UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Region
7600 Sand Point Way N.E., Bldg. 1
Seattle, WA 98115

March 31, 2006

Mr. Donald K. Hansen, Chairman
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 200
Portland, Oregon 97220-1384

Dear Don,

NOAA Fisheries is concerned about the long-term status of Klamath River fall Chinook (KRFC), and the consequences that additional fishing in 2006 may have on the spawner escapement. At the same time, we are very aware and concerned about the severe consequences to the fishing community associated with fishery closures of the magnitude described under Option III. Given the past two years failure of KRFC to achieve its escapement floor and the prospect that the lower KRFC returns may continue into the near term, we believe it is imperative to consider the best available scientific information relative to the risks to the KRFC to produce maximum sustained yield on a continuing basis. From our perspective, the critical task is to address the biological question that requires that the long-term health of the stock not be decreased by the proposed fisheries consistent with the terms of the Magnuson-Stevens Act related to overfishing.

To address this question, we asked our Northwest and Southwest Fisheries Science Centers to review all relevant information in the available time. In particular, we asked the scientists at the Science Centers whether there were escapement levels below the 35,000 floor that would not jeopardize the capacity of KRFC to produce maximum sustainable yield on a continuing basis. The Science Centers' report is enclosed for your information. Based on this review, NOAA Fisheries finds that the risk to KRFC associated with the fishing regime proposed in Option II is too great to justify an emergency rule that satisfies the requirements of the Magnuson-Stevens Act. As a consequence, we suggest the Council focus its effort on shaping seasons around Option III that add little or no KRFC impacts.

Also, as you may now be aware, NOAA has determined that the best available information did not support a declaration of a commercial fishery failure in 2005. The commercial fishery failure could not be justified because the commercial fisher's sales of salmon either met or exceeded the average value of recent years because the price to fishermen was high and offset the effects of the more restrictive fishing seasons. Community impacts also were assessed in the disaster consideration and the 2005 economic activity generated by commercial salmon fishing in each of the ports affected by the restrictions was found to be near the average of recent years. However, because of the circumstances related to KRFC in 2006, NOAA Fisheries will analyze the projected impacts of the 2006 ocean salmon management measures as soon as those measures are established. Governor Kulongoski of Oregon has informed us that he is sending a letter to the Secretary of Commerce requesting a commercial fishery failure declaration for 2006 due to a fishery resource disaster.

We remain committed to working with the Council to address the difficult management issues before us this year.

Sincerely,

D. Robert Lohn

D. Robert Lohn
Northwest Regional Administrator

D. Robert Lohn

Rodney R. McInnis
Southwest Regional Administrator

Enclosure

Comments on the Klamath River Fall-Run Chinook Salmon Fisheries Management Plan Escapement Floor

29 March 2006

Prepared by: Northwest Fisheries Science Center
Southwest Fisheries Science Center

Introduction

This report is in response to a request from the Northwest and Southwest Regions to comment on escapement levels developed by the Pacific Fishery Management Council (PFMC) to regulate ocean fisheries in response to run forecasts for the 2006 return year. These forecasts predict that the escapement goal of naturally-spawning fall-run Chinook salmon will fall below the established floor of 35,000 adults. This report reviews previous information used to establish the current escapement floor, discusses the potential biological effects of escapements below the floor, and evaluates uncertainty in the forecasted ocean abundance and spawning escapement estimates.

Klamath River Chinook Salmon – Historical Perspective

Early in the development of West Coast fisheries the Klamath River was identified as a major supplier of salmon, and (at the time) distinct in that it was one of only four coastal rivers that had both spring and fall runs of salmon (Collins 1892). In 1888, the in-river salmon catch was estimated at 734,000 pounds[1], 50,000 fish at 15 pounds each (Collins 1892, Snyder 1931). Snyder (1931) estimated that between 1915 and 1928 the peak in-river catch was 1.2 million pounds, (1915) with an average catch of 725,000 pounds. Additionally, near shore fisheries from Ft. Bragg to Eureka and the California border captured nearly 2.1 million pounds of salmon annually from 1916-1928 (Snyder 1931), although it is unclear what proportion of these fish would have originated from the Klamath River. Myers et al. (1998) provided a peak run estimate, based on cannery pack, of 130,000 fish in 1912. The contribution of hatchery origin fish to these run estimates (hatcheries have been present in the Basin for over 100 years) is thought to be minimal given the state of hatchery culture at the time. At best, during the late 1800s and early 1900s hatchery production may have replaced the adults removed from the river for broodstock purposes. In estimating the historical run size for the Klamath River Basin it is also important to consider that habitat degradation, primarily related to mining activities, had already impacted much of the basin during the years of the catch estimates provided above. Moyle (2002) estimated that the total fall run to Klamath River may have been as large as 500,000.

Population Structure and Biological Diversity

The Klamath River Basin includes two major rivers: the Klamath and Trinity. Anadromous access to much of the basin has been lost due to the construction of impassible dams, the Iron Gate Dam (1962, RKm 306) on the Klamath River and the Lewiston and Trinity Dams (1963, RKm 249) on the Trinity River. This habitat loss primarily affected spring-run populations in the Trinity, and Klamath Rivers, although some fall-run Chinook salmon habitat was also lost. More significantly for the fall-run populations, these dams have altered the flow dynamics and temperature profiles for

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[1] The catch is listed only as salmon and likely include Chinook and coho salmon and steelhead. Where a break-down of these catches is available, it is clear that the majority of fish were Chinook salmon.

downstream mainstem areas. These changes may be correlated to increases in mortality among outmigrating juvenile salmon, in part from exposure to *Cerratomyxa shasta* (Bartholomew 2005).

Fall-run Chinook salmon spawning aggregations exist throughout the basin. While the current conservation objective and fishery management plan considers fall-run fish as belonging to a single stock, it is almost certain that the Klamath fall Chinook "stock" contains multiple distinct populations (effectively the Demographically Independent Populations defined in McElhany et al. 2000). The sustainability of the Klamath fall Chinook stock complex will depend on the preservation of locally-adapted populations that possess sufficient diversity to adjust to short-term and long-term environmental variability.

Snyder (1931) described significant differences in the spawning time for fall-run Chinook salmon in different tributaries to the Klamath River. These differences suggest diverse local conditions, and the potential for reproductive isolation. Barnhart (1995) used geographic, genetic, and life history information to identify fall-run metapopulations in the Klamath River Basin. According to Barnhart twelve "breeding populations" of fall-run Chinook salmon exist, clustered within four "metapopulation" units (Table 1).

Table 1. Population structure for Klamath River Basin fall-run Chinook salmon, as proposed by Barnhart (1995)

River System	Metapopulation	Breeding Population
Klamath River	Upper Klamath River	Iron Gate Hatchery and Bogus Creek
		Upper Mainstem Klamath River
		Shasta River
	Middle Klamath River	Scott River
		Salmon River
		Upper Middle Klamath Tribs
		Lower Middle Klamath Tribs
Trinity River	Lower Klamath/Trinity River	Lower Klamath River Tribs
		Lower Mainstem Trinity, below South Fork
	Mainstem Trinity River	South Fork Trinity River
		Upper Mainstem Trinity River
		Mainstem Trinity River

The criteria utilized by Barnhart (1995) are similar those used by NOAA Fisheries Technical Recovery Teams to identify demographically independent populations. Given the size of the Klamath River Basin, identifying twelve "populations" for the fall-run life history comports with the findings of the coastal and Lower Columbia TRTs (Bjorkstedt et al. 2005, Myers et al. 2006). Barnhart (1995) based his findings, in part, on a preliminary genetic population survey by Gall et al. (1990). Subsequent analysis of an expanded California Chinook salmon genetic data set provided further support to the population structure presented by Barnhart (NMFS 1999). On a course scale, populations in the Klamath River Basin clustered together relative to other samples from coastal and Central Valley populations. Within the Klamath River Basin, populations from the Klamath and Trinity River were distinct from one another, and on a finer scale there appears to be significant population structure within each of the major tributaries (Figure 1).

