9255

Optimal Harvest Rates for Mixed Stocks of Natural and Hatchery Fish

Robert G. Kope

National Marine Fisheries Service, Southwest Fisheries Science Center, Tiburon Laboratory, 3150 Paradise Drive, Tiburon, CA 94920, USA

Kope, R. G. 1992. Optimal harvest rates for mixed stocks of natural and hatchery fish. Can. J. Fish. Aquat. Sci. 49: 931–938.

Optimal harvest rates were computed using dynamic programming for mixed-stock fisheries exploiting two stocks of either natural or hatchery origin. Natural stocks were described by a Ricker spawner–recruit relationship and hatchery stocks were described by a rectilinear spawner–recruit relationship. Harvest rates were optimized for both risk-neutral and risk-averse utility functions. For two natural stocks with low productivities, optimal harvest rates generally appeared to favor the stronger stock for a risk-neutral utility function and the weaker stock for a risk-averse utility function. For both utility functions, optimal harvest policy became less sensitive to relative stock strength as the productivity of the stocks increased. When at least one of the stocks was of hatchery origin, optimal harvest policy favored the weaker stock using either utility function.

En utilisant une programmation dynamique, l'auteur a calculé des taux d'exploitation optimum dans le cas de pêches axées sur deux stocks, soit d'origine sauvage ou d'élevage. Il a décrit les stocks d'origine sauvage à l'aide d'une relation géniteur–recrue de Ricker et les stocks d'élevage, d'une relation rectilinéaire géniteur–recrue. Il a ensuite optimalisé les taux d'exploitation des fonctions d'utilité à risque neutre et à aversion pour le risque. Dans le cas de deux stocks naturels à faible taux de productivité, les taux d'exploitation optimum semblaient généralement favoriser le plus important stock pour ce qui est de la fonction d'utilité à risque neutre, et le stock le moins abondant pour ce qui est de la fonction d'utilité à aversion pour le risque. Dans le cas des deux fonctions d'utilité, une politique d'exploitation optimum a moins réagi à l'abondance relative d'un stock lorsque la productivité des stocks augmentait. Lorsque au moins un des stocks était issu de l'élevage, une politique d'exploitation optimum favorisait le stock moins abondant pour ce qui est des deux types de fonctions d'utilité.

Received April 9, 1991
Accepted November 14, 1991
(JA987)

Reçu le 9 avril 1991
Accepté le 14 novembre 1991

Mixed-stock fisheries present some complex and persistent problems in the management of renewable resources. Problems associated with identification of spawner–recruit relationships (Ricker 1973; Hilborn 1985a), loss of stock diversity (Ricker 1958; Paulik et al. 1967), and optimal harvest from mixed-stock fisheries (Ricker 1958; Paulik et al. 1967; Hilborn 1976, 1985b; Collie et al. 1990) have all been investigated using Pacific salmon as examples. Pacific salmon stocks are particularly suited for investigating mixed-stock problems. Because of their fidelity to natal streams, individual salmon stocks can be clearly identified on the spawning grounds, and it is possible to monitor individual stocks over time. Virtually all salmon fisheries harvest a mixture of stocks that can differ widely in size, productivity, and variability. Natural salmon production is also supplemented by production from hatcheries that have been constructed to mitigate the impacts of water development projects and to enhance fisheries. Hatcheries are typically more productive than natural stocks in the sense that they produce more recruits per spawner than do naturally spawning stocks. The proliferation of hatcheries has prompted concerns that fisheries supported by hatchery stocks may severely deplete less productive natural stocks (Wright 1981).

The particular problem addressed here is that of optimal harvest of mixed stocks by a common fishery. Ricker (1958) presented a graphical solution to this problem and showed that maximum equilibrium yield for mixed-stock fisheries could, in some cases, be obtained at harvest levels that would drive some component stocks to extinction. Paulik et al. (1967) derived a general solution demonstrating that maximum sustainable yields from mixed-stock fisheries may entail elimination of less productive stocks, and declines in the spatial heterogeneity of Pacific salmon stocks have been observed coincident with increasing fishing mortality rates (Walters and Cahoon 1985).

Hilborn (1976), using dynamic programming, investigated optimal harvesting of two stocks by a common fishery. This technique allows for inclusion of uncertainty about future production and relaxation of the assumption of equilibrium conditions. Hilborn (1976) solved for optimal harvest rates for specific combinations of stock abundances, demonstrated that optimal harvest rates depend on the relative abundance of the component stocks, and concluded that, in general, mixed-stock fisheries should be harvested more heavily when the ratio of stocks differs from 1:1. Optimal harvest policies determined by dynamic programming assume that managers have the ability to forecast the abundance of individual stocks that contribute to a mixed-stock fishery. Hilborn (1985b) later pointed out that the requirement of individual forecasts for the component stocks was unrealistic and sought optimal management strategies from a class of strategies that does not require forecasting of individual component stocks.

