Future Generations, Discount Rates and the Optimal Harvest of Fisheries Resources

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Abstract. The role of discounting in determining the optimal harvest of natural resources has been extensively debated in the economic and natural resources literature. Differing approaches to discounting to address sustainability and intergenerational equity issues have the potential to significantly affect the allocation of resources between harvesting and conservation for this generation and the stock of resources available for future generations. This presents a very real problem in New Zealand where legislation requires fisheries managers to maintain the potential of the resources to meet the "reasonably foreseeable needs of future generations." This paper investigates the appropriate use of discount rates in evaluating policy decisions that involve the intergenerational allocation of fisheries resources. Dynamic bioeconomic optimisation is used to model the effect of discount rates on the optimal harvest of a stock characterized by moderate longevity and growth. The economic and biological effects of alternative rebuilding strategies that are assumed to meet the needs of future generations are explored under alternative prices, variable costs, and rebuilding horizons. The preliminary empirical analysis revealed that higher discount rates produce lower net present values, slower rebuilding rates, and more pronounced harvest reductions as the rebuilding deadline approached. However, at discount rates that are common and justified in the literature, the effects may be insignificant. Whether these results are dependent on the assumed moderate growth characteristic of the stock, the failure to account for perceptions regarding biological and economic risk, or the use of a common discount rate are subjects of continuing research.

Keywords: Discount rates, future generations, bioeconomic modelling, New Zealand Fisheries Act

1. INTRODUCTION

Imagine developing a fisheries agreement between generations, for example between a grandparent and a grandchild. The grandchild understands the need for the grandfather to harvest fish today in order to feed the family, generate income, and/or continue traditional customs. In turn the grandfather promises to leave enough fish to provide (through growth and regeneration) for the grandchild to use in the future.

Just such an agreement is mandated by New Zealand's fisheries legislation where managers are required to maintain the potential of fisheries resources to meet "the reasonably foreseeable needs of future generations." The choice of policies to address this key sustainability and intergenerational equity issue has the potential to profoundly affect the allocation of resources between harvesting and conservation for this generation and the stock of resources available for future generations.

Commensurate with its importance in domestic and international environmental legislation, sustainability is a central theme of New Zealand's fisheries legislation. The New Zealand Fisheries Act passed in 1996 provides for the utilisation of fishery resources while ensuring sustainability. In the Act, utilising fisheries resources is described as conserving, using, enhancing, and developing fisheries resources to enable people to provide for their social, economic, and cultural wellbeing. Ensuring sustainability is defined as (1) maintaining the potential of fisheries resources to meet the reasonably foreseeable needs of future generations, and (2) avoiding, remedying, or mitigating any adverse effect of fishing on the aquatic environment.

The key issue in intergenerational allocation agreements is likely to be the rate at which society is willing to trade off present consumption for future potential abundance. In monetary values, this rate is known as the discount rate. Discounting is simply taking a future value and determining what it is worth today. The discount rate is commonly described as the rate that equates money values over time. For example, if a dollar today is worth more next year due to the potential for that dollar to earn (at least) the market rate of interest, the potential investment of the dollar is being discounted at a positive rate. Using this approach, it is possible to compare projects or investments (such as leaving fish in the ocean for future generations) with different time horizons. In evaluating the economic effects of managing fisheries resources, the discount rate can affect how fast fish stocks should be fished down, how fast they should be rebuilt, or what level they should be maintained. If, however, discounting is unfair to future generations in that values are being compared in terms of the current generation – as has been suggested – the use of a positive discount rate is potentially in conflict with the principle of sustainability in general and New Zealand's fisheries legislation in particular.

The organization of this paper is as follows. First, key issues that surround the role and selection of discount rates in determining the efficient and equitable allocation of fisheries resources are addressed. Second, a single-species bioeconomic model of a stock characterized by moderate growth and longevity is developed to evaluate alternative rebuilding strategies and the corresponding trade-offs (economic and biological) associated with each decision. Lastly, the results from the empirical example are used to draw tentative conclusions regarding the relative impact of the biological and economic assumptions (including the discount rate) on the optimal resource allocation. This model is intended to demonstrate the utility of dynamic bioeconomic models for fisheries management decisions that require consideration of the needs of future generations.

2. DISCOUNTING

Determining and providing for the reasonably foreseeable needs of future generations is not straightforward. This is because the needs and aspirations of future generations depend on the preferences, technologies, and environmental conditions in the future, which are unknown today. According to Solow (1974),

> *the intergenerational distribution of income or welfare depends on the provision each generation makes for it's successors. The choice of social discount rate is, in effect, a policy decision about that intergenerational distribution.*

Although this is a commonly-held and utilized view, there are actually two competing philosophical views in the economic and legal literature on how to consider future generations in resource allocation decisions.

