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Cutting the Cake in a Shared Fishery with a Minimally Managed Non Commercial Sector

Report

for the

New Zealand Ministry of Fisheries

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Executive Summary

Around the world, many fisheries are shared fisheries in the sense that a common fish stock is accessed by both commercial and non-commercial fishers. Non-commercial fishers can include recreational fishers, or customary fishers, or both. A prevalent problem in these fisheries is competition between commercial and non-commercial fishers for access to a resource that is subject to increasing utilisation pressure.

This paper explores some of the issues that managers who are charged with the task of maximizing the value to society from multiple uses of a sustainable catch need to consider when allocating fish stocks between the various competing interests.

The analysis of the issues is set within the New Zealand management framework with particular reference to the biology and management of the New Zealand snapper (SNA 1) and Kahawai fisheries (KAH 1). The snapper fishery is one of the largest coastal fisheries in New Zealand. Snapper are highly valued by both the commercial and non-commercial sectors. Kahawai is a pelagic schooling fish that is more highly valued by the non-commercial sector than by the commercial sector. Stocks of snapper and kahawai in the Bay of Plenty, Hauraki Gulf, and East Northland constitute SNA 1 and KAH 1 respectively.

Under current management arrangements for most shared fisheries in New Zealand, the commercial sector is effectively and efficiently managed with a regime of individual transferable quota (ITQ) for almost all species. However, while non-commercial fishing is subject to a set of general recreational fishing regulations that can prescribe a range of measures such as minimum fish size and bag limits, gear and method restrictions, and area and season closures, relatively the non-commercial sector is only minimally managed. Unlike the commercial sector, there is a lack of any direct connection between the non-commercial fishing sector and the system of management, while commercial stakeholders have quantified rights and obligations, and are registered along with these rights in the management system.

Models are therefore developed in which the commercial catch is regulated via a total allowable commercial catch (TACC) while the non commercial catch (NCC) is self regulating. The first challenge in these models is to pick a total allowable catch (TAC) such that the sum of the regulated commercial catch and the self regulating non-commercial catch are consistent with achieving a sustainable biomass outcome. The second is to pick that aggregate catch and associated catch shares so that the value of the harvest is maximized whilst still being consistent with the sustainable biomass objective.

The models are used to simulate how the optimal allocation is affected by changes in the key variables, in particular the way that non commercial effort varies with increasing stock biomass, the relative value of commercial and non commercial catch and the way that non commercial catch value varies with increasing stock biomass. Subject to all

solutions being consistent with having a sustainable biomass, the models are used to identify circumstances under which the total allowable commercial catch (TACC) should be larger, smaller or even zero in some cases.

Application of the models to the New Zealand snapper (SNA 1) and Kahawai fisheries (KAH 1) is based on currently available information on the underlying biology, the commercial catch values and non commercial catch values. Results are generated based on simulating the value of the commercial catch and non commercial catch under a range of strategies. For snapper these were:

- small TACC such that SSB = 50% of B_0,
- current TACC (e.g. 4500 t for SNA 1),
- moderate TACC such that SSB = 40% of B_0
- TACC set so that combined catch = MSY.

For Kahawai these were:

- bycatch only TACC = 500 t,
- conservative TACC (e.g. 994 t for cases a and c, and 680 t for cases b and d),
- current TACC = 1075t
- liberal TACC to achieve SSB = 40% (2308 t for cases a and c, and 1492 t for cases b and d).

The model results developed in the paper allow an assessment of strategies specific to shared fisheries where the commercial catch is completely under the control of the fishery manager (via setting a TACC) and the non-commercial catch is minimally managed and at any given stock biomass level is therefore effectively self regulating.

In these cases, virtually the only regulatory instrument available to the fishery manager to allocate the available catch between the commercial fishing sector and the non commercial fishing sector is to set the TACC, and then let stock biomass, non-commercial catch, and sustainable yield (SY) adjust to equilibrium levels consistent with the chosen TACC (i.e. such that SY=TACC+NCC).

If the TACC is set at too high a level, no sustainable equilibrium catch allocation will be achievable, and the TACC will have to be reduced to a level consistent with the maximum sustainable yield biomass, B_{msy} (i.e. $TACC_{msy}$). Hence, the sustainable range for setting the TACC is $TACC_{msy}$>TACC>0, and the corresponding range to target for the spawning stock biomass (SSB) is B_{msy} < SSB < B*.

Marginal value to recreational fishers of reallocating one tonne from the commercial catch (i.e. by reducing TACC by one tonne) equals the increase in aggregate annual value of the non-commercial catch from the consequential increase in stock biomass due to:

- Extra non-commercial catch from a higher catch rate
- Extra non-commercial catch from greater effort motivated by more value
- Non-commercial catch valued more highly because bigger fish are caught,
- Non-commercial catch valued more highly because of higher catch rates

The primary determinants of the optimal catch allocation that maximises value to the NZ economy of the combined catch from both the commercial and non-commercial sectors are:

- the **relative** size of the aggregate increase in annual value to recreational fishers from an increase in stock biomass due to a unit decrease in the TACC **vis-à-vis** the value of one unit of ACE to the commercial fishing sector
- whether the aggregate increase in annual value to recreational fishers from an increase in stock biomass is constant, or increases as stock biomass increases

The secondary determinants of the optimal catch allocation are:

- the biology, and in particular the population dynamics of the fishery
- the nature of the functional relationship between the self regulating non-commercial catch and stock biomass. (In particular, how does non-commercial effort respond to an increase in stock biomass; and how does the non-commercial catch rate respond to an increase in stock biomass? In aggregate, is the non-commercial catch coefficient (ϕ) invariant with respect to stock biomass, or does it vary as stock biomass varies?)

If the unit value of the non-commercial catch differs markedly from the unit value of the commercial catch, the optimal catch allocation is quite likely to be a corner solution where TACC is equal to either zero or to $TACC_{msy}$.

A fairly general result is that if the unit value of the non-commercial catch is less than that for the commercial catch, then provided that both values are constant at all catch levels, the value of the combined catch from both sectors of a shared fishery will be maximised by setting the TACC so that the level of spawning stock biomass (SSB) equals B_{msy}. In other words, $TACC_{msy}$, the TACC consistent with an equilibrium level of stock biomass equal to B_{msy}, is likely to be optimal provided that the size of the aggregate increase in annual value to recreational fishers from an increase in stock biomass due to a unit decrease in the TACC is **smaller than** the value of one unit of ACE to the commercial fishing sector.

Alternatively, when the annual value to recreational fishers from an increase in stock biomass is **greater than** the value of one unit of ACE to the commercial fishing sector, and/or the former value increases as stock biomass increases, it is possible that the optimal catch allocation will be achieved by setting the TAAC such that $B_{msy} < SSB < B^*$. In other words, if the unit value of the non-commercial catch is greater than that for the commercial catch by a sufficient margin, then an upper bound corner solution where TACC = 0, and SSB = B^* will be optimal.

Interior solutions, where $B_{msy}<SSB<B^*$, are more likely to be optimal if one or other unit values decrease as catch size increases, although corner solutions are still possible if the difference between unit value of the non-commercial catch and unit value of the commercial catch is sufficiently large.

Introduction

Around the world, many fisheries are shared fisheries in the sense that a common fish stock is accessed by both commercial and non-commercial fishers. Non-commercial fishers can include recreational fishers, or customary fishers, or both. A prevalent problem in these fisheries is competition between commercial and non-commercial fishers for access to a resource that is subject to increasing utilisation pressure.

Although fishers from each sector want to catch fish, there are significant differences in the values that they gain from doing so. While the commercial sector is focussed on maximising the net returns from catching fish, the motivation for non-commercial fishers is more complicated. Specifically, the non commercial fisher is best thought of as maximizing the utility or net benefit from fishing where this incorporates both a catch and experiential component. The former relates to species, size and catch rate while the latter encompasses the benefit associated with the broader experience including sporting and social benefits.

Unlike the commercial sector, the relationship between stock abundance and the size and /or value of the catch may not be linear for the non-commercial sector. To improve aggregate value obtained by all stakeholders as a result of allocation decision, it is important to clarify the nature of the relationship between catch allocation and the different values sought by the respective sectors from their participation in fishing.

However, it needs to be recognized that politically driven constraints on management mechanisms exist in most shared fisheries and this further complicates the issue of dividing the “available catch” between sectors.

The management challenge

The main challenges facing managers of fisheries accessed exclusively by commercial fishers are to ensure that the total allowable catch is set at a sustainable level, and to manage the fishery so that economic benefits to the community are optimized. In effect this means setting an allowable commercial catch to maximize economic rents.

However, in many fisheries, the fish stock is shared by multiple users, including commercial and non commercial sectors, and often by indigenous customary users as well. This paper explores some of the issues that managers who are charged with the task of maximizing the value to society from multiple uses of a sustainable catch need to consider when allocating fish stocks between competing interests.

Even in fisheries where the fish resource is shared only between commercial and non commercial users, the existence of the non commercial user adds significantly to the management task because managers must then take on the additional challenge of allocating the available resource among these competing uses.

Allocation decisions involve explicit trade-offs between the competing uses. If they are to be effective in the sense that the resulting economic benefits from the harvest are optimized, allocation decisions need to be explicitly based on the value of the fish resource in each of the alternative uses

The New Zealand framework

Under current management arrangements for most shared fisheries in New Zealand, the commercial sector is effectively and efficiently managed with a regime of individual transferable quota (ITQ) for almost all species. However, the non-commercial sector is only minimally managed.

The management of the commercial sector is dominated by the quota management system (QMS): a proportional ITQ based regime. Under this scheme, a fixed total quantity of tradable quota shares is held by individuals and firms for each fish stock. A total allowable commercial catch (TACC) applies to each stock and this may be varied annually by a decision of the Minister of Fisheries. These TACCs are set in advance of the start of the fishing year, at which point each ITQ shareholder's annual catch entitlement (ACE) for the coming year is determined and issued. ACE is the currency used by fishers during the year to cover catch, and can be freely traded independently of the long-term ITQ.

The catch allocation process starts with setting an overall total allowable catch (TAC) covering all sectors that is set with regard to the biological state of the stock so as to satisfy the statutory objective to manage stock biomass at or above the level that will produce maximum sustainable yield (MSY). This setting is classified as a "sustainability measure" under the Act and implies that this biomass level equal to or greater than B_{msy} is primarily an environmental bottom line.

In setting the TACC, the Minister of Fisheries must have regard to the TAC, and must also allow for Maori customary and non-commercial interests. Hence, the allocation of the TAC between commercial and non-commercial sectors is achieved by estimating the self governing level of the non-commercial catch, and then setting the TACC to ensure that realised total catch does not exceed the TAC. This is the primary tool in the system for allocation of catch. Under this system the total allowable commercial catch (TACC) is effectively a residual calculation.

Non-commercial fishing is divided under the Fisheries Act 1996 (the Act) into "recreational" and "Maori customary" components. The statutory and regulatory provisions for Maori customary fishing apply to non-commercial fishing activities for traditional customary purposes, including providing food for customary purposes as defined by local traditions, as well as designation of non-commercial fishing areas managed by local Maori. Non-commercial fishing by Maori for other reasons falls under the general recreational regulated open access regime.

"Remaining non-commercial fishers, the so-called "recreational" sector, remain largely undifferentiated by the management system in terms of the broad range of activities carried out and values they seek. They are not registered or licensed, do not report catch, and have little input into management decision-making outside of general public consultation processes." (Connor 2006).

Non-commercial fishing is subject to a set of general recreational fishing regulations that can prescribe a range of measures such as minimum fish size and bag limits, gear and method restrictions, and area and season closures, and legally the Minister is expected to use these tools to constrain non-commercial catch. However, apart from such broad constraints in a number of shared fisheries, there are few if any limits on individual's fishing effort. Nor are there restrictions on participation rates by non-commercial catch fishers. A key point of difference between this regime and that for the other two sectors is the lack of any direct connection between the non-commercial fishing sector and the system of management. Commercial stakeholders have quantified rights and obligations, and are registered along with these rights in the management system.

A review of the economic approach to catch allocation

The standard economic model

Figure 1 illustrates the standard economic interpretation of the optimization of total net economic benefits of allocating a defined total allowable catch between commercial and non commercial fishing activties by equating the marginal net benefit from each of the competing uses.

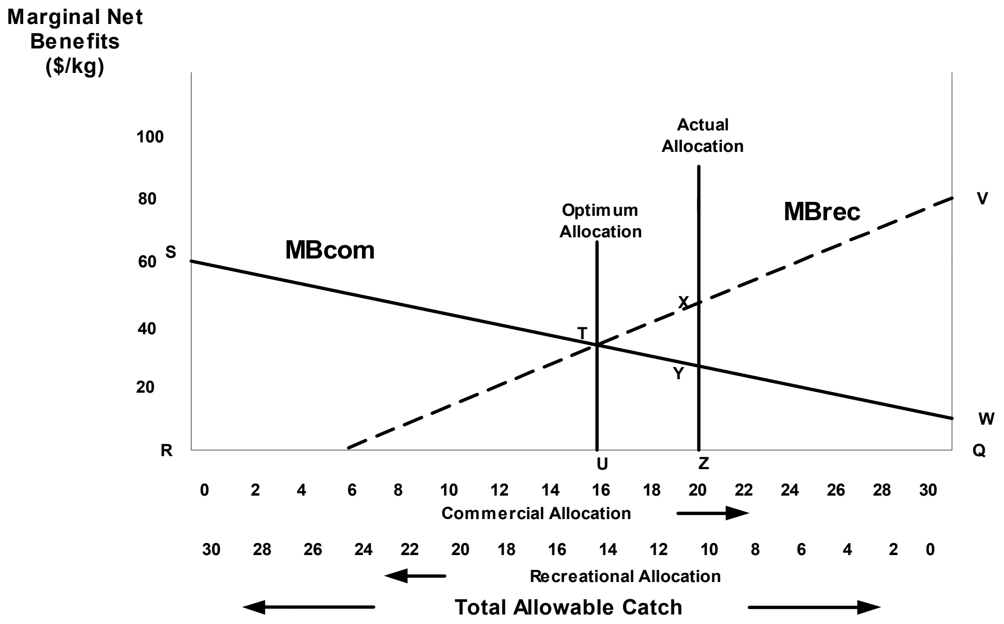

FIGURE 1. OPTIMAL ALLOCATION OF FISH RESOURCE BETWEEN NON COMMERCIAL AND COMMERCIAL FISHING

The vertical axis shows marginal net economic value for the commercial and non commercial sectors. The horizontal axis shows the total allowable catch to be shared among these two competing uses. The possible commercial and non commercial fishing shares run in opposite directions, such that at any point along the horizontal axis, the sum of the two shares equals the total allowable catch, which is assumed to be 30 million kilograms.

