Relative Effects of Mixed Stock Fisheries on Specific Stocks of Concern: Application to Fixed Escapements and Norton Sound Chum Salmon

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ABSTRACT: An algebraic model relating annual changes in harvest rate and catch of various fisheries to the percent of total catch in each fishery contributed by a particular stock is examined to explore implications pertaining to harvest sharing and related escapements. Results indicate that mixed stock fisheries, especially those in which the stock of concern composes a small proportion of the total catch, tend to achieve much of their proportional responsibility for fixed escapement without adjustment of total catch. More terminal fisheries with high contributions from a particular stock must adjust total harvests to achieve similar responsibility. Adjusting total catch of mixed stock fisheries to fully achieve a strict proportional sharing of escapement comes at a cost of many times the number of fish forfeited from the harvest compared to the number of fish added to the stock's escapement. Such additions to the escapement are often insubstantial. Harvest adjustments in single stock fisheries, however, provide a 1-fish benefit to the escapement for each fish forfeited from the harvest, and often such contributions compose a substantial portion of the total escapement objective. Implications for Norton Sound chum salmon *Oncorhynchus keta* escapements are explored for the South Peninsula June mixed stock fishery compared to more terminal fishing in Norton Sound.

INTRODUCTION

Obtaining accurate information on relative stock contribution to most mixed stock fisheries and evaluating a fishery's impacts on those component stocks is not an easy task. Stock identification of catches can be difficult and expensive, as can obtaining comprehensive and accurate information on annual total run or population size of each component stock, or even their relative vulnerability to various fisheries.

In my companion paper (Lloyd 1996 in this issue) an algebraic model is presented that is not so data-intensive and allows the relative impacts of various fisheries on a declining stock to be compared.

For fisheries managed on total catch or harvest rate, the model can be used to compare the relative impacts of various fisheries in which the stock or population in question composes different proportions of the catch. For salmon fisheries, however, which are often managed on fixed-escapement objectives rather than total catch or harvest rate (Eggers 1993), the model needs amendment. Here, those amendments are developed to explore proportional sharing of responsibility among fisheries to achieve that escapement. Two mixed stock salmon fisheries that reportedly harvest salmon from a common stock are used as a case study: the South Peninsula June (also known as False Pass) fishery and the Norton Sound salmon fishery on chum salmon *Oncorhynchus keta* spawning in Norton Sound.

METHODS

The model described in Lloyd (1996) relies upon general estimates or assumptions of (1) the proportion of the fishery's catch (ρ_x) composed of fish from a particular stock, and (2) the proportional change (θ_x) in population size exhibited by that stock from one period or year to the next. Model outputs describe annual (1) rates of change in total catch (θ_c) and stock-specific catch ($\theta_{c,x}$) of the fishery if harvest rate were to remain constant, and (2) rates of change in harvest rate ($\theta^*_{\mu,x}$) on the stock and in stock-specific catch ($\theta^*_{c,x}$) if total fishery catch were to remain constant.

Parameters and Definitions

Management of fisheries for constant or fixed escapement results in oscillating catches and harvest rates depending upon annual return size and consequent surpluses available for harvest once escapement is secured. Although actual escapements vary around fixed-escapement objectives, for purposes of this conceptual

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model it is sufficient to assume that actual escapement is equal to the fixed objective over time. In addition, fisheries close to spawning areas (i.e., terminal fisheries) are assumed to be managed directly for escapement objectives, whereas mixed stock fisheries further from spawning areas are generally managed under other criteria, such as constant total catch quotas or limits, because managers usually cannot assess stock run strengths or effect stock-specific fishing effort.

Recognizing these differences, the model is presented to produce comparisons of θ_c and $\theta_{c,x}$ under constant harvest rate and $\theta^*_{\mu,x}$ and $\theta^*_{c,x}$ under constant catch using the original derivation by Lloyd (1996). The model is then extended to examine the sharing of responsibility for providing fixed-escapement objectives by the respective fisheries. That responsibility is allocated in proportion to the fraction of the stock's harvestable surplus taken by each fishery in year 1. Similar to Lloyd (1996), I assume the specific stock of concern is the only one to change population size and that other aspects of vulnerability for all stocks to each fishery remain constant.

For fisheries managed under fixed escapement, begin with

$$E = \frac{N_{x,1}}{R}, \tag{1}$$

where E is the fixed-escapement objective, $N_{x,1}$ is the abundance of stock x in year 1, and R is the stock's presumed return per spawner. Then

$$C_{x,1} = N_{x,1} - E, \tag{2}$$

where $C_{x,1}$ is a fishery's catch of stock x (i.e., harvestable surplus) in year 1. To allow comparison of fisheries sharing responsibility for achieving escapements,

$$C_{x,1} = (N_{x,1} - E)(P_e), \tag{2a}$$

where P_e is the proportion of harvestable surplus of stock x allotted to each fishery being evaluated and as such reflects each fishery's proportionate responsibility toward achieving the stock's annual escapement objective.

A fishery's total catch, C_1, in year 1 is

$$C_1 = \frac{C_{x,1}}{\rho_{x,1}}, \tag{3}$$

where $\rho_{x,1}$ is the proportion of total catch composed of stock x in year 1.

Other initial parameters are similar to Lloyd's (1996) original derivation:

$$\mu_{x,1} = \frac{C_{x,1}}{N_{x,1}}, \tag{4}$$

where $\mu_{x,1}$ is the fishery's harvest rate on stock x in year 1, and

$$N_{x,2} = N_{x,1}(\theta_x + 1), \tag{5}$$

where $N_{x,2}$ is the stock size in year 2 and θ_x is the proportionate change in stock-x abundance from 1 year to the next.

Constant Harvest Rate

Assuming harvest rates remain the same in year 2 as in year 1, then derivation of change in stock-specific catch and total fishery catch is the same for fixed-escapement fisheries as it is in the general model (Lloyd 1996):

$$\theta_{c,x} = \frac{C_{x,2} - C_{x,1}}{C_{x,1}} = \theta_x,$$

and

$$\theta_c = \frac{C_2 - C_1}{C_1} = (\rho_{x,1}\theta_x).$$

These rates of change in catch result from decline in a component stock's return size and the fishery's consequently reduced catch of fish from that stock under a constant harvest rate. And because relative abundances of the stocks have changed in year 2, so has the proportion of total catch (ρ_x) composed of fish from stock x:

$$\rho_{x,2} = \frac{C_{x,2}}{C_2}. \tag{6}$$

Constant Total Catch

Derivation of change in stock-specific harvest rate and catch, if total fishery catch remained constant, is

also the same for fixed-escapement fisheries as in the general model (Lloyd 1996):

$$\theta^*_{\mu,x} = \frac{\mu^*_{x,2} - \mu_{x,1}}{\mu_{x,1}} = \frac{-(\rho_{x,1}\theta_x)}{1+(\rho_{x,1}\theta_x)} \ ,$$

and

$$\theta^*_{c,x} = \frac{C^*_{x,2} - C_{x,1}}{C_{x,1}} = \frac{\theta_x - (\rho_{x,1}\theta_x)}{1+(\rho_{x,1}\theta_x)} \ .$$

These rates of change in stock-specific harvest rate and catch result from the decline in the size of stock x and subsequent intensification of the fishery on the entire mixture of stocks to make up for the shortfall.