The first approach holds that the price system, especially the rate of return available in financial markets, reflects the scarcity of natural resources, future expectations, and societal tradeoffs between future consumption and current consumption. The predominant consensus in the literature is that positive rates (such as the market rate) of discount are appropriate since they appear to be consistent with sustainability when applied to public decision-making (e.g., Norgaard and Howarth 1991). There is less agreement, however, on the appropriate rate. For example, Hueting (1991, p. 43) writes that "using the market [rate of] interest as the discount rate for calculating the present value of long term costs and benefits means that the preferences for sustainable use of the environment amount to zero..." This view assumes that the optimisation problem is made once and never revisited. In fact, in the case of most renewable resources, this issue gets revisited every few years. Consequently, the preferences for sustainable use are not zero. In other words, since environmental concerns are addressed directly, there is no justification for using the discount rate as a proxy for these specific intergenerational preferences.

Irrespective of what the discount rate represents (e.g., whether it is adjusted for environmental concerns), positive discount rates imply that the future impacts of today's decisions do not receive explicit equal weighting in the decision-making process. Thus, the use of positive discount rates may be problematic where the interests of future generations are an explicit consideration. First, resource allocations with costs that occur well into the future and benefits that occur in the short-term are favoured such that future generations may be denied resource allocations that may otherwise benefit them. Consequently, it has been argued that it is unethical for the current generation to discount resource allocations that may make future generations worse off (Morrison 1998). Second, the higher the discount rate, the lower the overall rate of investment and hence the lower the capital stock inherited by future generations (Pearce et al. 1989). Third, uncertainty exacerbates the effect of discounting on intergenerational fairness since an expected outcome is valued less than an uncertain outcome (Clark 1991; Farber and Hemmersbaugh 1993; Portney and Weyant 1999). This is because uncertainty is expected to increase with time, hence, shifting the burden of risk from the present generation to future generations.

A common policy response to these arguments is to lower the rate of discount to assist the intergenerational distribution of resources (Cline 1992; Portney and Weyant 1999; Thaler 1981). However, the use of low discount rates (i.e., rates below the return on investment) is widely challenged in the literature. In particular, Norgaard and Howarth (1991, p. 94) state that:

> *trying to help future generations through policies to lower discount rates is analogous to trying to help*

> *the poor through low food price policies when the poor are also farmers.*

According to Norgaard (1992), ongoing debates as to whether intergenerational equity can be addressed through ad-hoc manipulations of the discount rate are rooted in an inappropriate theoretical framing of the choices. Consequently, transferring wealth to future generations – for example, through youth education, environmental protection, and developing technologies for sustainable management of renewable resources – is recommended as an alternative to engaging in inefficient investments.

The second approach is based on ethical principles relating to the way that the well-being of future generations ought to be weighed, such as the principles of justice developed by Rawls (Portney and Weyant 1999). According to Rawls, there is justice between generations when the worst off generation is as well off as possible. Today's generation is unfair to future generations if future generations would be willing to trade places with today's generation, but this generation would not be willing to trade places with future generations. Under this principle it is not necessary to know the needs and aspirations of future generations, only for this generation to be able to make an explicit ethical decision whether it would trade places with a future generation.

While conventional approaches to discounting (i.e., the first approach) may not provide a complete basis for decision-making, we should recognise that such approaches provide information on the trade-offs that must be confronted (Portney and Weyant 1999). This information can allow the present generation to ask, when assessing the intergenerational consequences of a resource allocation decision, whether it believes the future generation would be willing to trade places (i.e., the second approach). Since the first approach provides specific information on explicit trade-offs and the second can use this information to further evaluate a proposed action, we focus the remainder of our discussion on issues related to conventional discounting. This approach seems the most appropriate given that discounting is a well-established and accepted practice and that renewable resource allocation decisions are dynamic, which allow for the explicit and continuous incorporation of environmental concerns.

If it is accepted that positive discounting, whether at or below the market return on investment, is the appropriate first step in dynamic resource allocation decisions, how is this rate selected? Theoretical discussions concerning the selection of the appropriate discount rate reflect two basic approaches: (1) the social rate of time preference (SRTP) or (2) the opportunity cost of capital (OCC).

The SRTP reflects the rate at which society values future versus current consumption; it assumes that each individual has the same rate of time preference. If the SRTP is r per year, then a sacrifice of one unit of consumption today would require $1 + r$ units of consumption in one year.

The SRTP is defined as a sum of two factors: 1) the discount rate associated with the utility of future generations (i.e., the pure rate of time preference) and 2) the degree to which we need to discount an additional unit of consumption to account for decreasing marginal utility (Arrow et al. 1996). The first term represents the degree of impatience we have for consumption now as opposed to later or alternatively the degree of closeness we feel toward future generations. The second term is composed of two variables, the per capita consumption growth rate and the elasticity of marginal utility. Many economists set the pure rate of time preference equal to zero to indicate equal utility between generations (Cline 1992). Thus, even if equal intergenerational utility is assumed, the SRTP discount rate still consists of two components that are likely to be positive.