If the current allocation is at Z, where the marginal net benefit from non commercial fishing (MB*rec*) exceeds the marginal net benefit from commercial fishing (MB*com*), indicating that to reallocating some of the total allowable catch to the non commercial sector would increase the "value" of the fishery. The most efficient allocation, occurs where the marginal net economic benefits for the competing uses are equal, illustrated in the diagram at point 'T'.

Key Assumptions for the Resource Allocation Framework

To repeat, the accepted conceptual framework for the analysis of optimal resource allocation is based on certain tacit assumptions. In particular, it is assumed that:

- The combined existing commercial and non commercial catch is equal to the sustainable catch, and is the amount available for inter-sectoral allocation,

- The total sustainable catch is known with certainty,
- All commercial and non commercial participants are subject to binding catch limits, so there is no unused or latent capacity to increase catch, and both the commercial and non commercial catch are caught in the most efficient manner possible,
- Management of both the commercial and non commercial sectors is efficient, and maximises fishery resource rent.

An important implication of the above is that, as for the commercial sector, the non commercial sector would have a defined catch which would be caught efficiently and would be managed so as to achieve the most efficient intra sectoral catch allocation. For some fisheries one way to do this would to have tradable fish tags where the number of tags defined the non commercial allocation and new fishers could enter the fishery by buying tags.

Problems with the standard economic model

Total Allowable Catch

A critical issue in the successful application of the standard theoretical framework is the ability to specify the aggregate sustainable catch to be allocated between the competing uses. The theoretical model implicitly assumes that size of the aggregate fish resource stock is both known with certainty and invariant over time. The latter assumption is never true, and in many fisheries the former assumption also is false.

Fish stocks are intrinsically highly stochastic, so there are significant year to year fluctuations in stock abundance and catch. Furthermore, predictions of the size of the stock at any point in time are at best guesstimates, and subject to considerable estimation errors. In most fisheries, not enough is understood about the population dynamics to know whether a fish resource stock is in steady state, or in transition from one steady state to another.

Compounding the problem is further uncertainty about the proportion of the aggregate stock being accessed by each sector. In some fisheries there will be uncertainty whether both sectors are accessing the same common stock. If they are not fishing the same stock, attempts to reallocate stock from one sector to another might be futile. Given this intrinsic uncertainty about the size of the stock to be allocated, the results of attempts to optimise resource stock allocations will be very sensitive to the underlying assumptions.

Implications of Inefficient Sectoral Regulations

Where catch in one sector is not restricted, resource rent is more likely to be dissipated in the non- restricted sector. Consequently, there will be gains from reducing rent dissipation by improving the efficiency of the management regime in the unrestricted sector independent of any allocation decision.

If there is sub optimal management in either or both sectors, then the conventional model does not have the correct starting point for the determination of an optimal allocation. Ideally the relative vales of fishing in each sector with optimal management will be needed to determine the optimal allocation.

Politically acceptable methods to manage non commercial fisheries

While the conventional model is based on efficient management in each sector, the political reality is different. In most fisheries, the socially and politically acceptable methods available to manage effort and/or catch in non commercial fishing typically are less effective than those deployed in the commercial fishery. Consequently, while aggregate effort and/or catch are effectively controlled in many if not most commercial fisheries, effectively most non commercial fisheries approximate open access fisheries. Typically, there is no limitation on entry and participation, and often there is no requirement to hold a fishing licence. Hence, there are few or no effective controls on aggregate effort and/or catch. Under these minimal management regimes, non commercial fishing effort can continue to grow.

As a result, fishery managers often have no effective means at their disposal to reallocate total allowable catch from the non commercial fishing sector to the commercial fishing sector. Likewise, total allowable catch can only be reallocated in the opposite direction indirectly by reducing the total allowable commercial catch, and then waiting for non commercial fishers to respond to a gradual increase over time in fish stock abundance. A risk in this approach is that, if non commercial fishing effort increases in the meantime, an increase in fish stock abundance may never eventuate.

Economic value

As argued above allocation decisions need to be explicitly based on the value of the fish resource in each of the alternative uses. However, there needs to be clarity about what the commercial and non commercial fishing values are and some understanding of the way they are influenced by the allocation process.

Commercial

On the commercial side, "economic value" is derived ultimately from the tastes and preferences of consumers, and is measured in terms of 'willingness-to-pay'. This can usually be inferred from analysis of market data on fish prices and, where this form of management is in place, annual catch entitlement (ACE).

While there are challenges in measuring net economic benefit for the commercial sector, from the allocation perspective, arguably the greater challenges arise in measuring net economic benefit for the non commercial fishing sector.

Non commercial

Non commercial fisheries differ from commercial fisheries in several important respects, including; the multi dimensional nature of non commercial fishing, the lack of markets for the outputs from non commercial fishing, the fact that some forms of non commercial fishing result in less than 100% mortality of landed catch, and political constraints on acceptable management methods for non commercial fisheries. First and foremost, in contrast to commercial fisheries where the value of the retained catch normally is the sole benefit derived by fishers, non commercial fishing is a more complex multi dimensional activity. Individual fishers may differ in the extent to which they derive benefits from the retained catch relative to the sport value of landing and releasing fish, and the experiential value from time spent on or adjacent to the marine or freshwater environment. Moreover, fish size, catch rate, time and place, and preferred species are all important determinants of the value to non-commercial fishers that tends to produce a conflict of interest with the commercial objective of simply maximising yield. (Connor 2006). The relative importance of these components of possible benefits from non commercial fishing can be shown to influence the effectiveness and efficiency of different fishery regulations, as well as the marginal value to non commercial fishers of an increase in stock abundance due to the reallocation of a part of the commercial sector total allowable catch (TACC) to the non commercial fishing sector.

Second, typically there are no established markets for non commercial fishing outputs where values can be observed. In such cases, surrogate and/or simulated (or experimental) market valuation methods and techniques have to be used to derive estimates of non commercial fishing values.

Third, depending on the biology of the species being caught, the possibility exists to limit fish mortality by regulations to encourage catch and release so that retained catch is controlled at sustainable levels without as severe controls on the level of non commercial fishing effort.

Analytical model of shared fisheries

In this section, only sustainable steady state level of stock biomass and catch allocation outcomes are considered. Discussion of situations where the current level of stock biomass is not the same as an optimal level, and the financial consequences of making the transition from one to the other will be considered in the individual case studies below.

The relationship between sustainable non-commercial catch, sustainable commercial catch, and stock biomass in a shared fishery

In a minimally managed fishery, non-commercial fishing effort is not regulated, so non-commercial catch (NCC) essentially is self regulating. Furthermore, the catch rate per unit of effort will be an increasing function of stock biomass (B_i). For the sake of simplicity, it will be assumed for the time being that non-commercial catch is a linear function of stock biomass, and a catch coefficient (ϕ) will define the rate of change in NCC as stock biomass changes.

Let B^* be the level of stock biomass at which the non-commercial catch equals the sustainable yield (SY) for the shared fishery. Obviously, for $B_i>B^*$, unregulated NCC would be unsustainable, and stock biomass would decrease until it equals B^*. Hence, sustainable non-commercial catch (SNCC) will be defined by:

$$\begin{aligned} SNCC &= \varphi * B_i \quad \text{if } B_i < B^* \\ &= SY\left(B^*\right) \quad \text{elsewise} \end{aligned} \tag{0.1}$$

The relationship between SY, SNCC, SCC, and stock biomass for a hypothetical fishery is illustrated in Figure 2. SY shows the sustainable yield at each level of biomass from 0% to 100% of $B_{0.}$ Note that B_{msy} is assumed to be 22% of $B_{0,}$ and that MSY at this point is 10,000. SNCC increases with biomass as B_i increases from zero to B^* as per equation 1.3. NCC reaches a maximum at B^*, which is at about 65% of B_0. Beyond this point, commercial catch must be zero if the fishery is to be sustainable. In other words, sustainable commercial catch is zero for $B_i>B^*$, and the whole catch is devoted to the non commercial sector. For $B_i<B^*$, SCC will equal the difference between the fishery SY and SNCC.

In New Zealand, B_{msy} is essentially an environmental bottom line, because under the Fisheries Act 1996, the minister has a statutory objective to manage stock biomass at or above the level that will produce maximum sustainable yield (MSY). Hence, the problem facing the fishery manager is to aim for the level of biomass, $B^{\#}$, within the range $B_{msy}<B^{\#}<B^*$, that maximises the combined value of the commercial and non-commercial catch.

In practice, to achieve a desired steady state stock biomass, $B^{\#}$, the fishery manager would need to select the sustainable commercial catch level that is consistent with $B^{\#}$ and allow the fishery to adjust to $B^{\#}$ over time. For example, if in Figure 2, the current biomass was B_{msy}, and the desired level of biomass was B^{*}, then the manager would need to set the TACC to zero. Initially, the non-commercial catch would be less than MSY, so stock biomass would increase over time until it reached B^{*}. Conversely, if the current biomass was B^{*}, and the desired level of biomass was B_{msy}, then the manager would need to set the TACC to the sustainable commercial catch level at B_{msy}[1]. Total catch initially would exceed sustainable yield, and stock biomass would decrease over time to B_{msy}.

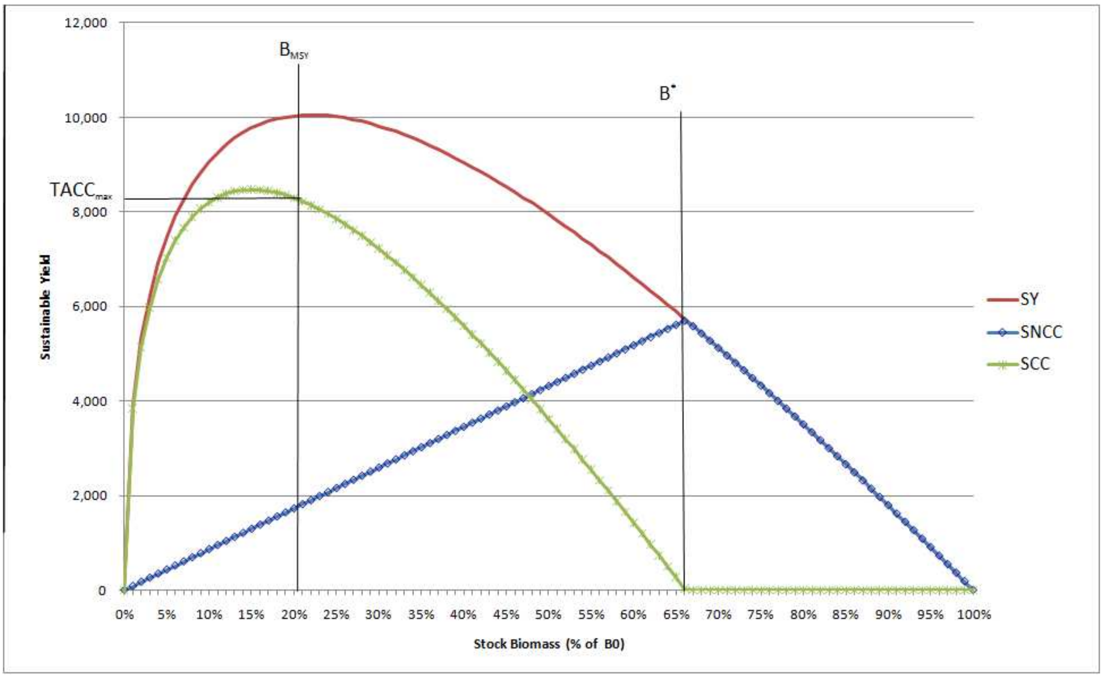

FIGURE 2. SUSTAINABLE YIELD AND SUSTAINABLE NON-COMMERCIAL CATCH AS A FUNCTION OF STOCK BIOMASS

The analysis embodied in Figure 2 centres around the relationship between SNCC and biomass. Clearly, it is important to have some understanding about the nature of this functional relationship between the self regulating non-commercial catch and stock biomass, including whether this relationship is linear or not. Non-commercial catch is the product of non-commercial fishing effort and the catch rate per unit of effort, both of which are likely to be a function of stock biomass. Catch rate is often assumed to be a linear function of stock biomass, but it is more likely to increase at a diminishing rate.

[1] In Figure 2, this would be about a little more than 8,000, and is labelled $TACC_{msy}$.

It is often asserted that non-commercial fishers value both catch rate and the size of fish caught[2], and since both are likely to increase as stock biomass increases, in a minimally managed fishery, many non commercial fishers are likely to increase effort if stock biomass increases. However, the actual response to a biomass increase will likely vary according to the circumstances of the fisher. Where the sole purpose of the non commercial fisher is to catch a set amount of fish, or for a fisher who stops at the bag limit, effort might decrease if stock biomass increases. Where a fisher is currently stopping at less than the bag limit because either size or catch rate do not justify further effort, an increase in biomass may induce an increase in effort. There may also be an increase in participation as biomass increases. The mix of fisher characteristics and circumstances will determine the catch coefficient (ϕ) for a fishery, and whether it increases, is invariant, or decreases as stock biomass increases.

Different fisheries will have different values for the catch coefficient ϕ. They may have a different mix of fisher types but even for a given mix of fisher types, some fisheries are simply more productive at any given biomass. The effects of differences in the catch coefficient are illustrated in Figure 3.

Figure 3 illustrates sensitivity of sustainable yield and sustainable non-commercial catch functions to catch coefficient, ϕ. It shows the relationship between SY, SNCC, SCC, and stock biomass for two hypothetical fisheries, differentiated only by the size of a constant catch coefficient, ϕ.

