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   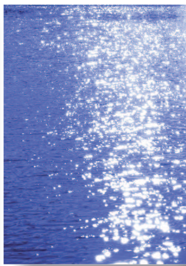 

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Modeling the impacts of a discard ban in a mixed fishery under catch-quota management

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SUMMARY

Abstract

Individual Transferable catch-Quotas (ITQs) have become a popular management tool to reduce excess competition and foster economic efficiency in marine commercial fisheries. They have increasingly been used in complex multispecies fisheries, where the by-catch of non-targeted species is common. In these fisheries, the reduction of discards is also being promoted, including recently in Europe with the adoption of a landing obligation under the Common Fisheries Policy (CFP). In part, the debate on the adoption of this obligation focuses on its potential socio-economic impacts, and whether these could be mitigated through either management or industry adaptation. In this paper, we propose a modeling framework to address these issues. We apply this model to a stylized representation of the Australian South-East Trawl fishery, and illustrate how it can be used to explore the bio-economic implications of a ban on discards under alternative scenarios relating to the quota management system, and to potential adaptation options for the fishery. Results show that a landing obligation induces overall short-term economic losses if quota is non-tradeable, while with tradeable quota, overall profits are only marginally affected, and are reallocated to the most selective fleet.

Keywords: Individual Transferable Quotas, mixed fishery, bycatch and discards, bio-economic modeling

Highlights:

- We propose a modeling framework of a quota-managed mixed fishery
- This is used to assess the impacts of a landing obligation with/without quota trading
- The obligation induces overall short-term economic losses if quota is non-tradeable
- With tradeable quota, profits are reallocated to the most selective fleet

1 Introduction

Ecosystem-based approaches are increasingly being adopted for the management of natural resources. This is the case in the marine domain, including marine capture fisheries, with the development of ecosystem-based fisheries management (EBFM) policies (Garcia et al. 2003, Pikitch et al. 2004). In recent years, the push towards EBFM has led to an increase in the implementation of output controls in fisheries, i.e. regulations of total catch. These regulations have increasingly been recognized as a way forward in developing sustainable fisheries, particularly if used in combination with adequately designed access rules for individual harvesters, i.e. individual catch shares. Allowing catch shares to be freely transferable between fishing operators has been argued to potentially reduce excess competition and foster economic efficiency (Grafton et al. 2006), eventually increasing the ecological viability of harvested fish communities. Indeed, by eliminating the race for fish, allocating individual catch shares has been shown to limit the development of excess capacity in fisheries. Recent reviews of the experience with ITQs in fisheries show that their adoption has been associated with improved status of fisheries from both ecological and economic perspectives (Newell et al. 2005, Costello et al. 2008, Branch 2009, Chu 2009, Hamon et al. 2009, Essington 2010, Thebaud et al. 2012).

The move towards EBFM has also led to the evolution of these regulatory regimes towards more comprehensive catch-based management systems, aimed at taking into account the entirety of fishing impacts on marine biodiversity, including targeted and non-targeted species. In doing so, management seeks to account for the problems of joint production, called by-catch in the fisheries literature, and the associated discards at sea of non-targeted and unwanted fish caught in the process of fishing. This is because discards may lead to increased threats to biologically vulnerable species, as well as losses in the potential economic value of fisheries (Kelleher 2005). Mitigation of by-catch has thus become a worldwide pressing issue in commercial fishing (Hall and Mainprize 2005). In Europe, specific management measures, such as the recent landing obligation of species subject to Total Allowable Catch (TAC) limitations under the Common Fisheries Policy, have been implemented in an attempt to address this issue. The aim is to limit the capacity for discarding of fish at sea, and to create the incentives for operators to avoid by-catch.

While the practical implementation of such management measures faces a number of challenges (Squires et al. 1998), studies of the potential impacts of introducing "land-all" regulations in multispecies fisheries have only recently begun to develop. Focusing on tuna fisheries, (Chan et al. 2014) highlight the potential impacts in relation to the daily operation of fishing activities, in terms of storage, crew labor and safety, and offloading and marketing, which can all add to the costs of fishing.

In practice, however, the first implication of a discard ban in a TAC-managed fishery, if effectively implemented, is likely to be an increase in the accountability of vessels for their entire catch at sea. This includes a fraction which, when it could be discarded, was likely simply to be overlooked, or at least seriously under-estimated in evaluating the uptake of catch possibilities at both individual vessel and fishery levels. This is the main reason why the debate on introducing a ban on discards is often associated with the issue of so-called "choke species" (Abbott and Wilen 2009, Schrope 2010). These correspond to jointly caught species for which the TAC is reached before all catch possibilities for other commercially important species can be achieved. The existence of such "choke species" is related to the production function of a fishery, which depends both on its technological characteristics and on individual fishing strategies. A key issue which has been highlighted in recent debates about the implementation of the landing obligation in Europe is the extent to which a fishery can adjust its fishing patterns to avoid this problem.

The objective of this paper is to characterize the bio-economic impacts of a ban on discards, under alternative scenarios regarding catch quota management, in a fishery characterized by joint production. We develop a bio-economic modeling framework which enables the exploration of these impacts, and apply it to a stylized representation of an Australian fishery managed under individual transferable catch quotas. Based on the results of this analysis, we identify the alternative pathways to the achievement of this aspect of an EBFM approach in such a fishery.

2 A model of a catch-quota managed mixed fishery

The bio-economic modeling framework used in this paper is extended from (Pereau et al. 2012). The model includes *S* ecologically independent species and *N* fishing companies (vessels) with different technical and economic characteristics ("métiers") and individual variability in technological characteristics (i.e. catchability of species). Vessels using the same métier are grouped into fleets. They jointly catch the different species in different proportions, hence the term "mixed fishery". The fishery is a price-taker: fish prices are fixed outside the fishery. The fishery is managed by the annual setting of a set of stock-specific Total Allowable Catches, which are allocated into individual transferable catch shares. The model thus includes a representation of the annual allocation of catch quotas, as *S* separate quota leasing markets for catch shares of individual species.

2.1 The bio-economic model

Fish population dynamics are modeled based on a (Fox 1970) surplus production model described in equation (1):

$$X_i(t+1) = X_i(t)\left(1 + r_i \ln\left(\frac{K_i}{X_i(t)}\right)\right) - H_i(t) \tag{1}$$

where $X_i(t)$ corresponds to the biomass of species *i* at time *t*, r_i is the intrinsic growing rate of species *i*, K_i is the carrying capacity of species *i* (i.e. the maximum stock level of the population in its habitat, reached when the stock is not exploited), and $H_i(t)$ corresponds to the harvest of species *i* at time *t* calculated as in equation (2).

$$H_i(t) = \sum_{k=1}^{N} q_{i,k} X_i(t) e_k(t) \tag{2}$$

where $q_{i,k}$ corresponds to the catchability of species *i* by vessel *k* (i.e. fishing mortality of species *i* associated with one unit of fishing effort from vessel *k*), and $e_k(t)$ the nominal effort of vessel *k* at time *t*.