In this paper, I use dynamic programming to evaluate harvest strategies that optimize risk-neutral (Hilborn 1976; Mendelssohn 1982; Deriso 1985) and risk-averse (Mendelssohn 1982; Deriso 1985; Walters and Ludwig 1987; Parma 1990) utility functions for a single fishery harvesting two stocks.

The spawner–recruit relationships (SRRs) used to model stock dynamics are chosen to represent naturally produced fish and hatchery-produced fish. I also reexamine optimal harvest policies for a fishery harvesting two natural stocks using a finer grid for stock sizes and a broader range of parameter values than were used by Hilborn (1976). I show that the functional forms of the SRRs and the utility function can profoundly affect optimal harvest strategies. Although I examine only a few specific cases for two-stock fisheries, the results suggest some general conclusions that may be applicable to cases where individual stock forecasts are not possible and to cases involving more than two stocks.

Methods

Following Hilborn (1976), I used a Ricker SSR to describe recruitment to a natural population. The particular form used was

$$(1)\quad R_{t+1} = S_t \exp\{\alpha[1 - (S_t/\beta)] + \epsilon_t\}$$

where R_{t+1} is the number of recruits resulting from S_t spawners, α is a productivity parameter (specifically, the natural log of the number of recruits produced by each spawner in the absence of density-dependent effects), β is the equilibrium stock size (i.e. the level of spawning escapement where each spawner exactly replaces itself in the absence of fishing mortality), and ϵ_t are independently distributed normal random variables with zero mean and variance σ^2. Hatchery stocks were assumed to have a rectilinear SRR of the form

$$(2)\quad R_{t+1} = \min(\alpha S_t, \beta)\exp(\epsilon_t).$$

This functional form presumes that recruitment of hatchery fish is, on average, proportional to the number of fish spawned at the hatchery, with no density dependence when the abundance of spawners is less than the hatchery capacity. If the number of spawners exceeds the hatchery capacity, the excess spawners have no effect on recruitment.

Omitting age structure and natural mortality, recruitment equals preharvest abundance, simplifying both the population model and the optimization problem. The description of population dynamics is completed by

$$(3)\quad S_t = R_t - C_t$$

where C_t is catch from generation t in numbers of fish and harvest rate is defined as

$$(4)\quad h_t = C_t / R_t.$$

I computed approximately optimal harvest policies using dynamic programming following the procedure outlined in Hilborn (1976), but using a finer discretization. Where Hilborn (1976) used 20 abundance levels, 18 harvest rates, and 10 stochastic outcomes, I used 80 abundance levels, 40 harvest rates, and 20 stochastic outcomes with $\sigma = 0.5$. This finer discretization increases the resolution of the approximate solutions and reveals details that are not readily apparent on the coarser grid.

Hilborn (1976) observed that for two stocks governed by equation (1), there are five nonredundant possibilities for the stock–recruitment dynamics: (1) $\alpha_1 = \alpha_2$, $\beta_1 = \beta_2$, (2) $\alpha_1 > \alpha_2$, $\beta_1 = \beta_2$, (3) $\alpha_1 = \alpha_2$, $\beta_1 > \beta_2$, (4) $\alpha_1 > \alpha_2$, $\beta_1 > \beta_2$, and (5) $\alpha_1 > \alpha_2$, $\beta_1 < \beta_2$. Other possible relationships involve simply interchanging stock 1 and stock 2. However, in addition to depending on the relative magnitudes of the stock productivities (i.e. the ratio of α_1 to α_2), optimal harvest strategies also depend on the absolute magnitude of the stock productivities with every unique combination of productivities producing a unique solution. In contrast, the equilibrium stock levels serve merely to scale the spawner–recruit curves, and a constant ratio of β_1 to β_2 will always produce the same solution relative to equilibrium stock sizes regardless of the absolute magnitude of the equilibrium stock sizes. Because it is impossible to examine all potential combinations of α and β, I considered only a limited number of cases. I examined optimal harvest rates for stocks of low ($\alpha = 0.5$), moderate ($\alpha = 1.5$), and high ($\alpha = 2.5$) productivities (Fig. 1) and with either identical βs or βs that differed by a factor of 2. Solutions were obtained for both risk-neutral and risk-averse objective functions by maximizing either the sum of expected catches over the planning horizon or the sum of the natural logarithms of expected catches over the planning horizon. Both of these utility functions are maximized in the last time period by harvesting the entire stock. As we work backward in time, the expected contribution of future catches to the objective function increases and lower harvest rates maximize the objective functions. Working backward from the last time period, optimal harvest strategies usually stabilize within 10 yr. In all cases presented here, harvest rates were optimized by calculating backward over a 20-yr planning horizon.

