STOCK ENHANCEMENT IN SALMON & MAINTENANCE OF HISTORIC RUNS

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Stock enhancement in salmon & maintenance of historic runs

Ricker (1973) has recently shown that the failure of present day salmon fisheries to maintain historically high yields may be due in part to the fact that different stocks, which are subjected to the same fishing pressure, have different biological productivities, and the equilibrium maximum sustained yield may cause smaller less productive stocks to reach very low levels or even go extinct. The basis of this problem is that all stocks within a given river system are subjected to the same fishing rate, unless the timing of the runs of different stocks is quite different. Using the Skeena River as an example, large productive runs such as the Babine sockeye are harvested by the same fishery as smaller runs. The upper Babine run which comprises 300,000 to 500,000 fish has twice the biological productivity of the Bulkley-Nanika sockeye run which is comprised of only 10,000 to 30,000 fish. Since the maximum sustained yield harvest rate is higher for the Babine stock, and is so large in relation to the Bulkley-Nanika stock, the maximum sustained yield harvest rate for both stocks may well lead to the extinction of the Bulkley-Nanika. Historically this poses serious problems. Native Indian groups that relied on the smaller runs may not consider the overall maximum sustained yield to be optimum in any sense of the word. Arguments can also be made for preserving any stock that is currently in existence for a number of reasons. However, the most serious potential danger is that future enhancement projects may create new stocks with productivities higher than any current stocks, and in order to optimally harvest these new stocks or perhaps even to prevent them from damaging the spawning grounds of the natural stocks, a harvest rate may have to be imposed which seriously reduces the natural stocks. In the event of a collapse of the enhanced stocks due to unforeseen difficulties in the culture techniques or other unspecified problems, the entire fishery could collapse.

I wish to explore this problem in two ways. First I will analytically examine the relationship between two stocks subjected to the same fishery, and then test these conclusions against a much more complex numerical simulation model of a salmon fishery.

The analytic model

The basic relationship between spawners at time t+1 and spawners at time t was first formulated by Ricker (1954) and has become the accepted standard for salmon fisheries. The relationship is:

$$S_{t+1} = S_t * (1-c) * e^{a(1S_t/S_{max})} \qquad (1)$$

where:

- S = the number of spawners at time t or t+1
- c = the harvest rate
- a = a parameter of biological productivity
- S_{max} = the equilibrium value of S when c = 0

To derive the equilibrium stock size for any c we set $S_{t+1} = S_t$ and solve:

$$S_t = S_{t+1} \qquad (2)$$

$$S_t = S_t * (1-c) * e^{a(1-S_t/S_{max})} \qquad (3)$$

$$\ln(1) = a(1-S_t/S_{max}) * \ln(1-c) \qquad (4)$$

$$S_t = \frac{S_{max}}{a} (\ln(1-c)+a) \qquad (5)$$

To solve for the maximum sustained yield we know that the catch (C) is

$$C = \frac{S_{max}}{a} (\ln(1-c)+a)\ c \qquad (6)$$

Solving for the rate of change of C with respect to c and setting this equal to zero to get the maximum sustained yield we get

$$0 = \frac{S_{max}}{a}\left[\ln(1-c)+a\right] + c\,\frac{S_{max}}{a}\left[\frac{-1}{1-c}\right] \qquad (7)$$

$$0 = (\ln(1-c)+a) - \frac{1}{1-c} \qquad (8)$$

$$a = \frac{c}{1-c} - \ln(1-c) \qquad (9)$$

Equation 9 represents the relationship between the productivity (a) and the optimum catch rate. The optimum catch rate as a function of the productivity can be plotted by plotting 'a' as a function of c and then reversing the axes. The question we wish to eventually ask is at what harvest rate will a stock go to zero. If we know the S_{max} and 'a' of the old stock and a new one, and can solve for the optimum harvest rate, we would then be able to answer the question, will this stock go extinct. Using equation 5 the harvest rate at which the stock will go extinct can be derived as follows:

