Can certification improve an open access fishery? An application to Pacific tuna

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Abstract

International and high-seas fisheries often lack the institutions that enable the use of negative incentives such as catch limits and taxes. This leads not only to overfishing, but also to excessive bycatch of charismatic species and juveniles of valuable commercial species. Certification has been proposed as an instrument that may reduce the bycatch issue, but it has also received criticism as it may increase overall fishing pressure. This issue becomes even more relevant when certification aims to shift fishing pressure from juveniles to adults in an already heavily exploited stock. In this paper we analyze under what circumstances certification can improve the efficiency of the Pacific tuna fishery, where fishing on Fish Aggregation Devices (FADs) is known to catch many juveniles of skipjack tuna and yellowfin tuna. We find that under plausible assumptions the positive effect of shifting fishing effort away from the FAD

fishery towards the fishery that does not use FADs can offset the negative effect of an increase in overall fishing effort.

1 Introduction

Environmental organizations have repeatedly turned to 'consumer power' to pressure government and industry to more sustainable directions. The first of these, the German Blaue Engel, was established in 1977 (Kirchhoff, 2000) to certify products that met a set of environmental standards, but labels focused on a specific product, notably wood and fish, have since been established. The most prevalent of ecolabels for fish and seafood is the certification by the Marine Stewardship Council (MSC) (Howes, 2008), but there are many others, including several 'dolphin-safe' labels, the Ecofish label, and the Friend of The Sea (FOS) label (Ward and Phillips, 2008). In addition to such labels, brands such as Sustunable [1] and Fish4Ever [2] include sustainable fishing in their marketing strategy as a distinctive feature of their products. It has been shown empirically that consumers are willing to pay a price premium for sustainable caught fish (Teisl et al., 2002; Erwann, 2009; Roheim et al., 2011).

Ecolabelling has not been without criticism, however. The MSC has been criticized for perceived leniency of requirements and poor representation of developing countries (Gulbrandsen, 2009; Jacquet et al., 2010). Moreover, a number of fisheries certified under MSC or FOS are nevertheless being overfished (Froese and Proelss, ress). More generally, the concept of ecolabelling has also been critized as it may perversely worsen the environmental problems for which they are designed (Mattoo and Singh, 1994; Gudmundsson and Wessells, 2000; Sedjo and Swallow, 2002). One of the mechanisms that may lead to this result is when the price premium for certified products drives some consumers, who are indifferent about sustainability issues but consume the sustainable product for other reasons such as quality, to the unsustainable product (Mattoo and Singh, 1994). Another possibility is that the eco-label increases overall harvesting pressure as it promotes demand for the product as such (Sedjo and Swallow, 2002).

Nevertheless, ecolabelling may be the only instrument at hand to exert pressure on an industry, especially when it concerns management of an international, non-exclusive resource. The Western and Central Pacific purse seine fishery is a case in point. Half the tuna harvested worldwide is caught by the Pacific purse seine fleet (Miyake et al., 2010). The main species, skipjack tuna

[1] http://www.sustunable.com

[2] http://www.fish-4-ever.com/

(*Katsuwonus pelamis*), makes up about 76% of total catches in the Western and Central Pacific Ocean (WCPO) (WCPFC, 2011). With a biomass very close to unexploited levels and about four times its value under maximum sustainable yield (MSY), skipjack tuna stocks are considered underexploited (Langley and Hampton, 2008). Yellowfin tuna (*Thunnus albacares*), however, which is the fleet's next important species, is considered fully exploited, and is included in the IUCN Red List as 'Near Threatened' [3]. It makes up about 21% of total catches in the WCPO (WCPFC, 2011), and its stock has been declining steadily in the past half-century, bringing the stock close to its MSY level (Langley et al., 2009). Further increases in fishing pressure are therefore likely to bring the stock to an overfished state.

The different tuna stocks are linked technically. Purse seines catch three main types of tuna: (1) schools that associate with dolphins; (2) schools that associate with floating objects; or (3) so-called unassociated schools. Targeting of dolphin-associated schools is almost absent in the Western and Central Pacific purse seine fishery, where tuna is mainly caught either through Fish Aggregation Devices (FADs) or through so-called school sets aimed at unassociated schools (Miyake et al., 2010). FADs are man-made floating objects, often carrying advanced sensing and tracking technology, whereas unassociated schools are found with sonar devices or even helicopters. Both sets typically catch a mixture of skipjack tuna, yellowfin tuna, and other species. The size composition, and hence the markets supplied by the sets, however, differ markedly. FAD sets typically catch small specimens of mostly skipjack tuna and juvenile yellowfin tuna, which are sold as canned tuna, or dried and sold as *katsuobushi*. Sets on unassociated schools, hereafter referred to as unassociated sets, catch larger skipjack tuna, which are also sold canned, and adult yellowfin tuna, which are sold canned but also fresh or frozen (An et al., 2009). Hence, FAD sets have the advantage of a higher success rate, but they also have a negative effect on the catch of tuna for the fresh market through their bycatch of juvenile yellowfin tuna.

Managing WCPO tuna stocks, however, is difficult for several reasons. Tuna's mobility combined with the division of the WCPO over many different small island states and high-seas areas make the stock practically an open-access resource (Sibert and Hampton, 2003). The costs of effective management are high, especially for poor countries such the Pacific Island Nations (PICs) (Barclay

[3] Collette, B., Acero, A., Amorim, A.F., Boustany, A., Canales Ramirez, C., Cardenas, G., Carpenter, K.E., Chang, S.-K., de Oliveira Leite Jr., N., Di Natale, A., Die, D., Fox, W., Fredou, F.L., Graves, J., Guzman-Mora, A., Viera Hazin, F.H., Hinton, M., Juan Jorda, M., Minte Vera, C., Miyabe, N., Montano Cruz, R., Masuti, E., Nelson, R., Oxenford, H., Restrepo, V., Salas, E., Schaefer, K., Schratwieser, J., Serra, R., Sun, C., Teixeira Lessa, R.P., Pires Ferreira Travassos, P.E., Uozumi, Y. and Yanez, E. 2011. Thunnus albacares. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.2. (www.iucnredlist.org). Downloaded on 16 May 2012.

and Cartwright, 2007), and the management process itself is hampered by corruption (Hanich and Tsamenyi, 2009). Although a Regional Fisheries Management Organization (RFMO) was established in the form of the Western and Central Pacific Fisheries Commission (WCPFC) in 2004 (Langley et al., 2009), management of WCPO tuna stocks has so far been inadequate (Barclay and Cartwright, 2007; Langley et al., 2009).

