A COMPARISON OF PRODUCTIVITIES FOR SNAKE RIVER AND LOWER COLUMBIA RIVER SPRING AND SUMMER CHINOOK STOCKS

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ABSTRACT

Loss of productivity due primarily to hydropower development in the Columbia River Basin prompted the 1992 listing of Snake River spring/summer and fall chinook salmon under the Endangered Species Act. State fishery agencies in Idaho, Oregon and Washington and the Columbia River Intertribal Fisheries Commission are jointly developing an analytical framework to systematically evaluate the various combinations of proposed management actions to assess Snake River chinook rebuilding. The productivity of a stock must be considered directly to analyze the performance of alternative regulatory strategies. Therefore, we estimated potential productivity of Snake River spring and summer chinook using two methods. First, we reconstructed spawner and recruit information on a brood year basis for 12 Snake River spring and summer chinook populations, and fit the data to recruitment models for the period before major hydropower development (brood years 1957-69). We also estimated productivity for a downriver stock with similar attributes (Warm Springs River) that has not been exposed to the same high levels of density-independent mortality. Pre-development productivity of most Snake River stocks, on average, closely matched the recent productivity of the Warm Springs River (respective intrinsic rates of increase, 2.34 and 2.35). Productivity of South Fork Salmon River summer chinook, which suffered severe habitat degradation in the 1960s, was considerably lower (1.23). Recent recruitment of Snake River populations has been highly variable, and is related significantly to the mainstem velocities experienced during the smolt migration when density dependence is taken into account. Empirical recruitment data should be an essential element in validating the parameters, assumptions and performance of hydrosystem smolt survival models.

INTRODUCTION

The critical status of Columbia River Basin chinook salmon stocks has been the focus of many efforts and studies over the past 20 years. In 1980, passage of the Northwest Power Act mandated balance between fish and wildlife and power interests. In addition, in 1984 the U.S. and Canada signed the Pacific Salmon Treaty and formed the Pacific Salmon Commission (PSC) to institute a coastwide chinook conservation program. But in spite of measures

contained in the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program (NPPC 1987), and reductions in ocean chinook harvest rates the Snake River chinook stocks continued to decline to extremely low levels (Blum and Simrin 1991). In 1992 the National Marine Fisheries Service (NMFS) listed Snake River spring/summer chinook as one threatened species, and also listed Snake River fall chinook as threatened.

Improved smolt survival is critical to recovery and rebuilding of chinook runs in the Snake River (CBFWA 1991). The development and operation of the hydroelectric system on the Columbia and Snake rivers completely changed the hydrological conditions under which chinook have evolved. The building of dams dramatically increased the cross-sectional area of the rivers, increasing the mean and the variability of water particle travel time (Fig. 1.; Idaho Department of Water Resources). In addition to migration delay for smolts (Sims and Ossiander 1981; Bergren and Filardo 1991), hydroelectric projects caused site specific mortalities and delays (Raymond 1979, 198B).

An analytical framework is needed to systematically evaluate the various combinations of proposed management actions to assess Snake River chinook recovery and rebuilding. State fishery agencies in Idaho, Oregon and Washington and the Columbia River Intertribal Fisheries Commission are jointly developing a system of models that relies to a large degree on empirical recruitment data and estimates of stock productivity.

The productivity of a stock should be considered directly to analyze the performance of an alternative recovery or rebuilding objective (PSC 1989). Therefore, the recovery objectives and anticipated responses of a stock are going to depend on estimating potential productivity of the stock. Without estimates of stock productivity, the combinations of changes in mortality rates (at various life stages) needed to recover or rebuild stocks will be extremely difficult to determine.

One approach to estimating a stock's potential productivity is to reconstruct spawner and recruit information on a brood year basis and fit the data to recruitment models (e.g., Ricker 1954, 1975; Beverton and Holt 1957). However, large amounts of unaccounted independent mortality in these data sets (from hydroelectric development) will grossly underestimate the potential productivity. One solution is to estimate the productivity of a stock using the data set prior to the large increases in independent mortality. An alternative is to use the estimates of intrinsic productivity for a stock with similar attributes that has not been exposed to the same high levels of independent mortality (i.e., downriver spring chinook stock) to represent a Snake River spring or summer chinook stock. This approach has been used for evaluating Snake River fall chinook management actions relative to rebuilding (Schaller and Cooney 1992). The intrinsic rate of increase from a lower Columbia River stock, coupled with an estimate of spawning and rearing habitat capacity (i.e., spawners needed at either maximum sustainable yield (MSY) or maximum sustainable production (MSP)) would yield a reasonable approximation for a production function.

Smolt survival models used to evaluate mainstem management actions can be highly sensitive to both the form of the relationship between survival and

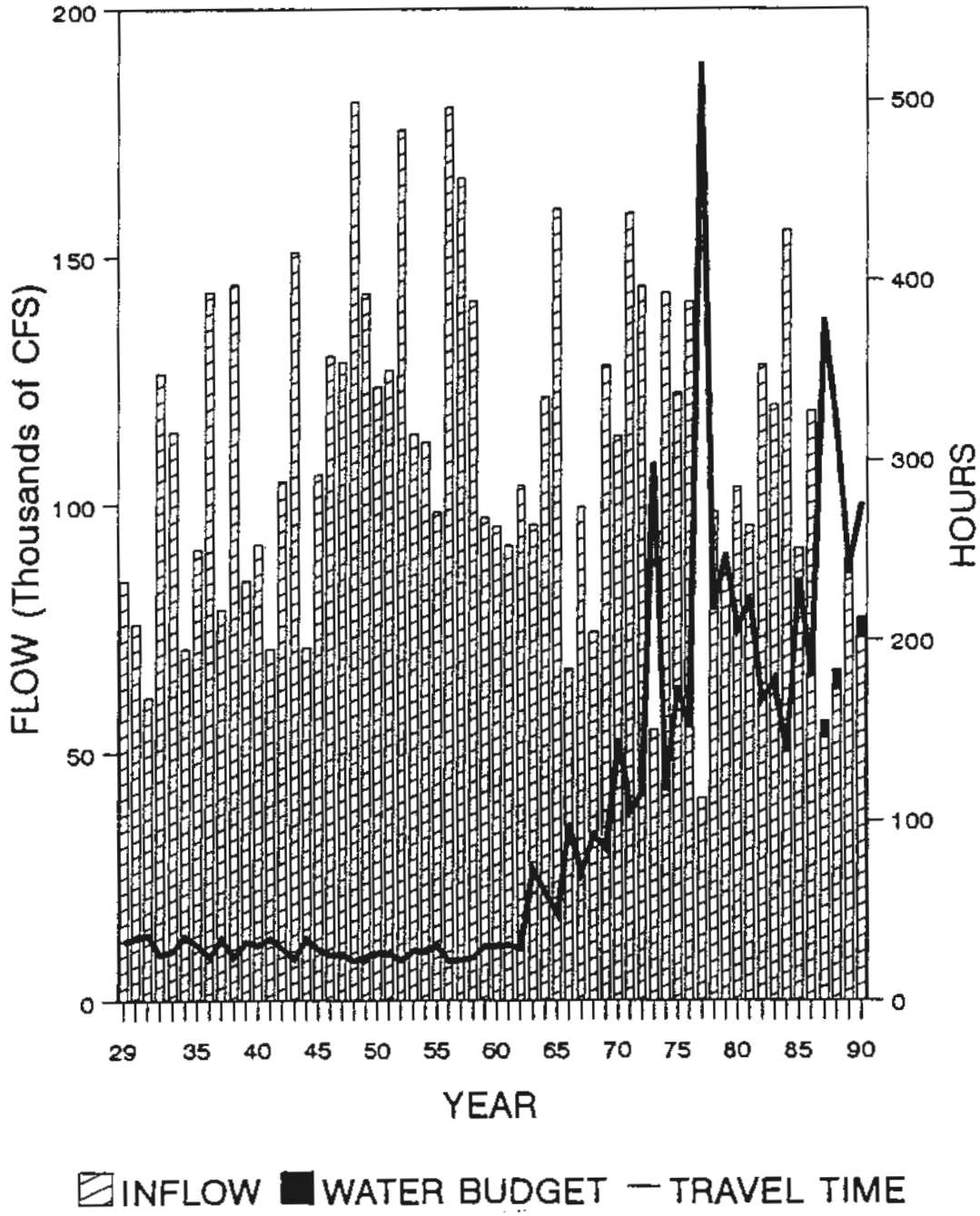


Figure 1. Mean Snake River flow (kcfs) and water particle travel time (hours) during the spring smolt migration period (April 15-June 15), 1960-90.

