Abstract.—The equilibrium contribution of hatchery-released juveniles to a rockfish fishery is evaluated by using a yield-per-recruit model. Hatchery-released juveniles may be worth up to an estimated US$0.16 per juvenile to the fishery. The use of hatchery releases to restore a depleted population of Pacific ocean perch *Sebastes alutus* is examined with the Deriso-Schnute model. This model indicates that hatchery releases have the potential to substantially increase a stock's yield and rate of recovery during the recovery period.

Evaluation of Hatchery Releases of Juveniles to Enhance Rockfish Stocks, with Application to Pacific Ocean Perch *Sebastes alutus* *

Jeffrey J. Polovina

Honolulu Laboratory, Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
2570 Dole Street, Honolulu, Hawaii 96822-2396

There is a long history of attempts worldwide to enhance marine fisheries by releasing hatchery-reared juveniles. However, few attempts have had long-term success (Yatsuyanagi 1982, Botsford and Hobbs 1984, Isibasi 1984, Ulltang 1984). In theory, hatchery releases can enhance fisheries in two ways. First, juvenile releases can be added to the natural stock on a long-term basis to support a higher level of fishery harvest than that achieved from the natural stock alone. Secondly, juvenile releases can be used on a short-term basis to increase a depleted natural stock more rapidly, then discontinued once the natural stock has recovered.

Pilot releases of the rockfish *Sebastes schlegeli* indicate that large-scale rearing and releases of rockfish may be biologically and technically possible (Sakai et al. 1985, Kusakari In press). The merit of hatchery releases of juveniles for fishery enhancement is examined in the present paper with mathematical models. Specifically, the Beverton and Holt (1966) yield-per-recruit model will be used to evaluate the sustainable increase in fishery catches from a long-term release of hatchery-reared juveniles. The Deriso-Schnute delay-difference age-structure model (Zheng and Walters 1988) will be used to evaluate the fishery benefits from short-term juvenile releases to increase the recovery of depleted rockfish stocks.

Models and methods

To evaluate the equilibrium contribution of hatchery-released juveniles to a rockfish fishery, the Beverton and Holt (1966) equation was used to express the equilibrium yield-per-recruit as a function of the following ratios: instantaneous natural mortality to von Bertalanffy growth (M/K), length at recruitment to asymptotic length, and fishing mortality to natural mortality (F/M) (Beverton and Holt 1966). If a recruit in the yield-per-recruit model is taken to represent a hatchery-released juvenile rather than a recruit from the natural population, then the equilibrium yield per hatchery-released juvenile can be computed from yield-per-recruit tables (Beverton and Holt 1966). Specifically, let Y/R_0 denote the yield per recruit where the recruits are of some reference age, say the age at which they have just become demersal. Then the yield per released fish at age t is just

$$\frac{Y}{R_0} e^{Mt}$$

where M is the natural mortality rate from the reference age 0 until release age t. The values of Y/R_0 are tabled as a function of M/K and F/M (Beverton and Holt 1966). The equilibrium yield per hatchery-released juvenile

*Presented at U.S.–Japan Symposium on Reproduction and Early Life History in the Genus *Sebastes*, Honolulu, Hawaii, June 1989.

Manuscript accepted 7 August 1990.
Fishery Bulletin, U.S. 89:129–136 (1991).

Table 1

Von Bertalanffy growth (K), natural mortality (M), M/K, and maximum age for seven commercially important species of rockfish (parameter estimates taken from Pacific Fishery Management Council 1989).

Common name	M/yr	K/yr	M/K	Max. age (yr)
Pacific ocean perch	0.05	0.09	0.56	70+
Yellowtail	0.07	0.16	0.44	64
Shortbelly	0.25	0.21	1.19	12
Widow	0.15–0.20	0.15	1.17*	58
Canary	0.01–0.09	0.16	0.31*	75
Chilipepper	0.20	0.18	1.11	16
Bocaccio	0.25	0.11	2.27	36

*M taken as the midpoint of the range.

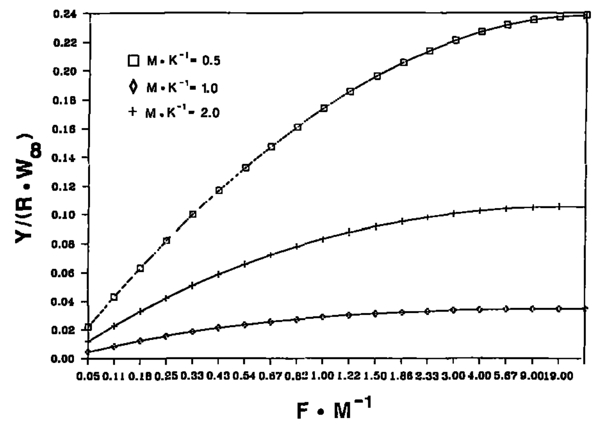

Figure 1

Beverton and Holt yield-per-recruit as a fraction of asymptotic weight at optimum size at entry to the fishery as a function of F/M for three levels of M/K.

will be estimated for values of release age t, M, M/K, and F/M, which are representative estimates for rockfish populations.