For the higher catch coefficient fishery ($SNCC^{50}$), B^{*50} is the biomass at which the unregulated non commercial catch biomass equals the sustainable yield biomass. At this point the commercial catch allocation is zero. For the lower catch coefficient fishery ($SNCC^{25}$), B^{*25} is the biomass at which the unregulated non commercial catch biomass equals the sustainable yield biomass. Again at this point the commercial catch allocation is zero. However, with the lower catch coefficient, ϕ, the range of non zero commercial catch allocations is greater. Commercial catch allocation is positive up to a biomass index of around 65% compared to around 48% for the higher catch coefficient case.

Figure 3 makes clear the way that non commercial behaviour with respect to changes in the biomass impact upon the allocation to the commercial sector in the case where the non commercial sector is minimally managed.

[2] For example, see Connor (2007)

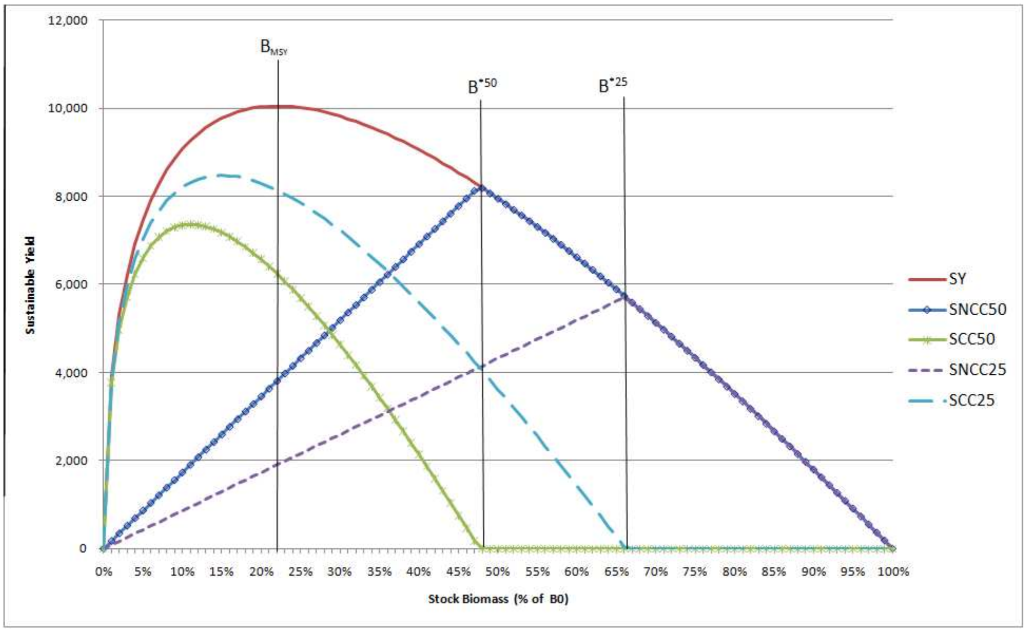

FIGURE 3. SENSITIVITY OF SUSTAINABLE YIELD AND SUSTAINABLE NON-COMMERCIAL CATCH FUNCTIONS TO CATCH COEFFICIENT, Φ.

Lastly, two cases where the catch coefficient, ϕ, does vary with stock biomass are illustrated in Figure 4 and in Figure 5.

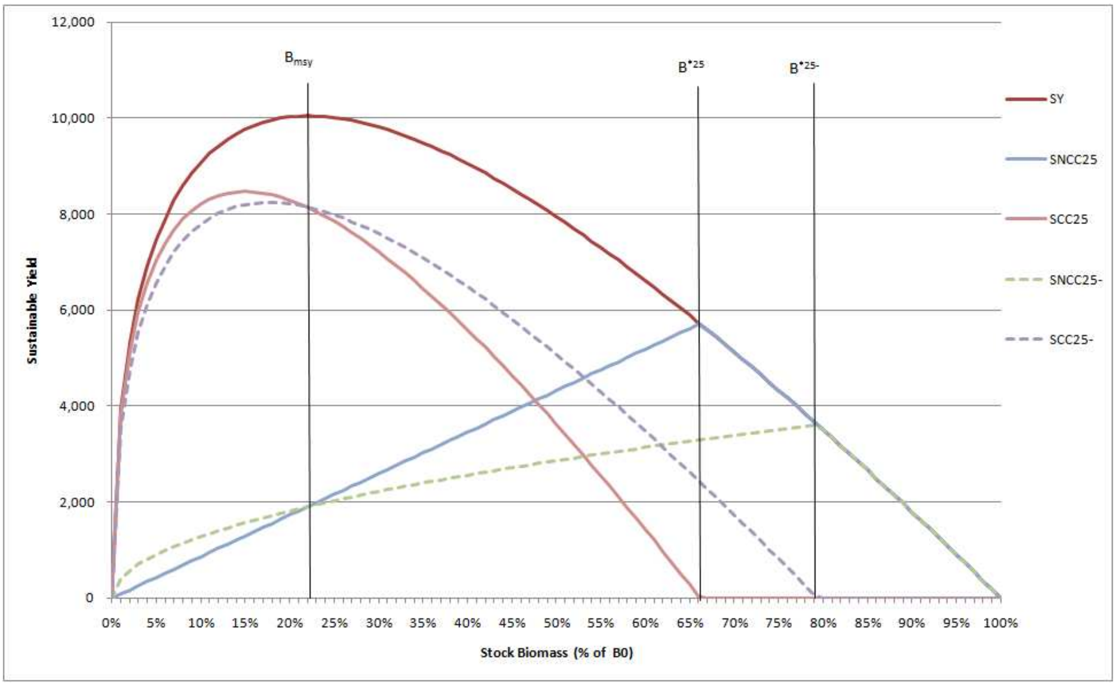

FIGURE 4. SENSITIVITY OF SUSTAINABLE YIELD AND SUSTAINABLE NON-COMMERCIAL CATCH FUNCTIONS TO A DIMINISHING CATCH COEFFICIENT, Φ.

Figure 4 illustrates the case where ϕ declines as stock biomass increases, while Figure 5 illustrates the converse case where ϕ increases with increasing stock biomass.

For the diminishing catch coefficient case (Figure 4) the biomass at which the unregulated non commercial catch biomass equals the sustainable yield biomass increases whereas for the increasing catch coefficient case (Figure 5) it declines, compared to the constant catch coefficient case.

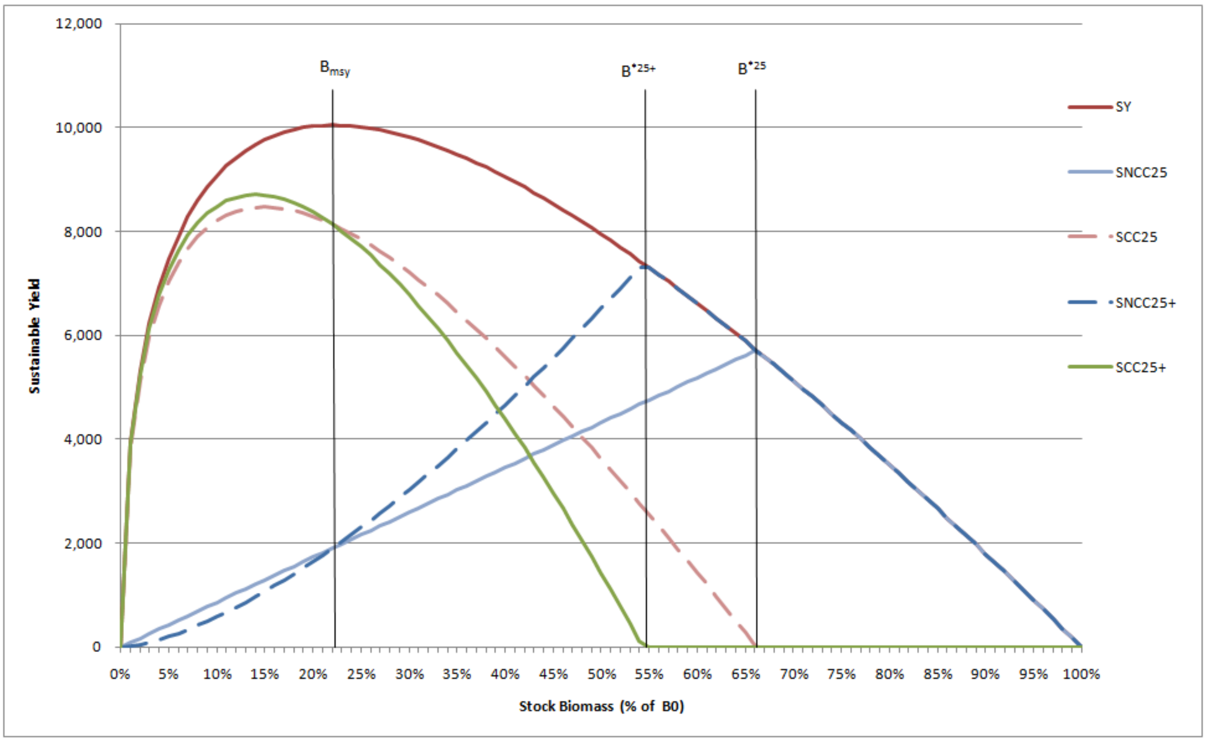

FIGURE 5. SENSITIVITY OF SUSTAINABLE YIELD AND SUSTAINABLE NON-COMMERCIAL CATCH FUNCTIONS TO AN INCREASING CATCH COEFFICIENT, Φ.

Effect of alternative catch allocations on the total economic value from a shared fishery

The focus of the conventional allocation model described above was to allocate a defined total catch, typically MSY, between the commercial fishing sector and the non-commercial fishing sector so as to maximise the economic value of the harvest. Figure 2 to Figure 5 above illustrate the range of acceptable TACC for shared fisheries with a minimally managed non commercial sector where the objective is to achieve a sustainable yield whilst having a biomass greater than or equal to B_{MSY}. They do not address the question of which TACC and associated level of stock biomass within the acceptable range will maximise the economic value to the NZ economy of the combined catch.

Therefore the model as represented in the above figures needs to be extended to allow for the values of commercial and non commercial fishing activities, and the effect of different catch allocations on overall value needs further consideration.

The sustainable total economic value from a shared fishery equals the product of the sustainable commercial catch by its average unit value plus the product of the sustainable non-commercial catch by its average unit value. For many fisheries where catch is internationally traded, the unit value of the commercial catch is exogenously determined and independent of the size of the catch, so catch value will be a linear function of catch size. In New Zealand, the ACE value for commercial catch under the QMS provides an observable and objective measure of the unit value of the commercial catch. However, as discussed above, there is typically no comparable market based measure of the unit value of the non-commercial catch, and values have to be inferred from non-market based studies.

The key determinant of the sustainable total economic value as a function of stock biomass size is the average unit value of the non-commercial catch relative to the average unit value for the commercial catch.

The simplest possible case is where both the commercial catch and the non-commercial catch have the same average unit value. In the analysis below this is nominally set at $1. We further assume that this value is constant, and does not change with either catch size or the level of stock biomass. The result is illustrated in Figure 6, where the curves CC$, NC$, and TC$ depict the value of the commercial catch, the non-commercial catch, and the total respectively. Predictably in this case, the position and shape of the sustainable economic value curves in Figure 6 are identical to the sustainable catch curves in Figure 2, and sustainable value is maximised at B_{msy}.

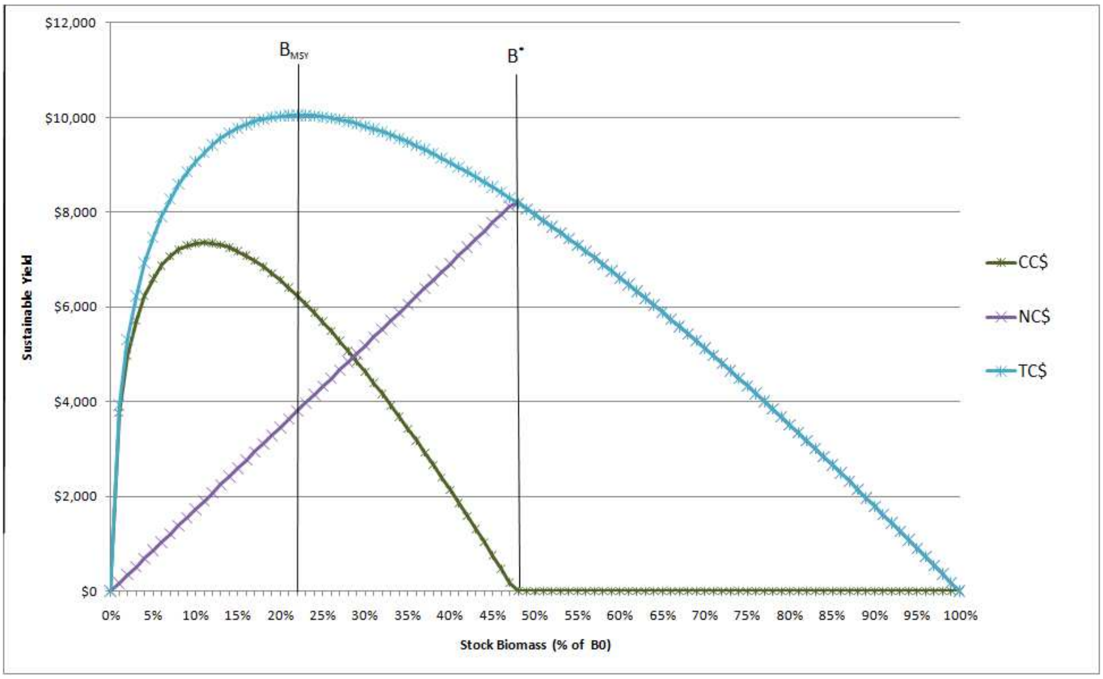

FIGURE 6. OPTIMAL ECONOMIC ALLOCATION WHEN COMMERCIAL AND NON COMMERCIAL CATCH HAVE THE SAME RELATIVE VALUE

The more interesting and relevant case is a shared fishery where the average unit value of the non-commercial catch is different from that of the commercial catch. For purposes of illustrating this case, first consider a scenario in which the average unit value of non commercial catch is half that of the average unit value for commercial catch.