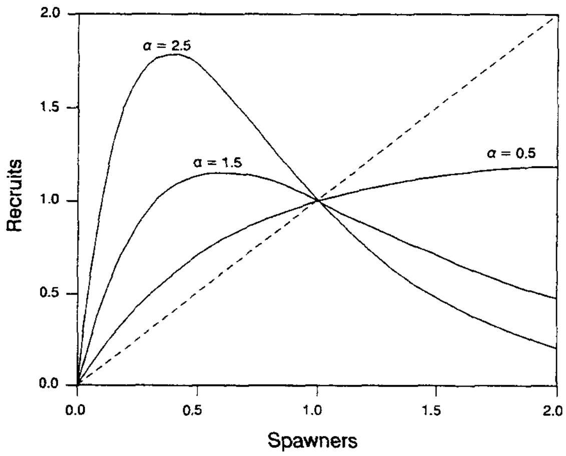

FIG. 1. Spawner–recruit curves used for the "natural" stocks in the dynamic programming estimation of optimal harvest rates for low-productivity stocks ($\alpha = 0.5$), moderate-productivity stocks ($\alpha = 1.5$), and high-productivity stocks ($\alpha = 2.5$). Unexploited equilibrium stock size (β) is equal to 1.0.

Results

Two Natural Stocks

For each possible combination of stock sizes, the dynamic programming algorithm computes the harvest rate that optimizes the objective function by maximizing the utility of the catch obtained in the present time period and the expectation of future catches from the spawning escapement. For a single

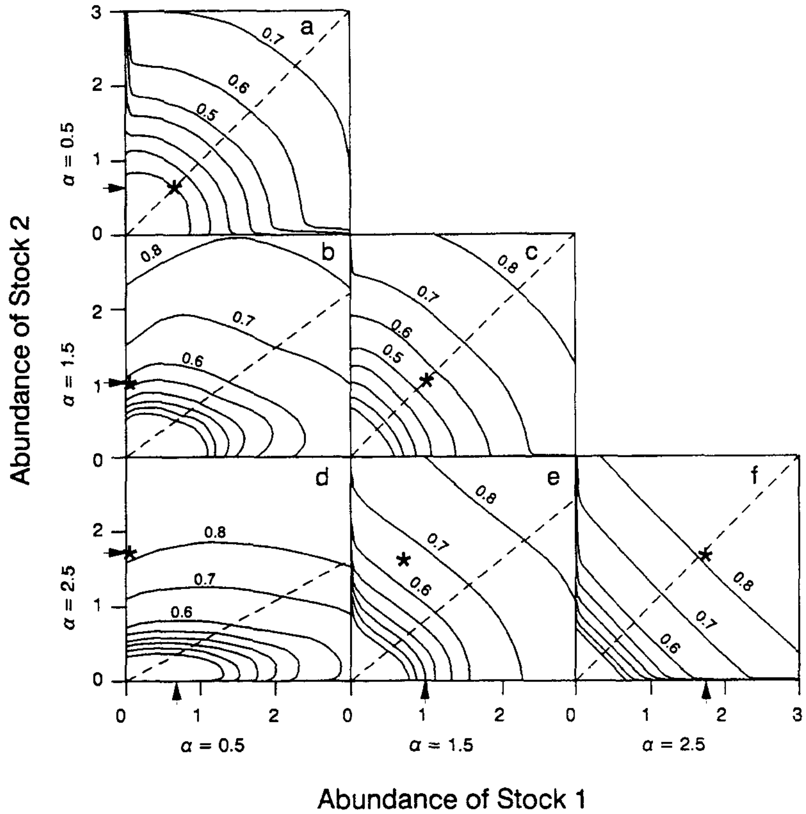

FIG. 2. Optimal risk-neutral harvest rate contours for stocks with identical unexploited stock size (β = 1.0). Individual stock MSY equilibria are indicated by arrows on the figure axes, and the joint MSY equilibria are indicated by asterisks. The broken line indicates isoharvest proportions where identical harvest rates are optimal for both individual stocks.

stock governed by the Ricker SRR the harvest policy that optimizes the linear (risk-neutral) utility function is to harvest that portion of the recruitment (abundance) that is in excess of some optimal spawning escapement. If abundance falls below this optimal escapement, then no harvest is taken and the stock is allowed to rebuild (Walters 1975; Parma 1990). Associated with each nonzero harvest rate is a single abundance level for which that harvest rate is optimal. In a two-stock fishery, the combinations of component stock abundances that share the same individual optimal harvest rates describe a path through the stock abundance plane. Along this trajectory, which I will call the "isoharvest" line, the optimal harvest rate for the mixed-stock fishery is also optimal for each component stock individually (Fig. 2). For combinations of stock abundances that lie above the isoharvest line, the harvest rates that would be optimal for the stock plotted on the ordinate (stock 2) are higher than the optimal harvest rates for the stock on the abscissa (stock 1). Thus, above the isoharvest line, stock 2 is, in a sense, the stronger stock and stock 1 the weaker stock. For any stock abundance combination that does not lie on this isoharvest line, the optimal harvest rate in the mixed-stock fishery will be intermediate between the harvest rates that are optimal for the two component stocks at their respective abundances.

