THE ECONOMICS OF BY-CATCH REDUCTION DEVICES IN REGULATED FISHERIES

by

Chris M. Alaouze

School of Economics
The University of NSW
Sydney, 2052
c.alaouze@unsw.edu.au
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Abstract

By-catch reduction devices increase the equilibrium population of the by-catch species at every level of effort directed at the target species of fish. Also, cost per unit effort is increased and this reduces effort and profit. It is shown that for effective by-catch reduction devices, the fall in effort makes an unimportant contribution to the increase in the equilibrium population of the by-catch species. Thus, it is concluded that mandatory by-catch reduction devices be introduced at minimum cost. That is, without additional regulations which mainly reduce effort and profit.

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/attach/the economics of by-catch reduction revised

1. Introduction

Recent legislation requires that Australian Commonwealth regulated fisheries be managed according to the principles of ecologically sustainable development (ESD) including the precautionary principle. A brief chronology of legislation follows.

The Fisheries Administration Act (1991) and the Fisheries Management Act (1991) set out the framework for the management of fisheries administered by the Commonwealth Government. These Acts created the Australian Fisheries Management Authority (AFMA) to manage Commonwealth regulated fisheries and set out management objectives. A principle objective of management is that:

"the exploitation of fisheries resources and the carrying on of any related activities are consistent with the principles of ecologically sustainable development, in particular the need to have regard to the impact of fishing activities on non-target species and the marine environment".

The 1991 Acts mentioned above did not define what was meant by ESD. The Fisheries Management Act 1991 was amended in the Fisheries Legislation Amendment Act 1997 to include the exercise of the precautionary principle as a management practice. The precautionary principle was defined with reference to the National Environment Protection Council Act 1994.

Paragraph 3.5.1 of the Schedule of the National Environment Protect Act outlines the precautionary principle as follows.

"Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

In the application of the precautionary principle, public and private decisions should be guided by:

(i) careful evaluation to avoid, whenever practicable, serious or irreversible damage to the environment; and

(ii) an assessment of the risk-weighted consequences of various options."

Further management guidelines for the management of Commonwealth fisheries may be found in the Environment Protection and Biodiversity Conservation Act, 1999 (EPBC). The EPBC contains, in Section 3A, a statement of what is meant by ESD.

"The following principles are principles of ecologically sustainable development:

(a) decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations.

(b) if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation;

(c) the principle of inter-generational equity – that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations;

(d) the conservation of biological diversity and ecological integrity should be a fundamental consideration in decision making;

(e) improved valuation, pricing and incentive mechanisms should be promoted ".

Principle (b), above, is essentially a statement of the precautionary principle. The management of Commonwealth fisheries by AFMA, in accordance with the principles of ESD, is described by Jones (2000) and Chesson and Warren (2000).

The principal focus of the precautionary principle is the avoidance of irreversible environmental damage. Species extinction is at present irreversible and the application of the precautionary principle is seen by Myers (1993) as a powerful aid in preserving species, and thus maintaining an option value for future generations.

Jones (2000) describes how species in the marine environment, which are listed as endangered or vulnerable, under the EPBC, are protected by fisheries management plans administered by AFMA.[1] Two important examples of threatened species are albatrosses (four species are listed as endangered and thirteen species are listed as vulnerable) and turtles (two species, the logger head turtle and the Pacific Ridley or Olive Ridley, are listed as endangered).

Any modified fishing practices (including equipment) which are used to reduce the by-catch of non-target species will be referred to in the paper as by-catch reduction devices. The aim of this paper is to present an economic analysis of by-catch reduction devices.

The remainder of the paper is as follows. Section 2 contains a brief discussion of by-catch reduction devices, which are used in the Australian Fishing Zone to reduce the by-catch of sea birds and turtles. Section 3 contains an economic analysis of by-catch reduction devices. The results of the paper are summarised in section 4.

2. By-catch reduction devices for sea birds and turtles in the Australian Fishing Zone

Klauer and Polacheck (1998, p. 305) outline the modified fishing practices which can be used to reduce the by-catch of seabirds by longline fishers in Australian waters. These practices include: "setting lines at night; trailing bird scaring lines and streamers behind fishing vessels during line setting ('tori poles' and 'tori lines'); using machines to cast baits clear of the vessel wash during line setting; weighting lines more heavily so that they sink more quickly; thawing bait; using bait that sinks more readily; closing fishing areas or seasons; and not dumping offal near the fishing lines during setting and hauling."

