BIOECONOMIC MODELING AND MANAGEMENT OF THE SOUTHERN BLUEFIN TUNA FISHERY

Harry Campbell, University of Queensland, h.campbell@uq.edu.au

John Kennedy, La Trobe University, J.Kennedy@latrobe.edu.au

ABSTRACT

The paper reviews the management and bioeconomic modeling of the Southern Bluefin Tuna stock. It describes two studies using simultaneous, non-cooperative, three player games to predict revenue and stock outcomes generated by a deterministic, discrete, age-structured model of the SBT population. Two versions of the model, corresponding to biological and harvesting conditions prevailing around 2000 and 2007 respectively are considered. Because of a significant downward revision of estimates of the productivity of the SBT stock between these two dates, the later model suggests that conservation and optimal utilization of the SBT stock will require a substantial cut in catch quotas as compared with the results of the earlier model.

Keywords: optimal utilization, conservation, Southern Bluefin Tuna

HISTORICAL HARVESTING AND MANAGEMENT OF THE SBT STOCK

The Commission for the Conservation of Southern Bluefin Tuna (CCSBT) publishes reported global catch of Southern Bluefin Tuna (SBT) from 1952 to the most recent years. The reported catch peaked in 1961 at 81,698 tonnes but since then has trended downwards to around 15,000 tonnes in the period from the late 1980s to the mid 2000's. Subsequent to 2005 the reported annual catch has been around 11,000 tonnes. Before 1961 Australia and Japan were the only two countries reporting catches. In more recent years Taiwan, New Zealand, Korea, Indonesia, The Philippines and South Africa have also participated in the fishery. A review of the research on, and management of, the SBT fishery is contained in Campbell, Herrick and Squires (2000).

A series of annual meetings of biologists, fishery managers and industry representatives from the three main countries then exploiting SBT, Australia, New Zealand and Japan, was launched in Wellington, New Zealand in 1982. Scientists attending the first of these Trilateral Meetings accepted evidence that the SBT stock was already fully exploited - meaning that further increases in fishing effort would not result in increases in total catch (Murphy and Majkowski (1981)). This work, relying on basic biological research on the size and structure of the SBT stock which began in the 1950s, suggested that the spawning stock had been reduced to around 50% of its virgin level and stressed that there was a significant time lag between a decline in the spawning stock and its detection. Research suggested that yield would be maximized by postponing capture until 4-5 years of age - a move which would have virtually eliminated the Australian fishery, which mainly targeted juvenile fish. Subsequently Hampton, Majkowski and Murphy (1984) found that a global catch of 32,000 tons could be sustained by an equilibrium population at its 1980 level, but that the then current catch of 40,000 tons was unsustainable; and Hampton (1989) concluded that in steady-state equilibrium, Australian and Japanese catches of 11,000 and 28,000 tons respectively would have equal impact on the parental biomass and would each be consistent with maintaining an assumed safe level of that biomass.

As research was up-dated on the basis of tagging, catch, and effort data, scientific opinion about the state of the SBT stock became more pessimistic. At the seventh Trilateral Meeting in Wellington in 1988 scientists concluded that the only safe catch would be zero, but that if management imperatives precluded this option, the total catch should be reduced by at least 50% in the 1989-90 season (following a 60% cut in the 1988-89 season). While this view was disputed by industry, it was recognized that the fishery faced serious problems of adjustment (Australian Fisheries 1989).

The ninth Trilateral Meeting in Hobart in 1990 concluded that the parental stock would reach its lowest level in 1990 or 1991 at around 20% of the unexploited level of spawning stock biomass (SSB).

Most models predicted a recovery to 1980 levels by 2010, but at least one model predicted a continuing stock decline (Australian Fisheries 1991). Recent stock assessments support that view, with SSB estimated at around 5% of virgin SSB, and 15% of SSB_{MSY}, in 2008. While scientists from Australia and New Zealand regarded a moratorium as the safest option, the existing quota regime was maintained. At the Eleventh Trilateral Meeting between Australia, New Zealand and Japan in Tokyo in 1992 the long-term goal of returning the SBT stock to its 1980 level (around 50% of SSB) was adopted.

In 1994 the voluntary management arrangement in the form of the Trilateral Meetings was formalized when the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) came into force. The CCSBT adopted the goal of achieving the target level of 50% of unexploited SSB (a target of 144,000 tonnes), setting a target date of 2020. The CCSBT has encouraged other countries participating in the fishery to become members; Korea joined in 2001, Taiwan in 2002, and Indonesia in 2008. The Philippines, South Africa and the European Community became cooperating non-members, a transitional stage to full membership, in the period 2004-6.