In Figure 7, curve NC$0.5 depicts the value of the non-commercial catch when average unit value of non commercial catch is half that for the commercial catch, and the curve TC$0.5 depicts the corresponding value of the total catch. Note that up to B^*, total value is the sum of commercial and non commercial catch values. Beyond B^*, commercial catch is zero and the catch value reflects the value of only non commercial catch.

It can be seen that while total economic value is maximised at a biomass level less than B_{msy}, taking account of the sustainability constraint means maximum sustainable total economic value is achieved at B_{msy}. This stock level will be referred to as a (lower bound) corner solution, because even though total economic value would be greater at a smaller stock level, smaller stock levels are inadmissible under New Zealand fishery legislation.

The result illustrated in Figure 7 is a general result, and applies to any shared fishery where the average unit value of the non-commercial catch is less than that for the commercial catch provided that both values are constant at all catch levels.

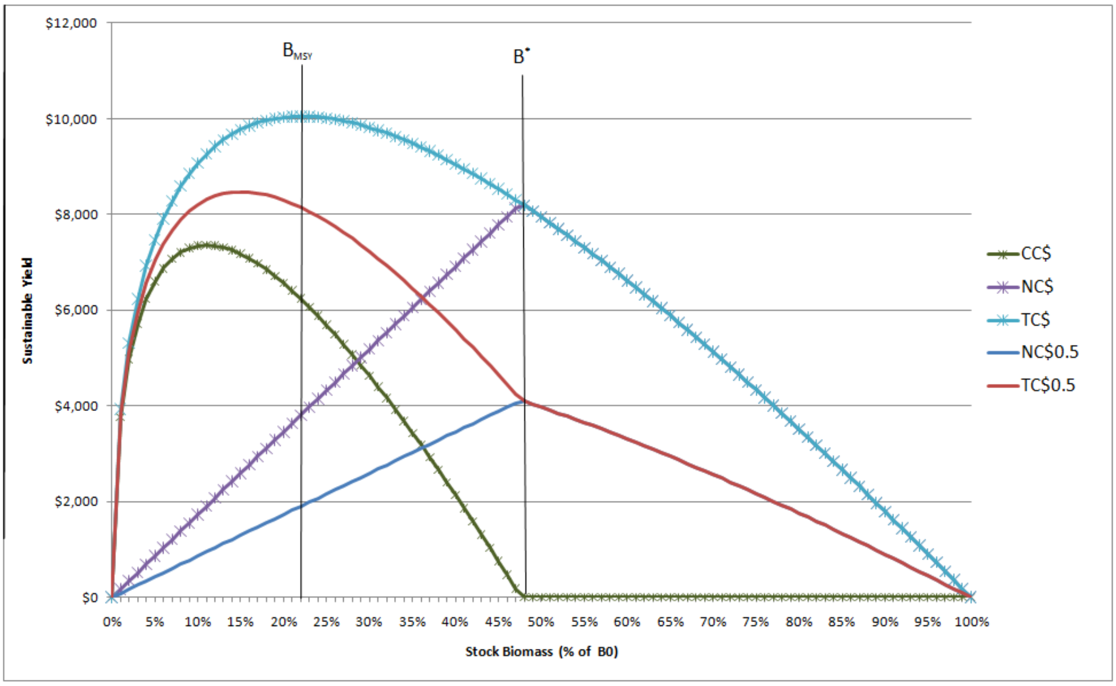

FIGURE 7. OPTIMAL ECONOMIC ALLOCATION WHEN NON COMMERCIAL CATCH HAS 50% THE UNIT VALUE OF THE COMMERCIAL CATCH

The converse case where the average unit value of the non-commercial catch is 50% greater than that for the commercial catch is illustrated in Figure 8, where curve NC$1.5 depicts the value of the non-commercial catch when average unit value of non commercial catch is 50% greater than that for the commercial catch, and the curve TC$1.5 depicts the corresponding value of the total catch. For this case, and in general whenever the average unit value of the non-commercial catch is greater than that for the commercial catch, the level of stock biomass at which sustainable total economic value is maximized will be greater than B_{msy}. In the case illustrated, sustainable economic value is maximized at a biomass level between B_{msy} and B^*, which is referred to as an interior solution. However, if the relative unit value of the non-commercial catch is sufficiently high compared to the unit value of the commercial catch[3], it can be shown that sustainable total economic value will be maximized at B^*, which is a second (upper bound) corner solution.

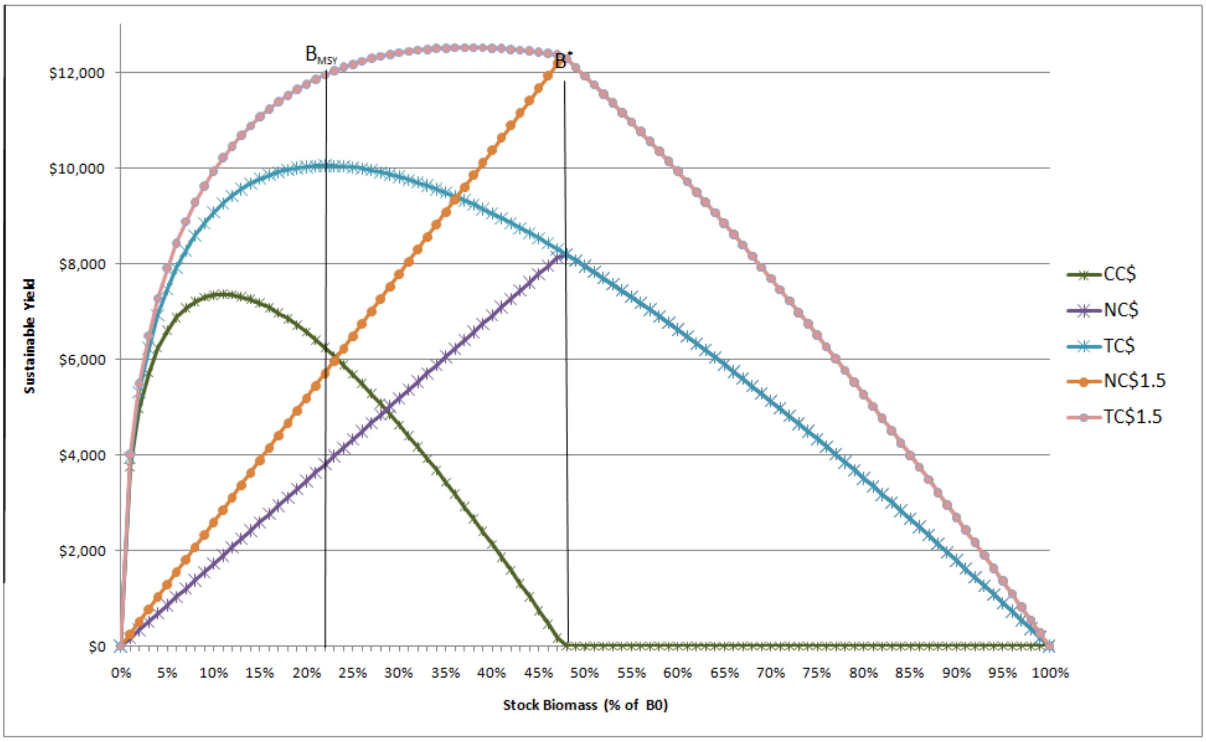

FIGURE 8. OPTIMAL ECONOMIC ALLOCATION WHEN UNIT VALUE OF THE NON COMMERCIAL CATCH IS 150% OF THE UNIT VALUE OF THE COMMERCIAL CATCH

[3] For the actual parameter values used to construct Figure 7, sustainable total economic value will be maximized at B^* if the relative unit value of the non-commercial catch is greater than 175% of the unit value of the commercial catch, and if both values are constant at all catch levels.

Another key issue is whether the average unit value of the non-commercial catch is a linear function of catch size (and stock biomass level), or whether average unit value actually increases as the level of the stock biomass increases. A case can be made that the latter assumption is more realistic for many shared fisheries. This argument is based on the view that non-commercial fishers value both catch rate and the size of fish caught and hence would place a higher unit value on catch where the catch rate was higher and the average size of fish caught was larger. As both catch rate and average fish size caught are likely to increase as stock biomass increases, then unit value for non commercial catch is likely to increase with biomass. This increasing unit value applies even when the underlying catch coefficient, ϕ, is constant. Figure 9 illustrates such a case.

In Figure 9 , average unit value for the commercial catch is \$1, but average unit value for the non-commercial catch = \$$(1+B_i/B_0)$. The corresponding value of the non-commercial catch and the total catch are depicted by curves NC\$+ and TC\$+ respectively. Unlike the previous casein which sustainable economic value was maximized at a biomass between B_{msy} and B*, in Figure 9 the biomass that maximizes economic value is B^*. This occurs because over the range B_{msy} to B^*, the average unit value for non commercial fishing is actually increasing relative to the average unit value of commercial fishing, which has the effect of increasing overall economic value as commercial allocation is reduced and non commercial allocation increases. As in previous illustrations, once the commercial catch is reduced to zero at B^*, future economic value follows the path of non commercial catch and biomass.

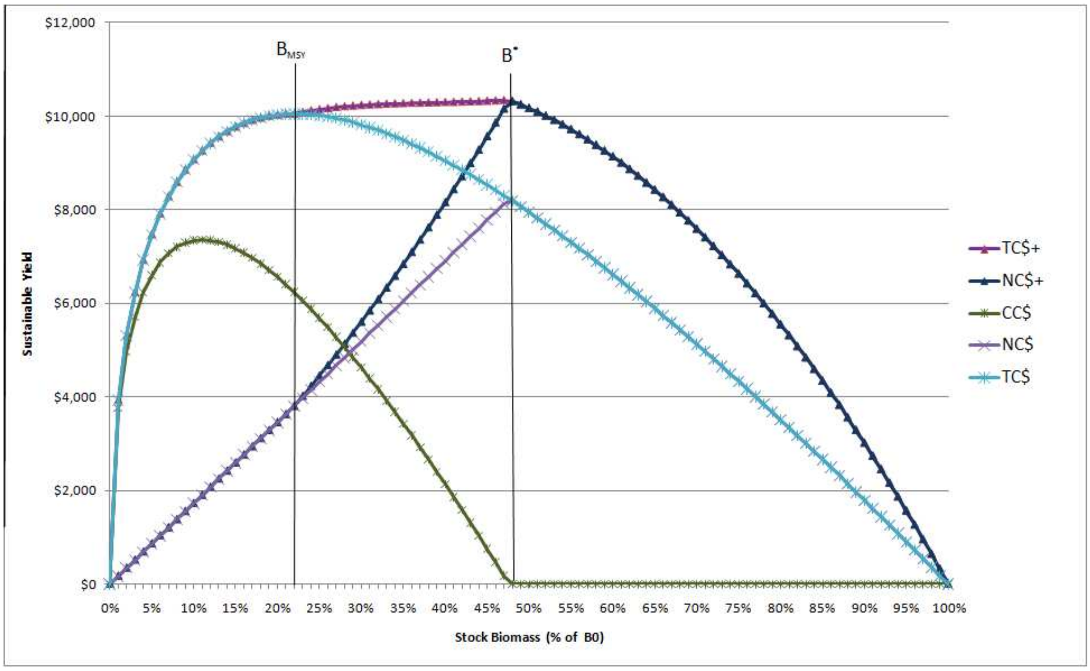

FIGURE 9. OPTIMAL ECONOMIC ALLOCATION WHEN NON COMMERCIAL CATCH HAS INCREASING UNIT VALUE

Figure 9 has an increasing unit value for non commercial fishing with the non commercial starting unit value being equal to the unit value for commercial catch. If the starting value for non commercial value exceeded that for commercial catch the result in Figure 9 would be reinforced. The optimum non commercial catch biomass B^* would prevail with optimal commercial catch equal to zero.

However, if the starting value for the non commercial catch is less than that for commercial catch the result is as illustrated in Figure 10. Figure 10 illustrates the case where average unit value for the commercial catch is \$1, but average unit value for the non-commercial catch = \$$(0.1+B_i/B_0)$. In this case, the optimal sustainable stock biomass equals B_{msy}.. Essentially, if the non commercial unit value is well below the commercial catch unit value, it doesn't increase enough with biomass to offset the value foregone with the reduction in commercial catch that occurs to accommodate the growth in non commercial catch and maintain the SY biomass. In this case the maximum economic value is maximised at a stock biomass level less than B_{msy}, which means that, taking account of the sustainability constraint, maximum sustainable total economic value is achieved at B_{msy}.

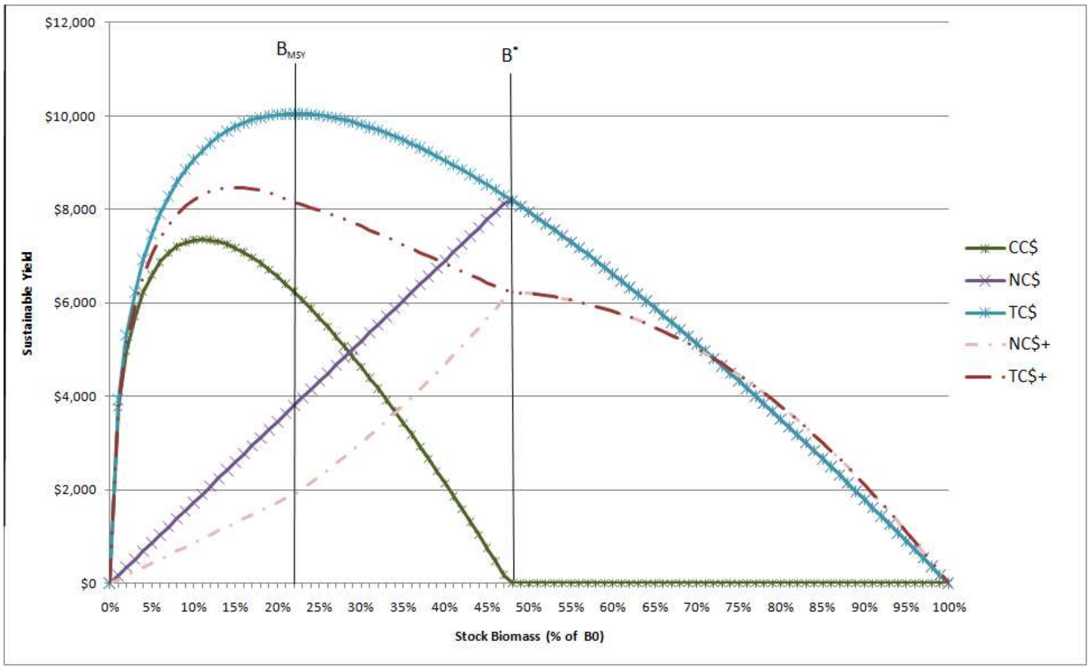

FIGURE 10. OPTIMAL ECONOMIC ALLOCATION WHEN NON COMMERCIAL CATCH HAS INCREASING UNIT VALUE AND A STARTING VALUE BELOW COMMERCIAL CATCH VALUE

Summation

In a minimally managed fishery, at most non-commercial fishing effort is lightly regulated, so non-commercial catch (NCC) essentially is self regulating. Furthermore, the catch rate per unit of effort will be an increasing function of stock biomass (B_i).