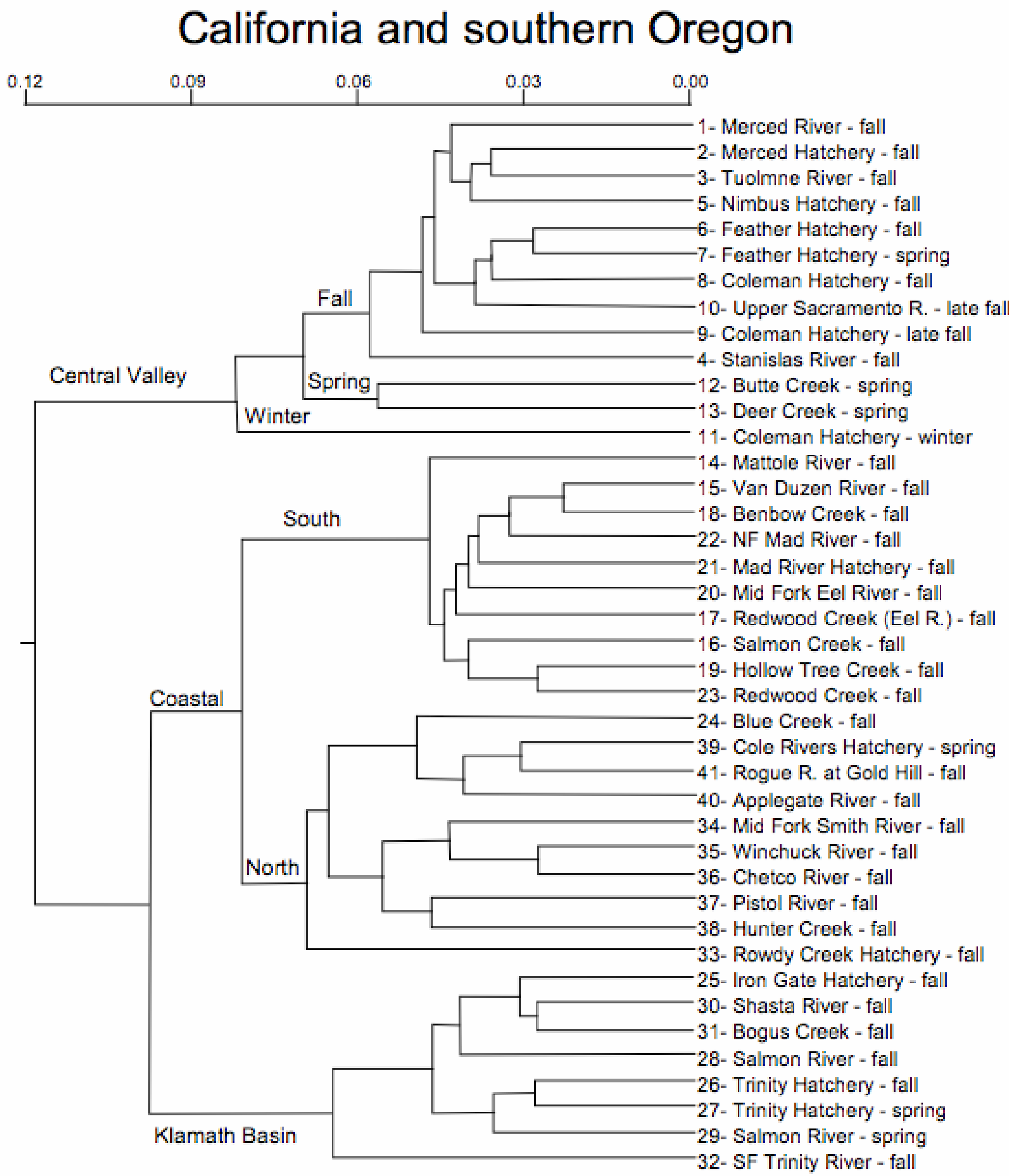

Figure 1. UPGMA dendrogram based on 34 allozyme loci from 41 composite samples of Chinook salmon from California and southern Oregon. (From NMFS 1999).

Banks et al. (2000) reported on genetic variation among 14 different spring and fall-run populations from the Klamath River Basin using DNA microsatellite analysis. This study confirmed that there are genetic differences between populations within the Klamath River Basin (Figure 2). Population structure appears to be more closely associated with geographic location rather than life history characteristics (i.e. run timing). Additionally, among population differences are evident for several life history characteristics (timing, spawn timing, age structure) in the Klamath River (Shaw et al. 1997, Andersson 2003, KRTAT 2006b). These life history differences are indicative of local adaptation and suggest that basin-wide productivity and overall fitness are likely to be related to the conservation of these locally adapted populations.

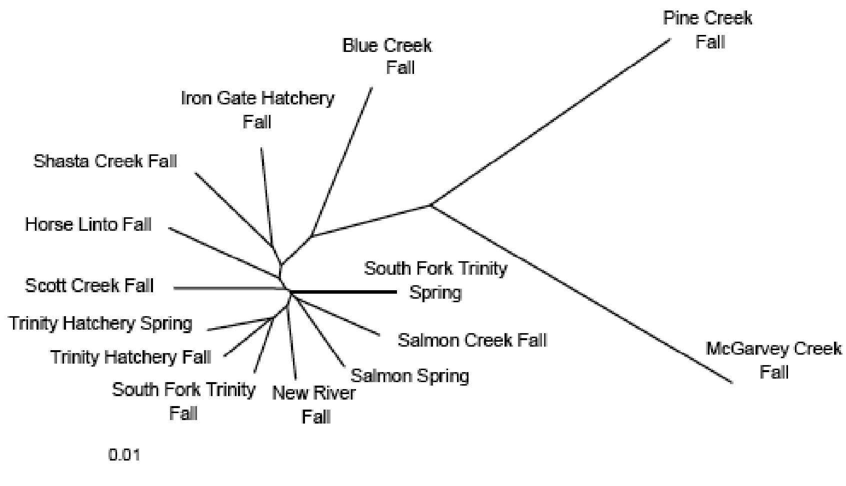

Figure 2. UPGMA phenogram for population samples from fall and spring Chinook of the Klamath and Trinity basins characterized at 7 microsatellite loci. (Reproduced from Banks et al. 2000).

If several populations of fall-run Chinook salmon exist in the Klamath River Basin then it is necessary to consider the demographic characteristics of each population in order to assess the potential effect of the proposed fishery management options. Based on information in Andersson (2003) and KRTAT (2006b) the typical spawning escapement of many of these populations is a thousand fish or less, with some in the low hundreds. Numerically small breeding populations are at higher risks from both demographic and diversity factors. When extended over several generations the effects of small population size on diversity may be compounded (through the cumulative effects of inbreeding). Additionally, small sized populations are more susceptible to introgression by hatchery-origin spawners. If naturally spawning hatchery fish exhibit lower reproductive fitness (see Berejikian and Ford 2004) then the affected population would exhibit a decrease in productivity. Returns to the hatcheries constitute a substantial portion (~40%) of the total run in the Klamath (Figure 3a). The proportion of hatchery-origin fish on the natural spawning grounds averaged 22% for the 1991 to 2004 return years (Figure 3b). The effect on productivity of this level of hatchery contribution cannot be estimated with currently available data; however, it is of some concern that the hatchery contribution is largest during years of low escapement, 48% in 2004, increasing the potential for the loss of local adaptation in populations. The recovery of coded wire tags (CWTs) from fish on natural spawning grounds suggests that the degree of hatchery influence varies considerably from population to population (KRTAT 2006b), with those natural spawning areas geographically proximate to hatcheries having the relatively high rates of CWT recovery.

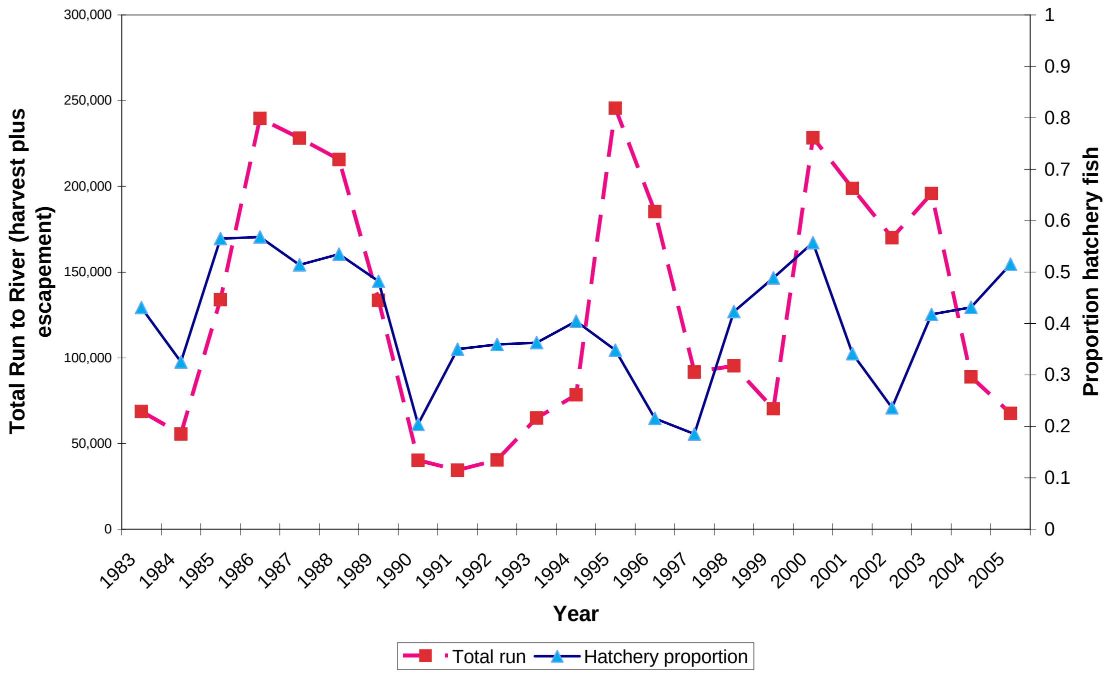

Figure 3a. Total fall-run Chinook salmon return to the river (dashed line) and the proportion of the run that returned to the hatcheries (solid line with triangles) (Data provided by M. Palmer-Zwahlen, CDFG).