To evaluate the short-term releases of hatchery-reared juveniles to restore a depleted rockfish population, a Deriso-Schnute delay-difference age-structure model is used (Zheng and Walters 1988). Deriso (1980) derived a population model that combined simple surplus production models with more detailed age-structure models. Schnute (1985) modified this model with a three-parameter Brody growth model. This Deriso-Schnute model depends on a Brody growth parameter (p), the age of recruitment to a fishery (k), body weights at ages k and k − 1 (W_k and W_{k-1}, respectively), and total annual survival in year t (s_t). Thus, the biomass in year t + 1 ($B_t + 1$) is described as

$$B_{t+1} = (1+p)s_tB_t - ps_ts_{t-1}B_{t-1} + R_{t+1} - ps_t\frac{W_{k-1}}{W_k}R_t,$$

where R_t is the recruitment to the fishery in year t (Schnute 1985). A Ricker stock-recruitment relationship is used to model the recruitment (in weight) from the natural rockfish population and from hatchery-released 1-year-old juveniles to the fishery to obtain the total recruitment (in weight) function (R_t):

$$R_t = AS_{t-k}\exp(-BS_{t-k})\exp(z) + H_{t-k+1}W_k\exp(-M(k-1));$$

where S_t is the spawning biomass, H_t is the number of hatchery-released 1-year-old juveniles, M is natural mortality, and A and B are constants. This model assumes hatchery juveniles are added to the natural population without any density-dependence. The term exp(z) is used to add a stochastic element to the natural recruitment function when the variable z represents a random variable, which has a normal distribution, a mean of 0, and a variance of σ^2. When σ^2 is set to 0, the stochastic term is eliminated, and deterministic recruitment is assumed. The Ricker stock-recruitment relationship appears to represent an appropriate model of recruitment in a natural rockfish population (Archibald et al. 1983).

The Deriso-Schnute model is fit to catch and fishing mortality data for Pacific ocean perch *Sebastes alutus* from Queen Charlotte Sound, Canada, during 1963–77 when the population was fished from an estimated biomass of 82,000 metric tons (t) to 13,000 t (Archibald et al. 1983). The model with its estimated parameters is then used to estimate the equilibrium yield curve to determine the biomass and fishing mortality that achieve maximum sustainable yield (MSY). Then the model with stochastic recruitment is used to simulate the recovery of this depleted stock to the biomass level that supports MSY under several management strategies, including the release of hatchery-reared juveniles.

Results

Values of M for rockfishes typically range from 0.01 to 0.25 per year, K from 0.09 to 0.21 per year, and M/K ratios from 0.44 to 2.27 (Table 1). Values of yield-

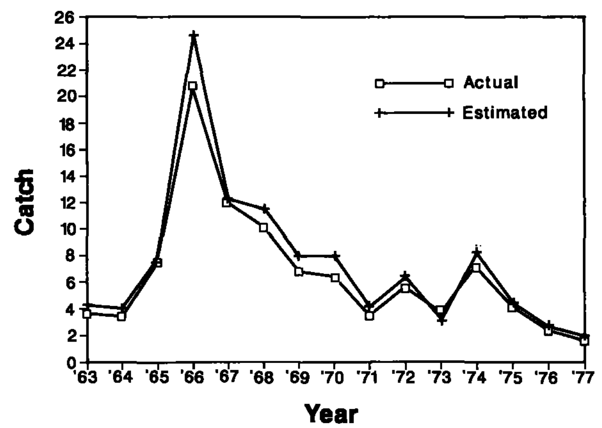

Figure 2
Historic catches (10^3 metric tons) of Pacific ocean perch from Queen Charlotte Sound and estimated catches from the fit of the Deriso-Schnute model, 1963–77.

Table 2
Parameters for the Deriso-Schnute model fit to Pacific ocean perch in Queen Charlotte Sound.

Parameter	Value	Source
Recruitment age (k)	9 years	Archibald et al. (1983)
Natural mortality (m)	0.05 per year	Archibald et al. (1983)
Weight at entry (W_k)	0.614 kg	Archibald et al. (1983)
Weight at age k − 1 (W_{k-1})	0.572 kg	Archibald et al. (1983)
Body growth (p)	0.52 per year	Estimated as mean of range: $1-\sqrt{\frac{W_k}{W_\infty}} \leqslant p \leqslant 1-\frac{W_k}{W_\infty}$
Recruitment model	Ricker	Archibald et al. (1983)
Recruitment parameters A, B	A = 0.29 B = 1.6×10^{-5}	From fit of model to 1963–77 data

