Current Analytic Concerns with Harvest Rate Management

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Abstract - Concerns with the implementation of harvest rate management can be lumped into two broad categories: strategic concerns - problems with the planning of a harvest rate management strategy, and tactical concerns - problems with actually carrying the strategy out. Strategic concerns are relevant for all management strategies while tactical concerns are more specific to harvest rate management. Strategic concerns include specification of a production function (stock-recruit relationship), estimation of stock productivity, and the problem of optimizing the harvest from fisheries that exploit both natural and hatchery fish. Harvest rate management was initiated for chinook salmon stocks of the Klamath River basin largely because of these strategic concerns. Implementation of harvest rate management has brought tactical concerns to the forefront. These include variability in the ocean distribution of Klamath basin stocks, unpredictability of the fishing industry response to attempts at managing harvest rates, and the imprecision of forecasts of the Klamath basin stocks. The future of harvest rate management will depend on the extent to which fisheries scientists are able to find solutions to these problems and the acceptability of the solutions to the management bodies and user groups.

When mathematicians speak of analytic problems they refer to problems that have analytic solutions. These are problems for which the solution can be expressed in closed form. The problems and concerns that I discuss here have no simple closed form solutions, but are concerns that relate to harvest rate management from the perspective of a fisheries analyst. These concerns can be divided into two broad categories: strategic concerns and tactical concerns. Strategic concerns are problems that relate to the development of a management strategy and tactical concerns are problems related to the implementation of the management strategy.

Strategic Concerns

All fisheries management depends on the premise that the per capita productivity of fish stocks is density dependent. When the density of a fish stock decreases, the growth rate of that stock increases, and when the density increases, the growth rate decreases. This means that if you harvest fish from a stock, the stock will tend to grow faster and will thus maintain itself, and if you stop harvesting a stock the growth rate will eventually slow so that the stock will not just continue to increase indefinitely. This density dependence is usually represented as a stock-recruitment relationship (SRR) which relates recruitment of fish in one generation to the spawning stock that produced it. We also know that any number of factors in addition to the size of the spawning stock influence recruitment and that this leads to variability about the SRR. However, in fisheries management, the size of the spawning stock is usually the only variable over which we have any direct control. If we can somehow characterize a stock's SRR, and the variability about it, then we can devise a harvest strategy that will optimize the yield from that stock.

There is no reason why the SRR of any stock of fish should be governed by any mathematical equation. Ideally what we would like to know is the probability distribution of recruitment for each possible spawning stock size. Unfortunately, if we picked just 10 stock levels and could somehow control the stock so that we could exactly achieve these levels, and we used just 10 recruitment observations to characterize the variability about the SRR at each stock level, it would take at least 100 years to accumulate the data, and by then the SRR would probably have changed. Instead, we assume some functional form for the SRR to reduce the amount of data required to estimate the relationship we are interested in.