When the two component stocks are governed by identical SRRs the isoharvest line is a straight line with slope 1.0 (Fig. 2a, 2c, and 2f). Stock combinations producing constant levels of total abundance describe straight lines in the stock abundance plane with slopes of -1.0. If optimal harvest rates depend only on the overall abundance, and not on the stock composition, optimal harvest rate contours will coincide with these constant levels of total abundance. If contours of optimal harvest rates deviate from these straight lines with slope -1.0, the optimal harvest policy is stock dependent.

The dependence of optimal harvest policy on stock productivities is readily apparent (Fig. 2). Hilborn (1976) reported that the optimal harvest policy for two identical stocks was a constant escapement policy which would be represented by straight contours with a slope of -1. This is approximately true only when the stocks have high productivity (Fig. 2f). For low-productivity stocks (Fig. 2a), and to a lesser extent moderate-productivity stocks (Fig. 2c), the optimal harvest rate contours are concave. This means that for identical stocks with low productivities or moderate productivities, if the stock composition differs from the isoharvest ratio of 1:1, the optimal harvest rate is higher than it would be for the same total abundance partitioned equally among the two component

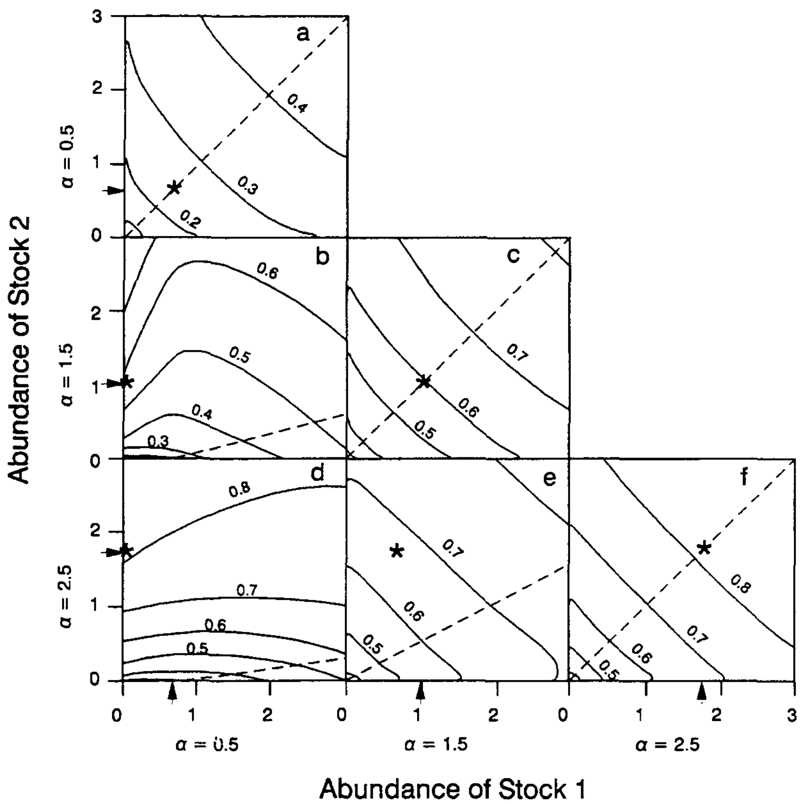

FIG. 3. Optimal risk-averse harvest rate contours for stocks with identical unexploited stock size (β = 1.0). Individual stock MSY equilibria are indicated by arrows on the figure axes, and the joint MSY equilibria are indicated by asterisks. The broken line indicates isoharvest proportions where identical harvest rates are optimal for both individual stocks.

stocks. For stocks with high productivities the optimal harvest rate contours are slightly convex, indicating that optimal harvest rates are slightly lower if abundance is not partitioned equally between the two component stocks, but the convexity is so slight that the optimal harvest policy could be considered stock indifferent for most reasonable abundance combinations.