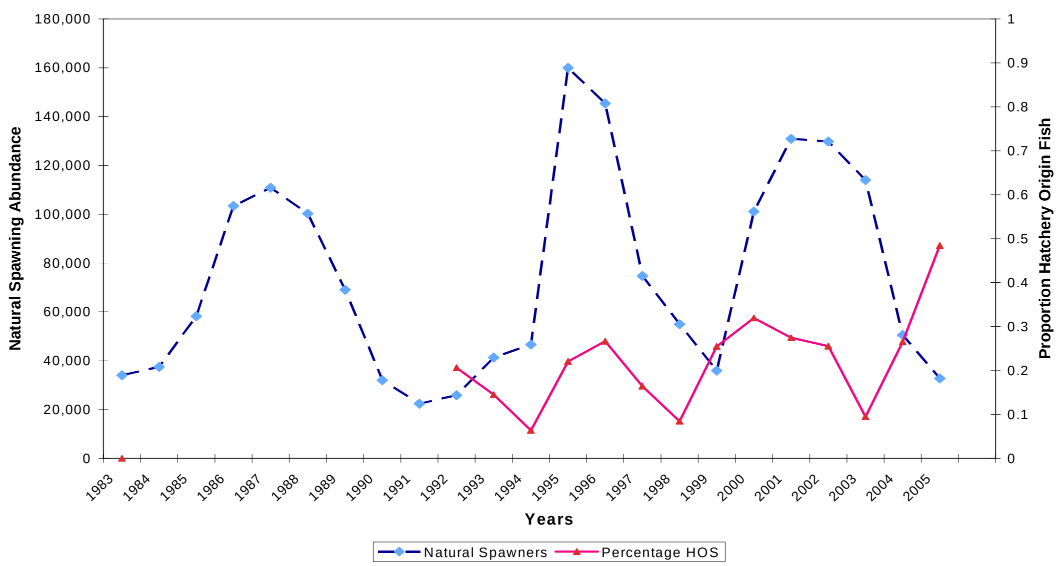

Figure 3b. Naturally spawning fall-run Chinook salmon (dashed line), and the proportion of natural spawners originating from a hatchery (HOS) (solid line with triangles). HOS estimates are based on the expansion of CWTs recovered from natural spawning grounds. (Data provided by M. Palmer-Zwahlen, CDFG).

In recent years, those natural spawning areas with a high proportion of hatchery origin spawners (i.e. Bogus Creek and mainstem Trinity River) also contribute substantially to overall escapement (Table 2). Hatchery-origin spawners will mask the decline of some populations and bias productivity estimates if not specifically accounted for.

Table 2. Hatchery and natural spawner escapement to the Klamath River Basin for the 2004 return year relative to the location of hatcheries. Distances are calculated as river kilometers from the mainstem spawning reach or tributary mouth to the hatchery in the Klamath and Trinity rivers. Data from KRTAT 2006b.

Survey Site	Hatchery Return	Natural Spawners	Distance to Hatchery (RKm)
Klamath River			
Iron Gate Hatchery	11,519		0
Bogus Creek		3,788	Adjacent
Klamath River (IGH to Shasta)		4,420	Adjacent - 21
Shasta River		962	21
Klamath River (Shasta R to Indian Creek)		822	21 - 145
Scott River		467	75
Salmon River		626	199
Klamath River (above Reservation)		557	145 - 233
Yurok Reservation		208	233 - 305
Trinity River			
Trinity River Hatchery	13,443		0
Trinity River (above Willow Ck Weir)		15,655	Adjacent - 138
Trinity River (below Willow Ck. Weir)		1,029	138 - 186
Trinity Tributaries (above Reservation)		333	47 - 147
Hoopa Reservation Tributaries		186	146 - 186
	24,962	29,053	

For example, returns of fall-run Chinook salmon to the Shasta River, a tributary which does not receive a large influx of hatchery-origin spawners, have declined substantially in the last 80 years (Figure 4). Similar declines in other historically important natural spawning areas, such as the Scott, and Salmon Rivers in the Klamath River Basin, may be obscured by an increasing hatchery contribution to basin-wide escapements.

Shasta River Fall Run Chinook Spawning Escapement

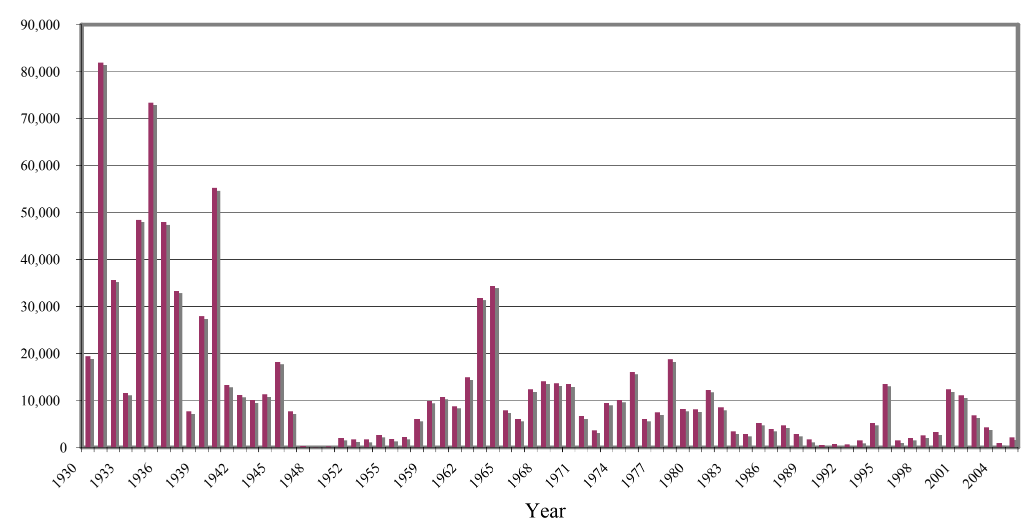

Figure 4. Chinook salmon fall run escapement to the Shasta River from 1931 – 2005. Data from STT 2006a.

Contribution of C. shasta to Chinook mortality in the Klamath River

The myxosporean parasite *Ceratomyxa* shasta was first described in 1948 (*Ceratomyxa* shasta Fact Sheet - 2002). The reported distribution of *C.*shasta in the Western part of the United States has reportedly expanded, however this may not be a true increase in distribution since the parasite does not colonize new habitat readily. Instead it is possible that new occurrences may be the result of more sensitive detection techniques. Currently these new techniques include a highly sensitive polymerase chain reaction (PCR) assay (Palenzuela, et al., 1999; Bartholomew, et al., 2004). Because of this, it is possible that *C.* shasta has been endemic in the Klamath system for a much longer time frame.

The intermediate host of *C.* shasta is the fresh water polychaete worm, Manayunkia speciosa (Bartholomew, et al., 1997). There is no documented proof that the parasite is transmitted horizontally (fish to fish) or vertically (fish to egg). The route of infection is through contact with the infectious stage, the actinospore, which is released from the polychaete into the water column. There is evidence of differential host susceptibility (Bartholomew, 1998), and differential life stage susceptibility. Out-migrating juvenile Chinook salmon experience higher mortality due to *C.* shasta than returning adults (W. Cox, CDFG, personal communication).

Based upon a review of available data on the impacts of *C.* shasta in the Klamath River, it is clear that infection potential is enhanced when water temperatures are high, water flow is low, conditions optimal for growth of *M.* speciosa. This results in a significant increase in the numbers of infectious *C.* shasta during this time. Within the Klamath, live box experiments with sentinel species (rainbow trout and Chinook salmon) show that while habitat is available throughout the river, surveys using the *C.* shasta PCR detection method support findings that there is a greater incidence below Iron Gate Dam (Oregon State University. 2004). This is based on multiple year survey records from 2001 through 2003 (Foote, et al., 2002, 2003, 2004). However, it is not yet known whether these results represent a true trend. In order to determine if variable temperature and flow patterns are directly correlated with pathogen prevalence, it will be necessary to conduct such surveys over several field seasons. These studies will be aided by the development of a new quantitative PCR detection method for the parasite (Hallet, et al., in press).

In terms of relevancy to the determination of Klamath River fall Chinook escapement goals, there is insufficient data to suggest that higher escapement would be counterproductive because of river conditions. While it is true that river conditions over the past several years have led to increased *C.* shasta incidence, the perception that most returning adults will succumb to *C.* shasta prior to spawning is unsupported by any available data. *C.* shasta can be a significant contributor to pre-spawning mortality but this is at least partially dependent on conditions that delay migration prior to spawning, and additional studies in this area are needed. However there are examples of pathogens causing significant pre-spawning mortality. The 2002 pre-spawning fish kill in the lower

36 mile stretch of the Klamath River (34,000 fish including 32,553 fall Chinook) was determined to be the ciliated protozoan parasite *Ichthyopthirius* mulitfilis (Ich) in combination with the bacterium *Flavobacterium* columnare (columnaris). Predisposing factors included the combination of high fish density and warm water conditions (California Department of Fish and Game 2004).

Fisheries Management Context

The Pacific Fishery Management Council's conservation objectives for natural salmon stocks are based on estimates for achieving Maximum Sustainable Yield (MSY) or a MSY proxy (PFMC 2003). The collection of these conservation objectives is the conservation portion of the Council's overall strategy for management of West Coast salmon stocks, the Salmon Fishery Management Plan (FMP).

The Salmon FMP (PFMC 2003) and Amendment 9 (PMFC 1988) define the Klamath River fall Chinook conservation objective as "33-34% of potential adult natural spawners, but no fewer than 35,000 naturally spawning adults in any one year." The Council may make a change to the escapement rate portion of the Klamath conservation objective if a comprehensive technical review by the STT provides conclusive evidence that justifies a modification. However, the 35,000 natural spawner floor portion of the conservation objective can only be changed by FMP amendment and this makes consideration of this portion of the conservation objective more rigid.