Given the difficulty of enforcing restrictions on WCPO tuna, ecolabelling may be one of the few instruments that work, if it works. Ideally, an ecolabelling scheme would divert fishing activities away from the use of FADs in favour of school sets. All else being equal, this would imply a lower bycatch of low-value juvenile yellowfin tuna and a larger catch of high-value adult yellowfin tuna. Promoting school sets, however, is a risky policy as the adult yellowfin tuna caught by unassociated sets is a fully exploited, and poorly managed, stock. Hence, the net effect of ecolabelling unassociated sets depends on the magnitude of several countervailing mechanisms.

This paper aims to analyse the possible effect of certification of unassociated sets on the sustainability and efficiency of the Western and Central Pacific purse seine fishery. We develop a conceptual model where a representative consumer consumes canned skipjack tuna and yellowfin tuna as well as fresh yellowfin tuna. Tuna stocks grow according to a simple two-cohort model, and are caught by two fisheries, namely a FAD fishery and fishery limited to unassociated sets. With this model we address the following research questions: (1) What is the effect of an increased preference for school set canned tuna on biomass of the two tuna species and consumer surplus? (2) To what extent does the change in consumer surplus result from an improved management of the tuna stocks? and (3) Under what circumstances can increased preference for school set canned tuna increase biomass of the two tuna species?

The paper is organised as follows. Section 2 presents the model structure, whereas Section 4 explains the parameter values. Section 5 presents the results, and Section 6 concludes.

2 The model

2.1 Global demand for tuna

We assume the global tuna market can be represented by a representative consumer who derives utility from overall tuna consumption, T and a quantity X of a numeraire commodity:

$$U(X,T) = \begin{cases} X + \gamma \frac{\eta}{\eta-1} T^{\frac{\eta-1}{\eta}} & \text{for } \eta \neq 1 \\ X + \gamma \ln(T) & \text{for } \eta = 1 \end{cases} \tag{1}$$

where γ is a coefficient denoting the weight for tuna consumption relative to the numeraire, and η denotes the overall elasticity of demand for tuna. Tuna consumption is composed of canned tuna (quantity C_C), and fresh tuna steaks, which are yellowfin tuna caught with unassociated sets (quantity C_F), as a CES aggregate:

$$T(C_C, C_F) = \left(C_C^{\frac{\sigma-1}{\sigma}} + (\varphi C_F)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{2}$$

where σ is the elasticity of substitution between canned and fresh tuna; and $\varphi > 1$ reflects the higher utility derived from fresh tuna as compared to canned tuna.

Canned tuna is composed of tuna caught with FADs (quantity C_A), and canned tuna caught with unassociated sets (quantity C_U), according to

$$C_C = C_A + \lambda C_U \tag{3}$$

where $\lambda \geq 1$ reflects the perhaps higher utility that consumers may derive from canned tuna from unassociated sets.

As regards harvests of tuna, supply of canned tuna and fresh tuna is related to harvests of skipjack tuna and yellowfin tuna as follows:

$$S_A = H_{Aj} + H_{AJ} + H_{Ay} \tag{4a}$$

$$S_U = H_{UJ} \tag{4b}$$

$$S_F = H_{UY} \tag{4c}$$

where H_{Aj}, H_{AJ}, and H_{Ay} denote harvest of juvenile skipjack tuna, adult skipjack tuna, and juvenile yellowfin tuna through FADs; and H_{UJ} and H_{UY} denote harvest of adult skipjack tuna and adult yellowfin tuna through unassociated sets. For harvests we assume Schaefer harvest functions:

$$H_{Aj} = q_{Aj} E_A B_j \tag{5a}$$

$$H_{AJ} = q_{AJ} E_A B_J \tag{5b}$$

$$H_{Ay} = q_{Ay} E_A B_y \tag{5c}$$

$$H_{UJ} = q_{UJ} E_U B_J \tag{5d}$$

$$H_{UY} = q_{UY} E_U B_Y \tag{5e}$$

where q_{Aj}, q_{AJ}, and q_{Ay} denote catchability of juvenile skipjack tuna, adult skipjack tuna, and juvenile yellowfin tuna through FADs; q_{UJ} and q_{UY} denote catchability of adult skipjack tuna and adult yellowfin tuna through unassociated sets; E_A and E_U denote the amount of fishing effort through FADs and unassociated sets, respectively; and B_j, B_J, B_y and B_Y denote the biomass of juvenile skipjack tuna, adult skipjack tuna, juvenile yellowfin tuna, and adult yellowfin tuna.

We assume an open-access fishery where all rents have dissipated:

$$p_A \left(q_{Aj} B_j + q_{AJ} B_J + q_{Ay} B_y\right) E_A = w_A E_A \tag{6a}$$

$$\left(p_U q_{UJ} B_J + p_F q_{UY} B_Y\right) E_U = w_U E_U \tag{6b}$$

where w_A and w_U denote the costs per unit of effort of the FAD fishery and the unassociated sets fishery, respectively.

2.2 Biological growth

For both species we assume that the stock of juveniles depends on recruitment, harvest, and maturation of juveniles. Recruitment is assumed to take place according to a Beverton and Holt (1957) stock-recruitment function, which implies that juvenile biomass growth is as follows:

$$G_j = \frac{a_j B_J}{1 + b_j B_J} - \alpha_j B_j - H_{Aj} \tag{7a}$$

$$G_y = \frac{a_y B_Y}{1 + b_y B_Y} - \alpha_y B_y - H_{Ay} \tag{7b}$$

(7c)

where G_j and G_y denote growth in juvenile biomass, a_j, b_j, a_y, and b_y are coefficients in the Beverton-Holt function, and α_j and α_y denote the fraction of juvenile biomass that becomes an adult, corrected for biomass growth of juveniles.