per-recruit (expressed as a fraction of the asymptotic weight of the fish, as a function of F/M, and for M/K equaling 0.5, 1.0, and 2.0) are shown in Figure 1. These yield curves assume that the ratio of the length-at-recruitment to the asymptotic length is optimum to achieve maximum yield-per-recruit. For M/K ranging from 0.5 to 2.0, the optimum length at harvest will be 45–86% of the asymptotic length (Beverton and Holt 1966). Thus, in the case of Pacific ocean perch, which has an asymptotic weight of about 1.4 kg, if M/K = 0.5, F/M = 1.0, and M = 0.05 per year, the contribution to the fishery of an individual juvenile released from the hatchery at age 0.25 is calculated as the product of 1.4 kg × 0.17 (from Fig. 1), multiplied by $\exp(0.05 \cdot 0.25)$ or 0.24 kg. The average 1988 ex-vessel price for all rockfishes was US$0.67 per kg (National Marine Fisheries Service 1989); therefore, each 3-month-old, hatchery-released juvenile on the average is worth $0.16 to the fishery. The contribution of a juvenile to the fishery is strongly inversely related to M/K (Fig. 1). For example, if M/K is 1.0 rather than 0.5, then the contribution is only about one-half as much. Also, as long as natural mortality is assumed to be low and constant, changes in the release age have little influence on the contribution of the juvenile to the fishery. However, it is quite possible that natural mortality of young juveniles varies considerably by age and an optimum release age exists, although we have no data to document either case.

Pacific ocean perch in Queen Charlotte Sound, Canada, underwent heavy exploitation from 1963 to 1977 (Fig. 2) (Archibald et al. 1983). A reconstruction of the history of this exploitation by using a catch-at-age model estimates annual exploitable biomass and average fishing mortality during this period (Archibald et al. 1983). The Deriso-Schnute model is fit to the catch history of this fishery during 1963–77 by using estimates of fishing mortality from the catch-at-age model (Fig. 2). All but two of the parameters required for the model are from published values (Table 2). Two parameters (A and B in Table 2) in the stock-recruitment relationship part of the model are estimated by fitting the model to the 1963–77 catch series.

Based on the Deriso-Schnute delay-difference model with the parameters used to fit the catch and effort series (1963–77) and to estimate the equilibrium yield curve, the maximum sustainable yield (MSY) of about 1800 t is achieved at F_{MSY} = 0.06 per year (Fig. 3). At that level of F_{MSY}, the corresponding equilibrium biomass (B_{MSY}) is estimated at about 35,000 t. At B_{MSY}, the recruitment of 1-year-old juveniles is estimated at 3.5 million fish, whereas an estimated 1.3 million 1-year-olds recruit if biomass is at the 1977 depleted levels.

Assuming that the goal of restoring the Pacific ocean perch stock is to increase the biomass to 35,000 t so it can be harvested at F = 0.06 to achieve MSY, three approaches to stock recovery are examined. One approach has as its goal to increase the biomass to B_{MSY} as quickly as possible by setting F at 0 until the biomass reaches 35,000 t, then the stock will be fished at

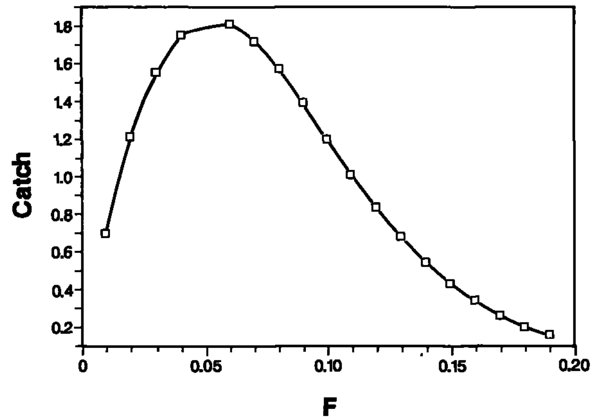

Figure 3
Equilibrium yield curve (10^3 metric tons) for Pacific ocean perch from Queen Charlotte Sound estimated from the Deriso-Schnute model.

F = 0.06. The second approach to stock recovery is to eventually achieve B_{MSY} while also maximizing the yield to the fishery. Under this approach, the stock is fished at F = 0.06 from the beginning. A third strategy, which represents a compromise between these two philosophies, will set F at 0.03 until the biomass reaches 35,000 t, then the stock will be fished at F = 0.06.

Each of these three sequences of F can be evaluated with and without hatchery releases. Catch and biomass series with and without hatchery releases for each sequence of F can be simulated with the stochastic Deriso-Schnute model with the parameters used to fit the population decline. When hatchery releases are used, 5 million 1-year-old juveniles will be stocked annually. This number represents almost four times the natural recruitment for the stock at the 1977 depleted level and about 40% more than the natural recruitment at the B_{MSY} level. The variance of the random variable z in the stochastic recruitment component is assumed to have a variance of 0.3 (Archibald et al. 1983). Based on 100 simulations of each of the six management approaches over 100 years, the mean annual catches, mean cumulative catches and the biomass distributions after 20 years can be computed (Figs. 4–6, Table 3).