Constant Escapement

If, in the face of a stock's decline, in year 2 the fishery is constrained to achieve the same escapement objective as in year 1, then

$$C^\circ_{x,2} = N_{x,2} - E \ , \qquad (7)$$

where $C^\circ_{x,2}$ is the catch of stock x in year 2 under constant escapement. The refinement, P_e, can also be added here if more than 1 fishery bears responsibility for achieving escapements and thus must share the available surplus:

$$C^\circ_{x,2} = (N_{x,2} - E)\,(P_e) \ . \qquad (7a)$$

The resulting total catch for each fishery would become

$$C^\circ_2 = \frac{C^\circ_{x,2}}{\rho_{x,2}} \ , \qquad (8)$$

and the resulting fishery harvest rate on stock x would be

$$\mu^\circ_{x,2} = \frac{C^\circ_{x,2}}{N_{x,2}} \ . \qquad (9)$$

Model outputs, in terms of rates of change in total catch, stock-specific harvest rate, and stock-specific catch for a fishery under conditions of constant escapement, are

$$\theta^\circ_c = \frac{C^\circ_2 - C_1}{C_1} \ , \qquad (10)$$

$$\theta^\circ_{\mu,x} = \frac{\mu^\circ_{x,2} - \mu_{x,1}}{\mu_{x,1}} \ , \qquad (11)$$

and

$$\theta^\circ_{c,x} = \frac{C^\circ_{x,2} - C_{x,1}}{C_{x,1}} \ . \qquad (12)$$

The first output equation, which describes proportional change in total fishery catch, can be simplified in terms of ρ_x, θ_x, and R of stock x, plus P_e for each fishery. Substituting relationships from equations (3) and (8) results in

$$\theta^\circ_c = \left[\left(\frac{C^\circ_{x,2}}{C_{x,1}}\right)\left(\frac{\rho_{x,1}}{\rho_{x,2}}\right)\right] - 1 \ .$$

By applying various relationships from above, then

$$\frac{C^\circ_{x,2}}{C_{x,1}} = \frac{\left[R\left(\theta_x + 1\right)\right] - 1}{R - 1} \ .$$

For the other portion of this derivation, substitute relationships found in equations (4) and (5) from Lloyd (1996) and several here:

$$\frac{\rho_{x,1}}{\rho_{x,2}} = \frac{1 + \left(\rho_{x,1}\theta_x\right)}{\left(\theta_x + 1\right)} \ .$$

By recombining and simplifying, then

$$\theta^\circ_c = \left\{\frac{R - \left[1/\left(\theta_x + 1\right)\right]}{R - 1}\left[1 + \left(\rho_{x,1}\theta_x\right)\right]\right\} - 1 \ . \qquad (13)$$

The second output equation, describing proportional change in stock-specific harvest rate, can also be expressed in terms of input parameters by substituting relationships from equations (4) and (9):

$$\theta^\circ_{\mu,x} = \left[\left(\frac{C^\circ_{x,2}}{C_{x,1}}\right)\left(\frac{N_{x,1}}{N_{x,2}}\right)\right] - 1 \ .$$

This can then be expressed as

$$\theta^{\circ}_{\mu,x} = \left\{ \frac{R - \left[1/\left(\theta_x + 1\right)\right]}{R-1} \right\} - 1 . \qquad (14)$$

The third output equation, describing rate of change in stock-specific catch under constant escapement, can be simplified from equation (12) as in the derivation for θ°_{c}:

$$\theta^{\circ}_{c,x} = \left\{ \frac{R - \left[1/\left(\theta_x + 1\right)\right]}{R-1} \left(\theta_x + 1\right) \right\} - 1 . \quad (15)$$

RESULTS

Under constant escapement, proportional change in total fishery catch is a function of θ_x, R, and ρ_x:

$$\theta^{\circ}_{c} = \left\{ \frac{R - \left[1/\left(\theta_x + 1\right)\right]}{R-1} \left[1 + \left(\rho_{x,1}\theta_x\right)\right] \right\} - 1 .$$

Changes in stock-specific harvest rate and in stock-specific catch are a function of R and θ_x, but not ρ_x:

$$\theta^{\circ}_{\mu,x} = \left\{ \frac{R - \left[1/\left(\theta_x + 1\right)\right]}{R-1} \right\} - 1 ,$$

and

$$\theta^{\circ}_{c,x} = \left\{ \frac{R - \left[1/\left(\theta_x + 1\right)\right]}{R-1} \left(\theta_x + 1\right) \right\} - 1 .$$

Note that respective fishery allotment, P_e, of stock x and responsibility for achieving escapement objectives does not influence within-fishery, between-year comparisons of catch and harvest rate. However, respective values of P_e can be useful in considering numerical differences in catch and harvest rate between fisheries, as well as in calculating the numerical contribution to total escapement provided by the respective "savings" obtained by reducing total catch in various fisheries.

To compare common management regimes for mixed stock fisheries (e.g., constant total catch quotas or limits) against those for more terminal fisheries (e.g., fixed escapement) harvesting a shared stock of concern, further development of this model is possible. For example, if the respective fisheries were allowed to maintain constant total catch in the face of a stock's decline, then what relative proportion of each fishery's adjustment of stock-specific catch needed to provide its complete proportional "share" of total escapement would be satisfied? This can be calculated by the equation

$$\frac{C_{x,1} - C^{*}_{x,2}}{C_{x,1} - C^{\circ}_{x,2}} = \frac{\theta^{*}_{c,x}}{\theta^{\circ}_{c,x}} = \frac{\left[\dfrac{\theta_x - \left(\rho_{x,1}\theta_x\right)}{1 + \left(\rho_{x,1}\theta_x\right)}\right]}{\left\{ \dfrac{R - \left[1/\left(\theta_x + 1\right)\right]}{R-1} \left(\theta_x + 1\right) \right\} - 1} . \qquad (16)$$

Figure 1 displays this relationship for 3 values of stock decline for each of 3 presumed rates of return per spawner. Because of a slightly increased harvest of other stocks in the mix, all curves for fisheries with low ρ_x show substantial satisfaction of proportional adjustment to stock-specific catch, even if total catch is not reduced. Fisheries with high ρ_x, however, show little or no adjustment in stock-specific catch.

