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ANALYSIS OF CHINOOK SALMON HARVEST MANAGEMENT

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Consulting Report for

Long-Live-the-KIngs

Oregon Trout

November, 1997

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ABSTRACT

Chinook salmon catches have declined sharply in contrast to stable or upward abundance trends of many other Pacific salmon stocks. The most extreme problem region is the central portion of the range, the Columbia River to Southern British Columbia. Causes for the decline include multi-jurisdictional mismanagement of wild stock harvest, habitat deterioration, declining survival of hatchery released chinook, and downward cycling of ocean productivity.

Fishing exploitation rates rose above the maximum sustained yield rate of about 70% during the 1960 and 1970 heydays of hatchery success and have not declined sufficiently since then to allow wild stock rebuilding, in spite of major institutional changes that were to have corrected the problem. Some wild stocks have continued to decline.

Compounding these problems, a high proportion of chinook are killed as immatures, either vis-a-vis directed fishing on juvenile populations, or indirectly when targeting stocks of mature chinook or other species. Directed fishing on immatures greatly reduces the value of the yield otherwise attainable by allowing only mature chinook to be harvested. Mortality due to the incidental capture and release of immature chinook too small to be utilized or legally retained is equivalent to at least 30% of the landed catch. High fishing mortality on immature chinook has probably operated selectively against older maturing and faster growing individuals; chinook salmon today tend to mature younger and grow slower than historically. Spawners today are substantially smaller than spawners in the past. Population fecundity has therefore been reduced since larger females have more eggs. Smaller body size may negatively affect natural propogation in numerous other ways.

The same biological standard that is applied to other species should be applied to chinook - the capture of mature fish only. Yields in weight and value would thereby increase. Incidental mortality losses would decrease. Selectivity against older maturation and faster growth would diminish. Optimal harvest rates in multijurisdictional fisheries would be easier to attain if chinook were exploited only in their last few weeks of ocean life. To prevent the capture of immature chinook, major changes would be required in gear deployment, seasons and areas of fishing. But all

fisheries would gain in catch value if the biological standard was uniformly applied and habitat productivity was maintained. Loss in quantity and quality of spawning and freshwater rearing habitat continues to be the major cause for chinook salmon decline. Chinook salmon runs will continue to decline even if all fishing ceases, unless the trends in habitat loss can be reversed.

INTRODUCTION

"The taking of immature salmon in the Puget Sound and on the banks of Oregon, Washington and Vancouver Island is responsible for a great loss in one of the important food products of the region." (Smith and Darwin, 1921)

"It has further been shown that the outside fishing is uneconomical in that it takes fish (chinook salmon) at a time when they are of poor quality and are much smaller than they would be at maturity. If it should prove impossible to prevent **outside fishing entirely, it would seem desirable to limit such fishing to the latter part of the fishing season." (Rich, 1925)**

A great deal of attention has been recently given to the plight of Pacific Salmon. The term, crisis, is often used by the media, the scientific community, user groups, and concerned citizens to describe the current status of salmon. Yet, many stocks are at, or near, historical high abundance. It may be useful to compare the successful species and stocks with those in serious decline to gain insight to the causes of decline.

The three most abundant Pacific salmon species - pink, chum, and sockeye are all doing remarkably well, according to increasing total Pacific catch trends over the recent 25 years (Figure 1). All three are harvested primarily by commercial net fisheries and have been exploited heavily for more than a century. With the exception of chum salmon and sockeye at the southern end of their ranges (coastal Oregon and the Columbia River, respectively), all three species are doing relatively well over their historical ranges, albeit their best success is in British Columbia and Alaska where detrimental watershed development is minimal. Although pink and chum salmon are being produced successfully in hatcheries, mainly in Japan and Alaska, wild stock management of all three species has been successful and catches from many of these stocks are averaging as high as, or higher, than at any previous time in history.

Coho and chinook salmon and steelhead, on the other hand, have not been doing so well. Comparable coast-wide catch trend data for steelhead are lacking, since most

steelhead are caught by recreational fishermen and most regions have promulgated catch-and-release regulations for wild fish. However, many wild steelhead stocks are declining at alarming rates, particularly in the southern range of their distribution (Mills, et al, 1996; Hassemer et al, 1996; Kostow, 1996; Johnson, et al, 1996; Busby, et al, 1996), and post-release survival of hatchery steelhead has been declining as well (R. Leland, Washington Dept. of Fish and Wildlife, Olympia, WA, personal communication). Thus, the coast-wide catch trend for steelhead is probably significantly downward.

The coast-wide total catch of coho has been trending downward over the recent 25 years (Figure 1), due to deteriorating marine survival of both hatchery and wild coho, overharvest of wild coho, and habitat loss at the southern end of the range (Johnson, et al, 1991). Moving northward, the status of coho improves, although there are some critically depressed stocks in Washington and British Columbia. (Johnson et al. 1966; Northcote and Atagi, 1966). In Alaska both wild and hatchery coho stocks have been doing well (Wertheimer, 1966). The high coast-wide catch levels of coho in the 1970's and early 1980's were as high as at any previous time in history, and due primarily to relatively good hatchery successes during these decades.

Chinook salmon is the species of Pacific salmon suffering the greatest decline, on a coast-wide scale, particularly in the most recent decade (Figure 1). Pacific catches (the Asian contribution of chinook is only about 5% of the total) averaged about five million annually during the 1970's and 1980's, which was as high as in any time in the well-recorded past (1920 onward). The high catch levels during the 70's and 80's were due to relatively good survival from sharply increasing hatchery production, as well as good marine survival from wild stocks. Catch levels of perhaps five million annually were probably taken before the turn of the century, after which over-exploitation began to take its toll. In the decade 1986-1995, chinook catch dropped to about 2.5 million annually. Preliminary data indicates that 1996 was the lowest year ever, less than 2.0 million total catch.

Why are chinook, coho and steelhead, as a group, declining while pink, sockeye and chum, as a group, are stable or increasing? One contributing reason is that the former group includes species distributed more towards the southern end of the anadromous salmonid range, where freshwater habitat disturbance is the greatest. Pink, chum and sockeye increase in abundance relative to chinook, coho and steelhead moving northward to British Columbia and Alaska, where watersheds are less disturbed. However, this does not wholly explain the differences, as several examples may show. Chum salmon in Puget Sound are currently approaching historically high abundance, while many Puget Sound chinook and coho are sinking to record low levels (Johnson, et al, 1996). In a specific Puget Sound river, the Skagit, wild chinook and coho stocks have dropped to critically low levels, and wild steelhead are also much less abundant than in the past. Yet Skagit chum, pink and even a small sockeye run are stable. The run of sockeye salmon in Lake Washington, right in the heart of the heaviest development in the State, is faring better than the wild chinook and coho stocks of this system. In the Fraser River pink and sockeye runs have been rebuilding rather dramatically, yet many chinook and coho stocks to southern British Columbia have recently declined to alarming levels (Northcote and Atagi, 1966). Even in the Columbia River, with its high degree of negative watershed alteration, two of the sockeye runs whose lakes remain open to upstream and downstream migration (Okanogan and Wenatchee) are relatively stable, yet numerous wild stocks of Columbia River chinook and coho are at ESA listing levels (Hassemer, et al, 1966; Kostow, 1966; Johnson, et al, 1966).

Hatchery production of chinook, coho and steelhead, as a group, has been much more extensive than for pink, sockeye, and chum. The implication is that hatcheries have not only been ineffective in maintaining the former group of species, but perhaps detrimental to wild stocks. There is a great deal of current debate on these issues (see Hilburn, 1992, and Kapuscinski, 1996 for perspectives). Perhaps the most detrimental effect of hatcheries on wild stocks has been the enhancement of mixed stock fisheries and the resultant overharvest of the intermixed wild stocks by overly aggressive fishing effort allowed on the apparently abundant stock mix. This negative effect of hatchery production on wild stocks is not so much a biological problem due to the hatcheries per se, but a failure of the harvest management regime. it is my belief, and the focus of the present report, that improper harvest management of chinook and coho salmon on a coast-wide scale, (steelhead management has separate and special issues from the above two and will not be considered further in this report), compared to harvest management of pink, sockeye and chum salmon, has been a major contributor to declines of the former two species.

Pink, sockeye and chum have been harvested mostly by commercial nets virtually exclusively as mature fish (i.e. in their last weeks or days of marine life) relatively closely to their rivers of origin, whereas, coho and particular chinook have an extensive history of targeted, immature harvest in hook and line commercial troll and recreational fisheries. These fisheries are allowed to catch coho in marine feeding areas that may be several months from maturation, and chinook that may be one, twoor even three years younger than their ultimate age. In addition, a great many small, immature chinook salmon have been allowed to be caught incidentally in fisheries that target other salmon species or that ostensibly target larger chinook. In the present report, I direct my analysis primarily to the consequences of these past harvest patterns on the overall condition of chinook salmon stocks on the Pacific Coast. I also discuss ways to improve the coast-wide chinook salmon harvest management regime.

Chinook salmon, though historically (and presently) least abundant of all (except steelhead), are highest valued commercially, as well as recreationally. Thus, they were the first species to be exploited. Limited commercial industries were underway on the Columbia and Sacramento Rivers by the mid-19th century, obtaining salmon primarily through trade with native American fishers. In the 1860's canning was introduced on these two rivers and the modern industry began. Chinook catch levels for the entire coast, including native American and other subsistence use, peaked at perhaps five million per year near the turn of the century, but had fallen substantially by 1920. From 1921-1950, the total catches of chinook averaged 3.3 million fish per year. The Columbia River was far and away the greatest producer of chinook salmon. The maximum commercial catch there averaged 2.5 million for the years 1880-85 (Chapman, 1986 from VanHyning, 1968). Adding in native American and other subsistence users, total Columbia River catch of chinook probably peaked at about 2.8 million, but declined after the turn of the century, probably from overfishing (Chapman, 1986).

Although there is no firm basis for accurately estimating the pre-development abundance of chinook salmon for the entire coast, an approximation of this may help put present day catches in perspective. During the period 1921-1950, the Columbia

River (including offshore, commercial trolling in the Columbia River ocean district) averaged 1.1 million annually, or one-third of the total Pacific catch average of 3.3 million for this period. By those years, the Columbia River with its intensive, early fishing industry was probably over-exploited relative to other major chinook producing rivers. Also, by the 1921-1950 period, major offshore commercial troll fisheries were underway along the entire coast, and troll tagging consistently indicated the Columbia River to be the main contributor all the way north to SE Alaska. Accordingly, it may be a fair estimate that the Columbia River contributed 40% of the total pre-development abundance of chinook. Chapman's (1986) reasonable estimate of pre-development abundance for the Columbia (there are other less reasonable estimates in the literature), was about four million chinook annually. Thus, pre-development abundance for the entire coast would have been on the order of 10 million chinook (401.40).

An alternative, confirming estimate of early chinook salmon total abundance was provided by Dr. P. Mundy, Lake Oswego, Oregon (personal communication). Dr. Mundy reviewed literature on recorded turn of the century chinook catches from the Sacramento River northward to the Yukon. By assuming that such catches represented on average 50% exploitation (i.e., 50% of each stock was caught and the remaining 50% escaped to spawn), he estimated a total coast-wide abundance of 102 million chinook salmon. If, indeed, the exploitation rates at the end of the nineteenth century were greater than 50%, the total abundance would have been less than this, and if exploitation rates were less than 50%, then abundance would have been greater than 10 million.

A pre-exploitation abundance of 10 million chinook in a pristine environment could have sustained catches of up to 7.0 million fish annually, with total spawning escapements averaging 3.0 million, according to scientific consensus that harvest rates averaging in the neighborhood of 70% of total brood year adult production will yield maximum sustained yield for chinook salmon stocks in healthy environments (Chapman, 1986; Healey, 1982; Van Hyning, 1973; Hankin and Healey, 1986; Overholtz, 1995). The fact that total annual catches in all likelihood never reached the seven million level is because deleterious watershed development started early, well before 1900, and fishery exploitation did not begin at once in all productive systems; it moved piecemeal up the coast with important rivers, notably the Columbia, overfished by the time others might have become optimally exploited.

The current (1990's) catch levels of about 2.5 million, therefore, represent less than half of pre-development productivity of North American wild spawning chinook.

salmon. Even more discouraging is that catches have declined to this level in spite of very extensive hatchery output. As I will show later, about 40% of the present catch of chinook is from hatcheries. Thus wild chinook salmon production is on the order of 25% or less of pre-development capacity.

REASONS FOR THE DECLINE

Loss of quantity and quality of freshwater spawning and rearing habitat has been the major cause for decline of chinook salmon. This is apparent from the simple fact that watersheds that have suffered the greatest development have seen the most precipitous losses of salmon; the Columbia River is the prime example. Habitat degradation has been associated with over 90% of the documented extinctions or declines of Pacific salmon (Gregory and Bisson, 1996; Nehlson, et al, 1991).

However, fishing has contributed to the decline, as numerous fishery managers have acknowledged (e.g., Fraidenburg and Lincoln, 1985; Marsal, 1995; Pacific Fishery Management Council, 1992; Pacific Salmon Commission, 1996). There are several important and unique facets of chinook salmon life history and our historical patterns of fishery exploitation which have lead to decades of careless harvest management. There are at least four specific problems to which the term careless applies in the context of chinook harvest management: incidental catch mortality, recruitment overfishing, growth overfishing, and alteration of population, size, age and sex structure.

Incidental Mortality

Incidental mortality is the death due to encounter with any form of fishing gear which does not result in. legally retainable, landed catch; such mortality is a much higher proportion of the total landed chinook catch than for any other salmon species . intolerably high levels of incidental chinook mortality from many fisheries have persisted for decades, even though we (the entire fishing and scientific community) have the technical knowledge on how to re-deploy ail forms of fishing gear to much reduce this. Controlling incidental mortality would do a great deal towards rebuilding wild stocks, as well as improve yields from hatcheries. This will be discussed in greater detail after presenting the pertinent aspects of the life history of chinook, and describing the fishing gear and methods in use today.

Recruitment Overfishing

Recruitment overfishing for chinook (or any other species) occurs when the rate of exploitation exceeds, on average, the optimal (maximum sustained yield) exploitation rate. As stated previously, the consensus opinion for the optimal rate for chinook salmon in productive habitats averages some 70%, which is similar to the optimal level for other salmon species. If habitat has deteriorated or the stock needs rebuilding, the exploitation rate should be less; 50% might fairly summarize the prevailing scientific consensus for many such stocks, although obviously such a rate would vary according to specific circumstances. For an ESA listed stock, the optimal rate could approach 0%. Many hatchery stocks were exploited at rates well above 70%, in fact often at rates in excess of 90%, according to fin marking studies of the 1960's and coded wire tagging (CWT) during more recent decades. That is, the total catch at all ages from all mixed-stock and terminal fisheries of a particular marked brood lot of fingerlings was often 90% or more of the total abundance of chinook salmon of that brood lot surviving to catchable size, as estimated from the total catch plus the total spawning escapement of that brood lot at all ages,l. Coded wire tagging

1 This simple "raw" measure of exploitation is numerically close to the "adult equivalent exploitation rate" estimated in the scientific literature from fin marking and CWT data, since natural mortality after about age two (the minimum catchable age for fall chinook) is relatively low. The adult equivalent exploitation rate reduces or discounts any catch of immature fish to account for natural mortality between data of catch and hypothetical date of maturity, had that fish not been caught

The raw rate of exploitation will be somewhat greater than the adult equivalent rate, but since neither statistic commonly includes the imprecisely known, but clearly significant incidental mortality, the raw rate of exploitation from CWT data, as defined above provides a simple, effective measure of overall fishing mortality intensity parallel to brood year exploitation rates commonly computed for terminally harvested species like chums and sockeyes from catch, spawning escapement, and age composition data.

estimates of wild stock exploitation rates comparable to those of hatchery stocks have rarely been made. I am aware of only two comparable efforts, for Lewis River (Columbia) wild spawning fall chinook (Mclsaac, 1988) and the wild fall chinook spawning in the Hanford reach of the Columbia River. Exploitation rates of 70-90% are not too high for hatchery stocks, but they imply the likelihood of recruitment overfishing of wild stocks mixed in time and space with hatchery stocks.

Recruitment overfishing of wild stocks mixed with hatchery stocks became a likely, severely negative consequence of the hatchery success of the 1960's and 1970's. Fingerling output from hatcheries expanded sharply then, and coupled with what in retrospect was unusually high marine survival, abundance of chinook was very high. Marine commercial trolling and sport fishing, as well as "terminal" net fishing (to "mop up" any hatchery surpluses), expanded with insufficient control in response to the artificially-produced abundance. In a later section, I present trend analyses of exploitation rates for several hatchery stocks from coded wire tagging that was conducted continuously until the present. In several major cases, such rates have not declined significantly and remain higher than optimal for wild stocks. The implied likelihood of continuing recruitment overfishing on wild stocks from these welt-known and readily-available data sources again evokes the term "careless" in reference to management of chinook.

To define the problem of recruitment overfishing as one of mixed -stock fishing misses the point, for it is the combination of mixed-stock and terminal fishing that has produced the greater than optimal fishing rates. Labelling specific fisheries in a Il pejorative, mixed-stock context has by and large only caused allocation disputes, which have been useless or even defeating in resolving the overfishing and incidental catch problems. Most marine sport and commercial troll, and even many net fisheries exploit multiple stocks in time and space. All fisheries should share in reducing the exploitation rate; the burden should not fall simply on those that, by someone's definition, are mixed-stock ("bad") versus terminal ("good").

Growth Overfishing

The two quotes from early twentieth century scientific literature given in my Introduction referred primarily to growth overfishing, which is the capture of too many fish at too small a size, independent of any consideration of spawning escapement adequacy. Chinook salmon have relatively low natural mortality by the time they reach about 2 years of age and 5 pounds in weight. A 2-year old therefore would have a relatively high probability of reaching an ultimate age of about 4 years and a weight of about 20 pounds if not caught as a 5-pounder. If a high fraction of a stock is caught as 5-pounders, the overall loss in potential yield, in terms of pounds, becomes substantial. The capture of 6-inch steelhead smolts, which might otherwise return as 10-pound adults was an extreme example of growth overfishing and was a common occurrence in coastal Washington rivers until the recent increase in the resident trout size limit from 6 to 12 inches. The magnitude of growth overfishing losses from capture of immature chinook depends on the interaction of growth rates, natural mortality rates and fishing rates. A numerical example is presented later to illustrate these points.

Alteration of Size. Age. and Sex Structure

Any form of non-natural mortality that operates non-randomly in regard to a particular population trait could alter the genetic structure of the population. Fishing mortality on immature chinook, both targeted and incidental, is potentially selective against older age at maturity and fast growth. Chinook salmon vary in age at maturity and those which are destined to mature at older ages would be exposed to more seasons of fishing than those which mature younger, under a fishing regime of immature harvest. If age at maturity is inherited, then the relative frequencies of older fish in the escapements would decline over time. Since female chinook, on average, tend to mature older than males, selective mortality against older age may also cause an imbalance of males over females on the spawning grounds. Faster growing individuals may take baits and lures more aggressively; they will also reach minimum size limits earlier in life. Both factors could lead to selective fishing on faster growing individuals by a fishery that kills immatures.

Later in this report, I review evidence that chinook salmon have tended to become younger on average, and smaller at given ages, and furthermore that sex ratios in spawning escapements tend to favor males. I discuss the potential downsides from such selectively induced population changes.

There are, of course, numerous contributory reasons for the chinook salmon decline. Loss of freshwater spawning/rearing habitat in terms of quantity (dams and other diversions) and quality (a great variety of well-known land use activities detrimental to salmonid productivity, such as logging, farming, mining, road building, land clearing, etc.) has contributed as much or more to the decline of wild chinook salmon than has mismanagement of the harvest. The list of things needed to protect and re-create habitat is immense: controlling development, removing dams, improving upstream and downstream passage at dams, re-creating ecosystems within logged or cleared land, enforcing logging and other land use practices, protecting streambanks with buffer zone and livestock fencing, etc. But sound habitat management and sound fishing practices go hand-in-hand. Fishers will have the strongest voice to positively influence habitat protection policies and politics if they are fishing in biologically sound ways. How can we expect the farmer to fence the streambanks against livestock damage if we do not fence off regions of the oceans and estuaries that have too many juvenile salmon or too great a mix of stocks of varying status and productivity? The Columbia River dams kill more juvenile salmon than do the fisheries, but if we ignore the shaker problems, we leave the hydropower industry a big sword to swing back at us when we fight for water releases to improve outmigration survival. We dull their sword by fishing responsibly.

There is increasing evidence that cycles in ocean productivity affect abundance of salmon and other stocks in parallel over wide expanses of the marine environment (Beamish and Bouillion, 1993, Hare, 1996). We may currently be at an ebb in a long term cycle of nearshore ocean productivity. Many hatchery and wild stocks of chinook from California to southern British Columbia experienced parallel, high survival in early 1980's brood years. Survival for some of these has nosedived since then. As one example, Hanford reach (mid-Columbia River) up-river-bright fall chinook (URB) released from Priest Rapids hatchery as brood years 1982-84 experienced post release survival rates averaging 1.8%, which is very high for O-age chinook. However, for brood years 1988-90 survival averaged only 0.2%, a decrease by a factor of nine. Furthermore, similarly low survival for the 1988-90 broods was experienced by both Priest Rapids hatchery-reared URB stock and wild-spawned URB stock (same genetic strain) seined as stream rearing fingerlings in the Hanford reach, and tagged. Thus the decline in survival was not obviously caused by some deleterious agent within the hatchery - for example, disease stress. Something broadly within the river or marine environment negatively affected hatchery and wild fish in a parallel manner.

As with freshwater habitat effects, ocean productivity cycles and corresponding effects on salmonid production are being intensely investigated. But in terms of fishery management, there is little we can do regarding such cycles, except perhaps to alter spawning escapement goals in response to fluctuating ocean conditions. Hare (1996) indicates that long term yields from salmon stocks might theoretically be improved as much as 10% if we could predict ocean productivity and adjust escapements optimally.

A final, important contributor to the decline in chinook salmon catch is a general, long-term and pervasive decline in post-release survival of hatchery fish. This trend is well summarized in Figure 2, which is from a recent PhD thesis (Coronado-Hernandez, 1995). Shown here are the average smolt to adult survival rates by brood year (adjusted to a common age, which tends to over-estimate the actual contribution rate to catch and escapement by about 10-15%) estimated from analysis of 1 1 ,051 wire tagged lots from 305 hatcheries from California to Alaska.