Companies are price takers and sell their catch of species *i* at price p_i. We assume that each company *k* has a cost function $C_k(e_k(t))$ depending on its effort $e_k(t)$ and constant unit production costs c_0^k, c_1^k and c_2^k,, as in equation (3):

$$C_k(e_k(t)) = c_0^k + c_1^k e_k(t) + c_2^k \frac{e_k^2(t)}{2} \tag{3}$$

Profit $\pi_k(t)$ of vessel *k* at time *t* can thus be calculated as in equation (4):

$$\pi_k(t) = \sum_{i=1}^{S} p_i H_i(t) - C_k(e_k(t)) - \sum_{i=1}^{S} m_i(t)\big(q_{i,k} X_i(t) e_k(t) - Q_{i,k}(t)\big) \tag{4}$$

with:

- $m_i(t)$ the quota price of species *i* at time *t*,
- $Q_{i,k}(t)$ the quota owned by vessel *k* at time *t* for species *i*.

2.2 Quota market

Quota prices, represented by the vector m=[m_1, …, m_i, … m_S], vary depending on the demand and supply for lease quota. Total Available Catch (TAC) limits are set by species, and each company receives a certain share of these TACs.

The goal of each individual company (vessel) is to maximize its profit by choosing an optimal level of fishing effort $e_k^*(t)$:

$$e_k^*(t) = \frac{1}{c_2^k}\left(\sum_{i=1}^{S}\big(p_i - m_i(t)\big)q_{i,k}X_i(t) - c_1^k\right) \tag{5}$$

From this, we derive the corresponding optimal individual harvest for each species. The total harvest of species *i* is then given by:

$$H_i^*(t) = \sum_{k=1}^{N} q_{i,k}X_i(t)\, e_k^*(t) \tag{6}$$

$$i.e. \quad H_i^*(t) = \sum_{k=1}^{N} q_{i,k}X_i(t)\frac{1}{c_2^k}\left(\sum_{i=1}^{S}\big(p_i - m_i(t)\big)\, q_{i,k}X_i(t) - c_1^k\right)$$

The sum of optimal harvests across the fishery determines the total demand for quota of each species on the quota market. We assume that the TAC must be respected, hence the market clearing condition (demand=supply) implies that demand $Y_i(t)$ for quota must equal the TAC for each species:

$$Y_i(t) = H_i^*(t) \tag{7}$$

In order to allow price determination for any initial set of TACs, we assume a Walras auction approach (Uzawa 1960). The dynamics of quota leasing is described in Figure 1 which represents a simplified view of exchanges on the quota market and the process of quota price adjustment in the model.

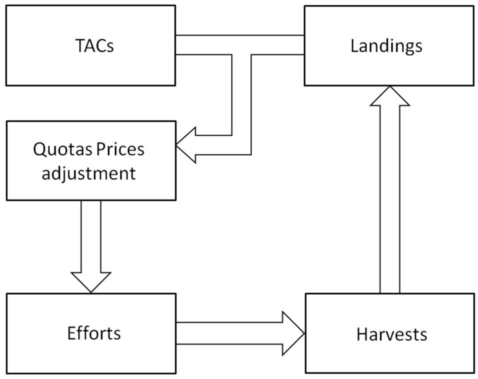

Fig. 1. Scheme of the Walras tâtonnement process loop.

In the applications presented in this article, we assume that the initial allocation of individual quotas for each species is spread equally across vessels. We then force the quota prices to be (non-strictly) positive, but companies are not constrained to catch their quotas. The approach provides a good approximation of the market clearing condition (indeed when m is stable, we have $\forall\, i \in [1, S]$, $m_i(t+1) = m_i(t)$ and $H_i^*(m) = Y_i$) while ensuring that individual fishing efforts are greater than or equal to zero. However, if the problem does not have a solution (i.e. there is no distribution of non-negative efforts among fishing firms that allows the N different TACs to be reached simultaneously), then this model may give approximate solutions only. In particular it may display oscillating behavior and prices may diverge. To avoid this in the runs presented, we select a high enough number of iterations (in each fishing period, we simulate the adjustment of quota prices by iterating the loop a thousand times) and use an initial calibration so as to have realistic solutions. In reality, such an efficient determination of quota prices is unlikely to be possible. As described in (Connor and Alden 2001), fishing quota markets are rather small, and asymmetric information as well as the small size of the market might lead to inefficient trading behavior and diverging and unstable prices. Our simulation model thus constitutes a 'best case' representation of the lease trade dynamics of a multi-species quota market in a mixed fishery.

2.3 Scenarios

2.3.1 Quota trading

The extent to which individual quota allocations can be traded between companies is considered an important determinant of the effectiveness of individual catch share systems in improving the overall economic efficiency of a fishery. While this has been shown in single species contexts, it can also be extended to the case where multiple species are jointly caught. To assess the consequences of quota tradability on the impacts of a discard ban, we thus assume that either (i) individual quotas are fully trade-able among individual vessels, as modeled above, or that (ii) individual quotas are not trade-able at all (i.e. $m=0$). These two cases capture the features of two alternative approaches to individual access regulation to fisheries which are frequently encountered around the world. A third case which is also typically encountered would be where trade in individual allocations can only occur within sub-fleets or sectors of the fishery. Being an intermediate situation between the two cases considered here, we exclude it from our analysis, for the sake of simplicity.

2.3.2 Discards allowed or banned

The outcomes with and without a discard ban are compared, assuming a fixed TAC policy schedule[1]. With discards allowed, fishers that cannot avoid the catch of some species when targeting another will land their entire catch only if the expected net profit of doing so is positive. If quota trade is allowed and it is profitable for them to do so, fishers will purchase quota on the leasing market up to the point where this is equal to the landing price of fish. However, as soon as the quota price is higher than the market price of the fish caught, it will

[1] While TAC could in principle be allowed to vary according to harvest control rules, a fixed TAC is set as a simplifying assumption, to enable a better understanding of the dynamics of the fishery in response to the other scenario components (discard ban, quota trade-ability and fleet response).

become more profitable for companies to discard the catch, which will then not be subtracted from their quota and will not earn any revenue to the vessel. If quota is non-trade-able, and optimal effort leads to above-quota catch of certain species, fishers will simply discard the over-quota catch. In order to capture this behavior, we thus consider that the trigger point for discarding is when the market price for fish equals the quota leasing price if quota can be traded, and that it is when catch exceeds quota when quota is not trade-able. With discards banned, all the catch must be accounted for in quota uptake, and where joint production of choke species exists, this will entail an increase in the demand for quota for this species on the quota leasing market, leading to an increase in quota leasing prices and an eviction from the fishery of those companies that are least efficient at avoiding the choke species.

