18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

A model for simulating trading of fisheries quota

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Abstract: Individual transferable quotas (ITQs) have long been proposed as a way of increasing the profitability of fisheries by introducing a rights based, tradeable permit system that fosters stewardship of the resource, breaking the cycle of over-capitalisation and over-exploitation. Under ITQs, fishers receive a share of total allowable catch (TAC) and are free to use it or sell it. In this paper we develop a model to simulate trading of fisheries quota in an ITQ market. We build on a multi-species population and vessel dynamics model developed for common coral trout (Plectropomus leopardus) and red throat emperor (Lethrinus miniatus) in the Coral Reef Fin Fish Fishery (CRFFF), a $AU 50 million fishery operating on the Great Barrier Reef of Australia, where an ITQ fisheries management system has been operating since 2004. The model considers initial quota allocation to vessels, seasonal fish prices and individual variable costs, fishing efficiency and experience., Vessel operators can either purchase or sell quota of either species, if it was in their interest to do so to maximise profit. This depends on the cost each vessel incurs per day fishing, seasonal fish prices and historical catch rates experienced by the vessel operator, which in turn depends on the catchable biomass of the species and the vessel's own fishing efficiency. Results show projected fishing effort trajectories under a range of TAC levels for coral trout and red throat emperor. Results also show the profitability of the fishery under a range of management options. In general, as the TAC for the primary targeted species, coral trout, increased, so too did the effort. Fishing effort under the current TAC arrangement decreased, mimicking the actual effort level since 2004. Effort dynamics were also more sensitive to the coral trout TAC, the more valuable primary target species, compared to the TAC of the less valuable red throat emperor. Discarding of red throat emperor was also high when the ratio of coral trout TAC to red throat emperor TAC was high. The results help managers in understanding the implications of their quota-related decisions, illustrate what might be expected with trading in a multi-species quota system and indicate what to expect in the CRFFF as that multi-species ITQ system matures.

Keywords: *Individual transferable quota, ITQ, vessel dynamics, coral reef fish, simulation modelling*

1. INTRODUCTION

Fisheries management is an inherently difficult and complex process that must balance competing ecological, economic and social objectives. Managers have tried to address these conflicts by constraining the short-term economic drive of fishers, by invoking output controls like a Total Allowable Catch (TAC), but this has tended to make fishers economically inefficient, driving them to improve their fishing effectiveness in any way possible. Individual Transferable Quotas (ITQs) have been proposed as a way of breaking this cycle (Branch 2008). The economics of ITQs originated in work on environmental pollution and international trade and was subsequently extended to fisheries (Grafton, 1996). ITQs allocate a share of a TAC to each fisher, which they are then free to use, lease or sell.

Proponents suggest that property or harvest rights given to the users of a resource in the form of an individual TAC share (or individual quota, IQ) create an incentive for fishers to minimise the cost and effort associated with catching their TAC share, while at the same time maximising their revenue by fishing at times when prices are high. Different costs and fishing abilities lead to variation among fisher profits. The addition of transferability of individual quotas (ITQs) provides the choice of fishers to either continue fishing or transfer (by sale or lease) their quota holdings to other fishers or, for efficient fishers, accumulate quota by purchase or lease. Fishing effort, and its broader ecosystem effects, should therefore decrease if the fishers that purchase quota are more efficient, and thus spend less time fishing, than those selling or leasing quota. Some (e.g. Dewees, 1998; Matulich and Clark, 2003) have claimed that ITQs result in privatisation and corporate concentration of a public resource and that other users and beneficiaries are ignored, but ITQs have proved an effective remedy for overcapitalisation in many single species fisheries (Branch 2008) and are increasingly being applied to fisheries world-wide (Costello et al., 2008).