In addition to satisfying a portion of these adjustments to stock-specific catch, the portion of the fishery's full share of responsibility toward the fixed-escapement objective, when total catch remains constant, can be expressed as follows:

$$\frac{\left(P_e N_{x,2}\right) - C^{*}_{x,2}}{P_e E} = \left(\theta_x + 1\right) \left\{ \frac{1 + \left[R\left(\rho_{x,1}\theta_x\right)\right]}{1 + \left(\rho_{x,1}\theta_x\right)} \right\} . \quad (17)$$

Figure 2 displays this relationship for 3 values of stock decline for a single return per spawner ($R = 2.0$). When ρ_x of a fishery is high and as stock decline becomes more severe, substantially less responsibility for proportional sharing of escapement is satisfied when total catch remains constant. Under the same conditions, there is substantially greater accommodation of responsibilities for sharing of fixed escapement by fisheries of low ρ_x.

It is apparent from Figures 1 and 2, however, that not the entire share of stock-specific catch reductions,

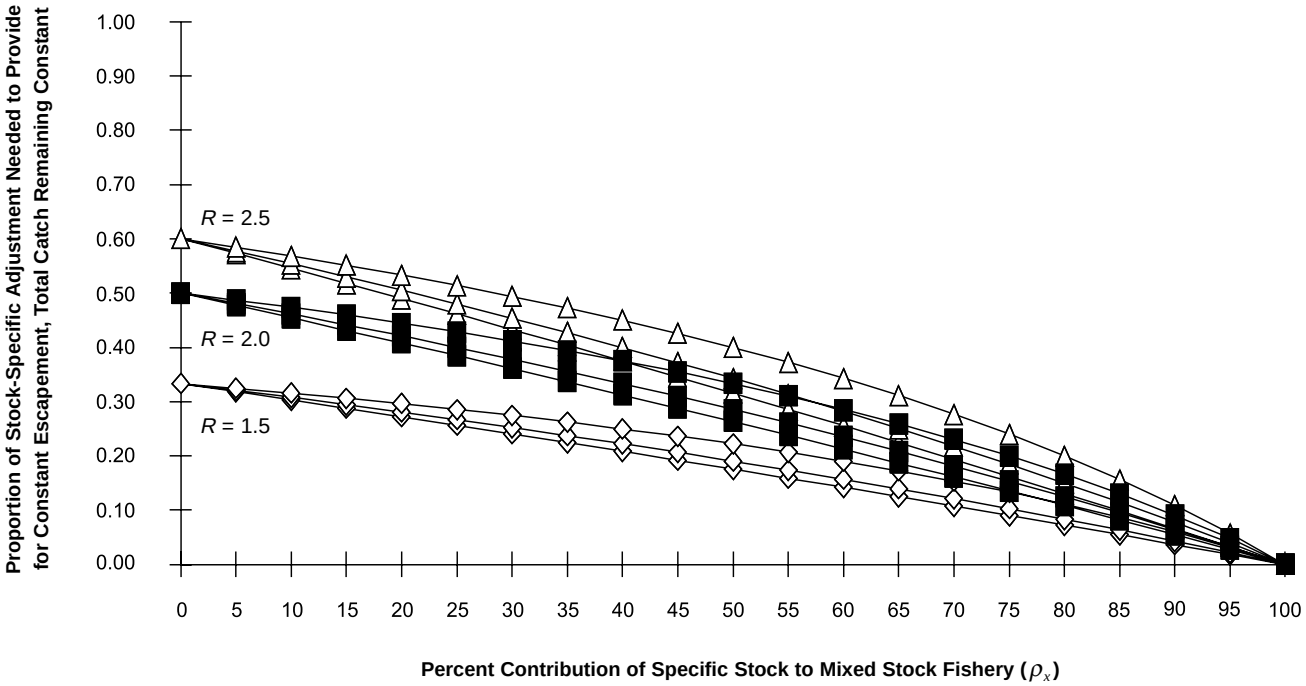

Figure 1. Relative performance of adjustments needed to satisfy constant escapement, with total catch remaining constant, at 3 levels of stock decline, θ_x = -0.1 (upper), -0.25 (middle), -0.50 (lower), and at 3 different presumed returns per spawner, R = 1.5 (triangles), 2.0 (squares), 2.5 (diamonds).

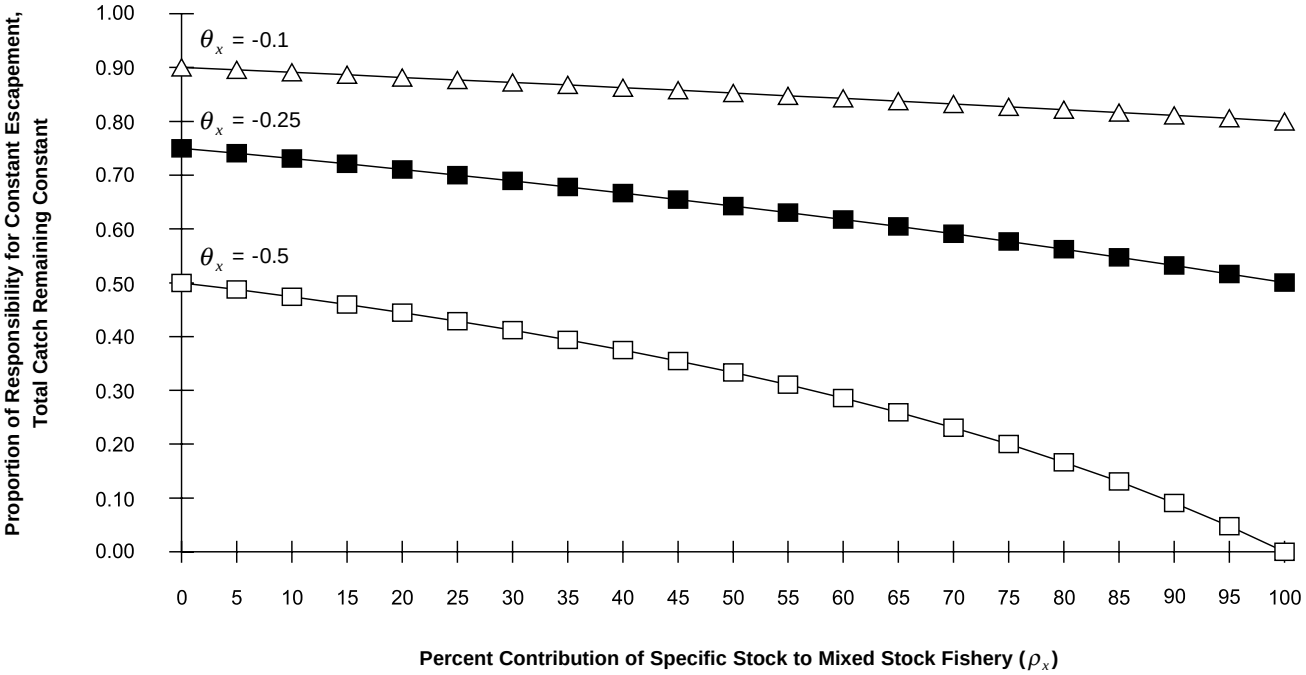

Figure 2. At various levels of stock decline (θ_x = -0.1, -0.25, -0.5) and R = 2.0, portion of responsibility in achieving fixed escapement when total catch is constant.