When the management strategy closes the stock to fishing to restore it as quickly as possible, B_{MSY} (35,000 t) is achieved in 21 years without stocking and 14 years if 5 million juveniles are stocked annually for 6 years (Table 3). After 20 years, the mean biomass levels are about the same for the stocked and non-stocked cases, so annual catches are about the same and the difference in cumulative yield remains con-

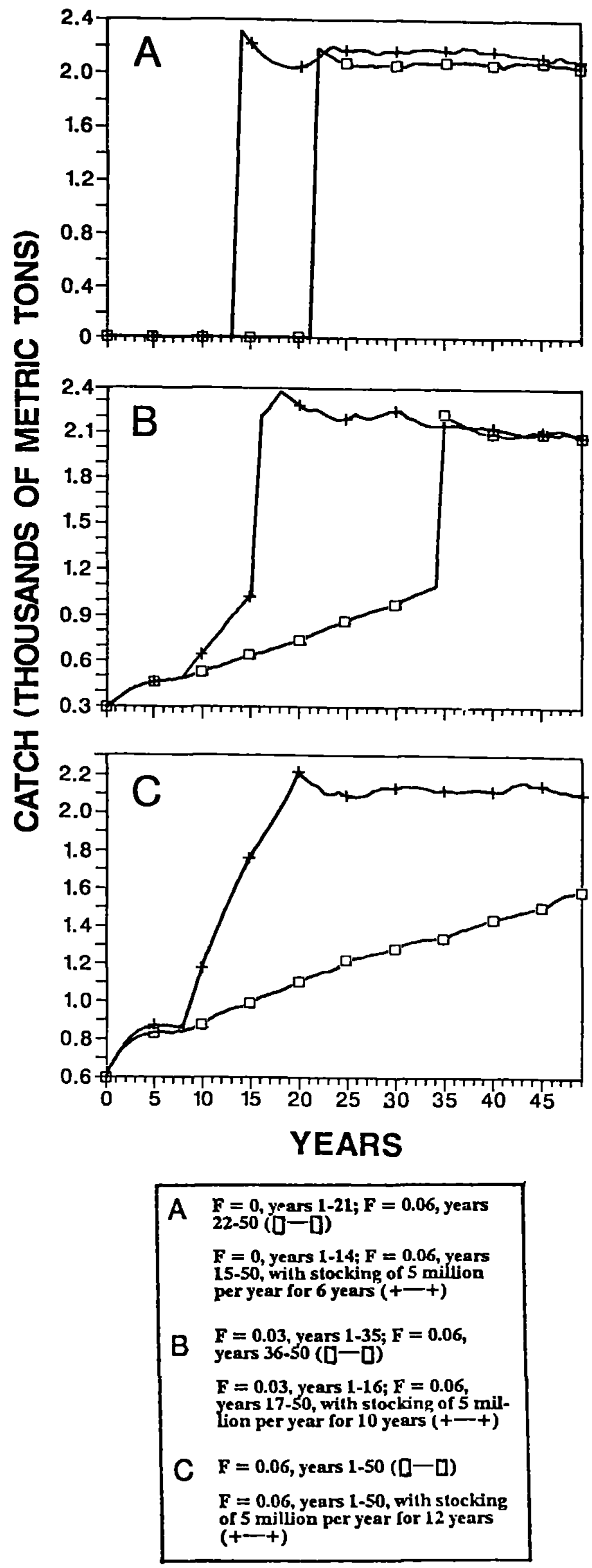

Figure 4
Simulated annual catches of Pacific ocean perch, with and without hatchery releases, for three management strategies.