Klauer and Polacheck (1998, pp.313-314) found that the night catch rates of sea birds were 91% less than day catch rates. Thawing of bait so that it sinks faster and the use of a bait thrower that throws bait clear of the vessel wash, thus allowing more effective sinking, were also found to be effective in reducing the by-catch of sea birds.

The effect of 'tori lines' on the by-catch of sea birds could not be determined by Klauer and Polacheck (1998), because 'tori lines' were used by all boats in their data set. Jones (2000, p.62) notes that the use of 'tori lines' is mandatory for Australian fishing vessels operating south of 30^0S in the Australian Fishing Zone.

The use of turtle exclusion devices and fish by-catch reduction devices is mandatory in the Australian Northern Prawn Fishery (Jones, 2000, p. 63). According to Brewer *et al.* (1998,pp.538-539), a turtle exclusion device is an aluminium panel with grids, which is placed inside the trawl net. The panel is set at an angle to the trawl net. The grids are wide enough to allow the target species (usually prawns) to pass through the grid into the cod-end of the trawl net.

Large animals, such as turtles, are guided by the panel to an opening (which can be at the top or bottom of the trawl net) from which they escape. It is expected that the use of turtle exclusion devices will reduce the by-catch of turtles in the Northern Prawn Fishery by 95% (Harris and Ward, 1999, p.150).

3. An economic model of by-catch reduction devices

Introduction

By-catch reduction devices improve the survivability of by-catch species in two ways.

(1) By-catch reduction devices increase the cost of effort directed at catching the target species and can therefore be expected to reduce fishing effort. Reducing fishing effort will increase the equilibrium populations of the by-catch species and the target species.

(2) Effective by-catch reduction devices can be expected to reduce the by-catch per unit effort directed at the target species. The reduced by-catch per unit effort directed at target species will also increase the equilibrium population of the by-catch species. This intuitive result will be formalised below.

By increasing the equilibrium population of the by-catch species, the survivability of the by-catch species is improved. The reduction of by-catch species caught, reduces the environmental damage caused by fishing, especially when by-catch species have low populations or high aesthetic value (King, 1995, p.275).

We shall use the static economic model of a fishery with a single target species, as described, for example, by King (1995), Clark (1990), Anderson (1986) and Munro and Scott (1985), to model the effects of regulations which impose effective by-catch reduction devices on a single-species fishery.

The assumptions of this model of a fishery are as follows. The price of fish, P is constant and exogenous, the total average cost per unit effort directed at the target species, C, per unit time is constant and the sustainable yield curve, $H = H(E)$, of the target species (where E is effort directed at the target species per unit time) is fixed.

In addition, we shall assume that the sustainable yield curve of the by-catch species, $H_b = H_b(E)$ is also fixed and that $H(E)$ and $H_b(E)$ are Schaefer (1954) sustainable yield curves. The Schaefer sustainable yield curve has useful symmetry properties and is widely used in fisheries management (King, 1995, pp.198-203).

Economic equilibrium with by-catch reduction devices

We shall assume that the fishery is regulated by individual transferable quotas (ITQs), which produce the profit maximising level of effort.[2] We shall also assume that the introduction of mandatory by-catch reduction devices increases average total cost by a constant amount of B, per unit of fishing effort, per unit time.

Let E_π be the profit maximising level of effort before the introduction of by-catch reduction devices, and E'_π be the profit maximising level of effort after the introduction of by-catch reduction devices. The corresponding open access equilibrium levels of effort are E_0 (before the introduction of by-catch reduction devices) and E'_0 after the introduction of by-catch reduction devices.