Adult biomass grows through the maturation of juvenile biomass, minus natural mortality and harvesting:

$$G_J = \beta_j B_j - m_J B_J - H_{AJ} - H_{UJ} \tag{8a}$$

$$G_Y = \beta_y B_y - m_Y B_Y - H_{UY} \tag{8b}$$

where G_J and G_Y denote growth in adult biomass; β_j and β_y denotes the amount of biomass added to adult stock through maturation of juveniles; and m_J and m_Y denote natural mortality of adults.

3 Theoretical results

3.1 Population dynamics: steady states

Substituting the harvest functions (5) in the biological growth functions (7) and (8), and assuming steady states gives:

$$B_j = \frac{a_j B_J}{(1 + b_j B_J)(\alpha_j + q_{Aj} E_A)} \tag{9a}$$

$$B_y = \frac{a_y B_Y}{(1 + b_y B_Y)(\alpha_y + q_{Ay} E_A)} \tag{9b}$$

$$\beta_j B_j - m_J B_J - q_{AJ} E_A B_J - q_{UJ} E_U B_J = 0 \tag{9c}$$

$$\beta_y B_y - m_Y B_Y - q_{UY} E_U B_Y = 0 \tag{9d}$$

Substituting (9a) in (9c) and (9b) in (9d) gives

$$\beta_j \frac{a_j B_J}{(1 + b_j B_J)(\alpha_j + q_{Aj} E_A)} - m_J B_J - q_{AJ} E_A B_J - q_{UJ} E_U B_J = 0 \tag{10a}$$

$$\beta_y \frac{a_y B_Y}{(1 + b_y B_Y)(\alpha_y + q_{Ay} E_A)} - m_Y B_Y - q_{UY} E_U B_Y = 0 \tag{10b}$$

Solving these equations for B_J and B_Y gives

$$B_J = 0 \text{ or } B_J = \frac{a_j \beta_j - (\alpha_j + q_{Aj} E_A)(m_J + q_{AJ} E_A + q_{UJ} E_U)}{b_j (\alpha_j + q_{Aj} E_A)(m_J + q_{AJ} E_A + q_{UJ} E_U)} \tag{11a}$$

$$B_Y = 0 \text{ or } B_Y = \frac{a_y \beta_y - (\alpha_y + q_{Ay} E_A)(m_Y + q_{UY} E_U)}{b_y (\alpha_y + q_{Ay} E_A)(m_Y + q_{UY} E_U)} \tag{11b}$$

$$B_j = \frac{m_J + q_{AJ}\, E_A + q_{UJ}\, E_U}{\beta_j}\, B_J \tag{11c}$$

$$B_y = \frac{m_Y + q_{UY}\, E_U}{\beta_y}\, B_Y \tag{11d}$$

$$\tag{11e}$$

Lemma 1. *(a) B_J and B_j are monotonically decreasing in both E_A and E_U. (b) B_Y and B_y are monotonically decreasing in both E_A and E_U.*

3.2 Demand

With p_C being the price for canned tuna and p_F the price for fresh tuna, the first-order conditions for the representative consumer are

$$\gamma C_C^{-\frac{1}{\sigma}} \left(C_C^{\frac{\sigma-1}{\sigma}} + (\varphi C_F)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\eta-1}{\eta} \frac{\sigma}{\sigma-1} - 1} = p_C \tag{12a}$$

$$\gamma \varphi^{\frac{\sigma-1}{\sigma}} C_F^{-\frac{1}{\sigma}} \left(C_C^{\frac{\sigma-1}{\sigma}} + (\varphi C_F)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\eta-1}{\eta} \frac{\sigma}{\sigma-1} - 1} = p_F \tag{12b}$$

with $p_C = p_A$, $C_A = C_C$ and $C_U = 0$ if $p_A < p_U/\lambda$; $p_C = p_U/\lambda$, $C_A = 0$ and $C_U = C_C/\lambda$ if $p_A > p_U/\lambda$; and $p_C = p_A = p_U/\lambda$, $0 \leq C_A \leq C_C$, $0 \leq C_U \leq C_C/\lambda$ with $C_A + \lambda C_U = C_C$ if $p_A = \lambda p_U$.

From (12) we further derive

$$\gamma^{1-\sigma} \left(C_C^{\frac{\sigma-1}{\sigma}} + (\varphi C_F)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\eta}} = p_C^{1-\sigma} + (p_F/\varphi)^{1-\sigma} \equiv P_T^{1-\sigma} \tag{13}$$

$$C_C = \gamma^\eta \, p_C^{-\sigma} \, P_T^{\sigma-\eta} \tag{14}$$

$$C_F = \frac{\gamma^\eta}{\varphi} \, (p_F/\varphi)^{-\sigma} \, P_T^{\sigma-\eta} \tag{15}$$

Indirect utility from fish consumption, which equals consumer surplus, thus is

$$v(p_C, p_F) = \gamma^\eta \left(\frac{\eta}{\eta-1} \, P_T^{1-\eta} - \left(p_C^{1-\sigma} + (p_F/\varphi)^{1-\sigma} \right) \, P_T^{\sigma-\eta} \right) = \frac{\gamma^\eta}{\eta-1} \, P_T^{1-\eta} \tag{16}$$

In a steady state, the prices can be expressed as functions of effort levels E_A and E_U only by using the conditions for equilibrium biomass, (11) in the market equilibrium conditions

$$C_C = (q_{Aj} B_j + q_{AJ} B_J + q_{Ay} B_y) \, E_A + \lambda \, q_{UJ} B_J \, E_U \tag{17a}$$

$$C_F = q_{UY} B_Y E_U \tag{17b}$$

and plugging this into (12).

3.3 Special case: Skipjack tuna only

To get some insights into the mechanisms at work, we simplify the analysis by assuming $\varphi = 0$.