In this analysis, at any given biomass level, the sustainable regulated TACC is effectively a residual equal to the difference between the overall fishery sustainable yield, and sustainable non-commercial catch at the level of stock biomass, B_i. Because, non commercial effort increases with biomass, at some point the sustainable non commercial catch equates to the whole of the sustainable yield biomass, and the optimal commercial allocation is zero

A key to understanding this outcome is the behaviour of non commercial fishers and the relationship between commercial and non commercial value.

The implications of various assumptions regarding these variables have been demonstrated above by documenting the relationship between sustainable yield biomass and the relative sustainable commercial and non commercial catch using a model where the sum of the two must equate to the sustainable yield biomass.

The starting point for the above analysis modelled the range of acceptable TACC for shared fisheries with a minimally managed non commercial sector where the objective is to achieve a sustainable yield whilst having a biomass greater than or equal to B_{MSY}.

Essentially model illustrates the way in which the biomass at which non commercial catch equals the whole of the sustainable biomass depends on the magnitude of the non commercial catch coefficient. Assuming a constant catch coefficient, the larger the catch coefficient, the lower the biomass at which the unregulated non commercial catch biomass equals the sustainable yield biomass.

The behaviour of non commercial fishers with respect to biomass could be such that the catch coefficient could be increasing or decreasing at the margin as biomass increases.

If the non commercial catch coefficient is increasing, the biomass at which the unregulated non commercial catch biomass equals the sustainable yield biomass is reduced whereas if the catch coefficient in diminishing it is increased.

In addition to simulating the TACC consistent with having a sustainable yield biomass greater than or equal to B_{MSY}, there is the further question as the TACC and associated biomass that will maximize the economic value of the combined non commercial and commercial harvests.

The model simulations above illustrate that the key drivers of this outcome are relative unit values for con commercial and commercial catch and the way that catch values behave as biomass increases.

Two cases are developed, one where the average unit value of non commercial catch is below that of the average unit value for commercial catch and one where it is higher.

In the case where average unit value of non commercial catch is half that of the average unit value for commercial catch, total economic value is maximised at a stock biomass level less than B_{msy}, This means that taking account of the sustainability constraint means maximum sustainable total economic value is achieved at B_{msy}. This can be regarded as a general result and applies to any shared fishery where the average unit value of the non-commercial catch is less than that for the commercial catch.

For the case where the average unit value of the non-commercial catch is 50% greater than that for the commercial catch, the level of stock biomass at which sustainable total economic value is maximized is greater than B_{msy}. Again this can be regarded as general outcome whenever the average unit value of the non-commercial catch is greater than that for the commercial catch, If the relative unit value of the non-commercial catch is sufficiently high compared to the unit value of the commercial catch maximum economic value arises where the TACC is equal to zero.

The non commercial catch value may be increasing or decreasing with respect to the level of stock biomass. In the case where it is increasing the biomass that maximizes economic value occurs where non commercial catch is equal to the sustainable yield harvest and the TACC is zero. In this case if the initial unit value for the non commercial catch exceeds that of the commercial catch the result I strengthened. However, if the initial unit value for the non commercial catch is below that of the commercial catch the total economic value is maximised at a stock biomass level less than B_{msy}, This means that taking account of the sustainability constraint means maximum sustainable total economic value is achieved at B_{msy}.

The models presented above simulate the range of possibilities. Each fishery will be different so that the exact solution for setting the TACC in the case where non commercial catch is minimally managed needs to be fishery specific. In the following section the model is applied to two case studies. - New Zealand snapper and kahawai fisheries in management area one.

Case Studies

Two examples of shared fisheries are the New Zealand snapper and kahawai fisheries in management area one, hereafter referred to as SNA 1 and KAH 1 respectively. The snapper fishery is one of the largest coastal fisheries in New Zealand. Snapper are highly valued by both the commercial and non-commercial sectors. Kahawai is a pelagic schooling fish that is more highly valued by the non-commercial sector than by the commercial sector. Stocks of snapper and kahawai in the Bay of Plenty, Hauraki Gulf, and East Northland constitute SNA 1 and KAH 1 respectively.

The SNA 1 case study

The state transition equation chosen to simulate the population dynamics for SNA 1 is based on a function that is a hybrid between a Richards and Ricker functions as follows:

$$N_{t+u+1} = N_{t+u} + a_* N_{t*}[\exp\{r_*(1-(N_t/K)^d)-1\}] \qquad (2)$$

Where: a is a calibrating coefficient
d is another calibrating coefficient
N_t is stock biomass in year t
r is a growth rate coefficient
u is a recruitment lag equal to the number of years it takes to reach sexual maturity
K is the virgin or unfished stock biomass, otherwise described by B_0

In the Report from the Mid-Year Fishery Assessment Plenary, November 2008: stock assessments and yield estimates, the chapter for SNAPPER (SNA) contains estimates of biomass and MSY for a base case scenario (case a). Also included in the table below are hybrid Richards/Ricker growth function parameter values so that this case a mimics the population dynamics for SNA 1 in the sense that key features of the sustainable yield to stock biomass relationship are consistent with biomass and MSY estimates from more sophisticated models of fishery population dynamics.

However, some scientists who have studied this fishery expressed scepticism about the estimates published in the Plenary report, and suggested that an alternative biology with a lower potential growth rate and a lower MSY also should be modelled. Accordingly, the alternative case b was developed with the some of the same key characteristics as case a, such as the levels of B_0, B_{msy}, B_{99},.and the same recruitment lag of three years, but with a growth coefficient of 5 rather than 10, and an MSY of 7,050t rather than 10,050t. Again, the hybrid

Richards/Ricker growth function was calibrated so that case b mimics the alternate population dynamics for SNA 1, and the parameter values are set out in Table 1.

TABLE 1. SNA 1 BASE CASE ESTIMATES: B0 IS VIRGIN BIOMASS, BMSY IS BIOMASS THAT SUPPORTS MSY, B99 IS ESTIMATED BIOMASS IN 1998–99, AND MSY IS MAXIMUM SUSTAINABLE YIELD

	B_0	B_{MSY}	B_{99}	MSY	r	a	d	u	NCC
Plenary case a	345,900	78,200	65,000	10,050	10	7.46%	7.1%	3	2,550
Alternate case b	345,900	78,200	65,000	7,050	5	19.0%	3.72%	3	2,250

The corresponding sustainable yield to stock biomass relationships are illustrated in Figure 11 below.

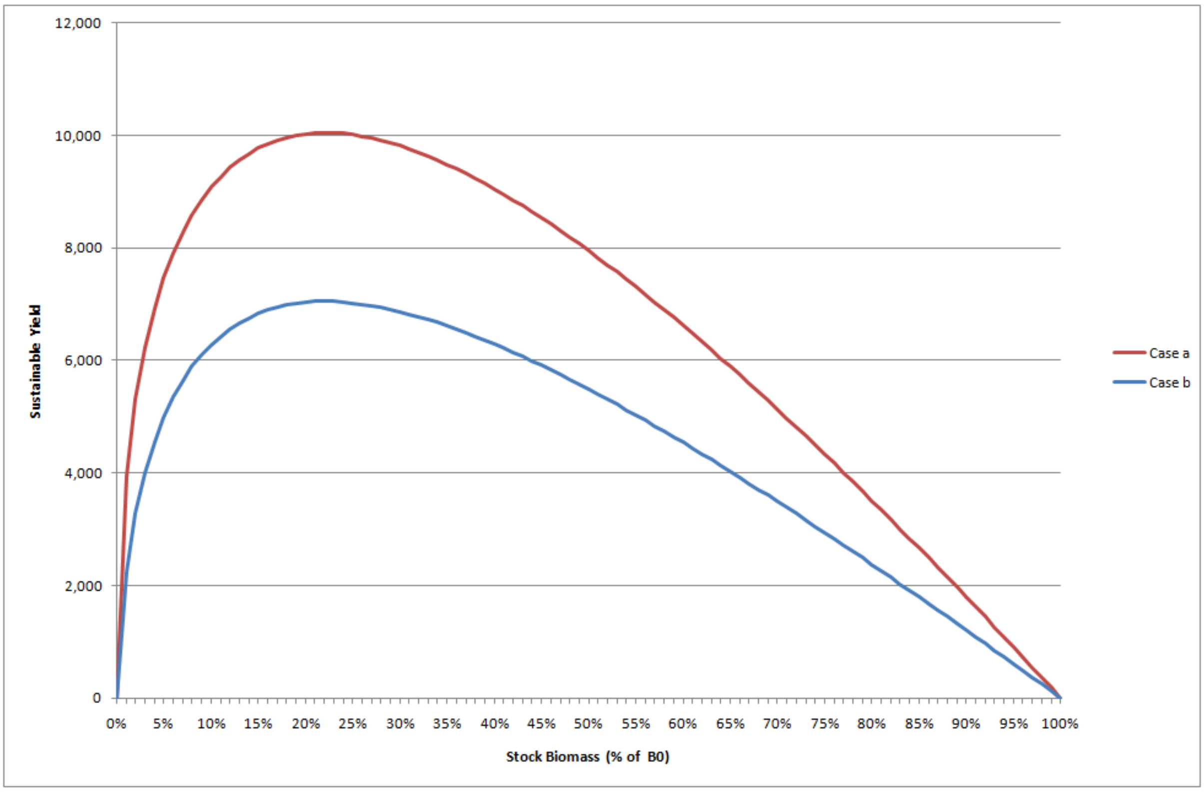

FIGURE 11. SUSTAINABLE YIELD TO STOCK BIOMASS RELATIONSHIP FOR PLENARY CASE A AND ALTERNATE CASE B SCENARIOS

Other assumptions in the bioeconomic model were:

- The key driver of stock allocation between the sectors is the TACC because the commercial sector is managed under a system of ITQs, while the recreational fishing sector is effectively open access.

- It will be assumed that the TACC is caught in the least cost manner, and that the annual value of the commercial catch to New Zealand will be equal to the product of annual catch in tonnes (CC) and the ACE value. Furthermore, in the long run, the demand for ACE will be perfectly elastic, and so will be invariant with respect to chosen level of the TACC.

- The current TACC is 4,500 tonnes.

- The ACE value for SNA 1 was $4,500/tonne

- The non-commercial sector is effectively an open access fishery in which fishing effort and catch rate are both likely to vary with stock biomass. Little is known about these relationships. Both are likely to increase with increasing stock biomass, but at a decreasing rate, so it was assumed the non-commercial catch is a linear function of stock biomass.

- Hartill et. al. (2007) estimated the recreational catch to be 2419 t in 2004-2005. On this basis, the annual non-commercial catch by 2010 was assumed to be 2,550 t for base case a, and 2,250 t for alternate biology case b.

- Annual value of the non-commercial catch is the product of the non-commercial in tonnes, and the recreational fishing value/tonne.

- A report by the SA Centre for Economic Studies (1999) estimated the value to New Zealand of the recreational catch for SNA 1 to be $5,790/tonne in 1998/99, which in current dollars is about $7,500/t, and one set of results is based on this assumed annual value of the non-commercial catch. Due considerable reservations about the methodology used to derive this value, a second set of results was based on an assumed value of $3,500/t as an approximation to net value as food.

- Another matter about which very little is known is whether the per unit value of the recreational catch is independent of stock abundance, or whether most recreational fishers place a premium value on catching larger fish and/or for a higher catch rate likely to be associated with a larger stock biomass. While cases a and b do not recognise such a premium, it is assumed in case c that as stock biomass increases above B_{msy}, the per unit value of the non-commercial catch does increase by a premium that starts at zero at B_{msy}, and increases to $2000/t under the most conservative catch allocation strategy evaluated.

- The model is a multi-year model because the starting level of fish stock, TACC, and initial level of recreational effort and catch, are unlikely to be consistent with a steady state equilibrium. Therefore, annual values of commercial and non-commercial catches from the stock were computed over a 100 year time frame, and annual values were discounted to present values (PV) using a discount rate of 5%.