As ever-increasing numbers of chinook fingerlings were released, survival declined for all races. A few regions, notably Oregon and Washington coastal hatcheries bucked the trend, but for the major hatchery systems - Columbia River, Puget Sound and southern British Columbia, the unfortunate story is very well known; hatcheries were unable to fulfill on the promises of their early high successes. By the 1988 brood year, total production of chinook hatchery fingerlings was about 220,000,000, while contribution to catch and escapement (survival to specific ages readjusted to reflect actual contribution of fish) averaged approximately 00.7%. Incomplete evidence indicates that contribution rates for brood years affecting current catch levels (1990-94) have fallen somewhat more since the 1988 brood. (I later use an estimate of 00.65% to project the percentage contribution of hatchery fingerlings to present catch levels.)

The reasons why hatcheries have not provided chinook, (or coho either) as well as hoped, are not known, although there is plenty of speculation. Hatchery "bashers" will say it is due to fish-cultural problems that only an idiot would not have foreseen, such as genetic inbreeding, unnatural disease-promoting environments, or insufficient opportunity for behavioral conditioning needed to successfully forage or avoid predation after release from the hatchery. At the other extreme, hatchery enthusiasts may say that their biological products are just fine, thank you, but simply needful of a more productive ocean environment. Such optimism would have the oceans plugged with chinook when (if) the cycle turns upward. Although the truth may lie between, the clear message from Figure 2, is that we should not rely on hatcheries to bring back chinook salmon abundance. Natural runs must be rebuilt by insuring adequate escapements on large and small stocks, as well as healthy environments. Hatcheries can be useful to supplement low natural runs or for captive brood stock, and to provide some level of catch until natural production rebuilds, provided that the hatchery fish are thoughtfully released and harvested to avoid wild overharvest.

RATIO OF WILD TO HATCHERY FISH

The total landed catch of chinook has recently been about 2.5 million fish annually. Current annual hatchery production of all races over the entire coast may have risen slightly to about 225,000,000 fingerlings since the 1988 brood last analyzed by Coronado-Hernandez (1995). At a prevailing contribution rate to catch and escapement of 0.65%, some 1.5 million catchable-sized fish of several ages are annually entering the fisheries from several successive brood years. Total hatchery escapement to all regions south of British Columbia currently averages about 300,000 adults. Hatchery escapement summaries for B.C. and Alaska were unavailable, but these regions together produce about one-third of the total hatchery fingerlings (Coronado-Hernandez, 1995). If we assume spawners to be in the same ratio as fingerling production, then total hatchery escapement including British Columbia and Alaska would be about 450,000. Consequently, of the total current hatchery contribution to catch and escapement, approximately 1.0 million are caught, and of the total current catch of 2.5 million chinook, about 40% are then from hatcheries and 60% (1.5 million) are from natural production.

Although only approximations, these computations indicate how badly naturally spawned chinook production has fallen. As earlier noted, naturally spawned chinook catches near the turn of the century may have been about 5.0 million annually, and pre-development populations may have been capable of sustaining catches higher than this (say 7.0 million) because by 1900 overfishing and habitat destruction had reduced productive potential. Accordingly, the present level of catch from naturally spawning chinook populations is some one-third to one-fifth its pre-development potential. How much of this can be regained is, of course, problematic. Much of the pre-development spawning/rearing freshwater habitat has been inundated or is otherwise inaccessible due to dams - particularly on the historically most productive river, the Columbia. Nonetheless, there is still very substantial room for improvement of wild chinook stock production through improved harvest management There are, without question, many potentially productive, but under spawned chinook stocks. The extent of the gains from more adequate spawning are uncertain, and depend on our environmental vigilance; but the gains from reducing incidental mortality and overharvest on immatures are substantial, measureable and in no way problematic.

LIFE HISTORY AND POPULATION DYNAMICS

Considerable detail is given by Healey (1991). I will summarize the salient features needed to put the harvest management concerns, problems, and potential solutions into perspective.

Spawning Stocks

There are probably well over 1,000 chinook salmon spawning populations in North America, from central California to Kotzebue Sound, Alaska, and a much lower number on the Asian coast. However, relatively few major rivers support most of the chinook. The only North American rivers with runs in the hundreds of thousands are the Sacramento-San Joaquin, Klamath, Columbia, Fraser, Nushagak, Yukon, and Kuskowkin. There are quite a few rivers with runs in the tens of thousands, but In the vast majority of smaller streams, the runs historically were on the order of 1 ,OOO fish or less.

Generally speaking there are two major races quite distinct in their life histories, spring chinook and fall chinook. Spring chinook are also designated stream-type because the fingerlings tend to rear in the rivers for one or more years before going to sea. Correspondingly, fall chinook are called ocean-type because they migrate to sea in their first year of life, typically spending only a few months in the river estuary.

Spring chinook spawners enter the river during spring and early summer, but may spend considerable time in the river ripening before spawning in late summer or early fall. Fall chinook enter the river from late summer through early winter in relatively mature condition and spawn shortly thereafter.

Spring chinook are most common in Asia, in northern North America, and in headwater tributaries of southern North America. Fall chinook are much more abundant than spring chinook in the southern part of the range at the present time, and were also more prevalent than spring chinook in the past. Naturally spawning spring chinook have suffered greater declines than fall chinook because their spawning and rearing habitats were in areas more subject to poor land husbandry. More fall chinook are hatchery produced than spring chinook, because fall chinook are easier to raise, needing only a few months of freshwater rearing rather than a year or more.

Many chinook stocks display variation within or outside of these two general patterns. Summer chinook are distinct from either spring or falls in some systems and were at one time the major component of upper Columbia River chinook. Remnant populations of winter chinook are recognized, such as in the Sacramento. However, the vast majority of chinook salmon now caught drop relatively simply into either the spring chinook or fall chinook category, with fall chinook the more numerous. Spring and fall chinook are distinguishable, if caught at sea, from different scale patterns; spring chinook have the larger freshwater growth zone, the central area of closely spaced rings (circuli), reflecting a slower growth rate in freshwater compared to that in the marine environment.

Fall chinook tend to be more nearshore-oriented during their ocean residency than spring chinook. This is another reason why most of the chinook caught along the Pacific coast and the inner sea environments of Puget Sound, Georgia Strait, and SE Alaska are fall chinook. The ocean distribution of spring chinook is not well known, but they apparently migrate farther offshore or farther northwesterly in the Gulf of Alaska than fall chinook, in either case beyond the limits of the intense North American coastal troll and sport fisheries.

Because of the differences in ocean distribution, combined with intensive nearshore fisheries on immature, feeding stocks, fall chinook are exploited at higher rates than spring chinook. For example, fall chinook from the Columbia River are typically harvested at rates on the order of 80% with much of the catch taken at sea, while spring chinook from the upper Columbia and Snake rivers currently sustain harvest rates of only about 20%, and relatively few enter the marine catch. Such a difference not only illustrates the startlingly different patterns of ocean migration, but provides insight into the relative weighting between fishing effects and habitat effects on the declines of Columbia River spring and fall chinook. Freshwater habitat development, notably in the hydropower system, has probably been the major negative factor for spring chinook, whereas overfishing is a relatively more important cause for declines of fall chinook.

Maturation

Although there is wide variation in age composition among stocks, the most common age at maturation for fall chinook is four years; however, maturation ages may vary from two to seven or eight years. Males tend to mature younger than females and in most populations the two-year maturing fish are virtually all males (jacks). The average age at maturation tends to average about half a year younger for males than for females. Fall chinook tend to mature younger at southern latitudes.

Thus, spawning runs of some important fall chinook stocks from California to the Columbia River have relatively high proportions of both male and female 3-year-olds. Chinook of ages six or greater are uncommon, except in Alaska.

Spring chinook, because of the extra year in freshwater, tend to mature older, averaging about half a year older than fall chinook in rivers where both occur. The predominate adult ages for spring chinook are presently four and five years, although six-year olds were common historically. Three-year-old spring chinook jacks (mostly males) are common in some rivers.

The factors affecting age at maturation are complex. Average age at maturation (and consequently average size) has decreased substantially over the century or more of exploitation (Ricker,1981 ; Hankin and McKelvey,1985). A likely explanation (Ricker, 1981) is that individuals which mature at older ages are available to the troll and sport fisheries as immatures for longer periods of time than younger-maturing chinook, and hence will be exploited at greater rates. This would tend to skew the spawning populations towards younger fish, relative to an unfished circumstance. Since age at maturation is heritable (Ricker, 1972; Donaldson, 1970), the average maturation age in the population would thus tend to decline over time. Under this

scenario it is not surprising that those rivers that still have relatively high proportions of older ages in spawning runs (6-8 years) are in central and western Alaska, north of intensive marine hook-and-line fishing on immatures.

It is known that hatchery environments can also affect maturation. Rapid growth induced by intense early feeding in the hatchery tends to promote early maturation. The relatively high proportion of 3-year-olds in Columbia River hatchery stocks of fall chinook may be due in part to such a cause.

Since females tend to mature older than mates, they will on average be exposed to targeted and incidental capture as immature for a longer period of life than males and could consequently suffer greater total fishing mortality than males. The expected result would be disproportionate numbers of males in spawning populations, with negative effects on stock reproduction.

Fecundity

The mean number of eggs per female ranges from about 3,600 to 12,900 for about 22 distinct stocks (Roni, 1992). As with other fish, egg number tends to increase with the size of the female (Galbraeth and Ridenhaur, 1964, McGregor, 1922), however the correlation between egg number and body size appears to be less obvious for chinook than other salmonids. Average egg number varies substantially between stocks, among years, and among individuals.

Average fecundity increases latitudinally, from south to north, however this trend may partly reflect increasing proportions of spring chinook (stream-type) from south to north. Spring chinook tend to have higher fecundity than fall chinook within the same river system, although the differences are not great. Egg size varies among chinook stocks, with an apparent tradeoff of larger eggs for less eggs. Larger females tend to have larger eggs (Lister, 1990). Larger eggs would produce larger fry, which would tend to survive better than smaller ones.

Marine Growth

Over 99% of the adult weight of chinook salmon is achieved by growth at sea, because the marine environment is so much more productive than that of the river.

And spring chinook, since they spend an additional year in freshwater, are considerably smaller at given ages than fall chinook.

Growth rates vary considerably among stocks and perhaps even more so by age at maturity within a stock. The younger the age at maturity, the greater the growth rate. For example, a Columbia River fall chinook destined to mature at age four will reach an average weight in the ocean of about 12 pounds by the end of its third year (Dec. 1 of calendar year i+3, where i is the brood year), whereas a chinook of the same stock destined to mature at age three will reach a 3-year-old (final) weight of about 15 pounds according to O'Conner, (1977).

Growth rates also vary greatly among individuals. A 4-year-old mature fish might be 15 pounds or 30 pounds. A 50 pounder could be a slow growing 7-year-old or a fast growing 5-year-old. Ocean growth is not constant. Growth is fastest during spring and summer, and slows down substantially during winter with colder temperatures, less feeding and lower conversion of food to body weight. For practical considerations, however, growth can be considered linear between reference points in time. Thus, simple growth functions that give average weights and lengths at successive ages can be extremely useful for assessing alternative management options. Table 1 presents such relationships for fall and spring chinook. Shown here are total lengths and weights at age, averaged for several stocks and age-at-maturity categories. These composite estimates were compiled from reviews by O'Conner (1977) and Healey (1991) of several decades of original field research. The reference dates are Dec. 1, the approximate end of each year's growing season. For example, an age-two fall chinook averages some 24 inches and 5.7 pounds by Dec. 1 of year i+2, where j is the calendar year during which it began its life as a fertilized egg. By Dec. 1 a year later (i+3), it is about three years old and has grown to about 31.3 inches and 124 pounds. Since these are averages for many stocks and life history types, a 3-year-old mature fall chinook would tend to be larger than 124 pounds, whereas a 3-year-old still at sea but destined to mature at an older age, would tend to be less.

Size-at-age relationships are crucial to understanding the gains and costs of alternative management regimes that may be deployed to improve the status of wild chinook stocks. The growth functions in Table 1 will be referred to later when discussing such alternatives.

Natural Mortality

Natural mortality includes all deaths in a population not related to fishing activities, such as by predation, parasitism, disease, or starvation. Rates of natural mortality of salmon at sea are difficult to estimate, but after several decades of study using tagging, age analysis and related means, there is relatively good scientific consensus on the average values of such rates (Healey, 1991).

Natural mortality is high in early ocean life when the salmon are small and vulnerable to many different bird, mammal and fish predators. The annual rate may be on the order of 90% during the first year, but it drops rapidly as the fish grow big enough to avoid most of the predators. Natural mortality varies among stocks and from year to year, but by the time chinook reach catchable size (about age two for fall chinook), the annual rate may average only some 20% per year. By this size and age, the major remaining predators are sharks and marine mammals, and disease is less a factor than at early ages.

Thus, of a cohort of 1 ,OOO chinook reaching age two and destined to mature at age four, 200 would be expected to die of natural mortality the next year (20% of 1 ,OOO) and 800 would survive to age three, in absence of ocean fishing. Of the 800 3year-old survivors, 160 would die the next year and 640 would survive to mature at age four. When we add in ocean fishing, the equations get a little more complex, but still fairly simple. Some simple numerical examples will be given later to show why it is so necessary to understand the interactions among growth, natural mortality, and fishing mortality in formulating an improved regime of chinook salmon harvest management.

Fishery Exploitation

The most commonly applied exploitation models for salmon are spawner-recruit models. Such models assume that the average number of salmon spawning of a particular stock is the major variable affecting the abundance of adult salmon. The theory postulates that there exists a precise relationship between the number of spawners and the average number of adult progeny of all ages from those spawners, termed the recruitment. To calculate the recruitment from a particular chinook salmon spawning escapement in year i, one needs to know the number of 2-, 3-, 4-, 5-, and 6year old mature fish in the catch and escapement of that stock in years i+2 to i+6 (assuming age 6 is the maximum). A graphical plot of the numbers of spawners and recruits for a series of years should follow some sort of humpback curve, such as Figure 3. Since there are so many other factors affecting recruitment, along with number of spawners, the observed data points will be well scattered around any curve. Nevertheless, if a mathematical curve can be fitted with any degree of statistical precision, this often becomes the basis of scientific management of exploitation rates.

Referring to Figure 3, the theoretically optimum exploitation policy can be found by superimposing a 45-degree line, called the replacement line, on the fitted spawner recruit curve. The portion of the curve lying above the replacement line represents sustainable harvest, because the vertical distance between the curve and the replacement line is the number of salmon that can be caught while leaving sufficient spawners to reproduce the same number of recruits at the next cycle. The stock can theoretically be held constant in adult abundance at any point where the spawner recruit curve is above the replacement line, by harvesting the difference between the two, year after year. Of course, due to variation in recruitment that would be expected even from the same number of spawners, the difference between the curve and the line represents the average or expected surplus.

Surplus production, the difference between the curve and the line, can then be considered a function of spawning escapement. Surplus production reaches a maximum at S* in Figure 3. Optimum exploitation policy for this stock would be to catch all fish above if the run happened to exceed S*, or to harvest none if the run were less than S* and then let the run build until it exceeded S*. Or, equivalently, the optimum exploitation policy can be stated in terms of the optimum exploitation rate, which is the ratio of the maximum surplus production (R* - S*) to the optimum recruitment   Optimum exploitation rate is usually given as a percentage.

The optimum exploitation policy stipulates a spawning escapement somewhat smaller than that producing the maximum recruitment (S** in Figure 3), because surplus production is smaller at the point of maximum recruitment. In reality it is difficult to precisely define either point for any stock, and they may not differ greatly. There are a number of reasons why a conservative, practical management policy might shade the escapement goal more toward the curve-fitted point of maximum recruitment, rather than the point of optimum recruitment as defined above.

Spawner recruit curves have been fitted for many salmon stocks, but not often for wild chinook stocks. For one reason, chinook tend to spawn in large rivers where it is hard to accurately estimate escapement. Secondly, recruitment from specific stocks is difficult to measure, since so much of the chinook harvest is in mixed stock fisheries, and data are often insufficient to assign portions of such catches to specific stocks.

Two of the most comprehensive spawner recruit analyses for chinook salmon were those of Van Hyning (1968) for Columbia River stocks, and Reisenbichler (1986) for Sacramento River stocks. Both authors used fortuitously-collected dam counts to estimate spawning escapements. Reisenbichler additionally used spawner carcass counts and redd counts. Van Hyning approximated total recruitment from age composition and catch estimates of Columbia River net fisheries; mixed-stock, marine catches were relatively minor components of total recruitment for early portions of his data series. Reisenbichler apportioned marine catches to various rivers, on the basis of ocean area stock composition and escapement data.

Both analyses indicated that fall chinook stocks were relatively productive in the middle of this century, before the advent of large scale hatchery production and severe habitat degradation. Stocks at that time were capable of sustaining maximum catches with exploitation rates of 75-80% or higher. For example, Columbia River fall chinook recruitment from 1938-46 broods averaged over 700 thousand, from spawning escapements averaging about 125 thousand. For more recent time periods, productivity declined for both the Columbia and Sacramento rivers, with indicated optimal escapment rates for fall chinook averaging some 65-70%. Columbia River spring and summer chinook were somewhat less productive than fall chinook, with indicated optimal exploitation rates on the order of 60-70%.

Healey (1982) analyzed the admixture of wild British Columbia stocks, estimating the combined spawning escapement and recruitment, including catch to all fisheries, for the period 1951 onward. This broad scale analysis indicated that the B.C.
stocks were similarly productive, and capable of sustaining catches of about 1.0 million fish with spawning escapements of 200-250 thousand. Improved escapement estimates since this analysis of Healey, particularly for the Fraser River, suggest that his escapements may have been too low (M. Healey, University of British Columbia, Vancouver, personal communication). Consequently an optimum exploitation rate
less than the indicated 80% would be appropriate, perhaps in the 65-70% range if the data were reanalyzed with updated escapements.

The above studies, the opinions of others with expertise on chinook salmon population dynamics (Chapman, 1986; Hankin and Healey, 1986; Overholtz, 1995), and the optimum exploitation rates for other salmon species suggest that 70% may be a reasonable benchmark value for the optimum exploitation rate of a healthy wild chinook stock in a healthy environment.

THE FISHERIES

Sport Fisheries

Sport fisheries and commercial fisheries for anadromous chinook occur over virtually their entire North American range. Sport fisheries for chinook often overlap with coho fisheries, and generally fall into one of three categories. These are coastal or open ocean, estuarial or inner sea, and freshwater (river or lake with river drainage). The open ocean fisheries, which extend from California to SE Alaska but are mostly from southern British Columbia southward, utilize chartered party boats or large, seaworthy, trailerable private boats. Estuarial fisheries occur in some bays and river mouths of coastal Oregon, Washington and British Columbia, but the most extensive fisheries of this type are in the inner seas of Puget Sound, Georgia Strait and SE Alaska. Much of the inner sea fishing is from private boats, and these can be quite small outboard or even row boats because of the protected waters. River fishing for chinook is allowed in most of the major rivers and many of the smaller ones. In smaller rivers bank access or wading are the common approaches, while in the larger rivers small boat access, either rowed or powered, is the rule.

Until recently, the ocean sport fisheries were relatively unrestricted, with long seasons and wide open areas during the months when weather and water conditions were safe and comfortable. They tended to operate on mixed, migrating, feeding chinook and coho. Recently, fishing in all areas has been severely restricted, and the allowable patterns of time, area, and other constraints are a checkerboard of complex regulations. These restrictions have been necessary for many reasons: to protect Endangered Species Act (ESA) listed stocks; to allocate to inside fisheries; to protect dwindling coho stocks, particularly off Oregon and California; to comply with U.S. - Canada treaty set quotas; and to target on stocks of maturing fish that may have surplus abundance.

The most severely restricted areas have been the northern Oregon and Washington coasts, which were virtually closed to ocean sport fishing in the most recent years. But British Columbia has also launched austere measures, going to chinook catch and release in 1996 for a major portion of the season, and Alaska has cut the daily bag limit from to one fish in response to dwindling quotas.

Area and time closures for the ocean sport fisheries have been the most prevalent restrictions, whereas minimum size and daily bag limits have remained more constant. The minimum size limits for the coastal fisheries vary as follows: California 26", Oregon - 20", Washington - 24", British Columbia - 18", and Alaska - 28". Bag limits have been chinook per day for most areas, except in recent circumstances of scarcity when they have been dropped to one or none (catch-and-release).

The inner sea fisheries, unlike the ocean fisheries, tend to be opened for chinook sport fishing year-around, however in recent years portions of Puget Sound, including the Strait of Juan de Fuca, have been closed for much of the summer to protect depleted chinook runs. Wintertime participation can be high. During the winter these fisheries harvest from stock mixtures of immature, feeding chinook. The minimum size limits are 22 and 25" in Puget Sound and Georgia Strait, respectively. Sport fishing for chinook in SE Alaska is also allowed for the entire year, but the size limit remains at 28" during the winter. Daily bag limits for the inner sea fisheries tend to be the same as for the ocean fisheries, two chinook per day.

The river fisheries harvest from runs of mature spring or fall chinook. Often such runs contain high proportions of 2-year-old jacks, which take lures and baits readily and are considered surplus to spawning needs. Consequently size limits are reduced accordingly. The daily bag limit in river fisheries tends to be two chinook per day, except in certain "trophy/' fisheries where it may be one per day, or if hatchery fish or jacks are available in super abundance in which case the limit may be liberalized.

Commercial Fisheries

There are two major categories of commercial salmon fishing, trolling and net fishing. Trolling operates primarily on feeding salmon at sea, whereas net fishing generally intercepts runs of maturing salmon as they pass from the sea through the estuary and to the river.

Trollers use multiple hook and line gear, towed at about three mph, usually rigged on a series (4 to 8) of hydraulically operated braided wire mainlines, each weighted by lead balls of 20-60 pounds. Anywhere from about 6-20 lures are attached to each mainline. Large boats may troll 100 lures or more, when targeting coho or other salmon species, but usually less when fishing specifically for chinook. Power troll boats, those with hydraulically operated gear retrieval systems, range from about 30-60 feet long. Most have the ability to ice down or freeze fish, and can therefore remain fishing for several days to several weeks before delivering the catch. Power trollers can be operated by one man, but commonly one or two additional deck hands will be employed. The fish are usually dressed and iced at capture, and a high quality product results. A small portion of the commercial troll catch is taken by hand trollers. These are smaller boats that use hand operated reels for gear retrieval and commonly return to port each day to deliver the catch.