The Schaefer sustainable yield curve for the fishery may be written as

$$H(E) = cE + dE^2 \qquad (c > 0, d < 0). \qquad (1)$$

The corresponding revenue function $R(E)$ is

$$R(E) = PH(E) = cPE + dPE^2 . \qquad (2)$$

The total cost function before the introduction of by-catch reduction devices, $TC(E)$ may be written as

$$TC(E) = C.E. \tag{3}$$

The profit function for the fishery is $\Pi = R(E) - TC(E)$ and the profit maximising level of effort, E_{π}, is obtained from the first order condition for profit maximisation, $d\Pi/dE = 0$ as

$$E_{\pi} = \left[(C - cP)/Pd\right]/2. \tag{4}$$

The open access level of effort E_0 is obtained by equating revenue to total cost as

$$E_0 = (C - cP)/Pd. \tag{5}$$

From (4) and (5), we find that $E_{\pi} = E_0/2$.

After the introduction of by-catch reduction devices, the profit maximising level of effort is:

$$E'_{\pi} = \left[(C + B - cP)/Pd\right]/2, \tag{6}$$

and the open access level of effort is

$$E'_0 = (C + B - cP)/Pd. \tag{7}$$

From (4) and (6), we find that the introduction of by-catch reduction devices has reduced the profit maximising level of effort. That is

$$E_{\pi} > E'_{\pi}. \tag{8}$$

These results are shown in Figure 1. The total allowable catch of the ITQ scheme is originally $H(E_{\pi})$ and this is reduced to $H(E'_{\pi})$ after the introduction of by-catch reduction devices.

The sustainable yield curve and the population equilibrium curve of the by-catch species are derived below. The derivation of the sustainable yield curve follows King (1995, pp.199-202) and the population equilibrium curve is derived, using the definition of this curve given by Anderson (1986, p.21).

The sustainable yield and population equilibrium curves of the by-catch species

We begin with differential equation of the logistic biomass function of the by-catch species,

$$\frac{dX}{dt} = \dot{X} = rX(1 - X/X_m). \tag{9}$$

In (9), X is the biomass of the by-catch species, t is time, X_m is the maximum attainable biomass of the by-catch species and r is a positive constant.

The catch or yield (H_b) of the by-catch species, is assumed to be related to the biomass of the by-catch species and effort (directed at the target species) by the formula

$$H_b = q \cdot E \cdot X. \tag{10}$$

In (10), q is the "catchability coefficient" of the by-catch species. The catchability coefficient is assumed constant and gives the proportion of the biomass of the by-catch species, which is harvested by one unit of effort directed at the target species (King, 1995, pp.83-84).

In equilibrium,

$$\dot{X} = H_b, \tag{11}$$

or

$$H_b = rX(1 - X/X_m). \tag{12}$$

To obtain the Schaefer sustainable yield curve, (10) is used to eliminate X from (12). The sustainable yield curve may be written as

$$H_b = aE + bE^2, \quad (a > 0, b < 0). \tag{13}$$

In (13), $a = q \cdot X_m$ and $b = -q^2 \cdot X_m / r$.

To obtain the population equilibrium curve, (10) is used to eliminate H_b from (12). The population equilibrium curve may be written:

$$X = X_m + eE. \tag{14}$$

In (14), X is the equilibrium population of the by-catch species and $e = -q X_m / r$.

A by-catch reduction device is assumed to reduce the catchability coefficient of the by-catch species to $q' = \alpha q$, where $0 < \alpha < 1$. The introduction of a mandatory by-catch reduction device into the fishery modifies the sustainable yield curve and the population equilibrium curve of the by-catch species as follows.

The sustainable yield curve of the by-catch species after the introduction of a by-catch reduction device may be written as

$$H_b' = \alpha aE + \alpha^2 bE^2, \tag{15}$$

and the modified population equilibrium curve may be written as

$$X = X_m + \alpha eE. \tag{16}$$

Thus, the modified sustainable yield curve has the same range as the original sustainable yield curve $\left[0, -a^2/4b\right]$ but the domain is changed to $\left[0, -a/\alpha b\right]$. In the case of the population equilibrium curve, the range remains unchanged at $\left[0, X_m\right]$ and the domain is changed to $\left[0, -a/\alpha b\right]$.

To interpret the changes to the sustainable yield curve and the population equilibrium curve of the by-catch species induced by the introduction of a by-catch reduction device, assume that $\alpha = 0.25$. With $\alpha = 0.25$, the proportion of the biomass of the by-catch species, which is harvested by unit of effort directed at the target species, is reduced to 0.25 times its value before the introduction of the by-catch reduction device.