If the SRTP approach to selecting the discount rate is employed, the following implications should be noted (Arrow et al. 1996). First, the discount rate should be derived from ethical considerations that reflect society's views concerning trade-offs of consumption across generations. Second, the SRTP will, in general, be below the producer interest rate. Third, project costs must include the foregone investments that would have been made in absence of this project investment (i.e., costs should be adjusted by the shadow price of capital).

The OCC approach relies on three propositions. First, since many projects displace other forms of investment, decision makers should choose the action that leads to the greatest total consumption over time. Second, all generations are better off when investments with the greatest return are chosen. In doing so, transfers to future generations should be dealt with separately. Third, the appropriate social welfare function is revealed by society's actual choices inferred from the current rates of return and growth rates.

Those advocating the OCC approach have debated whether to use the private rate of transformation between investment today and investment in the future (i.e., the producer interest rate) or the producer rate after taxes (i.e., the consumer interest rate), or something in between. This choice largely depends on the amount of distortion that results from the tax system and, thus, is dependent on the particular characteristics of any given industry.

Based on the previous discussion, it is not surprising that empirical analysis concerning the management of fisheries resources often involves the use of a discount rate (especially studies attempting to predict the best long-run harvest plan). Consequently, there is a vast literature of examples that can serve as a basis in determining the appropriate selection and use of discount rates for any particular fishery. In a recent summary of empirical fisheries studies published in *Marine Resource Economics*, discount rates used to determine appropriate harvest plans (either sustainable or to rebuild) ranged from 0% to 25% (Harte et al. 2000). With regards to fisheries in New Zealand in particular, a recent report to the Treaty Tribes Coalition evaluated quota allocation alternatives using both 5% and 10% rates (Strong and Clark 2000). "Implicit" discount rates (i.e., rates consistent with observed economic behaviour in the fishery) have also been calculated specifically for several commercially fished species in New Zealand (Akroyd et al. 1999). These rates were calculated as the ratio of a one-year quota lease price to the market price of the underlying harvest right. Over time, these implicit rates have declined toward the market interest rate and currently range from approximately 5% to 20%. Implicit discount rates are expected to be relatively high in the initial years under a new management regime, such as occurred in New Zealand, due to the uncertainty associated with the market effects of transitioning from open-access levels of capital investment to those associated with rights-based management regimes. Uncertainty can also result from the fugitive nature of the resource and the limits of science in assessing stock abundance. In addition, economic factors such as poor institutions (e.g., insufficiently defined rights), lack of support from financial institutions, and variable market conditions all add to the uncertainty. Thus, the discount rate selected for empirical fisheries analysis or calculated via historical market information will reflect some of these uncertainties. As conditions in the fishery become more stable and predictable, discount rates are expected to decrease as was observed by Akroyd et al. (1999).

In summary, the debate over the use and selection of the appropriate discount rate in studies involving the management of publicly owned resources is overwhelmingly extensive and exhaustive. It is not, therefore, an issue that can be easily solved or even summarized to complete agreement in a single study. In fisheries, the inherent uncertainty in estimating stock abundance and continual change in management regimes and/or operational goals has resulted in the use and calculation of discount rates that are above the market rate of interest (which is the rate commonly used in other public investment studies). However, as stability and predictability improve, these rates have converged toward the market rate. This observation is important in that it suggests fishermen are rational in their decision making since they are considering long-run effects. It also suggests that their behaviour is a result of, in part, the institutional structure of management. As an extreme example, open-access management systems are consistent with an infinite discount rate. This does not indicate that individuals will over-exploit the resource because they have an infinite discount rate. Instead, the lack of institutional constraints on an apparently abundant public resource causes individuals to behave as if they had a very high discount rate (Grafton et al. 2000). Consequently, there is a profound difference between these explanations for the cause of the over-exploited resource in terms of the responsibility of resource managers. As a first step it may be helpful to ask why a particularly high discount rate may be observed in practice. Is it the institutional setting, biological uncertainty, or variability in market price and/or harvesting costs? The answer to these questions can help to determine research efforts and, ultimately, effective management plans.

In the remainder of this paper we use an empirical example to shed light on the issues and approaches that can be used to help managers make better-informed decisions. The empirical model assumes an institutional structure exists to set annual harvest quotas. In particular, the model will be used to answer the following question: Under what biological and economic conditions does the choice of a particular discount rate affect the present value of the fishery, the annual harvest quota, and the underlying spawning biomass? The answer(s) are expected to provide valuable information regarding the trade-offs and sensitivity (or lack of sensitivity) of the management plan to particular discount rates.