ITQs have been implemented recently in the commercial sector of the Coral Reef Fin Fish Fishery (CRFFF) on the Great Barrier Reef (GBR). The GBR is one of the largest coral reef ecosystems in the world, with over 2,900 individual coral reefs scattered over more than 2000 km of coastline. The CRFFF consists of three sectors: a commercial sector, a charter sector that caters to a lucrative tourism industry, and a recreational sector. All sectors use similar gears consisting of single baited hooks on heavy line with a rod or hand reel. The fishery is multi-species, with over 125 species groups recorded in the compulsory commercial logbook system managed by the Queensland Department of Primary Industries and Fisheries (QDPI&F) (Mapstone et al., 1996). The two major target species are common coral trout (Plectropomus leopardus Lacepède) and red throat emperor (Lethrinus miniatus Forster), which together comprise over 50% of the total catch by the commercial sector (Mapstone et al., 1996, 2004, 2008) and 90% of the revenue (Anonymous, 2007). Since 1993, the fishery has increasingly retained live coral trout for export to Asian fish markets. By 2006, approximately 90% of coral trout was marketed in this manner. The annual economic value of the commercial sector is about AU$60-100 million (Williams, 2002). Only the commercial sector is managed using an ITQ system. Other management restrictions including seasonal spawning closures, size and hook limits applied to all sectors, limited entry applied to the commercial and charter sectors, and bag limits applied to the recreational and charter sectors.

We have developed a model, the Effects of Line Fishing Simulator (ELFSim) that simulates the meta-population dynamics and harvest by all sectors of the two primary target species to evaluate management strategies in the CRFFF (Mapstone et al., 2004, Little et al., 2007, 2008). This model has been used to examine the effectiveness of alternative management strategies against diverse and conflicting management objectives (Mapstone et al., 2004, 2008), to show the value to fisheries of larval subsidy from marine reserves (Little et al., 2007), to illustrate the effects of spatial infringement into marine reserves (Little et al., 2005), and to determine the effects of information sharing among fishing vessels (Little et al., 2004). We have recently added a model that simulates the behaviour of individual vessels (Little et al., 2008) and a model that allows for trading of quota among the fishing vessels. In this paper, we document the method of simulating the ITQ system and show the possible effects of the ITQ system in a multi-species context of the CRFFF.

2. METHODS

The Effects of Line Fishing Simulator (ELFSim) is a decision support tool designed to evaluate management strategies for reef fish species in the CRFFF. ELFSim consists of three components (biological, harvest, management) and operates at a monthly time step, with each simulation consisting of two parts. The first ('initialisation') step operates historically from the assumed beginning of the fishery and determines the present population size of each species on each of the individual reefs on the GBR, accounting for historical catch and the physical characteristics of the reefs. Reef-specific populations are then projected into the future ('projection period') by subjecting them to simulated fishing pressure from the harvest model, which is affected by user-specified management strategies. Unlike other fishery simulation models (e.g. Campbell et al., 2001; Mahévas and Pelletier, 2004), management strategies can be constructed at a relatively fine spatial scale of individual reefs for area closures, changes to fishing gear selectivity, minimum legal sizes for harvest, the annual allowable fishing effort for each of the fishing sectors, and, now, individual quota allocations for each fisher.

The quota model allows fishing behaviour to be determined by output controls in the form of IQs or ITQs. IQs and ITQs mainly affect the temporal allocation of effort throughout the quota year as vessels attempt to maximize profit based on the seasonal distribution of profit (influenced by fish prices and catch rates) and costs. The allocation of effort among reefs within a trip, outlined above, is consequently not affected by output controls.

Several broad steps happen at each monthly time step during the projection period depending on whether quota management and trading are implemented. A detailed description of the main parts of the algorithm follows, but the general order of events, as portrayed in Fig. 1, is:

1. If there are no output controls, fishing effort is scheduled at the start of the year, based on historical catch and effort data. First, a year is selected randomly from 1989-2003. Second, for each vessel, a month is selected based on the seasonal distribution of effort in that year and fishing days are scheduled to that month. This process is repeated until the effort allocated equals the user-specified annual amount.

2. If there are output controls, each vessel schedules effort to fill its quota allocation. This is done first by allocating effort to months stochastically according to the seasonal distribution of effort since 1989. Effort scheduling ceases when the expected catch of both species, calculated over all the months of the entire year, and based on prior fishing experience for that vessel, exceeds the allocated quota. This method does not guarantee that a vessel will use its quota allocation in an economically optimal manner.