The forms most commonly used in fisheries are the Ricker SRR

(1) $R = \alpha \times S \times \exp(-\beta \times S)$,

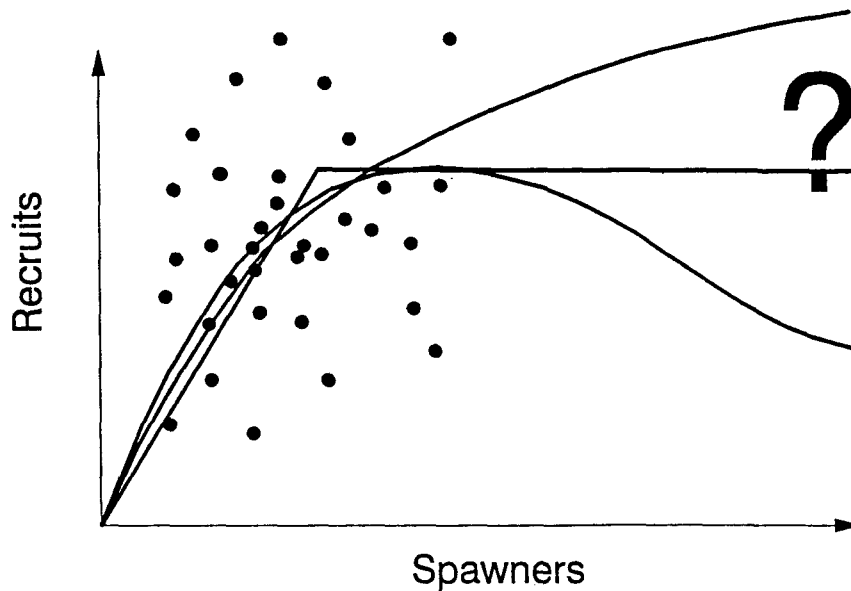and the Beverton-Holt SRR

(2) $R = 1 / (\alpha - \beta \times S)$,

Figure 1. Variability in recruitment can lead to ambiguity in choosing between possible stock recruitment relationships. From top to bottom the curves are Beverton-Holt, rectilinear, and Ricker.

where R is recruitment, S is spawning stock, α is a parameter related to stock productivity, and β is a scaling parameter related to equilibrium stock size. These two forms can often similarly fit a stock and recruitment data set, but they can make very different predictions for stock levels outside the range of recent experience and have different implications for managing a fishery (Figure 1). In the event of a very abundant stock, the Beverton-Holt SRR predicts that under-harvesting the stock will produce a larger recruitment than harvesting the optimal yield. In the same situation, the Ricker recruitment curve predicts that under-harvesting may produce a much smaller recruitment. This difference can be substantial. It means that under-harvesting a stock governed by a Beverton-Holt SRR, you give up some harvest now, but you will be able to obtain a larger harvest in the future that will partially compensate for the loss. However, a Ricker SRR can carry a double penalty for under-harvesting in that you obtain a smaller harvest now and a smaller harvest in the future. Choosing between potential forms of SRRs can have substantial consequences on resulting management policy, but the choice is often hampered by the fact that most stock and recruitment data come from stocks that have been harvested down to where most mathematical forms for SRRs closely resemble each other.

Once an SRR is selected (usually a Ricker SRR for Pacific salmon), the key population characteristics from a management standpoint are

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estimated by fitting the SRR to a spawning stock and recruitment data set. Once fitted, the SRR can be used to estimate the optimal harvest rate and the spawning escapement that will, on average, produce the optimal harvest. There are a number of different methods for fitting the Ricker SRR, and for dealing with some of the biases in these techniques (Ricker 1975, Walters 1990), but the simplest method is the one most frequently used and it serves well to illustrate some of the problems with fitting SRRs. The Ricker SRR is usually fitted by taking the natural log of (1) and rearranging to obtain

(3) $Ln(R/S) = Ln(\alpha) - \beta \times S.$

The parameters α and β are then estimated by least-squares linear regression of $Ln(R/S)$ on S. Because of the dynamics of the Ricker SRR and the fact that the data points used in the regression are not independent (the stock in one generation is the recruitment from the previous generation) the parameters estimated for a Ricker stock-recruit relationship are biased (Walters 1985, Kope 1988). The bias tends to overestimate the productivity of the stock and to underestimate the optimal spawning escapement, and increases as the variability in spawning stock levels decreases. The result is that when an SRR is fitted to a stock and recruitment data set from an over-harvested fishery, there is a built in tendency to perpetuate over-harvesting and depressed stock levels (Hilborn 1985a). The only way to gain more information about the shape of the SRR and to improve the estimates of parameter values is to increase the contrast in spawning escapements.