The effect on the sustainable yield curve of the by-catch species of the use of a by-catch reduction device, is to increase the effort over which a positive yield of by-catch can be obtained, by a factor of four $(1/\alpha)$. The effect on the population equilibrium curve of the by-catch species of the by-catch reduction device is to increase the effort directed at the target species over which a positive equilibrium population is obtained by a factor of four.

Thus, a modest reduction in the catchability coefficient of the by-catch species can have a dramatic effect on the equilibrium population of the by-catch species. This is particularly important for those by-catch species which have low biomass or are endangered.

The graphs of the sustainable yield curves of the by-catch species, before and after the introduction of the by-catch reduction device (with $\alpha = 0.25$), are shown in Figure 2. The graphs of the population equilibrium curve of the by-catch species, before and after the introduction of the by-catch reduction device (with $\alpha = 0.25$) are shown in Figure 3. It is evident from Figure 3 that the by-catch reduction device has increased the equilibrium population of the by-catch species at every level of effort directed at the target species.

Economic analysis

The introduction of a by-catch reduction device increases cost per unit effort from C to C+B. The increase in costs induces a reduction in the profit maximising level of effort, (E_{π} falls to E'_{π}) as shown by equations (4) and (6) and also causes a reduction in profit. This latter point may be shown as follows.

Let Π^* be the profit function evaluated at E_{π}, then direct application of the envelope theorem (Varian, 1993, pp.490-491) yields

$$d\Pi^*/dC = -E_{\pi} < 0. \qquad (17)$$

The introduction of a by-catch reduction device reduces the contribution of a unit fall in effort to the equilibrium population of the by-catch species. This is because the population equilibrium curve is flatter after the introduction of the by-catch reduction device. (See (14) and (16)).

This can be seen in Figure 3, where the reduction in effort from E_{π} to E'_{π} increases the equilibrium population of the by-catch species by AB, before the introduction of the by-catch reduction device and by CD after the introduction of the by-catch reduction device (CD < AB).

This indicates that the more effective the by-catch reduction device (the smaller is α), the less important is the increase in equilibrium population attributed to the fall in effort due to the introduction of the by-catch reduction device. This may be formalised as follows.

Since $E_{\pi} > E'_{\pi}$, $E'_{\pi} = pE_{\pi}$ where: $0 < p < 1$. Let $X_1 = X_m - eE_{\pi}$ be the equilibrium population of the by-catch species before the introduction of by-catch reduction devices. Let $X_2 = X_m - \alpha eE_{\pi}$ be equilibrium population of the by-catch species after the introduction of by-catch reduction devices, when effort equals E_{π} and let $X_3 = X_m - \alpha eE'_{\pi}$ be the equilibrium population of the by-catch species after the introduction of by-catch reduction devices, when effort equals E'_{π}. Since $E'_{\pi} = pE_{\pi}$, $X_3 = X_m - \alpha pE_{\pi}$.

Let $s_1 = (X_3 - X_2)/(X_3 - X_1)$ be the proportion of the total gain in the equilibrium population of the by-catch species (due to the introduction of the by-catch reduction device), which is attributable to the fall in effort from E_π to E'_π. Then $s_2 = (X_2 - X_1)/(X_3 - X_1)$ is the proportion of the total gain in the equilibrium population of the by-catch species due to the introduction of by-catch reduction devices, holding effort constant at its original level, E_π.

It may be shown that

$$s_1 = \alpha(1-p)/(1-\alpha p), \tag{18}$$

and

$$s_2 = (1-\alpha)/(1-\alpha p). \tag{19}$$

Table 1 shows the values of $s_1 \times 100$ for selected values of α in the range $0 < \alpha \leq 0.25$ and for selected values of p in the range $0.99 \leq p \leq 0.8$. From Table 1, it can be seen that as the effectiveness of the by-catch reduction device increases (α falls), the percentage contribution of a reduction in effort to the gain in the equilibrium population of the by-catch species, attributable to the introduction of the by-catch reduction device, falls.

Also, from Table 1, it is evident that the contribution of the fall in effort to the gain in the equilibrium population of the by-catch species is small and becomes unimportant for very effective by-catch reduction devices. For example, for $\alpha = 0.25$, a 20% fall in effort $(p = 0.8)$ contributes only 6.25% of the total gain in the equilibrium population of the by-catch species. When $\alpha = 0.01$, a 20% fall in effort contributes only 0.20% of the total gain in the equilibrium population of the by-catch species.