3. BIOECONOMIC MODEL

Bioeconomics is a modelling approach that is used to determine the optimal or efficient use of resources (be it through harvest quotas, allocations, conservation, and/or recreation) by taking into account biological and economic considerations. For an overfished stock, a dynamic bioeconomic analysis can reveal the rate at which rebuilding would need to occur to reach legal mandates (e.g., B_{MSY}) and the economic and biological tradeoffs associated with different rebuilding rates. Using this approach, discounting plays a major role in determining the optimal level of harvest and hence the optimal stock size and sustainable yields.

In this study, a dynamic bioeconomic optimisation model has been designed to evaluate the impacts of different discount rates under alternative assumptions about the economic components of the fishery. Although the stylised model is abstracted from the complex reality of actual fisheries, it has been designed to incorporate many of the essential features of the management problem. The model has been structured to serve as an example for developing fisheries-specific models consistent with meeting the mandates of the 1996 New Zealand Fisheries Act. For example, biomass constraints that are consistent with B_{MSY} harvest levels can be included to provide for the "reasonably foreseeable needs of future generations."

The model is defined over years (denoted by t) since long-term implications of differing discount rates are of primary concern. Lowercase and uppercase letters represent exogenous parameters and endogenous variables, respectively. All equations are solved simultaneously using the General Algebraic Modeling System. The time path of harvest is chosen to maximize the net present value of the fishery subject to the biological dynamics of the stock, economic conditions, and rebuilding requirements. Sensitivity analysis is conducted on the price and cost functions, discount rate, and rebuilding horizon.

The biological component of the model is based on conventional population dynamics of a species characterized with moderate growth and longevity. The stock is assumed to consist of multiple cohorts that are distinguished by age in years (a). The size of the population is assumed exogenous in the first year (i.e., $N_{t=1,a}$ known). This initial stock size was constructed assuming an initial recruitment level ($N_{t=1,a=1}$=1 million fish), instantaneous natural mortality rate (M=0.20), and average life span (a=20 years) using the following:

(1) $N_{t,a+1} = N_{t,a} \cdot \exp^{-M}$

An accumulator age equation was used to estimate the initial size of the oldest cohort using the average life span. Accumulator cohorts are included to account for fish that would otherwise move out of the equation. The resulting initial stock size (i.e., $N_{t=1,a}$) is depicted in Figure 1.

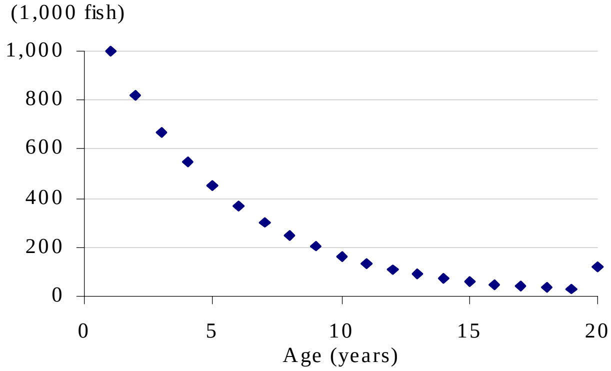

Figure 1. Initial (Pristine) Stock Size

Growth of the individual fish is assumed to follow the von Bertalanffy growth function for length at age (L_a):

(2) $L_a = L_\infty \cdot (1 - \exp(-Y \cdot (a - a_o)))$

where L_a is measured in centimeters, L_∞ is the maximum length (L_∞=90 cm), Y is the Brody growth coefficient (Y=0.24), and a_o is the intercept when L_t=0 (a_o=-1.10). Weight is a function of length and, therefore, varies with age:

(3) $W_a = \gamma \cdot L_a{}^{\phi}$

Weight is measured in grams and uses the following parameters: γ=0.005 and ϕ=2.90.

Using the initial stock size and growth equations, the initial biomass can be calculated:

(4) $B_{t=1,a} = N_{t=1,a} \cdot W_a$

The biomass is the total weight of all fish in the stock, including the recruits. This measure is contrasted with the spawning biomass (SB) that only contains mature cohorts. For simplicity, cohorts are considered fully mature at age 2 and thus there is little difference between $\Sigma_a B_{t,a}$ and SB_t in this analysis. Given the assumed parameters, the pristine (i.e., unfished) spawning biomass is 4.5 million fish or 5,239 metric tons (mt).

Recruitment is defined as the number of fish of the youngest harvestable age, which is assumed to be a=1, added to the stock in each year ($N_{t,a=1}$=R_t). The common Beverton-Holt specification is assumed such that recruitment is a function of spawning biomass (SB):

(5) $R_t = \alpha \cdot SB_t / (1+SB_t/\beta)$

where α was assumed to be 2.2 and, using a sustainable recruitment level of one million fish, β was found to equal 505.4 (assuming the stock size is measured in thousands).