Fixed harvest rate management addresses these strategic concerns by allowing variation in spawning escapement that is proportional to the variation in recruitment. This variation can improve both the characterization of SRRs and estimation of parameters. Because the optimal harvest rate depends only on the productivity of the stock, and is independent of the equilibrium stock size (Hankin and Healey 1986), it may be possible to increase the accuracy of parameter estimates. In addition, depending on the management objective, fixed harvest rate management can be nearly optimal. If the management objective is to maximize the total expected harvest from a stock, then a constant escapement policy is optimal (Ricker 1958, Walters 1975). Such a management strategy is termed "risk neutral" because it ignores variability in harvests, and carries no penalty for the risk of having to shut down the fishery in the event that abundance falls below the optimal spawning escapement (Mendelssohn 1979). If a constant escapement strategy could actually be achieved, it would allow no variability in spawning escapement, and thus, provide no further information about the SRR except for the distribution of variability in recruitment at that spawning escapement level. When reasonable levels of productivity and variability in recruitment are considered, a constant escapement policy also results in no fishery about 5% to 10% of the time (Mendelssohn 1979). Recently, it has been argued that fishery management tends to be "risk averse" in that there is a tendency to stabilize harvests thereby reducing the risk of having to shut down the fishery (Mendelssohn 1979, Deriso 1985, Parma 1990). Risk averse management can be justified on the basis of sociological and economic impacts of fluctuations in harvest or obtaining no harvest, and is characterized by an increasing marginal value of
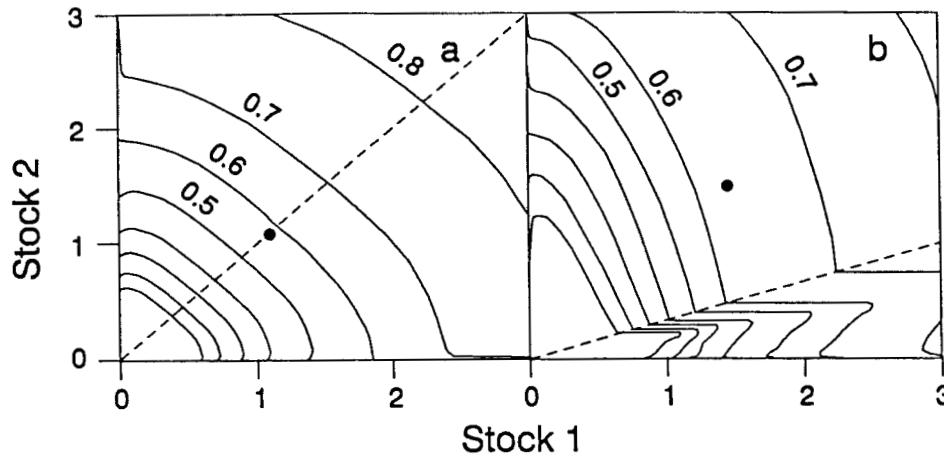
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Figure 2. Optimal harvest rates for a 2-stock fishery with a risk neutral utility function for (a) 2 natural stocks governed by a Ricker SRR, and (b) a natural stock (stock 1) and a hatchery stock (stock 2) governed by a rectilinear SRR. The mixed-stock equilibrium producing MSY is indicated by a dot. The dashed line describes abundance combinations where the optimal mixed-stock harvest rate is also optimal for each stock individually.

harvest when harvest levels decrease (Deriso 1985). Constant harvest rate policies have been shown to be optimal, or nearly optimal, when the management objective is risk averse (Deriso 1985, Hilborn 1985b). In addition, by distributing variability between catch and escapement, constant harvest rate policies provide variability in spawning escapement necessary to improve estimates of stock productivity and adaptively manage for changing conditions (cf. Walters 1986).

Even if the SRRs are assumed to be known, estimating optimal harvest rates is complicated by the mixed stock nature of salmon fisheries. Optimal harvest rates can be calculated for each stock individually, but the fisheries, especially the ocean fisheries, harvest a mixture of stocks that differ in size, productivity, and origin. Using dynamic programming it is possible to calculate optimal harvest rates in a 2-stock fishery for different combinations of individual stock abundances, allowing for uncertainty about future stock dynamics (Hilborn 1976). These optimal harvest rates depend on the productivities and on the relative abundance of the two component stocks, but the degree of this dependence is strongly influenced by the form of the SRRs for the two stocks. If both stocks are governed by Ricker SRRs with similar productivities, as may be the case with 2 natural stocks from different rivers or different runs, optimal harvest rates are relatively insensitive to mixture of stocks that makes up a given abundance (Figure 2a). If we change the SRR of one of the stocks to simulate a hatchery stock by making it a rectilinear SRR

with higher productivity, the optimal harvest policy depends very strongly on the relative abundances of the component stocks (Figure 2b).

