THE EFFECT OF QUOTA TRADING LIMITATION IN A FISHERY MANAGED THROUGH INDIVIDUAL TRANSFERABLE QUOTAS

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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. Preliminary results are presented on how the different harvesting patterns induced by a cap on trade and concentration of quota impact on the socio-economic performance of the fishery and the biological resource.

The initial simulations show that 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 also allows to simulate the possible trajectory of quota leasing prices over the first decade of the ITQ system, and to assess its sensitiveness to external drivers such as the market crisis observed in the early 2000s.

Keywords: ITQs, agent based model, quota trading, location choice, rock lobster, Tasmania
INTRODUCTION

Individual transferable quotas (ITQs) have been used for regulating access to marine fisheries resources in developed countries for the past three decades (Chu, 2009). Although seen as successful management tools to improve the economic efficiency of fisheries, their social consequences have been regarded as an issue (Bromley, 2009, McCay, 1995, Pinkerton and Edwards, 2009, Bradshaw, 2004, Copes, 1986). The theory behind ITQs is 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. However, the increase in efficiency comes at the cost of concentration in quota ownership. The aggregation of quota shares in the hands of fewer operators and a shift towards investors rather than owner-operators are among the issues potentially entailing negative social impacts. According to Anderson (2008), accumulation of quota is bad for two reasons, i) monopoly issues, if all quota is held by a single company, it has the control on the quota leasing price and can manipulate the market; and ii) equity issues. In particular, artisanal or small scale fishers often lack the cash flow needed to expand their allocation and the market only profits the big companies or industrial fishers (Bernal et al., 1999). Moreover the transferability of quotas and the possibility of concentrating quota shares can have an impact 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 would not fish at least 25% of his allocation for two consecutive years would forfeit his permanent holding (Arnason, 1996). New Zealand, the only country using individual transferable quota as the default management tool for its fisheries, restricted the holding of quota shares to New Zealand residents and to companies with at most 25% of foreign voting power (Boyd and Dewees, 1992). In addition, all countries have limits on how much quota one can hold. The limits range from fairly large, e.g. 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, e.g. 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 also restricted exchanges of quota between different regions even if in practice most trades were allowed between regions (Arnason, 1993). However, there is a trade-off between economic efficiency of the fishery and tight aggregation limits (Anderson, 2008). Limiting quota trade can result in inefficiency 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 fig 1)(Winstanley, 1973). The fishery had been managed through input control for about a century when in the late 1980’s, concerns were raised regarding the decrease of catch rates and the sustainability of the rock lobster fishery. Limit on the number of fishing traps per vessel, a seasonal closure for molt and minimum legal size were 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 1500t, the 10 507 quota units1 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% and despite the possibility of nominating family members as beneficial owners, as a

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1 The number of quota units was set at 10507 equal to the number of traps used in the fishery since the cap on lobster trap was reduced in 1983 (Bradshaw, 2004).
way around the limit, evidence for concentration of quota has been minimal. Although some concentration of quota ownership occurred over the 1998-2006 period (Hamon et al. 2009), aggregation of quota remained at a relatively low level (figure 2). A common measure of wealth distribution, the Gini index (Gini, 1921) stayed far below values observed in other fisheries. 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 (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.

![Figure 1 Map of Tasmania with the eleven assessment areas](image1)

![Figure 2 Evolution of the concentration of quota ownership in the Tasmanian rock lobster fishery from 1998 to 2006](image2)

The aim of this paper is to 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 of fishers as to where and when to fish depending on the returns they obtain from fishing, as well as quota trading. Individual responses to management perturbations will differ because of the heterogeneity of fishers in terms of their port of origin, cost structure and quota ownership. In this study, we consider preliminary results on the ways in which different regulation systems implemented to prevent quota concentration may influence individual behaviors of fishers/quota-owners and therefore the whole fishery.