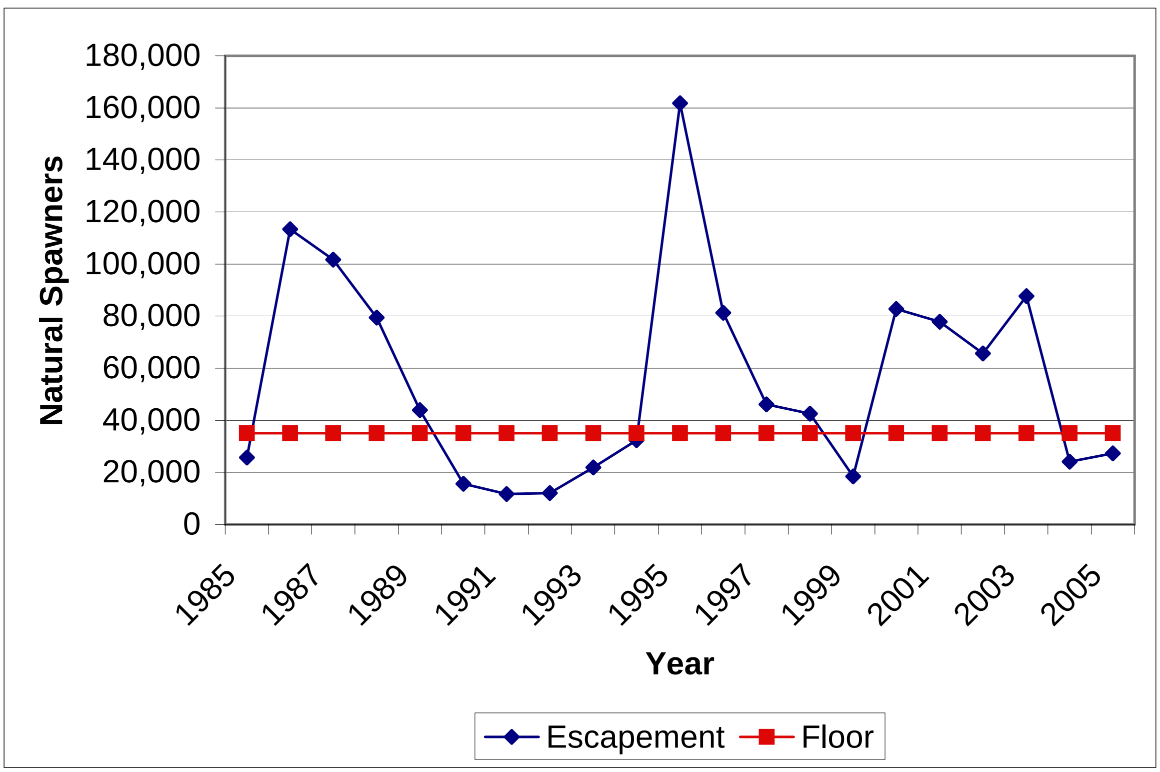

Figure 5. Klamath River fall Chinook natural spawner escapement and the 35,000 spawner floor. (from KRTAT 2006a).

The 35,000 fish Klamath floor has been reviewed and reconfirmed several times. Originally in 1978, the Council adopted a Klamath Chinook salmon spawner escapement goalof 97,5000 natural spawners based on observed returns to the basin in the early 1960s (CDFG 1965). Because the Klamath stock was depressed, the Council (PFMC 1985) implemented an interim rebuilding schedule beginning in 1983 which called for an average river run size of 68,900 adults during the 1983-1986 period, to be followed by 20% increases every four years. However, in 1983-1984, the river return failed to meet these goals and the Council responded by closing the Klamath Management Zone (KMZ) troll fishery in 1985 and directing work that lead to Amendment 9 of the Salmon FMP (PFMC 1988). Amendment 9 analyzed four alternative conservation objectives; three of which included a spawning floor of either 43,000 or 35,000 natural spawners. The rationale provided for the spawning floor requirements was "to prevent extremely low escapements in any one year" and "to protect against extended periods of depressed natural production and failure to meet hatchery escapement needs." In 1992, the inriver spawning escapement fell below the 35,000 spawner floor for the third consecutive year (Figure 5) and this prompted the closure of most of the California commercial fishery and portions of the recreational fishery. Further consideration of the appropriateness of the 35,000 spawner floor (Prager and Mohr 1999 and STT 2005b) concluded, "The results of this study suggest that the present spawner floor of 35,000 is prudent."

Klamath Assessment Description

<u>Sampling Programs for Klamath River Fall-Run Chinook Samon</u>

West coast ocean fishery sampling programs are comprehensive with respect to coverage (coastwide) and estimation (well-defined random sampling designs). The sampling rate is approximately 20% of all landings in all salmon-directed fisheries. Estimated harvest is stratified by fishery type (commercial, recreational), geographic area, month, and year. For Klamath River fall Chinook, which are impacted by ocean fisheries from Cape Falcon, OR, to Point Sur, CA, there are seven geographic areas ("major port areas") with fishery-area-month-specific regulations and associated sampling that used to manage the fisheries impacts on Klamath River fall Chinook: northern Oregon (NO), central Oregon (CO), Oregon KMZ (KO), California KMZ (KC), Fort Bragg (FB), San Francisco (SF), and Monterey (MO). CWT salmon recoveries in the sample, after expanding for the sampling fraction and hatchery mark-rate, are used to estimate stock-age-specific harvest, and in the case of Klamath River fall Chinook in particular, are used to reconstruct cohorts and thereby estimate various fishery and biological vital rates for the stock.

The annual Klamath River fall Chinook run is also comprehensively sampled with respect to coverage (river fisheries harvest, natural area spawning escapement, hatchery returns) and estimation (well-defined random sampling designs). Age-composition is estimated for all strata based on the analysis of sampled scales (over 10,400 scales were read in the 2005 run assessment, of which over 1,500 were from known-age CWT fish allowing for scale reader bias-adjustment). CWTs are recovered in all strata and expanded for the sampling and mark-rate as in the ocean fishery sampling.

Population Assessment Based on Historical Data

The CWT recoveries along with the age-specific accounting of river returns for the hatchery and natural stock enable cohort reconstructions (a form of virtual population analysis) to be performed on all hatchery release groups and on the natural stock. For each hatchery release group, the cohort reconstruction leads to estimates of ocean harvest rates (fishery-area-month-age-year-specific), maturation rates (age-year-specific), and ocean preseason abundance (age-year-specific). For the natural stock, with the assumption that ocean fishery contact (encounter) rates are equivalent for hatchery and natural fish (conditional on being alive at the time), the natural stock age-specific returns enables cohort reconstruction of this stock component as well, and estimates of maturation rates (age-year-specific) and ocean preseason abundance (age-year-specific). There are now over twenty years for which all of these quantities have been estimated. Together, the estimated fishery and biological vital rates and quantities form the basis of ocean fishery forecast models (e.g. the Klamath Ocean Harvest Model (KOHM)), stock-recruitment analyses, estimation of release-to-age-two survival rates of hatchery fish (indicator of early-life marine survival), etc.

Models for Forecasting Fishery Impacts and Spawner Escapement

Ocean preseason age-specific abundance is forecast using "sibling regressions" of "age(a) preseason ocean abundance" (from cohort reconstructions) versus "age(a-1) river return" (same cohort).

The KOHM is used annually by the PFMC to forecast the impacts of ocean and river fisheries on the Klamath River fall Chinook stock, and the expected number of natural area spawners as a result of these fisheries. All model components are estimated using over twenty years of estimates provided by the cohort reconstructions. The KOHM assesses the impacts of ocean salmon-directed fisheries between Cape Falcon, OR, and Point Sur, CA (Klamath River fall Chinook recoveries to the north and south of this region are rare). Fishery management of this area primarily takes the form of time-area openings and closures rather than through the use of quotas. This form of management requires an impact forecast model that is spatially and temporally explicit consistent with the management sub-areas and time-periods for which regulations are developed. The KOHM contact rate submodel forecasts are fishery-area-month-age-specific over the seven contiguous management areas between Cape Falcon, OR and Point Sur, CA. These contact rates are defined as the fraction of the month-specific cohort ocean-wide abundance contacted (legal size and sub-legal size) by a fishery. The KOHM contact rates depend on the expected level of fishing effort under the regulations proposed (a separate KOHM submodel forecasts effort as a function of, e.g., days-open), which is fishery-area-month-specific.

The KOHM contains an ocean length-at-age submodel to estimate the fraction of contacted fish that exceed the minimum size limit (and are thus harvested versus released), which is month-age-specific. The KOHM thus forecasts fishery-area-month-age-specific impact rates (fraction of the month-specific cohort abundance killed by a fishery) as (contact rate) * [p + (1-p)v + d.o], where p is the fraction of fish that are legal size, v is the release mortality rate, and d.o is the ocean "drop off" rate (additional deaths expected from fishing due to predation of fish from the gear, etc).

The KOHM river submodel components include a fishery harvest submodel. River tribal and recreational fisheries are managed by quotas, and the model assumes that these fisheries take their full harvest allocation (i.e. quota expected to be met). The age-specific harvest expected under these quotas is forecast as a function of the fishery-specific gear selectivity. Fishery-specific impacts are then forecast as (harvest) * (1+d.r), where d.r is the fishery-specific river "drop off" rate. The age-specific number of adults which will spawn in natural areas (vs. hatcheries), are forecast using sibling regressions of "age(a) proportion natural areas" versus "age(a-1) proportion natural areas the year prior" (same cohort).

The KOHM thus consists of projecting the age-specific (ages 3, 4, 5) preseason ocean forecast abundance through the various ocean fisheries by month. Fishery-area-month-age-specific ocean impact rates are applied to the age-month-specific ocean abundance. Following that an age-month-specific natural mortality rate is applied, and this alternating cycle of fishery impact rates followed by natural mortality rates is applied from September 1 (of the previous year) to the end of August (current year). At the end of August, the age-specific river return is forecast as the age-specific number of surviving fish times the age-specific expected maturation rates. River fisheries age-specific expected harvest impacts are deducted from the age-specific river return abundances, and of the remaining fish are apportioned into the hatcheries and natural areas according to the age-specific expectations for the proportion of fish in natural areas. The sum of the age-3, age-4, and age-5 natural area number of spawners is the forecast number of adult natural area spawners; a quantity which must exceed 35,000 under the current PFMC FMP conservation objective for this stock.