Tactical Concerns

Once the decision was made to manage on the basis of fixed harvest rate, technical attention for the Klamath basin has focused on problems associated with implementing harvest rate management. As with strategic concerns, many of the problems associated with implementation stem from the multistock nature of the fisheries. Harvest rate goals have been set for Klamath Basin stocks, but the ocean fisheries harvest a mixture of stocks, of which the Klamath stocks are a component. In theory, by accounting for the ocean distribution of Klamath stocks, it should be possible to adjust harvest rates in different port areas to precisely obtain the desired harvest rate for Klamath stocks. However, in practice, regulating the fishing mortality rate is very difficult and imprecise.

There are basically two different approaches that can be taken to regulate the harvest rate in a fishery. The first is to try to manipulate the amount of fishing effort directed at the stock. This can be accomplished by limiting the number of participants in the fishery, implementing gear restrictions, fishing season closures, or any combination of these measures. The second approach is to limit harvest directly by setting landing quotas and shutting down fisheries when the quotas are reached. All of these tools are employed in the management of Pacific salmon fisheries. Within the Klamath Management Zone (KMZ), and in areas adjacent to the KMZ, commercial fisheries are regulated by a combination of seasonal closures and quotas in an attempt to limit impacts on Klamath stocks while providing access to other salmon stocks in the ocean. Some of the fisheries are of very short duration and restricted to small areas for the purpose of targeting specific stocks. Sport fisheries have operated under seasonal management with target quotas, and all fisheries are subject to gear and size restrictions.

The ocean distribution of Klamath chinook can be inferred from the pattern of recoveries of coded wire tags (CWT) from fish marked primarily at Trinity and Iron Gate hatcheries. Based on the recoveries of CWTs in past years it is possible to calculate the effects that changes in harvest rates in various portions of the coastal ocean will have on the overall harvest rate of Klamath chinook, assuming that the ocean distribution of salmon will be the same as in the base years. Operationally this accomplished using the Klamath Ocean Harvest Model (KOHM) discussed by Baracco and Dixon (this volume). The problems arise when we try to implement the harvest rate changes that we can evaluate relatively easily with the KOHM.

The first impediment to effectively regulating harvest rates is that the ocean distribution of Klamath Basin chinook changes year to year (Figure 3). It is readily apparent that in 1989 the Klamath stocks were distributed farther north than they were in 1986 and 1987. Because of the very low contribution rate of Klamath stocks to the fisheries south of the KMZ, in-season closures of the Fort Bragg fishery had very little effect on the overall harvest rate of Klamath stocks in 1989. Presently we have
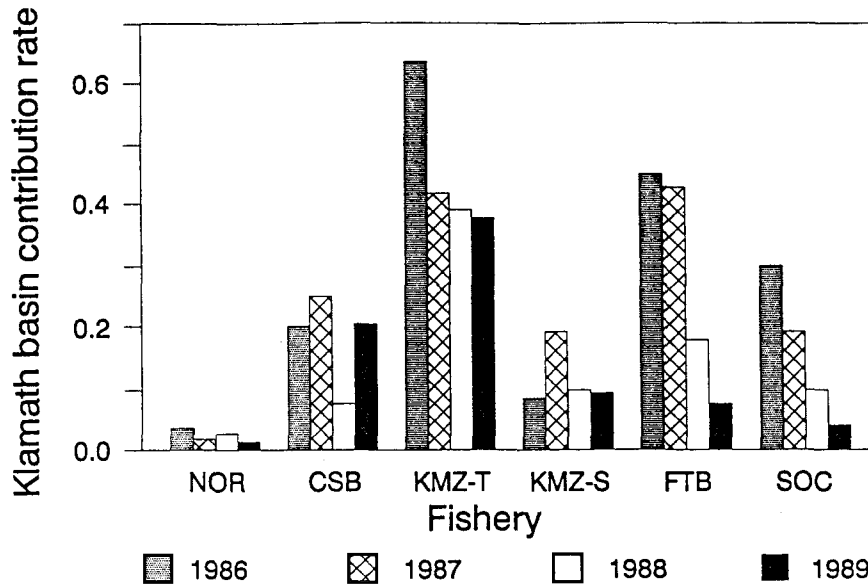
Figure 3. Fraction of chinook salmon landings originating from the Klamath basin as estimated by the recovery of coded-wire-tagged hatchery fish in northern Oregon (NOR), Coos Bay (CSB), Klamath management zone commercial fishery (KMZ-T), Klamath zone sport fishery (KMZ-S), Fort Bragg (FTB), and California ports south of Fort Bragg (SOC).

