonnes données économiques à l'échelle appropriée.

4.6.3   Perspectives pour la recherche future

Le modèle élaboré pour cette thèse ne tient compte que de comportements à court terme et ne peut donc être utilisé pour des projections à court terme. La flottille de pêche de langouste Tasmanienne a beaucoup changé en dix ans et les changements continuent. Sur le long terme, des décisions économiques comme l'investissement et de désinvestissement dans du quota et des navires et l'entrée / sortie de pêcheurs devraient être incluses pour toute projection au delà de 5 ans. De plus, les processus de décision déjà inclus dans le modèle (allocation de l'effort et location de quotas) sont basés sur l'hypothèse que les agents maximisent leur profit et ne basent leurs décisions que sur leurs futures performances économiques. Dans d'autres pêcheries, d'autres facteurs tels que le risque ou des caractéristiques individuelles incluant des facteurs normatifs et sociaux (Hatcher et al., 2000), ont été intégrés dans le processus de prise de décision (van Putten et al., Sous presse) et les modèles de choix discrets tels que les modèles d'utilité aléatoire (RUM) ont été utilisés et ont réussi à capturer l'effet de ces facteurs

supplémentaires (Vermard et al., 2008, Wilen et al., 2002). Une telle approche du processus de décision pourrait être développé dans le modèle de la pêcherie de langouste Tasmanienne.

Le partage de l'information est supposé parfait dans le modèle, tant sur le marché des quotas que sur les CPUE. En réalité, le partage de ces information est probablement limité aux réseaux sociaux. Les défenseurs des QIT semblent supposer que les marchés de quotas sera parfait, en particulier en termes d'information (Arnason, 1990, Batstone et Sharp, 2003). Toutefois, van Putten et al. (2011) ont montré que le marché des quotas de Tasmanie a été subdivisé en sous-marchés dans les premières années après la mise en place des quotas. Différentes structures de marché de quotas pourraient être étudiées afin de tester les effets des marchés de quotas non-parfaits.

Enfin, les rejets devrait être pris en compte. Bien que les rejets ne semble pas induire de mortalité car les langoustes rejetées à l'eau survivent, la sélection de langoustes de tailles spécifiques a des implications pour les performances économiques de la pêcherie. Pour l'instant, le modèle biologique suppose que toutes les langoustes de taille légale sont débarquées par les pêcheurs. Toutefois, il existe des preuves que les pêcheurs rejettent les plus grosses langoustes qui atteignent un prix au kg inférieur. Dans un modèle de projection où les décisions sont basées sur le profit marginal, garder ces langoustes de grande taille entraîne une plus faible attractivité des zones où on les pêche, expliquant que les agents simulés évitent les régions du Nord. Une solution simple à ce problème serait d'avoir la possibilité de choisir entre différentes options de sélection variant avec la taille / prix du langouste.

Le modèle amélioré pourraient être utilisé comme support de décision de gestion. Alors que les pêcheurs commerciaux ont réduit leurs captures au cours des dernières années (Gardner et Ziegler, 2010), la pêche récréative reste sans restriction en pratique. Le nombre de pêcheurs récréatifs n'a jamais été aussi élevé, augmentant ainsi la pression de pêche sur le stock de langouste près des régions peuplées (Lyle, 2008). Utiliser le modèle pour séparer et étudier les effets de la pêche récréative et commerciale pourrait être utile à l'élaboration des futurs plans de gestion. De plus, nos résultats suggèrent que limiter le nombre de casier par navire pourrait limiter l'efficacité économique de certains pêcheurs de langoustes qui pourraient accroître leur effort dans les mois d'hiver à des coûts réduits en utilisant plus de casiers. Le modèle pourrait être utilisé pour tester divers scénarios de limitation de casiers comme un outil d'aide à la décision.

4.6.4   sur l'utilisation des QIT pour gérer les pêcheries

Les QIT ont réussi à restaurer la viabilité de la pêcherie de langouste Tasmanienne. Malgré les difficultés rencontrées par la pêcherie conduisant à la réduction du TAC commerciale ces dernières années, le sentiment général parmi les pêcheurs rencontrés lors de la préparation de cette thèse est qu'il ne resterait peut-être pas de pêcherie professionnelle si les QIT n'avaient pas été mis en place en 1998. Le succès des QIT dans cette pêcherie semble être lié en grande partie aux discussions menant à la mise en œuvre des quotas individuels qui ont inclus tous les acteurs de la pêcherie (Ford et Nicol, 2001).