Following a review of SBT farming and Japanese market data conducted in 2006 it was found that the SBT catch had been substantially under-reported over the past 10-20 years (Taipei Times 2006). The implications of this revelation for the stock assessments are still being worked out, but in the meantime the member countries of the CCSBT agreed to a 3,115 tonne reduction in the total allowable catch (TAC) to 11,810 tonnes for the years 2007-09. For members the quotas were (in tonnes): Japan 3,000, Australia 5,265, Korea and Taiwan 1,140 each, and New Zealand 420. However Korea and Taiwan undertook to maintain their actual catch below 1,000 tonnes. Cooperating non-members and observers were allocated a total 845 tonnes for 2007. At the 16th Annual Meeting of the CCSBT quotas totaling 80% of the 11,810 tonne TAC were allocated to member countries as follows: Japan 2261, Australia 4270, Korea 859, Taiwan 859, New Zealand 754, and Indonesia 651 tonnes. Cooperating non-members were allocated residual amounts: The Philippines 45, South Africa 45 and the EC 10 tonnes (the latter to cater to by-catch).

The total quota for 2010-11 was set at 9449 tonnes and it was agreed that a management procedure needed to be developed to set quotas in 2012 and beyond. Sun and Squires (forthcoming) discuss and compare alternative management plans. In the event that a management plan cannot be finalized by 2012 the TAC for 2012 is to be reduced to the 5000 - 6000 tonne range unless the Commission decides otherwise on the basis of a new stock assessment.

MANAGEMENT OBJECTIVES

The aim of the Convention for the Conservation of Southern Bluefin Tuna (CCSBT) is to *"…ensure, through appropriate management, the conservation and optimum utilization of southern bluefin tuna"* (CCSBT, Article 3). The concepts of conservation and optimum utilization can be examined within an economic framework which can be used to assess the contribution of alternative harvesting strategies and management arrangements to meeting these goals. The goal of conservation can be interpreted as a constraint which should be imposed on the utilization of the resource, although it need not be a binding constraint in all cases. It can be argued that optimum utilization means maximizing the use-value of the resource.

Conserving, rather than using, a resource could be the way in which its value is maximized. In that case, the conservation and optimum utilization goals would not be in conflict. Where use-values are significant, as in the case of a fish stock which supports a commercial fishery, the conservation and optimum utilization goals may still not be in conflict since the stock level which maximizes the use-value of a fish stock may be higher than the maximum sustainable yield (MSY) level. Most recent fisheries legislation identifies conservation with sustainability, which, in turn is defined as fish stocks maintained at or above MSY levels.

The two goals can be incorporated in a management plan designed to maximize the use-value of the resource, subject to the conservation constraint. An example of this approach is provided in the model of Bertignac et al. (2000), where a bioeconomic model constrains exploitation of tuna stocks in the western and central Pacific to maintain stock levels of at least 40% of virgin population biomass. For a long-lived species, such as SBT, the age structure of the population, as well as the size of the total biomass, can have important implications for conservation. Both these variables can be taken into account by specifying the SBT conservation constraint in terms of the spawning stock biomass (SSB). The CCSBT target of restoring the SSB to its 1980 level of 50% of unexploited biomass (144,000 tonnes) could be used as the conservation constraint in an analysis of use-value.

The use-value of the fishery is defined as the present value of producer revenues plus consumer benefits less harvesting costs. It should be noted that the measurement of consumer surplus is based on estimates of market elasticity of demand which are obtained from analysis of current consumption patterns. These estimates are only approximate, and they become increasingly less reliable as the scenario being considered departs from the consumption levels currently observed.

BIOECONOMIC MODELING

Bioeconomic modeling can be used to estimate the value of alternative harvesting plans for the SBT fishery. Kennedy and Watkins (1985) based their economic analysis on the results of biological studies of the fishery by Murphy and Majkowski (1981), Shingu (1981) and Hampton and Majkowski (1983). Their deterministic model suggested that the negative feedback effects on harvesting incentives of falling stocks were sufficient to prevent a stock collapse in the immediate future. However they recognized the validity of stochastic models, such as that of Hampton and Majkowski (1983), which suggested that a stock collapse was a real possibility. They found that an overall quota on the Australian catch of 8-10,000 tons would contribute to an increase in total returns from the fishery. A reduction in the Australian quota would increase the value of the Japanese fishery in the Australian Fishing Zone (AFZ) and access fees could be raised accordingly.

Kennedy (1987) further investigated the economic relationship between the Australian and Japanese SBT fleets. A bioeconomic model based on the population analysis by Hampton and Majowski (1986) was developed to predict duopoly and joint profit maximizing outcomes for an SBT fishery exploited by Australia and Japan. The model suggested that, because the Japanese vessels targeted larger SBT with a higher unit value, joint profit maximization could be achieved by Australia reducing its catch to zero and sharing in the value of the Japanese catch. Under a duopoly regime individual country returns would be maximized by Japan taking 8-10,000 tons per year, and Australia taking 5-8,000 tons. The total profit under duopoly was predicted to be around 88% of the level under joint profit maximization. The implication was that 12% of the potential value of the fishery is available to motivate the development of a cooperative management regime.