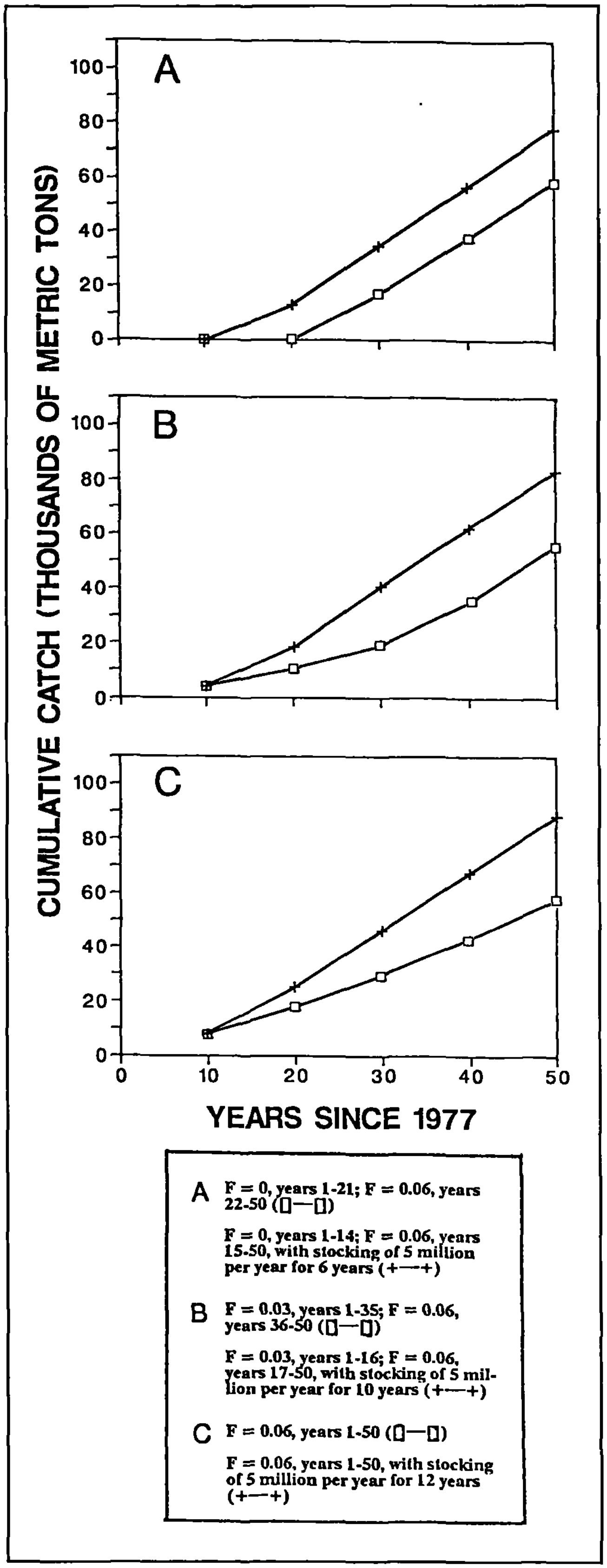

Figure 5
Simulated cumulative catches of Pacific ocean perch, with and without hatchery releases, for three management strategies.

stant (Figs. 4, 5). The biomass distributions with and without stocking are very similar after 20 years (Fig. 6).

When F = 0.03, B_{MSY} is achieved in 35 years without stocking and in 17 years when 5 million juveniles are stocked annually for 10 years (Table 3). The annual catches for both the stocked and nonstocked strategies are the same for the first 8 years because of the 8-year lag between the release of juveniles and their entry into the fishery; but beginning in year 9, the annual catches in the stocked strategy exceed those for the nonstocked strategy. In year 16, B_{MSY} is achieved in the stocked strategy, and F is increased to 0.06, which results in a substantial increase in annual catches. The annual catches for the nonstocked strategy lag behind the stocked catches until year 35 when B_{MSY} is achieved and F is increased to 0.06 (Fig. 4). The difference between the cumulative catches for stocked and nonstocked is initially very small, because the two strategies have the same annual catches at the beginning, but the difference grows once the annual catches diverge (Fig. 5). After 20 years, the distribution of biomass for the stocked population is about 10,000 t greater than for the population without stocking (Fig. 6).

When F = 0.06, B_{MSY} is not achieved within 100 years without stocking, whereas B_{MSY} is achieved in 20 years with stocking (Table 3). The patterns of annual and cumulative catches for the stocked and nonstocked cases are similar to the F = 0.03 situation (Figs. 4, 5). After 20 years, the distribution of biomass without stocking shows very little change from the level at the beginning of the recovery period, whereas the distribution of the stocked population centers close to B_{MSY} (Fig. 6).

The value of stocking to increase yields while restoring the depleted Pacific ocean perch population can be evaluated by computing the break-even cost of a hatchery-released juvenile based on the increase in cumulative landings. Suppose a hatchery, built and operated by government funds, must meet the economic criterion of a 3% return on investment. Then the break-even cost per juvenile, as a function of *n* years after the start of stocking, can be calculated as follows: (1) Compute the increase in cumulative yield between the comparable stocked and nonstocked strategies, *n* years