2.3.3 Fleet Adaptation

A key question regarding the potential impacts of a discard ban relates to the risk that it would lead to a significant reduction in the economic viability of the fishing fleets, with social impacts in terms of reduced activity and employment. Related to this is the question of whether fishing fleets might be able to develop new fishing techniques and practices which might enable a reduction in the amount of unwanted catches, thereby reducing these negative outcomes. To address the possible adaptation of a fishery to the impacts of a discard ban, we consider the change in the average catchability of "choke species" which would be required for the ban to be neutral with respect to the optimal fishing effort of companies. In other terms, we examine the change in catchability which would allow a fleet in the fishery to keep its level of activity unchanged after the introduction of a discard ban. We thus seek to identify the extent to which the catchability of the "choke species" by the least efficient fleet would need to be adjusted, so as to minimize the difference between the simulated efforts of the vessels with and without a discard ban. Numerically, we search for a multiplier of catchability $delta\_q$ such as to minimize the square of the difference between the effort with a discard ban e_k and the effort without a discard ban $e_{k,ref}$ for a group of vessels or fleet f, at a particular point in time, as described in equation (8):

$$\begin{cases} q_{I,k} = q_{I,k,ref} * delta_q \qquad for\ k = 1, \ldots, K \\ \min_{delta_q}\left(\sum_{k=1}^{K}\left(e_k(T) - e_{k,ref}(T)\right)^2\right) \end{cases} \tag{8}$$

where $q_{I,k,ref}$ is the average catchability of a "choke species" I by vessel k belonging to a selected group of K vessels, or fleet, and T is a particular point in time, generally the terminal time of the simulation.

2.4 Case study: the Australian South-East Trawl Fishery

We apply the model to a section of the Australian Southern and Eastern Scalefish and Shark Fishery (SESSF): the South East Trawl fishery (SET). This is one of Australia's oldest commercial fisheries, and is a multi-species and multi gear fishery (Smith and Smith 2001). It covers an area of the Australian Fishing Zone extending southward from Sandy Cape in southern Queensland, around the New South Wales, Victorian and Tasmanian coastlines to Cape Jervis in South Australia. The bulk of the catch in the fishery consists of twenty species or species groups managed by quota. A range of methods are used to catch fish in the fishery. Among them are trawls and Danish seines. These two fleets of respectively 39 and 13 boats in 2009 are interesting because although they have different economic and technical characteristics, some of their targeted species are the same. Trawl vessels generally operate on the continental shelf and upper shelf to around 500 meters, while the Danish seine fleet comprises generally smaller vessels, of lower engine power, operating in shallower waters.

Models and scenarios described in section 2.1 to 2.3 are applied to a highly stylized representation of the SET including two fleets (trawlers and Danish seiners), and three species (Tiger flathead, *Neoplatycephalus richardsoni*; Jackass morwong, *Nemadactylus macropterus;* John Dory, *Zeus faber*). Technical interactions between species and fleets are summarized in figure 2.

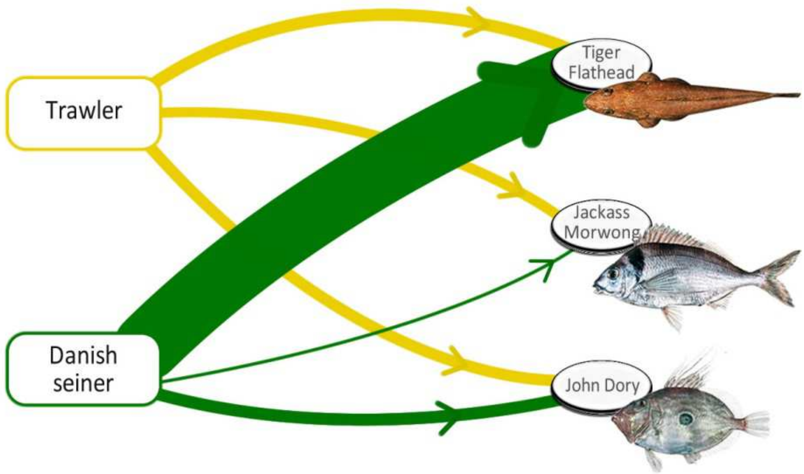

Fig. 2. Stylized representation of the Australian South East Trawl Fishery model used in this study. The widths of the arrows between fleets and species are proportional to the mean values of catchability of the species (i.e. fishing mortality per effort unit) by vessel of the different fleets (see table 2).

The three species were selected for their contrasting characteristics illustrating the complexity of a mixed fishery with joint production: Tiger flathead is a high abundance, relatively high growth rate and high value species which constitutes a significant proportion of the economic value generated from the fishery and the stock is in good condition in the reference year; John Dory is a low abundance, low growth rate but high value species, which only represents a limited part of the economic value of the fishery and is in relatively good condition in the reference year; finally, Jackass morwong is a medium abundance, moderate growth rate, low value species, the biomass of which is depressed in the reference year.

Calibration[2] of this simplified representation of the fishery is based on published data for both the biological characteristics of the species and the cost and earnings of the fleets. Parameters of the model are given in tables 1 to 3.

Table 1. Biological parameters, fish sale prices (p) and TACs. Data source: (Pascoe 2015)

	r	K (in tons)	X (2009) (in tons)	p (in AU$ per ton)	TAC (in tons)
Tiger Flathead	0.153	44 566	23 070	5 230	2750
Jackass Morwong	0.128	30 231	7 412	2 520	450
John Dory	0.044	5 431	1 666	6 800	221

Table 2 shows the average values for the catchabilities of the different species by the two fleets, derived from ABARES reports and stock assessment studies. Differences between vessels within each fleet are introduced for each species using a normal distribution around these average values, with 10% variance. These differences between vessels are crucial in the model as they are the driving force behind exchanges on the quota market.

[2] Although the model only intends to provide a stylized representation of aspects in the fishery, calibration of the model was carried out with the aim to best represent the reality of the three species and their role in the economics of the two fleets.

Table 2. Estimated mean catchabilities (in days-1 *10-6).

	Q - mean catchabilities	
	trawlers	**Danish seiners**
Tiger Flathead	8.4	46.6
Jackass Morwong	7.2	2.4
John Dory	7.9	8.2

The three modeled species stand for respectively 13% and 43% of the fishing incomes of trawlers and Danish seiners. To take this into account in estimating the returns associated to fishing these three species, we assume that fishing costs can be adjusted proportionally. Table 3 displays the adjusted cost parameters (c_0^k, c_1^k, c_2^k) by fleet, estimated from the available data, as well as the characteristics of the fleets in terms of annual effort and fleet size.