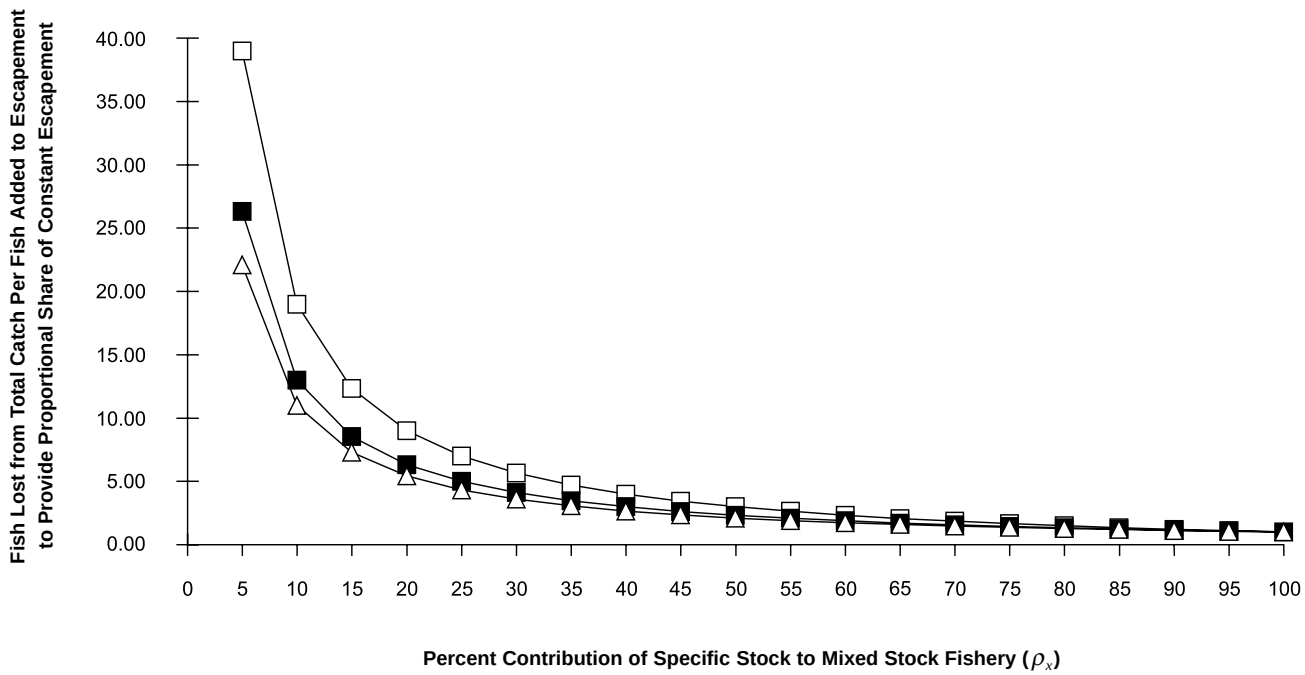

Figure 3. Relative cost from total catch of providing remainder of proportional escapement, not otherwise provided at constant total catch, at 3 levels of stock decline: θ_x= -0.1 (triangles), θ_x= -0.25 (solid squares), and θ_x= -0.5 (clear squares).

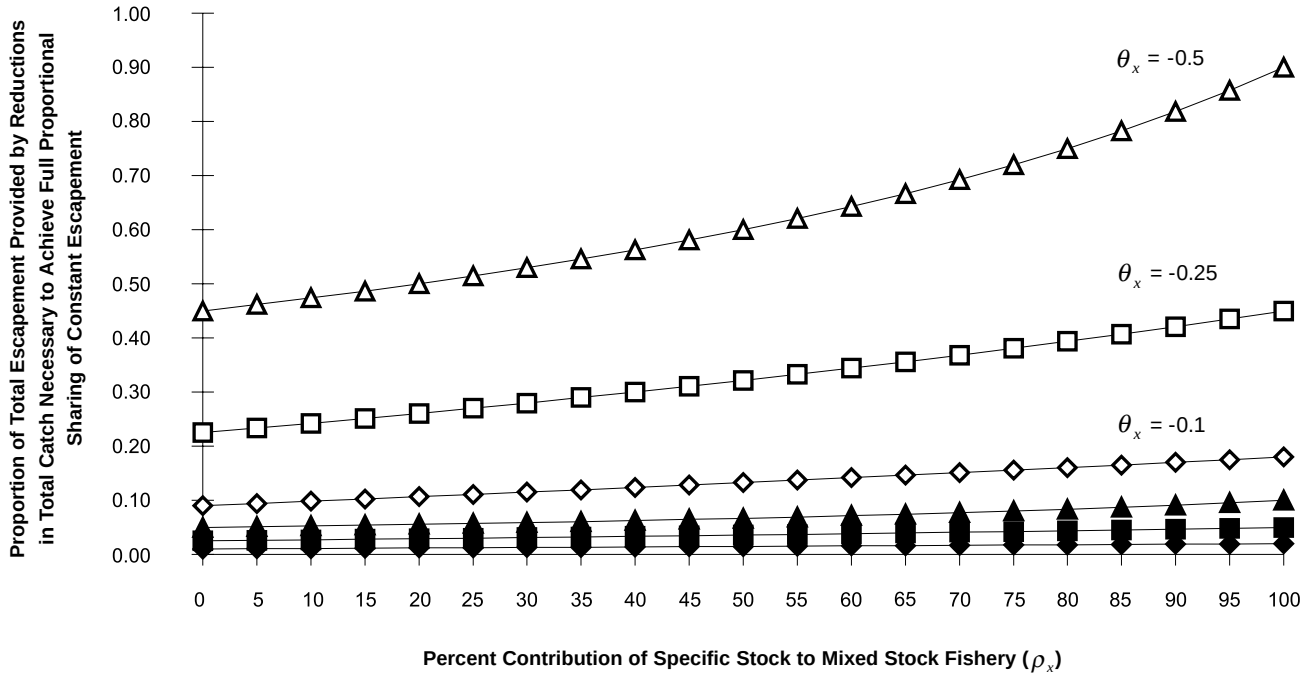

Figure 4. Proportion of total escapement provided by reductions in total catch necessary to achieve complete proportional sharing of constant escapement at P_e = 0.1 (closed symbols) and 0.9 (open symbols), R = 2.0, and at various levels of stock decline.

nor full share of contributions to total escapement, are made automatically, even by mixed stock fisheries. Therefore, reductions in total catch would be required to completely fulfill responsibility toward fixed escapement. In terms of reduced total catch, the cost of providing the remaining incremental adjustment not already provided under conditions of constant total catch can be calculated by the equation

$$\frac{C_2^* - C_2^\circ}{C_{x,2}^* - C_{x,2}^\circ} = \frac{1}{\rho_{x,2}} = \frac{1 + \left(\rho_{x,1}\theta_x\right)}{\rho_{x,1} + \left(\rho_{x,1}\theta_x\right)} \quad . \quad (18)$$

Figure 3 depicts this relationship and shows that each fish forfeited from total catch in a single stock fishery (ρ_x = 1.0) is applied toward that fishery's responsibility in maintaining constant escapement. As ρ_x becomes low, however, the relative cost in forfeited total catch increases dramatically for each fish added to stock-*x* escapement. This relative cost becomes very high at very low ρ_x.