Forecast and Modeling Uncertainty

The KOHM assesses the impacts of ocean salmon fisheries in a spatially- and temporally-specific framework. Due to this structure, there are great many model inputs with accompanying variation associated with the inputs. Much of the variation associated with the individual input variables is described in various reports (KRTAT 2006a, 2006b) and we will only describe the most significant ones below.

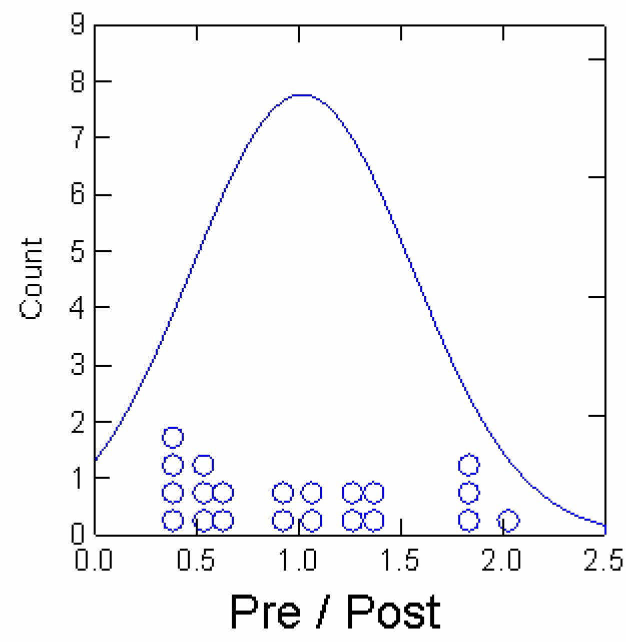

Figure 6 -- Distribution of pre/post season total adult abundance estimates. Data from Table 2, KRTAT 2006a.

Preseason and postseason Klamath fall Chinook ocean abundance estimates can be considerably different from each other (Figure 6). Preseason and postseason estimates can differ from 2 to 100%, and in recent years postseason estimates have been consistently higher than the preseason forecasts (Figure 7). Since the preseason forecasts are the starting point of the KOHM analysis, a matrix of the differences between preseason and postseason abundance estimates would the appropriate starting point for a Monte Carlo analysis of uncertainity in providing management advice. Differences between preseason forecasts and postseason estimates of ocean abundance seem to be autocorrelated (Figure 7), perhaps due to fluctuations in ocean conditions, even though over the entire time-series the forecast appears to be unbiased. Also, there is a consistently large divergence between preseason and postseason estimates prior to 1989. Methods were different during this period, so it is difficult to determine the underlying cause.

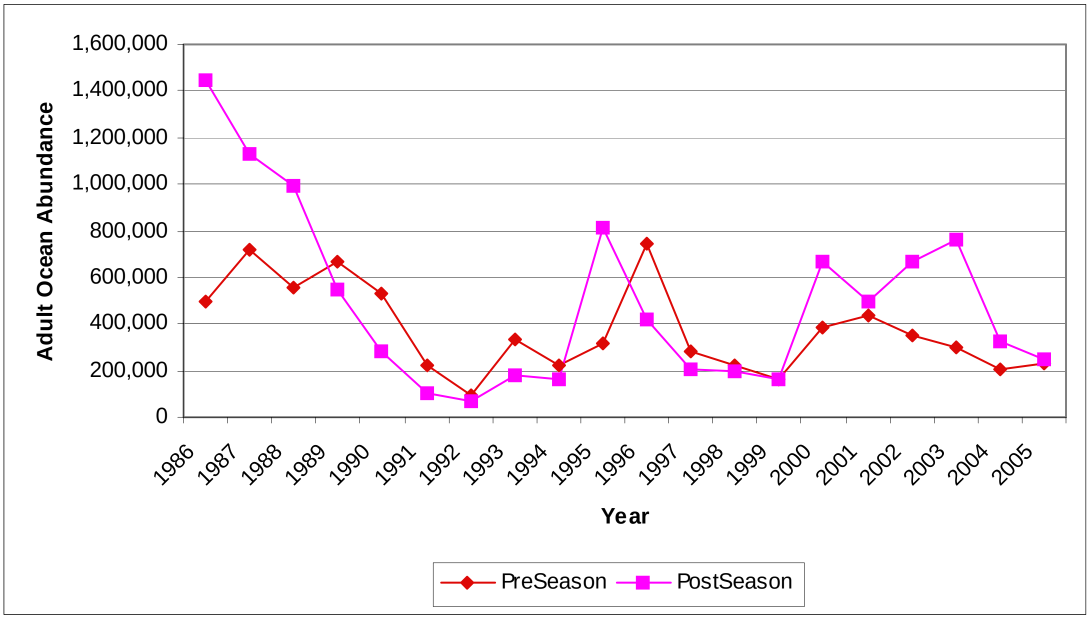

Figure 7. Comparison of preseason and postseason ocean abundance estimates of Klamath fall Chinook salmon. (from KRTAT 2006a)

A similar comparison of preseason and postseason ocean harvest estimates is instructive about model performance of this principal model output (Figure 8). In two of the last three years, ocean harvest has been substantially underestimated by the KOHM. One reason for this underestimate is the dramatically higher fisheries contact rates for Klamath River fish, particularly in some months off San Francisco and Central Oregon (shown for commercial fisheries in Figure A-1 from STT 2006c). This is particularly so in San Francisco area, where the largest Chinook fishery off Washington, Oregon, and California occurs. In the last three years, contact rates (the large dots in the Figure A1) have been extremely high, often double or triple their average value. It is the Klamath Chinook salmon caught in this fishery, as well as the Oregon fishery, that has driven up harvest rates for Klamath Chinook salmon and reduced escapement to below the 35,000 spawner floor. Why these contact rates have increased in the last three years is unknown, but the underestimation of harvest has contributed substantially to the failure to reach escapement in the past two years.

The uncertainty in harvest predictions would suggest that a more biologically-conservative estimate may be warranted. For example, assuming that the past performance of the preseason total adult abundance estimator is a good predictor of the future, the middle 50% (i.e., likely) confidence interval for the 2006 total abundance estimate is 80,175 – 195,730 (110,000/1.372 – 110,000/0.562, from Table 3, 110,000 adult prediction from KRTAT 2006a).

Assuming the estimated escapement varies similarly, actual likely escapement estimates would range from 10,100 – 24,600 under PFMC Option 1, 13,700 – 33,500 under PFMC Option 2, and 18,500 – 45,200 under Option 3, based on the KOHM point estimates under these options of 13,800, 18,800, and 25,400, respectively (STT 2006c). In fact, due to additional uncertainty in the model converting ocean abundance to escapement, the range of likely escapement values is probably even larger.

Table 3 – Estimated quantiles for pre/post season total adult abundance estimates. Data from Table 2 KRTAT 2006a.

Quantile	PRE/POST
1 %	0.340
5 %	0.368
10 %	0.402
20 %	0.525
25 %	0.562
30 %	0.586
40 %	0.628
50 %	0.950
60 %	1.121
70 %	1.354
75 %	1.372
80 %	1.503
90 %	1.824
95 %	1.937
99 %	2.030

In conclusion, the KOHM inputs are probably the best estimated of any ocean salmon fishery impact model used off of Washington, Oregon, and California, due the long-term, comprehensive data collection for the Klamath stock. However, all of these inputs contain some, sometimes considerable, uncertainty. The cumulative effect of this uncertainty in the input parameters results in considerable uncertainty about forecasted abundance and escapement

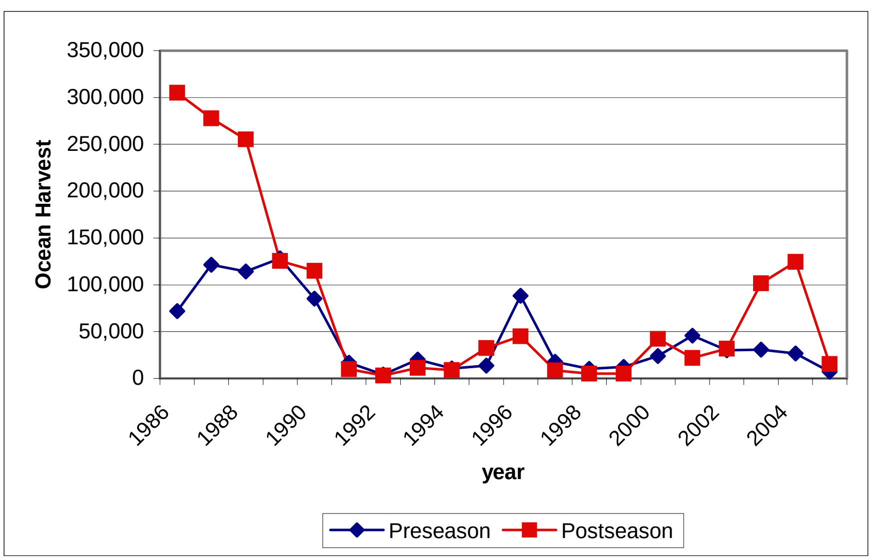

Figure 8. Preseason and postseason ocean harvest estimates of Klamath River fall-run Chinook salmon (from KRTAT 2006a)