There are two major types of net gear presently used for salmon, gillnets and purse seines. Gillnets are walls of large-mesh, fine-twine nets that are set perpendicular to the path of migrating salmon. Suspended by floats at the top and weighted by leaded rope at the bottom, they ensnare or entangle salmon that attempt to swim through the large meshes. Marine area gillnetting is usually done from boats of 20-40 feet with crews of one to three people. In these circumstances the 900-1800 foot long net is drifted freely with the tide. After an hour or two, the net is retrieved via an hydraulically operated net drum, and the fish are picked from the net one by one. Gillnetters often deliver fish every day, but some carry ice to improve fish quality, and may hold fish for several days.

In certain river mouth areas set nets are allowed. These are short gillnets anchored to the shore or bottom. They also ensnare migrating fish. Small, outboard powered boats are used to tend the set nets, or they may simply be picked as the tide goes out.

Purse seines are walls of small-mesh, heavy-twine nets that are towed in a circle around a school of fish. Two boats usually do this job, the seiner, a 40-75 foot long boat with a crew of 4-6 at one end of the net, and a seine skiff, a high-powered
16-20 foot open boat at the other end. In Canada the seine skiff is not used; one end

of the net is anchored to the shore or a drogue, and the other is towed in a circle by the seiner. The purse seine is suspended by floats at the top and a leaded rope at the bottom. Also running along the bottom of the net is a series of rings through which a rope (the purse line) passes. When the net has completely encircled the fish, the purse line is drawn back aboard the seiner on a capstan, which draws in the bottom of the net, essentially creating a bag from which the fish cannot escape. The net is then carefully worked back aboard the seiner via an overhead boom-mounted power-block or a deck-mounted drum, until only a small pocket holding the payload remains in the water. The fish are then rolled aboard in the remaining portion (bunt) of the net, or removed with a large, winch-operated dip net (brailer).

Purse seines are capable of much larger catches than either trollers or gillnetters, for they do not have to handle each fish individually during the retrieve. However, seine boats and gear are more costly, and the crews larger. Seiners often deliver the catch every day, in the round, but many carry ice or have refrigerated holds.

Along with these major commercial gear types, there remains in operation a single large fish trap, typical of the many employed decades back, when such gear was broadly legal. This trap is in SE Alaska (Annette Island) and run by the Metlakatla Indian Tribe. Also reef nets, unique forms of stationary trap-like gear, are employed at a few remaining sites in northern Puget Sound, and beach seines are allowed in a few restricted circumstances.

Troll fisheries for chinook and other salmon species operate from California to SE Alaska. Historically, these were relatively free-roaming fisheries, tending to catch mixes of migrating mature and feeding immature chinook. Commercial trolling began in rudimentary forms over a century ago, but began moving offshore about 1915. Early on, troll fisheries were opened 7 days a week for many months of the spring, summer, and fall. There were no quotas on catch, closed ocean areas, or restrictions on lures.

As demand for high-quality fish rose with improving world economies after World War II, these fisheries expanded. Since about 1980, however, troll fisheries have been increasingly regulated. Like the ocean sport fisheries and for the same reasons, there is now a virtual checkerboard of time, area, and quota restrictions for trollers up and down the coast. Off northern Oregon and Washington, trolling has been all but closed down for the past several years. In Alaska, the dwindling chinook summer season

quota is often taken in just a few days. Sometimes there is a complex array of lure restrictions imposed to promote species selectivity and reduce incidental catch mortality.

With the exception of Indian gillnet fishing in the Klamath River, there are no net fisheries south of the Columbia River. Estuarial, inner sea, and river mouth gillnet fisheries targeting mature chinook operate from the Columbia River to the Yukon River. Such fisheries have been operating for over a century in major estuaries such as the Columbia River and Bristol Bay, Alaska. Often chinook are a minor portion of the total catch, since gillnets also target runs of other salmon species. In these fisheries, the daily catch rates are closely monitored, and the boats are allowed to fish only as much time on each run of fish as the managers decide is appropriate for the indicated strength of that run.

Purse seining is less extensive in terms of numbers of boats than gillnetting, but highly effective on migrating schools of pink, sockeye and chums. Relatively little of the purse seining effort targets chinook salmon, although immature chinook are often caught in substantial numbers incidentally to fishing for the other three species. The major purse seine fisheries are in Puget Sound, the Strait of Juan de Fuca (U.S. and Canadian sides), Johnstone Strait, SE Alaska, Prince William Sound, Kodiak Island, and the Alaska Penisula. Purse seining began in Puget Sound early this century. Until the advent of hydraulic equipment, the seines were hand pulled by large crews.

Purse seine fisheries are regulated in time similarly to gillnet fisheries. If the runs appear weak, the fisheries are closed down for long periods; if stronger, more fishing time may be allowed. Commonly, purse seiners are allowed less fishing time than gillnetters in areas where both gears fish, because of the greater fishing power of seines compared to that of gillnetters.

CATCHES

About 50% of the chinook salmon landed in California, Oregon and Washington are caught by commercial trollers, 28% by sport fishermen, and 22% by commercial nets, mostly gillnets (Figure 7) Similar catch distributions for chinook salmon prevail in

British Columbia, but in Alaska the net fisheries may exceed the troll fisheries in total, and the sport fisheries take a smaller fraction than further south. As shown earlier, the total North American landed catch of chinook has declined over the recent 25 years from about 5 million fish per year at its peak to about 2.5 million fish per year at present. This occurred despite very extensive hatchery output during this time, indicating that wild populations have suffered severely.

Not all areas have suffered equally (Figure 5). California and Southern Oregon experienced precipitous declines through the early 1990's due to drought conditions, but appear to be bouncing back. Preliminary catch data for 1996 appears to extend the rebound indicated in 1995 for this region. The Columbia River has had a long downslide, albeit punctuated by some relatively strong hatchery and wild runs during the mid-1980's. The trends for Washington and Georgia Strait have been, in a word, dismal; catches for both regions have fallen by about 80%. The trend is also downward for the rest of British Columbia, primarily ocean troll and sport fisheries; however, moving from south to north in British Columbia, the downward trends become less severe. Alaska has the most stable catches, and the moderate decline indicated in Figure 5 represents decreases primarily in SE Alaska, where the chinook fishery is supported largely by runs from south.

The main reason for the decline in the Asian catch was the phase out of the Japanese high seas gillnet fishery, which took substantial numbers of immature North American chinook.

INCIDENTAL CATCH MORTALITY

The number of chinook that die from encounter with fishing gear, but which are not part of the landed catch is more significant than for any other Pacific salmon species. Not only does a higher fraction of chinook stocks die this way, but the absolute number so killed is probably higher than for other species. All types of salmon fishing gear contribute to incidental catch mortality, although hook-and-line and net fisheries in marine waters where immatures are in high abundance are the worst offenders.

The incidental catch problem arose from several interconnected circumstances. Foremost is that chinook salmon, particularly fall chinook, are more coastal and inshore in their marine distribution than other species. They are therefore relatively accessible to fishers in many areas, throughout much of their life span, and at all seasons of the year. They are also easy to catch on a great variety of lures and baits. These factors encouraged the early growth of nearshore sport and commercial troll fisheries over much of the year. When chinook were abundant in the past, seasons, minimum size limits and other restrictions perhaps did not seem important. As fisher populations grew and fish populations shrank, restrictions became necessary.

Managers recognized early that since chinook grow fast and natural mortality declines with size, minimum size limits were desirable, and these have tended to increase through time. But with larger size limits, more sub-legal fish will be caught, other things remaining equal.

Life became even more complex: for example, sometimes all chinook must be released, such as occurs in Alaska when the chinook troll quota has been reached, but capture of coho and other species is still allowed. Yet another throwback situation occurred when a maximum size limit was imposed, in addition to a minimum, such as in Puget Sound to protect runs of maturing spring chinook (30" maximum sport limit).

Hook-and-line capture obviously stresses fish, and some fraction of those released will die. The Chinook Technical Committee (CTC) of the U.S.-Canada Pacific Salmon Commission (Pacific Salmon Commission, 1997), reviewed numerous and varied field studies of incidental mortality of chinook salmon in troll, sport, and net fisheries. They present consensus values of hook-and-release mortality rates which they recommend for harvest management considerations in U.S. and Canadian fisheries. For commercial trolling, the recommended mortality rates were 19.8% and 23.8% for legal (greater than 28 inches total length) and sublegal chinook, respectively taken on barbed and barbless hooks. (They present separate rates for barbed and barbless hooks, but the differences were slight.) The CTC recommended that a further component of incidental mortality due to commercial trolling be considered in managing such fisheries, to account for fish that escape from the hooks, but are stressed by the encounter, and those removed from the gear or lethally maimed by predators. Such "drop-off" mortality is on the order of 2% of all legal and sublegal chinook salmon brought into the boat, according to the CTC.

For sport fisheries, the CTC recommended the following hook-and-line release mortality rates: 12.3% for chinook greater than 14" total length and 32.2% for chinook smaller than 14", whether caught on barbed or barbless hooks. It is unlikely that there is a sharp discontinuity between fish over and under 14", although this disparity is not explained by the CTC. In all likelihood the mortality rate decreases continually with size, from over 30% for the smallest chinook hooked to about 10% for the largest. Their recommended factors to account for drop-off mortality from sport gear differed between ocean and inside (Puget Sound) regions; for ocean regions, drop-off mortality averages 3.2% of total legal and sublegal chinook brought into the boat, and for Puget Sound the recommended drop-off mortality factor was 14.5% of the total legal and sublegal catch. Presumably the higher rate for Puget Sound is due to the relatively high number of small fish in Puget Sound which encounter the gear, but subsequently escape.

To estimate the absolute number of fish which die incidentally from hook-and-line fisheries, one needs, in addition to the hook-and-release mortality rates, the encounter rates, i.e. the ratios of sublegal to legal sized fish caught. Troll monitoring indicates that, on average, about one chinook shaker may be released for every chinook legally retained (Pacific Salmon Commission, 1987). Such a rate would be less if targeting on a mature run, but greater if fishing feeders on offshore banks in the spring. The landed troll catch for the entire coast is currently on the order of one million chinook; accordingly the shaker catch would be about the same. Of the shaker catch, some 240,000 (23.8%) would die from their capture. On top of this is the dropout mortality, 2% of total legal and sublegal catch of 2 million, or 40,000 fish. Finally, there is the incidental mortality of released legal-sized fish in those circumstances where chinook cannot be legally retained while trolling for other species, such as occurs in Alaska after the summer chinook quota is reached. This latter mortality may be up to about 20,000 legal chinook per season (Alaska Department of Fish and Game, 1987). Thus, the total incidental mortality from commercial trolling must I **currently be on the order of 300,000 chinooks per year.**

Less sampling has been done for sublegal encounter rates in sport fisheries compared to troll fisheries. One might expect the ratio of sublegals to legals to be less for ocean sport fishing compared to trolling, because the minimum size limits are less for sport fishing. However, ocean sport fisheries tend to operate more nearshore than the troll fisheries, (e.g., Columbia River mouth), and small chinook are relatively more abundant in nearshore waters. Thus, a one-to-one ratio of sublegals to legals is a reasonable approximation for the encounter rate in ocean sport fisheries, as well as troll fisheries. For inside fisheries of Puget Sound and Georgia Strait, the encounter

rate is highly variable, but probably averages a good deal higher than one-to-one, particularly during the winter. Research studies wherein chinook were collected by rod-and-reel give a fair indication of the sublegal encounter rate for Puget Sound. For example, of 313 immature chinook caught by mooching and trolling during a hooking mortality study that encompassed parts of 1992 and 1993 winter seasons, 234 were sublegal (less than 22 inches total length) and 79 were legal length or greater. This is a 3:1 encounter rate. Similar rod-and-reel sublegal encounter rates occurred in two other wintertime Puget Sound studies that used rod-and-reel for collection: one a 1969 tagging study (l was a collaborator), and the other a 1996 hooking mortality study

(D. McNair, Natural Resource Consultants, Inc. Seattle, personal communication). Estimating total incidental mortality from sport fishing is more difficult than for trolling because of imprecisely known, but widely variable encounter rates among seasons, areas, gear types, and fish sizes. Total incidental mortality is quite likely to be less for sport fishing than for commercial trolling because the overall intensity of effort (number of hook-days per year) is less for sport fishing and the landed sport catch is less than the landed troll catch. It is nonetheless substantial. The potential for reduction is encouraging, in light of recent studies which show that hooking mortality is less than previously assumed for relatively large chinook (Pacific Salmon Commission, 1997). Furthermore, much could be done to reduce incidental sport caught mortality vis-a-vis public education on benign methods of handling and releasing fish.

With hook-and-line fisheries on chinook of mixed ages and sizes, you are damned if you do and damned if you don't. With a larger size limit, more fish will be released to die subsequently from their hooking stress. But if one decreases the size limit to reduce the number of releases and consequently the hook and release mortalities, the fishery then may take too many fish at small sizes that have a good chance to grow to 20 pounds or more. Short of living with the status quo, there are some ways out of this dilemma', such as better handling and release methods, use of lures selective for larger fish, or closure of fishing at times and places where too many juveniles are present. There are examples of management moving in such directions, but none of these alternatives has been sufficiently investigated or applied.

The nearshore marine distribution of chinook also gets them in trouble with the net fisheries, most often those that do not target on chinook. The paths along which targeted chum, pink, sockeye, or coho migrate may at times house high densities of immature chinook that are caught along with the target species. This situation is unique for chinooks, because immatures of the other species rear more offshore, well outside of any of the North American fisheries. There are some notable hotspots in portions of the Strait of Juan de Fuca, Johnstone Strait, and Puget Sound. However, other migration paths within these same waters are relatively clear of immature chinook. Upper Hood Canal is one example; chum salmon can be harvested there at high rates with purse seines or gillnets, with less incidental catch of chinook than many people assume.

Some 50-90% of immature chinook caught in gillnets are dead or moribund when brought aboard (Pacific Salmon Commission, 1997). Even in seines, small fish tend to get stuck by the gills in the larger, top meshes of the net. Many of those that may still be alive when brought aboard by either gear type are critically descaled. Not all of these are thrown back. Gillnetters are usually allowed to retain small chinook, since most would die anyway. However, the market value of small chinook is low. Seiners are generally required to release them, but an unknown portion may be retained for personal consumption or sold as other species (Pacific Salmon Commission, 1987). However, even if some or all of the incidental catch were retained, this is not efficient utilization of this valuable resource because the fish are small and their market value tow. Later discussion of ways to reduce this catch includes consideration of selective fishing methods, improved handling and release, and closure of times and/or areas.

Published estimates are available for incidental net catch of immature chinook in certain fisheries. Cole (1975) sampled the inner Puget Sound fishery and estimated that the gillnet and purse seine incidental catch of immature chinook averaged 24,000 per year for 1965-73, and that this mortality represented about 3% of the chinook population present. Incomplete sampling summarized by the CTC (1987) indicated that some 100,000 immature chinook were caught per year by nets throughout Puget Sound, including San Juan Islands and Point Roberts, in 1983-86. Alaska Department of Fish and Game (1987) estimated that some 10-20 thousand sublegal (<28 in.) chinook were caught in the SE purse seine fishery in 1985 and 1986.

Healey (1982) stated that " the seine catch of small chinook in Canada, though unknown, could be as high as 300-400 thousand fish". Chinook populations at the time of Healey's approximation were greater than at present, so his figures represent an upper bound.

It is important to add that although the measured mortality rates for immature chinook are high for both purse seines and gillnets, there is at least one published study that shows that chinook salmon approaching maturity can be released from purse seines with almost no mortality. Ruggerone and June (1996) caught and live held 91 chinook 30-45 days from maturity, in a terminal chum salmon fishery. Only one of the chinook died during several days of holding.

In addition to the sources of incidental mortality discussed above, some incidentally-caught chinook are retained illegally for personal consumption or illegally sold, in every sport and commercial salmon fishery, human nature being what it is. Estimating these catches is probably impossible.

What is the total impact of the incidental mortality by all gear types? No summary estimate has been made, but the Pacific Salmon Commission's Chinook Technical Committee has compiled data from which its magnitude may be assessed. For example, the adult equivalent number of chinook salmon incidentally killed by the Central Oregon to SE Alaska coastal ocean hook-and-line fisheries from 1979-1992 averaged some 18% of the annual chinook catches in these regions. (Pacific Salmon Commission, 1993), or about 375,000 adult equivalents per year. These fisheries took approximately 60% of the coast-wide chinook catch during the 1979-1992, the remaining 40% being in other coastal ocean fisheries (California to central Oregon), inside sport fisheries, and net fisheries, each having significant incidental mortality. A simple extrapolation of the 18% rate to these remaining fisheries yields an estimate of 250,000 adult equivalent loss to incidental mortality for such fisheries, or a total of 625,000 adult equivalents for all Pacific Coast salmon fisheries. However, this simple extrapolation probably under rates the loss for a variety of reasons. In an earlier report (Pacific Salmon Commission, 1987), it was estimated that " The coast wide magnitude of the incidental fishing mortality for all sizes of fish (chinooks) is likely to be in the range of 30-50 percent of the reported catch." Recent estimates of fishery specific gear encounter mortality, based on new studies (Pacific Salmon Commission, 1997), are somewhat less than assumed for the PSC, 1987 report. Thus the low end of the range (30% of reported catch) may be most realistic. For the years 1979-1992 reported chinook catch for the Pacific Coast averaged about

3.5 million annually, consequently the incidental catch would have been on the order of 1.0 million per year, which in terms of adult equivalents would be somewhat less, since most of the incidental catch is immatures. These various calculations and extrapolations indicate clearly that there is substantial incidental catch waste, approaching one million dead chinook per year. If such waste was eliminated, and some of the savings converted to additional spawning escapement, total catch of chinook salmon in the long run could be increased even more than one million fish per year.

INCIDENTAL MORTALITY IN HIGH SEAS FISHERIES

Both bottom trawling and high seas gillnetting are frequently blamed for causing declines of North American salmon stocks. While perhaps contributing, there is relatively good evidence that catches of chinook salmon in either of these fisheries have been relatively inconsequential compared to the incidental catches of chinook in the directed domestic sport and commercial salmon fisheries.

The domestic trawl fisheries from California to the Bering Sea have been well sampled by on-board observers whose jobs are, among other things, to estimate the incidental catches of salmon, halibut and other prohibited species. Erikson and Pikitch (1994) analyzed California to Washington trawl observations from several thousand representative hauls made between 1985 and 1990; chinook catch rates were relatively low. They extrapolated the observed 1987 chinook salmon catch rates over the entire 1987 California to Washington trawl fishery effort, and estimated that the total trawl catch was 7,761 chinook, mostly immatures, which was about 1% of the 1987 ocean troll and sport catch of chinook off California, Oregon, and Washington. Berger (1996) estimated the 1990-1996 incidental trawl fishery salmon catches for the entire U.S. from observer data. This represents most of the trawl catch by all nations, since no other countries but Canada now trawl these waters, and the Canadian trawl catch is relatively small. Observer coverage was 100% for U.S. trawlers longer than 125 feet and 30% for vessels 60-125 feet. Vessels less than 60 feet were not monitored by observers; sampling of their catches was done on shore, thereby missing probably most chinook. However, ground fish taken by trawlers less than 60-feet represent a minor portion of the total trawl catch. According to Berger, the trawl fisheries averaged 63,500 chinook per year, which was about 2% of the annual average 1990-

1996 Pacific ocean catch by all sport and commercial fisheries including trawling. About two-thirds of the incidental trawl catch of chinook was from the Bering Sea/Aleutian Islands region and would be fish of primarily western Alaska origin, stocks in relatively good condition. Thus, there seems little evidence that trawling has been a significant factor causing reduction of chinook stocks from more southerly latitudes.

The relevant high seas gillnetting was of two forms: (1) the Japanese mothership fleet, that specifically targeted on salmon; this fishery operated primarily in the Bering Sea/Aleutian's and was restricted to operate west of 175 degrees west longitude (Central Aleutians) under the North Pacific Fisheries Treaty; and (2) the flying squid fisheries of Japan, Taiwan, and Korea which operated in the approximate latitudes of Southern California to Washington and east to about 150 degrees west longitude (Kenai Peninsula).

The salmon mothership fishery took major quantities of N. American salmon of all species, including up to 700,000 chinook annually at its 1980 peak. Most of the chinook taken by this fishery were from rivers of central and western Alaska (Yukon, Kuskokwin, Bristol Bay, Kenai, etc.) according to scale analysis (Myers, et al, 1987), and the uniquely high 1979-80 catches were apparently related to unusually high recruitment from western Alaska in those years (K. Myers, Fisheries Research Institute, U.WA., personal communication). The last year of directed high seas gillnetting for salmon by the Japanese was 1991. Under international agreement, this fishery then ceased entirely, although for a number of years before 1991, it had been scaling back, in response to political pressure from U.S. and Canada, and declining economic returns.

Unlike the directed salmon gillnet fishery by the Japanese, there are not good records of the incidental salmon catch by the squid fishery, although there is considerable evidence that salmon catches were substantial and that salmon may have been targeted under cover of squid fishing. However, from what is known of chinook distribution at sea, particularly fall chinook which are nearshore in their ocean distribution, it is unlikely that the squid fishery took many chinook. Other species probably made up the bulk of the squid fishery catch of salmon. Under U.N.

agreement all high seas gillnetting, including that for squid, became illegal under international law after 1992. Some sporadic, illegal high seas gillnetting of salmon occurred after 1992, but by 1996 this had virtually ceased. The U.S. Coast Guard maintains strong surveillance, utilizing observations of merchant and other ships at sea, coupled with limited aerial and on-water patrols. Such salmon fishing would not only be subject to vessel seizure and severe penalties, but would probably be unprofitable at today's low salmon prices (L. Low, U.S. National Marine Fisheries Service, Seattle, personal communication). It is unlikely that high seas gillnetting was a significant contributor to the decline of chinook salmon. We should not use high seas gillnet fisheries, which have all been closed, as an excuse to delay cleaning up our domestic harvest management problems.