The paper is structured as follows. The first section provides a synthetic description of the simulation model which was developed to examine the dynamic response of the fishery to the quota management system. The second section presents the scenarios which were considered in the current study. Initial results are presented in the third section and the fourth section discusses these results and concludes with perspectives for future work based on the model. The equations used in the economics component of the model are shown in appendix 1.
MODEL

Rock lobster dynamics

With the introduction of ITQs in the fishery, the need to set a TAC called for a better evaluation of the resource. The Tasmanian rock lobster fishery has been assessed annually since 1997 using models to review the state of the fishery and forecast its future (Punt and Kennedy, 1997, Frusher, 1997). The central model of the dynamics of the Tasmanian rock lobster stock used for these assessments is described in Punt and Kennedy (1997) and Punt et al. (1997). 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, hence the comprehensive biological processes included in the model will only be briefly mentioned here. The rock lobster population is structured using 5mm size-classes. Biological processes occur during “periods”, with periods of one or three months (three month periods occurring during the Austral winter, from May to October). During each period, lobsters die due to natural and fishing mortality (full-line light-grey boxes, fig 3), while migration, growth and lobster settlement at the end of the larval stage only happen during some periods (dashed-line light-grey boxes, fig 3). 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 make the use of several areas when modelling the population unavoidable. In addition to the 8 stock assessment areas used to divide Tasmanian waters, three areas have been divided into shallow and deep water to account for the difference of lobster quality in deeper water (areas 9, 10 and 11 on fig 1).

Dynamics of rock lobster fleet

The effort allocation for the Tasmanian rock lobster fleet is modeled using an agent-based approach (Uchmanski and Grimm, 1996). Every agent in the model is a quota-owner. 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 have to make decisions on whether, where and how much to fish under their fishing right allocation constraint.

At the beginning of the year, agents choose their monthly fishing activities or “métiers”. Métiers are defined as an activity with specific fishing locations (see the map figure 1 for the areas and Hamon et al, in prep, 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 to not fish for rock lobster. The choice by fishers among alternative fishing activities can be based on several alternative approaches (see Van Putten, Kulmala et al., this volume). In this study, choices are 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 the
métier is stochastic with the probability of a fisher choosing a métier increasing with the expected short-
term profit of fishing in the métier for the month following a logistic function.

The expected short-term profit for the month in a métier is the product of the daily marginal profit
expected for the métier and the maximum number of days spent fishing in the métier. The maximum
number of fishing days for a métier during a month for a vessel of a certain size is constrained 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 technical maximum
number of fishing days in a month in a métier for a vessel is thus set in the model as the maximum
number of fishing days ever observed in the month in the métier by a vessel of similar size for the period
1993-2008. The daily marginal profit is based on daily revenue, which varies according to the métier
chosen and to daily variable costs induced by fishing (equation 1). Variable costs include costs related to
fishing rock lobster regardless of the location and include bait costs, food costs, ice costs, gear
replacement costs, ropes and clothes, and costs dependent on the métier chosen such as fuel costs, quota
leasing costs, deckhand and skipper wages (see equation 2). To assess the relative attractiveness of each
alternative métier, the expected marginal profit of each métier is calculated for each vessel, each month.
The expected values of revenue and costs are calculated based on past observations updated with the most
recent information on prices and catch rates evolutions. The resulting expected value of the daily marginal
profit is shown in equation 3. An “inactive” métier is included as an option, where vessels are either not
fishing, or fishing for other species than rock lobster. For the current study, lack of data on alternative
activities did not allow an estimation of the expected returns from this option, which was set to zero. This
almost certainly under-estimates the opportunity cost of lobster fishing, as vessels may operate in several
alternative fisheries at different seasons of the year, and vessel owners may in some cases also have
alternative sources of income to fishing.[5] (Frusher et al, 2003). Quota leasing costs included in the
calculation of short-term profit integrate the quota value of the entire expected catch, even if some of the
catch will be covered by the quota owned by the fisher. This allows to account for the opportunity cost of
fishing their own quota rather than leasing it out.[5] Every vessel chooses only one métier in which
to operate for each month. The métier selected for a month is characterized by expected catch-rates, a
maximum number of fishing days resulting in an expected catch, expected revenue and expected profit.
Those expectations are updated every month taking into account the most recent knowledge about the
catch rates obtained in a métier, the fuel prices and the evolution of the lobster price.