Spawner-Recruit Analysis

Several spawner recruit analyses have been conducted on Klamath River fall Chinook salmon with remarkably similar results even as the amount of model complexity increases. The Klamath River Technical Team (KRTT) conducted the first Klamath spawner recruit analysis (KRTT 1986). They constructed a fishery stock dynamics model, which coupled a Ricker stock-recruitment function (Ricker, 1975) to a cohort life-cycle model that included ocean and river fishery mortality. The model was used to simulate stock dynamics and resulting fishery harvests over a 40-year period at various combinations of ocean and river harvest rates. The results of the KRTT modeling work depend on a number of parameters, but are most sensitive to the stock productivity (Ricker α) parameter. The KRTT assumed that $\alpha = 7$ for recruitment at age 3, based on a review of the literature and on the available data for the Klamath basin. The results indicated that a brood escapement rate of about 35% would maximize the long-term average annual harvest of the stock. KRTT recommend the adoption of an annual minimum escapement floor based on the finding that a floor was needed "to protect the production potential of the resource in the event of several consecutive years of adverse environmental conditions." They analyzed the results of modeling three consecutive years of poor recruitment (20% of expected recruitments) followed by 7 years of expected recruitments. The average catch over the 10-year period was 17% greater with the spawner floor in place, and the KRTT concluded that "recovery was quicker, more complete, and led to higher yields with the spawner floor of 35,000 fish." In addition, the KRTT also felt that the 35,000 spawner floor was justified based on their expert opinion by noting that "a minimum spawning escapement of 35,000 natural spawners would be higher than any natural escapement since 1978, [escapement] levels that have been widely regarded as too low for the basin."

The second modeling study of the relationship between MSY and a spawning floor was conducted by the Klamath River Technical Advisory Team (Prager and Mohr 1999). The modeling approach used here was similar to that used by the KRTT (1986) but included several improvements: 1) the Ricker spawn-recruit model was based on a direct fit of Klamath River basin data, as was the stochastic component of recruitment; 2) the model was started with "Pre-Season" estimates of stock abundance rather than the dynamic pool model; and 3) fishery harvest and mortalities were determined using a harvest model (Prager and Mohr 2001). The model was run subject to the 33% escapement rate conservation objective, and spawner escapement floor values ranging from 15,000 to 50,000 adults in increments of 5,000 were examined. The model results were: 1) the fitted Ricker parameters were remarkably similar to those used in the KRTT (1986) model; 2) average catch was strongly reduced by increased variance in stock abundance forecasts, and 3) average catch increased slightly as the spawner floor was raised from 15,000 to 35,000, but decreased with higher floor values. The KRTAT study (Prager and Mohr 1999) concluded that "The results of this study suggest that the present spawner floor of 35,000 is prudent."

The final modeling study of Klamath River fall Chinook stock recruitment (STT 2005a) was largely an attempt to look at environmental and habitat impacts on the stock recruit relationship. The analyses looked at three alternative models: 1) the standard Ricker model that uses parent spawner abundance as a predictor of subsequent brood recruitment; 2) a model that used both parent spawner abundance and a computed measure of post-freshwater-rearing survival; and 3) a meta-analyses of Ricker stock recruitment relationships for Chinook salmon populations using accessible watershed area as a predictor of subsequent recruitment. Model 1 used essentially the same configuration and data as the KRTAT report (Prager and Mohr 1999)and resulted in very similar results, suggesting an MSY spawner level of 32,700 fish. The data did not fit the model terribly well as only 3.7% of the total variation in recruits was explained as a function of spawners.

Model 2 is similar to Model 1, but also included a measure of post-freshwater-rearing survival. The post-freshwater-rearing survival estimate was computed for hatchery fish to cover the period from the onset of juvenile outmigration in May-June, through the end of August of that same year. No comparable data were available for natural fish. Analyses of the spawners versus post-freshwater-rearing survival suggested that high recruits per spawner at low spawner abundance were partially accounted for by high post-freshwater-rearing survival in those particular years. The converse was also true: low recruits per spawner at high spawner abundance was partially accounted for by low post-freshwater-rearing survival in those particular years (Figure 9). Based on our understanding of *C. shasta* epidemiology, fish infected in freshwater during emigration do not succumb to the disease until after saltwater entry. Survival estimates for specific broodyears may reflect, in part, the effects of in-river exposure to *C. shasta*. The Model 2 results suggested a productivity coefficient 30% lower than that estimated under Model 1 under average survival conditions, and assuming these average survival conditions results in an estimated MSY spawner level of 40,700. Model 2 fit the observed data significantly better than Model 1 and explained a much higher fraction (50%) of the variation in recruits. This strongly suggests the (well established) notion that environmental variation plays a critical role in determining salmon survival and hence the number of recruits per spawner.

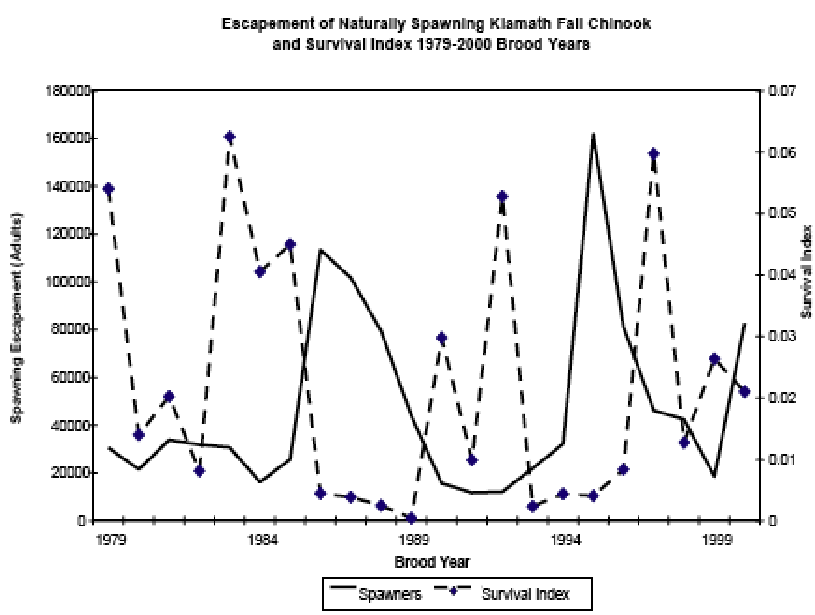

Figure 9. Natural spawning escapements and early life-stage survival index for Klamath River fall-run Chinook salmon the 1979 to 2000 brood years. Figure reproduced from STT (2005a).

The STT's Model 3 was a meta-analysis-based method under development by the Canadian Department of Fisheries and Oceans that estimates spawning escapement associated with MSY, maximum production, and unfished equilibrium based on accessible watershed area. Its development and application to the Klamath Basin are relatively complex and are not dealt with here, but the results of the Model 3 analysis suggests a MSY spawner level of 70,900, nearly double the other models' estimates.

Because of evidence of serial correlation in the preseason and postseason ocean abundance estimates and the greatly improved fit of Model 2 compared to Model 1, we also investigated incorporating ocean conditions into the spawner-recruit analysis. A rich literature has developed over the past decade showing how changes in the ocean environment due to climate change affect the productivity of various fish stocks (Beamish and Bouillon 1993; Mantua et al. 1997; McFarlane et al. 2000). In the case of Pacific salmon, climate-induced changes in survival rates have been identified for nearly all species over a large portion of their range (e.g., Peterman et al. 1998; Welch et al. 2000; Pyper et al. 2001, 2002; e.g., Lawson et al. 2004) . Recently, incorporating the effects of ocean conditions on Pacific salmon has proven useful in a forecasting context (e.g., Logerwell et al. 2003; Scheuerell and Williams 2005). In light of this, we examined whether including data on ocean-climate conditions in the stock assessment for Klamath River fall-run Chinook salmon would improve model fits to the data.