While optimal harvest rates for all stock combinations are of interest, some stock combinations are far more likely to occur than others. Solutions presented here assume that future harvest rates will also be optimized, and continual management for optimal yields will tend to hold the stocks near the equilibrium levels that would support maximum sustainable yields in the absence of random variability (MSY equilibrium). If the low-productivity stock is harvested jointly with either the moderate- or high-productivity stocks, the low-productivity stock becomes extinct at MSY equilibrium (Fig. 2b and 2d). When MSY equilibrium supports only one stock, optimal harvest rates are understandably more sensitive to changes in the abundance of the stock that will remain at equilibrium than they are to changes in the stock destined for extinction. For the combination of moderate- and high-productivity stocks (Fig. 2e), MSY equilibrium results from a mixed-stock fishery and the optimal policy is nearly stock indifferent in the vicinity of this equilibrium. However, optimal harvest policy is more sensitive to the less productive stock if it is either at extremely low levels or at high levels relative to the more productive stock, reducing harvest rates if the less productive stock is in danger of extinction and increasing harvest rates if it becomes superabundant.

Optimal risk-averse harvest policy is less dependent on overall abundance, with higher harvest rates at low stock levels and lower harvest rates at high stock levels, than risk-neutral management (Fig. 3). This is consistent with the tendency for optimal risk-averse policies to approach constant harvest rates, producing less variability in catches. The decrease in variability of harvest rates produces a greater disparity in the isoharvest abundance ratios for stocks that differ in productivity (Fig. 3b, 3d, and 3e). Like optimal risk-neutral harvest policies, optimal risk-averse policies are less sensitive to stocks destined for extinction at the MSY equilibrium (Fig. 3b and 3d). In the remaining cases, where the MSY is obtained from a mixed-stock fishery, the deviations in optimal harvest rates associated with variation in stock composition appear to be the opposite of deviations in optimal risk-neutral harvest policy. For low-productivity stocks, optimal policy decreases harvest rates when the composition of stocks is inequitable, and the stock dependency of optimal harvest policy decreases as stock productivity increases.

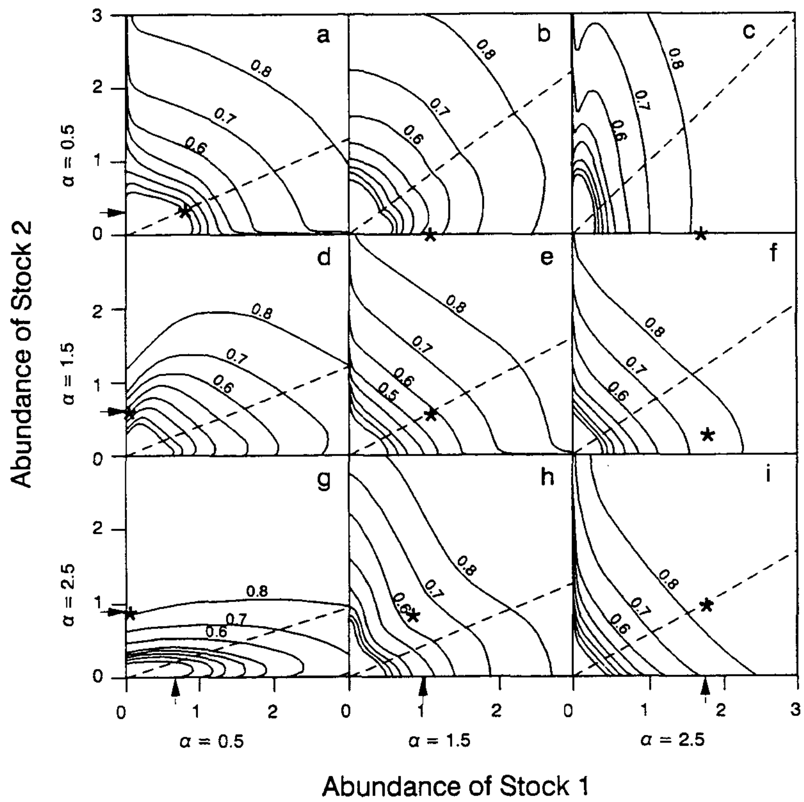

FIG. 4. Optimal risk-neutral harvest rate contours for stocks with different unexploited stock equilibria (β_1 = 1.0, β_2 = 0.5). Individual stock MSY equilibria are indicated by arrows on the figure axes, and the joint MSY equilibria are indicated by asterisks. The broken line indicates isoharvest proportions where identical harvest rates are optimal for both individual stocks.

For two natural stocks with different βs, optimal risk-neutral and risk-averse harvest policies are qualitatively similar to corresponding cases with identical βs (Fig. 4 and 5). In all cases, optimal harvest rates are less sensitive to stocks that will be extinct at the MSY equilibrium than to the stocks that will survive. Again, optimal risk-averse harvest policy is less sensitive to the relative abundance of the two component stocks at a given level of overall abundance than is risk-neutral management. Of particular interest is the case of a moderate-productivity stock with large β and a high-productivity stock with small β under risk-neutral management (Fig. 4h). With this combination of stocks, the expected contributions from the two component stocks to the combined yield are very similar. In the vicinity of the MSY equilibrium, there is a ridge in the optimal harvest rate contours. This depicts an optimal harvest strategy that decreases harvest rates when the ratio of stock abundances differs from the equilibrium ratio at MSY.