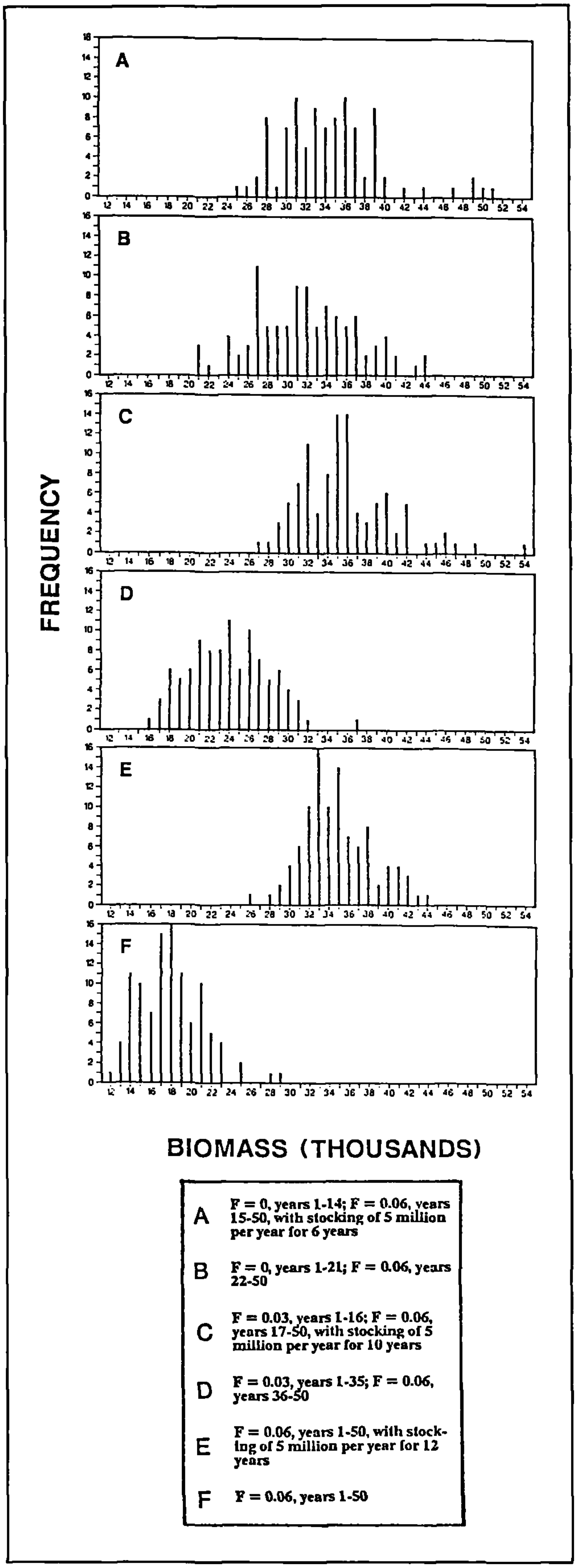

Figure 6
Biomass distributions of Pacific ocean perch 20 years after the onset of hatchery releases (from 100 simulations), with and without stocking, for three management strategies.

after the start of stocking; (2) divide this increase in yield (the result from step 1) by the total number of juveniles stocked to obtain the increase in yield per stocked juvenile; (3) multiply the result of step 2 by the unit value of the yield to the fishery to compute the value to the fishery per stocked juvenile; and, finally, (4) discount this yield cumulated over n years to a present value by dividing the result of step 3 by $(1.03)^n$. Using this approach, based on a wholesale value for Pacific ocean perch of \$0.67 per kg (National Marine Fisheries Service 1989), the break-even cost per juvenile ranges from \$0.04 to \$0.16. For example, under the scenario where the fishery is closed until B_{MSY} is reached, if hatchery juveniles can be stocked at a cost of \$0.16 per juvenile, then hatchery releases result in increasing the value of the catches over the nonstocked strategy equivalent to a 3% annual return on stocking costs for the first 20 years after stocking (Table 4). However, under the scenario where F = 0.06 from the beginning of the recovery period, the break-even cost of a hatchery-released juvenile cannot exceed \$0.04 if the release program is to achieve a 3% annual return over the first 10 years and \$0.08 over a 40-year period.

Looking at just the cumulative yields does not show all of the benefits of stocking, since some of the released juveniles contribute to an increase in standing stock. When the contribution of the released juveniles to both the fishery and standing stock is considered, the relative benefit is the same for all three stocking and harvesting strategies (Table 5).

A delay-difference model very similar to the model used in this analysis, but with a Cushing rather than Ricker recruitment function, has been fit to data on the Pacific ocean perch fishery in waters off Washington and Oregon (Ito et al. 1987). When the Cushing recruitment function is used in our model, the estimates of MSY, F_{MSY} and B_{MSY} change, but the relative contribution of hatchery releases to biomass and yield is unchanged (Table 5). Further, based on simple sensitivity analyses, the relative benefits of hatchery releases by increasing biomass and yield apparently are most sensitive to the ratio of natural mortality to growth (Table 5). Thus, as in the yield-per-recruit model, the relative benefits of hatchery releases are inversely proportional to the ratio of mortality to growth.

Table 3
Catch of Pacific ocean perch cumulated by 10-year periods from the mean of 100 simulations of the Deriso-Schnute model (thousands of metric tons).