From the open-access conditions (6) we then have

$$p_A = \frac{w_A}{q_{Aj} \, B_j + q_{AJ} \, B_J} \tag{18}$$

$$p_U = \frac{w_U}{q_{UJ} \, B_J} \tag{19}$$

Proposition 1. *For $\varphi = 0$, a sufficient condition for $E_U = 0$ is*

$$\lambda < \frac{w_U \, q_{AJ}}{w_A \, q_{UJ}} \left[1 + \frac{m_J}{\beta_j} \, \frac{q_{Aj}}{q_{AJ}} \right]. \tag{20}$$

Proof. When both fleets are active, $E_A > 0$ and $E_U > 0$, the market equilibrium condition for canned tuna is

$$
\begin{aligned}
& & \frac{1}{p_A} &= \frac{\lambda}{p_U} \\
&\Leftrightarrow & \frac{q_{Aj}}{w_A}\,B_j + \frac{q_{AJ}}{w_A}\,B_J &= \lambda\,\frac{q_{UJ}}{w_U}\,B_J \\
&\Leftrightarrow & \frac{q_{Aj}}{w_A}\,\frac{m_J + q_{AJ}E_A + q_{UJ}E_U}{\beta_j} + \frac{q_{AJ}}{w_A} &= \lambda\,\frac{q_{UJ}}{w_U} \\
&\Leftrightarrow & m_J + q_{AJ}E_A + q_{UJ}E_U &= \frac{w_A\,\beta_j}{q_{Aj}}\left[\lambda\,\frac{q_{UJ}}{w_U} - \frac{q_{AJ}}{w_A}\right] && (21) \\
&\Leftrightarrow & E_U &= \frac{1}{q_{UJ}}\left[\frac{w_A\,\beta_j}{q_{Aj}}\left[\lambda\,\frac{q_{UJ}}{w_U} - \frac{q_{AJ}}{w_A}\right] - m_J - q_{AJ}E_A\right] && (22)
\end{aligned}
$$

This condition cannot be fulfilled for a positive level of E_U if condition (20) holds. Hence, under condition (20) the unassociated sets fishery will be inactive, $E_U = 0$. □

Condition (20) states that there will be no unassociated sets fishery if the markup on the price will not at least cover the cost markup for adult skipjack tuna, multiplied by a factor larger than one, which captures the additional advantage of the FAD fishery that it catches juvenile skipjack tuna as well.

3.4 Steady state with canned and fresh tuna

Now we turn to analyzing the case where fresh tuna is consumed as well, i.e. where $\varphi > 0$. In this case, the unassociated sets fishery will always be active:

Lemma 2. *If $\varphi > 0$, $E_U > 0$ for all $\lambda > 0$.*

Proof. Marginal utility of fresh tuna goes to infinity when supply goes to zero. Hence $C_F > 0$, which requires $E_U > 0$. □

For low values of λ, yellowfin tuna will be the main target of the unassociated sets fishery and harvest of skipjack tuna will occur as bycatch (or, joint product) of fresh yellowfin tuna in this fishery. These 'bioeconomies of scope' tend to give the unassociated sets fishery some cost advantage (**?**). However, the FAD fishery will typically have a cost advantage for catching canned tuna in the first place. So, for low values of λ, the FAD fishery will be active as well. If both fisheries are active, the FAD-fishery will determine the price for canned tuna, as they are producing canned tuna only, while the unassociated sets fishery is producing canned tuna as a joint product of fresh yellowfin tuna. Thus, $p_C = p_A = p_U/\lambda$.

Proposition 2. *There exist a value $\lambda^\star$ such that the FAD fishery will be inactive, $E_A = 0$, for all $\lambda > \lambda^\star$.*

Proof. Condition for $E_A = 0$:

$$\lambda \, \frac{q_{UJ} \, B_J}{q_{UY} \, B_Y} \, C_F = C_C \tag{23}$$

Thus,

$$p_C = \gamma \left(\lambda \, \frac{q_{UJ} \, B_J}{q_{UY} \, B_Y} \, C_F \right)^{-\frac{1}{\sigma}} \left(\left(\lambda \, \frac{q_{UJ} \, B_J}{q_{UY} \, B_Y} \, C_F \right)^{\frac{\sigma-1}{\sigma}} + (\varphi C_F)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\eta-1}{\eta} \frac{\sigma}{\sigma-1} - 1} \tag{24}$$

$$= \gamma \left(\lambda \, \frac{q_{UJ} \, B_J}{q_{UY} \, B_Y} \right)^{-\frac{1}{\sigma}} \left(\left(\lambda \, \frac{q_{UJ} \, B_J}{q_{UY} \, B_Y} \right)^{\frac{\sigma-1}{\sigma}} + \varphi^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\eta-1}{\eta} \frac{\sigma}{\sigma-1} - 1} C_F^{-\frac{1}{\eta}} \tag{25}$$

$$p_F = \varphi^{\frac{\sigma-1}{\sigma}} \left(\lambda \, \frac{q_{UJ} \, B_J}{q_{UY} \, B_Y} \right)^{\frac{1}{\sigma}} p_C \tag{26}$$

In open access with $E_A = 0$, the supply price for canned tuna thus follows from the open-access condition (6b)

$$p_C \lambda \, q_{UJ} B_J + p_F q_{UY} B_Y = w_U \tag{27}$$

$$\Leftrightarrow \quad p_C \left(\lambda \, q_{UJ} B_J + \varphi^{\frac{\sigma-1}{\sigma}} \left(\lambda \, \frac{q_{UJ} \, B_J}{q_{UY} \, B_Y} \right)^{\frac{1}{\sigma}} q_{UY} B_Y \right) = w_U \tag{28}$$

$$\Leftrightarrow \quad p_C = \frac{w_U \, (\lambda \, q_{UJ} B_J)^{-\frac{1}{\sigma}}}{(\lambda \, q_{UJ} B_J)^{\frac{\sigma-1}{\sigma}} + (\varphi \, q_{UY} \, B_Y)^{\frac{\sigma-1}{\sigma}}} \tag{29}$$

$$p_F = \frac{w_U \, \varphi^{\frac{\sigma-1}{\sigma}} \, (q_{UY} B_Y)^{-\frac{1}{\sigma}}}{(\lambda \, q_{UJ} B_J)^{\frac{\sigma-1}{\sigma}} + (\varphi \, q_{UY} \, B_Y)^{\frac{\sigma-1}{\sigma}}} \tag{30}$$