Table 3. Adjusted cost parameters (in AU$) and characteristics of the fleets.

	c_0	c_1	c_2	**number of vessels**	**mean annual days at sea per vessel**
Trawlers	13 411	21.59	5.21	39	210
Danish seiners	24 342	55.55	41.43	13	96

3 Results

3.1 Non-tradeable quotas, discards allowed / banned

Bio-economic outputs of the stylized bio-economic model when quotas are not tradeable, under two scenarios: without and with a ban on discards, are displayed respectively in figures 3 and 4. Where individual quotas cannot be traded and discards are allowed (Figure

3), catch initially exceeds TAC for Tiger Flathead, leading to significant discards of this species. A reduction in the stock leads to a drop in individually optimal levels of effort for both fleets, and a drop in catch of Flathead. This drop in effort is not enough, however, to curb the increase in catch of Jackass Morwong, due to a continuous increase in the biomass of this species[3], leading to an increase in discards of catch over and above the TAC, mainly by trawlers. Catch of John Dory remains limited, and below TAC. By construction, the price of quota is zero for all species. Under this scenario, the fishery sees a major reduction in overall economic performance as compared to the reference year, borne largely by the Danish seiners, although the individual performance of these vessels remains above that of the trawlers throughout the simulation period.

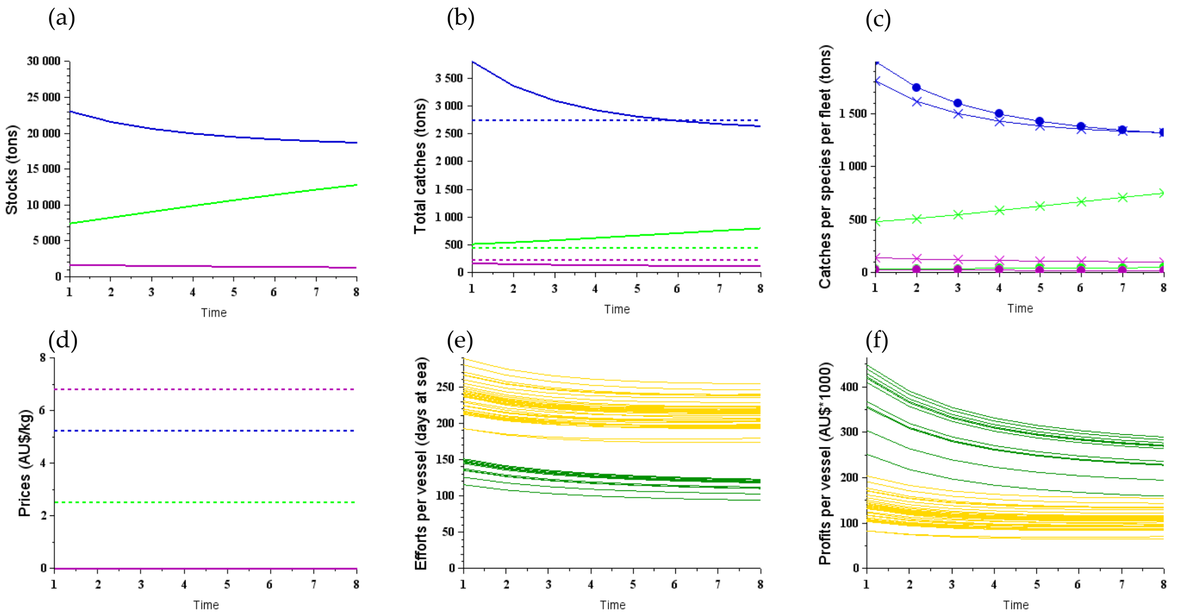

Fig. 3. Biological and socio-economic trajectories when discards are allowed in a case without tradability. Evolution of the stock biomasses (in tons) in (a) (blue: Tiger Flathead, green: Jackass Morwong, purple: John Dory), total catches per species (tons, plain line) and Total Allowable Catches (set at the 2011-12 values, dashed line) in (b), catches per species and per fleet (tons, crosses: trawlers, circles: Danish seiners) in (c), quota price per species (AUD$/ton, plain line) and fish landing price (AUD$/ton; dashed line) per species in (d), and fishing effort (days at sea) and profit per boat (AUD$) in (e) and (f) respectively (yellow: trawlers; green: Danish seiners).

[3] If a flexible TAC schedule was implemented, such an increase could lead to an upward revision of the TAC, which could lead to increased landings of this species (see discussion section).

With the ban on discards and no tradability of quota (Figure 4), the profile of the fishery is significantly modified. Total catches are maintained much lower than the TAC due to constraints imposed by the least efficient vessels. The consequence is an increase in the biomass of the two key fish stocks, leading to additional constraints on fishing activity. The adjustment is stronger for trawlers, which have more difficulty avoiding Jackass Morwong, leading to a strong reduction in the overall effort of this fleet. However, the effort of Danish seiners is also reduced compared to the case without a discard ban: in proportion, it is divided by 3 compared to trawlers for which it is reduced by half. This leads to a reduction in overall economic performance of the fishery as compared to a case where discards are allowed (see figure 3), which is borne largely by the Danish seiners, while trawlers are relatively less impacted. The price of quota is zero by construction.