Ce projet a été co-financé par l'institut de recherche marine française, l'IFREMER. Le but était d'utiliser un cas d'étude avec suffisamment de données pour tester un modèle de comportement de pêche dans un système de QIT, et fournir des connaissances de base et d'alimenter le débat actuel sur la nouvelle politique européenne commune de la pêche (PCP). Des problèmes ont été identifiés dans les pêcheries européennes et plusieurs options de gestion sont étudiées pour régler les difficultés rencontrées dans les pêcheries européennes actuellement (Anon, 2009). Il est clair que la Commission européenne est en train d'évaluer les moyens de mise en place de QIT à plus grande échelle dans l'Union européenne (UE). En effet, les Pays-Bas et le Danemark ont déjà recours aux QIT pour gérer certains de leurs pêcheries.

"Notre objectif devrait être un système qui contribue à formaliser des droits de pêche individuels, de manière à faciliter une plus grande transparence, de sécurité juridique, de sécurité et, finalement, une plus grande efficacité économique pour les pêcheurs, ce qui implique également une réduction des coûts pour le reste de la société. "(Anon, 2007)

Bien qu'il y ait une impulsion forte vers les QIT dans plusieurs pays d'Europe septentrionale, la Commission européenne reconnaît que les QIT ne sont pas une panacée et que la mise en œuvre de ce régime de régulation de l'accès est une question délicate, nécessitant une discussion préalable à sa mise en place. Plusieurs questions ont été identifiées comme des sujets clés pour les discussions à venir (Marchal et al., 2009b, Anon, 2007). Parmi ces sujets, certains sont d'ordre politique tels que le principe de «stabilité relative» entre pays de l'UE qui consiste à maintenir une proportion constante des TAC au niveau des pays. Ces sujets et

d'autres pourraient être étudiés au moyen de modèles bio-économiques comme celui présenté dans cette thèse, se concentrant sur les questions de concentration de quotas et des limites de détention de quotas (chapitre 4). En outre, des scénarios sur l'allocation initiale et sur qui peut posséder du quota peuvent également être envisagés par la modélisation. Enfin, la question des rejets dans les pêcheries mixtes a également été étudiée (Branch et Hilborn, 2008) et modélisée (Poos et al., 2010, Little et al., 2009). Le type de modèle présenté dans cette étude, combinant allocation de l'effort et marché de quotas, doit être utilisés pour étudier les conséquences biologiques, économiques et sociales de la mise en œuvre de QIT

5   Acknowledgements

I first would like to thank the ones who made this adventure possible by providing the funding. Merci au conseil scientifique et technologique d'Ifremer pour avoir cofinancé cette thèse et m'avoir permis de rester en Australie dans les meilleures conditions. Thanks to the UTAS-CSIRO conjoint PhD program in quantitative marine science (QMS) for the other part of the co-funding. I also want to acknowledge all the financial support I received for the traveling I did during the past three years, the French embassy for the co-tutelle traveling grant, the University of Tasmania, Ifremer, CSIRO and the International Council for the Exploration of the Sea, you allowed me to fully enjoy the co-tutelle experience and to share my research in international conferences.

Of course I had a lot of administrative support from fantastic people on both side of the globe to help me build the co-tutelle project and agreement between the University of Brest and the University of Tasmania. Merci à Anne-Marie Galliou Scanvion et Denis Bailly pour la partie française and thanks to Richard Coleman on the Australian side. Pour son aide précieuse dans les méandres de l'administration universitaire française, merci à Elisabeth Bondu, son efficacité et sa rapidité a répondre à mes requêtes lancées du bout du monde n'ont d'égal que son professionnalisme et son humour. Merci aussi a Séverine Julien pour son aide de dernière minute. On the other side of the world, Denbeigh Armstrong has been a precious support to help me through the administrative maze. I have been fortunate to be part of the QMS PhD program which gave me the opportunity to meet and learn from great scientists and great people. Among those not cited later, I especially would like to thank Beth Fulton and Tom Trull for their lectures.

The PhD project was born from the meeting of six men who wanted to collaborate, Jean-Pierre Boude, Stewart Frusher, Craig Johnson, Rich Little, Jean-Christophe Soulié and Olivier Thébaud. Thanks to all of your for accepting to supervise me during those three (and a half) years. A special thank you to Rich, Olivier and Stewart who have done much more than most supervisors would during those years. My gratitude cannot be expressed with words (maybe champagne would help). Thanks for always being available when I needed, and contributing immensely to this thesis with your advice and comments during all the stages of preparation. I enjoyed our time at work and off work with you and your families and I certainly look forward to seeing you and collaborating with you again.