EXPLOITATION RATE TREND ANALYSIS

Chinook have been coded wire tagged (CWT), and the fisheries comprehensively sampled for tags over the entire NW region since the early 1970's. Utilizing the computerized data base for these experiments, several hatchery stocks were selected, and trends in total fishery exploitation rates and marine fishery exploitation rates were determined. The purposes of this analysis were Five-fold. The first, was to estimate the prevailing rates of harvest for chinook stocks. Albeit these were hatchery stocks (since very little CW tagging has been done for wild chinook stocks), and hatchery stocks can tolerate higher exploitation rates than wild ones. However, to the degree that wild and hatchery stocks are mixed in ocean and even so-called terminal fisheries, the exploitation rates for hatchery stocks indicate prevailing rates for wild stocks. The second purpose of the analysis was to indicate the degree to which exploitation rates have been trending downward. Over the period of CWT record, there have been several substantial changes in the harvest management institutions that should have promoted positive corrections to chinook overharvest. These include major Indian fishing rights decisions, the Federal Fishery Conservation and Management Act which lead to regional council management of multi-state ocean fishing, and the U.S.-Canada Pacific Salmon Treaty, which had major emphasis on joint management of ocean chinook salmon fisheries.

Eight representative stocks were selected for CWT analysis. These were chosen primarily according to size (large hatcheries with substantial chinook

production) and availability of reasonably continuous tagging over time. These stocks

1. **Sacramento fall chinook (Coleman hatchery)**
2. **Rogue spring chinook (Cole Rivers hatchery)**
3. **Lower Columbia fall chinook (Spring Creek hatchery)**
4. **Lower Columbia spring chinook (Cowlitz hatchery)**
5. **Upper Columbia fall chinook (Priest Rapids hatchery)**
6. **Puget Sound fall chinook (Soos Creek hatchery)**
7. **B.C. outer coast fall chinook (Robertson Creek hatchery)**
8. **B.C. Georgia Straits fall chinook (Qualicum hatchery)**

For each stock, the CWT data base was reviewed to find representative lots of production fish for as many years as possible. Minimal tagged lot size deemed appropriate was 30,000 fingerlings. In some instances smaller lot sizes were combined to give a total of 30,000 or more for a particular brood year.

For each selected lot, expanded (estimated) recoveries were tallied by marine catch, freshwater catch, and escapement. Thus, estimates of total exploitation rate per brood year (total catch divided by total catch plus escapement) and marine exploitation rate (marine catch divided by total catch plus escapement) could be derived. Such rates were plotted over time (Figure 6).

Sacramento Fall Chinook

Continuous CWT data were available for the 1980-1990 brood years. Most of the catch is taken in the marine sport and troll fisheries off California and Oregon.

Consequently, the total exploitation rate and marine exploitation are virtually the same.

The total exploitation rate declined during the early portion of the period, from over 90% to less than 70%, but trended upward in the latter portion and is currently about

80^0/0. Over the entire period there was no significant trend upward or downward (p=O. 170, where p is the significance probability of a test of the null hypothesis that there is no trend; in statistical terms, p would need to be less than .10, in order to

conclude that there was a significant trend at this commonly-accepted statistical level of significance).

Rogue Spring Chinook

Continuous CWT data were available for the 1979-1990 brood years. Most of the catch is by the marine sport and troll fisheries of California and Oregon. There is a river sport fishery of unknown but probably relatively modest effect on the stock, which was apparently not sampled regularly for CW tags. The marine exploitation rate has varied widely, from about 20% to 70%, and averaged about 40%. Overall, there was no significant trend upward or downward (p=0.456).

Lower Columbia Fall Chinook

Spring Creek hatchery, located in the Bonneville pool of the Columbia River, had CWT data available since the 1977 brood, with gaps in the record for 1982 and 1986 brood years. Major fisheries include the marine sport and troll fisheries from northern Oregon to central B.C., and the net fisheries within the Columbia River. Both total exploitation rate and marine exploitation rate have trended downward (p = O. 108 and p = 0.023, respectively). Total exploitation declined from about 90% to about 80% over the period.

Lower Columbia Spring Chinook

The Cowlitz River is a tributary of the Columbia below Bonneville Dam. CWT data were available from 1972, with gaps for the 1976, 1980, 1981, and 1985 brood years. Major fisheries are the marine fisheries of Washington and British Columbia, and a river sport fishery. Total exploitation rate and marine exploitation rate have both trended significantly downward (p = 0.068 and p = 0.089, respectively). Total exploitation rate declined from about 80% to 60% over the period of record.

Upper Columbia Fall Chinook

The Priest Rapids hatchery has released CWT fall chinook into the Hanford reach continuously since the 1975 brood. The catch is divided approximately equally between marine and in-river fisheries. Marine troll and sport harvest occurs from Washington to SE Alaska. The in-river fisheries include both net and sport, the latter operating primarily on the Hanford reach downstream of Priest Rapids hatchery. Neither total exploitation nor marine exploitation rates have declined significantly (p =

0.144 and p =0.230). Total exploitation rates have ranged between about 70-80%.

Puget Sound Fall Chinook

The Soos Creek hatchery is in central Puget Sound. The CWT record began with the 1972 brood, but there are gaps for the 1977, 1978, 1983, 1984, and 1985 broods. Major fisheries include those of the British Columbia marine fisheries, the Puget Sound sport fishery, and the estuarial / river tribal gillnet fishery. Both total exploitation rate and marine exploitation rate have trended significantly downward (p = 0.021 and p = 0.003, respectively). The total exploitation rate was over 90% early in the period of record, and has declined to about 80%.

B.C. Outer Coast Fall Chinook

The Robertson Creek hatchery is located on Barkley Sound, on SW Vancouver Island. Major fisheries include ocean troll and sport fisheries from British Columbia to SE Alaska. There are also terminal marine net and sport fisheries in Barkley Sound, but no freshwater fisheries. Continuous CWT data are available since the 1973 brood year. The total exploitation rate has remained quite constant at about 80%.

B.C. Georgia Straits Fall Chinook

The Qualicum River is located on the east side of Vancouver Island, emptying into central Georgia Strait. Major fisheries on this stock include SE Alaska and British Columbia marine troll and sport, and Johnstone Strait net. There is little estuarial or in-river harvest. CW tagging has been done since the 1972 brood year, however 1972 had an aberrantly low exploitation rate, which suggests incomplete CWT sampling at

that early time. The trend in total exploitation rate (equivalent to the marine exploitation rate), declined significantly, excluding the 1972 brood outlier (p = 0.020). This rate was over 80% at the beginning of the period, and has declined to about 70%.

Summary

The analysis indicates that in spite of some modest declines in exploitation rates, hatchery fall chinook over a brood geographical range are currently exploited at rates in excess of 70%. Much of the harvest is in mixed-stock marine waters, where wild chinook would also be caught. Even where estuarial or freshwater harvest accounts for a significant portion of the harvest (Spring Creek, Priest Rapids, and Soos Creek hatcheries), wild stocks are mixed in time and space in these "terminal" fisheries (Lower Columbia wild, Hanford Reach wild, and Green River wild, respectively). Thus, harvest rates on wild fall chinook stocks originating from California to Southern British Columbia could be near or above maximum sustained yield levels, and at rates well above levels at which depleted stocks could rebuild. Furthermore, fall chinook exploitation rates have not declined very much over the 20-odd years of record, in spite of major changes in management institutions that were supposed to improve harvest management of chinook and other species. Apparently not all wild stocks are exploited at the high rates indicated for hatchery stocks, although many probably are. For the single wild stock well studied with coded wire tagging, the 1977-1979 broods from the North Fork of the Lewis River (lower Columbia) sustained exploitation rates averaged only 50%, whereas Columbia River hatchery stocks for those same brood years consistently sustained rates in excess of 80% (McIsaac, 1990).

Harvest rates for spring chinook are not so critically high as for fall chinook. Less continuous data for other spring chinook hatchery stocks on the Columbia River indicate even tower exploitation rates than for the two stocks whose trends are plotted in Figure 6. Spring chinook are less vulnerable to marine harvest than fall chinook, apparently because of different ocean distributions.

SPAWNING ESCAPEMENT TRENDS

Published escapement estimates (numbers of male and female spawners) for some 90 separate wild chinook stocks over the entire California to Alaska range were available in reasonably continuous series for the 20-year period 1975-1994. The estimates are variable in their methods and accuracy, but in most instances are reported as absolute escapements. Washington, Oregon and California escapements were from The Pacific Fishery Management Council (1996). British Columbia and SE Alaska (including transboundary rivers) were from The Pacific Salmon Commission, (1996). Escapements to central and western Alaska were from Alaska Department of Fish and Game reports (Anderson et al. 1994, Brannian et al. 1995, Davis et al. 1992, Fox 1996, Lingnau and Lean 1995, Hammerstrom 1995a, Hammerstrom 1995b, Miller et al. 1994, Moffit et al. 1994, Owen et al. 1995, Prokopowich 1995, Schultz, et al. 1994, Stratton and Crawford 1994, and Waltemyer 1995). Major shortcomings in the record include: (1) Lack of absolute escapement counts for a number of Oregon coastal rivers; (2) Lack of absolute escapement counts for some of the major Alaska rivers, particularly those wherein water clarity is affected by glacial melt; and (3) non-availability of records for hundreds of minor streams. Nonetheless, the existing, published record is subjectively judged to be on the order of 80% complete, because most of the chinook spawning occurs in relatively few, larger rivers and there has been intense, recent scientific effort to improve the estimates in many of these. Furthermore, since a significant, but unknown, portion of chinook salmon spawners counted in streams are in fact strays from hatchery production, the sum of the available stream counts may be a realistic assessment of the number of naturally derived spawners.

Escapement is broadly distributed over the entire range, with relatively large populations from California to NW Alaska (Figure 7). The region with the fewest spawners is SE Alaska, including transboundary rivers like the Taku and Stikine, which flow from British Columbia through the SE Alaska panhandle.

The spawning abundance from these monitored stocks held quite constant at about 1.2 million for the 20-year period (Figure 8), in contrast to the total chinook catch, which declined from about 5.0 to 2.5 million over a similar time period. Thus, the overall exploitation rate on wild fish apparently declined over this time period, if we assume that wild and hatchery chinook remained in roughly the same ratio, i.e. declined at the same rate. Assuming that the present catch level of about 25 million per year contains 60% wild fish, as previously estimated, the overall exploitation rate for wild stock currently averages some 55% (1.5/2.7), which is less than previously indicated from hatchery marking experiments. The discrepancy indicates that while many wild stocks probably are harvested at rates similar to those on hatchery stocks, particularly those tall chinook stocks with relatively short ocean migration pathways, others are harvested relatively lightly; Columbia River spring stocks at only about 20%, Lewis River wild falls at about 50%, Western Alaska stocks at 50%, etc. Some of the discrepancy could also be explained by hatchery strays within the so-called wild escapements. If this factor could be resolved, the exploitation rates for hatchery and wild, which on face value from the data present seem disparate, might approach one another. It is a positive measure of management efficiency that wild stock exploitation rates have declined, but this has not been enough. Catches are still declining and wild escapements in total remain at less than one half of the level that would support pre-development maximum sustained yields (previously estimated to be 3.0 million spawners). The Chinook Technical Committee of the Pacific Salmon Commission judged that over half of those stocks between the Columbia River and SE Alaska with established escapement goals were either in decline or not rebuilding toward escapement goals (Pacific Salmon Commission, 1996).

The sheer number of fish in the present day escapements (1.2 million compared to a pre-exploitation MSY escapement of 3.0 million), in and of itself inadequately represents the full measure of the apparent crises in reproduction for many stocks. Due to disproportionate exploitation by sex, age at maturity, and growth rate, present day escapements are likely to be relatively impoverished compared to the past in terms of female ratios, older fish, and faster growing fish. A numerical unit of spawners may have one half or less of the smolt re-seeding ability as the same number of spawners historically. Total egg numbers will be less, eggs will be smaller, and depth of spawning less. These are only the most obvious deficiencies. There are other potential downsides from the extensive selection pressures that overfishing patterns have probably caused, such as unpredictable or unmeasurable changes in physiology, behavior or anatomy unlikely to benefit survivability, which might be correlated with measureable responses in growth and maturity parameters.

Furthermore, as emphasized by Dr. Donald W. Chapman (Bioanalysts, Inc. Boise, ID, personal communication) we know far too little about the degree to which "over escapement' (in the sense of escapement beyond MSY level) is needed to improve opportunities for rigorous mate selection, cleansing of spawning gravels, and fertilization of riverine/riparian zones.

Natural escapement trends by region are given in Figure 9: In California, escapement has varied almost 5-fold, between the good years of the mid-1980's and the drought years of the early 1990's; escapements have begun to trend upward from the low years. In the Rogue and Umpqua rivers, where absolute counts are available, escapements have also been highly variable, but trended downward since the productive mid-1980's. For other Oregon coastal stocks, mainly fall chinook, the trends in the spawners-per-mile indices are upward, and according to preliminary figures, 1995 and 1996 have continued to show this upward trend. For the Columbia, the escapements have been relatively constant at about 150 thousand, with the exception of the productivity "bump" of the mid-1980's seen for other areas. However, some of the critically low chinook stocks such as those of the Snake River had already been largely decimated by the onset of this 20-year period, and in 1995 and 1996, spring chinook escapements throughout the system were at record low levels.

For Washington, excluding the Columbia system, escapements trended upward from about 60 t0120 thousand until 1988, but have since dropped sharply to the 60-80 thousand range. Several major Puget Sound stocks are contributing most to this decline (Pacific Fishery Management Council, 1997). These depressed Puget Sound stocks have averaged about half the combined escapement goals, and reached or exceeded the goal only four times in 20 years (Figure 10). The trend for British Columbia appears stable to upward, primarily because some of the Fraser stocks, which contribute in total some 60% or more of the B.C. escapement total, are doing relatively well. However, many of the smaller runs have declined or are not rebuilding toward escapement goals (Pacific Salmon Commission, 1996). Escapement to the SE Alaska panhandle region, including transboundary rivers has trended upward, though again there are some specific stocks averaging below escapement goals and not rebuilding (Pacific Salmon Commission, 1996). Elsewhere in Alaska, escapements are broadly stable and have tended to be near escapement goals.

It is unfortunate that absolute escapement estimates are broadly available for only the recent 20-25 year period. Before then, escapements were regularly monitored in many of the rivers with spawners-per-mile index counts - boat, aerial or foot surveys of selected stream areas at peak spawning times. Published records indicate that reasonably systematic index surveys in most regions were made since about the middle of the present century. However, it is a virtual guessing game to attempt to extrapolate absolute escapements from the early index data. A 20-25 year record, with only fragmentary glimpses farther into the past, clearly compromises our ability to determine what is adequate or optimum for any system. Often the target escapements become in effect, simply the highest escapement or perhaps the average for a series of relatively good years within the 20-25 years of record, which emphasizes the inadequacy of the data base not the individual setting the goal.

I wilt site tho specific cases for comparison of current to past spawning escapements, to give a degree of historical perspective of the adequacy of present escapement levels: The Skagit summer/fall naturally spawning run and the Columbia River spring, summer and fall runs combined. The Skagit River was, and may still be, the most important chinook producing river in Washington, outside of the Columbia; and the Columbia was, of course, the major chinook producer in the world. For the Skagit, a series of relatively accurate absolute escapements is available from various Washington Department of Fisheries management reports back to the mid-1950's. These are based upon aerial surveys of redds, which are relatively visible during late summer/ early fall spawning. For the Columbia, upriver escapements are known with good accuracy since 1938, from Bonneville dam fish way counts. Fragmentary, but probably realistic, published estimates of absolute escapements to the four major lower river tributaries - Willamette, Kalama, and Lewis - are available for the 1940's and 1950's.

For the Skagit, the escapements routinely ran between about 12 and 25 thousand, averaging about 14 thousand from the mid-1950's through the 1980's. But in the five-year period 1991-1995, escapements have ranged narrowly between 6 to 8

thousand, or about half of the "modern" level. It is clear that for these five years the Skagit has been badly under spawned, but exactly how badly, remains in doubt.

For the Columbia, the major hatchery buildup began in the 1950's. Thus, the Bonneville counts during 1938-1955 (less the commercial tribal catch and non-tribal catch above the dam) reflect mostly natural spawners. Up-river escapement for spring, summer and fall runs (combined) during those years averaged 233,000, and it is reasonable to assume that 200,000 would represent the average natural spawning portion. The four major lower tributaries referred to earlier sustained spring and fall run escapements during a similar period on the order of 80,000 per year. Other lower river tributaries likely added approximately 20,000 more, bringing the total lower river escapement to about 100,000 and the total Columbia escapement of natural spawners to about 300,000. The total natural spawning escapement to the Columbia during the 1990's has averaged about 150,000, about half of what any reasonable person would set as a minimum, responsible level according to the known record. Even 300,000 seems low for a river system that sustained catches of over 2.0 million for a number of years prior to 1900; albeit, a great deal of the Columbia spawning and freshwater rearing potential has been destroyed by dams.

CHANGES IN POPULATION AGE AND SIZE STRUCTURE

Considering both the directed hook-and-line catch of immature chinook, as well as the incidental fishery induced mortality by all gear forms, it is clear that the majority of chinook killed by fishing activities have, for many decades, been immatures. Predictably such mortality forces would be greatest on fish destined to mature at older ages because such fish would be vulnerable over more years of life than younger ones. A chinook destined to mature at five years could be vulnerable during its third, fourth and fifth years, whereas a 3-year maturing chinook might be vulnerable for only one year, its third and last. Since age at maturation is partly heritable, pairing of younger adults tending to produce younger maturing progeny and visa versa (Ricker, 1972), the average age would decline over time due to this selective force. Another predictable form of selective mortality would be against faster growth, because fast growing individuals would reach minimum sport and commercial size limits before slow growing ones and thus be vulnerable for directed capture for longer

time periods. Since growth rate is also heritable (Donaldson, 1970) then within each maturation class the average growth rate would decline with time.

The net result of either or both of these effects would, of course, be smaller fish which is exactly what the evidence indicates. Ricker (1981) showed that the average weight of chinook salmon landed by commercial trollers in British Columbia declined 20-30% depending on region, between 1951 and 1975. He discusses several compounding reasons for such a dramatic decrease in size, in addition to selective fishing against older maturing and faster growing individuals.

Hankin and McKelvey (1985) reviewed age composition data for Klamath River fall chinook and indicated that the average age in spawning runs may have declined by about one year. Today, the Klamath River runs are dominated by ages three and four, compared to ages four and five in the past Hankin and McKelvey discuss a number of reasons, including those I have discussed, why the decrease in average size from this shift to younger spawners would negatively affect stock reproduction.

Smaller fish might be less able to construct nests in streams with large gravel. Their energy stores for long distance migrations in streams would be less. As shown for coho and other salmonids (Vander Breghe and Gross 1984) smaller spawners would not be able to bury their eggs as deeply; this could increase the risk of flood washout.

I attempted to compare historical and present day age and size composition for Columbia River chinook as evidence of fishery selection against older and faster growing fish. Unfortunately, the historical data are tacking in several regards, and the increasing presence of hatchery fish over time, further confuses the analyses, since artificial mate selection at hatcheries has probably altered heritable growth and maturity parameters over time.

The best evidence of the historical age distribution of Columbia River chinook runs appears to be from a series of hatchery fin marking studies on 1914-1923 brood year spring and fall chinook summarized by Rich and Holmes (1928).[2] At that early time, perhaps, hatchery mate selection may not yet have altered the natural distribution of age at maturity. From these marking experiments adults were recovered in the Columbia River fisheries and at the hatcheries. No information is given on mark sampling rates, but if these were relatively constant over the period of

any particular experiment, then the distribution of recoveries by year should indicate the age compositions that prevailed within spring and fall spawning runs. For spring chinook, ages three to six were encountered. Age five was the most frequent. Six-year-olds were more frequent than four-year-olds and very few three-year-olds occurred. The average spring chinook age from eight separate experiments involving three hatcheries was 5.3 years. For the fall run, age four was most frequent followed by age five and then age three. Few two-year-olds occurred. The average fall chinook from five experiments involving three hatcheries was 4.2 years.

a Age composition analysis from scale sampling of Columbia River commercial catches by Rich (1925) is likely deficient for inferring historical age distributions because of the apparent presence in the samples of non-resolvable mixtures of mature fish from the Columbia and immature fish caught by purse seines and trollers off the in the ocean off the river mouth.

The current ages for both spring and fall runs average less than this, however the difference is striking only for spring chinook. Spring chinook sampled at Bonneville dam from 1987-1996 (a mixture of hatchery and wild fish) averaged 4.3 years of age (Fryer, et al, 1966), which is exactly one year less than the average age from the earlier period. The major difference between the two periods is the virtual absence of six-year-olds at present. Naturally spawning fall chinook - from Washington tributaries and the main stem of the Columbia averaged 3.9 years of age for years 1988-1994 (Washington Department of Fisheries, 1989-1994) or only about 0.3 years less than for the earlier period. Frequency of two-year-olds appears to be higher at present than historically, which is the main cause of the lower present day average age.

Comparative weights at age between present and historical samples were estimated, to indicate the degree to which growth rates may have declined. Historical size at age data for spring and fall runs are from Rich (1925), who sampled Columbia River commercial net and river-mouth troll fisheries in 1919 and 1920. The scale aging techniques described by Rich seemed quite comparable to today's technology. The likely presence of unknown portions of immatures in his samples would, if anything, tend to underestimate average size by age of maturity, since immatures of any given age tend to be smaller (slower growing) than matures of the same age. Rich reported

fork lengths of individuals. I converted these to weights with a race specific weight-length relationship from Demory (1965). Present day average lengths at age for spring chinook are from 1987-1996 Bonneville Dam samples (Fryer, et al, 1996). These were converted to average weights by Demory's relationship. Present day average lengths at age for Columbia fall chinook were computed from mean 19891993 length at age data for Hanford Reach and Lewis River natural spawners, provided by K. Harlan, Washington Department of Fisheries, Battleground, WA (Personal communication). Mean lengths were converted to mean weights from the fall chinook weight-length relationship of Demory. For both spring and fall runs, present day weights tend to be less than past weights (Table 2). Some of the differences are striking.

The combined effect of younger fish and slower growing fish in present populations can be expressed in terms of both average weight (weight of a fish of average age, as linearly interpolated between weights at integer ages above and

below the average), and average fecundity for fish of the average size. Average fecundities were from the relationships between fecundity and fork length for Columbia River chinook estimated by Galbreath and Ridenhour (1964). Spring chinook spawners now average about half their historical weight, and their fecundity has declined by one third. Declines have been less dramatic for fall chinook, with a 19.2% decrease in average weight and an 8.6% decrease in average fecundity (Table 3).