Kennedy and Pasternak (1991) extended the analysis of the duopoly regime. Their model suggested that it would be in Japan's interests to purchase and freeze (ie. not catch) Australian quota; following negotiations in 1986 Japan did, in fact, agree to purchase and freeze 3000 tons of Australian quota for three years starting in 1987. While the model takes account of Australia's ability to control Japanese access to the AFZ, this makes little difference to the outcome from Australia's point of view. The authors find that Australia's best strategy is participation in the fishery; the duopoly results in higher present value of profits for Australia as compared with joint profit maximization, mainly because the latter regime involves a three-year moratorium on the Australian catch.

Kennedy (1999) published a *deterministic*, *discrete* and *age-structured* biological model of the SBT stock: *deterministic* refers to the fact that the model does not take account of the year to year fluctuations that occur in nature as a result of fluctuations in environmental conditions; *discrete* refers to the fact that changes in stock levels are calculated and reported on a yearly basis; and *age-structured* refers to the fact that the experience of each age class of fish is modeled separately. This model, with some adjustments, was the basis for the analyses reported in Campbell, Kennedy and McIlgorm (2002) and Campbell and Kennedy (2007).

Model Specification

The model of the SBT fishery incorporates 21 age classes, or cohorts. Each cohort, with the exception of the last one, contains all the fish of a given year class. The 21st cohort contains the relatively small number of fish that live to be aged 21 or older. The life history of each fish is described by following its growth in weight and its experience of natural and fishing mortality. A fish which survives to sexual maturity at 8 years of age joins the spawning stock biomass (SSB) which is the combined weight of all the mature fish. The size of the SSB in any given year determines the size of the recruitment to the population in the following year.

The natural and fishing mortality experienced by the stock vary with age class. The natural mortality rate declines over the first 11 years, reflecting the fact that younger fish are more vulnerable to predators, and remains constant thereafter. The fishing mortality rate depends on the type of gear used as well as on the age of the fish. While each gear type may catch the same range of age classes of fish, long-line gear takes a higher proportion of older fish compared with purse-seine gear. Since fishing grounds and practices vary from one fleet to another, the fishing mortality rate inflicted by the long-line or purse-seine fleet of one country may differ from that inflicted by another.

The fishing mortality rate of each gear type on each age class per standardized unit of fishing effort is termed a selectivity coefficient. The weight of catch of each age class by each fleet is determined by a harvest function which is given by the amount of fishing effort, measured in standardized units, multiplied by the selectivity coefficient, and multiplied by the biomass of that age class of fish raised to a power with a value in the range 0-1. Total weight of annual catch by a fleet is the sum of its catches across age classes.

The reason the harvest function incorporates the biomass raised to a power in the range 0-1 is to reflect the schooling nature of SBT. While, for all species of fish, the catch per unit effort (CPUE) tends to fall as the size of the stock falls, the decline in CPUE is less marked for schooling species because of the continuing availability of significant concentrations of fish to the fishing gear. The value of the exponent on biomass in the harvest function determines the extent of the fall in CPUE as stock declines. For example, in the Western and Central Pacific Ocean purse seine fishery Campbell, Kennedy and Reid (2010) report exponent values of 0.7 and 0.3 respectively for skipjack and yellowfin tuna catches, but retain the assumption of a unitary exponent for longline harvesting. As there is insufficient information to determine the appropriate value of the biomass coefficients in the SBT fisheries, they are set at unity in the model's base case, implying that a unit of effort catches the same proportion of stock irrespective of the stock level. The results of a sensitivity analysis reported in Campbell, Kennedy and McIlgorm (2002) indicate that when the coefficient on stock in the harvest equation is set at 0.6 instead of 1 the qualitative conclusions of the model do not change, and the results discussed here are for the base case only.

Each fleet's catch may attract a different market price per unit of weight because of differences in the size of fish marketed, or other perceived quality differences. The market price for the product of a given fleet depends on the quantity supplied by that fleet, as well as on the quantities supplied by the other fleets. The larger the quantity of fish supplied by a given fleet the lower the market price for that fleet's product, and the lower the market price for the product of other fleets. These relationships reflect the standard laws of demand for consumer products and their close substitutes. In the absence of information about the responsiveness of market prices to catch levels own-elasticities of demand of unity were assumed in the model (implying that a one percent rise in quantity sold of a product is associated with a one percent fall in price), and cross-elasticities of demand were set at zero (implying that the demand for a product is not affected by the price of competing products). Subsequently Sun and Squires (forthcoming) have quoted and used substantially higher values of the own-elasticities of demand for fresh and frozen tuna. However Campbell, Kennedy and McIlgorm (2002) found that the qualitative nature of the results was not significantly affected by incorporating alternative values of these elasticities in the model.

The gross value of the harvest of each fleet depends upon the demand and cost conditions. Gross value includes the value to consumers and producers. The net value of the harvest in a given year is the gross value less the fishing costs, which depend on the level of effort expended in catching the harvest for that year. The net value of the fishery in total is obtained by summing across fleets to give a total figure for the year. The annual figures for a series of years into the future can then be discounted to give a net present value which is a single summary measure of the net benefit generated by the fishery. This measure can be divided into the net benefits gained by each participating country: all consumer benefits accrue to Japan which is assumed to be the only market for SBT; the distribution of producer net benefits depends on the relative levels of effort they contribute to the fishery.