Finally, it is of interest to estimate the relative value toward total escapement that such reductions in total catch provide:

$$\frac{C_{x,2}^* - C_{x,2}^\circ}{E} = (R-1)(P_e)\left(\theta_{c,x}^* - \theta_{c,x}^\circ\right) =$$

$$[R-1][P_e]\left\{\frac{\theta_x - \left(\rho_{x,1}\theta_x\right)}{1 + \left(\rho_{x,1}\theta_x\right)} - \left[\left(\frac{R - \frac{1}{(\theta_x + 1)}}{R-1}(\theta_x + 1)\right) - 1\right]\right\}. \quad (19)$$

Here, values for P_e are needed in addition to inputs for *R*, θ_x, and ρ_x. For a limited set of such values, Figure 4 illustrates the proportion of total escapement provided by reducing total catch in an amount required to achieve complete proportional sharing of constant escapement. This figure illustrates the primary importance of P_e. At low P_e, as usually exhibited by mixed stock fisheries, only a small portion of the stock's total escapement objective would be supplied by reductions in total catch under any conditions of stock decline. At high P_e, as usually exhibited by terminal fisheries, the severity of stock decline (θ_x) and the proportion of total catch composed of stock *x* (ρ_x) more substantially influence the proportion of total escapement provided by reductions in total catch. For fisheries with high P_e it becomes increasingly important to reduce total catch in order to achieve constant escapement objectives, especially as ρ_x increases and as θ_x becomes more severe.

In summary, results exhibited in Figures 1–4 indicate that mixed stock fisheries (low ρ_x) tend to automatically provide substantial portions of their share of incremental reductions in stock-specific catch needed to achieve constant escapement, even when the stock declines and total mixed stock fishery catch remains constant (Figures 1, 2). This is because reduced abundance of stock *x* in the fishery's total catch is compensated by increased pressure exerted upon the suite of other available stocks. If total catch in the mixed stock fishery is reduced to provide the needed additional escapement for stock *x*, then this comes with added cost: for each additional fish provided to the stock-*x* escapement, many more fish must go unharvested (Figure 3). Furthermore, the percent of stock-*x* escapement provided by the reduced total catch in the mixed stock fishery (low ρ_x and usually low P_e) is often small (Figure 4).

Results are clearly different for terminal fisheries (high ρ_x). In the face of stock decline, little or no adjustment for escapement needs is made if total catch remains constant (Figures 1, 2). Reducing total fishery catch to provide needed stock-*x* escapement provides about a 1:1 benefit in added escapement (Figure 3). In addition, the proportion of total escapement provided by these adjustments of total catch can be substantial, especially in the face of severe stock declines (Figure 4).

Because most management concern centers around response to stock decline, these equations have thus far been displayed for $\theta_x < 0$. However, they can be equally applicable to increases in stock size and thereby show the relative benefits of increased abundance of a specific stock to fisheries with low and high ρ_x. Figure 5 compares management regimes for mixed stock fisheries (constant total catch) and terminal fisheries (constant escapement) by depicting the differences between changes in stock-specific catch at constant total catch ($\theta_{c,x}^*$) and constant escapement ($\theta_{c,x}^\circ$) for fisheries of various ρ_x at both a 25% reduction and a 25% increase in stock size. Figure 6 depicts the differences between changes in total fishery catch under the same conditions of θ_x = -0.25 and +0.25.

When stock size increases, benefits of increased stock-specific and total fishery catch accrue more substantially to single stock fisheries (high ρ_x), whereas such benefits are again diluted by the presence of other stocks in mixed stock fisheries (low ρ_x). Further, for those mixed stock fisheries managed under catch quo-

tas or limits, total catch may not be allowed to increase so much as to take full advantage of a major increase in the single stock's abundance. Under these conditions, the mixed stock fishery would contribute more than its complete share toward the stock's escapement objective, which may actually promote a reallocation of harvest opportunity to more terminal fisheries.

CASE STUDY

As indicated in tagging experiments conducted by the Alaska Department of Fish and Game (ADF&G) in 1987 (ADF&G 1992), some Norton Sound chum salmon are captured almost 1,000 mi away in the mixed stock fishery off the South Alaska Peninsula during June. Although Norton Sound harvests have declined since the early 1980s (Buklis 1994), there has been ongoing fishing within Norton Sound on these salmon as well.

Because most escapements and subsistence harvests in Norton Sound are unknown, Buklis (1994) used a conservative return per spawner of 2.0 to estimate an average annual total chum run of 346,000 fish for 1980–1989. This was composed of local commercial plus subsistence harvests of 173,000 and an average escapement of 173,000, for a 50% exploitation rate. These harvest estimates did not include harvest allowances for the South Peninsula or elsewhere.

The South Peninsula June fishery on the other hand has, since the mid 1980s (except for 1987), been restricted to a chum harvest limit currently set at 700,000 fish per season. The actual average catch for the period 1980–1989 was calculated from McCullough et al. (1994) to be approximately 550,000 chum salmon.