In open access with both fisheries active ($E_A > 0$), the open-access conditions (6) lead to the following supply prices for canned and fresh tuna

$$p_C = \frac{w_A}{q_{Aj} \, B_j + q_{AJ} \, B_J + q_{Ay} B_y} \tag{31a}$$

$$p_F = \frac{1}{q_{UY} \, B_Y} \, [w_U - p_U \, q_{UJ} \, B_J] = \frac{1}{q_{UY} \, B_Y} \, [w_U - \lambda \, p_C \, q_{UJ} \, B_J]$$
$$= \frac{1}{q_{UY} \, B_Y} \left[w_U - \lambda \, w_A \, \frac{q_{UJ} \, B_J}{q_{Aj} \, B_j + q_{AJ} \, B_J + q_{Ay} B_y} \right] \tag{31b}$$

Thus, for given stock sizes p_C as given by (31a) is independent of λ, while p_C as given by (29) is monotonically decreasing in λ. Thus, at most one λ exists such that conditions (31a) and (29) hold simultaneously. If, in addition, the FAD fishery is active for $\lambda = 1$, such a value $\lambda^\star > 0$ actually exists. □

Table 1: Parameter values in the biological model

Math	Description	Value
m_J	Mortality rate adult skipjack tuna biomass	0.05
m_Y	Mortality rate adult yellowfin tuna biomass	0.60
α_j	Fraction skipjack tuna leaving juvenile cohort	0.50
α_y	Fraction yellowfin tuna leaving juvenile cohort	0.95
β_J	Fraction skipjack tuna entering adult cohort	1.00
β_Y	Fraction yellowfin tuna entering adult cohort	0.95
a_j	Coefficient a recruitment skipjack tuna	5.4
a_y	Coefficient a recruitment yellowfin tuna	4.1
b_j	Coefficient b recruitment skipjack tuna	6.5
b_y	Coefficient b recruitment yellowfin tuna	2.8

Consumer surplus changes with λ as follows

$$\frac{dv(p_C,p_F)}{d\lambda} = -\gamma^{\eta}\, P_T^{\sigma-\eta} \Bigg[-\varphi^{\sigma-1}\, p_F^{-\sigma}\, \frac{\partial p_F}{\partial \lambda} + \left[p_C^{-\sigma}\, \frac{\partial p_C}{\partial B_j} + p_F^{-\sigma}\varphi^{\sigma-1}\, \frac{\partial p_F}{\partial B_j} \right] \frac{\partial B_j}{\partial \lambda} + \left[p_C^{-\sigma}\, \frac{\partial p_C}{\partial B_J} + p_F^{-\sigma}\varphi^{\sigma-1}\, \frac{\partial p_F}{\partial B_J} \right] \frac{\partial B_J}{\partial \lambda} + \left[p_C^{-\sigma}\, \frac{\partial p_C}{\partial B_y} + p_F^{-\sigma}\varphi^{\sigma-1}\, \frac{\partial p_F}{\partial B_y} \right] \frac{\partial B_y}{\partial \lambda} + \left[p_C^{-\sigma}\, \frac{\partial p_C}{\partial B_Y} + p_F^{-\sigma}\varphi^{\sigma-1}\, \frac{\partial p_F}{\partial B_Y} \right] \frac{\partial B_Y}{\partial \lambda} \Bigg] \tag{32}$$

The direct effect, captured by the first term in the brackets, is always positive – this is true by construction. The more interesting question is in which directions goes the indirect effect, captured by the second and third terms.

4 Parameter values

4.1 Biological parameters

The values of the biological parameters (Table 4.1) were chosen in order to match the steady-state recruitment and spawning biomass of skipjack tuna and yellowfin tuna given by Langley and Hampton (2008) and Langley et al. (2011) as closely as possible within the assumption that $0 \leq m_J \leq 1$, $0 \leq m_Y \leq 1$, $0 \leq \alpha_j \leq 1$, and $0 \leq \alpha_y \leq 1$ (see Appendix A).

Table 4.1 compares the values predicted by our model with those estimated by Langley and Hampton (2008) and Langley et al. (2011).

Table 2: Biomass in the absence of fishing and biomass and harvests under Maximum Sustainable Yield according to the biological model compared with the values estimated by Langley and Hampton (2008) and Langley et al. (2011)

		Our model	WCPFC
B_j^0	Unexploited biomass juvenile skipjack tuna (mln mt)	0.82	1.30
B_J^0	Unexploited biomass adult skipjack tuna (mln mt)	8.15	6.30
B_j^{MSY}	MSY biomass juvenile skipjack tuna (mln mt)	1.50	1.11
B_J^{MSY}	MSY biomass adult skipjack tuna (mln mt)	1.44	1.32
H_J^{MSY}	MSY harvest skipjack tuna (mln mt per year)	1.43	2.26
B_j^0	Unexploited biomass juvenile yellowfin tuna (mln mt)	1.32	1.74
B_J^0	Unexploited biomass adult yellowfin tuna (mln mt)	2.08	2.00
B_y^{MSY}	MSY biomass juvenile yellowfin tuna (mln mt)	0.95	0.84
B_Y^{MSY}	MSY biomass adult yellowfin tuna (mln mt)	0.58	0.58
H_Y^{MSY}	MSY harvest yellowfin tuna (mln mt per year)	0.56	0.54

4.2 Economic parameters

Values for the economic parameters in the model (Table 3) were chosen to give catch estimates in the same order of magnitude as public domain catch data provided by the WCPFC [4].

5 Numerical analysis

In this section we present the numerical results. All computations have been done in Matlab, codes are made available as online appendix.

5.1 Reference parameter set

Under the parameter values in Table 3 we see that stimulating demand for certified canned tuna (i.e. increasing λ) induces a shift from fishing activity on FADs to fishing activity on unassociated sets (Figure 1, top). Although this effect is to be expected, it is striking that the FAD fishery disappears entirely if λ nears a value of 4. Because from that point on the fishery on unassociated sets is the only fishery left, the only effect of certification is an increase in overall demand for tuna.