The level of effort contributed by the fleet of each participating country can be regarded as a *control variable* – a variable the chosen level of which determines the net benefit the participant receives from the fishery. The net benefit accruing to any participating country depends upon the levels of effort chosen by all countries. The bioeconomic model generates a single outcome corresponding to each possible set of values of the control variables. That single outcome includes unique values for the size and composition of the SBT stock, as well as unique values for the net benefits, or payoffs, accruing to the individual participating countries. The unique mapping of sets of values of the control variables into sets of values of the payoffs provided by the bioeconomic model is the basis of the game theory analysis described in Section 5. The present section concludes by describing the model specification and its up-date and Section 4 reviews the model findings relating to optimal exploitation.

Two versions of the model were constructed. The first model, described in Campbell, Kennedy and McIlgorm (2002) and referred to as *SBT v1* in the present paper, was based on the structure of the fishery in 2002. Six countries then participated in the SBT fishery but for the purpose of the analysis they were divided into three groups, each one of which could be treated as a player in a non-cooperative game. The three players were: Australia and New Zealand (ANZ), both major resource-owners, both harvesting SBT in their own EEZ, with the predominant share of catch being taken by purse seine gear and devoted to aquaculture, both members of the CCSBT, and neither a significant consumer of SBT; Japan, a major distant water fishing nation, a member of the CCSBT, and the major consumer of SBT; and Korea, Indonesia and Taiwan (KIT), countries which at the time were expanding their distant water fishing activities, are not significant consumers of SBT, and were not members of the CCSBT. It was argued that these three groupings captured the interests and characteristics of the stakeholders in the SBT fishery: as domestic or distant water fishing nations; as consumers and/or producers; and as members or non-members of the CCSBT.

The second model described in Campbell and Kennedy (2007), and referred to here as *SBT v2*, took account of changes in the structure of the fishery which occurred in the early 2000's: Korea and Taiwan joined the CCSBT as cooperating members and were allocated catch quotas. Indonesia remained outside the quota system and The Philippines and South Africa were now identified as harvesting nations. The eight countries participating in the SBT fishery were again divided into three groups for the purposes of the analysis: ANZ as described above; Japan, Korea and Taiwan (JKT) using longline gear; and Indonesia, The Philippines and South Africa (IPSA), countries which were expanding their distant water longline fishing activities, were not significant consumers of SBT, and at that time were not members of the CCSBT.

Experience of one or two years of reduced catches of small fish in the Japanese and Korean longline fleets in the early 2000's suggested poor recruitment to the stock which could possibly be explained by variability of year to year recruitment performance but raised questions about the values of the parameters in the stock recruitment function underlying *SBT v1*. Following up-dated stock assessments (Kolody et al. (2004)), the biological modeling in *SBT v2* was based on revised estimates of weight, maturity, numbers and mortality of fish by age, virgin spawning stock biomass, and selectivity coefficients in the SBT fishery as discussed in CCSBT (2004). The revised estimates are based on three different values of the steepness parameter, *h*, which is the slope of the stock recruitment function at low levels of SSB and reflects the intrinsic growth of the stock[i]. The different *h* values generate different estimates of the stock structure and of recruitment to the stock.

COOPERATIVE HARVESTING

Results of *SBT v1*

Before presenting the results of the optimal exploitation analysis the results of running *SBT v1* under the management regime prevailing in 2002 can be considered. The initial SSB in the model in year 1 is 43,631 tonnes (approximately the level in 2002), well below the conservation target of 144,000 tonnes. Under the 2002 regime Japan, Australia and New Zealand agreed to annual catch quotas, while other countries (Korea, Indonesia and Taiwan) operated outside the CCSBT. Since New Zealand’s catch is a very small proportion of the total catch (around 3% and less than 10% of Australia’s catch) Australia and New Zealand are treated as a single entity (ANZ) in the analysis. Japan uses longline gear to take its quota, while ANZ is assumed to use purse seine gear to catch younger age classes of fish to stock its tuna farms. Two possible assumptions about the behaviour of the other countries are that they set their fishing effort level so as to maximize profit, given the levels of effort supplied by Japan and ANZ, or that they make no attempt to regulate their effort, in which case it is assumed that their vessels will contribute effort up to the point at which their total revenue equals total cost (zero profit). Under the former assumption the NPV of the fishery over a 20-year time horizon is estimated to be $8 billion, and under the latter assumption, $7.6 billion (all values reported in the paper are in 1997 Australian dollars). SSB levels in 2020 under these two assumptions are predicted to be 136.4 and 74.4 thousand tonnes respectively.

These results demonstrate that a better outcome in terms of the efficiency and conservation goals can be achieved under the 2002 regime if non-member countries regulate their levels of fishing effort to maximize the returns to their producers. However a still better outcome can be achieved if all countries combine to contribute the level of effort which maximizes the combined total net present value of the fishery. Under this cooperative scenario the efficiency and conservation outcomes are a NPV of $8.2 billion and a SSB of 149.3 thousand tonnes. These results illustrate the extent to which all parties stand to lose if KIT were to stay outside a cooperative CCSBT framework, and non-cooperative strategies were adopted.