To evaluate different catch allocation strategies, the model was run for the following assumptions:

i) Small TACC such that SSB = 50% of B_0
ii) Current TACC (e.g. 4500 t for SNA 1)
iii) Moderate TACC such that SSB = 40% of B_0
iv) TACC set so that combined catch = MSY

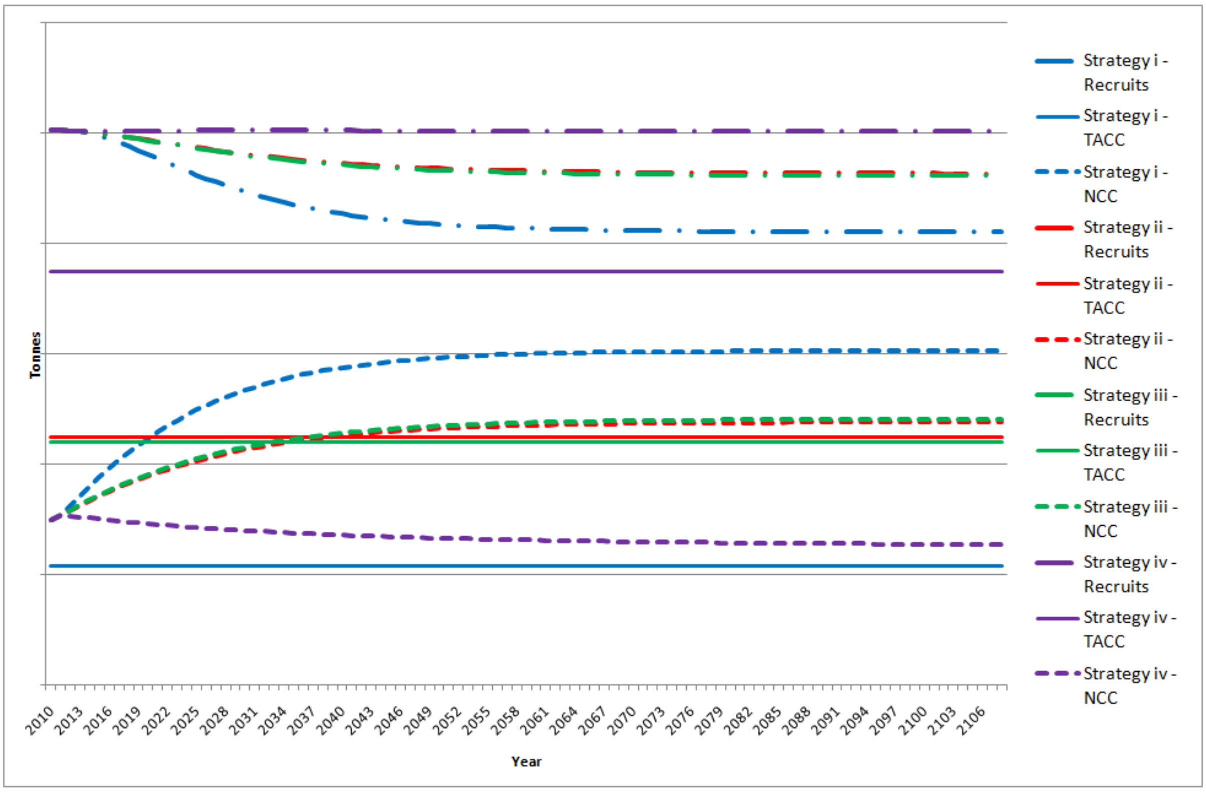

FIGURE 12. TIME PATH OF RECRUITS, COMMERCIAL CATCH, AND NON-COMMERCIAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR THE PLENARY BIOLOGY –CASE A AND CASE C.

Figure 12 illustrates the time path of annual recruits, commercial catch (=TACC), and non-commercial catch for four catch allocation strategies defined above for the plenary biology (i.e. case a and case c). Figure 13 illustrates how the same variables adjusted over time to equilibrium steady state levels for the alternate biology (i.e. case b and case d).

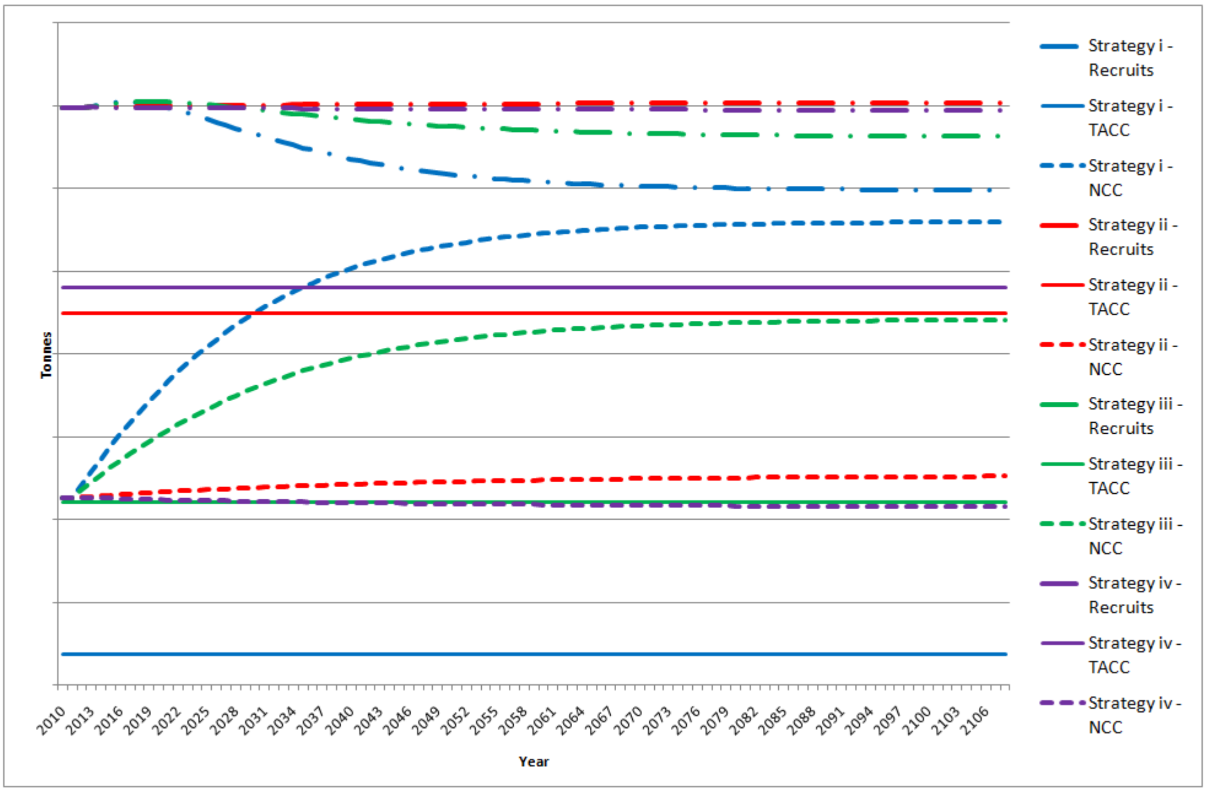

FIGURE 13. TIME PATH OF RECRUITS, COMMERCIAL CATCH, AND NON-COMMERCIAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR THE ALTERNATE BIOLOGY –CASE B AND CASE D

The estimated PV of benefits for the commercial catch, the non-commercial catch, and the combined total catch in SNA 1 for the four catch allocation strategies defined above for the plenary biology (i.e. case a) for two different assumptions about the unit value of the non-commercial catch that does not vary with stock biomass are set out in Table 2. Clearly, the MSY strategy is the superior catch allocation strategy for this case because even though the non-commercial catch will be larger at higher SBB levels; the more valuable commercial catch will be smaller both because sustainable yield (the cake) will be smaller, and because the non-commercial catch will be larger in absolute terms (a bigger piece out of a smaller cake). This result is robust with respect to the two assumed unit values for the non-commercial catch, although the margin of difference in value of the combined catch is greater for the lower unit value. This is because when the unit value of the non-commercial catch is greater, so to is the total value of the non-commercial catch, which means that increases in size of the non-commercial catch are more likely to offset falls in the size, and value of the commercial catch.

The same variables for the alternate biology (i.e. case b) are set out in Table 3. Again, the MSY strategy is the superior catch allocation strategy, and for essentially the same reasons. In comparison to case a, the assumed biology of the fishery in case b is more conservative resulting in a less productive fishery, and this is reflected in the lower values for the combined catch under all catch allocation strategies.

TABLE 2. STEADY STATE STOCK BIOMASS, TACC, AND PV OF COMMERCIAL CATCH, NON-COMMERCIAL CATCH, AND TOTAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR SNA 1 CASE A

SNA 1 plenary biology - base case a					
non-commercial catch unit value	**Strategy**	**i) SSB-50%**	**ii) Status quo**	**iii) SSB-40%**	**iv) MSY**
	TACC	2,154	4,500	4,415	7,500
	SSB	172,950	136,968	138,360	76,098
$3,500	PV CC	$212,571,144	$422,016,191	$414,431,390	$689,860,318
	PV NCC	$337,715,505	$284,664,641	$286,650,778	$208,684,916
	PV TC	**$549,351,311**	**$705,944,801**	**$700,338,403**	**$898,151,419**
$7,500	PV CC	$212,571,144	$422,016,191	$414,431,390	$689,860,318
	PV NCC	$723,676,081	$609,995,660	$614,251,667	$447,181,963
	PV TC	**$936,247,225**	**$1,032,011,850**	**$1,028,683,057**	**$1,137,042,280**

TABLE 3. STEADY STATE STOCK BIOMASS, TACC, AND PV OF COMMERCIAL CATCH, NON-COMMERCIAL CATCH, AND TOTAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR SNA 1 CASE B

SNA 1 alternate biology - case b					
non-commercial catch unit value	**Strategy**	**i) SSB-50%**	**ii) Status quo**	**iii) SSB-40%**	**iv) MSY**
	TACC	376	4,500	2,205	4,800
	SSB	172,950	85,481	138,360	76,098
$3,500	PV CC	$53,857,935	$422,016,191	$217,084,434	$448,800,603
	PV NCC	$280,352,880	$171,961,913	$234,918,318	$162,666,298
	PV TC	**$333,346,720**	**$593,588,623**	**$451,321,421**	**$611,134,054**
$7,500	PV CC	$53,857,935	$422,016,191	$217,084,434	$448,800,603
	PV NCC	$600,756,171	$368,489,813	$503,396,396	$348,570,639
	PV TC	**$654,614,105**	**$790,506,004**	**$720,480,830**	**$797,371,242**

TABLE 4. STEADY STATE STOCK BIOMASS, TACC, AND PV OF COMMERCIAL CATCH, NON-COMMERCIAL CATCH, AND TOTAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR SNA 1 CASE C

SNA 1 plenary biology - case c - premium for fish size and catch rate					
non-commercial catch unit value	**Strategy**	**i) SSB-50%**	**ii) Status quo**	**iii) SSB-40%**	**iv) MSY**
	TACC	2,154	4,500	4,415	7,500
	SSB	172,950	136,968	138,360	76,098
$3,500	PV CC	$212,571,144	$422,016,191	$414,431,390	$689,860,318
	PV NCC	$459,087,099	$337,254,779	$341,436,213	$208,684,916
	PV TC	**$670,188,454**	**$758,296,745**	**$754,875,990**	**$898,151,419**
$7,500	PV CC	$212,571,144	$422,016,191	$414,431,390	$689,860,318
	PV NCC	$845,047,676	$662,585,798	$669,037,102	$447,181,963
	PV TC	**$1,057,618,819**	**$1,084,601,988**	**$1,083,468,492**	**$1,137,042,280**

TABLE 5. STEADY STATE STOCK BIOMASS, TACC, AND PV OF COMMERCIAL CATCH, NON-COMMERCIAL CATCH, AND TOTAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR SNA 1 CASE D

SNA 1 alternate biology - case d - premium for fish size and catch rate					
non-commercial catch unit value	**Strategy**	**i) SSB-50%**	**ii) Status quo**	**iii) SSB-40%**	**iv) MSY**
	TACC	376	4,500	2,205	4,800
	SSB	172,950	85,481	138,360	76,098
$3,500	PV CC	$53,857,935	$422,016,191	$217,084,434	$448,800,603
	PV NCC	$375,278,538	$174,823,376	$281,268,400	$162,666,298
	PV TC	**$427,778,724**	**$596,433,104**	**$497,420,694**	**$611,134,054**
$7,500	PV CC	$53,857,935	$422,016,191	$217,084,434	$448,800,603
	PV NCC	$695,681,828	$371,351,276	$549,746,478	$348,570,639
	PV TC	**$749,539,763**	**$793,367,468**	**$766,830,911**	**$797,371,242**

Table 4 and Table 5 display the same variable values for case c (i.e. the plenary biology) and case d (i.e. the alternative biology), but these simulations have increasing rather than constant unit value of the non-commercial catch to reflect increasing fish size and/or catch rate as stock biomass increases above B_{msy}.

A comparison of the results for case a with those for case c, and for case b with those for case d, reveals that, as might be expected, for most catch allocation strategies the total value of the combined catch is larger when unit values are increasing with stock size rather than invariant. However, for the MSY catch allocation strategy, the comparison of the results reveals an apparent anomaly in that the combined catch value is identical for cases where unit values of the non-commercial catch are increasing with stock size, and cases where they are constant. The explanation for this “finding” is that stock biomass does not increase above B_{msy} because the TACC is set to equal the difference between sustainable yield at B_{msy} and the non-commercial catch at B_{msy}.

Furthermore, the MSY strategy is the superior catch allocation strategy again under all assumptions. Thus, given the assumed values for model parameters, a corner solution is still optimal in this particular case even though it was demonstrated in the last section that an interior solution is more likely when unit values for the non-commercial catch are increasing with stock biomass.

To sum up, the results in Table 2 through Table 5 indicate that the MSY catch allocation strategy (iv) (i.e. setting TACC to $TACC_{msy}$ to maintain stock biomass at B_{msy} and sustainable yield at MSY) is the optimal strategy for a wide range of different assumptions. This catch allocation strategy has the largest combined PV of CC plus PV of NCC for all of the evaluated assumptions about fishery biology, relative unit value of the non-commercial catch, and value premium for large fish and higher catch rate.

The KAH 1 case study

The state transition equation chosen to simulate the population dynamics for KAH 1 is based on a recruitment function that is a hybrid between a Richards and Ricker functional form as follows:

$$N_{t+u+1} = N_{t+u} + a_* N_{t*}[\exp\{r_*(1-(N_t/K)^d)-1\}]$$

Where: a is a calibrating coefficient
- d is another calibrating coefficient
- N_t is stock biomass in year t
- r is a growth rate coefficient
- u is a recruitment lag equal to the number of years it takes to reach sexual maturity
- K is the virgin or unfished stock biomass, otherwise described by B_0

The hybrid Richards/Ricker growth function was parameterised so that it mimics the population dynamics for KAH 1 in the sense that key features of the sustainable yield to stock biomass relationship are consistent with biomass and MSY estimates from more sophisticated models of fishery population dynamics. Because there is considerable uncertainty about the level of recreational harvest from KAH 1, in the two most plausible scenarios for the KAH 1 population stock taken from Hartill (2008), it is assume that annual recreational harvests are either 800 t or 1865 t. Estimates of key modelled quantities for these two scenarios are shown in Table 6, together with selected values for the calibrating coefficients.