water velocity or fish travel time and assumptions about survival of transported fish (Petrosky 1991a; Fisher 1992; McConnaha and Anderson 1992; Weber et al. 1992). Because the use of different functions and assumptions can often yield widely varying responses to proposed management actions, it is important that smolt survival models used to forecast responses can also realistically hindcast recent adult recruitment trends.

This paper presents empirical run reconstructions and stock-recruitment relationships for Snake River populations and a downriver spring chinook population from the Warm Springs River in the Deschutes River Subbasin. Stock-recruitment functions for Snake River populations were fitted for brood years prior to final hydropower development. Recent recruitment for selected Snake River populations was compared to the baseline recruitment and to recruitment for the Warm Springs River. For two populations, we investigated the relationship of adult recruitment, at spawner density, to mainstem flows, water velocities and smolt travel times during the smolt migration. Finally we compared adult recruitment to estimates of smolt survival under different assumptions about smolt transport survival.

METHODS

Stock-Recruitment and Base Productivity

Twelve index populations of Snake River spring and summer chinook were used in the analysis. Most index areas represent only a fraction of the total spawning population. Oregon index populations included the Imnaha River spring/summer chinook and an aggregate Grande Ronde River spring chinook population (Lookingglass and Catherine creeks, and upper and lower Minam River transects). Idaho index populations were all from the Salmon River subbasin. Summer chinook indices were from the South Fork Salmon River and Johnson Creek. Spring chinook indices were from Marsh, Bear Valley, Elk and upper Big creeks (Middle Fork Salmon River), Lemhi River, upper East Fork Salmon River, upper Valley Creek, and upper Salmon River.

The methods to reconstruct the Snake River index populations of spawners and subsequent recruits, on a brood year basis, were outlined in Petrosky (1991b). The recruits were estimated to the Columbia River mouth based on annual redd counts, carcass surveys, estimates of spawner age composition, prespawning mortality, sport harvest in Idaho and Oregon, Columbia River harvest, and adult upstream passage conversion rates (Matylewich, CRITFC, personal communication). Prespawning mortality was assumed to be 10 percent as suggested by tributary weir counts of adults and redd count data in Salmon River streams (Ortmann 1968, Bjornn 1978, Kiefer and Forster 1991). In the run reconstructions, the effect of increasing the pre-spawning mortality rate would be to proportionately increase estimated recruitment to the Columbia River mouth.

Numbers of spawners and recruits were estimated for Snake River populations for brood years 1957-86. Lack of recent carcass data and/or inability to separate hatchery and natural adult returns precluded reconstruction of recent recruitment for four Salmon River populations.

Similar methods were used to reconstruct the Warm Springs River (downriver population) spring chinook spawners and recruits (Lindsay et al. 1989). The recruits were estimated based on annual redd counts, carcass surveys, estimates of spawner age and sex composition, prespawning mortality, fish taken for broodstock, and Deschutes River harvest (Lindsay et al. 1989 and Olsen 1992). Presence of a weir allowed for accurate accounting of escapements and age structure. The Lindsay et al. (1989) methods were updated to also account for Columbia River harvest and adult upstream passage conversion rates. Numbers of spawners and recruits were estimated for brood years 1975-86.

Spawner-recruit models were fitted to Snake River populations for the base period (brood years 1957-69) and to the Warm Springs population for the recent period (brood years 1975-86). Ricker (1975) models were fitted by least squares linear regression and nonlinear regression (Wilkinson 1989) techniques.

The recruit per spawner ratios (R/S) were compared relative to the percent of the maximum sustained production (MSP) spawning escapement levels achieved in each brood year. The %MSP escapement level, which accounts for density-dependent mortality, was approximated from the best fit stock-recruitment model for the Snake River base period and the Warm Springs recent period.

Post-Hydropower Recruitment

Recent recruitment of Snake River spring and summer chinook populations was assessed by comparing brood year success to recruitment predicted for the base period and for the downriver population. The ratio (observed R/S)/(predicted R/S) at spawner density (%MSP) produces a relative survival index for each brood year.

The relative survival index reflects primarily the density-independent mortality due to annual smolt survival conditions, as well as density-independent mortality in freshwater, estuary and ocean environments, and estimation errors. It excludes density-dependent mortality, for the most part, by expressing recruitment relative to seeding level (MSP).

Relationships to Smolt Migration Conditions and Modeled Smolt Survival

We investigated the influence of mainstem water velocity during smolt migration on recent recruitment for two Snake River populations, Marsh Creek spring chinook and Imnaha River spring/summer chinook (brood years 1975-86). First we regressed ln(R/S) against spawner seeding (% MSP) and mean Snake River flow during the peak chinook smolt migration period (April 15-May 5). We also estimated smolt travel times from the FLUSH Model (Weber et al. 1992) for the same period and substituted these in the multiple regressions for the flow variable.

We investigated the sensitivity of two assumptions about survival of transported fish by comparing estimated smolt survival from the FLUSH Model (Weber et al. 1992) with the relative survival index of adult recruitment for brood years 1975-86. Alternative transport survival assumptions were TBR-1

and TBR-2 used in the NPPC Phase 3 analyses (McConnaha and Anderson 1992). TBR-1 assumes that transport survival is independent of water velocities faced by smolts prior to collection and transportation. TBR-2 assumes that transport survival decreases under poor flows and velocities.

RESULTS AND DISCUSSION

Stock-Recruitment and Base Productivity

Stock-recruitment data from the Warm Springs River spring chinook population for brood years 1975-86 exhibited classic density dependence (Fig. 2). A Ricker function fit the data set exceptionally well ($r^2 = 0.96$; Table 1). This downriver index population appeared to be quite stable and moderately productive, with an intrinsic rate of increase of 2.35 (this is equivalent to an absolute rate of productivity of 10.49 progeny for each parent).

Base period (brood years 1957-69) productivity of Snake River populations, on average, closely matched the recent productivity of the Warm Springs stock (Fig. 3, Table 1). Excluding South Fork Salmon River summer chinook populations, which suffered severe habitat degradation in the 1960s (Platts and Megahan 1975), the intrinsic rates of increase ranged from 1.75 to 3.49. The average intrinsic rate of increase for these Snake River populations was 2.34 (10.38 progeny per parent), compared to 2.35 for the downriver index population.