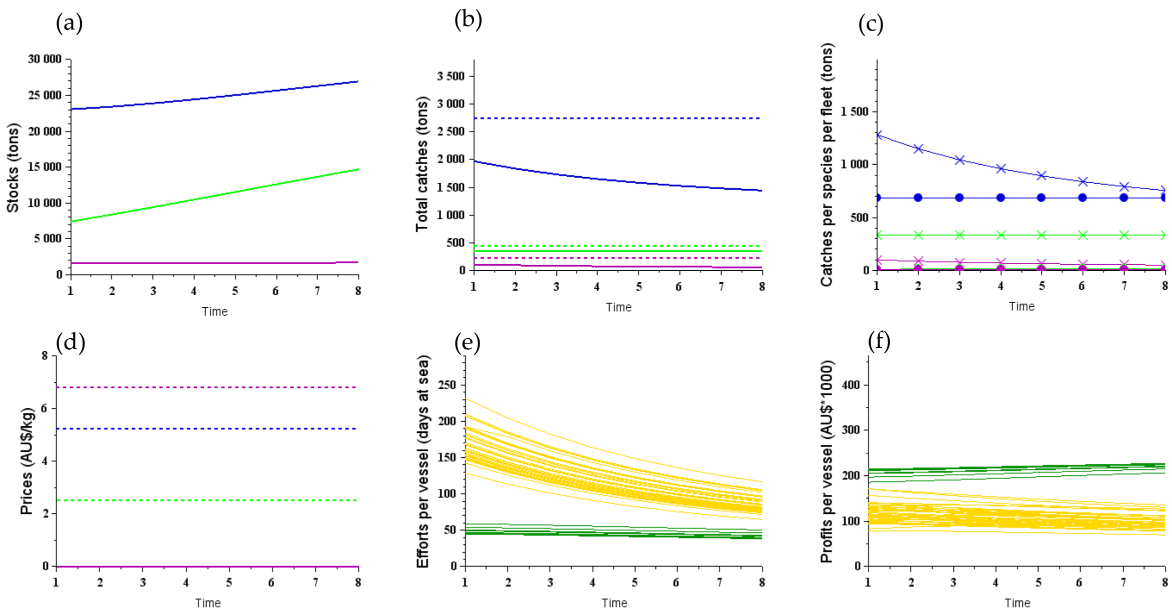

Fig. 4. Biological and socio-economic trajectories when discards are banned in a case without tradability. Evolution of the stock biomasses (tons) in (a) (blue: Tiger Flathead, green: Jackass Morwong, purple: John Dory), total catches per species (tons, plain line) and Total Allowable Catches (set at the 2011-12 values, dashed line) in (b), catches per species and per fleet (tons, crosses: trawlers, circles: Danish seiners) in (c), quota price per species (AUD$/ton, plain

line) and fish landing price (AUD$/ton; dashed line) per species in (d), and fishing effort (days at sea) and profit per boat (AUD$) in (e) and (f) respectively (yellow: trawlers; green: Danish seiners).

3.2 Tradeable quotas, discards allowed / banned

Figures 5 and 6 exhibit the bio-economic outcomes with tradeable quotas, under an allowance or a ban of discards respectively. With quota trading and discards allowed (Figure 5), the TAC constraint generates positive quota leasing prices for Tiger Flathead and Jackass Morwong, leading to catching of the first species at its TAC, with an increase in the fraction caught by Danish seiners. This does not curb the decrease in biomass of Tiger Flathead, leading to a progressive decline in the quota price for this species[4]. Meanwhile, the increase in the biomass of Jackass Morwong leads to an increase in catch and associated increase in the quota price, up to a level at which it equals the sale price of fish, and catch is discarded. Under this scenario, losses by the trawlers are more than compensated by gains of the Danish seiner fleet in economic terms.

[4] Again, the TAC, initially set too high, could in principle be adjusted, in this case downward, as stock declines (see discussion).

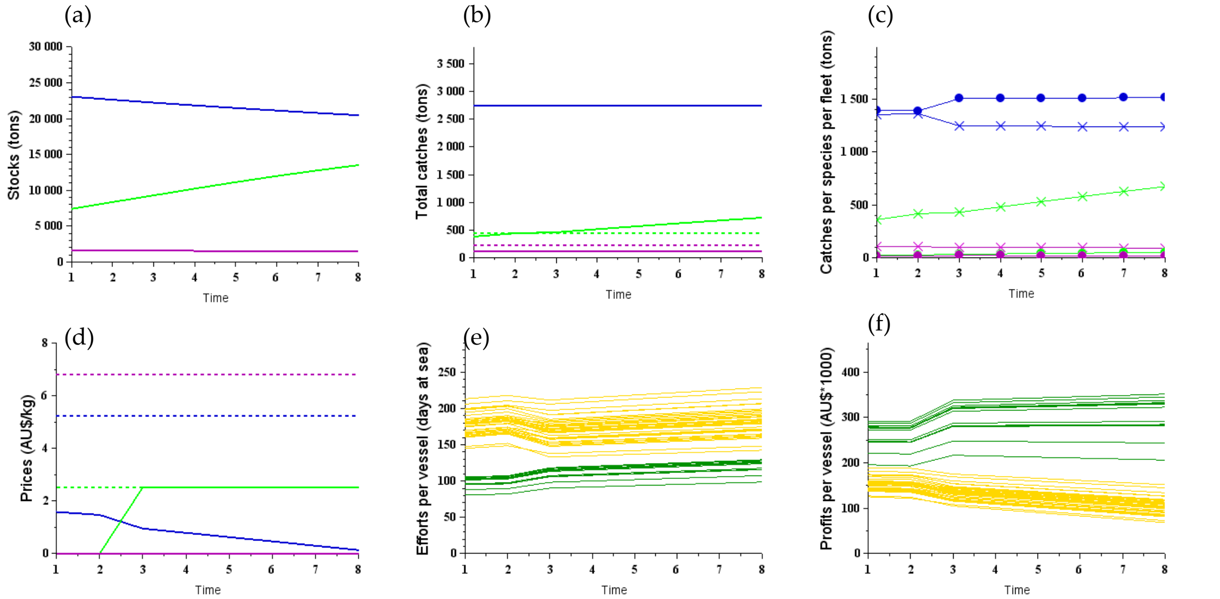

Fig. 5. Biological and socio-economic trajectories when discards are allowed in a case with tradability. Evolution of the stock biomasses (tons) in (a) (blue: Tiger Flathead, green: Jackass Morwong, purple: John Dory), total catches per species (tons, plain line) and Total Allowable Catches (set at the 2011-12 values, dashed line) in (b), catches per species and per fleet (tons, crosses: trawlers, circles: Danish seiners) in (c) , quota price per species (AUD$/ton, plain line) and fish landing price (AUD$/ton; dashed line) per species in (d), and fishing effort (days at sea) and profit per boat (AUD$) in (e) and (f) respectively (yellow: trawlers; green: Danish seiners).

Finally, when discarding is banned but quota trading is allowed (Figure 6), the response of the fishery is again significantly modified. Catch of Tiger Flathead is initially equal to TAC, leading to positive prices on the quota market and a slight decrease in biomass for this species. However, as the population of Jackass Morwong increases, its catch rates also increase, more strongly so for the trawler fleet which has more difficulty to avoid it. This leads to an increase in catch up to the TAC, after which the most efficient vessels need to purchase quota at higher prices to keep fishing. The trawlers being disadvantaged tend to sell off their quotas to the Danish seiners who clearly benefit from the management system, allowing quota prices for Jackass Morwong to rise over and above the market price of this species: i.e. catch of this species is being made at a loss, in order to support the catch of Tiger Flathead.