Hatchery and Natural Stocks

The optimal risk-neutral harvest strategies for mixed fisheries of hatchery and natural stocks differ dramatically from those involving two natural stocks (Fig. 6). An abrupt ridge occurs in the optimal harvest rate contours coincident with the isoharvest line, and optimal harvest rates decrease as the ratio of stocks departs from the isoharvest ratio. The MSY equilibrium entails far greater relative abundance of the hatchery stock than the isoharvest ratio. In all cases the MSY equilibrium occurs with both stocks present and the hatchery stock at its individual MSY abundance level, but bear in mind that the rectilinear SRR used for the hatchery stock ensures that the expected abundance of the hatchery stock is constant unless harvest rates are greater than the productivity of the hatchery stock. The MSY equilibrium for the natural stock is noticeably less than its individual MSY level only in the case where the unfished equilibrium for the hatchery stock is larger than that of the natural stock. In the region of the MSY equilibrium the optimal harvest rates are much more sensitive to changes in the natural stock than to changes in the hatchery stock.

Under risk-averse management, this prominent ridge in the optimal harvest rate contours is even more pronounced (Fig. 7). Again, optimal risk-averse harvest rates are less sensitive to changes in total abundance than are optimal risk-neutral harvest rates. However, unlike cases involving two natural stocks, optimal harvest rates are more sensitive to changes in the stock composition than are harvest rates under risk-neutral management. In the region of the MSY equilibrium, which is now even

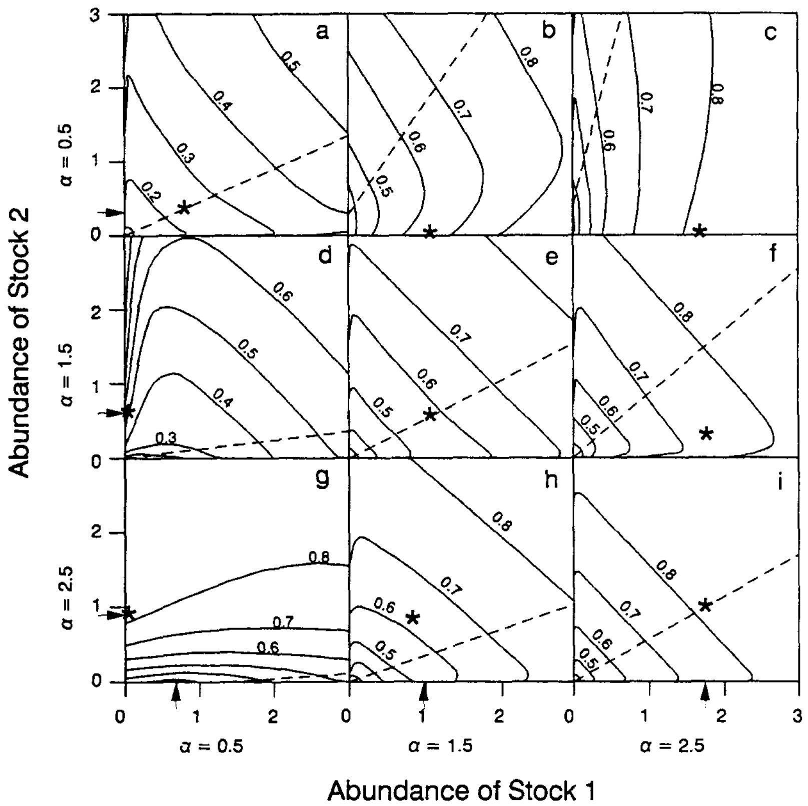

FIG. 5. Optimal risk-averse harvest rate contours for stocks with different unexploited stock equilibria (β_1 = 1.0, β_2 = 0.5). Individual stock MSY equilibria are indicated by arrows on the figure axes, and the joint MSY equilibria are indicated by asterisks. The broken line indicates isoharvest proportions where identical harvest rates are optimal for both individual stocks.

further from the isoharvest line, optimal harvest rate contours are vertical, indicating that optimal harvest policy is independent of changes in the hatchery stock.