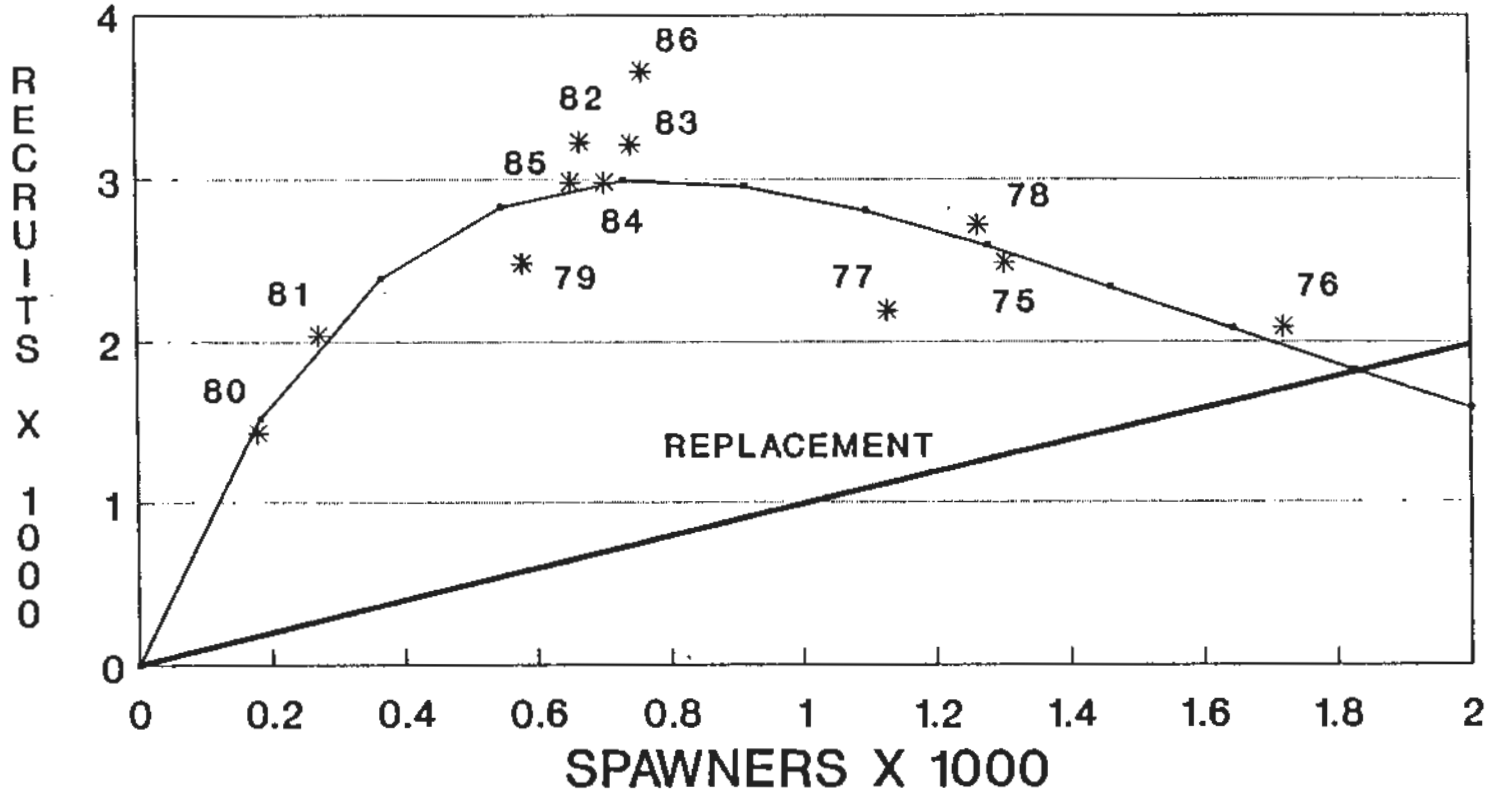
Base period productivity was considerably less in Johnson Creek (1.57) and South Fork Salmon River (0.88) index areas than in other Snake River populations. Productivity appeared to be declining for these two populations during the 1957-69 period, based on inspection of spawner and recruit plots of the individual brood years (T.E.C.H. 1992).

The fit of Ricker functions to base period stock-recruitment data was poor for some of the Snake River populations. Coefficients of determination were less than 0.25 for five index populations (Table 1), all of which had less-than-average productivity and some degree of habitat degradation during the base period.

Post-Hydropower Recruitment

Recent productivity of Snake River populations has been more variable and considerably lower than either the base period productivity or the recent productivity of the downriver index population (T.E.C.H. 1992). The recent recruit/spawner ratios (R/S) of Marsh Creek spring chinook, for example, were less than predicted for either the base period or the downriver stock in 11 of 13 years when density dependence is taken into account (Fig. 4). Similarly, recent R/S ratios for the Imnaha River spring/summer chinook were less than the base period prediction in all but one year, and less than the downriver population in all years (Fig. 5).

Density-independent survival of Snake River populations declined and became more variable following hydropower development. The relative survival index,



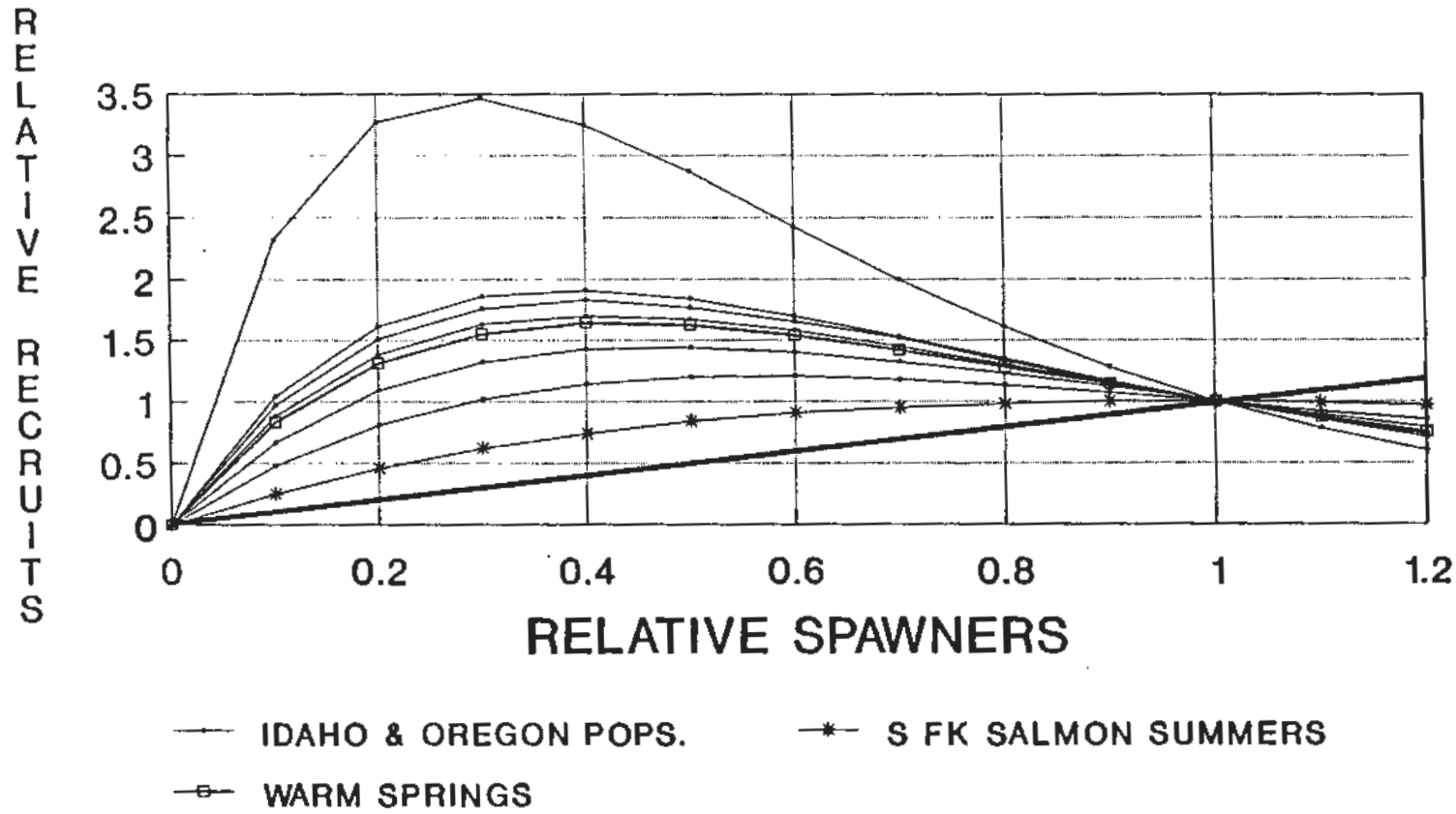
Alpha = 2.349; Beta = -0.00128
R^2 = 0.96
(Schaller, ODFW)

Figure 2. Stock recruitment of Warm Springs River, Oregon spring chinook, brood years 1975-88.