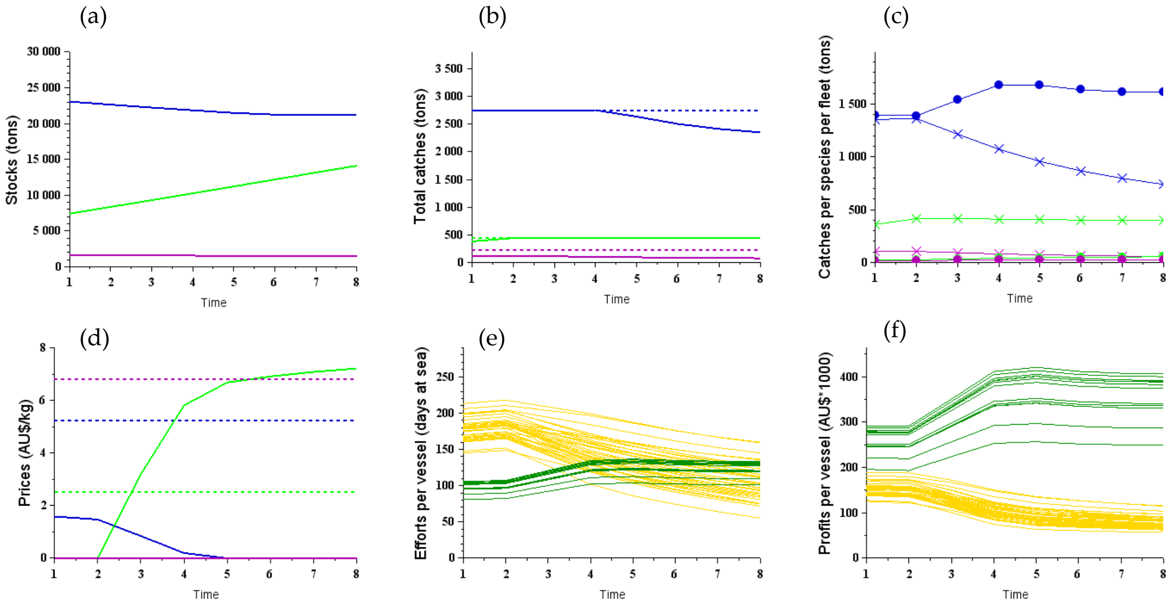

Fig. 6. Biological and socio-economic trajectories when discards are banned in a case with tradability. Evolution of the stock biomasses (tons) in (a) (blue: Tiger Flathead, green: Jackass Morwong, purple: John Dory), total catches per species (tons, plain line) and Total Allowable Catches (set at the 2011-12 values, dashed line) in (b), catches per species and per fleet (tons, crosses: trawlers, circles: Danish seiners) in (c), quota price per species (AUD$/ton, plain line) and fish landing price (AUD$/ton; dashed line) per species in (d), and fishing effort (days at sea) and profit per boat (AUD$) in (e) and (f) respectively (yellow: trawlers; green: Danish seiners).

3.3 Scenario comparison

To compare the scenarios in terms of their economic consequences for the fishery and for its component fleets, we calculate the total net present value (NPV) of profits accumulated over the simulation period (T=8 years):

$$NPV_f = \sum_{t=t0}^{T} \frac{\pi_f(t)}{(1+\sigma)^t}$$

with NPV_f the NPV of fleet f, σ, the discount rate set at 5%, and $\pi_f(t)$ the annual profit of fleet f at time t.

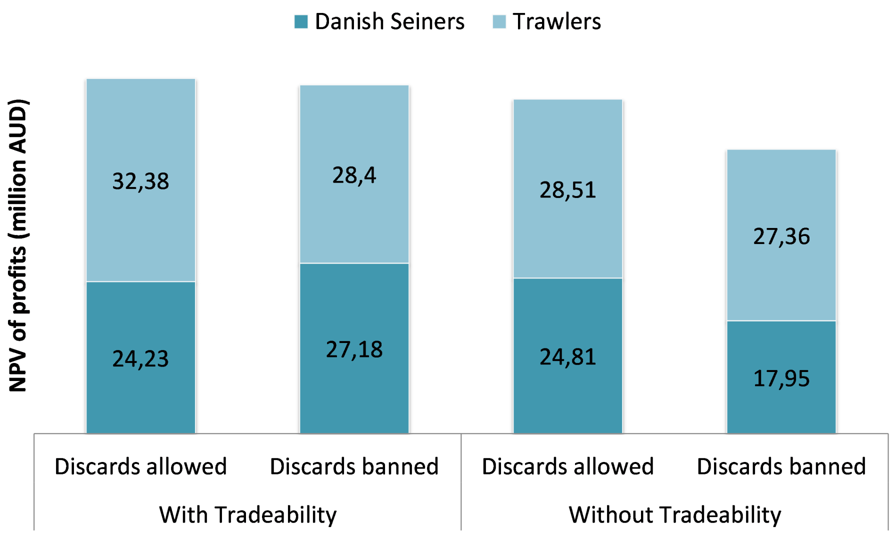

Fig. 7. Net present value of accumulated profits under the 4 different scenarios regarding quota tradeability and discarding

As illustrated in figure 7, the discard ban entails a strong reduction in profitability of the fishery when quota is non tradeable, which is mainly due to the inability for the more efficient vessels, notably the Danish seiners, to operate at full capacity, the quota limitations being binding. The equitable initial allocation of quota to vessels, associated with a stock effect leading to improved catch rates, enables the trawler fleet to minimize its losses, despite the need to reduce its level of fishing activity significantly. When quota trading is possible, the introduction of a discard ban leads to a reallocation of fishing possibilities towards the Danish seiners, and an increase in the share of returns going to this fleet. The overall economic performance of the fishery is barely affected. In addition, the total returns from a fishery without discards are significantly higher with quota trading being made possible. On the other hand, the benefits of introducing tradeability are relatively limited if discards are allowed.

3.4 Impacts with changes in fishing patterns in response to the discard ban

To assess the change in catchability of Jackass Morwong (i.e. the "choke species" in this case study) by trawlers which would enable the fleet to maintain its level of fishing activity after the introduction of a discard ban, we search for the multiplier of the average catchability of Jackass Morwong by trawlers which minimizes the difference between the average optimal level of fishing effort, with or without the ban. The results are presented in figure 8.

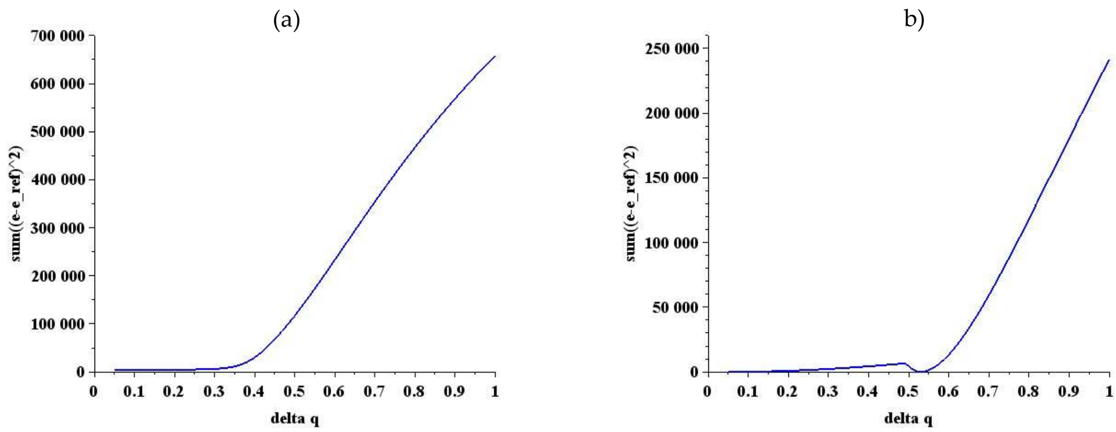

Fig. 8. Sum of the square of the differences between nominal efforts (in number of days at sea) when discards are allowed and when they are not, according to the values of delta q, in (a) in a case without tradability and in (b) in a case with tradability