TABLE 6. CALIBRATING COEFFICIENTS FOR THE HYBRID GROWTH FUNCTION FOR KAH 1 FOR TWO KEY SCENARIOS

	NCC (t)	B_0 (t)	B_{06} (t)	B_{MSY} (t)	MSY (t)	R	d	a	u
Case a	800	40,722	17,420	11,640	2,569	10	6.1%	23.3%	3
Case b	1,865	57,095	23,147	16,194	3,535	10	7.1%	13.1%	3

The corresponding sustainable yield to stock biomass relationship is illustrated in Figure 14.

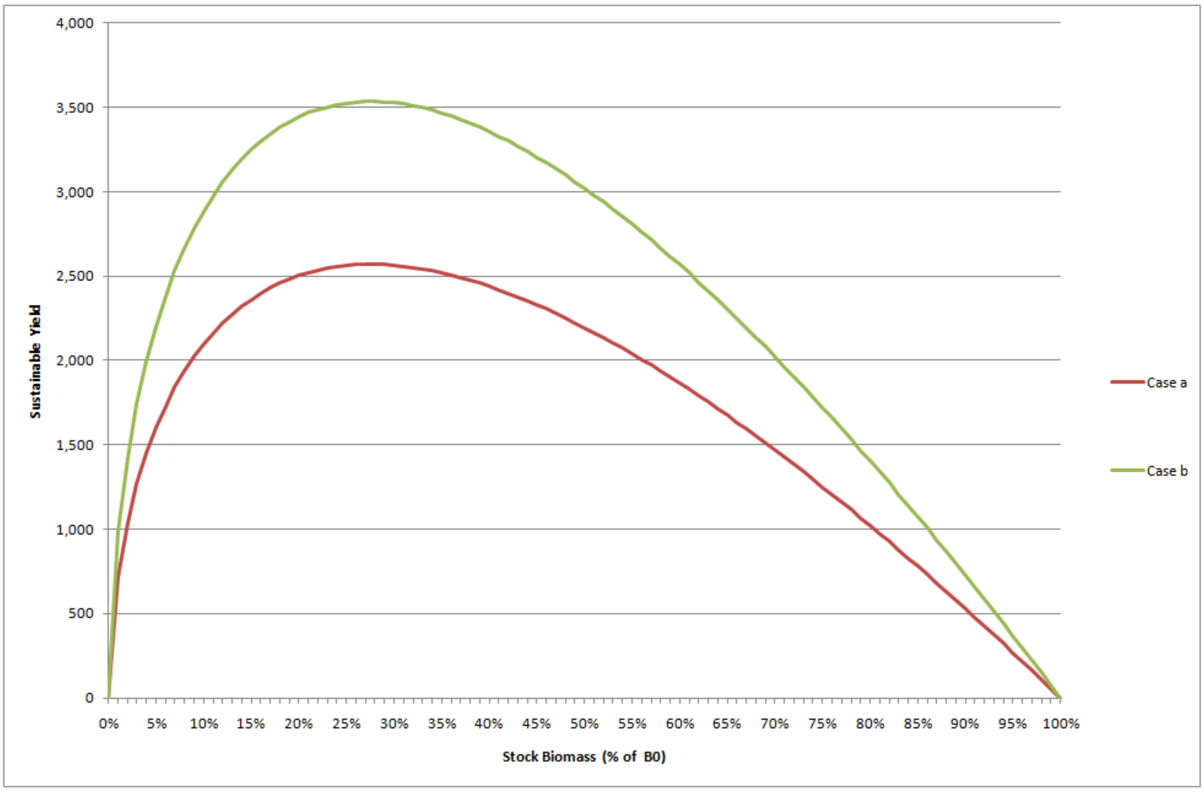

FIGURE 14. SUSTAINABLE YIELD TO STOCK BIOMASS RELATIONSHIP FOR KAH 1 FOR TWO SCENARIOS FROM HARTILL (2008)

Other assumptions in the bioeconomic model were:

- The key driver of stock allocation between the sectors is the TACC because the commercial sector is managed under a system of ITQs, while the recreational fishing sector is effectively open access.
- It will be assumed that the TACC is caught in the least cost manner, and that the annual value of the commercial catch to New Zealand will be equal to the product of annual catch in tonnes (CC) and the ACE value. Furthermore, in the long run, the demand for ACE will be perfectly elastic, and so will be invariant with respect to chosen level of the TACC.
- The current TACC is 1,075 tonnes.
- The ACE value for KAH 1 was $212/tonne[4]
- The non-commercial sector is effectively an open access fishery in which fishing effort and catch rate are both likely to vary with stock biomass. Little is known about these relationships. Both are likely to increase with increasing stock biomass, but at a decreasing rate, so it was assumed the non-commercial catch is a linear function of stock biomass.
- Hartill (2008) notes that the level of recreational harvest was one of the key sources of uncertainty about KAH 1. The biology of the fishery has been modelled on the assumption that the non-commercial catch was 1,865 t (case a) or 800 t (case b).
- Annual value of the non-commercial catch is the product of the non-commercial in tonnes, and the recreational fishing value/tonne.
- A report by the SA Centre for Economic Studies (1999) estimated the value to New Zealand of the recreational catch for KAH 1 to be $2,800/tonne in 1998/99, which in current dollars is about $3,500/t, and one set of results is based on this assumed annual value of the non-commercial catch. Because of considerable reservations about the methodology used to derive this value, a second set of results based on a much smaller assumed value of $350/t also was generated. This second value was estimated to be an approximation to the net value of kahawi as food, and as a value only slightly larger than the unit value of the commercial catch, even though there is strong and convincing anecdotal evidence that the unit value of the non-commercial catch is a lot larger than that for the commercial catch,

[4] This assumes that the market for ACE is fully contestable, so the returns derived by fishers and other fishing inputs just equals their opportunity cost.

- Another matter about which very little is known is whether the per unit value of the recreational catch is independent of stock abundance, or whether most recreational fishers place a premium value on catching larger fish and/or for a higher catch rate likely to be associated with a larger stock biomass. While cases a and b do not recognise such a premium, it is assumed in case c that as stock biomass increases above current levels, the per unit value of the non-commercial catch does increase by a premium that starts at zero at current levels of SSB, and increases to $500/t under the most conservative catch allocation strategy evaluated. Since other modelling seems to indicate that increases in KAH stock does not have much impact on the average fish size, this premium is most plausibly attributed to a higher catch rate and associated more frequent surface “boils” of schooling fish.

- The model is a multi-year model because the starting level of fish stock, TACC, and initial level of recreational effort and catch, are unlikely to be consistent with a steady state equilibrium. Therefore, annual values of commercial and non-commercial catches from the stock were computed over a 100 year time frame, and annual values were discounted to present values (PV) using a discount rate of 5%.

Estimates of the current stock biomass exceed B_{msy}, so the TACC would have to be increased above the current level to drive stock biomass down to B_{msy}. Four catch allocation strategies were evaluated, one being to maintain the current TACC, and another to limit the increase in stock biomass to 40% of B_0. Given uncertainty about the ongoing demand for the commercial catch, another strategy involved reducing the TACC to 500t which may approximate the size of Kahawai bycatch for commercial vessels targeting other species. The last strategy is a very conservative strategy designed to increase stock biomass to 60% of B_0. This target was achievable for the biology underpinning cases a and c by setting the TACC to 994t, but was not achievable for the biology underpinning cases b and d because at this level of stock biomass, the estimated non-commercial catch would exceed the sustainable yield. Hence, for cases b and d, the TACC was set to 680t to target a stock biomass ≥ 50% of B_0. Thus, the model was run for the following assumptions:

i) Bycatch only TACC = 500 t
ii) Conservative TACC (e.g. 994t for cases a and c, and 680t for cases b and d)
iii) Current TACC = 1075t
iv) Liberal TACC to achieve SSB = 40% (2308t for cases a and c, and 1492t for cases b and d).

Figure 15 illustrates the time path of annual recruits, commercial catch (=TACC), and non-commercial catch for four catch allocation strategies defined above for the biology underpinning case a and case c. Case a is based on a constant per unit value of non commercial catch which is independent of stock abundance. For case c, it is assumed that the per unit value of the non-commercial catch increases as stock biomass increases above B_{msy}. Note that for the biology underlying cases a and c, non-commercial catch increases for all four catch allocation strategies. As NCC is proportional to stock biomass, this indicates that SSB also increases for all four catch allocation strategies.

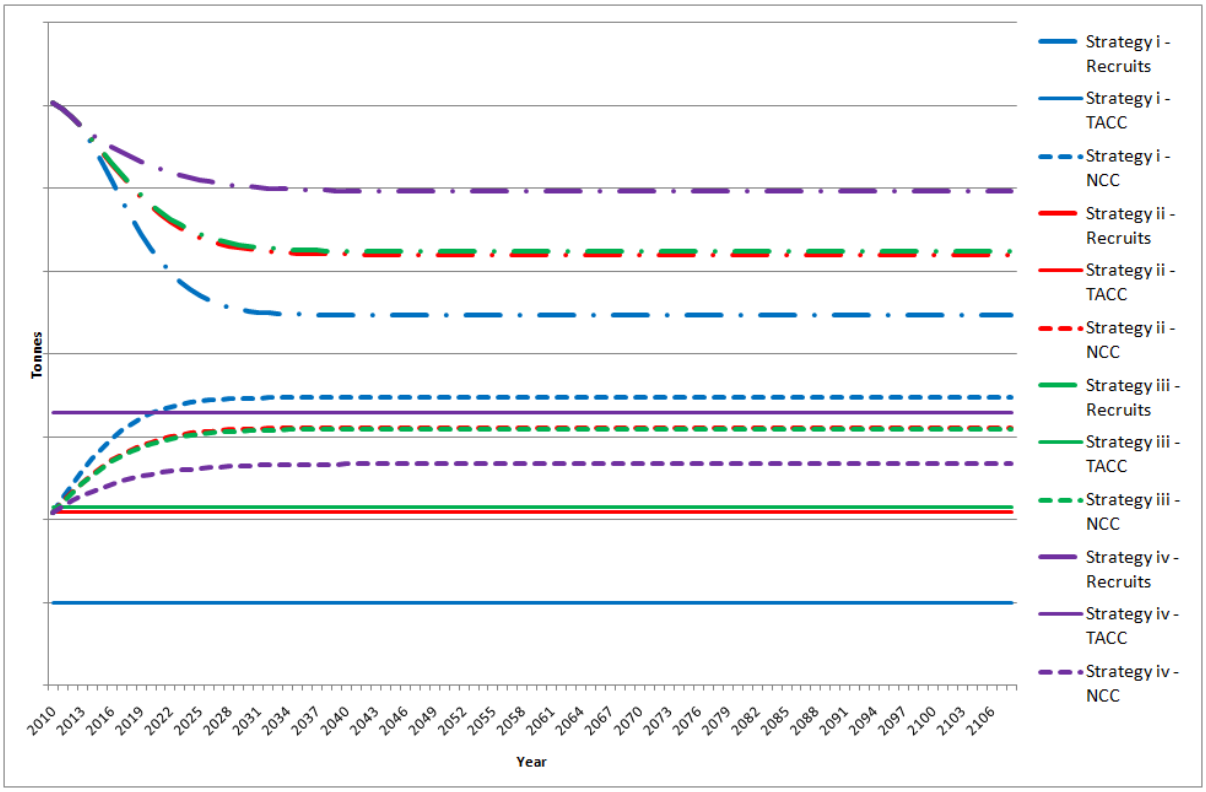

FIGURE 15. TIME PATH OF RECRUITS, COMMERCIAL CATCH, AND NON-COMMERCIAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR KAH 1 – CASE A AND CASE C.

Figure 16 illustrates how the same variables adjusted over time to equilibrium steady state levels for the alternate biology where case b assumes a constant per unit value of non commercial catch and c assumes that the per unit value of the non-commercial catch increases as stock biomass increases above B_{msy}. In contrast to the previous two cases, non-commercial catch and stock biomass only increases markedly for the by-catch only strategy, and do not change much for catch allocation strategy ii. For the other two catch allocation strategies, stock biomass actually decreases, so the unit value for the non-commercial catch will not increase over time, and there will not be a premium for these catch allocation strategies.

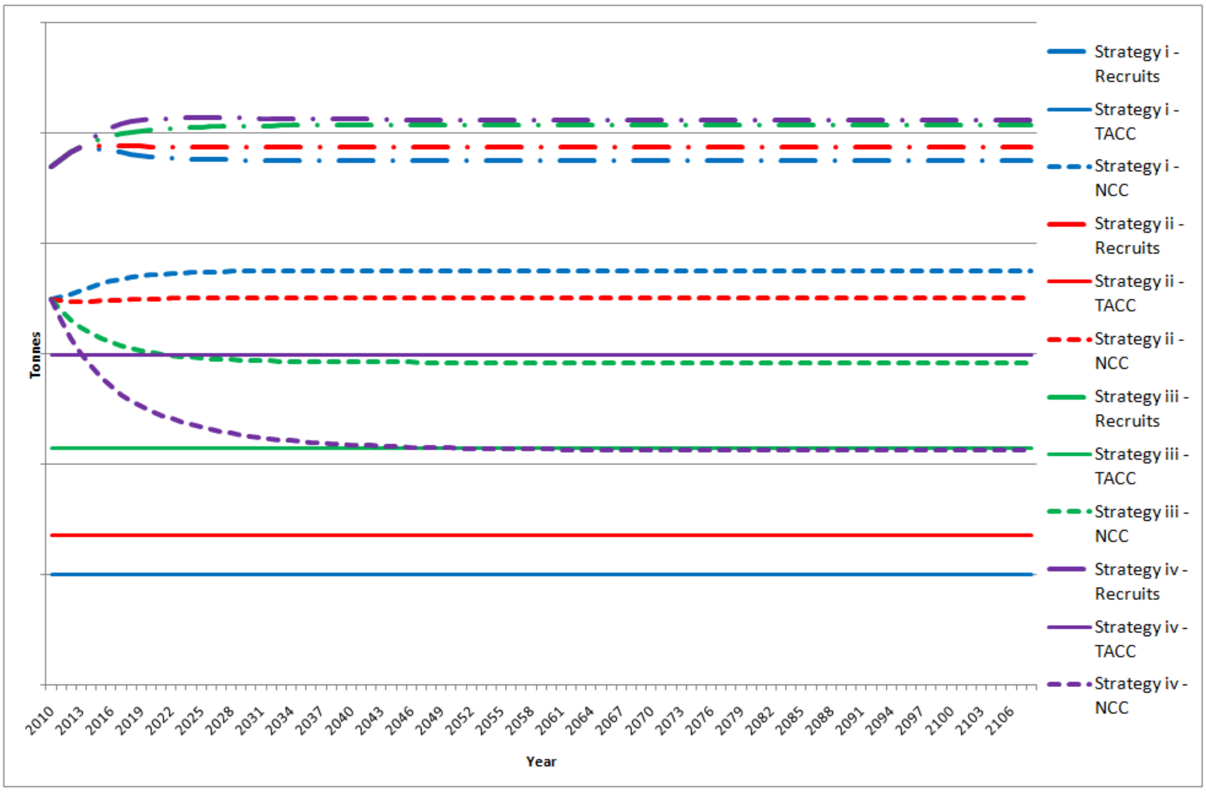

FIGURE 16. TIME PATH OF RECRUITS, COMMERCIAL CATCH, AND NON-COMMERCIAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR KAH 1 – CASE B AND CASE D.