Table 1. Ricker stock-recruitment coefficients fit to Warm Springs River spring chinook population (downriver), brood years 1975-86, and to Snake River spring (SP) and summer (SU) chinook index populations, brood years 1957-69.

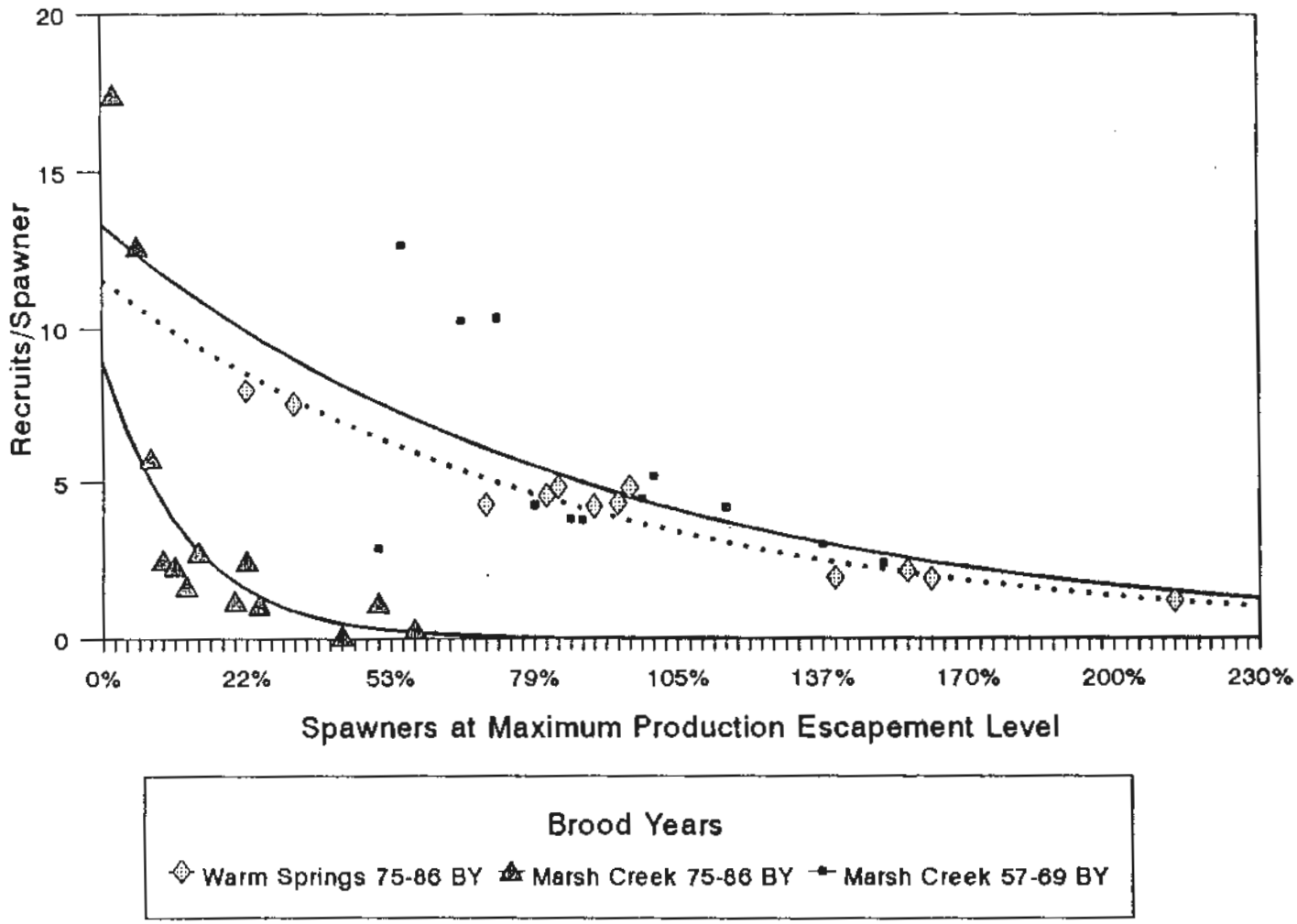
Area, Population	Run	Coefficient alpha	Coefficient beta	r^2	Spawners at MSY	Spawners at MSP	Spawners at Replacement
Deschutes River, OR							
Warm Springs	SP	2.349	0.0013	0.96	630	805	1825
Snake River, OR							
Grande Ronde	SP	2.529	0.0012	0.80	700	848	2145
Imnaha[a]	SP/SU	1.780	0.0008	0.63	820	1219	2170
Middle Fk. Salmon, ID							
Marsh	SP	2.414	0.0012	0.42	710	861	2078
upper Big	SP	1.968	0.0026	0.34	290	385	758
Bear Valley	SP	1.947	0.0008	0.09	1000	1324	2579
Elk	SP	2.817	0.0017	0.41	520	582	1641
Upper Salmon, ID							
Lemhi	SP	1.747	0.0002	0.15	2650	3987	6963
upper E. Fk.	SP	2.603	0.0009	0.55	950	1140	2966
upper Valley	SP	3.492	0.0038	0.88	250	263	919
upper Salmon	SP	2.119	0.0004	0.22	1970	2642	5598
South Fk. Salmon, ID							
South Fk.	SU	0.880	0.0001	0.07	4150	10679	9401
Johnson	SU	1.571	0.0012	0.24	500	727	1083

[a] Model assumes summer chinook timing through Columbia River fisheries.



