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

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

Keywords: Behaviour, ITQ, leasing, quota, safety, southern rock lobster.

Introduction

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

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

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

With lease quota fishing now representing the majority of the fishing effort in many ITQ fisheries it is important to understand how the behaviour of those who lease the majority of their quota units (i.e. lease quota fishers) may vary from that of quota owners. Lease quota fishers are not guided by the same incentive structure as efficient owners to sell their quota units to more efficient owners and leave the fishery, thereby reducing capitalization and stimulating fleet rationalization (Herrmann, 2000; Branch et al., 2006; Grafton et al., 2006). For example, if the average revenue per kilogram of fish increased by AUD $10, from AUD $50 to AUD $60, with the cost of fishing estimated at AUD $30 kg$^{-1}$, the overall profit of a quota owner would increase by 50%, but for a lease quota fisher it would increase by 300%, when factoring in a lease price of AUD $15 kg$^{-1}$ (Figure 1). Similarly, with a lease price of AUD $21 kg$^{-1}$ and a revenue of AUD $50 per potlift, a quota owner would only have to set 2000 pots to make AUD $100,000 (not taking into account individual fixed and variable costs). Conversely, a lease quota fisher (who owned none of their quota units) would have to set 4596 pots to achieve the same result, which is > 100% more. Therefore, there may be an incentive for lease quota fishers to target higher volume and valued catch relative to quota owners, resulting in them fishing many more days at sea and having less flexibility in deciding when to fish.

The fishing incentives and behaviour of quota owners and lease quota fishers is particularly important when considering regulatory changes that have ramifications for the operational health and safety of fishers (Smith and Wilen, 2005). Fishing is a dangerous occupation with high rates of fatalities and injuries due to the nature of the working conditions and unpredictability of the environment (Mayhew, 2003; Windle et al., 2008; Roberts, 2010; Brooks, 2011). Most empirical evidence on the risk behaviour of fishers suggests that they are generally risk averse (Sutinen, 1979; Mistiaen and Strand, 2000; Nguyen and Leung, 2009), particularly to physical risk caused by weather (Smith and Wilen, 2005; Kahu and Alexander, 2008). Risk aversion may vary, however, depending on the interactions of factors such as the current management system, expected revenue, skipper experience, vessel size and financial security (Brooks, 2007). While ITQ management is often associated with reductions in fishing practices that are hazardous and have the potential to cause harm (Brooks, 2005; Hughes and Woodley, 2007; Woodley et al., 2009), a literature review on physical risk in fisheries by Windle et al. (2008) found mixed results, which were dependent on the concentration of quota ownership in the fishery. Likewise, the expected safety benefits of ITQ management
may be reduced for lease quota fishers, who in targeting higher volume and valued catch to cover fixed debt costs and increase daily profits, may choose to fish more often in hazardous weather conditions.

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

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

**Methods**

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

**Data**

Two separate datasets were used to analyse changes in fisher decision-making: fishery catch and effort data and weather data from around Tasmania, Australia. Fishery data containing information on rock lobster vessels [i.e. vessel length, gross registered tonnage (GRT), home port, quota holdings, beach price and catch and effort are compiled in several databases, which are maintained by the Tasmanian Government’s Department of Primary Industries, Parks, Water and Environment (DPIPWE). Catch and effort data was derived from the compulsory rock lobster logbook, which provided information on the spatial and temporal details of fishing, as well as catch (kg), number of lobster caught and number of potlifts. Beach price data was derived from processor records, which provided the monthly amount and price of rock lobster purchased from fishers. All price data was adjusted to account for inflation (i.e. deflated) using the Australian consumer price index [http://www.rba.gov.au/calculator/ (last accessed 14 December 2013)]. The amount of quota owned in each year was derived by subtracting quota units leased in and/or adding quota units leased out from quota held at the end of the fishing season.