SEX RATIO ALTERATION

Since females tend to mature older than males, fishing on immatures would be expected to induce greater mortality on females. We should expect, therefore, to see a preponderance of males in spawning escapements, and in hatchery stocks, males commonly predominate. At the University of Washington hatchery, the sex ratio of spawning fall chinook averaged 65% males for return years 1991-1995, not even counting the two-year-old jacks (personal communication, W. Hershberger). Ellis and Noble (1961) reported that 71% of the age three to six fall chinook spawners that returned to the Deschutes River (WA) from 1955 brood hatchery plantings were males. The data I reviewed for wild stocks were mixed. Sex ratios favored males in 1965-66 gillnet test catches from the Fraser, Skeena and Nass Rivers; male proportions ranged from 51% - 80% depending on river and race (Healy, 1991). For the North Lewis River (lower Columbia) and the Hanford Reach (mid-Columbia) the sex ratios for spawned fall chinook carcasses were, surprisingly, approximately 50:50 for years 1991-1995 (personal communication, K. Harlan, Washington Department of Fisheries and Wildlife, Battleground, WA). Additional review of sex ratios in wild spawning populations of chinook salmon is needed.

GROWTH OVERFISHING

It is well known that the rate of growth of individual chinook salmon in weight exceeds the natural mortality rate of the population for most of their life at sea. Therefore, any unfished cohort will continue to increase in biomass until the end of its ocean life, even though its numbers may continually decline from natural mortality causes. Furthermore, large chinook are more valuable per pound than small chinook. Immature net-caught chinook less than about five pounds are practically valueless. Troll caught chinook are generally graded at the dock into small (less than 8 pounds), medium (8-12 pounds), and large (greater than 12 pounds), and the ex-vessel price may differ as much as two-fold among grades. Such relative, size-based values tend to carry through to the retail level. With sport fisheries there is probably a similar size-based value differential, although definitive economic studies have not been done. For example, it is well known that sport fishers spend great effort and expense seeking "trophy/' salmon; therefore, it is likely that a 20-pound chinook would attract more effort and expenditures on average than two 10-pounders or four 5-pounders.

To indicate the relative losses from growth overfishing in terms of yields i weight and yields in value caused by fishing on immature chinook, consider a hypothetical population of fall chinook, all of which mature at age four. Assume that i can sustain a run of 3,000 mature fish each year with an optimum spawning escapemen of 1,000 fish. There is, then, an annual surplus equivalent to 2,000 adult fish, or more i terms of numbers if the surplus is allowed to be caught as immatures. Assume tha these fish grow according to the average weights at age given earlier (Table 3), reachin 5.7 pounds, 12.4 pounds and 22.2 pounds at ages 2, 3, and 4, respectively. Assum further that natural mortality is equal to 20% per year of the cohort numbers present a the start of a year, in absence of fishing. A final assumption is that prevailing ex-vesse troll values apply - $12511b. for fish under 12 pounds and $1 .7511b. for fish over 1 pounds. These values could be anything in absolute value, but should reflect th different, relative values for small and large chinook.

Let us compare the yields in total weight that any cohort would provide under A and B scenarios, where scenario A is that only mature, four-year-olds are caught and scenario B is that there is a year round troll/sport fishery with a 24" minimum size limit, which is the average length these fish reach by age two (Table 3).

Under scenario B we will first assume, for simplicity, that there is no incidental catch mortality, but then add in such mortality for a second comparison. For each scenario we will assume that 1 ,OOO spawners must be left after fishing.

Now, in the absence of fishing, the annual survival rate would be 80^0/0, since 20% would die per year. And, the survival rate for two years, age two to age four, would be 80% x 80% or 64%. Thus, an unfished cohort yielding 3,000 four-year-old adults would have had a two-year-old abundance of 4,687 individuals (3,000 / .64).

Let us therefore compute scenario B yields in weight and value from a cohort of 4,687 two-year-olds, under the constraints of a natural mortality force equivalent to 20% of an unfished stock per year, and a required spawning escapement of 1 ,000 four-year-olds. It turns out that an exploitation rate of 38.3% per year for the last MO years of life will reduce the cohort to 1 ,OOO surviving four-year-olds, according to well known equations from fishery modeling theory (the equations are omitted). And, under the same theoretical conditions and equations for modelling competing mortality risks, the percentage of the cohort that would die annually from natural mortality causes would drop to 15.5% from 20% (because some of the fish that would otherwise die from natural causes if the stock were unfished, would no longer have the possibility of natural death since they would end up in the catch). Total mortality per year, with fishing, would then be 38.3% + 15.5% or 53.8% of the cohort number present at the start of any year, and the annual survival rate would be 100%-53.8%, or 46.2%.

Table 4 traces the fate of our cohort of 4,687 two-year-olds through two years of continuous fishing. During the first year as this cohort ages from two-years to three-years, 38.3%, or 1795 individuals would be caught. At an average weight of 9.05 pounds (midway between the weights of a two-year-old and a three-year-old), the yield in weight for fish of ages two to three (designated often as 2+ years of age) would be 16,245 pounds; and at $1.25/pound their catch value would be $20,306. The surviving numbers of three-year-olds would be 2,165 (46.2% of 4,687). Their yields over the ensuing year in terms of numbers, weight, and value are computed as previously for the 2+ component, except that the $1.75 per pound value now applies.

The total yields from this cohort under scenario B are the sums of the catch, weight of catch, and value of catch columns.

Compare now these yields to scenario A, which yields 2,000 mature fish each

fish weighing 222 pounds:

	Catch in Numbers	Average Weight	Weight of Catch	Value of Catch
Scenario A Mature Fish Only	2,000	22.2 lbs.	44,400	$77,700
Scenario B Immature Fish	2,624	11.6 lbs.	30,587	$45,404
% increase of A over B	-23.8%	91.30/0	45.20/0	71.1%

The mature fish scenario yielded 23.8% less fish, but the average weight per fish was almost twice as much. This scenario increased the catch in weight by 45.2% and the catch value by 71 .1%.

The gains in weight and value from mature-fish-only are even more startling when incidental mortality is superimposed, as an added item of reality. The suppositions in this case were (1) that incidental mortality from all sources (including sub-legal throwbacks from the sport and troll fishery, as well as incidental net mortalities on this stock) was equivalent to 30% of the landed catch, and (2) that management simply reduced the exploitation rate such that the new rate equaled the old rate divided by 130%, by some combination of area/ time restrictions. Thus, the combined rates of retained fishing and incidental mortality remained at 38.3% and the cohort escapement remained at 1,000 spawners. (This model is simplistic since incidental mortality would affect mostly fish less than age two; however, its ultimate effect on the stock would need to be corrected for in some manner equivalent to that shown here, in order to maintain the spawning goal.)

The yields for scenario A and scenario B with compensating catch rate decreases due to incidental mortality are compared below:

	Catch in Numbers	Average Weight	Weight of Catch	Value of Catch
Scenario A Mature Fish Only	2,000	22.2 lbs.	44,400	$77,700
Scenario B Immature Fish and Incidental Mortality	2,022	11.6 lbs.	23,571	$34,991
% Increase of A over B	1%	91.30/0	88.37%	122.06%

The catches in numbers are virtually the same, but the average weight per fish is far smaller for scenario B. The weight of catch and value of catch are far greater, 88% and 122% respectively, from fishing matures only.

The relative gains in weight and value from eliminating fishing on immatures, as expressed in the above numeric example, represent theoretical quantities under a set of relatively rigid conditions. Actual gains from any management regime intended to reduce or eliminate harvest of immatures will depend upon the degree to which these conditions are met in reality, and may in fact fall somewhat less than expressed in the example. The important conditions are these:

(1) Recruitment to age is unaffected by fishing policy.

(2) Fishing under a regime allowing immature capture (Scenario A) is constant and continuous over the last two years of life.

(3) Fishing under a regime of mature harvest (Scenario B) can be done with zero encounters of immatures

Condition (1) is needed to demonstrate the loss from immature harvest due simply to growth overfishing. There are other benefits from eliminating immature harvest, such as improved escapements, but the purpose of the present example was to express the potential magnitude of perhaps the most obvious and correctable costs of immature harvest.

Condition (2) is not totally realistic because the present circumstances represent a mix of directed mature and immature harvest. However, for many stocks we do have year-round fishing on immatures, in essence, if not in full measure as modeled. There are major directed or incidental capture fisheries somewhere each month of the year. Minimum size limits vary but tend to average about 24" in the various directed sport and troll fisheries, which is the average length for a two-year-old fall chinook. Wintertime sport fishing for chinooks is allowed on inner sea waters from Puget Sound through SE Alaska. Winter trolling occurs in the Strait of Juan de Fuca (tribal only) and SE Alaska. Marine sport fishing for chinook opens by mid-February off California and trolling by May 1 off California and Oregon. Net fishing, with associated incidental mortality, is open somewhere from Puget Sound to SE Alaska over a six-month period, June-November.

Condition (3) could be best met in theory with river-mouth traps and in-river sport fishing. But, there are many reasons why such a fishing regime would not be a good idea, including loss of quality and disruption of historical patterns of commercial and sport fishing. The present mix of fishing gear could, in fact, do a pretty good job of harvesting mature fish with far less immature encounters than at present. Albeit, many fisheries would need to be constrained even more so than at present in terms of seasons, areas, and allowable gear. Even hook and line fisheries are fully capable of intensive, and effective targeted fishing on matures. For example, the summertime troll fishery in SE Alaska operates relatively closely to the mature fish ideal. Spot openings are allowed in hatchery release areas prior to July 1 to harvest the returning adult spring chinook; and during the general troll season that opens July 1 the quota of mostly mature chinook is usually taken in a very short time, a few days to a few weeks. Intensive sport fisheries would be sure to develop on the strong runs of mature chinook that would become available if everybody stopped killing immatures.

Considering the array of races, there could be good fishing opportunities somewhere on mature chinook from mid-April through September, and river fishing for a considerable period thereafter. Even if fishing were not as free as in the past, or pursued away from a crowd, the fish would be big and the weather good. Furthermore, the alternative is apparently steadily declining fishing on small chinook.

CORRECTING THE HARVEST PROBLEMS

The Problem

Chinook catches have declined sharply, in contrast to the stable to upward abundance trends of many other Pacific salmon stocks. The most extreme problem region is the central portion of the range, the Columbia River to southern British Columbia. This region not only has the heaviest human population densities and associated watershed development, but also supports intensive net, troll, or sport fisheries in many months of the year. These fisheries take chinook of all ages either directly or incidentally.

Exploitation rates rose to exceed MSY rates during the 1960 and 1970 hatchery heydays, and this, combined with habitat degradation, depressed many wild runs. Although such rates have declined somewhat, they are still too high for depressed stock rebuilding. Adding to the predicament is the incidental catch mortality, equivalent to 30% or more of the recorded catch, and the genetic changes in the stocks wrought by fishing on immatures, which is manifest most obviously in declining body size.

The solution will require a different biological standard for this species, a new conservation principle, that can readily be understood and embraced by all scientists, managers, fishers of all types, and the resource-minded public at large. Acceptance of this standard will require outreach and education; a sufficient, critical mass of concerned people must become aware of the problem, understand its technicalities in some detail, and clearly perceive their roles in its solution. The current fishery institutions and agencies have had difficulty achieving a satisfactory harvest management regime for chinook salmon. The most hopeful alternative would be a bottom-up action plan for harvest management developed by groups of fishers working in some fair spirit of cooperation among themselves and with the agencies.

The biological standard given below should become the litmus test for fishery regulations in all cases where chinook salmon are caught directly or incidentally.

The Biological Standard

Such a standard is virtually self-evident: Chinook salmon should be caught only when mature. Such a concept has been presented and defended extensively in the scientific literature, and aired in numerous management forums. It was the basis for international agreements to stop high seas gillnetting of salmon. It is the fundamental principle for management of most other North American salmon stocks. Most stocks are harvested in the last few weeks or days before migrating to the spawning grounds, because this is the time at which individual fish achieve their greatest weight; this is

the time they have separated from immature components of their stock and segregated into more discrete genetic units. Not only are chinook unique among salmon stocks in being targeted at immature ages, they are unique among <u>most other marine</u> <u>and freshwater fish species</u> in this regard. Most other fish do not die after spawning, so are mature over several to many years. But usually we establish fishing regulations to let them reach the size and age of maturity before harvesting them, such as minimum allowable mesh size, minimum size limits, and seasonal or area closures to protect juveniles. There are so many examples of successful management of other species based upon the mature fish standard, that it is amazing we continue with the notion that chinook can be exploited so differently than other salmon, i.e. at multiple ages by means that kill small and large fish indiscriminately.

We started off on the wrong foot with chinook salmon decades ago when they were relatively plentiful. But for the sake of this dwindling, extremely valuable resource, it is time to change the harvest management paradigms. Perhaps we can develop hook-and-line techniques that catch only large, mature individuals in mixed-age situations, or find ways to deploy nets that avoid immature chinook, or perfect non-lethal ways to handle and release incidentally captured fish. In all likelihood, we will additionally need more restrictive time and area harvest mosaics for all fisheries that catch chinook. We will not be able to fish as freely as before. This does not mean that any gear group or political unit should suffer at the expense of others. There is so much inefficiency in the present harvest regime that everyone's chinook salmon catch would immediately improve with acceptance of the mature fish standard, even before the longer-term benefits of larger spawning escapements and improved riverine habitats might kick in.

<u>Enacting the Mature-Fish Standard</u>

Acceptance of the mature-fish standard would be the cornerstone of a better chinook salmon harvest management regime. The mature-fish standard would directly address the incidental catch problems, since fishers would redirect all fishing activity for mature chinook or other species away from immature fish, in terms of fishing methods, times, and places. Such a standard would directly increase yields in weight and value. It would decrease the likelihood of fishing-induced selectivity against desirable, evolutionarily derived population traits Spawning escapements would immediately improve from reduction of incidental mortality, and would, in the long run, improve as the fish became less subjected to potential harvest over multiple political jurisdictions.

It is far easier to espouse the mature-fish standard than to enact it. If it were uniformly applied, then everybody who fishes salmon in marine waters would be seriously impacted in how, where and when they fished. Sport and troll fisheries targeting immature chinook in the winter, mixtures of mature and immature chinook in the summer, coho at

times and places where immature chinook are abundant would all be affected. Al: fisheries that target other species at times and places where immature chinook are p would be restricted.

Some of the important elements to consider in bringing such a standard to fruition include: (1) working definition of such a standard; (2) preservation of historical fishing patterns; (3) uniformity of the standard across all fisheries; (4) scientific criteria for defining mature fish; (5) institutional acceptance; and (6) individual and community responsibility. These separate elements are discussed below, with examples of some potential management measures for Washington fisheries.

(1) Working Definition

A practical definition is needed, one that recognizes historical patterns of fishing. We do not need a strict, terminal harvest policy for chinook salmon or any other species to preserve them. Mixed-stock harvest is acceptable as long as the harvest rates for each stock in the mix is within sustainable levels. Nor is there anything biologically wrong with harvesting chinook a long way from their river of origin, as long as they have achieved their ultimate age and size and their stock specific rates of harvest are sustainable. Furthermore, certain fisheries, particularly sport fisheries, are so inefficient that they need a sufficiently long season to take their reasonable share. Such fisheries cannot be expected to mount the power of concentrated net fisheries which can often take sustainable harvests in merely a few days. Thus, the mature standard need not, nor should not, be synonymous with "terminal fishing" or "single stock" fishing. The mature standard cannot be totally inflexible either, because of the complex life history of chinook (maturation at multiple ages) and their tendency to mix as matures and immatures on feeding grounds. A suggested starting point for harvest management purposes would be to define a

(l mature chinook as one in its last calendar year of life. The mature standard would then be an embodiment of a simple principle; i.e. that harvest regulations be such as to limit to as great an extent as possible the targeted and incidental capture of chinook salmon that had not reached their last calendar year of life. If uniformly and seriously applied, this criteria would go a long way toward reducing harvest problems previously discussed, since so much of the present targeted and incidental catch is of fish that have not yet reached their ultimate calendar year. Perhaps as the benefits of the mature standard, as defined and applied above, became apparent, the criteria could be further refined, such as restricting the catch of chinook to fish to say, in their last three months of marine life, to as great an extent as possible. Whatever criteria are chosen should be a matter of public scrutiny, understanding and informed choice. I am merely offering the above suggestions to enable stakeholders to visualize how, in actuality, an important biological principal (avoidance of directed and incidental fishing mortality of too many juveniles) could be met.

1.0

(2) Historical Fishing Patterns

Most management institutions of the Pacific Northwest are grounded in two fundamental principles, the first being the need to conserve and protect the resources, and the second to preserve, to as great a degree as possible, the historical patterns of fishing. These tenets are basic to the Fishery Council management decision process and the U.S.-Canada Salmon Treaty. The Boldt decision was a milestone societal statement about protecting the historical fishing rights of individuals and the cultures of people dependent on fishing. It is often advanced that the best way to achieve the mature-fish standard for chinook and other species is to harvest the runs terminally, with commercial river mouth traps or fish wheels, and in-river sport fishing. While technologically appealing on the surface, no one has demonstrated how such a system could reasonably preserve the historical interests of individual tribal or nontribal commercial fishers, or sport fishers for that matter. Furthermore, such a system would produce a lower-grade commercial product than a well-managed marine harvest system because salmon degrade rapidly as they approach and enter rivers. If traps were to be fished farther out in marine waters to maintain commercial quality, the same, or perhaps worse, incidental catch problems would develop as with existing gear. The common sense alternative is to modify the physical structures and time and space deployment within the present mix of commercial and sport gear type. This would largely maintain the historical fishing patterns yet achieve the conservational needs. Every one of the present gear types - troll, gillnet, purse seine, reef net, and individual rod and reel - is sufficiently flexible in design and use to be capable of catching mature salmon (fish in their last calendar year) while avoiding immature chinooks, as much so, certainly, as any economically practical system of traps or other devices that might be devised. Achieving the mature-fish standard with the current mix of gear will require imagination and flexibility, and will not be without some costs and loss of operational freedom to individual fishermen.

(3) Uniformity of the Standard

Harvest policies to achieve conservation needs are far more acceptable and enforceable if they apply uniformly to all fishers, than if they cut different groups differently. It is easier to accept a fishing closure to protect a weak run if others upstream are also prevented from fishing. The 640 Initiative in 1995 in the State of Washington, the stated purpose of which was to reduce incidental fishing mortality of salmon and other species, failed at the polls. It failed apparently because it would have restricted primarily the non-tribal net fisheries. The 640 provisions were designed to leave sport fisheries relatively unimpeded, and furthermore, this Initiative would have had no direct effects whatsoever on tribal net fishing. The mature-fish standard, defined in common, understandable biological terms, would , unlike 640, let no one off the hook. If a sport, commercial, or tribal fishery killed immature chinook, participants would have to figure out how not to do so in order to keep fishing.

(4) Scientific Protocols

A set of practical criteria would be needed to define a mature chinook for harvest management concerns, i.e. one in its last year of life. No problems are presented for freshwater fisheries or even many estuarine fisheries which have no immatures present. But most marine fisheries contain mixes of matures and immatures that change seasonably. For such fisheries body length provides a simple, understandable, enforceable, and biologically appropriate criteria. Age, length, maturity sampling like that of Wright and Bernhardt (1972) would need to be done for various fisheries and regions, if such data are not already available. Wright and Bernhardt sampled 2,500 chinook caught off the Washington coast during April-Sept. of 1970-1971. Both males and females were readily classified into mature (last year of life) or immature components by model analysis of gonad volume-frequency graphs. Their data indicate that about 85% of the immature chinook were less than about 27 in.

in total length, regardless of age, and about 85% of the mature chinook were longer than 27 in. Thus, although there is no minimum size limit that perfectly separated matures from immatures a 27 or 28 in. limit would do a reasonable job of this. Most of the immatures greater than 27 in. were stream type (0+ age when they went to sea) i fish in their third year of life, destined to mature at ages 4 or greater. The mature fish less than 27 in. were mostly maturing two-year-old males (jacks) and maturing three-year-old males and females. The predominant age group in the ocean was stream type fish in their third year, of which some 60% were mature and 40% were immature. The significant life history feature that allowed reasonably good (about 80% chance of correctly classifying either a mature fish or an immature fish with a 27 in. size limit) separation even for this age group, which had the greatest chance of error, was that maturing three-year-olds were much larger on average than immature three-year-olds.

Due to differing age, growth, and stock composition parameters, different regions may require different minimum size limits to achieve similarly precise mature/immature separation as in the above example. For example, those chinook residing in Puget Sound may grow slower than those in the ocean and warrant a smaller size limit. In Alaska with older and faster growing fish, a larger size limit might be appropriate.

Additional scientific protocols required would be working definitions for maximum allowable immature catch rates or mortality rates. No form of fishing is 100% clean, and like other fisheries with incidental catch concerns, scientifically acceptable allowances for levels of immature chinook capture and dropout mortality would have to be established, and some minimal standard applied to each and every fishery. Also, sampling plans to determine compliance with allowable levels would be needed. The appropriate forums for developing mature/immature criteria and incidental mortality protocols would be the Scientific and Statistical Committees of the Pacific States and North Pacific Regional Councils, and the Chinook Technical Committee of the Pacific Salmon Commission.

(5) Institutional Acceptance

Unlike reduction in exploitation rate, a problem greatly confounded by migrations across political boundaries, there is no compelling need for international or interstate cooperation to successfully address incidental chinook catch problems, although cooperation would certainly be helpful. All states and British Columbia have full authority to manage within their territorial waters for reduction of immature capture and incidental mortality of chinook. What if, for example, the State of Washington, including the co-managing tribes, were to adopt a mature-fish standard for chinook, and manage its waters accordingly, regardless of whether or not British Columbia or the Pacific Council or anyone else did so? The potential gains in yields and escapements to Washington streams are sufficient for all Washington fishers to benefit to some degree. Fishers elsewhere would share the benefits. Would that be so bad? Obviously, universal acceptance of the mature-fish standard would be the preferable approach. However, waiting for unanimity before proceeding may be a bogus excuse for doing nothing.

While promulgating regulations according to the mature-fish standard, the State of Washington could also be requesting of its commissioners on The Pacific Salmon Commission that this standard be considered by the entire international commission and perhaps embedded officially within the Treaty. And similar conferences should be held with Washington representatives of The Pacific and North Pacific Councils, which could lead to debate and acceptance of the standard at this high policy level too. For there may be many influential fishers, managers, and concerned citizens in British

Columbia and the Northwest states who have concluded also that we cannot continue to waste immature chinook salmon, and who are concurrently working toward management solutions of this problem.