$$0 = \frac{S_{max}}{a}\left[\ln(1-c)+a\right] \qquad (10)$$

$$\ln(1-c) = -a \qquad (11)$$

I shall now solve the optimum harvest rate for a two species situation, and then calculate the values of S_{max} and 'a' which will lead to the extinction of the old stocks under management for maximum sustained yield. Using equation 6 for two stocks we know at equilibrium

$$C = \frac{S_{max\ 1}}{a_1}\left[\ln(1-c) + a_1\right] c + \frac{S_{max\ 2}}{a_2}\left[\ln(1-c)+a_2\right] c \qquad (12)$$

setting q=(1-c) and solving for $\frac{dC}{dq}$ and setting equal to zero we set

$$0 = \frac{S_{max2}}{a_1} \left[(\ln(q) 1 + a_1) \right] \frac{-1}{q2} + \frac{1 \cdot q}{q2} +$$

$$\frac{S_{max2}}{a^2} \left[(\ln(q) + a_2) \frac{-1}{q^2} + \frac{1-q}{q^2} \right] \quad (13)$$

$$\ln(1-c) - c = \left[\frac{S_{max1} a_2 (1-a_1) + S_{max2} a_1 (1-a_2)}{S_{max1}\ a_2 + S_{max2}\ a_1} \right] - 1 \quad (14)$$

Thus if we know the S_{max} and 'a' values for a specified pair of salmon stocks, we can derive,using a simple fitting procedure,the optimum harvest rate . Paulik et al. (1967) did this for the general case of n stocks using an iterative set of rules by ranking the stocks in order of their productivities. Calculating the optimum harvest rate we can then plug this into equation 5 to see if the less productive stock will go extinct. However it is not only the possibility of extinction that is a potential problem, fisheries managers may be concerned with any significant lowering of the natural stocks. In fact it is reasonable to assume that a charge they might be given in any enhancement program would be that i could not reduce the natural runs. It is easily demonstrated that no matter how small the S_{max} of a new stock might be, as long as its productivity was higher than the old stock, a higher harvest rate would then be optimum. Using the equations in this paper we are now able to analyze any possible combination of new and old stock parameters.

As an example of how equation 14 might be utilized, I have constructed figures 1 and 2. Fig.1 shows the equilibrium density of the old stock as a function of the S_{max} and 'a' values for a new stock. The old stock is assumed to be similar to the lower Babine sockeye (a=1.5, S_{max}=600,000), and the new stock was tested over a values from 1.0 to 3.0 and S_{max} from 0 to 2,000,000. The equlibrium density contours are drawn in for the remaining old stock. Fig.2 is similar to Fig. 1 except the total catch under maximum sustained yield is drawn as contours. A manager could play a number of games with these graphs. For example, given that any new sockeye stock we establish will have a productivity of x (perhaps 2.5), how big an enhancement facility can we create without lowering the equilibrium density of the old stock below a certain established minimum (perhaps 100,000). Going across the x axis to 2.5 and up to the 100,000 contour, we see that the S_{max} value we could use in order to maintain the 100,000 fish from the old stock, would be about 800,000. We could also see from figure 2 that in such a situation the optimum sustained yield would be around 1 to 1.2 million fish per year totalled from both the old and the new stocks. Similar management games could be played by saying, "how low will I reduce the old stock in order to get an optimum sustained yield as high as X". Variations on these themes are many, but there are two major flaws which provide the stepping stones for future work along these lines.

The obvious next approach is to construct similar diagrams from the large scale simulation models of salmon stocks which already exist , and use more realistic models of harvest (in general managers prefer to harvest at a lower rate than optimum sustain yield). This would require a great deal of simulation and is probably best done on a large computer. The second avenue of pursuit is to change the assumptions of the stock dynamics model. The Ricker model (equation 1) assumes no competition between the fry or smolts of the old and new stocks . What would happen if this assumption were changed? If we assume that each individual of the new stock competes equally with the old stock, then we would construct a "worst case" scenario, which would show what the results of enhancement would be at worst. This work is currently in progress.