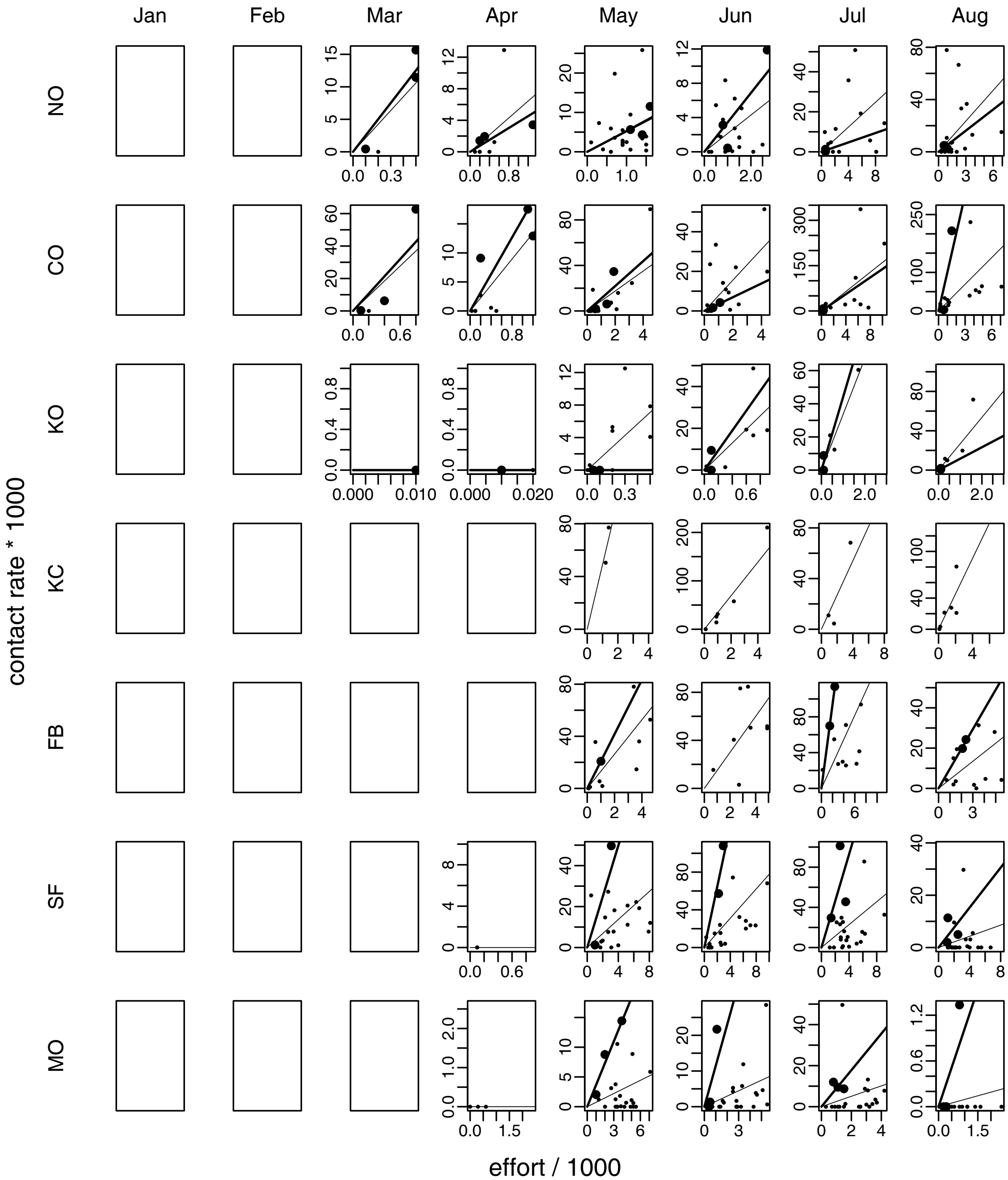

Figure A−1. Klamath River fall Chinook commercial age−4 contact rate versus effort for KOHM management areas by month, Jan−Aug. Large dots are 2003−2005 postseason values; small dots are 1983−2002 postseason values; thick lines are predictors based on the 2003−2005 data; thin lines are KOHM default predictors based on all data (1983−2005). See Appendix A text for further details.

From Appendix A-1, STT 2006c.

An exhaustive search over all possible ocean-climate indices was not possible due to time constraints. Nor was there adequate time to examine additional model structures other than the Ricker spawner-recruit model. As an example, however, we included the winter Pacific Decadal Oscillation (PDO) index as a predictive term. Our model took the form

$$R_{BY} = \alpha' S_{BY} \exp[-\beta S_{BY} + \phi PDO_{BY+1 \to BY+2} + \varepsilon] \text{ and } \varepsilon \sim \mathrm{N}(0, \sigma_{\varepsilon}^{2}), \tag{M2}$$

where the winter PDO index was measured during the first winter at sea and equals the average of November and December of the brood year + 1 and January through March of the brood year +2 (i.e. five months in total). The first year at sea, particularly the winter, is generally thought to be the most important in determining year class strength (Pearcy 1992; Gargett 1997; Beamish et al. 1999; Beamish and Mahnken 2001). We obtained the PDO indices from http://jisao.washington.edu/pdo/PDO.latest.

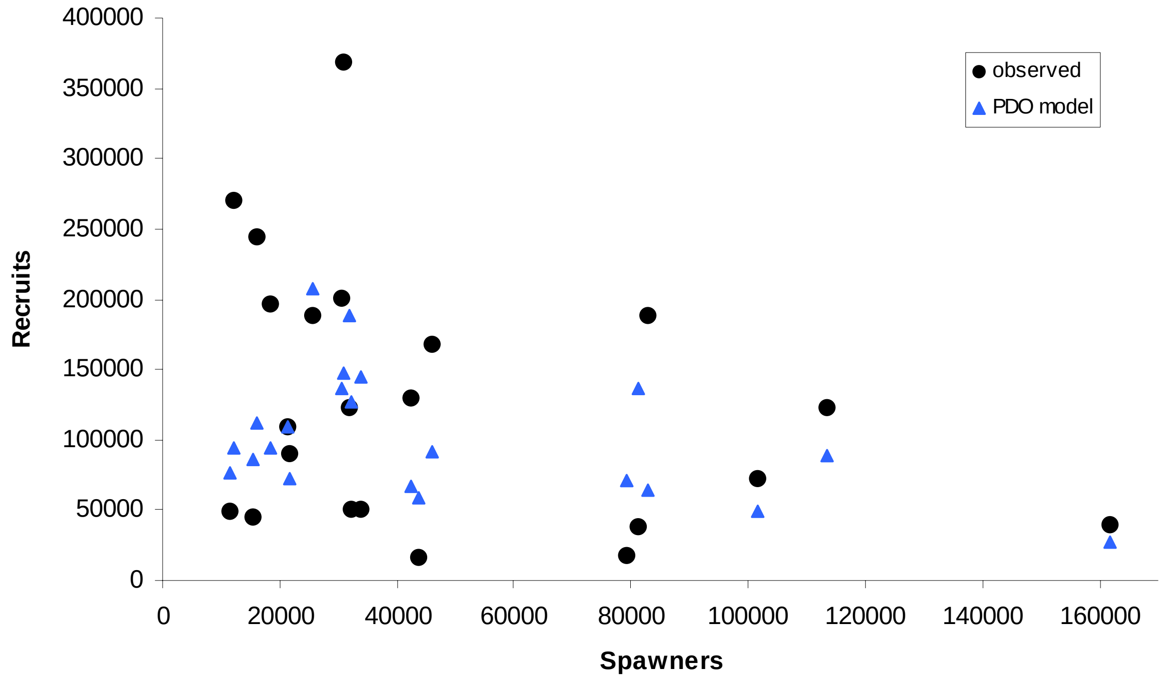

Figure 10. Spawner-recruit data for Klamath River fall Chinook salmon (dots) and the estimated Ricker stock-recruit relationship that includes a term for winter PDO (triangles).

Model parameters were estimated from the linear form of the equation using maximum likelihood analyses. The estimated model with climate effects fit the data much better (r^2 = 0.12, where r^2 is the squared correlation between the observed and predicted R values) than the simple Ricker function (r^2 = 0.037), but still rather poorly overall (Figure 10), and not nearly as well as the STT (2005a) Model 2 (r^2 = 0.50). We found modest evidence in support of the climate model over the simpler spawner-only model (likelihood ratio test, χ^2 = 2.0, df = 1, P = 0.050), suggesting that climate impacts could be important to fall Chinook from the Klamath River as well.

Risk of Recruitment Failure

A variety of risk factors concerning the productive capacity and viability of KRFC have been identified and discussed in this report. Because of the complexity and inter-relatedness of these factors, and the lack of necessary data, it would be difficult (if not impossible) to construct a quantitative model that would accurately determine "escapement levels below the 35,000 floor that would not jeopardize the capacity of KRFC to produce the maximum sustained yield on a continuing basis." However, it is possible to construct a quantitative model to assess the more immediate risk to KRFC natural production (recruitment) as a result of a low spawning escapement in 2006. The risk that will be evaluated is the probability that the recruitment resulting from the natural spawner escapement levels currently being considered for 2006 will be the lowest on record.

The most appropriate stock-recruitment model for KRFC that currently exists for evaluating this probability is STT Model 2 (STT 2005a, equation 2.1), in which recruitment *R* depends on the early-life survival rate *s* in addition to parental spawning abundance *S*:

$$R = \alpha S e^{-\beta S + \theta(s-\bar{s}) + \varepsilon}, \ \varepsilon \sim N(0, \sigma_\varepsilon^2).$$

This model implies that $\log(R \mid S, s)$ is a normally distributed random variable

$$\log(R \mid S, s) \sim N\left(\log(\alpha S) - \beta S + \theta(s - \bar{s}), \sigma_\varepsilon^2\right),$$

and thus for any particular benchmark level of recruitment R^*, the probability that $R \leq R^*$ is

$$P(R \leq R^* \mid S, s) = \Phi\left(\frac{\log(R^*) - \left[\log(\alpha S) - \beta S + \theta(s - \bar{s})\right]}{\sigma_\varepsilon}\right),$$

where $\Phi(\cdot)$ is the cumulative probability distribution function of a $N(0,1)$ variable. The relative risk, ρ, of any particular level *S* compared to the floor level, *S* = 35000, is

$$\rho(R^*, S, s) = P\left(R \leq R^* \mid S, s\right) \Big/ P\left(R \leq 35000 \mid S, s\right).$$

The lowest KRFC recruitment currently on record was taken as the benchmark for this risk analysis: R^* = 16200 (STT 2005a, brood year 1989). Considered spawner escapements included the floor value (35000) and those associated with the current PFMC options (STT 2006c): 25400 (Option 3), 18800 (Option 2), and 13800 (Option 1). Two values for the early-life survival rate[2] based on the 22 year time series of estimates reported by the STT (2005a, Table B1) were evaluated: (a) the average rate observed

[2] The survival rate time period in question is May–September, 2007.

($s = \bar{s}$ = -4.4225, log-scale), and (b) the poorest rate observed[3] (s = -7.7600, log-scale). The Model 2 parameter estimates used in the analysis were those reported by the STT (2005a, Table 2): $\hat{\alpha}$ = 5.9218, $\hat{\beta}$ = 1.7567e-05, $\hat{\theta}$ = 0.54327, $\hat{\sigma}_{\varepsilon}^{2}$ = 0.38821. The risk analysis results are provided in Table 4.