An important issue also addressed by *SBT v1* is that of the impact of tuna farming. It will be recalled from Section 2 that biologists (eg. Hampton (1989)) noted the differential impact on the parental biomass of harvesting juveniles, using purse seine gear, as compared with harvesting adults with longline gear. More recently, Sun and Squires have suggested that a 5000 mt reduction in the purse seine catch would reach the same biomass recovery target in 2022 as a 3100 mt reduction in the longline catch. In *SBT v1* the effect of tuna farming was investigated by supposing that, instead of harvesting juveniles with purse seine gear to stock tuna farms, ANZ operated under Japan's fishing practices, and all countries cooperated to maximize the NPV of the fishery. Under this scenario the NPV of the fishery falls slightly to $7.9 billion and the SSB rises slightly to 149.5 thousand tonnes in 2020 as compared with 149.3 thousand tonnes in the purse seining case. In comparison with the previous estimates, these figures suggest that tuna farming confers a small economic benefit without compromising the conservation objective. These results suggest that further analysis of purse seining for aquaculture would be of interest.

Results of *SBT v2*

Given the pessimistic nature of the revised stock recruitment functions referred to in Section 3, *SBT v2* was run first with no exploitation of the stock. The results suggested that, even with no fishing, the conservation objective could be achieved only under the most optimistic of the three assumptions about the stock recruitment function (*h*=0.8). Under this assumption, and with no fishing, the stock rises to just exceed the conservation target of 144,000 tonnes in year 20, and continues to rise slowly to reach a value of 161,000 tonnes in year 30. Under less favourable assumptions about the stock recruitment function the stock rises at first, based on the mean stock numbers estimated for 2003, but declines thereafter as the new recruits determined by the stock recruitment function begin to predominate in the population; for *h*=0.55 the stock is estimated to remain close to its current level, whereas for *h*=0.4 it declines significantly, and perhaps irretrievably.

The revised model was then run on the assumption that all parties, whether CCSBT members or not, observed the 2005-06 CCSBT quotas totaling 14,886 tonnes: the individual quotas were (in tonnes) Japan 6065, Australia 5265, New Zealand 420, Korea 1140, Taiwan 1140, Indonesia 800, The Philippines 50, and South Africa 45. This model failed to find a feasible solution for *h* values of 0.4 or 0.55 for a planning horizon of 30 years. The longest planning horizon for which a solution was obtained was 5 years for *h*= 0.4 and 9 years for *h*=0.55. These are the number of years over which, according to the model, the quotas can be maintained. A solution for the 30 year planning horizon was found for *h*=0.8 showing a year 30 stock level close to zero. In this case all producers start to make significant losses as catching costs rise due to the stock decline. This suggests that the fishery would become commercially non-viable and that fishing would cease before year 30. The net present value (NPV) of the fishery over a 20 year time horizon (the period before significant losses to producers start to set in) is around $4.5 billion.

As an alternative cooperative model to the CCSBT quota regime, the objective of maximizing joint returns to consumers and producers was considered. The results of this model represent the use-value maximizing regime for each assumption about the stock recruitment function, leaving aside the issue of conservation. The NPV over a 30 year time horizon varies from $1.91 billion for the most pessimistic assumption about the stock recruitment function to $5.52 billion for the most optimistic assumption. The latter estimate is around 60% of the equivalent value calculated in the Campbell, Kennedy and McIlgorm (2002) paper. Estimated stock levels are low and declining over the 20 year period for *h*=0.4 and *h*=0.55.

In the case of *h*=0.8, SSB increases slightly over its 2003 level over the 20 year target period in the use-value maximizing case. Subsequent to year 20, however, the SSB is predicted to decline to just less than 90% of the 2003 level by year 30. This decline, to 35.87 thousand tonnes, is attributable to the fishing down effect associated with the finite planning horizon model. An alternative model with an infinite time horizon solution can also be run in the *h*=0.8 case. This model estimates the stock in year 30 at 52.98 thousand tonnes, suggesting that, in the most optimistic case in which *h*=0.8, a stock of at least 53 thousand tonnes can be maintained indefinitely from year 30 onwards.

NON-COOPERATIVE HARVESTING

The Structure of the Game

For game theory to be effective as a policy analysis tool, the game should be kept as simple as possible. The number of players, and the number of strategies available to each player, should be limited to facilitate obtaining a solution to the outcome of the game, and also to limit to a reasonable number the player/strategy combinations that must be considered in policy assessment. As noted in Section 3 the number of players in both versions of the SBT model was restricted to three: a purse seining player (ANZ) and a longlining player (Japan or JKT) operating as members of the CCSBT, and a fringe non-member player (KIT or IPSA). It was argued that three players capture the interests and characteristics of the stakeholders in the SBT fishery: as domestic or distant water fishing nations; as consumers and/or producers; as members or non-members of the CCSBT, and as longliners or purse seiners.