Strategy	Years to B_{MSY} (*N*)	No. of years for which catch is cumulated: 10	20	30	40	50
F = 0, years 1–21; F = 0.06, years 11–50	21	0	0	16.8	37.7	58.6
F = 0, years 1–14; F = 0.06, years 15–50, with stocking of 5 million/year for 6 years	14	0	13.0	34.5	56.5	77.9
F = 0.3, years 1–35; F = 0.06, years 36–50	35	4.4	10.6	19.2	35.2	56.2
F = 0.03, years 1–16; F = 0.06, years 17–50, with stocking of 5 million/year for 10 years	16	4.5	18.5	39.7	61.2	82.3
F = 0.06, years 1–50	100+	8.0	17.8	29.8	43.3	58.3
F = 0.06, years 1–50, with stocking of 5 million for 12 years	20	8.3	25.1	46.3	67.5	88.9

Table 4
Break-even cost of hatchery-released juveniles of Pacific ocean perch at a 3% annual rate of return (US$ per juvenile) as a function of years after start of releases.

Strategy	Years: 10	20	30	40	50
F = 0, years 1–21; F = 0.06, years 22–50 **versus** F = 0, years 1–14; F = 0.06, years 15–20, with stocking of 5 million/year for 6 years	0	0.16	0.16	0.12	0.09
F = 0.03, years 1–35; F = 0.06, years 36–50 **versus** F = 0.03, years 1–16; F = 0.06, years 17–50, with stocking of 5 million/year for 10 years	0	0.06	0.11	0.11	0.08
F = 0.06, years 1–50 **versus** F = 0.06, years 1–50, with stocking of 5 million/year for 12 years	0	0.04	0.07	0.08	0.07

Table 5
Contribution of juvenile releases of Pacific ocean perch to biomass and cumulative yield 20 years after the start of releases.

Strategy	I: Change in biomass per released juvenile (kg/fish)	II: Change in yield per released juvenile (kg/fish)	II + III (kg/fish)
A	0	0.43	0.43
B	0.25	0.16	0.41
C	0.31	0.11	0.42
D	0.33	0.08	0.41
E	0.28	0.14	0.42
F	0.18	0.05	0.23
G	0.22	0.26	0.48
H	0.33	0.14	0.47

A: F = 0, years 1–21; F = 0.06, years 22–50 vs. F = 0, years 1–14; F = 0.06, years 15–50, with 5 million juvenile releases for 6 years.
B: F = 0.03, years 1–35; F = 0.06, years 36–50 vs. F = 0.03, years 17–50, with 5 million juvenile releases for 10 years.
C: F = 0.06 vs. F = 0.06, with 5 million juvenile releases for 12 years.
D: F = 0.04 vs. F = 0.04, with 5 million juvenile releases for 12 years.
E: F = 0.08 vs. F = 0.08, with 5 million juvenile releases for 12 years.
F: M = 0.1 instead of M = 0.05 and strategy C.
G: F = 0.08 vs. F = 0.08, with 5 million juvenile releases for 3 years with growth, mortality, and Cushing recruitment model (parameter estimates are from Ito et al. 1987).
H: F = 0.04 vs. F = 0.04, with 5 million juvenile releases for 5 years with growth, mortality, and Cushing recruitment model (parameter estimates are from Ito et al. 1987).

Discussion

The Beverton and Holt (1966) model provides a simple means of evaluating the equilibrium contribution of a long-term hatchery release program to the fishery. The model shows that if M/K is 0.5 for the hatchery-released juveniles from the time of release to capture in the fishery, and if the cost of each released juvenile is less than US$0.16, its value to the fishery exceeds its cost. The length-at-entry for fish in these analyses is assumed to be the length that maximizes the yield-per-recruit, that is, 45–86% of the asymptotic length. If the length-at-entry to the fishery is below this level, as with some long-lived, slow-growing fishes, the contribution of the hatchery releases to the fishery will be less than the value calculated by the model. However, the yield-per-recruit surface is relatively flat, so unless the length-at-entry is widely different from the optimum length, the reduction in the contribution of the hatchery releases should not exceed 10–15% of the value corresponding to the optimum length-at-entry (Beverton and Holt 1966). The results of the model are particularly sensitive to levels of M/K, asymptotic weight, and market price. Interestingly, the results depend only on the ratio of M to K, and the slow growth of rockfish does not have a bearing on the equilibrium benefit of the released juveniles. Three commercially important species—Pacific ocean perch, yellowtail rockfish *Sebastes flavidus*, and canary rockfish *S. pinniger*—have M/K values around 0.5 and, from a population dynamics standpoint, offer the most potential for hatchery releases (Table 1).

Based on the Deriso-Schnute model, the level of F_{MSY} for Pacific ocean perch in Queen Charlotte Sound is estimated at 0.06 per year. This value is consistent with the finding of Archibald et al. (1983) and considerably less than the F levels of 0.2–0.5 per year during the depletion of the stock. Given the slow growth and long lag between spawning and recruitment to the fishery, stock recovery for rockfish is a long-term process. Fishery managers must decide whether the goal of the recovery program is to return the stock to B_{MSY} as quickly as possible or to follow a more gradual return while allowing fishing. Under both approaches, stocking reduces the time to reach B_{MSY} and increases the yield to the fishery. Both benefits must be considered in evaluating the merits of a hatchery-release program for stock recovery. As with the yield-per-recruit analysis, Pacific ocean perch, yellowtail rockfish, and canary rockfish are the three commercial species, based on their low M/K ratios, that offer the most potential for stock recovery with hatchery releases (Table 1).