The estimated PV of benefits for the commercial catch, the non-commercial catch, and the combined total catch in KAH 1 for the four catch allocation strategies defined above for biology case a for two different assumptions about the unit value of the non-commercial catch are set out in Table 7Table 7 The unit values for the non-commercial catch of $3500 and $350 do not vary with stock biomass.

Here the results are not as straightforward as for the snapper case study. If the assumed unit value of the non-commercial catch of $3,500 is correct, then the “by-catch only” catch allocation strategy involving the smallest TACC yields the largest combined catch value because the very large difference in value between the non-commercial catch and the commercial catch means that combined catch value will be maximised by maximising the former and minimising the latter. Furthermore, while it was not tested in the modelling exercise, an upper bound corner solution setting the TACC equal to zero would probably yield the largest sustainable combined catch value. However, if the actual unit value of the non-commercial catch is only about 10% of that indicated by a previous economic study, and something like equal to the unit value for the commercial catch, then the catch allocation strategy involving the largest TACC evaluated generated the largest combined catch value. In fact, while an MSY catch allocation strategy was not evaluated because of doubts that the commercial sector would actually catch a TACC that was large enough to achieve B_{msy}. Also, there was greater community interest in reducing the TACC rather than increasing it. Again, a corner solution almost certainly would be optimal, but this time at the lower bound of B_{msy}. The logic is the same as for the snapper case study.

TABLE 7. TACC, STEADY STATE STOCK BIOMASS, AND PV OF COMMERCIAL CATCH, NON-COMMERCIAL CATCH, AND TOTAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR KAH 1 - CASE A

KAH 1 case a - constant unit value for non-commercial catch					
non-commercial catch unit value	**Strategy**	**i) Bycatch only**	**ii) SSB-60%**	**iii) Status quo**	**iv) SSB-40%**
	TACC	500	994	1,075	2,308
	SSB	37,814	33,873	33,647	29,105
$3,500	PV CC	$2,334,601	$4,630,518	$4,756,899	$7,158,133
	PV NCC	$112,694,428	$102,601,764	$102,030,991	$90,799,530
	PV TC	**$115,029,029**	**$107,232,282**	**$106,787,890**	**$97,957,663**
$350	PV CC	$2,334,601	$4,630,518	$4,756,899	$7,158,133
	PV NCC	$11,269,443	$10,260,176	$10,203,099	$9,079,953
	PV TC	**$13,604,044**	**$14,890,694**	**$14,959,998**	**$16,238,086**

Table 8 sets out the same variables for the alternate biology (i.e. case b). Again, the “by-catch only” strategy yields the largest total value for the combined catch if the unit value of the non-commercial catch is assumed to be $3,500. However, if the unit value of the non-commercial catch is assumed to be only $350, then the combined catch value is virtually the same for all of the catch allocation strategies evaluated, but with the combined catch value for catch allocation strategy iii being the largest by a small margin.

TABLE 8. TACC, STEADY STATE STOCK BIOMASS, AND PV OF COMMERCIAL CATCH, NON-COMMERCIAL CATCH, AND TOTAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR KAH 1 - CASE B

KAH 1 alternate biology case b - constant unit value for non-commercial catch					
non-commercial catch unit value	**Strategy**	**i) Bycatch only**	**ii) SSB-50%**	**iii) Status quo**	**iv) SSB-40%**
	TACC	500	680	1,075	1,492
	SSB	17,525	16,390	13,651	9,935
$3,500	PV CC	$2,334,601	$3,092,885	$4,756,899	$6,526,229
	PV NCC	$134,416,098	$127,774,511	$112,366,461	$93,866,949
	PV TC	**$136,750,699**	**$130,867,396**	**$117,123,360**	**$100,393,178**
$350	PV CC	$2,334,601	$3,092,885	$4,756,899	$6,526,229
	PV NCC	$13,441,610	$12,777,451	$11,236,646	$9,386,695
	PV TC	**$15,776,211**	**$15,870,336**	**$15,993,545**	**$15,912,924**

Table 9 and Table 10 display the results for case c (i.e. low non-commercial catch biology) and case d (i.e. the high non-commercial catch biology) for the simulations where the unit value of the non-commercial catch is increasing rather than constant reflecting the increase in fish size and/or catch rate as stock biomass increases above current levels. The starting unit values for non commercial catch are the same as in the constant unit value case, namely $3,500 and $350.

TABLE 9. TACC, STEADY STATE STOCK BIOMASS, AND PV OF COMMERCIAL CATCH, NON-COMMERCIAL CATCH, AND TOTAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR KAH 1 - CASE C

KAH 1 case c – increasing unit value for non-commercial catch					
non-commercial catch unit value	**Strategy**	**i) Bycatch only**	**ii) SSB-60%**	**iii) Status quo**	**iv) SSB-40%**
	TACC	500	994	1,075	2,308
	SSB	37,814	33,873	33,647	29,105
$3,500	PV CC	$2,334,601	$4,630,518	$4,756,899	$7,158,133
	PV NCC	$125,604,298	$111,398,614	$110,613,912	$95,583,061
	PV TC	**$127,938,899**	**$116,029,132**	**$115,370,810**	**$102,741,194**
$350	PV CC	$2,334,601	$4,630,518	$4,756,899	$7,158,133
	PV NCC	$24,179,313	$19,057,026	$18,786,020	$13,863,484
	PV TC	**$26,513,913**	**$23,687,544**	**$23,542,919**	**$21,021,617**

TABLE 10. TACC, STEADY STATE STOCK BIOMASS, AND PV OF COMMERCIAL CATCH, NON-COMMERCIAL CATCH, AND TOTAL CATCH FOR FOUR CATCH ALLOCATION STRATEGIES FOR KAH 1 - CASE D

KAH 1 alternate biology case d – increasing unit value for non-commercial catch					
non-commercial catch unit value	**Strategy**	**i) Bycatch only**	**ii) SSB-50%**	**iii) Status quo**	**iv) SSB-40%**
	TACC	500	680	1,075	1,492
	SSB	17,525	16,390	13,651	9,935
$3,500	PV CC	$2,334,601	$3,092,885	$4,756,899	$6,526,229
	PV NCC	$135,599,253	$127,774,511	$112,366,461	$93,866,949
	PV TC	**$137,933,854**	**$130,867,396**	**$117,123,360**	**$100,393,178**
$350	PV CC	$2,334,601	$3,092,885	$4,756,899	$6,526,229
	PV NCC	$14,624,765	$12,777,451	$11,236,646	$9,386,695
	PV TC	**$16,959,365**	**$15,870,336**	**$15,993,545**	**$15,912,924**

Contrary to case a, in case c when unit values of the non-commercial catch increase as stock biomass increases, the "by-catch only" strategy dominates the other catch allocation strategies irrespective of whether starting unit values are small ($350) or large (3,500). The explanation is that as stock biomass increases, the value of the non-commercial catch increases at an increasing rate that more than offsets the combined impact of reduced sustainable yield for the fishery plus a rapid decline in value of the commercial catch. It will be noted from a comparison of Table 8 with Table 10 that the total value of the combined catch is the same for catch allocation strategies ii, iii, and iv because stock biomass declines rather than increases over the duration of the simulation, so there is no premium unit value for the non-commercial catch from larger stock biomass.

To sum up, the results in Table 7 through Table 10 illustrate the impact of the key assumptions. For the case where the unit value of non commercial fishing is held constant (Table 7 and Table 8) strategy i (by catch only with TACC=500t) yields the highest combined value of commercial and non commercial catch and is therefore preferred when the unit value of non commercial catch is assumed to be the high value of $3500. When the unit value of non commercial catch it is at the lower unit value of $350, strategy iv (liberal TACC to achieve SSB = 40% B_0) gives the highest combined value of commercial and non commercial catch. These results are driven by the differential in relative values of the non commercial catch compared to commercial catch.

The results for the case where the unit value of non commercial catch is assumed to increase as stock biomass increases above B_{msy}, are somewhat different (Table 9 and Table 10). When the unit value of non commercial catch increases with biomass, the conclusions are reinforced. For the low unit value of $350 strategy iv (liberal TACC to achieve SSB = 40%) yields the highest combined value of commercial and non commercial catch and is therefore preferred (Table 7), but when the unit value for non commercial catch is increasing from this value with increasing stock biomass, strategy i (by catch only with TACC=500t) yields the highest combined value of commercial and non commercial catch (Table 9).

For the alternate biology, when the unit value is the lower $350, strategy iii (status quo) yields the highest combined value of commercial and non commercial catch, but the aggregate value varies only marginally across the four strategies evaluated (Table 8). When the unit value for non commercial catch is increasing from this lower $350 value with increasing stock biomass, strategy i (by catch only with TACC=500t) yields the highest combined value of commercial and non commercial catch (Table 10) and is significantly superior.

These results emulate the cases described conceptually in Figure 9 and Figure 10. Importantly, when the per unit value of the non commercial catch is much larger than for the commercial catch, it is almost certain that closing the commercial fishery, and letting stock abundance increase, would not only maximise the value of the non commercial catch, but also maximise the combined value of the non commercial and commercial catch (which would be zero).

Summary and Conclusions

The advice below is specific to shared fisheries where the commercial catch is completely under the control of the fishery manager; while the non-commercial catch at any given stock biomass level is effectively self regulating. The advice is as follows:

1. Virtually the only regulatory instrument available to the fishery manager to allocate the available catch between the commercial fishing sector and the non commercial fishing sector is to set the TACC, and then let stock biomass, non-commercial catch, and sustainable yield (SY) adjust to equilibrium levels consistent with the chosen TACC
(i.e. such that SY=TACC+NCC).
2. If the TACC is set at too high a level, no sustainable equilibrium catch allocation will be achievable, and the TACC will have to be reduced to a level consistent with B_{msy} (i.e. $TACC_{msy}$).
3. Hence, the sustainable range for TACC is: $TACC_{msy} > TACC > 0$, and the corresponding range to target for the spawning stock biomass (SSB) is $B_{msy} < SSB < B^*$.
4. Marginal value to recreational fishers of reallocating one tonne from the commercial catch (i.e. by reducing TACC by one tonne) equals the increase in aggregate annual value of the non-commercial catch from the consequential increase in stock biomass due to:
    - Extra non-commercial catch from a higher catch rate
    - Extra non-commercial catch from greater effort motivated by more value

- Non-commercial catch valued more highly because bigger fish are caught
- Non-commercial catch valued more highly because of higher catch rates

5. The primary determinants of the optimal catch allocation are:
   - the **relative** size of the aggregate increase in annual value to recreational fishers from an increase in stock biomass due to a unit decrease in the TACC **vis-à-vis** the value of one unit of ACE to the commercial fishing sector
   - whether the aggregate increase in annual value to recreational fishers from an increase in stock biomass is constant, or increases as stock biomass increases
6. The secondary determinants of the optimal catch allocation are:
   - the biology, and in particular the population dynamics of the fishery
   - the nature of the functional relationship between the self regulating non-commercial catch and stock biomass. (In particular, how does non-commercial effort respond to an increase in stock biomass; and how does the non-commercial catch rate respond to an increase in stock biomass? In aggregate, is the non-commercial catch coefficient (ϕ) invariant with respect to stock biomass, or does it vary as stock biomass varies?)
7. If the unit value of the non-commercial catch differs markedly from the unit value of the commercial catch, the optimal catch allocation is quite likely to be a corner solution where TACC is equal to either zero or to $TACC_{msy}$.
8. A fairly general result is that if the unit value of the non-commercial catch is less than that for the commercial catch, then provided that both values are constant at all catch levels, the value of the combined catch from both sectors of a shared fishery will be maximised by setting the TACC so that the level of spawning stock biomass (SSB) equals B_{msy}. In other words, $TACC_{msy}$, the TACC consistent with an equilibrium level of stock biomass equal to B_{msy}, is likely to be optimal provided that the size of the aggregate increase in annual value to recreational fishers from an increase in stock biomass due to a unit decrease in the TACC is **smaller than** the value of one unit of ACE to the commercial fishing sector.
9. Alternatively, when the annual value to recreational fishers from an increase in stock biomass is **greater than** the value of one unit of ACE to the commercial fishing sector, and/or the former value increases as stock biomass increases, it is possible that the optimal catch allocation will be achieved by setting the TAAC such that $B_{msy} < SSB < B^*$. In other words, if the unit value of the non-commercial catch is greater than that for the commercial catch by a sufficient margin, then an upper bound corner solution where TACC = 0, and $SSB = B^*$ will be optimal.
10. Interior solutions, where $B_{msy}<SSB<B^*$, are more likely to be optimal if one or other unit values decrease as catch size increases, although corner solutions are still possible if the difference between unit value of the non-commercial catch and unit value of the commercial catch is sufficiently large.

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