In the framework of the game each of the three players chooses a strategy, and the interaction of the strategies chosen by the players determines the outcome of the game. In the case of the SBT fishery each player's strategy is its choice of the level of fishing effort to be devoted to the fishery. It would be possible to consider choices among additional dimensions of strategy, such as the type of fishing technique used (long-line, purse-seine, or pole-and-line gear), the range of fishing grounds exploited, and the location and segment of the market supplied. However, in order to keep the game as simple as possible, certain existing choices are built into the base case model: the choice of gear as described above; all countries fish in their current fishing grounds; and all players supply the Japanese SBT sashimi market.

Results of *SBT v1*

In *SBT v1* it is assumed that KIT remains outside the CCSBT and does not regulate its fishing effort to maximize its returns, with the result that its payoff is zero profit irrespective of the strategies adopted by ANZ and Japan. ANZ and Japan can choose to cooperate to maximize their joint returns, in which case the fishery NPV is $7.7 billion with a 2020 stock of 103.9 thousand tonnes, or to adopt the strategy of maximizing individual profit, which results in an NPV of $7.7 billion and a stock of 102.2 thousand tonnes. While there is very little difference between the aggregate results of these two models, the distribution of the benefits of cooperation, in the absence of side payments, is very much in favour of Japan's producers and consumers, with ANZ producer benefits actually falling by $0.1 billion, or 17%, in the cooperative case as compared with the non-cooperative outcome. The model suggests that stock levels are probably sustainable, but lower than the year 2020 objective.

Results of *SBT v2*

SBT v2 is first used to examine the situation in which ANZ and JKT observe the CCSBT quotas but IPSA chooses its effort level to maximize the NPV of the profits of its producers. This model fails to find a feasible solution for the two lower *h* values because recruitment is too low to maintain the quota catches for the full 30-year planning period. In the case in which *h*=0.8 the solution is slightly more favorable in NPV terms than in the case described in Section 4, in which all parties observe the CCSBT quotas, because the profit maximizing requirement does not allow IPSA to continue fishing once losses start to be made due to low stock levels. In this case NPV is $4.52 billion over a 20-year time-frame, and $4.25 billion over 30 years. However the solution is similar in conservation terms with the stock virtually extinct by year 30.

Another possibility is that while ANZ and JKT continue to observe the CCSBT quotas there is no control over the effort of IPSA producers who, instead of choosing their effort level to maximize their profits, contribute effort up to the point at which profit falls to zero. This would be the outcome if IPSA producers were not organized and acted as a competitive open-access fringe, as assumed for KIT in *SBT v1*. This situation is expected to lead to worse economic and stock outcomes than the previous situation in which IPSA controlled its effort level, and, in fact, no solution to the game was found for any of the three values of *h*.

The model can be used to predict the outcome of a non-cooperative game in which each of the three players chooses its effort level to maximize its net returns, given the stock conditions resulting from the behaviour of the other two players. The NPV results in the three-party Nash Equilibria generated by this non-cooperative game for each of the *h* values are very similar to, but slightly lower, over the model time horizon of 30 years, than the results of the joint net returns maximization case reported in Section 4. The closeness of the results of this model to those of the joint profit maximization model is partly due to the game having only three players. Similarly the predicted stock outcomes are close to, but slightly lower than, the stock equilibria generated by the joint net return maximization model.

Finally the revised model is used to predict the outcome of a non-cooperative game between ANZ and JKT, with IPSA acting as a fringe player allowing its vessels open-access to the SBT fishery. While a Nash Equilibrium to this non-cooperative game could not be obtained under the most pessimistic assumption about the stock recruitment function, solution values were obtained for the other two cases. In both these cases predicted NPVs are slightly lower than in both the joint net returns maximization case and the three-party non-cooperative game, reflecting the excessive level of effort contributed by IPSA compared to the other two sets of models, but the stock outcomes are similar.

Since concluding the modeling and analysis associated with *SBT v2*, however, the revelation of significant under reporting of the Japanese catch over the past 20 years has come to light. The under-reporting of Japanese catches by 20-25% has important implications for the accuracy of recent biological, and hence bioeconomic, modeling. Initial thoughts might be that the SBT stock is less vulnerable to commercial extinction than prognoses based on recent stock assessments (such as CCSBT 2004 and 2005) might suggest. However, it will take time to reassess the catch history and generate a new set of parameters for the SBT biological model, and no conclusions can presently be offered. This means that more than the usual uncertainty surrounds the projections of SSB over the next 20 years and the present values of net returns reported by *SBT v1* and *SBT v2*. Comparisons of SSB and present values of net benefits under different management regimes and different competitive behaviours are still of interest for indicating likely trends in outcomes, and the results reported in the paper should be viewed in this light.

CONCLUSIONS

The contrasting results of *SBT v1* and *SBT v2* offer an object lesson on the need to be cautious when using the results of bioeconomic models in managing the fishery. This conclusion is strengthened by the fact that a third SBT model, with a different set of results, could be generated on the basis of revised biological modeling taking account of the under-reported catches over the past 20 years.