[4] http://www.wcpfc.int/science-and-scientific-data-functions/public-domain-data

Table 3: Parameter values in the economic model

Symbol	Description	Value
γ	Weight for tuna consumption	9.0
η	Demand elasticity of tuna	1.1
ψ	Substitution elasticity MSC vs non-MSC canned	3 or 1000
σ	Substitution elasticity canned vs fresh	2
λ	Extra utility from MSC label	1
φ	Extra utility from fresh tuna	2
q_{AJ}	Catchability FAD adult skipjack tuna	0.001
q_{Aj}	Catchability FAD juvenile skipjack tuna	0.017
q_{Ay}	Catchability FAD juvenile yellowfin tuna	0.005
q_{UJ}	Catchability unassociated adult skipjack tuna	0.001
q_{UY}	Catchability unassociated adult yellowfin tuna	0.007
w_A	Fishing costs	0.08
w_U	Fishing costs	0.11

This effect is also visible when we consider the relation between the steady-state biomass and λ (Figure 1, bottom). As the FAD fishery declines, biomass of skipjack tuna and juvenile yellowfin tuna increases, whereas biomass of adult yellowfin tuna declines due to the increased unassociated sets fishery. Once the FAD fishery has disappeared altogether, biomass of juvenile tuna (both skipjack tuna and yellowfin tuna) is stable, whereas biomass of adult tuna declines slightly. The stability of juvenile biomass under the slight decline of adult stocks suggests that recruitment of juvenile tuna is close to its maximum capacity.

As long as there is still an FAD fishery, the change in consumer surplus from an increased λ is largely due to the shift from FAD fishery to unassociated sets fishery (2). Again, when the FAD fishery has disappeared altogether the effect from this shift also disappears and the remaining increase in consumer surplus is due to the direct effect of increased satisfaction from eating certified tuna.

5.2 Effect of increasing aggregate demand

It is very likely that the results discussed thus far depend strongly on the effect of certification on overall tuna demand. We therefore also consider the effect of increasing λ if the parameter η is

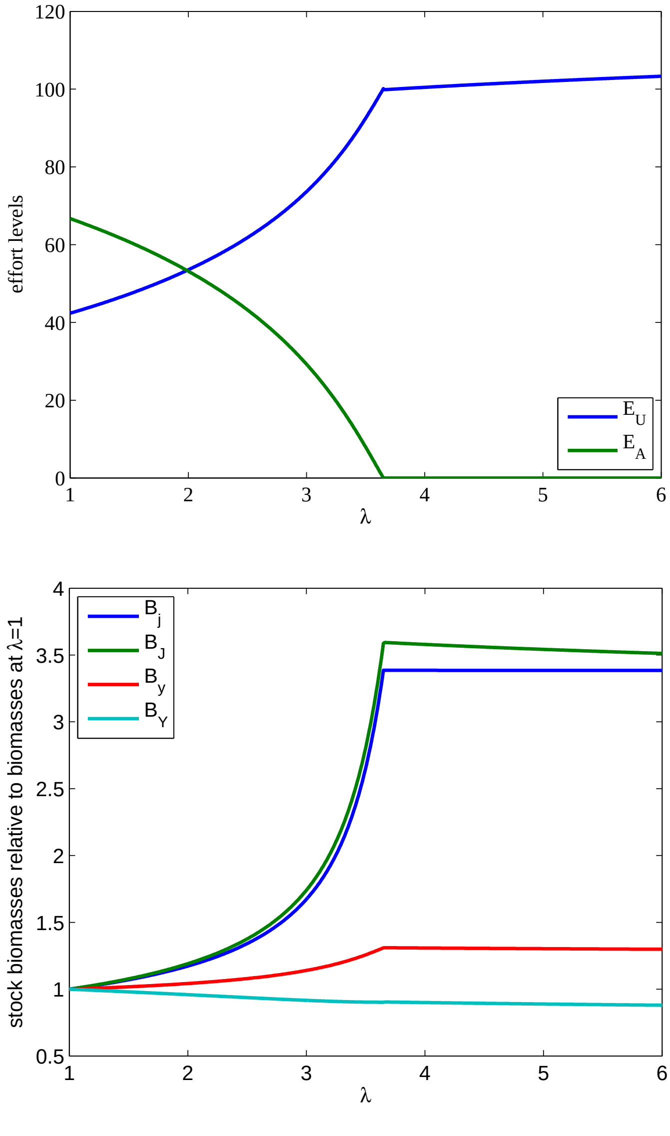

Figure 1: Effort levels in the FAD (E_A) and unassociated sets (E_U) fishery, and biomasses (measured relative to biomasses at $\lambda = 1$) for the reference parameter set as a function of λ.

increased from the reference value $\eta = 1.1$ to $\eta = 3.0$. To keep the senarios comparable, we adjusted the expenditure parameter to $\gamma = 4.63$ such that aggregate effort in the baseline case $\lambda = 1$ is the same for $\eta = 1.1$ and $\eta = 3.0$. Figure 3 shows that under this assumption the effect on overall demand for tuna is so large that increasing λ has a detrimental effect on yellowfin tuna stocks. Increasing λ still increases consumer surplus, but now the indirect effect, i.e. the effect due to the shift from FAD fishery to unassociated sets fishery, is negative (Figure 4).

5.3 Effect of decreasing growth overfishing

Here we study the effect of decreasing growth overfishing by increasing the catchability parameter for juvenile yellowfin tuna, q_{Ay}, from the reference value $q_{Ay} = 0.005$ to the same value as for juvenile skipjack tuna, $q_{Ay} = 0.017$. What we see is that under these parameter values all stocks benefit from increasing λ as long as it does not fully eliminate the FAD fishery (Figure 5). This result indicates that if juvenile yellowfin tuna forms a substantial share of the FAD fishery's catch, moving some fishing effort away from the FAD fishery towards the unassociated sets fishery can be beneficial to adult yellowfin tuna stocks, even if it increases fishing effort of adult yellowfin tuna.

6 Discussion and conclusion

Stimulating an open access fishery, for instance by certification or other promotional activities, seems like the last thing that a conservationist should want to do. Our analysis suggests that in a multispecies open-access fishery like the Western Pacific tuna fishery, certification of 'less unsustainable' fisheries (a lesser evil, so to speak) does indeed bring risks. Nevertheless, our analysis also shows that it is very well possible that such a policy induces a shift away from even worse fishing activities, so that the benefits from this shift offset its costs.

The essential question here is under what circumstances we can expect the benefits from certification to offset the costs. Our analysis suggests that certification can improve open-access stocks if (1) overall demand for the product is relatively insensitive to an enhanced interest in the certified version; (2) the stock that needs protection most urgently (in this case juvenile yellowfin tuna) forms a substantial part of the catch of the non-certified fishery; and (3) the effect of certification does not entirely wipe out the non-certified fishery. Given the rapid developments in MSC certification it is difficult to say whether these conditions are met, but it seems unlikely that certification of tuna caught with unassociated sets has sufficiently strong effects on overall tuna demand or the FAD fishery to be ineffective.