(6) Individual and Community Responsibility

Little progress can be expected at any level unless the fishers have a broad understanding of the problems and can see solutions that involve their own activities. No one wants to waste immature chinook, and everyone is more comfortable if adequate escapements are achieved. But too often it is the other person at fault. The mature-fish standard becomes acceptable only to the extent that each of us can visualize how our own catch of dead, descaled, stressed, eye-hooked, gill-hooked shakers, squishers and gillers adds to that immense, stinking heap of soft-fleshed, immature chinook and detract from once-abundant runs of fat, bright, firm-scaled mature chinook. When the light clicks on, the finger-pointing will stop, consciences will kick in and solutions will be found,

A Plan for Enactment

This section will put the previous comments on the mature-fish standard into concrete terms and begin a dialogue for developing a harvest management plan for enacting the mature-fish standard in the State of Washington. The practical elements of these should include size limits, gear modifications, removal and release techniques, time closures, and area closures. I have avoided consideration of the various commonly proposed management options that would alter the allocation of the harvest among users, such as commercial or Indian fishery buyouts, individual quotas, limited entry for charter boats and guides, use of traps or similar commercial gear not presently in use, elimination of specific gear types, etc. These can be contentious issues and are usually more focused on the needs of the fishers, rather than the needs of the fish. Before considering some specific harvest management options, I will present two broad options that might negate the need for cumbersome regulations.

The first is to close all targeted chinook fisheries that take wild chinook, in any proportion, as well as all marine commercial or sport fisheries that catch immature chinook while targeting other species. This would resolve the incidental catch problem, but reduce the fisheries to river mouth harvest of hatchery chinook and other species. If stocks of wild chinook continue to decline to the point of ESA listing, this is a likely management outcome. It would be informative, to say the least, to see how the chinook escapements might rebuild over time.

The second broad option would be to establish numerical chinook quotas for each fishery, based on prior assessments of runs, historical allocation percentages and treaty rights constraints. Under this alternative there would be no size limits, or other restrictions, but all salmon caught would have to be retained regardless of size. This should encourage voluntary actions to reduce catches of juvenile chinook by voluntary selective fishery and time/area redeployment, since a two-pounder would count against the quota as much as a 20-pounder. There would also be numerical quotas on chinook catches in net fisheries targeting other species, and retention requirements. Since reaching these quotas would trigger net fishery closures, then voluntary efforts would similarly arise to fish in ways that avoided immature chinook. The major drawback of this scheme of quotas and mandatory chinook retention regardless of size is that it would require extensive monitoring and enforcement.

The above options may have worthwhile facets, but a mosaic of more detailed, enforced regulations and voluntary actions may be more palatable.

A practical, relatively enforceable starting point would be to establish a minimum size limit for chinook applicable to all marine area commercial and sport fisheries of a region. Most regions currently have confusing arrays of size limits for the different net, troll and sport fisheries. For the stock mix of each region, it is relatively straightforward to determine the single minimum length that gives the greatest chance of correct classification of the maturity status of a chinook. This biologically based standard should apply to all fisheries of a region. Alaska, which probably manages closer to the mature-fish standard than any other region, has a 28" minimum for all fisheries except gillnetting because most gillnet caught fish are dead when brought aboard. (Alaska sometimes restricts gillnetting to only daytime hours, since chinook are relatively more vulnerable at night than other species; this js discussed later as an example of selective fishing.)

It is conceivable that by simply increasing the size limit, fishers would take appropriate steps to control their own fishing activities to avoid times and places where too many immatures are present. Sorting through many small fish to retain one of legal size could be an onerous task. For example, increasing the resident trout size limit in Washington coastal streams from 6 to 12 inches probably reduced the catch of steelhead smolts significantly, even though there was nothing in the regulations preventing people from sorting through dozens of smolts to catch a 12- inch trout; the size limit change may have been a simple and effective way of informing fishers that catching steelhead smolts was improper. Similarly, a 26" or 28" limit for Puget Sound could help get the message across that catching immature chinook is not the best use of this resource. (The current sport size limit is 22".)

Selective fishing gear should be encouraged everywhere. Both seines and gillnets should be made shallower by regulation, because chinook tend to be deeper than other species, particularly in the daytime. Chinook also have greater visual acuity, probably because they are adapted to feeding at greater depths than other species, and are therefore substantially less vulnerable to daytime gillnet fishing than night time. Since the other species can be caught during daylight hours, often as effectively as at night, gillnetting in areas of immature chinook abundance should be closed at night. Also seining, which for the most part occurs during the day, should be further restricted in time to avoid pre-dawn or late dusk time periods when chinook tend to be shallowest.

Minimum mesh regulations should be strictly enforced. The 6-1/4 inch gillnet minimum for the Puget Sound fall chum season will pass almost all chinook less than about six pounds, and probably in excess of 90% of the chinook in Puget Sound at that time are less than six pounds. But 5-inch sockeye nets, which in the past were sometimes used illegally into the fall season because enforcement was not sufficient, are designed to be maximally efficient on six-pound fish. The immature chinook catch rate is reduced by about 80% in the 6-1/4-inch mesh compared to the 5-inch mesh. The appropriate minimum mesh size for the top, escape strip of purse seines is not as easy to establish. It is presently 5-inches, but perhaps could be bigger to allow more immature chinook to escape while still retaining most of the targeted fish.

In troll fisheries and perhaps sport fisheries at certain times, greater use should be made of the known advantages of exclusive use of large plugs. There are several studies showing that while plugs 6" in length or more may only be 50-75% as efficient on harvestable sized chinook as alternative tackle (flashers with hootchies or baits, and spoons) they reduce the chinook and coho shaker catch rate by about 80% (Milne, 1955; Pitre, 1970; Boydston, 1972). Trollers could probably become quite efficient with plugs on mature chinook, if restricted to this gear type when targeting chinook. Mature coho can also be taken on plugs, although when targeting coho, there might need to be other forms of regulation to limit shaker catches.

Use of downriggers in sport fishing should be discouraged or perhaps eliminated, if they prove on thoughtful inspection to be as destructive as indicated by both incidental mortality studies (Natural Resources Consultants, 1993) and anecdotal reports. If not, yet universal, barbless hooks should be required for all hook-and-line fisheries. Common sense suggests that small fish caught on flasher gear would be more stressed than if caught on lures or baits without such an attractor, and at least one study also indicates this (Natural Resource Consultants, 1993). Thus, perhaps use of flashers should be illegal for sport as well as commercial troll fishing. Common sense suggests that multiple hooks should also be illegal, although study results have not clearly proved their damage.

Everyone should be thinking about better ways to promote and enforce nonlethal handling and release methods. Ideas should be tested, and formal and informal education should follow. For example, small fish that are dip netted aboard

to then be measured for legal size are stressed and descaled by this process. In-water release for fish of questionable size should be encouraged, or perhaps enforced with an appropriate regulation. Salmon can be easily released without dip-netting if caught on single, barbless hooks. Or the leader can be cut with relatively little cost considering the value of the fish saved. Some dip net materials are less destructive than others; this needs further investigation and possibly regulation.

Seiners can slow down their retrieves to reduce gilling, chafing and other stresses, and should be regulated to do so. Live-holding tanks for seine-caught fish

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recovery have been tested, but if one adds the stress of dip-netting a fish from a seine into a live tank to the stress of capturing, then the use of such recovery tanks may be self-defeating. Slower retrieves or other measures to avoid capture of immatures in the first place may be preferable.

Selective fishing and better handling regulations are part of the answer, but unlikely to be sufficient. Oftentimes they are promoted in lieu of real, but unpopular solutions and can be like bandaids on arterially-bleeding wounds. Or, they can be difficult to understand, abide by and enforce. For example, is there any commonly understood, legal definition of a "barbless hook", a long standing regulation of modest effect that has probably caused a missed heartbeat of most sport and troll fishers in presence of a patrol officer?

Effective regulations that are not hard to understand or enforce are time and area closures. Commercial trolling for chinook should be compressed to the period when mature fall chinook are running inshore, which is about mid-July to mid-August. In the most recent years when harvest quotas were allowed, the general season was open as early as May 1, even though there is a lot of growth remaining even for maturing fish between May 1 and July 15, and quotas could have been taken later. Areas of chinook shaker abundance should be closed, both (1) known hotspots prior to the season based upon accumulated knowledge, and (2) developing hotspots during the season as fishers and managers become aware of these (the necessary degree of cooperation and trust would likely be forthcoming if all fishers were managed equally and fairly under the mature fish standard). Flexibility in allowable troll fishing areas would encourage stock selectivity and reduce incidental capture of immatures. For example, if north coast rivers needed protection, trolling could be restricted to the southern portion of the Washington coast or even finer subdivisions. Or trolling might be allowed into the Strait of Juan de Fuca or Puget Sound, if such would be biologically most suitable for selective harvest of those mature stocks with available surplus for troll harvest.

In many places, gillnet fisheries operate according to the mature-fish standard, including the Columbia River, Willapa Harbor, Grays Harbor, Samish Bay and similar river mouth or in-river areas fished by the tribes. It is when net fisheries target other species that immature chinook can become a problem. As with the troll fisheries, chinook shaker hotspots should be closed either before the season by prior knowledge or within the season by communication and cooperation between fishers and managers. Again, management flexibility would be needed to ensure that specific fisheries impacted by hotspot closures be allowed upstream harvest opportunities for their share of the target species. This could mean opening sections of Puget Sound traditionally closed to non-tribal fishers.

Different areas of Puget Sound may be better for certain gear types than others, and exclusive use of one type or another may be sensible, as long as historical catch balances are maintained overall. For example, there is evidence that by using shallow, 6-1/4" minimum mesh gillnets in daytime only, central Puget Sound chums can be effectively harvested with minimum interference on blackmouth. But there may be no equally clean way of purse seining chums in that area. However, the blackmouth encounters in Hood Canal, which has a large chum run, are much less than in central Puget Sound. Perhaps gillnets could be allowed exclusively for central Puget Sound chums, with Hood Canal becoming an exclusive purse seine area during the chum season to offset the loss of purse seining opportunity in Central Puget Sound. Such tradeoffs should be carefully negotiated to insure equity to both groups, but could be quite beneficial to the chinook resources.

Probably the knottiest problem of all is the winter sport fishery in Puget Sound, which, as everyone knows, targets immature chinook. The value of this close-to-home fishing in all its ramifications, including waterfront property values and pleasure boat purchases is immense. There has always been the year round opportunity to fish Puget Sound, and restricting such a valuable opportunity cannot be considered lightly, regardless of biological necessity. But, if a six-pound blackmouth in Puget Sound is a valuable fish, even more so is a 20-pound mature king at Sekiu. And in recent years the summertime Juan de Fuca Strait sport fishery has been closed to protect the same wild chinook stocks that make up a good portion of the Puget Sound winter population.

The Puget Sound sport fishery is heavily enhanced with delayed release hatchery chinook paid for directly by sport fishing from a $5.00 fishing license add-on.

Nonetheless, only 40% of recently sampled catches were from delayed releases. (L. Blankenship, WDF&W, personal communication). The rest of the population is a mixture of standard hatchery releases and wild stocks. Coded wire tagging shows that chinook from such rivers as the Skagit, Stillaguamish and Snohomish,

which are currently under review for endangered species listing, occur throughout the Sound,

including south of the Tacoma Narrows. The Tribes and WDF&W are jointly attempting to restore the White River spring chinook run, but the current exploitation rate of about 65%, (much of the catch is taken by the Puget Sound sport fishery), is probably too high for rebuilding. (Muckleshoot Indian Tribe, et al. 19E.)

History should remind us that heavily enhancing a region that has a mixture of hatchery and wild fish increases the risk of inducing too great a harvest rate on the wild stocks. Oregon coast wild coho have recently approached endangered status listing largely because of 80-90% harvest rates induced in the past by hatchery successes. The Puget Sound delayed release program could similarly contribute to the downfall of the Skagit, Stillaguamish, Snohomish, and White River, as well as, other natural stocks if we continue to regard Puget Sound as a big pond full of hatchery fish and do not take adequate harvest control measures to protect the wild.

Closing Puget Sound to winter sport fishing would not necessarily negate the benefits of the delayed release program; it could, in fact enhance such benefits, so long as those fish not captured in the winter remained in Washington to contribute at a larger size in the summer. Coded wire tagging indicates that, in fact, a high proportion of the delayed released fish would stay in Washington throughout their lives. Of 15 separate lots of delayed-release chinook, 4,262 marine recoveries were made of which 03^{0}/0 were from Oregon and California, 5.9% were from Canada, and 93.8% were from Washington (mostly Puget Sound and the Strait of Juan de Fuca). All ages, two to five, were represented in the Washington fisheries, in the sort of proportions that one might expect, only if there was no significant emigration. For example, all lots that contributed well as three-year-olds also contributed well as four-year-olds, and those that contributed well as four-year-olds also did so as five-year-olds. The lots that contributed relatively well to Canada did so at all ages, indicating that these were lots that migrated outward in early marine fife.

Closure of the Puget Sound winter fishery would increase the likelihood of reopening sport fishing opportunities on mature chinook in the Strait of Juan de Fuca and upper Puget Sound. But, it would be irresponsible to unequivocally promise the latter to make up for loss of the former. However, a complimentary management effort, the mass marking of hatchery chinook, would be the best, and perhaps the only alternative, to ensure that sport fishers do, in fact, reap the benefits of more summer time opportunities to overcome the sacrifice of closing the winter fishery. For this

reason, presented in the next section is a discussion of mass marking of hatchery chinook, its negative as well as positive aspects.

Whether the Puget Sound winter sport fishery should be closed entirely, managed in some less austere way with some combination of alternative regulations, or simply left in present form, is an important set of questions for all fishers to consider. I hope I have adequately presented the issues of concern in this report, so that fishers can develop an informed choice.

A final Washington fishery that would potentially be closed by a mature-fish standard is the tribal winter troll fishery in the Strait of Juan de Fuca. With a 22" minimum size limit, this fishery also targets immatures. The tribal winter troll fishery operates by Treaty rights, and if closed, allowances for complimentary quotas of mature fish in the summer to those tribes affected, would be mandatory. Mass marking would be desirable, to ensure that the promise of such quotas would be met without threatening wild stocks.

IMMATURE CHINOOK ALLOWANCE

A factor for immature chinook allowance will have to be established, based upon accumulated technical knowledge, even though this may be a difficult and acrimonious task. It must be the same for everybody and encourage simultaneous reduction of both the absolute number of immatures caught and the mortality rate of those released. A recommended factor is the multiple of the absolute number of shakers caught times the scientifically determined average release mortality rate for the specific fishery. This numerical product represents the absolute number of immature chinook killed incidentally by a specific fishery. If this product were larger than a common, agreed-upon percentage of the mature chinook catch or other targeted species catch, such as 1%, 5% or 10%, the fishery in question would be so altered as to bring it in line with the common allowance factor. This is a better allowance standard than simply the use of the release mortality rate that has been alternatively proposed (e.g., Initiative 640) , since the latter standard might leave unaffected specific fisheries that kill unacceptable numbers of chinook by some combination of a high absolute shaker rate yet a low release mortality rate. Agreeing upon the protocols for estimating the mortality parameters for each fishery, as well as the allowable mortality factor common to all fisheries, will require considerable fair-minded exchange among all affected groups. Without acceptance of fundamental principles as starting points, it is unlikely that agreements will be reached. These fundamental principles are that (1) fisheries should minimally exploit immature chinook either directly or indirectly to the catching of mature chinook or other salmon and (2) a common, minimum allowable percentage of targetted catch should apply to all fisheries. A reasonable test of the null hypothesis that a virtual closure on marine capture of chinook salmon by everyone is the only solution to the decline in abundance of wild chinook, would be to convene such a meeting of minds as soon as possible and see if agreements can be reached.

MASS MARKING

Mass marking has received considerable attention as one alternative for decreasing the harvest rate on wild salmon while allowing continued fishing on hatchery fish. All hatchery-reared chinook (or coho, or both) from some particular system such as the Columbia River or Puget Sound, would be given an external mark prior to release, such as removal of the adipose fin. Ideally, if there was negligible mortality from catching, handling, and releasing salmon, then the distinguishable hatchery fish could be selectively harvested while the unmarked, wild fish would be released to spawn. Unfortunately, there is substantial mortality associated with capture and release of immature chinook, in all fisheries. Thus, promoting mass marking as a management panacea for chinook salmon, without first developing a new regime of management grounded in the biologically-sound principle of the mature-fish standard, would be irresponsible fishery management. For fisheries that target immatures, or where there is too great a mix of immatures, wild fish might suffer excessive mortality rates through multiple gear encounters as juveniles, and relatively high probability of mortality at each encounter.

Other concerns are cost, mortality during the marking process, enforcement, and effect on the coast-wide coded wire tagging program, which uses the adipose mark to identify fish bearing the internal tags.

If present hand methods of fin clipping were to be used, the cost of mass marking would represent a significant percentage of the hatchery operating costs.

Since money is scarce, it is probable that the cost of mass marking would be borne from current hatchery operating costs, and hatchery output would, therefore, decline directly with the cost of marking. Consider this: Hatchery operating costs (feed, personnel, electric power, drugs, etc.) currently average about $3.00 per pound of chinook, coho or steelhead smolts (H. Senn, Olympia, WA, personal communication). Chinook are released at an average size of about 50 smolts per pound. Thus, hatchery operating costs are on the order of $.06 per chinook smolt. Adipose fin marking costs run about $.023 per fish, including supervision and administration (L. Blankenship, WDF&W, Olympia, WA). With marking, total cost per smolt would, therefore, rise to $.083, and the hatchery output would have to be reduced by about 28% if the operating budgets were not increased to cover marking costs.

However, there is a better mousetrap in the pipeline. An automated, mechanized system has been built and tested, which has the potential for adipose marking (and/or coded wire tagging) 50,000 smolts per day with one skilled operator and an assistant (P. Bergman, WDF&W, Olympia, WA, retired, personal communication). This machine is rather complex, and no estimate of its cost in a production scale application is yet available. It appears capable of marking fish with no greater handling mortality than that of hand marking (1 or 2%). In its present stage of development, it can place coded wire tags in fish at close to 100% success rate, but it can presently achieve only a 60% success rate with adipose fin removal. With relatively straightforward refinements, requiring perhaps a year of additional development and testing, this machine will be able to adipose clip at a satisfactorily high rate (L. Blankenship, WDF&W, Olympia, WA, personal communication).

Even though personnel requirements would be less than with hand marking, the required skill levels would be greater and the equipment amortization and maintenance expenses would be substantial." I foresee that the costs of adipose fin marking would be reduced by no more than 50% using mechanized marking. Under this scenario, marking costs per fish would drop to $.0115 per fish. Total operating costs would be $.0715 per smolt, and hatchery output would have to be reduced by 16%to meet the costs of mass marking chinook salmon within current operating budgets.

Reducing hatchery production by 16-28% to cover the costs of mass marking would probably not reduce adult production by an equivalent rate, because post-release survival tends to rise as rearing density declines. It is conceivable, in fact, that adult production from a hatchery system might not decline at all, particularly if marking costs were absorbed sensibly by reducing production disproportionally among hatcheries. Those with histories of low survival would be reduced the most, etc. Furthermore, if the allowable harvest rate on hatchery fish in mixed wild/hatchery fisheries increased due to mass marking, the net effect could be a greater adult contribution rate to the fisheries from the hatchery system.

Marking by either machine or hand stresses the fish. To the direct loss of about 1-2% during the marking process, one must weigh in a risk factor to account for the increased likelihood of a disease outbreak resulting from stresses of crowding and individual handling. Perhaps for the first ten hatcheries, there would be no such problem, but for the eleventh, a serious loss might occur. It is hard to put a numerical value on such risk, but any experienced hatchery person knows that crowding, exciting or stressing fish in anyway should be avoided to have a high probability of getting the fish out in good health.

Enforcement is yet another concern. Will fishermen have enough integrity to throw back that 50-pound, unmarked wild fish? How often in our fishing lives do we actually encounter an enforcement officer? Fundamentally we must ask how great a leap of faith in human nature are we willing to take, given the severity of the status of so many wild stocks. One reassuring circumstance is that selective fishing for hatchery steelhead, using the adipose marker system, has worked well according to experienced creel samplers (T. Mathews, WDF&W, Forks, WA, personal communication).

The final concern is that mass marking could compromise the CWT program. The presence of the adipose marker makes it easy for samplers to find fish with the internal tags. If all hatchery fish were adipose marked, in addition to those with tags, an improved system of tag detection would be needed. Such a system, if not fully developed, is technologically quite feasible (P.Bergman, personal communication), and of all the mass marking concerns, its interference with the current CWT program may be relatively easy to surmount.

It is my assessment that mass marking would be a desirable adjunct to chinook salmon management if and only if there were an overriding mature-fish standard governing the deployment of all types of fishing gear. Regardless of what sport or commercial fishery is considered, the catch-and-release mortality rate on immature chinook is too great to encourage fisheries on mixed wild and hatchery immatures with the hollow promise of it being acceptable, as long as unmarked fish are returned. However, available evidence indicates that mature chinook could be released from hook-and-line as well as purse seine or beach seines with sufficiently low mortality, (specifically with proper education and enforcement). cannot foresee circumstances where mortality due to gillnet release would be low enough to warrant release of the unmarked, wild chinook; however, with the improved survival of wild chinook through the other fisheries from wild release, and the improved survival of both hatchery and wild chinook from reduction of immature capture, gillnet fishers would benefit also.

DO WE REALLY NEED THE MATURE FISH STANDARD?

For the salmon fisheries of Washington, which are already heavily restricted compared to the past, I have recommended an even more austere set of regulations to specifically reduce the targeted and incidental fishing mortality on immature chinook (Table 6 summarizes these). Probably no one would argue against reduction of incidental mortality, but a fair question is "do we really need to stop targeting on immature chinook?" After all, a salmon is just as dead if caught as a five pound two-year-old as if caught as a 20 pound four-year-old. Couldn't we just as well achieve optimum spawning escapements in our wild populations by cutting back fishing mortality at all ages? Why the concern specifically for immatures? Furthermore, why don't we simply mass mark the hatchery fish, release the unmarked wild fish, and keep on catching the hatchery fish as immatures as well as matures?

I'll summarize the current report from the perspective of the above questions.

First, the catching of immatures probably has had and would continue to have selective effects on the populations, tending to reduce the reproductive potential of the average spawner. Such effects are decreased age at maturity, body size, egg number, and viability; imbalance of males over females; and less obvious, correlated genetic effects more likely to decrease survival probability than increase it. The scientific evidence for these effects is not certain and may even seem scant. But the observed effects are as one would predict, given how the fisheries operate. Furthermore, why take chances with these valuable resources, particularly since we can catch any biological surplus in either wild or hatchery stocks as mature, larger individuals later on in their lives.