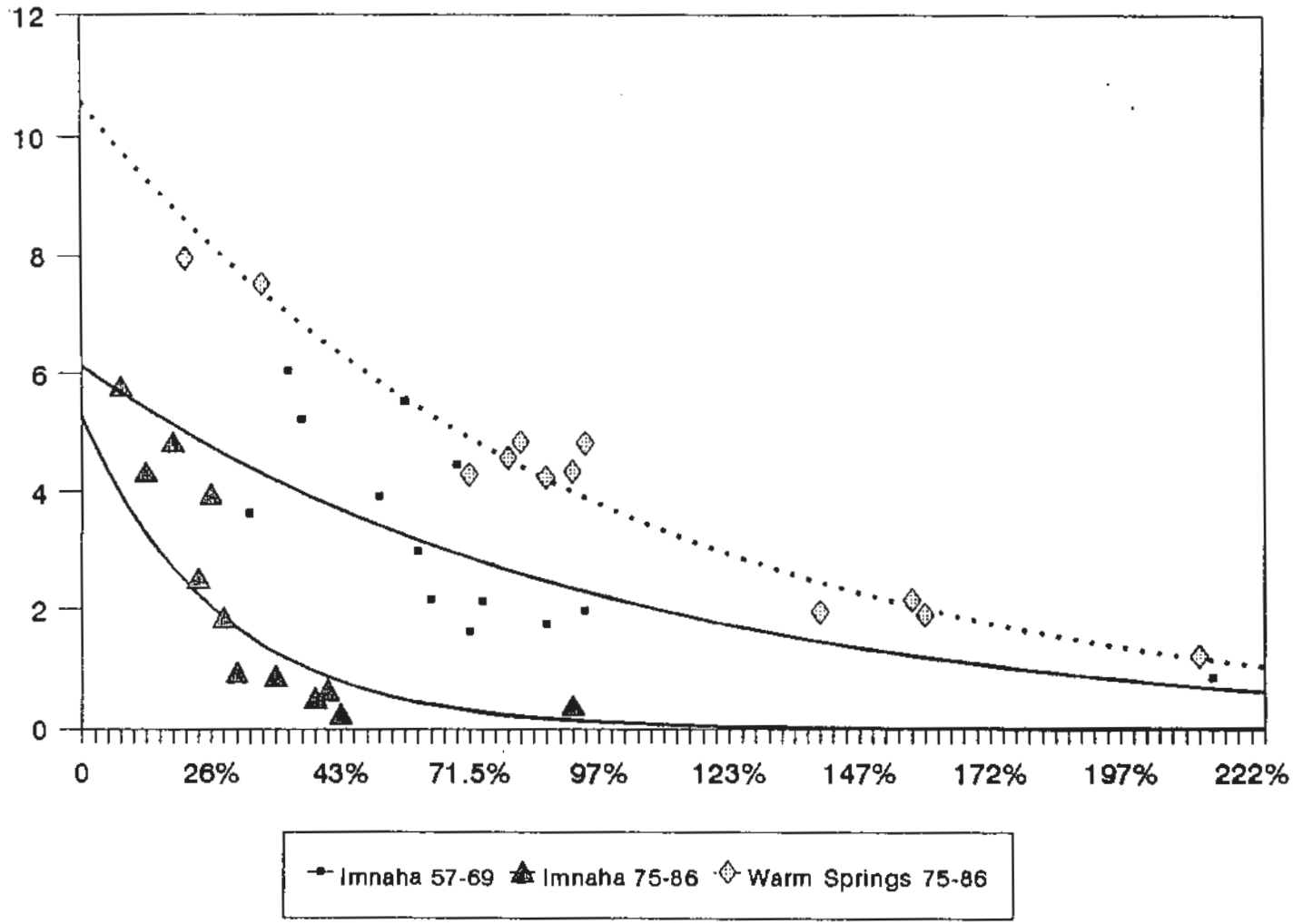
ALPHA = 2.35, WARM SPRINGS
ALPHA = 2.34, SNAKE RIVER MEAN

Figure 3. Stock recruitment of Snake River spring and summer chinook (Idaho and Oregon), before final hydropower development, brood years 1957-69, compared to recent Warm Springs River spring chinook (downriver population), brood years 1975-86.



Maximum Production Escapement Level estimated from Spawner/Recruit Analysis (Schaller&Petrosky 1992)

Figure 4. Recruits per spawner at spawner density (% MSP) for Marsh Creek spring chinook, brood years 1975-86, compared to the base period (brood years 1957-69) and to the Warm Springs River spring chinook, brood years 1975-86.



Maximum production escapement estimated from Spawner/Recruit analysis (Schaller & Petrosky 1992)

Figure 5. Recruits per spawner at spawner density (% MSP) for Imnaha River spring/summer chinook, brood years 1975-86, compared to the base period (brood years 1957-69) and to the Warm Springs River spring chinook, brood years 1975-86.

which expresses density-independent recruitment, equals 1.0 (by definition) when observed R/S for a brood year equals the predicted R/S for the base period. For the four Snake River index populations during the base period, the mean relative survival index was approximately 1.0, and coefficients of variation ranged from 33 percent to 52 percent (Table 2). The relative survival index after hydropower development averaged about a third to half that in the base period, with coefficients of variation ranging to greater than 100 percent.

The relative survival index for Snake River populations varied widely between brood years in the recent period, ranging from 0.04 in 1975 to 1.43 in 1980 (Fig. 6, Table 2) . This is in sharp contrast to the between-year stability of the downriver population in the same period. Presumably the downriver and Snake River populations should be affected by similar estuary and ocean conditions (within a brood year) because they are similar in terms of juvenile life history characteristics (age and outmigration timing), low ocean interception levels (Lindsay et al. 1989; Hassemer, IDFG, personal communication) and adult return timing the Columbia River. The disparity of density-independent survival between Snake River and downriver populations suggests that much of the Snake River variation was due to smolt survival conditions, rather than differing estuary or ocean conditions.

Relationships to Smolt Migration Conditions and Modeled Smolt Survival

Multiple regression analyses of R/S ratios with seeding level (% MSP) and mean Snake River flow were significant ($p \leq 0.0003$) for Marsh Creek and Imnaha River populations (Table 3). The regressions of R/S ratios with seeding level and estimated smolt travel time were also significant ($p \leq 0.0004$) for both populations. Inspection of the coefficients and response surfaces indicated that the alternative models produced similar results. At a given seeding level, the R/S ratio increased with increased flows (Fig. 7) or faster smolt travel times (Fig. 8). These findings are consistent with the findings outlined in the CBFWA (1991) biological justification for mainstem flow. That is, there appear to be significant benefits to survival for velocities up to at least the 140 kcfs equivalent in the Snake River during the spring migration.

Since 1977 an aggressive smolt transportation program has been underway in the Snake River to attempt to compensate for reduced water velocities and poor inriver survival. Transport benefits have been measured as a ratio of return rates of transported and "control" groups. Although ratios have generally exceeded 1:1 (Hatthews et al. 1990), the transportation program has not rebuilt Snake River runs of spring and summer chinook.

Because a large proportion of Snake River spring and summer chinook smolts are transported, smolt survival models are by nature highly sensitive to the assumptions and parameter values used for transport survival. FLUSH model runs for brood years 1975-86 (smolt years 1977-88) for inriver survival (transportation turned off) yielded estimates of smolt survival that correlate significantly ($r^2=0.34$, $p<0.05$) with the relative survival indices for Snake River populations (Fig. 9). Use of both transport models TBR-1 and TBR-2 in FLUSH yielded total smolt survival estimates that deviated considerably from

Table 2. Mean relative survival index and coeffient of variation (C.V.) for Warm Springs River spring chinook population (downriver), brood years 1975-86, and four Snake River spring/summer chinook populations, brood years 1957-69 and 1975-86.

Population	Base Period (1957-69)		Recent Period (1975-86)	
	Mean	C.V.(%)	Mean	C.V.(%)
Downriver				
Warm Springs River	--	--	1.00	10.4%
Snake River				
Imnaha River	1.06	33.4%	0.48	75.3%
Marsh Creek	1.07	35.9%	0.43	117.5%
Bear Valley Creek	1.15	49.7%	0.48	113.5%
Elk Creek	1.02	52.0%	0.28	118.7%