This leaves the question whether an unmanaged, or poorly managed, fishery like the Pacific tuna fishery should be certified at all. The Marine Stewardship Council, for instance, follows three principles, namely that (1) the fishery is conducted in a manner that does not lead to overfishing; (2) the fishery is conducted such that it allows for the maintenance of the structure, productivity, diversity, and functioning of the ecosystem; and (3) the fishery is subject to an effective management system (**?**). It is unlikely that the Western Pacific tuna fishery meets these criteria, so MSC certification of this fishery seems unlikely in the foreseeable future. Our analysis suggests that in such fisheries, where management is difficult for several reasons, improvements can still be made if some principles are applied less stringently.

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A Steady-state conditions for the calibration of the biological model

Biomass in the absence of fishing is found by setting all harvests at zero and solving the system formed by Equations 7 and 8 for juvenile and adult biomass:

$$B_j = \frac{\beta_j a_j - \alpha_j m_j}{\alpha_j \beta_j b_j} \tag{33a}$$

$$B_J = \frac{\beta_J a_J - \alpha_J m_J}{\alpha_J m_J b_J} \tag{33b}$$

$$B_y = \frac{\beta_y a_y - \alpha_y m_y}{\alpha_y \beta_y b_y} \tag{33c}$$

$$B_Y = \frac{\beta_Y a_Y - \alpha_Y m_Y}{\alpha_Y m_Y b_Y} \tag{33d}$$

Biomass under maximum sustainable yield is found by solving Equations 7 and 8 for total harvest of that cohort (i.e. FAD and school sets) and substituting these in the expression for total harvest of the species:

$$H_{SKJ} = H_j + H_J = \frac{a_j B_J}{b_j B_J + 1} + (\beta_j - \alpha_j) B_j - m_J B_J \tag{34a}$$

$$H_{YFT} = H_y + H_Y = \frac{a_y B_Y}{b_y B_Y + 1} + (\beta_y - \alpha_y) B_y - m_Y B_Y \tag{34b}$$

Maximizing H_{SKJ} and H_{YFT} has an interior solution in adult biomass (B_J and B_Y):

$$B_J^{MSY} = \frac{\sqrt{a_j m_J} - m_J}{b_j m_J} \tag{35a}$$

$$B_Y^{MSY} = \frac{\sqrt{a_y m_Y} - m_Y}{b_y m_Y} \tag{35b}$$

Equation 34 shows that the marginal harvest of juvenile biomass is $\beta - \alpha$. Because $\beta \geq \alpha$, we assume harvests of juvenile biomass are zero in the optimum, which results in the following expressions for juvenile biomass:

$$B_j = \frac{a_j \sqrt{a_j m_J} - a_j m_J}{\alpha_j b_j \sqrt{a_j m_J}} \tag{36a}$$

$$B_y = \frac{a_y \sqrt{a_y m_Y} - a_y m_Y}{\alpha_y b_y \sqrt{a_y m_Y}} \tag{36b}$$

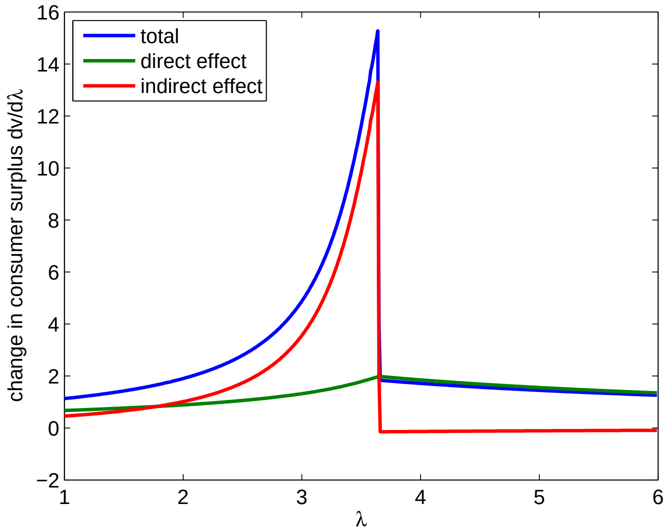

Figure 2: Consumer surplus and the change of consumer surplus with λ (total, and disaggregated in direct and indirect effects) for the reference parameter set as a function of λ.

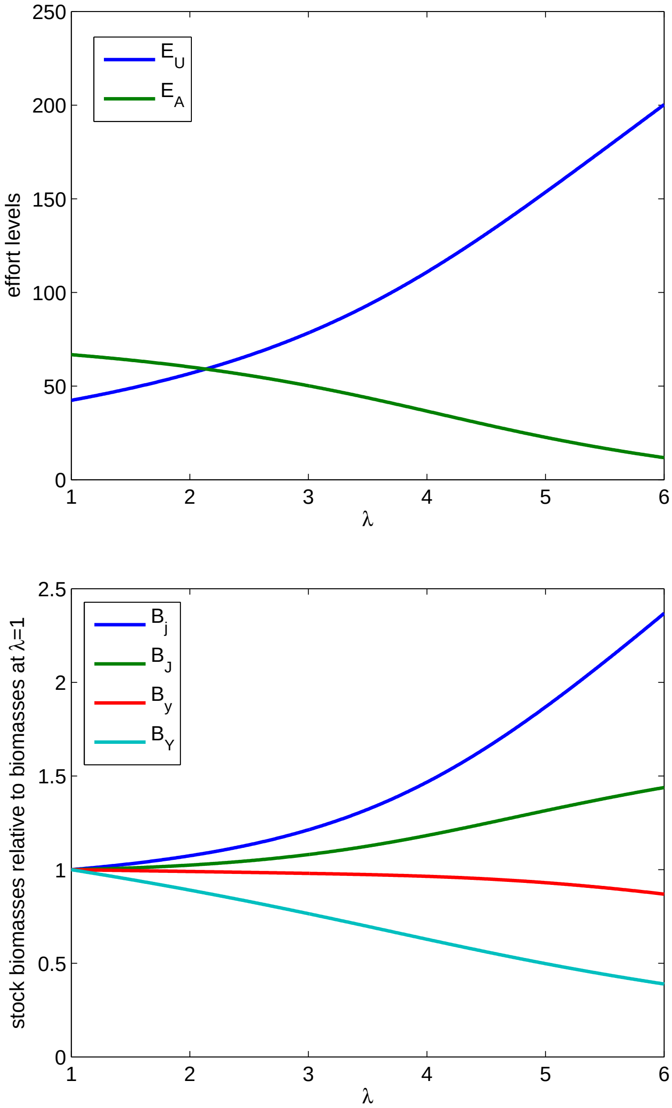

Figure 3: Effort levels in the FAD (E_A) and unassociated sets (E_U) fishery, and biomasses (measured relative to biomasses at $\lambda = 1$) with η increased to $\eta = 3.0$ as a function of λ.