The results are contingent on STT Model 2 being an adequate characterization of the KRFC stock-recruitment relationship, and do not account for the fact that the stock-recruitment model parameters are estimates rather than known values. The analysis also assumes that the *S* values considered are in fact options that can be realized precisely (not subject to forecast error). As a consequence of this uncertainty, the actual range of probabilities of a recruitment failure is likely larger than indicated by the results in Table 4. The results suggest that if the 2007 early-life survival conditions are average (or good), the risk of the 2006 escapement yielding a recruitment lower than any on record is very small, but that the risk is substantial if these survival conditions are poor. Under poor conditions, the risk associated with the Option 1 and Option 2 spawner levels is 80% and 50% greater, respectively, than that for the floor level escapement. While the time-period for the early-life survival rate explicitly incorporated into Model 2 is May–September (downstream migration and early ocean residence) of the year following spawning, if survival conditions are poorer than average during the juvenile freshwater rearing phase (e.g., due to poor water quality, and/or a high *C. shasta* infection rate), this too would effectively reduce the Model 2 productivity coefficient and thereby increase the level of recruitment risk beyond that reported in Table 4.

Table 4. Recruitment failure risk analysis results. See text for description of terms.

Early-life survival s	Spawning escapement S	Risk $\hat{P}(R \le 16200)$	Relative risk $\hat{\rho}$
Average: -4.4225	Floor: 35000	0.1%	1.0
	Option 3: 25400	0.2%	2.2
	Option 2: 18800	0.5%	5.4
	Option 1: 13800	1.4%	14.3
Poor: -7.7600	Floor: 35000	42.3%	1.0
	Option 3: 25400	52.0%	1.2
	Option 2: 18800	63.6%	1.5
	Option 1: 13800	75.9%	1.8

Model Assumptions and Diversity Concerns

Prager and Mohr (1999) and STT (2005a) emphasize that the use of spawner-recruit analyses to estimate S_{MSY} necessarily involves many simplifying assumptions that may not incorporate all of the biologically important information that should be considered when evaluating the long-term viability of a population. Two important issues that are

[3] We note that the poorest observed *s* in fact coincided with the lowest observed recruitment (brood year 1989).

not fully captured in the spawner-recruit analyses are stock structure and the influence of hatchery produced fish on the estimates of stock productivity. These two issues are discussed further below.

The modeling analyses assumed that all of the populations of Klamath River fall Chinook could be modeled as a single stock with identical dynamics. Based on genetic, life history, ecological, and geographic characteristics there appear to be a number of distinct fall-run populations in the Klamath River Basin. Management of fall-run Chinook salmon in the Basin as a single unit may subject smaller populations to risk of extirpation. Furthermore, management of the fall run should also consider effects to the ESU, which includes spring-run fish, specifically the Salmon River spring run which persists at a relatively low abundance level. These concerns were also emphasized by Prager and Mohr (1999, pg. 29):

> *Lumping together all stocks in the Klamath-Trinity basin was done for lack of extensive data on substock structure on any scale. The relative strength of subpopulations can be assumed to vary through time, and thus there is an element of risk specific to using stock-wide management goals. Under such goals, it may be possible to seriously deplete, or even extirpate, certain local subpopulations and thereby reduce the long-term productive potential of the overall stock. This possibility would seem to call for caution in implementing a positive minimum spawner-reduction rate (a de minimis fishery), if one is indeed implemented.*

While sufficient information may be available to identify component populations in the Klamath River Basin, an expanded monitoring effort would be required to develop population-specific demographic models to evaluate harvest effects on the individual populations.

The spawner-recruit models also necessarily make some simplifying assumptions about hatchery fish. Although the models track natural (spawning gravel) escapement separately from escapement back to the hatcheries, the natural escapement itself consists of a varying fraction of hatchery-origin fish that may not have the same productivity as natural origin salmon. There is very limited information on the origin of naturally spawning fall-run fish in the Klamath River Basin. Escapement levels only consider natural spawners, regardless of origin. Changes in the proportion of hatchery-origin fish on the spawning ground may have a substantial effect on the relative productivity of specific broodyears, given the relatively extensive history of artificial propagation in the basin and the large number of known hatchery-origin fish returning to the river. Hatchery-origin fish can bias productivity estimates upward by inflating the apparent number of recruits produced. Conversely if hatchery fish have relatively lower fitness than wild fish, the proportion of hatchery fish on the spawning grounds may be an important, and unanalyzed, factor explaining variation in recruitment.

Summary and Conclusions

Uncertainty in adult abundance forecast. An important issue to consider in evaluating the consequences of alternative fishing strategies impacting the Klamath stock is the uncertainty around the estimated adult abundance. On average the pre-season forecasts are good predictors of ocean abundance, but there is considerable variation around these estimates, and it is not unusual for the post-season abundance estimate to be 50% higher or lower than the pre-season estimate. There is also uncertainty in the harvest model. For example, in the last two years, the post-season harvest rate estimate has been approximately three times higher than the preseason forecast. This underestimate has contributed to the recent failures to meet escapement. A similar degree of error in the 2006 preseason harvest rate forecast coupled with abundance on the low end of the likely forecast range could result in a very low escapement.

Spawner-recruit analyses. Several studies, most recently Prager and Mohr (1999) and STT (2005a) have estimated S_{MSY} (spawning escapement generating maximum sustainable yield) for the Klamath fall Chinook stock using stock-recruit models. Depending on the specific model used, point estimates for S_{MSY} range from 32,700 – 70,900 (STT 2005a). The lower 90% confidence interval for the lowest point estimate was 25,800 (STT 2005a). The model favored by the STT as being the most realistic produced an S_{MSY} of 40,700.

There have been large recruitments in the past from spawning escapements below 35,000 (e.g., brood years 1979, 1983, 1984, 1985, 1992, and 1999). There have also been poor recruitments (e.g., brood years 1981, 1990, 1991, and 1994). The STT (2005a) found that annual variability in early life-stage survival explained a large part of this variability in recruitment. The additional modeling done for this current report emphasizes this conclusion. In particular, using the spawner-recruit model favored by the STT (Model 2), we estimated that the probability of a recruitment lower than any previously observed was 52%, 64%, and 76% for escapements of 25,800, 18,800, and 13,800, respectively, assuming poor early marine survival conditions. If average survival conditions are assumed, the estimated probability becomes 0.2%, 0.5%, and 1.4% for the same three assumed spawning escapements.

Expectations for future conditions. The Klamath Chinook stock is not unusual in its sensitivity to river and ocean conditions. Considerable research over the past decade has shown how climate-induced variation in ocean and freshwater ecosystems can influence the population dynamics of salmon stocks across the west coast of North America (e.g., Beamish and Bouillon 1993, Mantua et al. 1997, Peterman et al. 1998, Scheuerell & Williams 2005). These shifts in productivity and subsequent catch rates are often abrupt and occur at non-regular intervals (Mantua et al. 1997). While there has been some recent success in forecasting climate-driven changes in marine survival rates of salmon (e.g., Logerwell et al. 2003, Scheuerell and Williams 2005. Lawson et al. 2004), our ability to forecast future changes is relatively poor, with typical lead times of less than one year. This suggests a real need for precaution when assessing the status of salmon stocks and projecting future trends in their abundance under various harvest management plans.

Some of the current problems with the status of KRFC are attributed to a series of low flow/low water conditions in the basin. Poor conditions in the river have likely contributed substantially to the low abundance and spawning escapement this year. Conditions in 2005 appear to be better and conditions in 2006 may be better still. However, the spawning escapement of Klamath fall Chinook is made up primarily ofage-3 and age-4 fish. This year's forecast for age-3 abundance is the lowest on record (STT 2006b). The age-2 fish in this year's run will be from the 2004 brood year, before river conditions began to improve. This does not bode well for the 2007 and 2008 return years. Any additional ocean fishing mortality will not only reduce this year's spawning run, but will also reduce the spawning runs for the next couple of years.

Diversity and stock structure. There are consequences to the diversity (and therefore viability) of the Klamath stock at low escapements that are not captured in the spawner-recruit analyses that have been used to estimate S_{MSY}. In particular, although the Klamath fall Chinook have been modeled and treated as a single population, multiple lines of evidence strongly suggest that there are multiple distinct demographic stocks of Chinook salmon that spawn in different parts of the Klamath. It is highly unlikely that these stocks all have the same population dynamics and managing at the aggregate level will result in high harvest rates on the less productive stocks. Most of the potentially independent spawning populations in the Klamath currently have spawning escapements well below 1000, and those populations that have larger spawning escapements are adjacent to hatcheries and likely receive large numbers of hatchery strays.

Long-term changes in stock productivity. The Klamath stock complex is almost certainly less productive now than it was under "pristine" conditions, and perhaps even than it was 20 years ago. It is possible that the stock complex's productivity will continue decline if climate change and/or local environmental degradation leads to lower water quality. For example, Bartholow (2005) analyzed available temperature and flow data and concluded that mean water temperatures in the Klamath have been rising since the 1960's. The California Department of Fish and Game (2004) concluded that elevated water temperature was a factor in the high level of pre-spawning mortality experienced by Klamath fall Chinook salmon in 2002. The productivity of the stock has been highly variable, but may be on a downward trend. From one perspective, it is tempting to argue that as watershed capacity declines, escapement goals should decline as well. From another perspective, not meeting the escapement floor for a stock that is already impacted by a deteriorating environment will only lead to a more rapid loss of the stock's ability to produce maximum sustained yield on a continuing basis.

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