To move the stock into subsequent years the model must advance the age of each cohort:

(6) $N_{t+1,a+1} = N_{t,a} \cdot e^{-Z_{t,a}}$

The stock size in year t+1 is determined by the stock size in year t and the total instantaneous mortality rate in year t (Z_t). The total instantaneous mortality rate is attributed to natural causes and fishing mortality, M and F, respectively:

(7) $Z_{t,a} = M_{t,a} + F_{t,a}$

For simplicity, knife-edge selectivity is assumed such that all cohorts are assumed to be fully vulnerable to the fishing gear. Thus, the number of fish harvested, H:

(8) $H_{t,a} = \left(\frac{F_{t,a}}{Z_{t,a}}\right) \cdot N_{t,a} \cdot \left(1 - e^{-Z_{t,a}}\right)$

is determined by multiplying the proportion of mortality from fishing by the total number of fish that died during the period.

The total annual harvest in weight, referred to as the total allowable catch (TAC), is determined by multiplying the catch in numbers by the weight-at-age,

(9) $TAC_t = \sum_a \left(H_{t,a} \cdot W_a\right)$

The net present value generated by this industry (NPV) is calculated as the sum of annual net benefits – gross revenues less variable and fixed costs – discounted at δ, society's real (i.e., inflation adjusted) annual discount rate:

(10) $NPV = \sum_t \left(\frac{1}{1+\delta}\right)^t \cdot \left[TAC_t \cdot \left(p - VC_t(SB_t)\right) - fc_t\right]$

where p represents the round weight price (p=$6,600 per mt), VC is the endogenous variable cost, and fc is the annual fixed cost (fc=$1,500). Variable costs are assumed to be a linear function of spawning biomass in weight,

(11) $VC_t(SB_t) = \psi - \eta \cdot SB_t$

Letting ψ=$7,200 and η=$1.5 implies that costs increase at lower stock levels and, thus, captures the additional costs fishers must incur to search for fish.

4. RESULTS

The time horizon selected was based on the biological characteristics of the stock. In particular, since the stock is represented by 20 cohorts, a 40-year time horizon was considered adequate to model the initial pristine dynamics, the unconstrained fishery where the stock is allowed to be depleted, and rebuilding. The sensitivity analysis regarding discount rates uses rates between 0% and 24% in 4% increments. These rates cover the range of rates used in several fisheries studies that have appeared in refereed journals (Harte et al. 2000).

In this base model, there are no restrictions on stock size. Consequently, with a 24% discount rate (the rate that will produce the largest stock decline) the average spawning biomass is approximately 32% of the pristine level. The spawning biomass for this scenario is depicted in Figure 2:

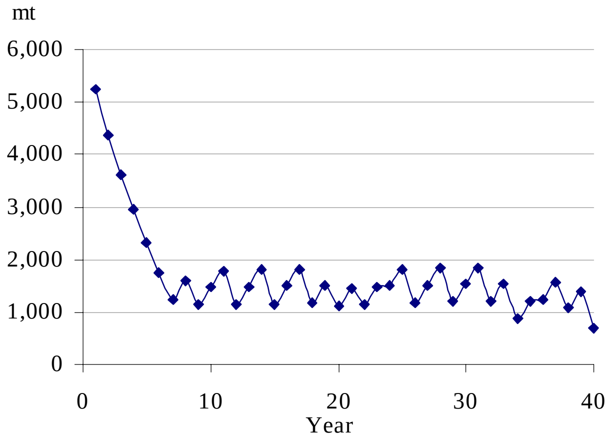

Figure 2. Spawning Biomass when δ=24%

In year 8 the spawning biomass begins to fluctuate in approximately 3-year cycles between 1,000 and 2,000 mt. When the model nears the end of the modelling horizon, NPV is maximized by reducing the spawning biomass even further. The pristine spawning biomass in this base model is 5,239 mt. However, the spawning biomass that achieves MSY is only 1,912 mt (36% of the pristine level). According to the Fisheries Act, this stock would be considered overfished beginning in year 6.

From a policy perspective, the primary issue concerns the stock size. Given a fishery that exhibits the characteristics of the base model, fisheries managers must decide (for example) how to set future quota levels (i.e., *TAC*'s) that will allow the spawning biomass to return to an acceptable level (e.g., 50% of the pristine spawning biomass). Implicit in this decision is the amount of time allowed for rebuilding. Before addressing this issue, it is important to determine the sensitivity of the model to biomass constraints. This is because in order to be useful the model needs to behave in a manner consistent with the magnitude of the imposed rebuilding constraints.

When the model is re-optimised with an annual constraint on the spawning biomass (i.e., that it exceed 50% of the pristine spawning biomass or 2,620 mt), *NPV* reductions increase from 3.8% when the discount rate equals 4% up to nearly 7% at a 24% discount rate. In other words, if the spawning biomass must exceed 2,620 mt in each year (versus the 1,000 to 2,000 observed in years 6 through 40 in Figure 2), *NPV* would fall only 7%. Note that if the spawning biomass requirement were lowered to the level that would produce MSY (i.e., 1,912 mt), the *NPV*-effect was lessened. That is, the model was robust to the level of the *SB* requirement.