Without quota trading, the difference between nominal efforts when discards are allowed and when they are banned is minimal for a delta_q =0.13. In other words, changes in fishing techniques and practices would need to reduce the catchability of Jackass Morwong by 87% for the level of activity of the fleet to be maintained. If quotas can be traded, a similar outcome could be achieved for a delta_q of 0.53. By favoring the (compensated) retirement of the least efficient companies, quota trading allows the trawler fleet to be less constrained by the choke species. In this case, maintaining levels of fishing activity in the trawler fleet would require chances in techniques and practices leading to a 47% reduction in the catchability of Jackass Morwong by trawlers.

4 Discussion and conclusion

There has been a growing interest in the potential implications of alternative regulations regarding discarding in multispecies fisheries, where these are managed under either common-pool (Abbott and Wilen 2009) of individual (Hatcher 2014) catch quota regimes. Our simplified model of a mixed fishery managed under individual catch shares allows us to explore the implications of quota trading arrangements on the potential consequences of a discard ban. In the stylized representation of the Australian SET, the results show that given the catchability and abundance of Tiger Flathead, there is a strong incentive to catch this species, particularly for Danish seiners. The Tiger Flathead catch however entails a by-catch of Jackass Morwong which leads to an increase in the demand for quota of this species. Where quota can be traded, and if discards are allowed, the fleet purchases Morwong quota up to a point where its price is equal to the market price for the species, but discards any catch beyond this level (with no obligation to hold quota for the discarded fish). Significant discards of Morwong catch thus occur. With discards banned, any increase in the catch of Morwong must be met with a purchase of quota on the lease market. This entails an increase in the quota price over and above the market price for this species, and a degraded economic performance of the trawlers that are less effective at catching Tiger Flathead, and have more difficulties avoiding Jackass Morwong. The fleet thus evolves towards a progressive eviction of trawl, in favor of Danish seine. Without tradeability however, given the constraints on landing of the “choke species”, Jackass Morwong, the fishery is constrained to operate at levels way below allowable levels, and much lower levels of economic performance.

Results of our simulations show that a discard ban (provided effectively implemented, and in particular that all catches are effectively landed and accounted for) is only likely to entail a reduction in the global economic performance of a fishery if individual quotas in this fishery are not tradeable. Where quota is tradeable, the ban leads to only a slight reduction in economic performance. In both tradeable and non-tradeable quota contexts, however, the ban entails a redistribution of economic returns between fleets and individual companies in the short run (figure 7). This is even without accounting for non-quota costs to vessels of a landing obligation, such as on-board or landing processing requirements. Social implications of fisheries policy being regularly put forward as an important dimension of fisheries management, as well as the potential social consequences of implementing individual catch share systems, we explore the changes in fleet catchability that would be needed to achieve the results of the ITQ case. These changes could be related to the adoption of new technologies or to changes in fishing practices which enable vessels to avoid the catch of species the supply of which is more restrictive, while maintaining their level of fishing activity. Our results for the stylized fishery show that these would need to be quite large to succeed, which begs the question of whether such large adjustments can be expected to be realistic.

Several important questions for future research arise from these results. First, the outcomes observed are directly tied to the levels at which Total Allowable Catches are set for each of the species. In the example presented, considering the case where quota is tradeable and discards are banned, the TAC for Tiger Flathead could be considered to be too high, and that for Jackass Morwong to be too low. In practice, the TACs could be made to dynamically adjust to the status of the stocks, following pre-determined harvest control rules. However, changing the level of allowable catch for one species would likely to entail modifications in the optimal level of fishing effort and catches of the vessels in the two fleets, leading to a modified level of pressure on the two other stocks. This interdependence of TAC setting for the different species is a central characteristic of catch-based management in mixed fisheries, and is likely to be accentuated by the imposition of a discard ban. A key question for future research using the modeling framework proposed in this article should thus be how it can be used to identify TAC schedules (including the possibility for these to incorporate harvest control rules) which meet multiple sustainability criteria for the overall fishery, including biological, economic and social dimensions. The way in which such schedules could then be adapted to changes in the status of the fishery, using pre-defined harvest control rules, could then also be explored. A second key question relates to the assessment of the likely adaptation possibilities of fishing fleets, to constraints imposed by the implementation of a discard ban. This could be done by confronting the predicted adaptation required to maintain levels of fishing activity to observed modifications in the average catchability of species in real-life experiments. Finally, a third key question for future investigation is how to include variability and uncertainty in model assumptions, in a framework that is currently fully deterministic. This is all the more important as by-catch of non-target species often occurs as a rare, and partially unintended event that is determined outside fisher's control, leading to a need to consider by-catch (and potential discards) in probabilistic terms.

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6 References

Abbott, J. K., and J. E. Wilen. 2009. Regulation of fisheries bycatch with common-pool output quotas. Journal of Environmental Economics and Management **57**:195-204.

Branch, T. A. 2009. How do individual transferable quotas affect marine ecosystems? Fish and Fisheries **10**:39-57.

Chan, V., R. Clarke, and D. Squires. 2014. Full retention in tuna fisheries: Benefits, costs and unintended consequences. Marine Policy **45**:213-221.

Chu, C. 2009. Thirty years later: the global growth of ITQs and their influence on stock status in marine fisheries. Fish and Fisheries **10**:217-230.

Connor, R., and D. Alden. 2001. Indicators of the effectiveness of quota markets: the South East Trawl Fishery of Australia. Marine and Freshwater Research **52**:387-397.

Costello, C., S. Gaines, and J. Lynham. 2008. Can catch shares prevent fisheries collapse? Science **321**:1678-1681.

Essington, T. E. 2010. Ecological indicators display reduced variation in North American catch share fisheries. Proceedings of the National Academy of Sciences **107**:754-759.

Fox, W. W. J. 1970. An exponential surplus-yield model for optimizing exploited fish populations. Transactions of the American Fisheries Society **99**:80-88.

Garcia, S. M., A. Zerbi, C. Aliaume, T. Do Chi, and G. Lasserre. 2003. The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook., FAO, Rome.