FIGURE 1

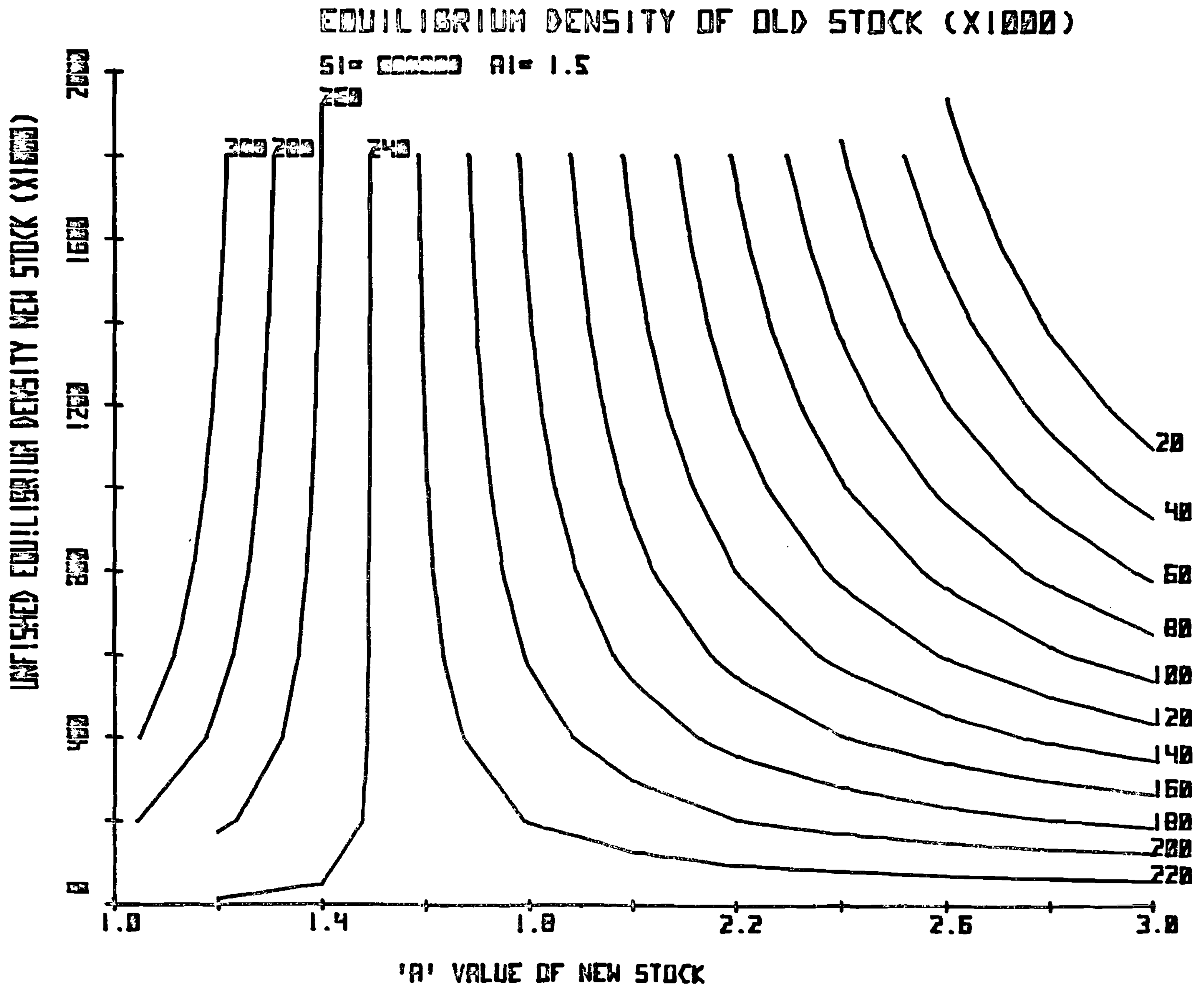
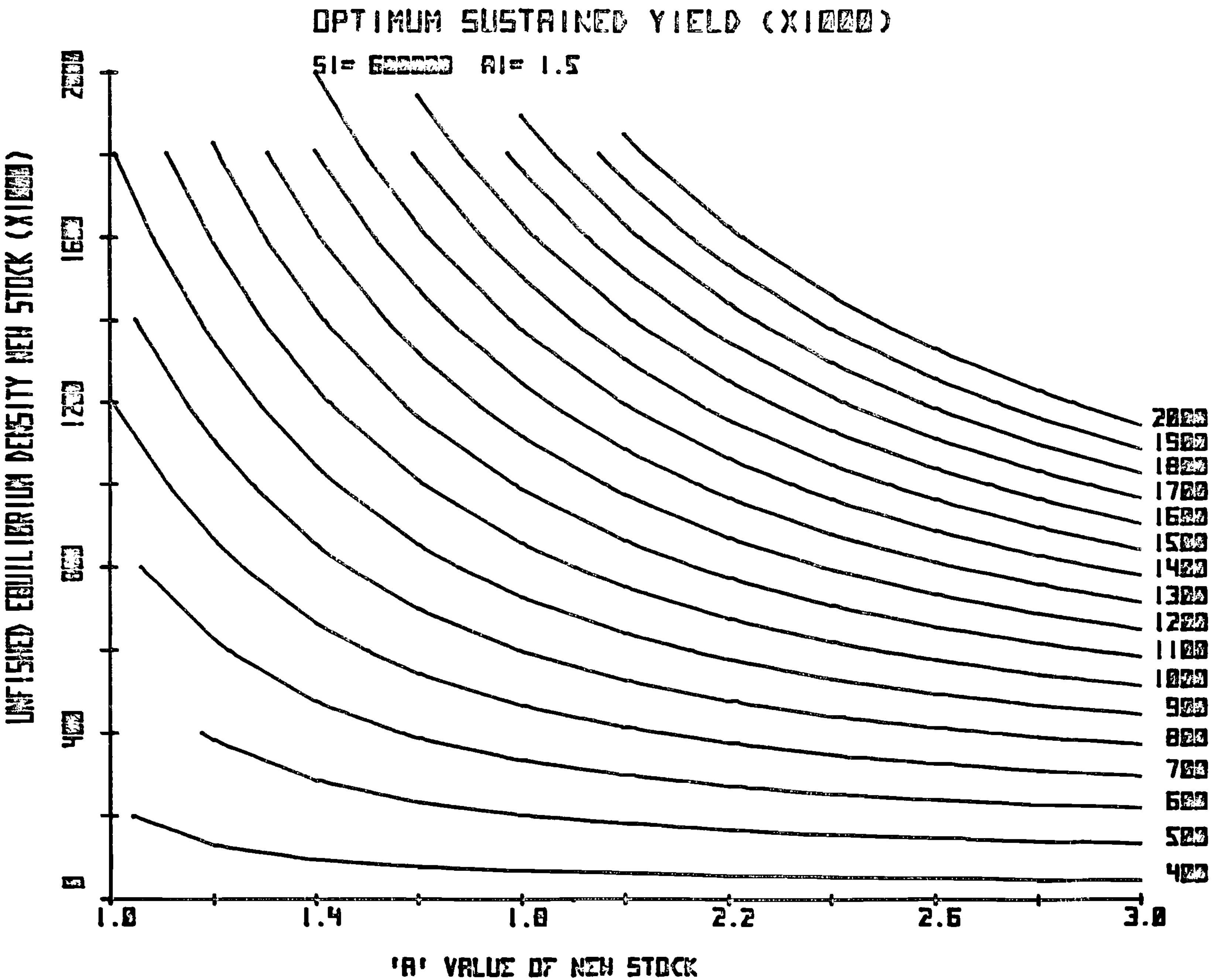

EQUILIBRIUM DENSITY OF OLD STOCK (X1000)
A1= 1.5
300
280
260
240
20
40
60
80
100
120
140
160
180
200
220
2000
1600
1200
800
400
0
1.0
1.4
1.8
2.2
2.6
3.0
'A' VALUE OF NEW STOCK
UNFISHED EQUILIBRIUM DENSITY NEW STOCK (X1000)

FIGURE 2


OPTIMUM SUSTAINED YIELD (X1000)
SI= 600000 AI= 1.5
UNFISHED EQUILIBRIUM DENSITY NEW STOCK (X1000)
2000
1600
1200
800
400
0
1.0
1.4
1.8
2.2
2.6
3.0
'A' VALUE OF NEW STOCK
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400

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