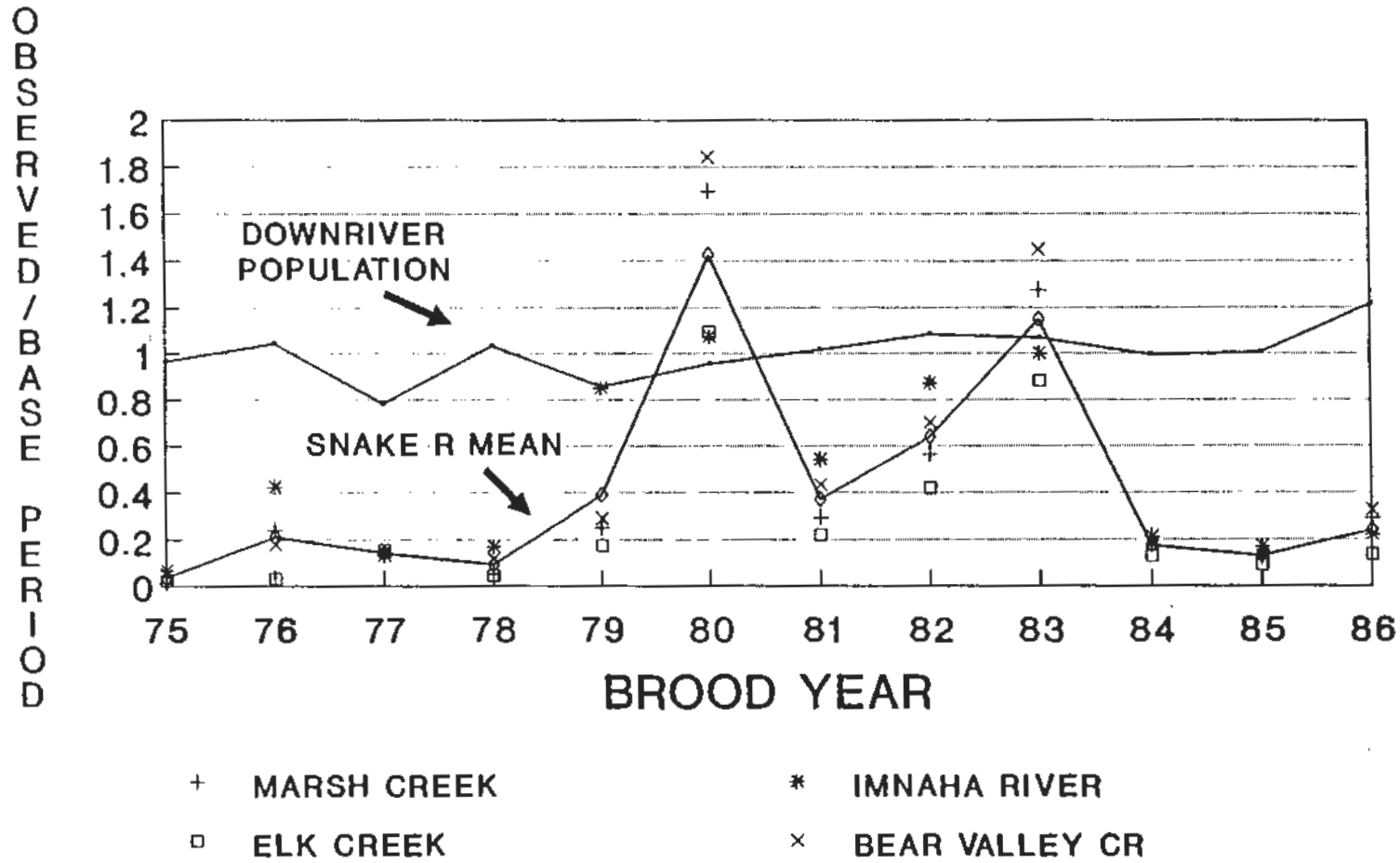
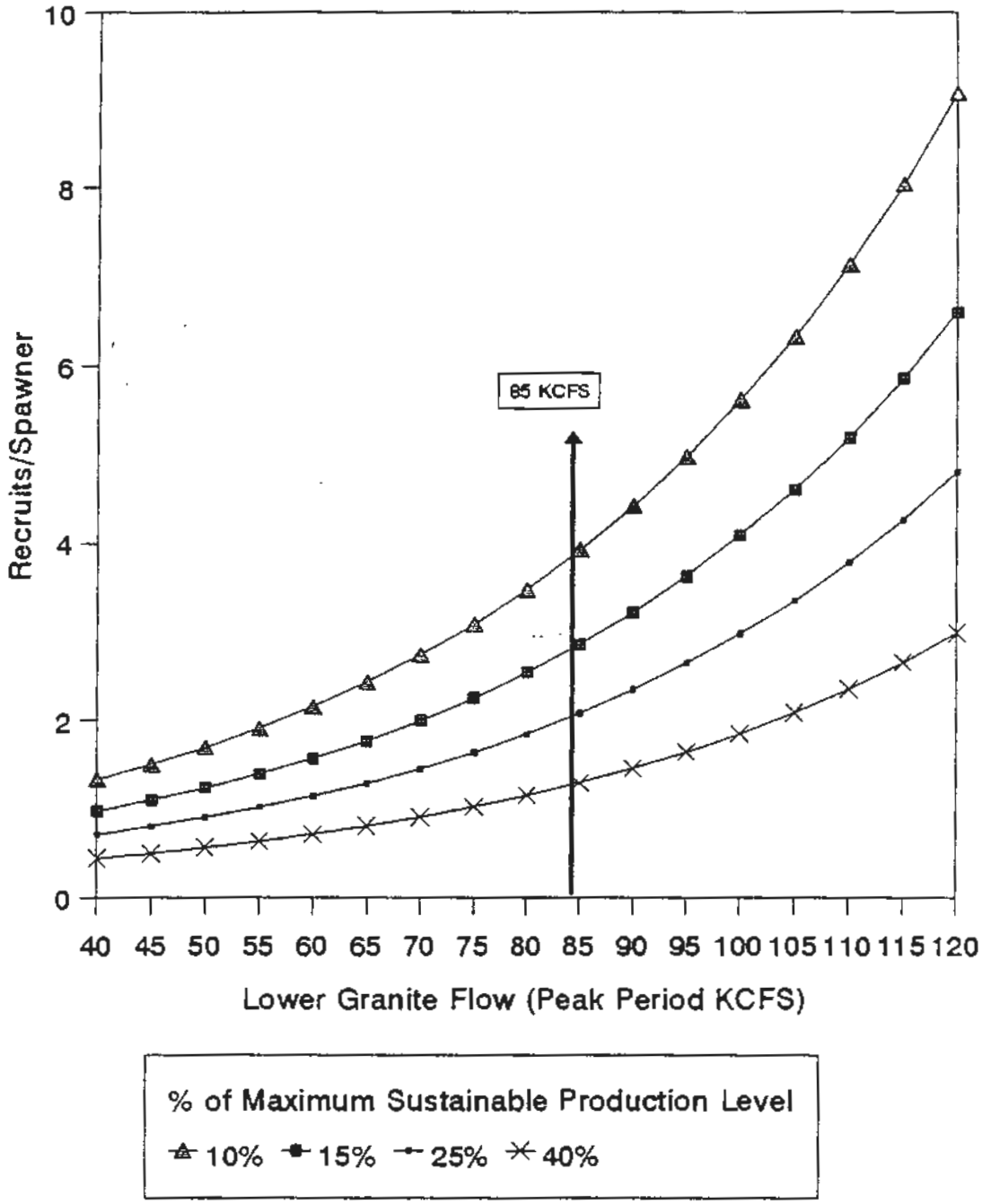


Figure 6. Relative survival index for four Snake River spring and summer chinook populations and for Warm Springs River (downriver population) spring chinook, brood years 1975-86.

Table 3. Multiple regression coefficients, coefficients of variation and probabilities for Marsh Creek and Imnaha River spring/summer chinook recruit/spawner (R/S) ratios, brood years 1975-86 (smolt migration years 1977-88)[a].