ITQ fisheries are characterized by individual constraints through individual allocation of quota. The
amount of quota held by a fisher at any time (being the initial allocation minus the catch and plus/minus
the quota exchanged on the market) represents the fishing allowance for the rest of season. Fishers need to
decide how to distribute their remaining quota to the different métier-months left. If fishers have enough
quota to cover their total expected catch they will fill their fishing plan, else, the allocation of quota to
months is based on the expected profit per kg of catch. Quota is allocated to the different months
proportionally to the expected profit per kg for each month within the limit of the expected catch if
fishing the maximum number of days during the month. This allocation of quota to fishing months is
updated every months considering the market exchanges, quota uptake and updated profit expectations.

The number of days needed to catch the monthly quota allocation defined in the previous paragraph is
calculated for the current month prior to fishing based on the latest knowledge about catch rates. The
spatial allocation of trap lifts per vessel in each fishing area (map fig 1) during a month depends on the
number of days fished, the number of traps on the vessel and the number of lifts a vessel can make in a
day.[6] (equation 4). The spatial distribution of these trap lifts is determined by the chosen métier, the month

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2 The number of traps a vessel can carry onboard depends on the size of the vessel because all traps should fit on the
vessel deck at anytime due to regulations on soaking time.
3 The number of lifts per day depends mainly on the day-length and light and thus depends on the season.
and the region of origin. All métiers combine fishing in several areas but in different proportions. The proportion of effort in each area for a given month in a métier is derived from logbook data and the métier definition.

The catch in each area for a month and a vessel is then calculated as the product of the vessel efficiency, the average catchability, the effort and the available biomass (equation 5). The biomass used for the calculation is the biomass left after half the catch has been taken. If the catch for a fisher exceeds the quota left then the effort is scaled down and the catch is recalculated for the entire fleet.

**Quota trading**

The constraint on how much fishers are allowed to catch can be relaxed by leasing in or buying additional quota. The decision to lease quota in or out is based on economic performance. Fishers compare the marginal profit they expect per kg fished to the quota leasing price. If their expected marginal profit per kilo is higher than the quota leasing price, they have incentives to fish and lease quota in. On the other hand, if their expected marginal profit per kilo is lower than the quota leasing price, they cannot lease in quota without fishing at a loss and they can obtain a larger profit by leasing out their quota and engaging in alternative professional activities. The reality is more complex, fishers may obtain a positive utility from fishing regardless of profit, and quota-owners may cross-subsidize less profitable months with their profit from the more profitable months. However, such behavior is not captured in the current version of the model.

In the model, temporary quota transfers (leases) occur twice a year. At the beginning of the quota season (in March) fishers can plan for the entire year; they can also adjust their allocation in November before summer fishing. At each trade event, lease price is calculated. Several options have been considered to calculate lease prices. Due to the lack of a quota price time-series, it is impossible to estimate quota price as the function of covariates as in Newell et al. (2005). Instead, the quota price is calculated by iteration as the price maximizing the exchanges using bisection method with a lower bound set to AUD$0 and a higher bound set to AUD$100. The initial quota price is the average expected marginal profit weighted by the expected catch exceeding the quota allocation each month (see equation 6).