Significant wave height (m), defined as equal to the average of the highest one-third of the waves, as measured from the trough to the crest (NOAA, 2011), was considered the single most important weather variable affecting safety in this study, as demonstrated in Canadian fisheries (Wu et al., 2005). Daily significant wave height data (m) for coastal Tasmania in the period 1 March 2001 to 28 February 2011 was compiled from the National Oceanic and Atmospheric Administration (NOAA) WAVESWATCH III (NW3) regional model for wave data (Tolman, 2002). Weather conditions were contrasted on the spatial scale of one-degree blocks (e.g. 3C in Figure 2) around Tasmania.

**Model development**

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

Individual logbook data was used to identify the location where a fisher chose to fish or could have fished each day. As the analysis was undertaken on a one degree spatial scale and there was not a large transfer of vessels between ports, rules were used to determine the location that a fisher could have chosen to fish on the days between fishing trips or during trips that were not reported in the logbook (i.e. where they did not set or haul any pots). These rules were conditional on the location of the previous and succeeding fishing event (i.e. where they last and then next set and hauled...
Fisher behaviour when leasing quota

their pots). Days during fishery closures, and periods of time incorporating the Christmas break and at the end of the quota year (late February) when a fisher may have caught all their available quota were excluded from analysis. If the number of days between fishing events exceeded 21 (i.e. 3 weeks) it was assumed the fisher was otherwise occupied (e.g. on holidays or participating in another fishery), and these days were also excluded from analysis. If the location of the previous fishing event was greater than two fishing blocks away from the location of the succeeding fishing event (e.g. 3C to 6E), then it was considered no longer viable to estimate a fisher’s location and the intervening days were also excluded from the analysis. For the periods during and/or between fishing events where none of the above exceptions were triggered, fishing location was assigned based on the area of the previous fishing event and the area of the succeeding fishing event. If these were the same (e.g. both 3E), then it was assumed a fisher could have fished the same location (3E) in the intervening period. If the fishing location of the previous fishing event (e.g. 3E) was not the same as the succeeding fishing event (e.g. 4D) then it was assumed that the fisher could have fished in either location (3E and 4D) with equal probability during the intervening days.

The binomial GLM was developed to analyse fishing behaviour using R (version 2.13.0) (R Development Core Team, 2011). Explanatory variables included: (i) significant wave height (m) (ordinal variable); (ii) expected revenue (AUD per potlift), expected revenue variability (AUD per potlift), vessel length (m) and the proportion of quota owned to held at the end of each quota year (%) (continuous variables) and; (iii) vessel, day, month, quota year, home port of vessel and block (location) (categorical variables). Non-significant variable interactions were removed from the model as indicated in Table 1. It was assumed that fishers would respond positively to expected revenue under the assumption that they either share information or are knowledgeable about the historical catch-per-unit-effort (cpue) at particular locations/times and/or current beach price for lobster. Expected revenue was derived by multiplying the monthly mean Statewide beach price by a prior five-day rolling average of cpue for a given day in each block fished. This period was chosen after preliminary testing five- and three-day rolling averages and observing similar results. Mean cpue was calculated by dividing the total lobster catch in each block by the total number of potlifts. Monthly mean beach price was determined by calculating the average price paid weighted by the quantities bought by processors. It was considered more appropriate to use monthly rather than daily mean beach price because it was unlikely a fisher would have been able to accurately predict the beach price for the day they returned in advance. Fishers’ decisions to go fishing were predicted to respond negatively to financial risk caused by variability in expected revenue, and expected revenue variability was calculated based on the same assumptions and methods for expected revenue, using the standard errors of cpue and beach price as a measure of financial risk. Determining the proportion of quota owned to held for each fisher was calculated by simply dividing the amount of quota owned (initial allocation), by that held (initial allocation plus leased in or out quota units) at the end of the fishing season. Significant wave height (m) was rounded to the nearest whole number and then grouped into five categories (≤1 m, 2 m, 3 m, 4 m and ≥5 m). Waves that were greater or equal to 5 m were considered “hazardous” for fishers.