no way to anticipate the shifts in ocean distribution or to predict where the fish will be in any given year. Consequently, season structures and quotas that should, on average, produce the desired harvest rates on Klamath stocks may be ineffective in any specific year.

The second tactical problem is the difficulty of anticipating the fishing industry response to changes in regulations. When changes are made in the regulations to reduce the harvest rate, the response of fishermen is to adjust in some way so that the reduction in realized harvest rate is almost always less than anticipated. This difficulty may best be illustrate by a couple of examples. Within and adjacent to the KMZ some of the measures taken to try to decrease harvest rates have involved in-season closures. These in-season closures have typically been two weeks in duration and two weeks apart resulting in two weeks "on" and two weeks "off" for the industry. A proposal was made to change this to a weekly pattern of four days on and three days off, supported by the argument that this would still achieve the desired reduction in fishing effort while providing a more steady supply fish to help stabilize the market. This seemed to be a sound proposal, but examination of past closures revealed that in a two week period subject to the four day on
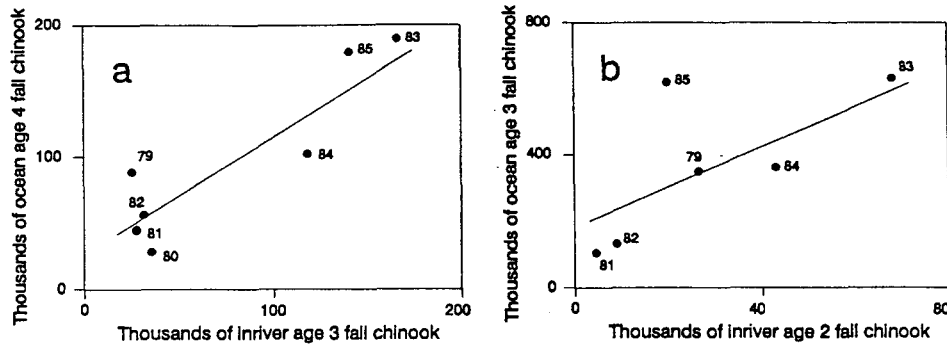
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Figure 4. Regression relationships used to predict ocean abundance of Klamath basin stocks.

three day off schedule, boats fished an average of 76 hours out of a total of 112 hours available. During a comparable two week period when the season was open continuously, boats fished and average of 80 hours out of 210 available hours. A 47% reduction in the time available for fishing resulted in only a 5% decrease in the time spent fishing.

A second example is provided by the commercial fishery quotas in the KMZ. In 1988 the commercial troll fishery operated under a quota of 48,000 fish. The season opened on June 5 and was closed on June 7 after three days with the quota already exceeded because of a large influx of commercial boats into the KMZ to take advantage of abundant stocks there. In an effort to hold the ocean harvest rate down to levels dictated by the 1987 Klamath Fisheries Management Council (KFMC) harvest sharing agreement, the commercial chinook quota for 1989 in the KMZ was set at 22,500 with an in-season adjustment to 26,900 fish. Of this quota 17,700 fish were allocated to the June "all salmon" season. In an effort to make the season last longer, a trip limit of 20 fish was also implemented. In spite of the restrictive trip limit and chinook abundance that was lower than the preseason forecast, the season lasted only four days until the quota of 17,700 chinook was met.

Quotas have been employed in the KMZ because of the difficulty in regulating harvest rate by managing fishing effort. In theory, quotas directly limit the harvest rate by translating the desired target harvest rate into a quota and then shutting down the fishery when the quota is reached. The problem with quotas is that the desired harvest rate must be applied some forecast of abundance to generate the quota, and the accuracy of recent forecasts of Klamath chinook abundance has been perceived as less than satisfactory.