I have traveled and moved a lot during those three years. The positive aspect of this is that I have been part of many research teams (the downside being the long list of affiliations coming with my name on each paper!). Chronologically, I have started in the marine economics department of Ifremer in Brest, then moved to Hobart and the marine research laboratories of the Tasmanian Aquaculture and Fisheries Institute. While at TAFI, I slowly made my way to the CSIRO Marine and atmospheric research labs before a move back to France and to the DEM. My last move brought me to a warmer area in the Cleveland laboratories of CMAR. The list is too long but I would like to thank everyone who made my stay in each place a special time. I would like to thank all the ones who I shared my tea breaks with, the ones who were with me to watch submarines leave or enter the harbour of Brest, the ones who warned me when there were penguins or whales to be seen in the Derwent river and the ones who got me out of the "geek pit" to show me koalas and lizards. I also want to acknowledge the amazing job of IT support and especially the efficiency of the CSIRO-Hobart team

I owe a lot to my colleagues, this thesis would not have been the same without them. Muriel, tu m'as aidée et m'a montré la voie dans mes premiers essais d'analyse économétrique dans la joie et la bonne humeur. Merci, ce n'était pas gagné d'avance ! Klaas and Caleb, you did not totally succeed in the attempt of driving me crazy while waiting for data and there would actually be no thesis without your valuable contributions. To Soile, Natalie, Trev and Sean, it was really nice to have the opportunity to work with you. Ingrid, it has been a great pleasure working with you, sharing your house and breaking your car (actually I didn't enjoy damaging your car!), I am looking forward to working with you again!

I pride myself to have benefited from the precious advice of some of the best scientists in the field. Malcolm Haddon, thank you for keeping your door always open and to have time to discuss my modeling issues. It has been a great pleasure to meet you and I certainly hope we will meet again, keep smiling! Andre Punt, thanks for your model, your time and your advices. I hope you are the only person I ever had to meet on a Sunday to discuss the integration of fleet dynamics in a biological operating model. Bill Venables, thank you for the advices in R and for the rest.

To all the people who made my life off work more enjoyable and made me discover Tasmania, thank you. To the Fredders, Corey, Shelly, Beth, Russ and Cam, thanks for welcoming me in our beautiful house, for the nice company and the incredible parties. Many

new friends made this adventure truly unforgettable, the French crew of Hobart, Martin, Clo, Seb, JB, Anais, Christel, Mathieu, Béné et les autres; the badminton team, especially Amelie and Eriko, the pump mates, Emma, Soile, Ana, Natalie and other gym buddy, Bee! Thanks the ones I shared a beer with at rektango, or a fish and chips at "fish on fire" and finally thanks to my great office mates, Katya and Jan, you are all pretty unique and I'll miss you all. Aux Français(es) de Brest, merci pour les petites soirées bien sympas, pour la bonne humeur autour de la machine à café, je suis sure qu'on aura l'occasion de se revoir bientôt.

Merci à mes parents qui ont eu la bonne idée de s'installer au bord de la mer et de nous transmettre leur passion pour les étendues d'eau salée. Je crois que tout est parti de là. Erwan nous a ensuite passé le virus de la plongée, qui a changé la vie de ses sœurs mais de manières différentes ! Et merci à Magali, j'ai peut être dépassé ce que tu aurais fait mais c'est en marchant dans tes pas que tout a commencé et que j'en suis arrivée là.

Merci à tous ceux qui étaient là avant et que j'ai honteusement négligés dans mes pérégrinations. A celle qui a été là depuis le tout début, Sophie, c'est toujours un plaisir de rentrer et de te retrouver pour parler du bon vieux temps, de notre autre vie, celle avant les études, les voyages et la recherche. On se retrouve en Hollande sur un vélo ! A Cécile, désolée d'être allée aussi loin, je sais bien que ton budget shopping ne te permettait pas de t'offrir un billet d'avion pour les antipodes. Promis, je reste dans le coin pour quelques années ! William, nos petites soirées en tête à tête étaient des bouffées d'oxygène dans mes semaines passées à travailler, j'espère qu'on se retrouvera bientôt du même côté du globe. Sonia, enfin on va pouvoir se retrouver dans le Benelux. Marie, merci d'être venue me voir en Tasmanie, c'est pas malin de partir juste quand je reviens, peut être à bientôt chez toi.

You were there before I started this adventure, despite the distance you supported me in this project, for this thank you. We did it! We are now free of theses and can go on with a real life without skype, time zones and day-long train journeys. I could not have done it without your love, your support and your trust. Dank je Jan-Jaap.

6   Publication list

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