As the TSRL fishery has distinct modes of fishing around the state as well as geographical and biological variations that influence wave height and revenue per potlift, the Statewide model was subdivided into three specific geographical areas for comparison. These included: the east coast and Hobart (blocks 5H, 6H, 6G and 7G), King Island (blocks 3C, 3D, 4C and 4D) and the southwest coast (blocks 5D, 6E, 7E and 7F) (Figure 2). The east coast and Hobart area is characterized by a multitude of ports and safe anchorages. Wave height there was the lowest of all areas studied but fairly constant through time, averaging (mean ± standard deviation) 1.84 ± 0.76 m in summer and 2.18 ± 1.07 m in winter. Due to its accessibility, historical effort was relatively constant through time (418 513 ± 19 264 potlifts) but average revenue per potlift was the lowest (AUD $35.53 ± 20.02) of all areas studied and has been declining since 2007. The east coast and Hobart area also had the smallest average vessel length (13.2 ± 2.4 m) and GRT (27.2 ± 13.3) of all areas, which reflected its geography and the nature of fishing trips, which ranged from day trips to week-long trips (see Supplementary data for detailed figures). King Island is located off the northwest coast of Tasmania, with wave heights that remained constant through time, averaging 2.36 ± 0.82 m in summer and 3.07 ± 1.22 m in winter. Historical effort was relatively low (249 568 ± 39 579 potlifts) over the period due to the smaller number of vessels based in this area, which also meant that the revenue per potlift was the highest (AUD $53.76 ± 20.77) of all areas. While King Island vessels usually make short day trips, average vessel length (14.8 ± 2.4 m) and GRT (35.3 ± 11.9) was comparable with those of vessels based on the southwest coast (see Supplementary data for detailed figures). The southwest coast is characterized by long stretches of exposed, uninhabited coastline with wave heights that were the highest of all areas studied, averaging 2.98 ± 1.36 m in summer and 3.91 ± 1.4 m in winter. The five fatalities in the rock lobster fishery since 2008 all occurred along the southwest coast of Tasmania, which is indicative of its hazardous nature. Despite its ruggedness, historical effort in this region was high (532 148 ± 81 260 potlifts) over the period studied, as well as

Figure 2. Map of the Tasmanian southern rock lobster fishery, Australia, with one degree squares (e.g. 3C) used for compulsory logging of the location of daily effort.
<table>
<thead>
<tr>
<th>Statewide</th>
<th>King Island</th>
<th>Southwest Coast</th>
<th>East Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient</td>
<td>Standard Error</td>
<td>p-value</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.564</td>
<td>0.0474</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>% Quota Owned/Held Length</td>
<td>-0.1391</td>
<td>0.0197</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Wave height 2 m</td>
<td>-0.1003</td>
<td>0.0018</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Wave height 3 m</td>
<td>-0.362</td>
<td>0.0298</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Wave height 4 m</td>
<td>-0.6688</td>
<td>0.0333</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Wave height &gt;5 m</td>
<td>-1.007</td>
<td>0.0395</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Variability</td>
<td>-0.0454</td>
<td>0.0005</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Revenue</td>
<td>0.0139</td>
<td>0.0005</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>% Quota Owned/Held:Wave height 2 m</td>
<td>0.0702</td>
<td>0.0184</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>% Quota Owned/Held:Wave height 3 m</td>
<td>0.134</td>
<td>0.021</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>% Quota Owned/Held:Wave height 4 m</td>
<td>0.1871</td>
<td>0.027</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>% Quota Owned/Held:Wave height &gt;5 m</td>
<td>0.1659</td>
<td>0.0333</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Wave height 2 m:Revenue</td>
<td>0.0026</td>
<td>0.0006</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>Wave height 3 m:Revenue</td>
<td>0.0023</td>
<td>0.0006</td>
<td>0.0004*</td>
</tr>
<tr>
<td>Wave height 4 m:Revenue</td>
<td>0.0031</td>
<td>0.0008</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Wave height &gt;5 m:Revenue</td>
<td>0.0076</td>
<td>0.0011</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>% Quota Owned/Held:Height</td>
<td>-0.0001</td>
<td>0.0002</td>
<td>0.7398</td>
</tr>
<tr>
<td>% Quota Owned/Held:Length</td>
<td>0.0043</td>
<td>0.0009</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>% Quota Owned/Held:Wave height 2 m:Revenue</td>
<td>0.0016</td>
<td>0.0004</td>
<td>&lt; 0.0001*</td>
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<td>% Quota Owned/Held:Wave height 3 m:Revenue</td>
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<td>0.0006</td>
<td>&lt; 0.0001*</td>
</tr>
<tr>
<td>% Quota Owned/Held:Wave height 4 m:Revenue</td>
<td>-0.0026</td>
<td>0.0008</td>
<td>0.0014</td>
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<tr>
<td>Observations</td>
<td>371711</td>
<td>68252</td>
<td>125347</td>
</tr>
</tbody>
</table>