For each iteration of the bisection method, fishers split their fishing plan in two categories: i) the months that are profitable when they should go fishing (i.e. with a marginal profit (per kg) higher than the quota price) and ii) the months that are less profitable (i.e. the marginal profit is only positive if quota is owned), for which it is not worth leasing in quota. Fishers will only lease in quota if their expected catch is higher than the quota they allocated to a profitable month. The individual demand in quota is equal to the difference between the expected catch in profitable months and the quota already allocated to those months up to the quota cap limits. Fishers do not lease in quota to supplement non profitable months. If fishers hold more quota than their expected catch for the rest of the year, then they are expected to sell the surplus and become what van Putten and Gardner (2010) have called “income supplementers”. If there is no profitable months in an agent's fishing plan, the fisher leases out all his quota, thus becoming an investor. The resulting demand and supply are compared and in case of mismatch the quota price is changed and the 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 set as the last quota price used. Using the bisection method, the quota price converges quickly and if two consecutive iterations give quota prices less than 1ct different the price is set as the last one calculated.
QUOTA TRADING SCENARIOS

In the current study, the model was used to simulate a set of scenarios relating to the influence of trade limitations on the evolution of the fishery. The simulations correspond to projections of the fishery based on the initial status of the lobster stock (as of 1997, based on the 2009 stock assessment, Gardner and Ziegler 2010), biological parameters, an initial fleet and economic parameters regarding variable input and output prices. Cost data includes historical fuel price data at the month level since 2001 (www.fuelwatch.wa.gov.au/) and average annual fuel price between 1997 and 2000 (www.abare.gov.au). The cost data collected in an economic survey in 2007 are used for the other short term costs of fishing (van Putten and Gardner, 2010). Beach price data include an estimated monthly price for a reference market category and constant price differences between the reference market category and the other market categories4 for summer and winter (derived from Chandrapavane et al., 2009). Agents are also described in terms of vessel length, geographical origin and fishing efficiency.

The projection model runs over the 1998-2008 period. Growth, lobster movement and natural mortality are set to those used for projections in the fishery assessment (Gardner and Ziegler, 2010). Recruitment is stochastic, log-normally distributed around the average settlement of 1994-1997. The economic agents modeled are the 302 quota owners present in the fishery at the beginning of the first quota season. In 1998, most quota owners were also vessel owners but 12 quota owners representing 2% of the total quota shares could not be linked to a rock lobster fishing vessel and were thus assumed not to fish.

Based on the literature and on the current management of the fishery studied, four scenarios were investigated regarding the extent to which quota trading is limited in the fishery. As the model includes only the short-term drivers of fishing activity, the exchanges modeled in this study are exclusively temporary quota trades or leases. The limit on quota trading investigated is thus on the effect of a limit of quota usage rather than on a limit on quota holding:

• The first scenario corresponds to a quota management system 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 must fish their quota;
• The second scenario assumes that 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);
• The third scenario corresponds to the legal limit of owning, holding or using a maximum of 200 quota units per year for any agent;
• The last scenario assumes 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 in the fishery (Anderson, 2008).

RESULTS

The results shown in this section are based on a single simulation for each scenario and should therefore be considered as preliminary.

4 Market categories for rock lobster are defined in terms of color and sizes. In the model 4 size categories (<0.8kg, 0.8-1.5kg, 1.5-2kg and ≥2kg) and 2 color categories (red, caught within 40m depth and non-red, caught deeper than 40m) are used so in total 8 market categories.
Economic and social impacts

A decrease in the number of vessels fishing every year can be observed for the three scenarios incorporating quota trading (figure 4), while prohibition of trade (blue dashed line) leads to a constant fleet of 290 vessels all fishing their allocation. The predicted decrease of the size of the fishing fleet in the scenarios with trade is higher than the historically observed fleet reduction (red line), even in the case with a 120 quota units limit.