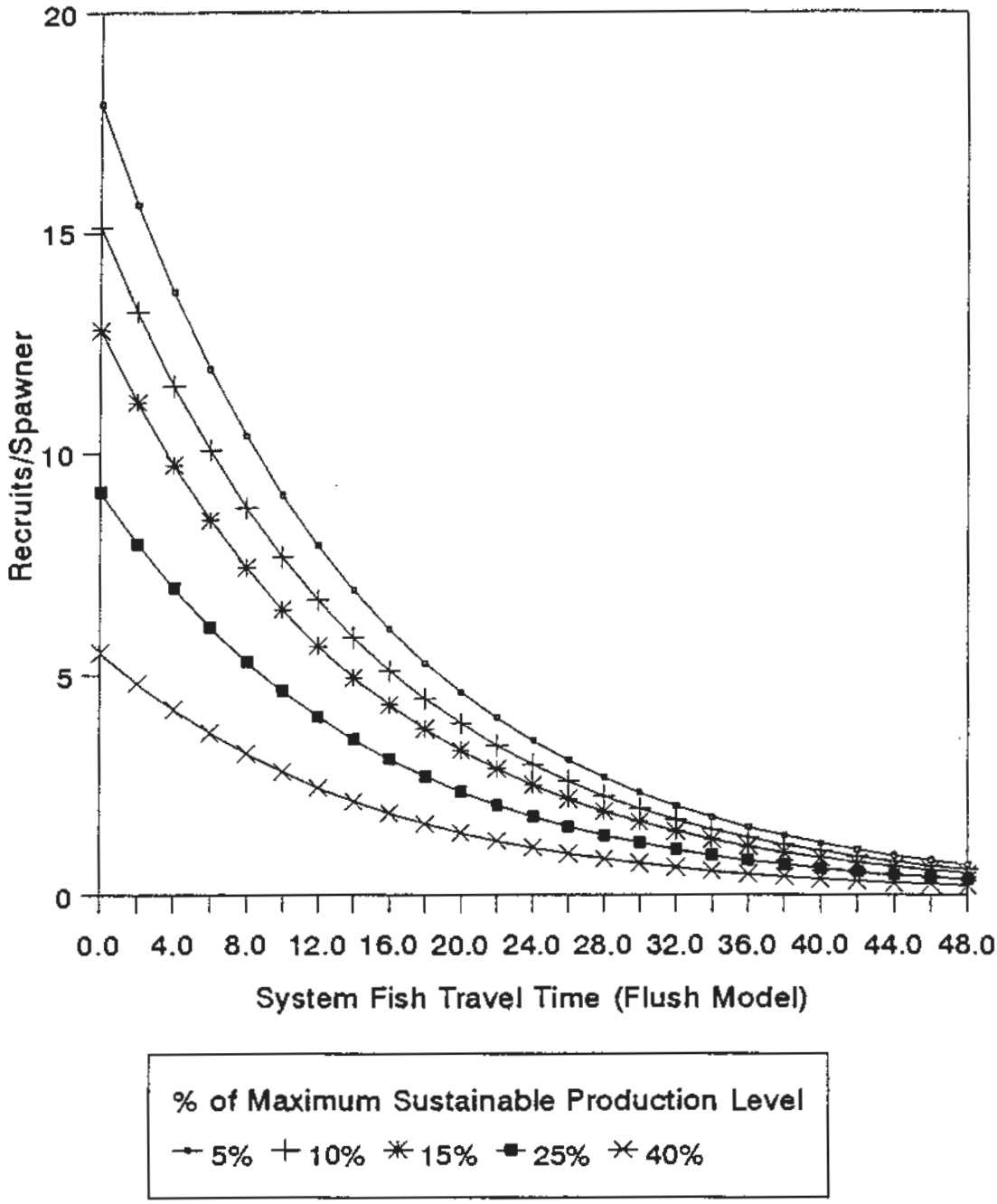
Velocity variable, population	Constant	Flow or %MSP	travel time	R^2	p =
Flow[b]					
Marsh Creek	0.2743	-6.3174	0.0202	0.83	0.0003
Imnaha River	-0.5151	-3.1849	0.0241	0.84	0.0002
Fish travel time[c]					
Marsh Creek	3.2715	-6.2705	-0.0599	0.83	0.0003
Imnaha River	3.0688	-3.3726	-0.0685	0.83	0.0004

[a] ln(R/S) = Constant + %MSP + Velocity Variable
[b] Mean Snake River flow (kcfs) during 4/20-5/5.
[c] Estimated (FLUSH model) mean smolt travel time (days) during 4/20-5/5.



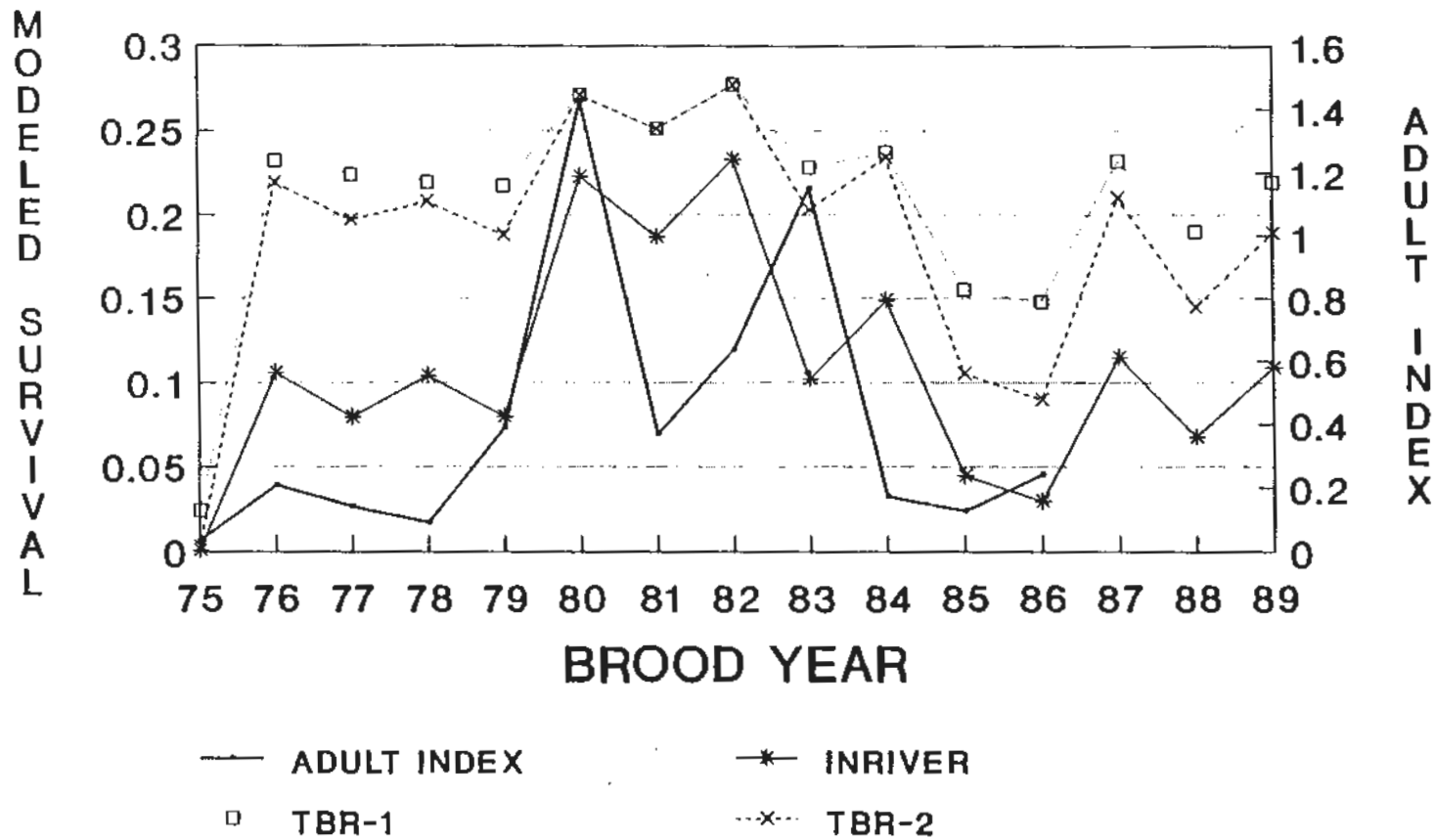
Migration Years 1977 - 1988
LN(Recruit/Spawner) = Constant + %Seeding(X1) +PFlow(X2)
R^2 = 0.84

Figure 7. Influence of mean Snake River flow (4/15-5/5) at four seeding levels (%MSP) on recruit per spawner ratios, Imnaha River spring/summer chinook, brood years 1975-86.