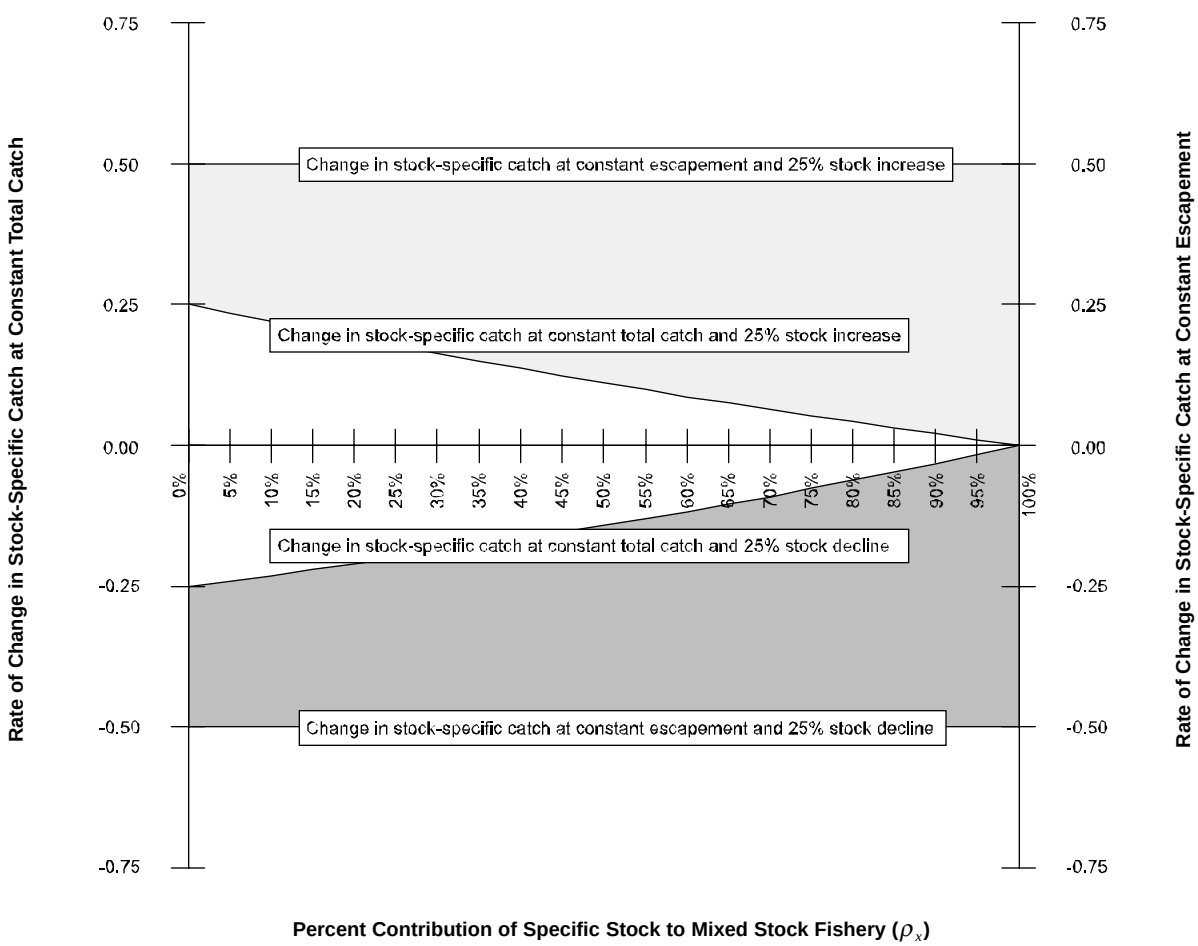

Figure 5. Comparison of potential changes in stock-specific catch, given total fishery catch remains constant or escapement remains constant, for a stock declining and gaining by 25% (θ_x = -0.25 and +0.25) and having an R = 2.0.

To estimate the proportion of the June fishery chum harvest composed of Norton Sound chum salmon, Eggers (1995) evaluated genetic stock identification information (Seeb et al. 1995) about the 1993/1994 South Unimak portion of the June fishery. Eggers concluded that a median scenario (Case 2) of the previous 1987 ADF&G tagging study best represented approximate stock composition within the June fishery as a whole. This was combined with revisions to the tagging study (ADF&G 1992) that estimated the contribution of Norton Sound chum salmon to the separate Shumagin Islands and South Unimak portions of the South Peninsula June fishery harvest. A weighted average of these estimates against harvest numbers produced an approximate average contribution of Norton Sound chum salmon to the South Peninsula June fishery of about 3.7%. Applying this percentage to average total catch yielded an estimated average catch of 20,320 Norton Sound chum salmon in this fishery. Adding this figure to the average return estimated without this catch produced an average Norton Sound chum salmon return of almost 370,000 fish.

In 1993 much of western Alaska suffered a notable drop in the chum salmon run; the estimated total run of 276,000 for Norton Sound was 80% of the 1980–1989 average estimate of 346,000 (Buklis 1994). With these inputs and presuming the Norton Sound fishery harvests only Norton Sound chum salmon (ρ_x = 1.0), the conceptual model described above can be used to compare relationships of these disparate fisheries to the Norton Sound chum runs (Table 1).

The model projects that, under constant harvest rate, total chum catch in the South Peninsula June fishery would decrease by 4,070, which reflects the decline from average conditions to those present in 1993. The Norton Sound fishery under the same scenario would decline by 32,930 fish. For the Peninsula fishery θ_c = -0.0074 while for Norton Sound θ_c = -0.20. In other words, catch in the Peninsula fishery would need to have been reduced by <1% of its original level to have kept harvest rates the same, but in the face of the same stock decline, the Norton Sound fishery catch would need to have been reduced by 20%.

If in 1993 both of these fisheries' harvests were maintained at their average levels, in spite of the shortfall of Norton Sound chum salmon (θ_x = -0.20), then the harvest rate of Norton Sound chum salmon would have barely increased from 5.50% to 5.54% in the Pen-