The lease price of quota follows similar trends across all scenarios with quota trade (see Figure 5). The model captures the impact on quota prices of the drop in lobster sale prices during the SARS outbreak in 2003 and 2004 (severe acute respiratory syndrome, see Hamon et al, 2009 for description of the effects of the outbreak in Asia on Tasmanian lobster beach price)[the038 7]. Expecting lower revenue from their catch, fishers could not afford to pay the high quota prices of the previous years; this is tracked by the simulated price which falls to less than $20/kg. Overall, however, anecdotal evidence suggests that the real quota leasing prices were actually lower than the simulated prices obtained in the current study ($7 the first year of quota, doubling in the early 2000s (Frusher et al., 2003) and around $20 per kg in the latest years of the studied period).

Effect on the lobster stock

While the seasonal pattern of effort distribution in the fishery was relatively well reproduced, the predicted geographical distribution of effort differed from the observations in a number of ways (figures not shown here). Predicted effort was remarkably higher in the Western and South-Western areas, where catch rates are higher (areas 6 to 11 on figure 1) and lower in Northern areas where lobsters are larger (areas 4 and 5). This increase in the proportion of effort allocated to areas with higher catch-rates and smaller lobsters was more important when trade was allowed. The causes for these differences between observed and simulated effort patterns are currently being investigated. They may partly relate to differences between the simulated biology of rock lobster and the actual stock assessments for the study period. In particular, annual simulated settlements in each areas being stochastic, and based on average estimates for years 1994-97, they differed from the real settlements where peak recruitments were observed in some areas during the study period. Analysis of the impacts of alternative management scenarios on effort allocation and the ensuing impacts on the biology of rock lobster will be carried out based on the inclusion of the assessment data for recruitment.
DISCUSSION

The rationalization of the fishing fleet is often a desired effect of individual transferable quotas that can be achieved if quota owners have the opportunity of trading their quota allocation. Fishers with the best strategies, highest skills or most efficient fishing gears buy out the less efficient fishers making the overall fishery more economically efficient. Where only leasing of quota is considered, this may serve as a way of temporarily removing excess capacity from a fishery. In effect, temporary transfers of quota units increase the short-term flexibility of fishers by giving them the options of not fishing while leasing their quota out, or of fishing above their fixed initial quota allocation. In the Tasmanian rock lobster fishery, the fishing fleet was reduced by 25% in the first three years after implementation of ITQs (Hamon et al., 2009). The simulation results presented in this study show a similar rationalization pattern, although this effect is much stronger in the model than was actually observed. This difference could largely be explained by the way in which profit is calculated in the model. Although fixed costs are not taken into account in the choice of fishing activity as this is considered a short-term decision, the skipper wage is. Yet, the fishery is mainly composed of owner-operators who did not seem to take their opportunity time and cost into account when making short-term decisions about their involvement in rock-lobster fishing, according to recent surveys (van Putten and Gardner, 2010). This has been shown to occur in other small scale fisheries in the world (Boncoeur et al., 2000) Including the opportunity cost of skipper’s activity in the fishery probably led to over-predict the shut down of fishing firms operated by their owners.

The quota leasing prices predicted by the model in the current study are higher than what has ever been observed. Several reasons could explain such a bias. First, in the first few years of quota, there was evidence of a leasing quota at a ‘fair’ price (Fruscher et al., 2003). This ‘fair market’ was principally composed of exchanges between family members and friends. Network analysis on the structure of the lease market seems to indicate that this form of quota trading declined with time and probably does not exist anymore (van Putten et al., Accepted). Another potential bias toward high lease prices lay in the crew wages calculation. Wages are calculated on a share basis, with the structure of shared costs, and the crew and skipper shares being negotiated every year on each vessel. In the model, based on recent survey data, quota lease costs are assumed to be shared, such that crew members are assumed to receive 14% of the difference between revenue and lease costs if quota is leased. Similar arrangements are assumed for skippers (who get 24% of the difference). Therefore, lease cost is supported by both the skipper and the crew at around 30 to 50% of its value (depending on the number of crew members). If the decision to lease in quota is based on expected profits for the vessel owner, as currently simulated, the fact that the crew supports part of the lease costs may be driving the quota leasing price higher than would be observed were lease costs paid in full by quota owners (Guyader and Thebaud, 2001). In practice, the decision to lease in additional quota may well be a combined decision by the vessel owners and their crews, such that the full lease costs are included in the assessment of the value of purchasing quota, leading to lower observed prices.