Grafton, R., R. Arnason, T. Bjorndal, D. Campbell, H. Campbell, C. Clark, R. Connor, D. Dupont, R. Hannesson, R. Hilborn, J. Kirkley, T. Kompas, D. Lane, G. Munro, S. Pascoe, D. Squires, S. Steinshamn, B. Turris, and Q. Weninger. 2006. Incentive-based approaches to sustainable fisheries. Canadian Journal of Fisheries and Aquatic Sciences **63**:699-710.

Hall, S. J., and B. M. Mainprize. 2005. Managing by-catch and discards: how much progress are we making and how can we do better? Fish and Fisheries **6**:134-155.

Hamon, K. G., O. Thebaud, S. Frusher, and L. R. Little. 2009. A retrospective analysis of the effects of adopting individual transferable quotas in the Tasmanian red rock lobster, Jasus edwardsii, fishery. Aquatic Living Resources **22**:549-558.

Hatcher, A. 2014. Implications of a Discard Ban in Multispecies Quota Fisheries. Environmental and Resource Economics **58**:463-472.

Kelleher, K. 2005. Discards in the World's Marine Fisheries: An Update. FAO, Rome.

Newell, R. G., J. N. Sanchirico, and S. Kerr. 2005. Fishing quota markets. Journal of Environmental Economics and Management **49**:437-462.

Pascoe, S., Hutton, T., Thebaud, O., Deng, R., Klaer, N., and Vieira, S. 2015. Setting economic target reference points for multiple species in mixed fisheries. CSIRO Oceans and Atmosphere Flagship, Brisbane.

Pereau, J.-C., L. Doyen, L. R. Little, and O. Thebaud. 2012. The triple bottom line: Meeting ecological, economic and social goals with individual transferable quotas. Journal of Environmental Economics and Management **63**:419-434.

Pikitch, E. K., C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E. D. Houde, J. Link, P. A. Livingston, M. Mangel, M. K. McAllister, J. Pope, and K. J. Sainsbury. 2004. Ecosystem-based fishery management. Science **305**:346-347.

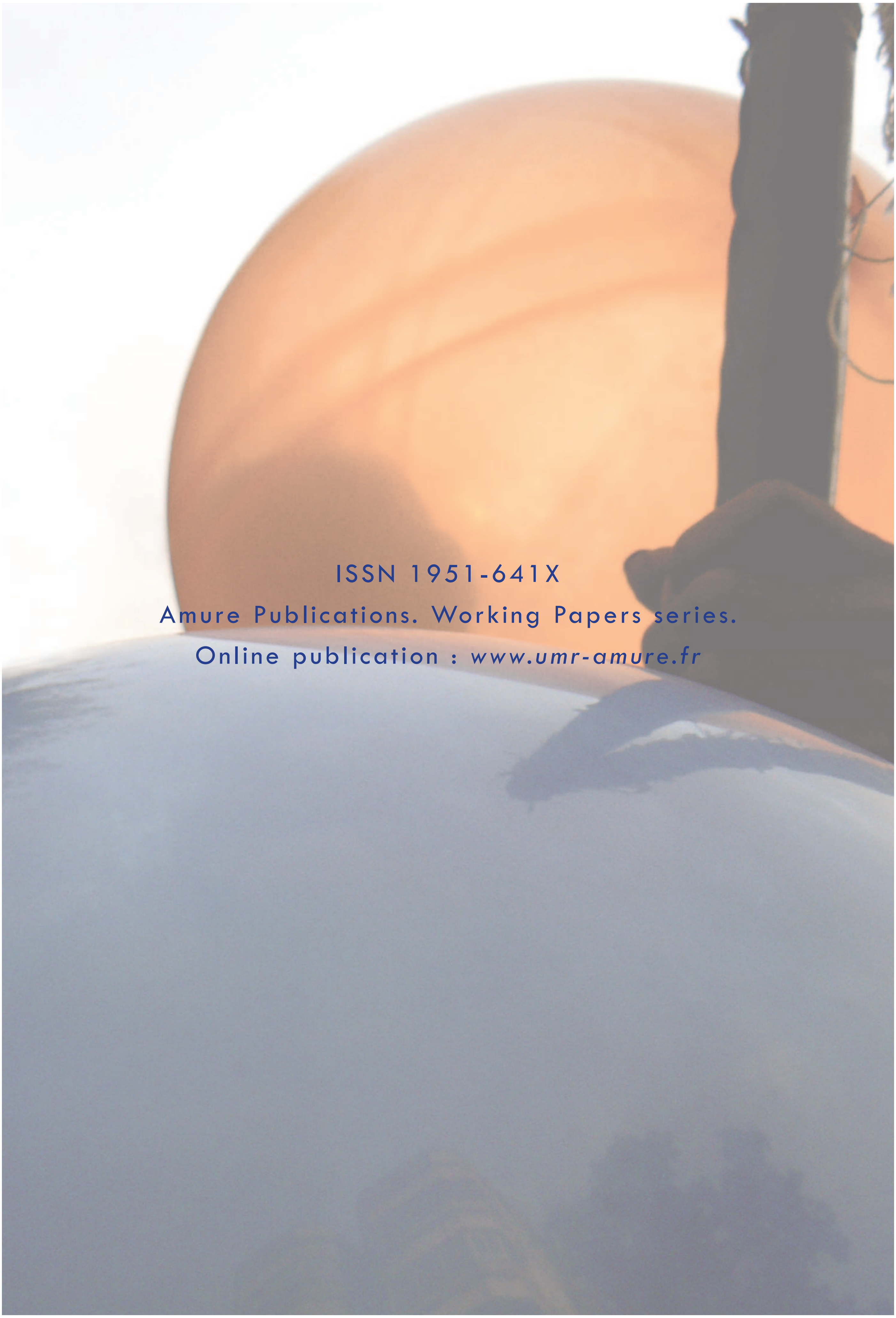
Schrope, M. 2010. What's the catch? Nature **465**:540-542.

Smith, A.D.M. and D.C. Smith (2001) A complex quota managed fishery: science and management in Australia's South East Fishery. *Marine and Freshwater Research*, 52: 353-359.

Squires, D., H. Campbell, S. Cunningham, C. Dewees, R. Grafton, S. Herrick, J. Kirkley, S. Pascoe, K. Salvanes, B. Shallard, B. Turris, and N. Vestergaard. 1998. Individual transferable quotas in multispecies fisheries. Marine Policy **22**:135-159.

Thebaud, O., J. Innes, and N. Ellis. 2012. From anecdotes to scientific evidence? A review of recent literature on catch share systems in marine fisheries. FRONTIERS IN ECOLOGY AND THE ENVIRONMENT **10**:433-437.

Uzawa, H. 1960. Walra's Tatonnement in the theory of exchange. The Review of economic studies **27**:182-194.



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