Dependent variable: Decision to fish. Insignificant variables were removed from the model. Other significant variables not displayed: quota year, home port of vessel, month and block (area).
average revenue (AUD $52.99 ± 23.77), but it has declined since 2006. Some vessels fishing this area travel from the east coast and Hobart area to conduct one- to two-week fishing trips, so the average length (14.5 ± 2.7 m) and GRT (34.9 ± 16.5) of vessels was higher than the statewide average over the period studied (see Supplementary data for detailed figures).

It is important to note that the discrete choice model has a non-linear response function (logit), which must be understood to interpret the results. Therefore, Figure 3 displays a logit index plot, which allows the reader to judge the potential variation in decision-making by adding together coefficients from the model(s) to obtain a logit index and then deduce the probability of fishing. For example, if the logit index is −1 the probability of going fishing is 27%. Similarly, if a factor increases the logit index by one, the maximum increase in fishing probability is 23%. This maximum increase is attained if the logit index was zero beforehand but could be negligible if it was already high or low.

Results
The overall effect of wave height was a significant factor in the decision to fish for all fishers in the TSRL fishery (Likelihood Ratio Test (LRT) \( p < 0.001 \) for all areas). Increasing wave height reduced the number of fishers choosing to fish on a given day in all areas, consistent with the expected widespread aversion to physical risk (Table 1, Figure 4). For example, when expected revenue and revenue variability were AUD $35 and AUD $10 per potlift, respectively, and significant wave height was 1 m, the model predicted that there was a 60% (59–62%, 95% CI) probability that a quota owner using a 15 m vessel in December 2008 would choose to fish along the east coast and Hobart (7G), compared with only 45% (42–47%, 95% CI), when significant wave height was ≥5 m. Geographical variation in physical risk tolerance was also evident as fewer fishers off the southwest coast chose to fish in more hazardous wave heights (i.e. ≥5 m) (Figure 5b). In contrast, along the east coast and Hobart (Figure 6b) and off King Island (Figure 7b), there was a higher tolerance to physical risk displayed by all fishers.

While increasing significant wave height acted as a disincentive for fishers to choose to fish this was offset by a higher expected revenue (LRT \( p < 0.001 \) for all areas). Expected revenue had a significant influence on a fisher’s decision to fish at hazardous wave heights, in all areas (Table 1, \( p < 0.001 \)) except the southwest coast (Table 1, \( p = 0.67 \)). For example, when significant wave heights were ≥5 m and expected revenue increased to AUD $70 per potlift.