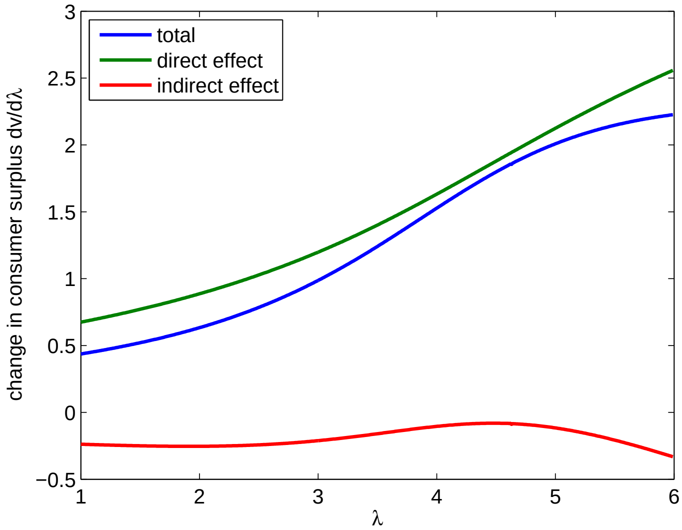

Figure 4: Change of consumer surplus with λ (total, and disaggregated in direct and indirect effects) with η increased to $\eta = 3.0$ as a function of λ.

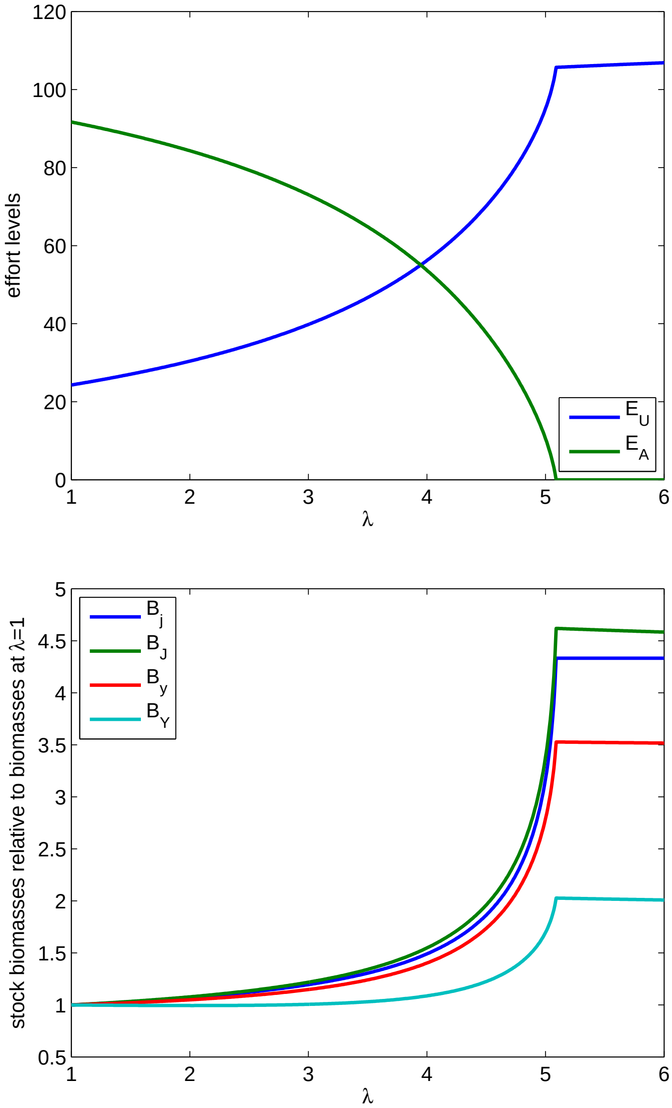

Figure 5: Effort levels in the FAD (E_A) and unassociated sets (E_U) fishery, and biomasses (measured relative to biomasses at $\lambda = 1$) and with q_{Ay} increased to $q_{Ay} = 0.017$ as a function of λ.

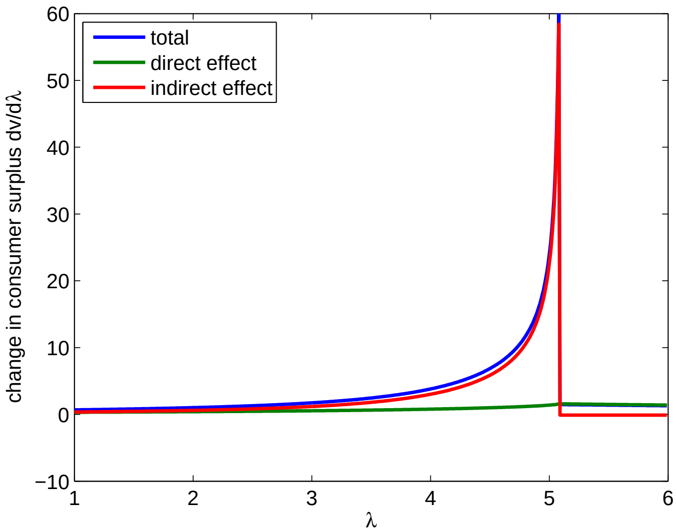

Figure 6: Change in consumer surplus with q_{Ay} increased to $q_{Ay} = 0.017$ as a function of λ.