Based on population-dynamics considerations, the use of hatchery releases for fishery enhancement appears to have merit for certain species of rockfishes. However, population dynamics represents only one part of the post-release ecology, and a fuller understanding of this ecology is necessary to predict the success of hatchery releases. For example, hatchery-reared Kuruma prawns *Penaeus japonicus* were released in a number of similar locations around Japan (Isibasi 1984). Increases in catches were documented in some instances, but no changes were evident in many others; researchers generally were unable to explain this variation (Isibasi 1984). While this analysis assumes that large-scale hatchery releases are possible, no such releases have been done, and nothing is known of the economics of a rockfish hatchery. Further, hatchery-released juveniles have been assumed to have the same behavior and natural mortality as wild stock. This may be an overly optimistic assumption because pilot hatchery releases for other species often have higher and more variable natural mortality than is thought to occur in wild stock (Kyokai 1983).

Citations

Archibald, C.P., D. Fournier, and B.M. Leaman
1983 Reconstruction of stock history and development of rehabilitation strategies for Pacific ocean perch in Queen Charlotte Sound, Canada. N. Am. J. Fish. Manage. 3:283–294.

Beverton, R.J.H., and S.J. Holt
1966 Manual of methods for fish stock assessment. Part II - Tables of yield functions. FAO Fish. Tech. Pap. 38 (Rev. 1), 67 p.

Botsford, L.W., and R.C. Hobbs
1984 Optimal fishery policy with artificial enhancement through stocking: California's white sturgeon as an example. Ecol. Modell. 23:293–312.

Deriso, R.B.
1980 Harvesting strategies and parameter estimation for an age-structured model. Can. J. Fish. Aquat. Sci. 37:268–282.

Isibasi, K.
1984 A statistical assessment on the effect of liberation of larvae in the sea farming—I. On the effect of liberation in the case of Kuruma prawn (*Penaeus japonicus*). Bull. Tokai Reg. Fish. Res. Lab. 113:141–155.

Ito, D.H., D.K. Kimura, and M.E. Wilkins
1987 Status and future prospects for the Pacific ocean perch resource in waters off Washington and Oregon as assessed in 1986. NOAA Tech. Memo. NMFS-F/NWC-113, Northwest & Alaska Fish. Sci. Cent., 7600 Sand Point Way NE, Seattle 98115, 50 p.

Kusakari, M.
In press Mariculture of kurosoi, *Sebastes schlegeli*. Environ. Biol. Fish.

Kyokai, S. (editor)
1983 Tsukuru gyogyo. Norin Tokei Kyokai (Agric. For. Stat. Assoc.), 753 p. [in Jpn., Engl. transl. of Table of Contents only by T. Otsu, 1987; full translation avail. from JJP].

National Marine Fisheries Service
1989 Fisheries of the United States, 1988. U.S. Natl. Mar. Fish. Serv. Curr. Fish. Stat. 8800, 116 p.

Pacific Fishery Management Council
1989 Pacific coast groundfish fishery management plan, draft amendment 4. Pac. Fish. Manage. Counc., Portland, OR, 52 p.

Sakai, K., H. Nagashima, and K. Kiso
1985 Growth and movement of artificially reared young rockfish, *Sebastes schlegeli*, after release in Matsushima Bay. Bull. Tohoku Reg. Fish. Res. Lab. 47:21–32 [in Jpn., Engl. abstr; Engl. transl. 125 by W.G. Van Campen, 1988, 19 p., avail. Honolulu Lab., Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396].

Schnute, J.
1985 A general theory for analysis of catch and effort data. Can. J. Fish. Aquat. Sci. 42:414–429.

Ulltang, O.
1984 The management of cod stocks with special reference to growth and recruitment overfishing and the question whether artificial propagation can help to solve management problems. *In* Dahl, E., D.S. Danielssen, E. Moksness, and P. Solemdal (eds.), The propagation of cod *Gadus morhua* L., p. 795–817. Flødevigen rapp., 1.

Yatsuyanagi, K.
1982 Productive effect in stocking of prawn seedling in waters adjacent to Yamaguchi Pref. and Suho-Nada. Bull. Yamaguchi Prefect. Naikai Fish. Exp. Stn. 10:1–52.

Zheng, J., and C.J. Walters
1988 Population dynamics and stock assessment of Wanshan Spring *Decapterus maruadsi* (T.&S.) in South China Sea. Fish. Res. (Amst.) 6:217–231.