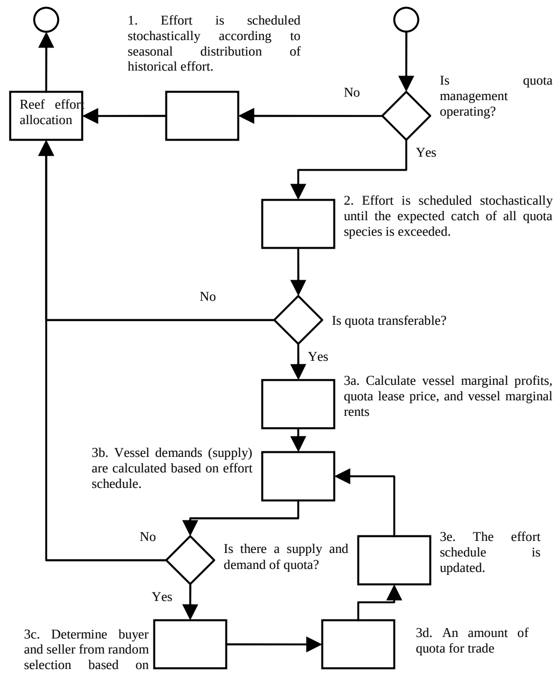

Figure 1 Steps in the quota trading model.

3. The following steps then occur at a monthly time step to inform quota trading and review of the initial effort schedule.

a. The vessel marginal profit for each month is calculated.

b. The quota demand in a given month is calculated based on vessels either filling or emptying that month of effort. Vessels with the economic incentive to fish in a month seek to fill that month with effort and attempt to purchase (or lease) quota to do so if necessary, and vessels without the economic incentive to fish in a month seek to sell (or lease) quota, to clear the effort that is scheduled in that month.

c. A potential trade between a vessel with a demand for quota and a vessel with a supply of quota is determined by selecting a buyer and seller randomly based on their marginal rent (i.e. their propensity to buy or sell quota).

d. An amount of traded quota is agreed upon based on constraining factors including supply and demand of quota.

e. The quota is exchanged and the effort schedule of the vessels is updated for the remainder of the year, given the residual effort and unfilled quota held by each vessel. Whether quota is permanently traded or leased is determined stochastically based on historical sales data.

f. Once the effort schedule is updated at step (e), the quota demand for each vessel is recalculated and steps (b) to (e) are repeated. The cycle stops when either there is no demand or supply of quota (i.e. all the vessels wanting to buy quota have no more profitable months in which to add effort or all months have been filled with possible effort, or all vessels wanting to sell quota have no more effort scheduled in months that are not profitable).

3. RESULTS

The quota price, which reflects the average expected profit, of each species was lowest at the start of the projection period (Fig. 2) This reflected the average profitability expected by the fishers prior to trading, followed by the increased profitability expected as a result of quota trading. The quota price of coral trout was higher than that of red throat emperor, reflecting the greater profitability of coral trout as a result of both higher prices and higher catch rates than other species (Little et al., 2009). Quota prices of coral trout were inversely related to the size of the TAC. Such an effect on the red throat emperor quota price was not as clear-cut since the quota prices under low and medium coral trout TAC cross in 2011.

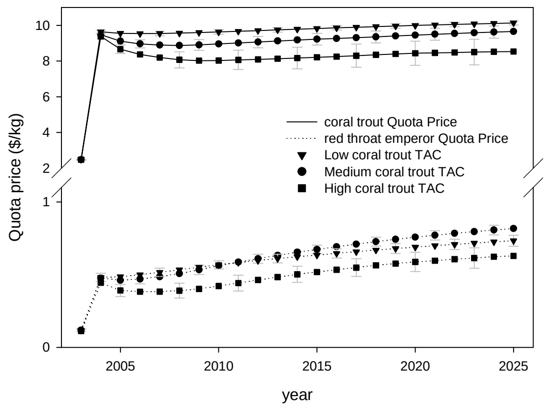

Figure 2 Average annual quota price for coral trout and red throat emperor (± SE) obtained from 100 simulated projections (2003 -2025) under three levels of coral trout TAC.