The differences between the three trading scenarios seem minor and the results shown in this study do not allow to draw conclusions on how the cap on trade influences the fishery. However the difference between the trading scenarios and the scenario where trade is prohibited is noticeable. While in the non-tradeable quota scenario, all vessels remain active in the fishery, the overall economic performance of the fleet is reduced as the remaining fleet is considerably larger, entailing higher fixed costs (graphs not shown).
CONCLUSION

At the time of the implementation of ITQs in the Tasmanian rock lobster fishery, in 1998, the main objectives were to reduce effort in the fishery to relieve the pressure on the stock and insure a decent living for fishers. The industry was aware of the overcapacity built into the fishery over the years and expected a decrease in the number of vessels in the fleet with the introduction of ITQs. The fishing fleet decreased by 25% in the first three years of implementation and remained stable in terms of vessel numbers since then. The rationalization of the fleet could only be achieved because individual quotas were transferable and quota owners did not have to fish their allocation.

As social issues were taken into account when designing the program, a very low quota aggregation limit was implemented, at 120 quota units or 2% of the total TAC. Whereas the 120 units cap has been efficient to prevent the socially undesired concentration of quota ownership (see Hamon et al., 2009), it is unclear if the limit on usage could have reduced the efficiency of the fishing fleet by restraining the size of individual operations. According to the initial results presented in this study, it would seem that removing the limit on quota usage would not lead to dramatic changes in the fishery. Further investigation is needed to understand why removing the utilization limit does not affect the size of the fishing fleet; it may be that the optimal operating size of most of the fishing firms in this fishery lies within the current quota limit.

Assessing the performances of the model against the reality is a useful tool to develop and improve modeling. Even though the model performed reasonably overall, some sensitivity analysis are needed to investigate how the profit structure of fishing firms affect their behavior and the overall dynamics of the fleet.

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**APPENDIX - EQUATIONS**

\[
dMP_{v,m,y} = dR_{v,m,y} - dvCost_{v,m,y} 
\]

\[
dvCost_{v,m,y} = dFuelC_{v,m,y} + dBaitC_{v,m,y} + dFoodC_{v,m,y} + dDeckieC_{v,m,y} + dLeaseC_{v,m,y} + \frac{IceC_{v,m,y} + GearC_{v,m,y} + Ropes_{v,m,y} + Clothes_{v,m,y}}{\sum_{a} E_{v,m,y}} 
\]

\[
dMP^{exp}_{v,m,y} = dR^{exp}_{v,m,y} - (dFuelC^{exp}_{v,m,y} + dOthC^{exp}_{v,m,y} + dLeaseC^{exp}_{v,m,y}) - dWage^{crew}_{v,m,y} - dWage^{skipper}_{v,m,y} 
\]

\[
TrapLifts_{v,m,y} = Days_{v,m,y} \cdot nTrapUsed_{v,m,y} \cdot nShot_{v,m,y} 
\]

\[
Catch_{v,a,m,y,t} = Efficiency_{v,a,m,y,t} \cdot TrapLift_{v,a,m,y,t} \cdot B_{a,m,y,t}^{max} 
\]

\[
QuotaPrice^{init}_{v,m,y} = \sum_{\text{month}=1}^{12} \frac{(Catch_{v,\text{month},y}^{\text{exp}} - Quota_{v,\text{month},y}^{\text{alloc}}) \cdot MP_{v,\text{month},y}}{\sum_{\text{month}=1}^{12} (Catch_{v,\text{month},y}^{\text{exp}} - Quota_{v,\text{month},y}^{\text{alloc}})} 
\]