The presence of the sharp ridge in the optimal harvest rate contours for mixed-stock fisheries results from the rectilinear SRR used for the hatchery stock. Above the isoharvest line the combinations of hatchery stock abundance and harvest rates that are optimal for the natural stock ensure that hatchery spawners will exceed hatchery capacity. Changes in the harvest of hatchery fish have no effect on future stock dynamics, only on harvest at the present time. At the same time, changes in the harvest of natural fish affect both the current harvest and future harvests. Consequently, optimal harvest rates are more sensitive to abundance of the natural stock than of the hatchery stock. Below the isoharvest line the hatchery stock is at sufficiently low abundance that harvest rates that are optimal for the natural stock will fail to provide enough hatchery spawners to fully utilize hatchery capacity. At this point, optimal harvest rates are driven by full utilization of hatchery capacity unless the disparity in stock sizes is so great that the cumulative loss from underharvesting the natural stock would exceed the loss from a one-time failure to fully utilize hatchery capacity. If we remove the abrupt transition in the hatchery SRR, by substituting a Beverton–Holt SRR for the rectilinear SRR, the ridge in the optimal harvest rate contours nearly disappears, as does much of the dependence on hatchery stocks (Fig. 8).

Discussion

Equilibrium analyses can place an upper limit on the average yield that can be expected from a mixed-stock fishery, and the component stocks that will still be around at equilibrium to contribute to this yield, but real fisheries are perpetually in a state of disequilibrium. Dynamic programming can approximate optimal harvest policies that embrace disequilibrium and uncertainty for specified SRRs, but the computational burden limits the size and complexity of problems that can be addressed. While the optimal harvest rates in any particular case depend on the SRRs chosen to describe stock dynamics and the specific parameter values used, a few general axioms can be inferred from the simulations presented here.

(1) For unproductive natural stocks, optimal risk-neutral harvest rates are more sensitive to changes in the stronger stock and optimal risk-averse harvest rates are more heavily influenced by the weaker stock.

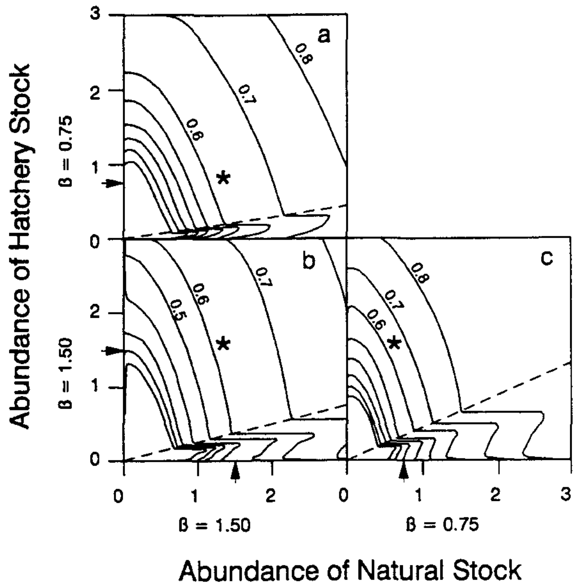

FIG. 6. Optimal risk-neutral harvest rate contours for stocks with different production functions. The natural stock is governed by a Ricker SRR with moderate productivity (α = 1.5), and the hatchery stock is governed by a high-productivity (α = 2.5) rectilinear SRR. Individual stock MSY equilibria are indicated by arrows on the figure axes, and the joint MSY equilibria are indicated by asterisks. Isoharvest proportions occur along the broken lines.

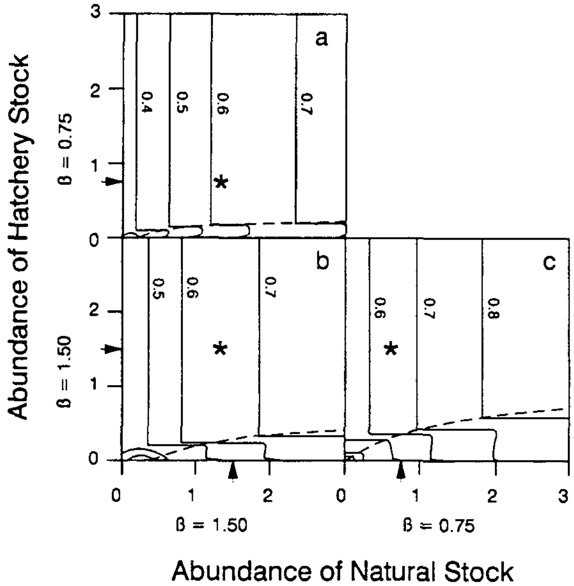

FIG. 7. Optimal risk-averse harvest rate contours for stocks with different production functions. The natural stock is governed by a Ricker SRR with moderate productivity (α = 1.5), and the hatchery stock is governed by a high-productivity (α = 2.5) rectilinear SRR. Individual stock MSY equilibria are indicated by arrows on the figure axes, and the joint MSY equilibria are indicated by asterisks. Isoharvest proportions occur along the broken lines.

(2) Over a fairly broad range of stock productivities, the stock dependence of both risk-neutral and risk-averse optimal harvest rates decreases as stock productivity increases.

(3) In hatchery-enhanced fisheries, jointly optimal harvest rates are more heavily influenced by the weaker stock over a fairly broad range of stock abundance combinations. The higher productivity of hatchery stocks ensures that the natural stock will nearly always be weaker than the hatchery stock.