The relatively small responsiveness of *NPV* to rebuilding mandates, which may have been expected given the stable *SB* pattern shown in Figure 2, is the result of two primary factors: (1) the moderate growth characteristic of the stock and (2) the stock-dependent variable cost function. The endogenous cost specification of equation 11 provided economic incentives for a larger stock, hence, requiring a higher spawning biomass (*SB*) actually lowered variable costs and increased the *NPV*. This assumed cost-biomass relationship is commonly used to represent schooling species. It should be evident that such a specification implies a market-induced conservation effect. For this analysis, however, we are interested in a model that will continue to drive the stock down over time (i.e., result in a severely over-fished stock). Since it is easier to change the economic assumptions, we proceed by changing the price function. Specifically, price is assumed to be inversely related to the level of harvest:

$$(12)\ P_t(TAC_t) = \theta - \tau \cdot TAC_t$$

where θ=\$11,200 and τ=\$9.2 and the variable cost is assumed to be a constant parameter (i.e., $VC_t(SB_t)$ in equation 11 is replaced by *vc*=\$2,000/mt). With these changes, higher TAC's will depress the output price. As with the endogenous cost specification, reasonable market assumptions tend to support lower harvests. In this case, the benefit to reducing the harvest level is a higher price. Thus, the actual effects predicted by the model should be considered conservative.

Using these new economic parameters, the trends in *NPV* and relative size of the terminal spawning biomass are shown in Figure 3.

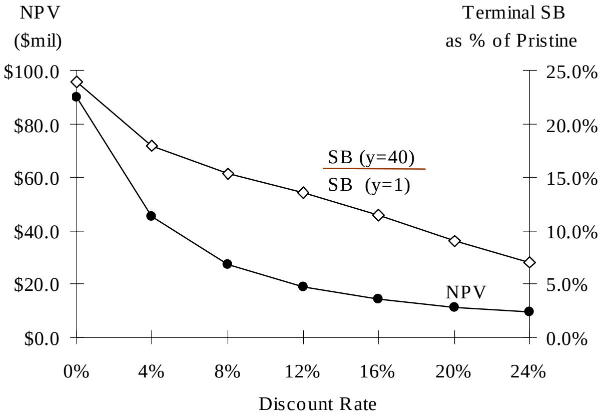

Figure 3. Effects of Alternative Discount Rates

At higher discount rates the *NPV* falls since future earnings are worth less in today's dollars. At the same time, the terminal size of the spawning biomass relative to the pristine biomass in year 1 falls. This is because future stock size is also worth less at higher discount rates. In terms of the stock, however, the spawning biomass declined in each year (Figure 4).

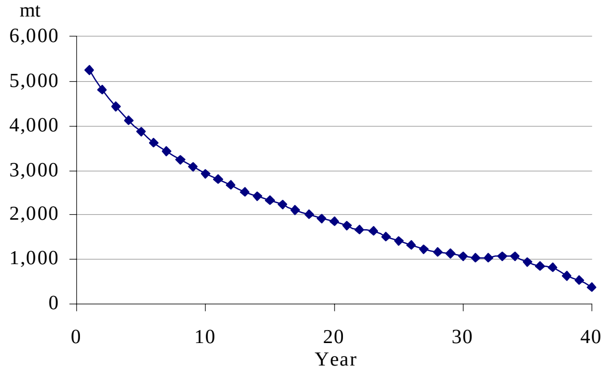

Figure 4. Spawning Biomass when δ=24% with Alternate Economic Parameters.

With the revised economic parameters, the spawning biomass declines to 362 mt (7% of the pristine level) in year 40. Due to the similarity of the observed trend with many current fisheries and the lower ending stock level, this model is used in the remainder of the analysis.

To examine alternative rebuilding scenarios, the ending stock size from Figure 4 (i.e., 362 mt) is used to begin a new 40-year time horizon. The advantage of this approach is that it better mimics the actual situation faced by many fisheries, that is, the rebuilding decision.

Requiring the stock to rebuild to the spawning biomass that would produce MSY (i.e., 1,912 mt) within 10 years would produce a *NPV* of $5.6 million with a 24% discount rate. Delaying the rebuilding requirement to 20 or 30 years would increase *NPV* by 17.7% or 19.4%, respectively. Table 1 summarizes the *NPV* effect from requiring rebuilding within 10, 20, and 30 years at alternative discount rates. Without discounting (i.e., δ=0%), delaying the rebuilding in 10-year increments has a negligible effect on *NPV*.