Abundance of each age-class of Klamath chinook is forecast separately from the run size of the corresponding age-class in the previous year. This method has worked relatively well for predicting age 4 abundance from 3-year-old spawners, but it has been less successful in
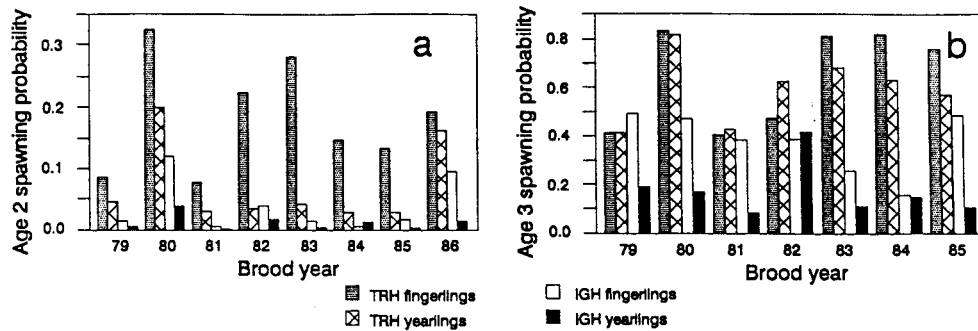
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Figure 5. Maturation probabilities for 2-year-old and 3-year-old fish from Trinity River hatchery (TRH) and Iron Gate hatchery (IGH) for fingerling and yearling releases. Probabilities were estimated by cohort analysis of coded-wire tag recoveries.

predicting age 3 abundance (Figure 4). Unfortunately, 4-year-old fish are only a small portion of the Klamath stock in most years, with the bulk of ocean abundance composed of 3-year-old fish. This is due in part to the difficulty in enumerating 2-year-old spawners, and in part to the variability in the maturation rate of 2-year-old fish. Variability in maturation rate occurs among substocks and life history patterns as well as on a year to year basis (Figure 5, cf. Hankin 1990). This variability among substocks means that as the composition of the Klamath basin stock varies, the average maturation rate also changes, while the temporal variability further decreases the accuracy of forecasts. It is doubtful that our ability to forecast age 3 abundance will improve substantially in the near future. Improved forecasting will require including environmental variables in the forecasting process, and attempts to use environmental variables to improve stock forecasts have met with little success in the past. Even if forecasts can be improved, there is some question as to the utility of improved forecasting to fisheries management (Walters and Collie 1988).

Solutions

Optimizing a fixed harvest rate management policy requires only information on stock productivity while optimizing a fixed escapement policy require information about both productivity and equilibrium stock size. In theory then, harvest rate management should require less data than managing for fixed spawning escapement. Harvest rate management also adjusts automatically to changes in habitat capacity, and provides more information in the data collected from the fishery by increasing the contrast of observable levels of spawning escapement. For these reasons, harvest rate management seems preferable to fixed escapement management. Some of the problems with harvest rate management will certainly be addressed by the technical staffs of the management councils. As more

data are collected from the fisheries we will learn more about the ocean distributions of various stocks both from CWT recoveries and from genetic stock identification. SRRs will continue to be refined as more data are collected from the spawning runs. If the recent diversity of management measures taken to try to regulate ocean harvest rates continues, we will gain a better understanding of the response to expect from the fisheries to future management. It may then be possible to manage on the basis of seasons rather than quotas, an option that most user groups would seem to prefer. However, both the commercial and sport troll fisheries have an excess of fishing power evidenced by the recent 3 and 4 day commercial seasons and a sport fishery in the KMZ that has exceeded the expected levels of effort and landings consistently in the last 4 years. Switching to seasonal management will probably entail substantial reductions in the fishing power of both the commercial and sport fishing industries if optimal harvest rates are to be obtained. While technical staffs may be able to provide recommendations and explore the implications of management options that may be considered in the future, the success or failure of harvest rate management will ultimately depend on the ability of the management councils to reconcile issues like harvest allocation, endangered species, and over-capitalization.

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