The actual profit realised in the simulated fishery increased slightly throughout the projection period (Fig. 3) mainly as a result of increasing available biomass (Fig. 4) and hence higher catch rates. The simulation results showed reduced effort under all three TAC levels (Fig. 5) as a result of economic rationalisation favouring vessels with greater economic and fishing efficiency. Actual annual effort experienced by the fishery agrees closely with simulated effort levels under the middle coral trout TAC, the management conditions that are closest to those currently operating in the fishery (Fig. 5, solid dots).

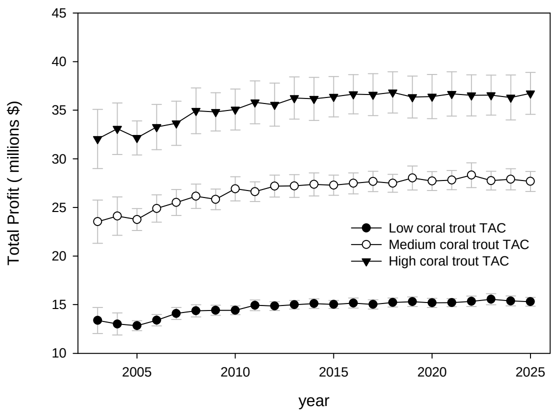

Figure 3 Total (across operators) annual profit (± SE) averaged across 100 projected simulations (2003-2025) under three levels of coral trout TAC.

The TAC for coral trout had a limiting effect on the biomass of red throat emperor with the biomass of red throat emperor decreasing as the coral trout TAC increased (Fig. 4) because more of the red throat emperor TAC was taken (Fig. 6). Only a relatively small amount of red throat emperor was taken under a low coral trout TAC since it would only be taken if there was coral trout quota available to motivate fishing. Fig. 7 shows that discarding of legal sized fish of both species is expected to increase over time but that discarding of legal sized coral trout is negligible (<<1%). Legal sized discards of red throat emperor were much higher (1-5%), and were correlated with the coral trout TAC. This is a consequence of assuming that vessels stop fishing when they have filled their coral trout quota but continue fishing until doing so, even if they can not obtain red throat emperor quota. The coral trout and red throat emperor catches in the model are higher than the actual catches that have occurred since the ITQ system was implemented, but they appear to be tracking toward the model values (Fig. 6).

4. DISCUSSION AND CONCLUSIONS

We have developed an approach that simulates ITQ trading in the multi-species Coral Reef Fin Fish Fishery off Queensland and show the long-term possible effects of changing the TAC for the primary target species, coral trout, on effort, quota price and overall fishery profitability, as well as the effect on the catch and discards of a secondary targeted species, red throat emperor. The approach we have taken to modelling fishery ITQs is based on those of Moloney and Pearse (1979), Lanfersieck and Squires (1992), Guyader and

Thébaud (2001) and Guyader (2002) in which quota is purchased by operators as long as the expected marginal profit of catching fish is greater than the cost of acquiring the associated quota. There are two main differences between our approach and earlier studies: a) we used an agent-based model to allow individual vessels the ability to use and trade quota; and b) our approach is designed for use in a multi-species fishery.

The multi-species nature of the fishery means that the lease or sale prices of quota depend not only on the catch-rates of the target species, but also on those of other species. Consequently, there are strong links among species. Specifically, in relation to the CRFFF, catches of red throat emperor were strongly linked to the TAC for coral trout, but did not reach the current TAC even when the TAC of coral trout was increased by 50% (Fig. 6, lower panel). One possible reason for this is that the relative catch-rates between the two species are not reflected in their TACs, but this is not sufficient. A more plausible mechanism for the fleet not catching the entire TAC for red throat emperor (in both the simulations and reality) is that it is not sufficiently profitable for fishers to harvest red throat emperor when they cannot also harvest the higher-valued coral trout. No vessel would fish exclusively for red throat emperor whereas most or all would fish exclusively for coral trout.