On the basis of *SBT v1* it was concluded that: the exploitation regime under the CCSBT in the early 2000's was reasonably efficient from an economic viewpoint (close to optimum utilization), and probably posed no threat to the conservation of the stock. This conclusion was found to hold irrespective of whether ANZ and Japan acted cooperatively or to maximize their individual benefits. Other results were that Japan's consumers are significant beneficiaries of the SBT fishery and that equilibrium stock levels are lower when consumer benefits are included in the objective functions because lower prices to consumers are achieved by higher catch rates which lead to lower stocks. Australian farming of purse seine caught fish, as opposed to longlining and selling the catch directly on the Japanese market, was found to be an efficient use of the resource and did not pose any threat to the conservation of the SBT stock. While few runs of the model met the 144,000 tonnes SSB target for the year 2020, over two-thirds of the run results from the model had year 2020 stock levels in excess of 100,000 tonnes.

The results obtained from *SBT v2* are very different and raise serious concerns about the prospects for conserving the SBT stock. The no fishing case is obviously the regime most favorable to the conservation objective but even in that case the SSB20 objective is achieved only under the most optimistic of the three assumptions about the stock recruitment function. On less favorable assumptions about the stock recruitment function, a 20 year moratorium on fishing is predicted to result in the stock remaining roughly at its current level or to experience a significant decline.

Continuation of quotas totaling around 15,000 tonnes under the CCSBT regime, either with the full cooperation of all parties, or with IPSA remaining outside the quota system and either regulating or not regulating its fishing effort, is predicted to lead to virtual extinction of the stock within 30 years. Joint net returns maximization by the parties currently involved in the fishery would lead to stock levels 50% above current levels over the long-run, but only under the most optimistic assumption about the stock recruitment function. Where the three players engage in a non-cooperative game, or JKT and ANZ engage in a non-cooperative game with IPSA acting as a fringe player, stock levels are similar to the joint net returns maximization case.

Joint maximization of consumer and producer surplus, under the most favorable assumption about the stock recruitment function in *SBT v2*, is estimated to generate, over a 20 year period, a net present value around $3.6 billion, which is just under half of the value estimated from the stock recruitment function used in *SBT v1*. Under a more likely recruitment function (h=0.55) *SBT v2* generates an NPV estimate around 20% of the estimate in *SBT v1*. Similar relative net present value results are obtained from the non-cooperative game models involving all three players or ANZ and JKT plus a fringe operator. Under the CCSBT quota regime of the mid 2000's the level of NPV is similar to that in the joint net returns maximization case, with the difference that, even under the most favorable assumption about the stock recruitment function, the NPV is obtained by virtually liquidating the asset over the 30 year time horizon.

The joint returns NPV maximization model in *SBT v2*clearly suggests that there is a trade-off between the conservation and optimal utilization goals. The only regime which met the SSB20 stock level objective was a moratorium on fishing over a 20 year period, and that result was obtained for the most favorable stock recruitment function. Having said that, there are exploitation regimes which yield similar net present values but have quite different outcomes for the stock: the CCSBT regime, the joint net returns maximization model, and the non-cooperative game models all yield NPVs of around $3.5 billion over a 20 year time horizon under the most favorable assumption about the stock recruitment function, yet the SSB20 level, under either the full CCSBT regime (incorporating Indonesia, The Philippines and South Africa (IPSA) as members) or a CCSBT regime, with ANZ and JKT observing the quotas and IPSA maximizing its profit, is around only 50% of the stock level achieved under the other regimes, with further significant declines predicted to year 30. While no solution could be obtained for the model in which ANZ and JKT observe the CCSBT quotas but IPSA fails to regulate its fishing effort, it can be inferred from the solutions to the other models that IPSA's membership in the CCSBT regime is important to both the economic and conservation aims.

The above results suggested that, to further both the economic and conservation objectives, the combined CCSBT annual catch quota needed to be cut from its present level of around 15,000 tonnes to a level closer to the combined catch levels under the other more favourable regimes, which are all well below 10,000 tonnes per annum. This is consistent with the CCSBT recommendation that "the global SBT catch should be reduced to 9,930t for 2006, which corresponds to a 5,000 tonne reduction in the assumed global catch of 14,930t for 2004 and 2005" (CCSBT (2005), (excerpt from paragraph 37).

It must be emphasized that the models used to generate the results reported in the paper are deterministic. If the stochastic draws of initial stock numbers, mortality and selectivity coefficients for each of the three *h* values used by the CSIRO in modeling were incorporated in a stochastic version of the economic model, economically efficient effort levels would likely be even lower. For example, if the disturbance term on SSB were symmetric about the mean, the concave nature of the function relating recruitment the SSB would lead to expected values in a stochastic model indicating lower stocks, and hence requiring lower optimal levels of fishing effort.