The influence that changes in expected revenue had on a fisher’s decision to fish, varied with the level of quota ownership. When the interaction between quota ownership and expected revenue was removed and the model rerun and then compared, there was a significant difference in all areas (LRT \( p < 0.001 \) for Statewide and King Island; \( p = 0.05 \) for East coast and Hobart), except off the southwest coast (\( p = 0.18 \)). This led to lease quota fishers both Statewide and off King Island being more tolerant of hazardous wave heights than quota owners.
in all areas but particularly, Statewide (Figure 4) and off King Island (Figure 7). For example, when significant wave heights were ≥5 m and expected revenue and revenue variability were AUD $70 and AUD $10 per potlift, respectively, the model predicted that there would be a 68% (64–73%, 95% CI) probability that a quota owner using a 15 m vessel in December 2008 would choose to fish off King Island (3C), compared with an 81% (75–85%, 95% CI) probability a lease quota fisher would choose to fish. While lease quota fishers were still more likely to choose to fish at hazardous wave heights than quota owners off the east and southwest coasts when expected revenue was high, the difference was not as marked (Figures 5 and 6). For example, when significant wave heights were ≥5 m and expected revenue and revenue variability were AUD $70 and AUD $10 per potlift, respectively, the model predicted that there would be a 72% (69–77%, 95% CI) probability that a quota owner using a 15 m vessel in December 2008 would choose to fish along the east coast and Hobart (7G), compared with a 74% (70–78%, 95% CI) probability a lease quota fisher would choose to fish.

To assess whether the amount of quota owned by a fisher influenced the size (i.e. length) of their fishing vessel, a secondary GLM was developed for each area of the TSRL fishery. Those fishers who owned smaller amounts of quota (i.e. lease fishers), used significantly smaller-sized vessels while fishing in all areas (p < 0.001) (Table 2). For example, the model predicted that a fisher owning only one quota unit would fish using a 13 m vessel compared with a 17 m vessel for a fisher owning 100 quota units, along the east coast and Hobart (Figure 8). Geographical variation among the vessel sizes of lease quota fishers was also evident, with those along the east coast and Hobart predicted to use smaller vessels than their equivalents at King Island (Figure 8).

Discussion

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

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

The costs of leasing quota

Quota lease prices should reflect the current resource rent generation in the fishery (Eythorsson, 1996). In many ITQ fisheries, quota lease prices have increased through time, partly as a result of capital adjustments (Lindner et al., 1992), greater efficiency (Eythorsson, 1996) and reduced interannual variability among ecological indicators (Essington, 2010). For example, the quota lease price increased by 45% between 1999 and 2007 in the TSRL fishery and by 49% between 1993 and 2008 in the British Columbia (BC) halibut fishery. From the annual value of their fishery and by 49% between 1993 and 2008 in the TSRL fishery, it is apparent that lease quota fishers face an intensifying “cost-price squeeze between what [they] must pay to lease the quota and what [they] are paid for [their] catch” (Pinkerton and Edwards, 2009). The cost of leasing quota can act as a barrier to entry into fisheries (van Putten and Gardner, 2010), create debt-service obligations (Bromley, 2005) and reduce the commercial viability of fishing operations (Davidson, 2010).

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

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

While not affected by issues of quota concentration, as a consequence of a cap on maximum ownership of around 1.9% of the TAC, the lease market in the TSRL fishery is effective in creating competition amongst lease quota fishers and generating a “cost-price squeeze”. This is evident in the lease payments made to quota owners, which appear to capture all the resource rent, as well as in the income of lease quota fishers, which are typically low and

Figure 8. Predicted size of vessel (length) based on the amount of quota units owned by a fisher in the TSRL fishery.
below their next best source of employment (van Putten and Gardner, 2010; van Putten et al., 2011). This can lead to the behaviour observed in the TSRL fishery where lease quota fishers, in operating at a lower profit margin, choose to fish during times of hazardous wave heights to maximize the landed value of their product and offset the increased costs of leasing quota. Similar behaviour has also been anecdotally noted in the BC halibut fishery (Davidson, 2010). It could also have led to fishers in the TSRL fishery using smaller (and potentially older) vessels in order to offset leasing costs, which can further increase their risk exposure when choosing to fish at hazardous wave heights.

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

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

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

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

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

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

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