Consider also that the negative effects of selection against older maturation age, faster growth etc. by harvesting as immatures would follow for hatchery and wild stocks alike. Do we want smaller, less fecund fish in our hatchery chinook populations any more so than in the wild? Increasingly, we are looking on hatcheries as the means to supplement impoverished wild stocks. Shouldn't we strive to maintain population characteristics in the hatchery stocks as similar as possible to wild stock characteristics? Mass marking, with continuing immature harvest allowed, could increase negative selection pressures by increasing the fishing pressure even above current levels.

Mass marking, to allow release of wild fish but retention of immature and mature hatchery fish, sounds appealing at first. But who has promoted this concept and why? It is an agency proposal and could be an attempt to find an easy way out of a hard job. The hard job is the restriction of harvest. It is not easy to tell people to cut back or change their fishing ways. Marking a bunch of fish, particularly if you can get Federal or BPA money to do so, is a lot less controversial. Mass marking is a perfectly sensible adjunct to a chinook rebuilding program if that program also includes reduction of immature harvest as a first principle.

In addition to the concern expressed above that selection for negative traits in hatchery stocks could follow from immature harvest, is the concern that released, immature, wild chinook would suffer relatively high hooking and handling mortality-up to 30% per encounter according to the most recent, objective review of available research (Pacific Salmon Commission, 1997). I have eye-hooked and descaled too many small chinook in my decades of commercial trolling and sport fishing to dispute this concern. Planting large quantities of marked hatchery fish would probably increase fishing effort, other things being equal. This would increase probability of multiple fishing gear encounters for wild fish, and with the high indicated probability of death at each encounter even if released, the resultant fishing induced mortality could end up higher than before. Reducing the capture rate of all immatures would seem mandatory, unless new protocols for benign capture and release were developed and proven successful. But even in this latter case, catch-and-release of both hatchery and wild stock immatures would be advisable, since negative selection pressures are as likely for either hatchery or wild chinook. [1]

Next, we need the mature standard across all fisheries to remove excuses for continuing wasteful fishing practices. I am still allowed to gillnet all night in Puget Sound even though most of the chums I catch come in the daylight or the change of light hours, while the blackmouth are caught during hours of darkness. Few people yet seem concerned that catch rates up to 10 or 20 sublegals for every legal chinook using downriggers remain common. Strait of Juan de Fuca tribes continue to target chinook in their winter troll fisheries with a 22-inch (four pound) minimum size limit. I could not convince anyone to consider a plugs-only restriction for last summer's Pacific Fishery Management Council's troll fishery, which would not only have reduced the chinook shaker catch, but also would have cut down significantly the incidental catch of protected Oregon coho, which seem destined for endangered species listing. For these reasons, as well as on-going habitat degradation, I remain pessimistic about the future of chinook salmon, most specifically in Washington, but elsewhere as well. We need biological standards for harvest management that allow no fishing group a. hiding place. As long as sportsmen have a 22-inch size limit, so will tribal trollers. What's wrong with my downrigger if seiners are continuing to gill blackmouth? And so forth. The need for the mature standard has long been obvious to thoughtful biologists; it is the best harvest management alternative I can offer for agency and individual lethargy and finger pointing.

Finally, I believe that such a standard applied internationally may pave the way toward a U.S.-Canada accord on management of chinook and other salmon. So far, allocation issues have driven the continually dead-ending salmon negotiations. The mature standard as a debatable issue at least would get us back on track for placing the biological needs of the fish ahead of the wants of the fishers and politicians.

Yes, adoption of the mature-fish standard is a critical cornerstone for rebuilding and perpetuating wild and hatchery chinook stocks.

ADDENDUM:

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[1] Selectively harvesting hatchery steelhead while releasing wild steelhead, a successful application of mass marking, is not an analogous situation since all such steelhead are mature at capture, unlike the present chinook situation. The hook-and-line release mortality rate is much less on the mature steelhead (about 5%) compared to that for immature chinook, and there is no induced selectivity against older age or slower growth in the steelhead situation, in contrast to the likelihood of this for the immature chinook harvest situation.

In emphasizing harvest management in this report, I do not intend to leave the slightest impression that the decline of chinook salmon can be unequivocally reversed by simply improving the harvest regime. I have seen too many streams run brown today from even moderate rainfall, when in the past they remained clear in heavy rainfall. Nor do I see the same abundance of aquatic life - minnows, crayfish, and insect larval - when I walk the streams today, as I did in earlier years. Many streams and rivers are sick.

The over-reaching effect of habitat degradation on salmonid abundance is brought home in a series of recently published case studies of declining chinook and coho stocks in northern Puget Sound streams (Pacific Fishery Management Council, 1997). The replacement rates (numbers of adults produced per brood year spawner) are dropping so fast in several cases that even if all fishing ceased tomorrow, stock recovery would be in doubt. Although uncontrollable marine factors may play a part, the degradation of freshwater productivity is without question the major cause. In Table 7, I have listed the major elements of degradation, identified in the PFMC report, for Skagit and Stillaguamish chinook, and the human activities responsible. I present these familiar lists, which would apply equally to thousands of other NW streams and rivers, to bring some closure to my repott and to remind the careless loggers and dam builders that they are part of the problem.

In fact, careless logging, careless land development, and careless fishing are generically the same sort of human activity; a fish is just as dead from an ill-deployed net or hook, as from siltation suffocation. Irresponsible logging, land development, and fishing are all attempts to put the cost of natural resource utilization on someone else. These activities, carelessly executed, do not express regard for the resource or for other people who might want to enjoy these fish in the future.

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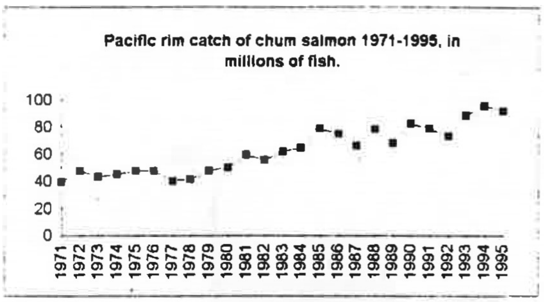

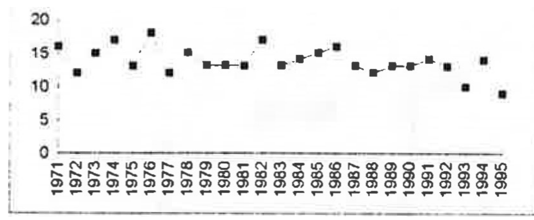

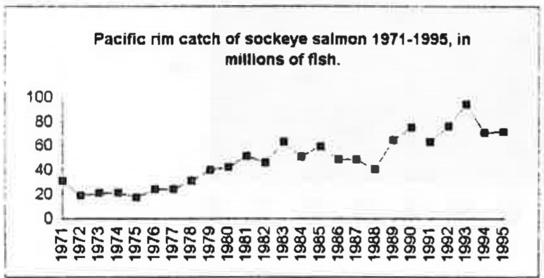

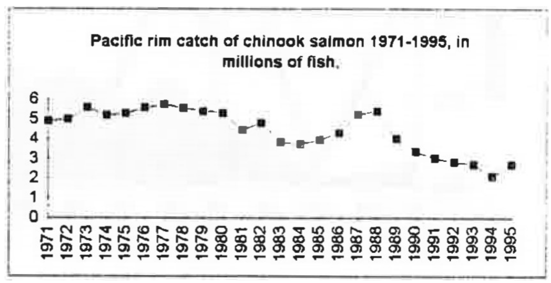

Pacific rim catch of coho salmon 1971-1995, in millions of fish

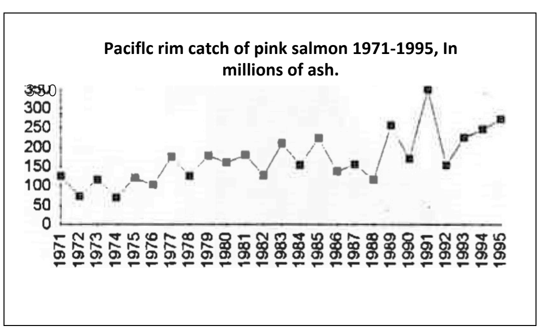

Figure 1. Total North American and Asian catches of Pacific Salmon, 1971-1995. Values are numbers of fish caught by all sport and commercial fisheries. (Source: Dr. DO Rogers, University of Washington Fisheries Research Institute, personal communication).

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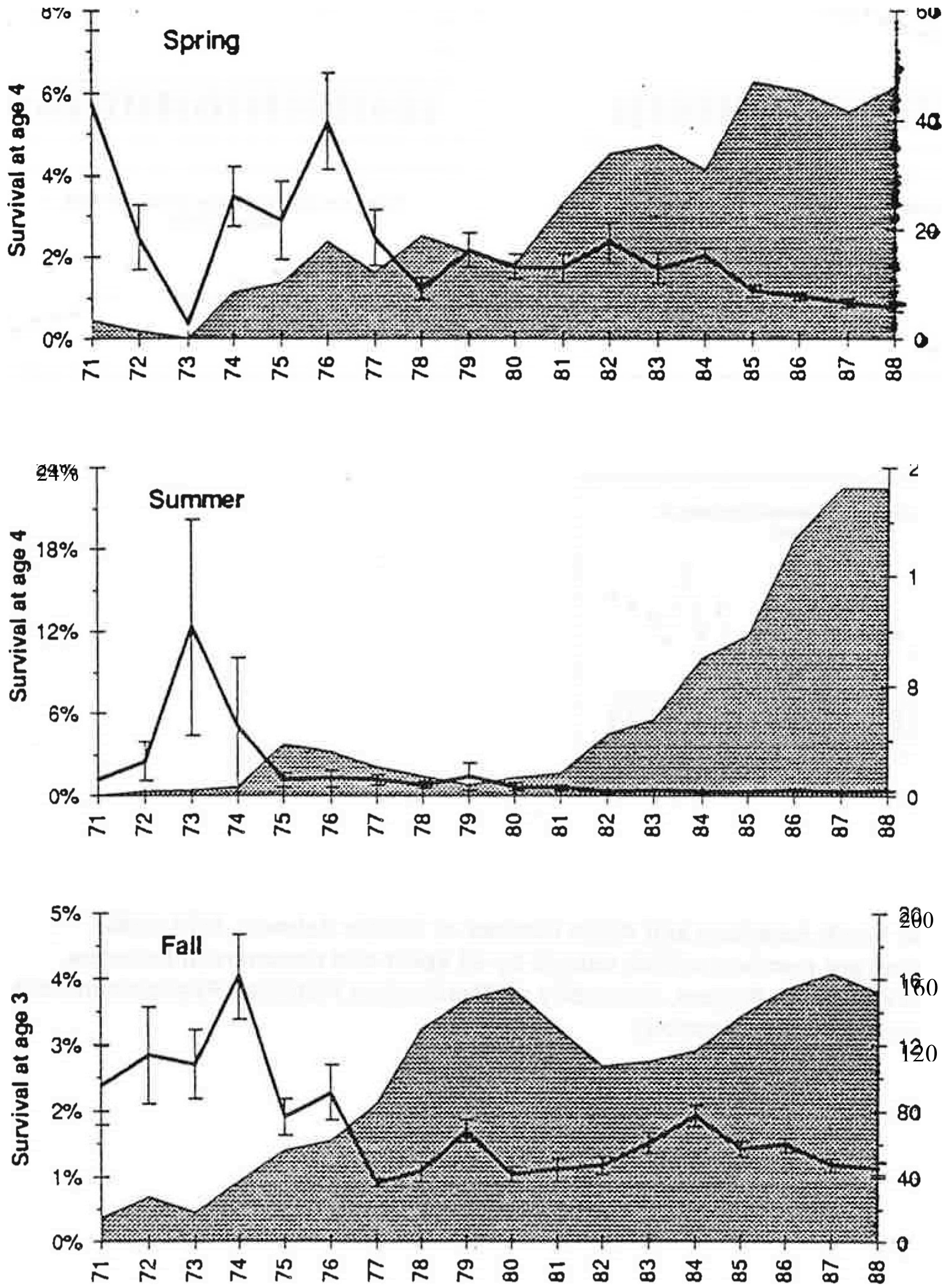

Figure 2. **Survival trends of North American hatchery released chinook salmon smolts. Line represents survival rate, error bars are the standard deviation of the mean, shaded area is millions of fish released by brood year. (From Coronado-Hernandez, 19$)**

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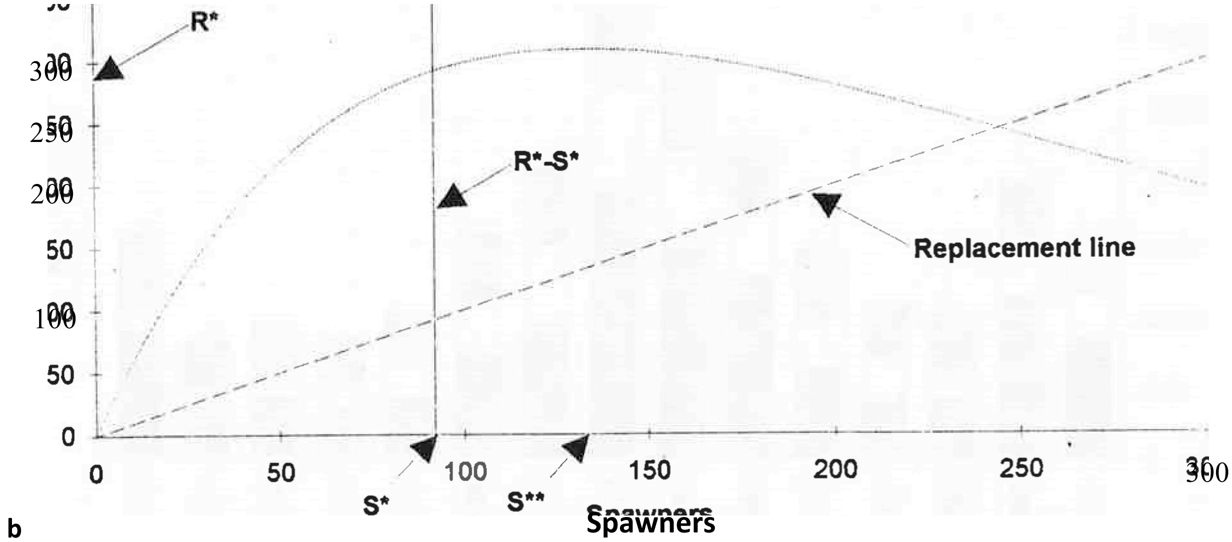

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Figure 3. Spawner-recruit curve, showing replacement line, optimum spawning level (S'), maximum surplus and spawning level for maximum recruitmentS).**

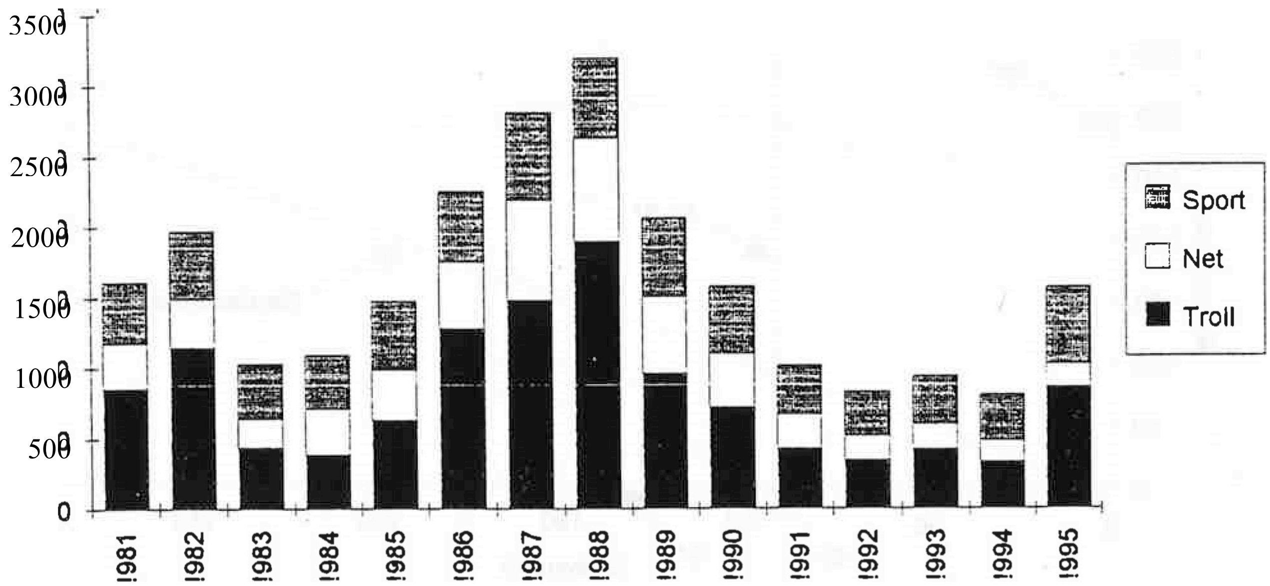


Figure 4. California, Oregon and Washington landed catches of chinook salmon by major gear type, in thousands of fish.

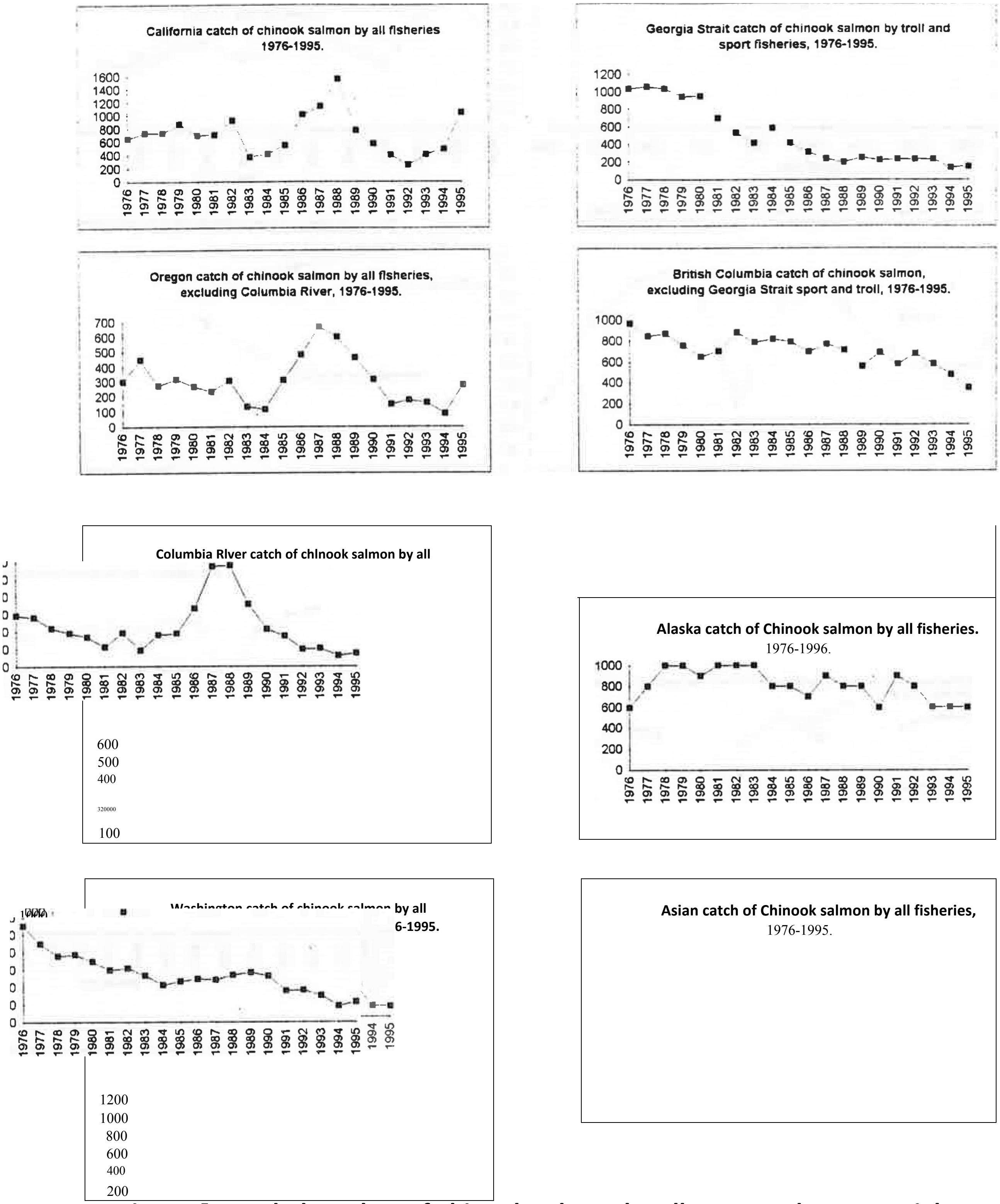
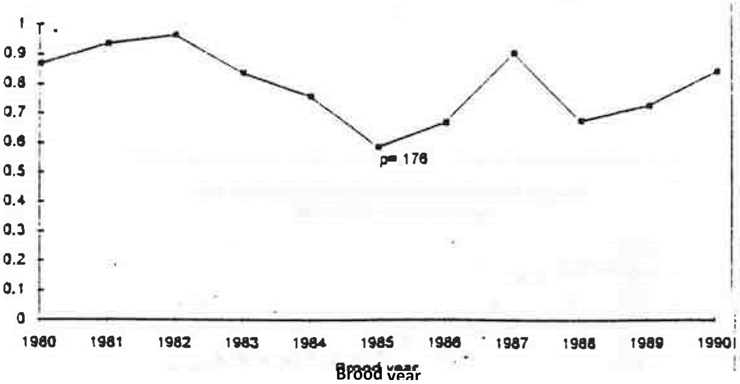
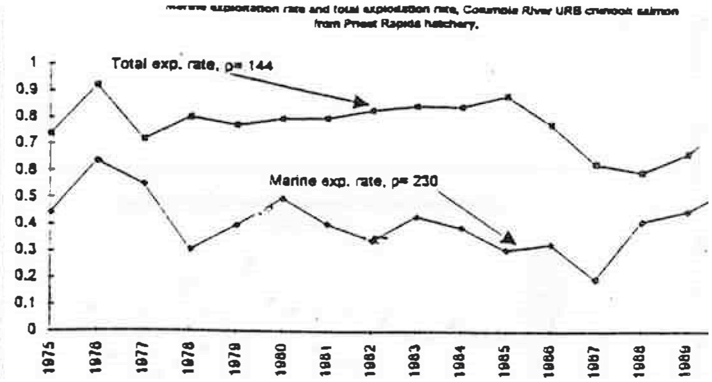
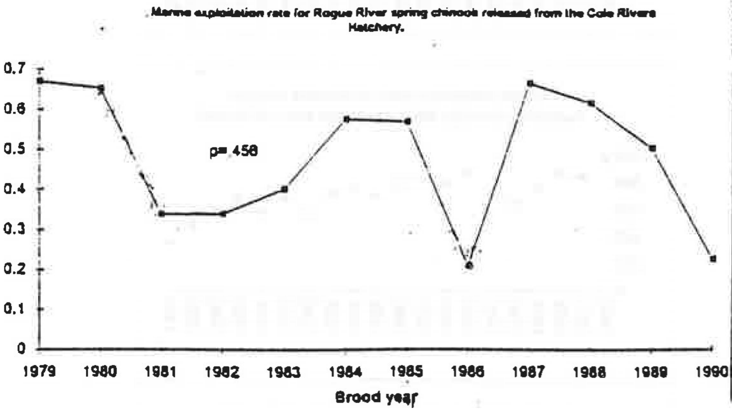
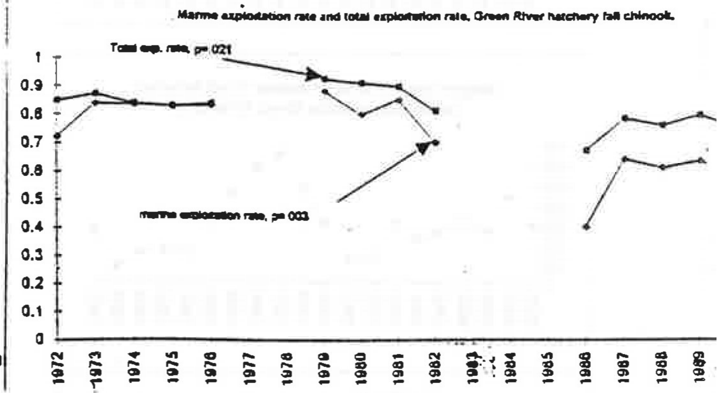