While it is unlikely that stock forecasting and harvest regulation in mixed-stock fisheries will ever have the accuracy necessary to attempt to regulate harvest based on the relative abundance of individual stocks on a season by season basis, these axioms do have applicability to long-term management strategies. While short-term forecasting may be unreliable, it is widely accepted that a number of natural salmon stocks in California, Oregon, and Washington are chronically depressed (Nehlson et al. 1991). Overharvest has been identified as a factor contributing to the decline or hampering the recovery of most of these stocks. Preservation of genetic diversity and variability are often invoked as reasons for restoring depressed natural stocks, but the results presented here indicate that by criteria based on yield alone, these stocks should be restored. Harvest rates that optimize the expected yield from mixed-stock fisheries for hatchery and natural fish should routinely produce healthy runs of natural spawners and substantial surpluses of hatchery spawners. This implies that yields from fisheries that cannot discriminate between natural and hatchery stocks could be increased by reducing the harvest rates to rebuild depressed natural stocks.

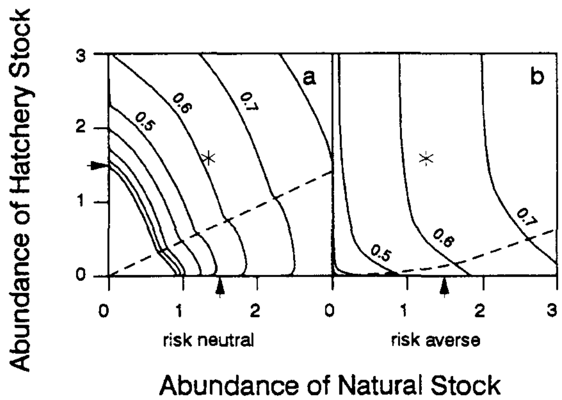

FIG. 8. Optimal harvest rate contours for a mixture of hatchery and natural stocks with hatchery stocks governed by a Beverton–Holt SRR. (a) Risk-neutral utility function, analogous to Fig. 6b; (b) risk-averse utility function, analogous to Fig. 7b.

Acknowledgements

I thank James Bence, Joseph Hightower, and two anonymous referees for their insightful comments on earlier versions of this paper.

References

COLLIE, J. S., R. M. PETERMAN, AND C. J. WALTERS. 1990. Experimental harvest policies for a mixed-stock fishery: Fraser River sockeye salmon, *Oncorhynchus nerka*. Can. J. Fish. Aquat. Sci. 47: 145–155.

DERISO, R. 1985. Risk averse harvesting strategies. Lect. Notes Biomath. 61: 65–74.
HILBORN, R. 1976. Optimal exploitation of multiple stocks by a common fishery: a new methodology. J. Fish. Res. Board Can. 33: 1–5.
1985a. Apparent stock recruitment relationships in mixed stock fisheries. Can. J. Fish. Aquat. Sci. 42: 718–723.
1985b. A comparison of harvest policies for mixed stock fisheries. Lect. Notes Biomath. 61: 75–88.
MENDELSSOHN, R. 1982. Discount factors and risk aversion in managing random fish populations. Can. J. Fish. Aquat. Sci. 39: 1252–1257.
NEHLSON, W., J. E. WILLIAMS, AND J. A. LICHATOWICH. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho and Washington. Fisheries 16: 4–21.
PARMA, A. M. 1990. Optimal harvesting of fish populations with non-stationary stock–recruitment relationships. Nat. Resour. Model. 4: 39–76.
PAULIK, G. J., A. S. HOURSTON, AND P. A. LARKIN. 1967. Exploitation of mixed stocks by a common fishery. J. Fish. Res. Board Can. 26: 2527–2537.
RICKER, W. E. 1958. Maximum sustainable yields from fluctuating environments and mixed stocks. J. Fish. Res. Board Can. 15: 991–1006.
1973. Two mechanisms that make it impossible to maintain peak-period yields form stocks of Pacific salmon and other fishes. J. Fish. Res. Board Can. 30: 1275–1286.
WALTERS, C. J. 1975. Optimal harvest strategies for salmon in relation to environmental variability and uncertain production parameters. J. Fish. Res. Board Can. 32: 1777–1784.
WALTERS, C. J., AND P. CAHOON. 1985. Evidence of decreasing spatial diversity in British Columbia salmon stocks. Can. J. Fish. Aquat. Sci. 42: 1033–1037.
WALTERS, C. J., AND D. LUDWIG. 1987. Adaptive management of harvest rates in the presence of a risk averse utility function. Nat. Resour. Model. 1: 321–337.
WRIGHT, S. 1981. Contemporary Pacific salmon fisheries management. N. Am. J. Fish. Manage. 1: 29–40.