Migration Years 1977 - 1988
LN(Recruit/Spawner) = Constant + %Seeding(X1) + Fish TT(X2)
R^2 = 0.83

Figure 8. Influence of estimated mean smolt travel time (4/15-5/5) at five seeding levels (%MSP) on recruits per spawner ratios, Imnaha River spring/summer chinook, brood years 1975-86.



NPPC TBR Model 1 and 2
T.E.C.H. Workgroup FLUSH Model

Figure 9. Comparison of the Snake River relative survival index (adult index), brood years 1975-86 and modeled smolt survival using FLUSH, brood years 1975-89. The FLUSH model was run with transportation ignored (inriver survival), and with two alternative assumptions about survival of transported smolts (TBR-1 and TBR-2).

adult indices; neither correlated significantly ($p>0.10$). The models imply that the most optimistic assumptions used for transport survival will deviate farthest from empirically based adult recruitment data.

Smolt survival and life-cycle models have been used increasingly in Columbia River salmon planning and management. To the extent that smolt survival models are used as decision tools and in forecasting future trends, it is important that they can also realistically hindcast recent adult trends. Empirical recruitment data should be an essential element in validating the parameters, assumptions and performance of hydrosystem smolt survival models.

SUMMARY

1. Productivity of Snake River spring and summer chinook populations declined and became more variable since hydropower development.

2. Pre-development productivity of most Snake River populations closely matched recent productivity of a downriver population that has not been exposed to the same high levels of density-independent mortality.

3. Productivity of South Fork Salmon River summer chinook, which suffered severe habitat degradation in the 1960s, was considerably lower than in other Snake River populations.

4. Recent recruitment (brood years 1975-88) of Snake River populations has been highly variable.

5. Recent recruitment of Snake River populations is related significantly to the mainstem velocities experienced during the smolt migration when density dependence is taken into account. There appear to be significant benefits to survival for velocities up to at least the 140 kcfs equivalent.

6. The FLUSH model produced smolt survival estimates that correlated significantly with adult recruitment indices when transport was ignored; the more optimistic transport survival assumptions caused the modeled survival to deviate considerably from the empirically based adult data.

7. Empirical recruitment data should be an essential element in validating the parameters, assumptions and performance of hydrosystem smolt survival models.

REFERENCES

Bergren, T. and M. Filardo. 1991. Analysis of variables influencing the migration of juvenile salmonids in the Columbia River Basin. Submitted to the Endangered Species Act record of the National Marine Fisheries Service. April 1992.

Beverton, R.H. and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fish Invest. London HMSO 19:533.

Bjornn, T.C. 1978. Survival, production and yield of trout and chinook salmon in the Lemhi River, Idaho. Forest, Wildlife and Range Experiment Station, University of Idaho, Bulletin 27, Moscow, Idaho. 97 p.

Blumm, M.C. and A. Simrin. 1991. The unravelling of the parity promise: Hydropower, salmon and endangered species in the Columbia Basin. Environmental Law 21:657.

CBFWA (Columbia Basin Fish and Wildlife Authority). 1991. The biological and technical justification for the flow proposal of the Columbia Basin Fish and Wildlife Authority. 72 p.

Fisher, T.R. 1992. Modeling the effects of transportation assumptions on the population trends of Snake River chinook salmon: a risk analysis. Presentation to the 1992 Chinook and Coho Workshop, Salmon Management in the 21st Century: Recovering Stocks in Decline. Idaho Chapter of the American Fisheries Society, Boise, Idaho.

Kiefer, R.B. and K.A. Forster. 1991. Intensive evaluation and monitoring of chinook salmon and steelhead trout production, Crooked River and upper Salmon River sites. Annual Report, 1989. Idaho Department of Fish and Game. Bonneville Power Administration Contract DE-AI79-84BP13381, Project 83-7.

Lindsay, R.B., B.C. Jonasson, R.K. Schroeder, and B.C. Gates. 1989. Spring chinook salmon in the Deschutes River, Oregon. Oregon Department of Fish and Wildlife, Central Region Administrative Report 74-2, Bend, Oregon.

Matthews, G.M., J.R. Harmon, S. Achord, O.W. Johnson and L.A. Kubin. 1990. Evaluation of transportation of juvenile salmonids and related research on the Columbia and Snake Rivers, 1989. Report to the U.S. Army Corps of Engineers, Contract DACW68-84-H0034, 59 p. plus Appendix.

McConnaha, W.E. and D.A. Anderson. 1992. Analysis of Snake River spring and summer chinook rebuilding schedules and biological objectives. Technical Appendix E to Northwest Power Planning Council Phase 3 Amendments.

NPPC (Northwest Power Planning Council). 1987. Columbia River Basin Fish and Wildlife Program. Northwest Power Planning Council.

Olsen, D. 1992. 1992 Run size prediction for wild and Warm Springs National Fish Hatchery stock spring chinook in the Deschutes River, Oregon. U.S. Fish and Wildlife Service, Vancouver, WA.

Ortmann, D.W. 1968. Salmon and steelhead investigations, Job 1, South Fork of the Salmon River, salmon and steelhead harvest and escapement studies. Federal Aid to Fish Restoration. Job Completion Report, Project F-49-4-6. Idaho Department of Fish and Game.

PSC (Pacific Salmon Commission). 1989. Chinook model documentation. Analytical Work Group of the Chinook Technical Committee. PSC, Vancouver, British Columbia, Canada.

Petrosky, C.E. 1991a. Analysis and implications of alternative flow-smolt survival models to Snake River spring/summer chinook recovery through mainstem velocity improvements. Staff Report. Idaho Department of Fish and Game. Submitted to the Endangered Species Act record of the National Marine Fisheries Service. March 1992.

Petrosky, C.E. 1991b. Influence of smolt migration flows on recruitment and return rates of Idaho spring chinook. Staff Report. Idaho Department of Fish and Game. Submitted to the Endangered Species Act record of the National Marine Fisheries Service. March 1992.

Platts, W.S. and W.F. Megahan. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. Transactions of the 40th North American Wildlife and Natural Resources Conference.

Raymond, H.L. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966 to 1975. Transactions of the American Fisheries Society 108(6): 505-529.

Raymond, H.L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer chinook and steelhead in the Columbia River Basin. North American Journal of Fisheries Management 8(1):3.

Ricker, W.E. 1954. Stock and recruitment. Journal of the Fisheries Research Board of Canada 11: 559-623.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish population dynamics. Bulletin of Fisheries Research Board of Canada 191: 382 p.

Schaller, H. and T. Cooney. 1992. Snake River fall chinook life-cycle model for recovery and rebuilding plan evaluation. State and Tribal Fishery Agencies T.E.C.H. Workgroup Report. Submitted to the National Marine Fisheries Service for 1993 Biological Assessment. November 1992.

Sims, C.W. and F.J. Ossiander. 1981. Migration of juvenile chinook salmon and steelhead trout in the Snake River from 1973 to 1979: a research summary. Final Report to the U.S. Army Corps of Engineers. Contract DACW68-78-C-0038. NOAA, NMFS, NMAFC, Seattle, WA. 42 p.

T.E.C.H. (State and Tribal Fishery Agencies T.E.C.H. Workgroup). 1992. Chinook analytical framework: presentation to Recovery Team. Submitted to the Endangered Species Act record of the National Marine Fisheries Service. July 1992.

Weber, E., C. Petrosky and H. Schaller. 1992. FLUSH (fish leaving under several hypotheses) Version 4.0 (Spring FLUSH) documentation. State and Tribal Fishery Agencies T.E.C.H. Workgroup Report. October 22, 1992. 15 p. Submitted to the National Marine Fisheries Service for 1993 Biological Assessment. November 1992.

Wilkinson, L. 1989. SYSTAT: The system for statistics. SYSTAT Inc., Evanston Illinois.

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