Table 1. *NPV* under Alternative Rebuilding Horizons

Discount Rate (δ)	Rebuilding Horizon 10 years	20 years	30 years
0%	$80.5 (mil)	+1.3%	+1.6%
4%	36.6	3.5	3.9
8%	20.0	7.0	9.1
12%	12.8	9.0	11.3
16%	9.1	12.8	15.0
20%	6.9	15.7	17.7
24%	5.6	17.7	19.4

The *NPV* sensitivity analysis summarized in Table 1 required the spawning biomass to be at least 1,912 mt by year 10, 20, or 30. From a biological viewpoint, an important issue is the path the stock takes to reach that level. To compare stock effects and recovery plans, we graph the annual *SB* and *TAC* under 10 and 30 year rebuilding mandates and 4% and 24% discount rates. Figure 5 shows the trend in stock recovery and the corresponding *TAC* requirements to rebuild in 10 years under a 4% discount rate.

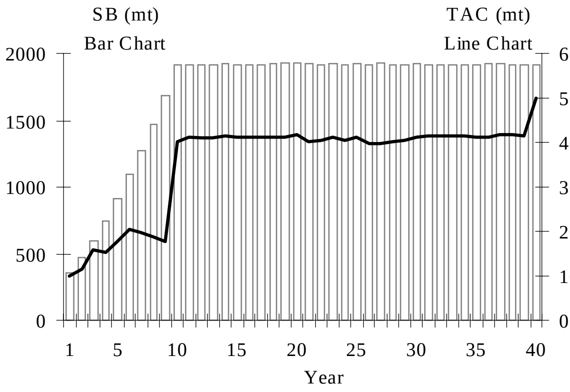

Figure 5. Spawning Biomass and *TAC*s under a 10-year Rebuilding Mandate and 4% Discount Rate

The *SB* increases steadily to the required minimum level, which indicates that this 20-cohort species is able to rebuild within 10-years. Just before the 10-year rebuilding deadline approaches, annual *TAC*s drop slightly to ensure the requirement is met. Following the 10-year rebuild, annual *TAC*s remain steady at approximately 400 mt and *NPV* would equal $36.6 million. Note that harvest increases in the final year since there is no *SB* level to maintain in the following year. If the rebuilding mandate is extended to 30-years, the effects are shown in Figure 6:

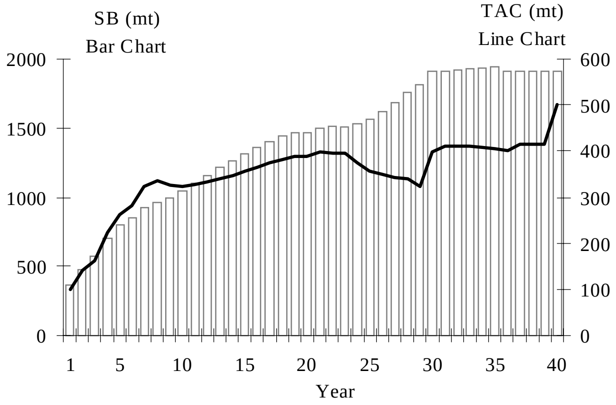

Figure 6. Spawning Biomass and *TAC*s under a 30-year Rebuilding Mandate and 4% Discount Rate

Although we know that the stock is capable of rebuilding in 10-years, a 30-year mandate allows recovery to occur gradually over time. In response, the *TAC*s increase over the first 8-years then stabilize briefly before falling just prior to the 30-year deadline. Again, *TAC*s stabilize at approximately 400 mt following the rebuild. Under the delayed rebuilding schedule, *NPV* increases just 3.9%. Next we examine the 10-year rebuild at the 24% rate:

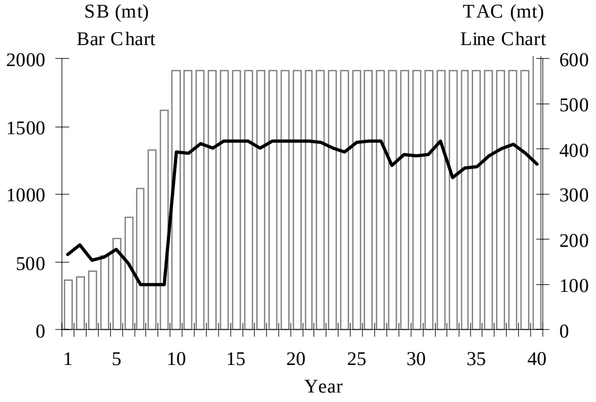

Figure 7. Spawning Biomass and *TAC*s under a 10-year Rebuilding Mandate and 24% Discount Rate

Figure 7 again shows that the stock is capable of rebuilding in 10-years, even at a very high discount rate.