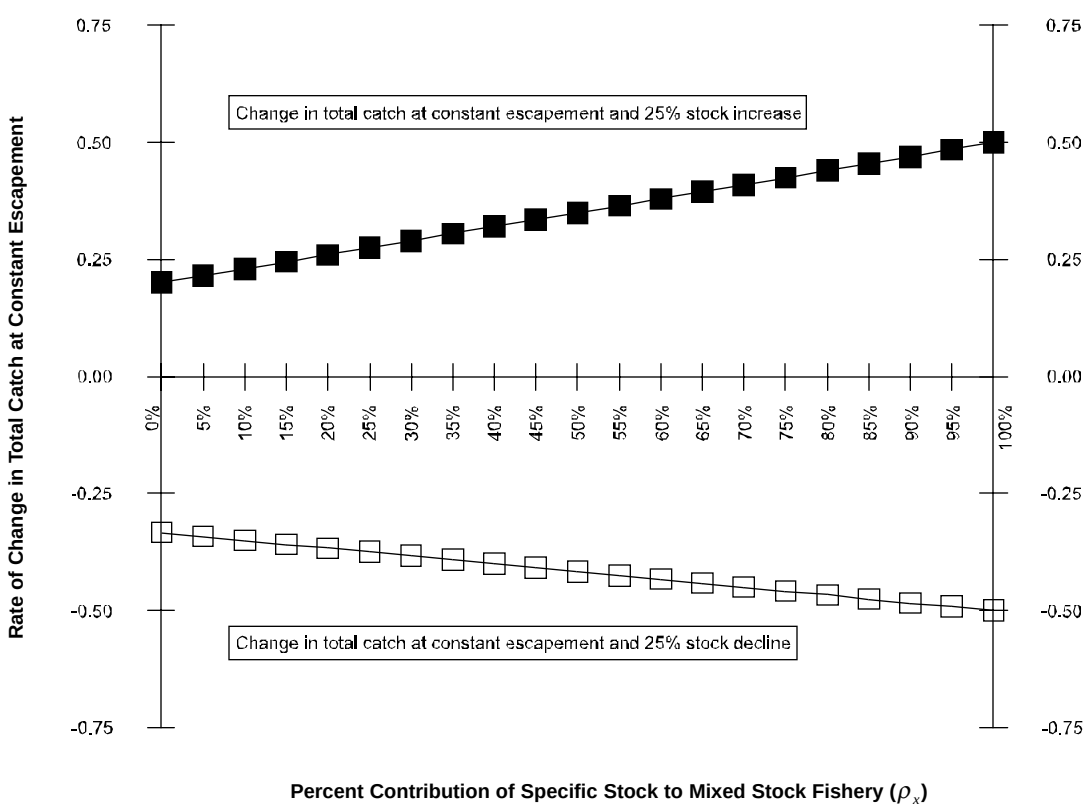

Figure 6. Changes in total fishery catch given escapement remains constant for a stock declining and gaining by 25% (θ_x = -0.25 and +0.25) and having an R = 2.0.

Table 1. Model worksheet and illustration for South Peninsula June and Norton Sound fisheries on Norton Sound chum salmon, prior to and during 1993.

	Model Parameters	S. Pen. June Fishery Number of Fish	S. Pen. June Fishery Rates and Percents	Norton Sound Fishery Number of Fish	Norton Sound Fishery Rates and Percents
Inputs					
Initial conditions:					
Average stock size (fish)		370,000		370,000	
Average total fishery chum catch		550,000		164,650	
Average proportion of fishery catch composed of stock in question	ρ_x		0.037		1.000
Resulting number of fish from stock harvested in average fishery		20,350		164,650	
Resulting average fishery harvest rate on stock of concern			5.50%		44.50%
Average return per spawner	R		2.00		2.00
Fixed escapement	E	185,000		185,000	
Total harvestable surplus		185,000		185,000	
Proportional management for escapement; access to harvestable surplus	P_e		0.11		0.89
Proportional change in stock size, from average to 1993	θ_x		-0.20		-0.20
Illustration					
For constant harvest intensity (harvest rate):					
Stock size in 1993		296,000		296,000	
Number of fish to be taken from stock in 1993, at same fishing intensity		16,280		131,720	
Decline in total fishery catch		-4,070		-32,930	
Resulting total fishery catch		545,930		131,720	
1993 proportion of stock in the fishery catch			2.98%		100.00%
Proportional change in total catch			-0.74%		-20.00%
Proportional change in stock-specific catch			-20.00%		-20.00%
On to constant harvest level (total catch):					
Increase in harvest to make up deficit		4,070		32,930	
Resulting total fishery catch		550,000		164,650	
1993 proportion of stock in the fishery catch			2.98%		100.00%
Additional fishery harvest of stock of concern		121		32,930	
Total 1993 harvest of stock of concern		16,401		164,650	
Resulting harvest rate on stock of concern			5.54%		55.63%
Proportional change in harvest rate			0.75%		25.00%
Proportional change in stock-specific catch			-19.40%		0.00%
On to constant escapement:					
1993 harvestable surplus of stock of concern		111,000		111,000	
Access to harvestable surplus		12,210		98,790	
Proportion of stock in fishery catch			2.98%		100.00%
Resulting total fishery catch		409,448		98,790	
Resulting harvest rate on stock of concern			4.13%		33.38%
Proportional change in stock-specific catch			-40.00%		-40.00%
Proportional change in harvest rate			-25.00%		-25.00%
Proportional change in total catch			-25.56%		-40.00%
Output (calculated directly from ρ_x, θ_x, and R)					
Constant harvest rate:					
Proportional change in total catch	θ_c		-0.01		-0.20
Proportional change in stock-specific catch	$\theta_{c,x}$		-0.20		-0.20
Constant total catch:					
Proportional change in harvest rate	$\theta^*_{\mu,x}$		0.01		0.25
Proportional change in stock-specific catch	$\theta^*_{c,x}$		-0.19		0.00
Constant escapement:					
Proportional change in stock-specific catch	$\theta^\circ_{c,x}$		-0.40		-0.40
Proportional change in harvest rate	$\theta^\circ_{\mu,x}$		-0.25		-0.25
Proportional change in total catch	θ°_c		-0.26		-0.40

Table 2. Model derivatives from consideration of constant escapement for Norton Sound chum salmon in the South Peninsula June and Norton Sound fisheries.

	Parameter or Equation	South Peninsula June Fishery	Norton Sound Fishery
Input			
Average proportion of fishery catch composed of stock in question	ρ_x	0.037	1.000
Average return per spawner	R	2.00	2.00
Proportional change in stock size, from average to 1993	θ_x	-0.20	-0.20
Proportional management for escapement; access to harvestable surplus	P_e	0.11	0.89
Output			
Percent reduction in stock-specific catch, of that needed to maintain constant escapement, if total catch remains constant	*Eq. 16*	48.51%	0.00%
Percent of full proportional responsibility toward fixed escapement provided under constant total catch	*Eq. 17*	79.40%	60.00%
Relative cost of reducing total catch to comply with full proportional share of escapement (1:1)	*Eq. 18*	33.53	1.00
Percent of total fixed escapement provided by reducing total catch	*Eq. 19*	2.27%	35.60%

insula fishery but would have increased dramatically from 44.50% to 55.63% in the Norton Sound fishery. This corresponds to $\theta^*_{\mu,x}$ for the Peninsula fishery of 0.0075 and $\theta^*_{\mu,x}$ for Norton Sound of 0.25. In other words, the Peninsula harvest rate on Norton Sound chum salmon would have increased by <1% of its average level compared to 25% for the Norton Sound fishery.

These values for change in total catch and harvest rate can be calculated directly from estimates or assumptions of ρ_x and θ_x alone. The simplified equations obviate the need for much of the data input normally associated with such an evaluation. And to provide these evaluations, specific estimates or assumptions for ρ_x do not need to be especially accurate, so long as ρ_x for one fishery is substantially different than ρ_x for another (Lloyd 1996). For example, if ρ_x for the South Peninsula June fishery was more appropriately twice the estimate of 0.037, and to account for possible contributions to the catch from neighboring stocks, ρ_x for Norton Sound was closer to 0.80 than 1.0, then changes in total catch and harvest rate for the respective fisheries would still be substantially different. Specifically, with θ_x still at -0.20, then θ_c = -0.015 for the Peninsula and -0.160 for Norton Sound and $\theta^*_{\mu,x}$ = 0.015 for the Peninsula and 0.191 for Norton Sound.