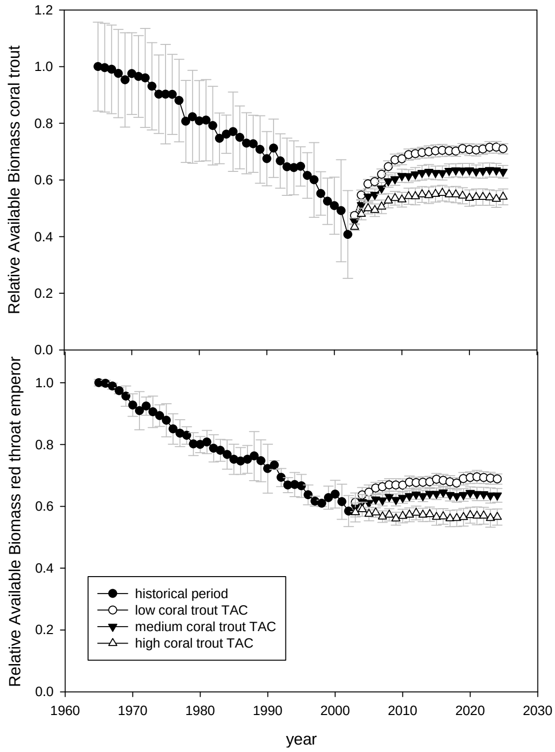

Figure 4 Average (± SE) annual relative available biomass of coral trout and red throat emperor across 10 different historical replicates and 100 projected simulations (2003-2025) under three levels of coral trout TAC.

Effort in the simulated fishery declined, even when the TAC for coral trout was increased by 50%. Effort reductions were expected, similar to in other fisheries that have moved to ITQs (Grafton, 1996), and have been experienced in the CRFFF (Fig. 5). These reductions have been attributed not only to the implementation of ITQs, but also to the relatively low market value of red throat emperor and other coral reef fin fish, rising fuel prices, and difficulty employing and maintaining reliable crew, given increasing employment opportunities in the mining industry (Anonymous, 2007).

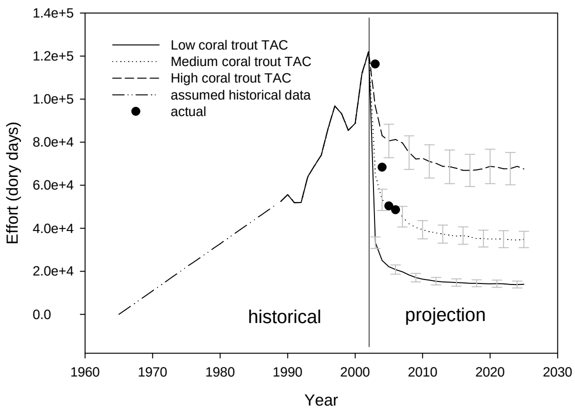

Figure 5 Average effort (± SE) over the historical period (1965-2002), and 100 simulated projections (2003 -2025) under three levels of coral trout TAC.

The multi-species nature of the fishery was also reflected in the differences between species in (legal sized) discard rates, with much higher discard rates for red throat emperor than for coral trout, particularly under the high coral trout TAC (Fig. 9). In principle, discards could decrease under an ITQ system as fishers adjust their targeting behaviour and buy quota to cover all species, but in practice the results are mixed (Branch et al., 2006). For example, fishers may have sufficient quota for some but not all species in a multi-species fishery (Annala, 1996) leading to high-grading or continual discarding of some species whilst continuing to fish to fill the quotas of others (Copes, 1986). Thus, the results show two consequences of our assumption that red throat emperor is not desirable enough to warrant fishing for it exclusively. The first consequence is that vessels with red throat emperor quota, but insufficient coral trout quota to warrant fishing, lead to unfilled red throat emperor TAC. Second, that vessels taking their red throat emperor quota, but continuing to fish to take their coral trout quota and consequently discarding any additional red throat emperor caught, results in a high amount of discards of legal-sized red throat emperor. This has led to the model of the ITQ market not functioning fully efficiently, and the degree to which this inefficiency operates in reality remains to be determined.

ITQs are principally an economic tool for managing fisheries but they can have an ecological effect, particularly in multi-species fisheries (Pascoe, 1993) where a major concern is incidental catches of less valuable species. Quota management of the CRFFF also consists of a third mixed species quota category of "other species" product that is typically less valuable than either coral trout or red throat emperor. We did not include the "other species" quota in the ITQ model because we lacked a valid population dynamics representation of such a taxonomically broad group as that included in the quota. It is possible that including this quota category in our model of the fishery could alter the results by increasing the profitability of vessels, even after they had filled their coral trout quota.