4. Conclusions

The introduction of a by-catch reduction device increases the unit cost of effort from C to C+B and this increase in costs induces a reduction in the profit maximising level of effort from E_{π} to E'_{π} and also reduces profit. However, we have seen that when an effective by catch reduction device is introduced, the contribution of the fall in effort to the increase in the equilibrium population of the by-catch species, is relatively unimportant.

This suggests that effective by-catch reduction devices should be introduced at minimum cost. That is, without any incidental regulations which mainly increase costs and hence reduce effort and profitability without making any important contribution to the equilibrium population of the by-catch species.

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Figure 1: Revenue and cost curves for the fishery

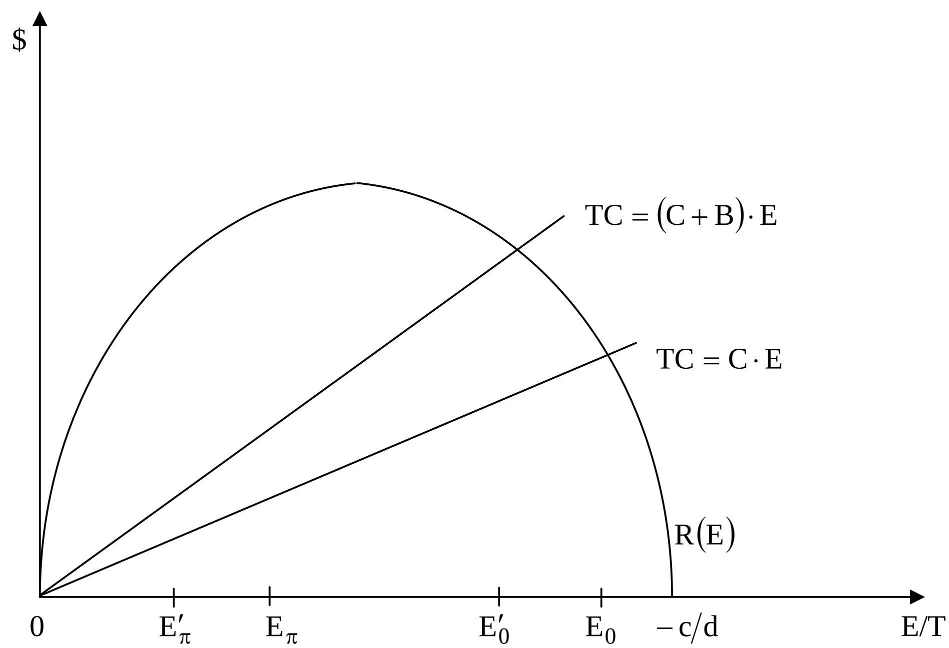

Figure 2: The sustainable yield curves of the by-catch species (α = 0.25)