Figure 5. **Landed catches of chinook salmon by all sport and commercial gear, by region, in thousands of fish for years 1976-1995.**









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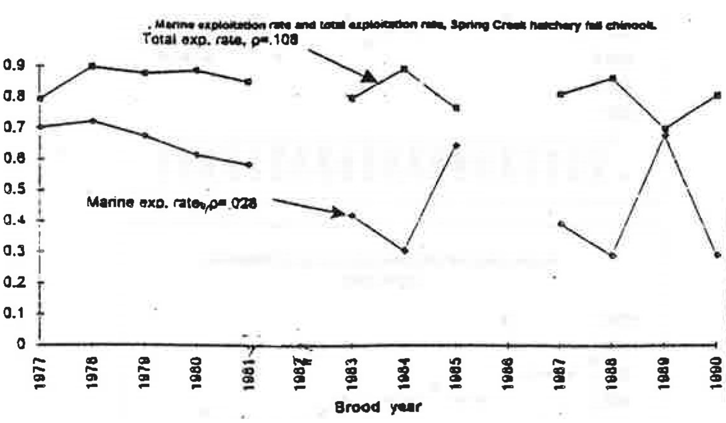

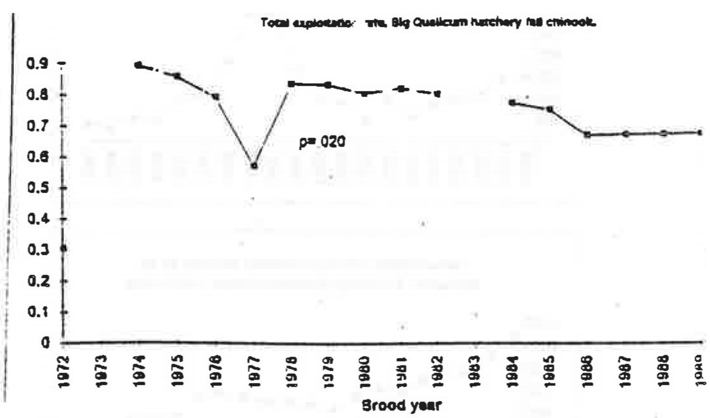

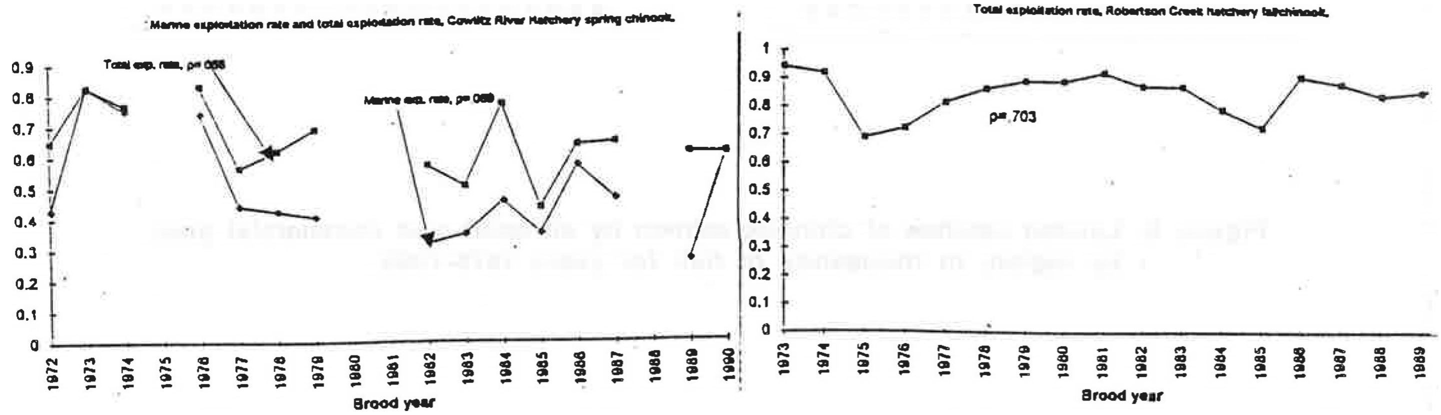

Figure 6. Total exploitation rates and marine exploitation rates for selected stocks.

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hatchery chinook

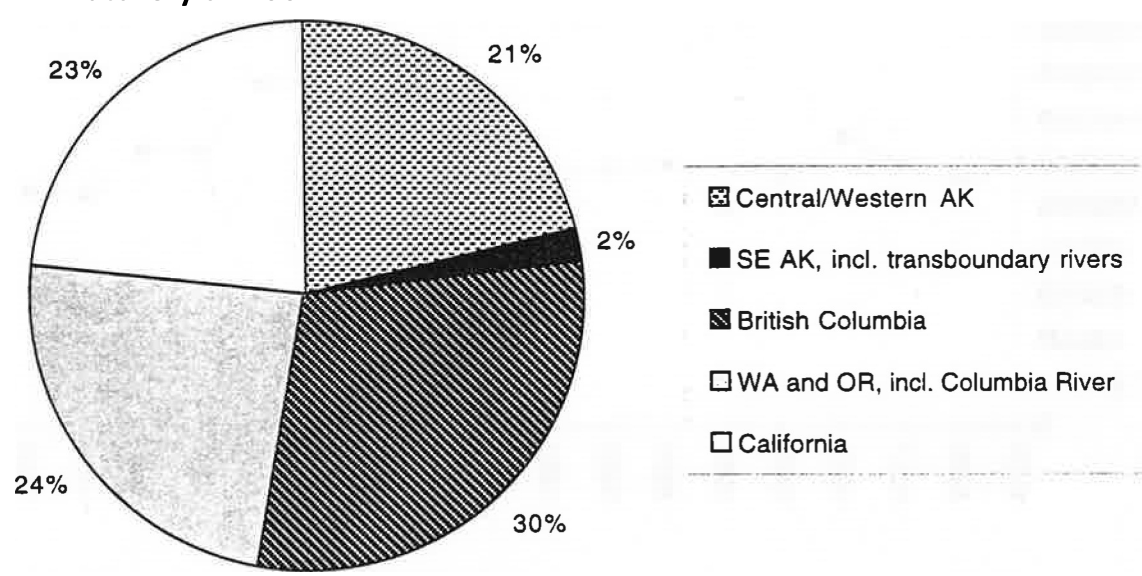

Figure 7. Natural chinook salmon spawning escapement distribution by major region, 1975 - 1994.

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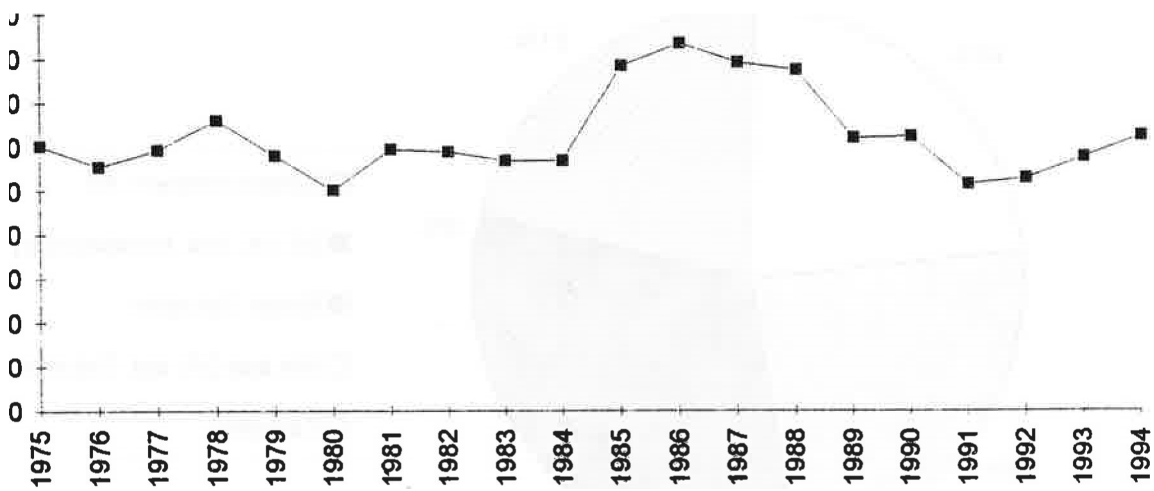
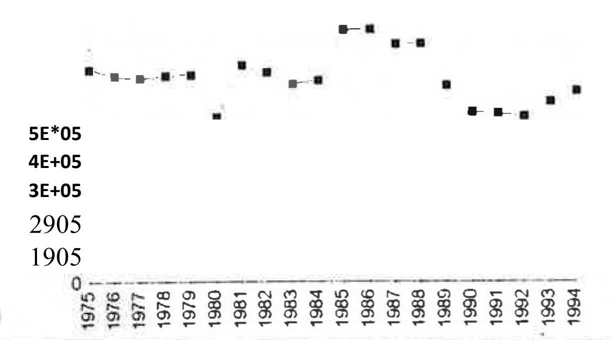
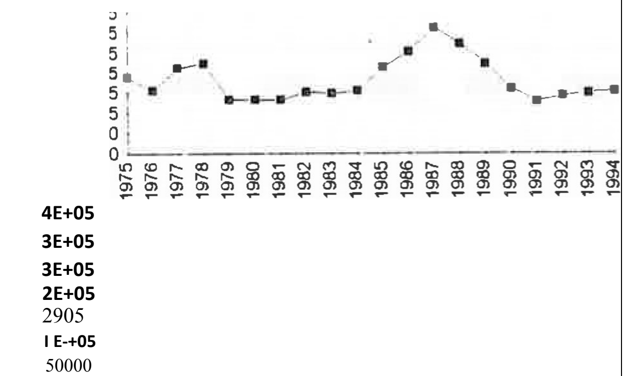


Figure 8. Natural chinook salmon spawning escapement from California to western Alaska, 1975-1994, in numbers of fish.

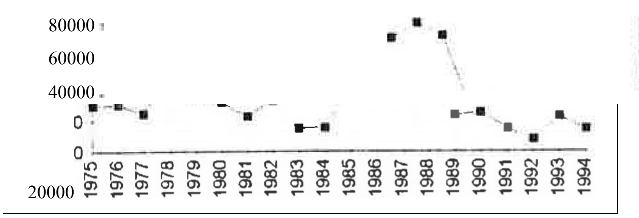
Natural chinook salmon spawnjng escapement
to California



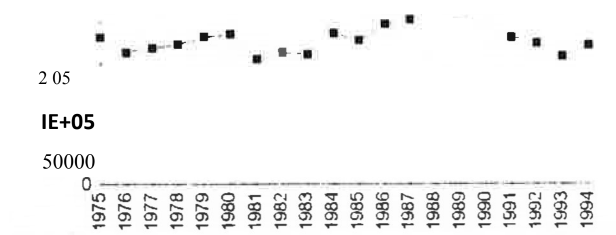
Natural chinook salmon spawnlng escapement to
Columbia River



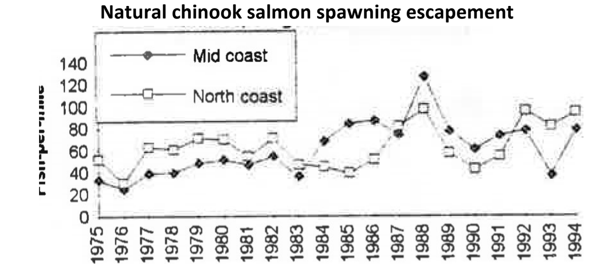
Natural chinook salmon spawning escapement to
Rogue and Umpqua Rivers



Natural chinook salmon spawnlng escapement
to Washington, excluding Columbia River.

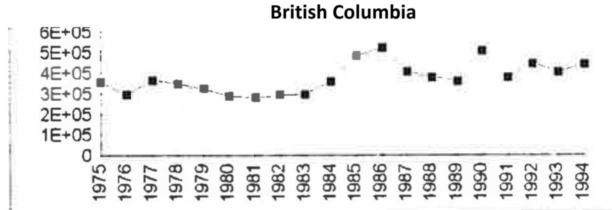


Natural chinook salmon spawning escapement

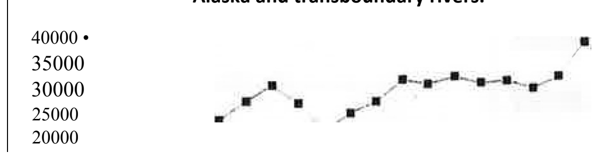


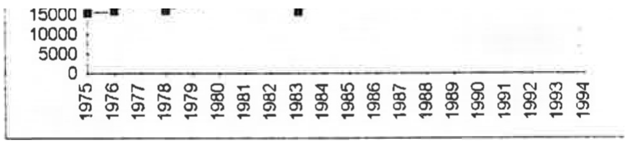
indices, Oregon north and mid coast

Natural chinook salmon spawning escapement to
British Columbia



Natural chinook salmon spawning escapement to SE
Alaska and transboundary rivers.





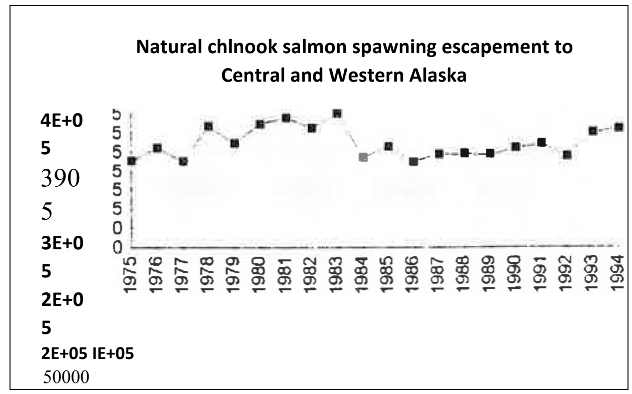
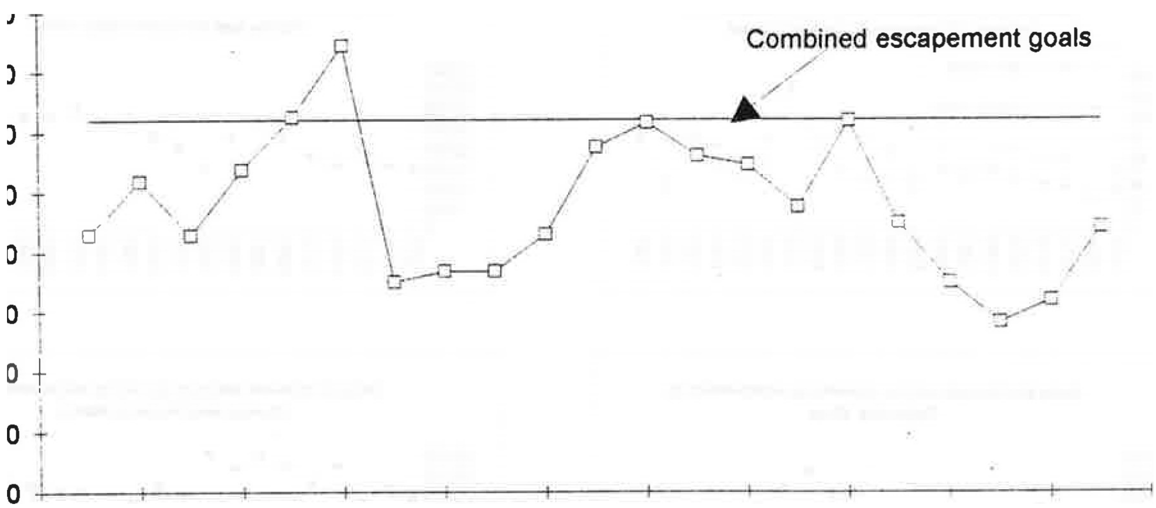


Figure 9. **Trends in natural chinook salmon spawning escapement by region, 1975-1994, in numbers of fish.**



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20000
15000
10000
5000

1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996

Figure 10. Combined natural chinook salmon spawning escapements to the Skagit, Stillaguamish, Snohomish, and Green Rivers, 1975-1995, in numbers of fish.

Table 1. Average total length(in.) and weight(lb.) at age, for fall and spring chinook. Values are composites from many stocks and maturity types.

Fall chinook

Length		24	31.3	38.2	42	4
Weight	0.3	5.7	12.4	22.2	29.7	3

Spring chinook

2 3

Length		18	27.9	35.2	39.9	42.9
Weight		2.5	8.6	16.5	23.5	28.9

TABLE 2: Past and present average round weights (lbs.) by age at maturity, for Columbia River spring and fall chinook.

Age	2	3	4	5	6
Spring					
Past		4.82	1 4.1 5	28.38	40.65
Present	-	4.33	1 2.1 8	19.74	**Not sampled**
% decrease	-	1 0.2%	1 3.99%	30.4%	
Past	2.48	1 3.70	23.27	34.62	63.48*
Present	3.09	1 0.02	21 .80	29.9 5	34.61
% decrease	-	25.5 %	6.3%	1	

Cone fish only)

TABLE 3: Average ages, lengths, weights, and egg numbers for Columbia River spring and fall chinook.

	Age	**Fork Length (in.)**	**Round Weight**	**Egg No.**
Spring				
Pa St	5. 3	41 .4		6,900
Present	4.3	31 .2	1 4.4	4,600
% decrease	1 8.9%	24.6%	55.1 %	33.3%
Fall				
Past	4.2		25.5	5,800

Present	3 . 9		20.6	5,300
% decrease	7.1 %	7.1 %	19.2%	

Table 4. Worksheet to demonstrate theoretical fishing yields from a cohort of four-year-maturing chinook salmon that is fished continuously for its last two years at sea.

Time	Age	Weight	Survival rate	Cohort abundance	Allowable fishing rate	Catch in numbers	Average weight per fish	Weight of catch	Value per 1b.	Value of catch
Fall, year i	2	5.7 lbs.		4687						
			46.20%		38.30%	1795	9.05 lbs.	16245 lbs.	$1.25	$20,306
Fall, year i+l	3	12.4 lbs.		2165						
			46.20%		38.30%	829	17 3 lbs.	14342 lbs.	$1 75	$25,098
Fall, year i+2	4	22.2 lbs.		1000						
Total						2624		30587 lbs.		$45,404

Table 5. Worksheet to demonstrate theoretical fishing yields from a cohort of four-year-maturing chinook salmon that is fished continuously for its last two years at sea, with incidental mortality equivalent to 30% of catch.

Time	Age	Weight	Survival rate	Cohort abundance	Allowable fishing rate	Catch in numbers	Average weight per fish	Weight of catch	Value per 1b	Value of catch
Fall, year	2	5.7 lbs.		4687						
			46.20%		29.50%	1383	9.05 lbs.	12516 lbs.	$1.25	$15,645
Fall, year i+l	3	12.4 lbs.		2165						
			46.20%		29.50%	639	17.3 lbs	11055 lbs.	$1.75	$19,346
Fall, ar i+2	4	22.2 lbs.		1000						
Total						2022		23571 lbs.		$34,991

Table 6. Regulations for Washington fisheries to reduce targeted and incidental fishing mortality on immature chinook.

* Establish a uniform 28-inch size limit
* Ban treble hooks - use only single barbless hooks
* Ban downriggers
* Ban flashers for sport and commercial gear
* Close winter fishing for all gear
* Condense summer troll season
* Enforce use of shallow, rubberized landing nets
* Require 6-inch or larger plugs for commercial troll
* Allow only daytime gillnetting - tribal and non-tribal
* Reduce depth of all tribal and non-tribal gillnets and purse seines to 50 feet
* Strictly enforce minimum mesh sizes
* Establish 5% incidental immature chinook catch allowance for all fisheries - close fishing in those areas or times when this catch is exceeded.

Table 7. Important elements of freshwater habitat degradation in the Skagit and Stillaguamish Rivers, and the human activities responsible.(Pacific Fishery Management Council, 1997).

Elements of Degradation

Increased sedimentation
Decline in bed particle size
Reduction in pool area, depth and numbers
Loss of natural streambanks
Loss of side channels
Loss of tributary access
Loss of tidal marshes
Physical modification of river channel
Loss of large woody debris
Increased summer temperatures
Greater flow extremes, both low and high

Human Activities Responsible for Degradation.

Livestock grazing
Bridge and road building
Salvage logging Deforestation
Tributary dam building
Agricultural and urban diking