These changes in total catch and harvest rate, given very different presumptions about ρ_x for the respective fisheries, still are very similar to the original calculations, which shows that this model is fairly robust in the face of even the few assumptions that are used. The South Peninsula June fishery is only slightly influenced by and exerts only slight influence on fluctuations in Norton Sound stocks. This is not true for the Norton Sound fisheries, which rely much more heavily upon these fish.

Proportional sharing of constant escapement objectives are also depicted in Table 1. At a 20% stock decline and the original R = 2.0, $\theta^\circ_{c,x}$ for both fisheries is -0.4 and $\theta^\circ_{\mu,x}$ for both is -0.25. However, total catch of the South Peninsula June fishery (ρ_x = 0.037) would need to be reduced by approximately 26%, whereas that of the Norton Sound fishery (ρ_x = 1.0) would need to be reduced by 40%.

Further derivatives under constant escapement are shown in Table 2. For example, if total catch in the South Peninsula June fishery was maintained in the face of a 20% Norton Sound chum stock reduction, under a fixed quota or limit, the Peninsula fishery would still be providing 49% of its share of reductions in stock-specific catch. That is, the Peninsula fishery's full share of harvestable surplus and coincident responsibility for escapement is 11% of the total. When the stock declines by 20%, the June fishery stock-specific catch should decrease by 40% and total catch by 26% to fully achieve P_e = 11%. But with total catch remaining constant, stock-specific catch declines

by 19.4% automatically, which equals 49% of the escapement adjustment and facilitates proportional sharing. And though only about half of the escapement adjustment is accommodated, the Peninsula fishery still contributes over 79% of its total proportional share to total escapement.

If, however, the Norton Sound fishery were to keep total catch the same in the face of the same 20% stock decline, it would fail to contribute to the needed escapement adjustments, and would provide only 60% of its total proportional share toward fixed escapement (Table 2). In order for the Peninsula fishery to provide the remainder of its share of the escapement adjustment, total catch would need to be reduced by a factor of 33.5 fish for each fish added to the escapement. For the Norton Sound fishery, however, total catch would need to be reduced by only a factor of 1 fish for each fish added to the escapement.

Finally, the 26% (140,553 fish) reduction in total catch for the Peninsula fishery required to fulfill its share of constant escapement would provide only 2.27% (4,191 fish) of the total escapement. Conversely, the 40% (65,860 fish) reduction in total catch of the Norton Sound fishery would provide 35.6% (65,860 fish) of the total escapement. It is apparent that such harvest controls in the more terminal Norton Sound fishery are much more important, as well as cost effective, than similar adjustments to mixed stock harvests in the South Peninsula fishery.

DISCUSSION

Salmon stocks in Alaska are largely managed to meet a fixed escapement objective or range; the remainder of each run is made available for harvest. Unlike terminal areas, where individual run size can be assessed and target harvests and escapements readily controlled, more distant mixed stock fisheries rarely provide comparably accurate assessments of individual run strengths or the ability to selectively harvest a specific stock (Eggers 1993). Because of these limitations, more distant mixed stock fisheries are often allocated a set total harvest limit (quota or cap). Conversely, terminal fisheries oscillate, benefiting directly from strong runs and accommodating poor runs.

Changes in total catch to accommodate proportional sharing of harvestable surplus and fixed escapement objectives varies greatly among fisheries, depending primarily upon the percent contribution of that stock to the fishery's total catch (ρ_x). Moreover, the relative benefit of harvest reductions to the stock's escapement also varies greatly, depending upon the ρ_x and P_e of each fishery.

The results show that, per unit reduction in total fishery harvest, terminal fisheries, rather than mixed stock fisheries, will contribute more escapement for a stock of concern. These are fairly intuitive results. However, the mechanics of equivalent influence and effect of fluctuating stocks between these 2 types of fisheries has not been extensively explored. In Alaska such questions have become more pressing in light of a mixed stock salmon fishing policy adopted by the Alaska Board of Fisheries (State of Alaska 1993), which states, ". . . the burden of conservation shall be shared among all fisheries in close proportion to their respective harvest on the stock of concern."

Another conclusion, of pragmatic importance, is that lack of precise management control in effecting stock-specific harvest adjustments in mixed stock fisheries is not nearly so critical as lack of management effectiveness in terminal fisheries. Of further interest, the mixed stock fishery cost, in terms of forfeited overall harvests to provide stock-specific escapement, can be substantial, but when the stock of concern rebounds to above-average abundance, the mixed stock fishery is unlikely to receive a compensatory increase in its harvest of that stock. Instead, it will probably be constrained by a harvest quota or other limitation that prevents it from taking a proportional share of the surplus.

A specific stock's abundance is rarely known before the return approaches the terminal area, largely because preseason forecasts have not been very accurate. Therefore, stock declines or increases are speculative in mixed stock fisheries, making it difficult to fine-tune total catch to achieve constant escapement. Fortunately, as shown above, constant total catch in mixed stock fisheries inherently compensates, to a degree, for changes in a single stock's abundance and does not exert a substantial impact on the resulting escapement. In addition, constant catch over time, in the face of above- as well as below-average stock abundance, would forfeit potential shares of harvestable surplus in some years and slightly exceed them in others. Therefore, there would be little benefit from fine-tuning a mixed stock fishery catch with low ρ_x, and given unknown or poorly forecasted annual return strengths, forfeitures would frequently be unjust (i.e., when actual run reductions are less than expected).

These conclusions can be applied to the decade-old controversy over appropriate sharing of harvest of Norton Sound chum salmon between fisheries in Norton Sound and along the Alaska Peninsula. Com-

peting user groups have appealed to regulatory bodies, the state legislature, and the courts to assign harvest shares of these stocks. This has prompted attempts to more specifically estimate respective harvest levels, stock compositions, relative stock vulnerabilities, and stock-specific harvest rates (Eggers 1995) and to devise distinct conservation actions for the South Peninsula June and Norton Sound fisheries. This, unfortunately, has only exacerbated the debate by relying upon more and more detailed assumptions that stretch the already thin data available. Arguments over the validity of minor parameters and assumptions, such as a reporting fraction within the analysis of ADF&G's 1987 tagging study (ADF&G 1992), have ruled rather than served the debate. Recently, focus has centered on attempts to provide detailed estimates of respective harvest rates (Eggers 1995), as well as ongoing attempts to reduce the South Peninsula June chum harvest cap.

This conceptual model allows some basic questions and a number of scenarios to be more easily addressed without the need for detailed estimates that cannot be reliably developed from the available data. The model shows that substantial adjustments in the Norton Sound fisheries are needed to provide for fixed escapements in the face of fluctuating stock abundance. On the other hand, adjustments to catches in the South Peninsula June fishery are not nearly so important to the Norton Sound escapements. Even if such adjustments were attempted, the costs in forfeited harvests from the South Peninsula fishery would greatly exceed additions to Norton Sound escapements.

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Postnote

97 Mar 10 — An errata to this article can be found in Vol 3 nr 2, page 136. Go to the errata.

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