As shown in Table 1, the *NPV* of this scenario is $5.6 million. A comparison of Figures 5 and 7 reveals that the higher discount rate produces more severe *TAC* reductions in the years immediately preceding the deadline. This effect is exacerbated when the rebuilding deadline is delayed as shown in Figure 8:

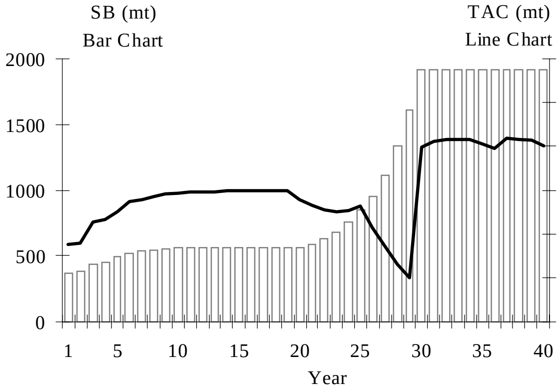

Figure 8. Spawning Biomass and *TAC*s under a 30-year Rebuilding Mandate and 24% Discount Rate

The annual *TAC*s stabilize at approximately 300 mt in years 10 through 20, but fall to just 100 mt in year 29 returning to the 400 mt harvest level in years 30 through 40. Again, the stock rebuild is delayed as long as possible. This scenario increases NPV by 19.4% compared to the management plan depicted in Figure 7 (Table 1).

In summary, annual harvest quotas fall rapidly in the years immediately preceding a rebuilding deadline (i.e., specified minimum *SB* level). This decline corresponds with the increased spawning biomass. At higher discount rates the pre-deadline *TAC* reduction is more pronounced as the spawning biomass increase is delayed as long as possible. The decision to delay rebuilding allows the harvests to remain higher in the early years when the discount rate has less of an effect. Note, however, that the *NPV*-effect of a delayed rebuilding schedule is negligible at a discount rate that is close to the market rate of interest (despite a lower average harvest level). In addition, at higher discount rates the *SB* remains as low as possible and for as long as possible. This pattern is contrasted to the scenario involving a lower discount rate in which rebuilding occurred gradually over time. Lastly, it bears repeating that the economic assumptions (i.e., the use of a downward sloping aggregate demand curve) cause the model to estimate conservative effects. This is because lower *TAC*s (which correspond with higher *SB* levels) result in higher product prices and, therefore, a higher *NPV*.

5. CONCLUSIONS

In New Zealand, the 1996 Fisheries Act requires that fish stocks be managed to meet: (1) the biological goal of B_{MSY} and (2) the "reasonably foreseeable needs of future generations." The first goal is fairly transparent in that data can be used to verify wether this mandate is being met. The second goal, however, is more difficult to evaluate since the 'needs' have not been clearly defined. Implicit in both of these mandates, however, is a notion of an optimal rebuilding rate. For the Ministry, the key issue is the duration of the rebuilding process, will it be 10 years, 20 years, 30 years, or longer (e.g., what is the trend in *SB*)? For the industry, a more pressing question is, what is the cost of meeting the mandates (e.g., what is the trend in *TAC* and change in *NPV*)? As shown in this paper, both of these questions can be addressed using a dynamic bioeconomic model.

The primary conclusions drawn from the review of the discount rate literature and the empirical example are summarized below.

- Positive discount rates are appropriate in the analysis of commercial fisheries.
- Discount rates between 4% and 15% are appropriate for applied fisheries models and these rates are consistent with recent implicit rates calculated for several New Zealand fisheries.
- Dynamic bioeconomic analysis can be an effective tool for investigating the effects of rebuilding.
- Economic assumptions affect rebuilding rates and harvest levels in addition to *NPV*.
- The trend in stock recovery is affected by the discount rate.
- In response to rebuilding strategies, higher discount rates result in lower *NPV*s, slower rebuilding rates (spawning stock increases are delayed as long as possible), and more pronounced harvest cut-backs as the rebuilding deadline approaches. However, at discount rates that are justified in the literature for use in evaluating the management of fisheries resources, the effects may be insignificant. Note that robustness to changes in the discount rate were also found in the recent study by Grafton et al. (2000).

The policy implications (i.e., change in annual TAC levels) that were derived from the empirical example were based on a species characterized by moderate growth and longevity (i.e., 20 years). Future research will examine the trade-off between discount rates, rebuilding horizons, and *NPV* with a slower growing stock (e.g., 70 years). In addition, the second modelling revision will include biological and/or economic risk directly, as opposed to having this risk embedded in the discount rate. Lastly, the economic parameters (i.e., ψ, η, θ, and τ) will be varied in order to determine the sensitivity of the model to both the level and elasticity of the cost and price functions. This later analysis may be especially crucial since, as we have shown, demand and cost functions can play a major role in determining the optimal management of marine resources. In particular, explicitly incorporating demand and cost functions may reinforce efforts to conserve and/or rebuild fish stocks (Olson and Roy 1996). Consequently, even if the discount rate is higher than the natural growth rate, conservation may be efficient when the stock effect (via the market functions) is significant.

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