The TACs for coral trout and red throat emperor have not changed since ITQs were implemented in 2004. A stock assessment has been attempted for red throat emperor but the appropriateness of the TACs for other species, including coral trout, are untested. The results from our analyses indicate that increasing the TAC for coral trout would result in increased fishery profitability but at an ecological cost of lower biomasses of both coral trout and red throat emperor. The biomass of coral trout was predicted to increase over time, however, even under the high TAC scenario, primarily because the high TAC for coral trout is still lower than the catches taken historically by the fishery.

The basic assumptions of the model are that the quota price is a direct reflection of the average profitability of the fleet. This makes the model myopic by making re-adjustments to short-term behavioural changes in fishing practices and does not capture the future expectations of the fishery, including potential longer-term behaviour in capital investment decisions that could change the fishing efficiency of individual operators. Another assumption that the behaviour governing the spatial effort allocation among reefs is not affected by output controls has not been addressed explicitly. Improvements to both of these issues, however, might be possible with better and more recent data. Nevertheless, the model is able to capture key expectations of a multi-species ITQ fishery and is able to anticipate reasonably well some of the initial data coming from the fishery following the introduction of ITQ management.

ACKNOWLEDGMENTS

We thank the Queensland DPI&F for providing anonymous catch and effort data from the Reef Line Fishery.

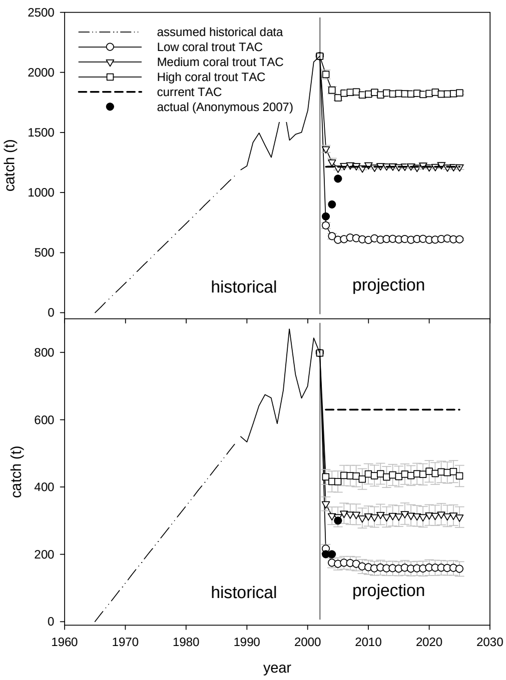

Figure 6 Coral trout and red throat emperor catch (± SE) over the historical time period (1965-2002) and averaged across 100 simulated projections (2003-2025) under three levels of coral trout TAC.

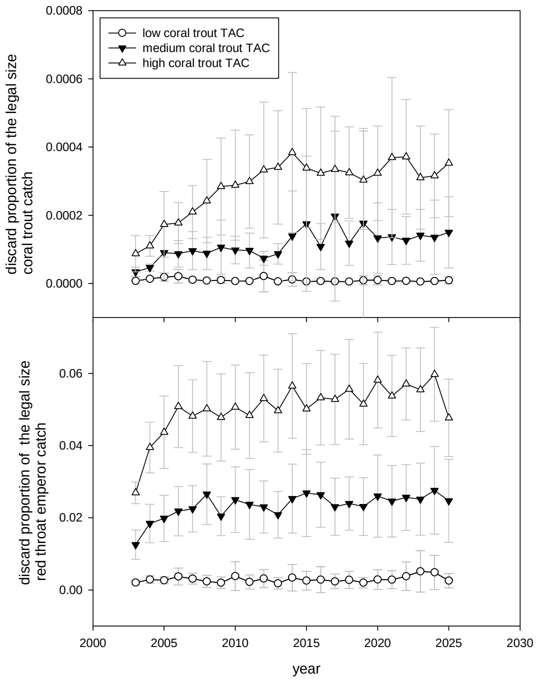

Figure 7 Average (± SE) proportion of legal size coral trout and red throat emperor catch that was discarded in 100 simulated projections (2003-2025) under three levels of coral trout TAC.

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