As noted earlier, there are significant uncertainties about the accuracy of the catch data which need to be resolved and this may lead to further revisions. Nevertheless the estimates of the steepness parameter were the best available in the mid-2000's and have to be taken into account in evaluating the prospects for the fishery and the SBT stock. Based on the subjective probabilities reported in Footnote (i) it can be concluded that h=0.55 is currently the best guess for assessing the stock status and biological parameters. When this value is used in the bioeconomic model, and where solutions could be obtained, the size of the year twenty spawning stock biomass ranges from around 50% above the current level, in the no fishing case, to less than 50% of the current level in the other cases, and the value of the fishery is estimated at just under $2 billion which is around 25% of the estimate obtained from the earlier stock recruitment model.

References

Australian Fisheries (1989), “Southern Bluefin Tuna – A Fishery in Crisis?”, August: 12-16.

Australian Fisheries (1991), “Scientists Report SBT Parent Stock at Lowest Level”, January: 14-16.

Bertignac, M., H.F. Campbell, J. Hampton and A.J. Hand (2000), “Maximizing Resource Rent in the Western and Central Pacific Ocean Tuna Fisheries”, *Marine Resource Economics*, Vol. 15, No. 3, pp. 151-177.

Campbell, H.F., S.F. Herrick Jr. and D. Squires (2000), “The Role of Research in Fisheries Management: the Conservation of Dolphins in the Eastern Tropical Pacific and the Exploitation of Southern Bluefin Tuna in the Southern Ocean”, *Ocean Development and International Law* Vol. 31, pp. 347-375.

Campbell, H., J. Kennedy and A. McIlgorm (2002),"Conservation and Optimum Utilization of Southern Bluefin Tuna", *Fisheries in the Global Economy*, Eleventh Biennial IIFET Conference, Wellington, August 19-22, 2002. CD ROM. (http://oregonstate.edu/Dept/IIFET)

Campbell, H. and J. Kennedy (2007), “Alternative Futures for Southern Bluefin Tuna”, *International Journal of Global Environmental Issues* 7(2/3): 240-254.

Campbell, H., J. Kennedy and C. Reid (2010), "Bioeconomic Modeling and Management of the Western and Central Pacific Ocean Tuna Stocks", in *Global Tuna Demand, Fisheries Dynamics and Fisheries Management in the Eastern Pacific Ocean*, Inter- American Tropical Tuna Commission and National Marine Fisheries Service Workshop, La Jolla, May 13-14, pp. 62.

Commission for the Conservation of Southern Bluefin Tuna (CCSBT) http://www.ccsbt.org

Hampton, J., J. Majkowski and G. Murphy (1984), "The 1982 Assessment of the Southern Bluefin Tuna (*Thunnus Maccoyii*) Population and the Determination of Catch Levels which Stabilize the Parental Biomass" *CSIRO Marine Laboratories* Report No. 165, Hobart, Tasmania

Hampton, J. (1989), Population Dynamics, Stock Assessment and Fishery Management of the Southern Bluefin Tuna (*Thunnus Maccoyii*) , Unpublished PhD Thesis, *University of New South Wales*, Australia

Kennedy, J. and J. Watkins (1985), "The Impact of Quotas on the Southern Bluefin Tuna Fishery", *Australian Journal of Agricultural Economics* 29 (1):63-83

Kennedy, J. (1987), "A Computable Game-Theoretic Approach to Modelling Competitive Fishing", *Marine Resource Economics* 4: 1-14.

Kennedy, J. and H. Pasternak (1991), "Optimal Australian and Japanese Harvesting of Southern Bluefin Tuna", *Natural Resource Modeling* 5(2): 213-238.

Kennedy, J. (1999), "A Dynamic Model of Cooperative and Non-Cooperative Harvesting of Southern Bluefin Tuna with an Open Access Fringe", paper presented at the *World Conference on Natural Resource Modeling*, Saint Mary's University, Halifax, Canada, 23-25 June.

Murphy, G. and J. Majkowski 1981, "State of the Southern Bluefin Tuna Population – Fully Exploited", *Australian Fisheries* November: 20-29.

Shingu, C. (1981), "Ecology and Stock of Southern Bluefin Tuna", *CSIRO Division of Fisheries and Oceanography* Report 131 (translated from Japanese), Hobart, Tasmania.

Sun C-H. J. and D. Squires (forthcoming) "Alternative Management Procedures for the Conservation of Southern Bluefin Tuna", pp. 25

Taipei Times (2006), http://www.taipeitimes.com/News/world/archives/2006/03/03/2003295497

---

[i] The Beverton-Holt stock recruitment function is: $R = \alpha X / (\beta + X)$ where R is recruitment numbers and X is SSB in tonnes. The values of the parameters α and β depend on the value chosen for the steepness parameter, h, according to $\beta = SSB_{unfished}(h-1)/(1-5h)$ and $\alpha = R^*(\beta + SSB_{unfished})/SSB_{unfished}$, where R* is recruitment numbers given for the start of model year 1. Three values of h are considered: 0.4, 0.55 and 0.8, with subjective probabilities (assigned by scientists from the CCSBT Scientific Committee) of 0.2, 0.6, and 0.2 respectively.