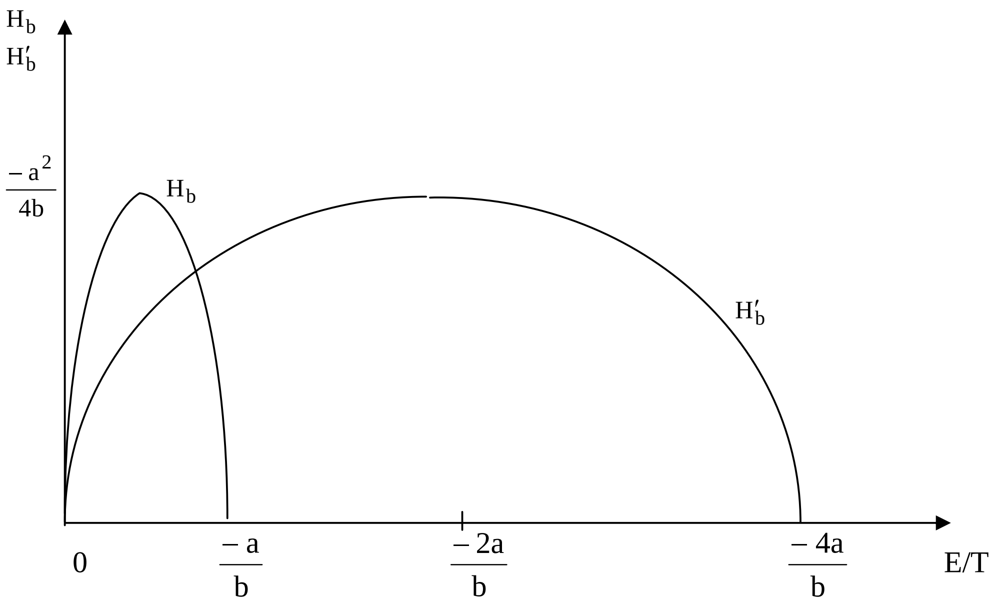

Figure 3: The population equilibrium curves of the by-catch species (α = 0.25)

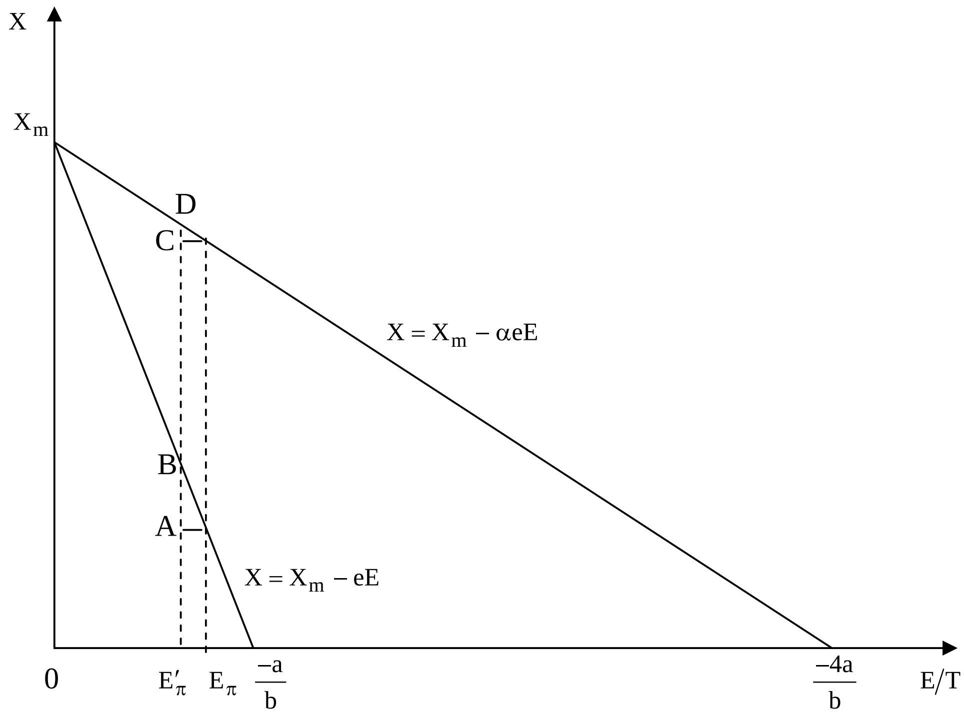

Table 1: The percentage of the gain in the equilibrium population of the by-catch species, attributable to the fall in effort associated with the introduction of a by-catch reduction device $(s_1 \times 100)$, for selected values of α and p.

	α					
p	0.01	0.05	0.10	0.15	0.20	0.25
0.99	0.01	0.05	0.11	0.18	0.25	0.33
0.95	0.05	0.26	0.55	0.87	1.23	1.64
0.90	0.10	0.52	1.10	1.73	2.44	3.23
0.85	0.15	0.78	1.64	2.58	3.61	4.76
0.80	0.20	1.04	2.17	3.41	4.76	6.25

Footnotes

[1] Species which are considered endangered or vulnerable were listed in the schedule of the Endangered Species Protection Act (1992), (ESP). The ESP has been replaced by the EPBC and species which are considered endangered or vulnerable are listed under the EPBC. The list of endangered or vulnerable species under the EPBC may be found at the following website: www.environment.gov.au (as at July 2001).

[2] Individual transferable quotas are discussed in detail in Anderson (1986), Clarke (1990) and Wills (1997).