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CHAPTER 9. HARVEST MANAGEMENT

"The way in which the Chinook salmon runs have held up under the excessive exploitation and a constant reduction in the available spawning area is remarkable."

Rich, Willis. H. 1941. The present state of the Columbia River salmon resources. Pages 425-430. *Sixth Pacific Science Congress*. Fishery Commission of the State of Oregon, Berkeley. (p. 429).

Harvest and Mortalities to Salmon

Salmon are harvested by many different activities in the Columbia River Basin. Intentional, or directed, harvest of adults and immature salmon for commercial, subsistence, ceremonial, and recreational purposes has occurred since time immemorial. Records of intensive commercial harvest dating from 1865 to present are readily available (Craig and Hacker 1940; Chapman et al. 1991; Chapman et al. 1994a; National Marine Fisheries Service (NMFS) 1995; National Research Council (NRC) 1996). Unintentional, or incidental harvest of salmon occurs in those activities which are not intended to capture the salmon species or life history stage which is taken. Incidental harvest of Columbia River salmon occurs in marine and freshwater fisheries for other species of fish, during salmon fisheries targeted on older life history stages of salmon, in the production of electricity at hydroelectric dams, during and after logging operations, during and after irrigation withdrawals, during land development operations such as road and real estate building, and during and after some types of mining operations.

Directed harvest

For the past several human generations, the number of salmon harvested in directed salmon fisheries has often been counted or estimated in an attempt to determine whether or not the productive capacity of the populations was being exceeded (Ricker 1954b; Beverton and Holt 1957), as well as for other purposes, such as taxation. The directed harvest estimates were made because in theory, and in practice, it is possible to harvest at a rate high enough to diminish a salmon population's spawning potential and to cause it to be extirpated (Cushing 1983). It was also assumed that the principal source of human-induced mortality on salmon were the directed harvests, hence it was assumed that the health of the salmon populations could be assured through appropriate limitations on directed harvests (Mundy 1985).

*Interactive E*ffects

In the Columbia River basin it is clear that directed harvest is only one of many sources of mortality, and it follows that all sources of mortality should be accounted for in order to permit the persistence of the salmon. In practice, all human induced mortalities are measured to the extent possible, with all remaining sources, such as predation by marine mammals, being attributed to natural mortality. Clearly traditional harvest management, which seeks only to control directed sources of fishing mortality (Ricker and Smith 1975), is not sufficient to provide for the sustainable production of the Columbia River basin's salmon. However the principles of sustainable harvest management (Beverton and Holt 1957; Cushing 1983) need to be carried forward in framing a harvest management paradigm which is appropriate to the persistence of the full diversity of species and life history types of the basin's salmon. Ricker (1958) examined the effects of a fluctuating environment (variable mortalities induced at early life stages) on the productive capabilities of fish stocks.

Ideals from traditional harvest management that need to be retained relate to protecting all identifiable populations, and accounting for all sources of fishing mortality. Specifically, the ideal of limiting fishing mortality to a level which permits persistence of the smallest identifiable stock, also called a deme or population (National Research Council (NRC) 1996), a spawning aggregate of a life history type of a species, needs to be retained. In practice, fisheries management agencies have defined stocks as some identifiable aggregate of local spawning populations. The number of populations in the pragmatic stock definitions might be more a function of logistic considerations and the amount of funding available for monitoring than of biological considerations. It is now essential that the definition of a stock consider the biological criteria engendered by Endangered Species Act definitions of stock, such as the Evolutionarily Significant Unit (ESU) (Waples 1991a; Mundy et al. 1995a; National Research Council (NRC) 1996). The practice of monitoring the populations, which includes counting or estimating the harvests by each of the "fisheries," needs to be retained. It is critically important for salmon recovery that the concept of “fishery” be extended to cover both the incidental and directed removals of salmon at all life history stages.

In addition to applying the principles of traditional harvest management, understanding the interactions and dependencies between harvest, the health of habitat, and the productivities of salmon populations is essential to improving our abilities to identify and implement salmon restoration efforts (Ricker 1954b). In examining the Columbia River Basin, habitat loss and degradation, and unlimited fishing emerge as parallel companions of the initial decline in population numbers of the principal commercial salmon species (see Chapter 5 on freshwater habitat). The evolution of harvest management protection for naturally spawning Columbia

River basin salmon was restrained by increases in hatchery production during the 1960s. The large numbers of hatchery salmon drove the public policy process to sanction intensive fisheries on mixtures of hatchery and natural salmon that obscured the downward trends in production of the natural salmon populations. In the present, continuing habitat losses combine with ineffective harvest regulation as probable causes for the continuing failure of Columbia River chinook salmon. Therefore, an effective harvest management paradigm cannot be developed outside of an ecosystem context.

Overfishing and Interactions with Habitat Loss

Harvests impact salmon productivities directly by reducing the numbers in the spawning populations, and indirectly by reducing the diversity of phenotypes in the population, which impacts factors important to basic productivity, such as average number of eggs per female (Miller 1957; Ricker 1981; Cushing 1983, citing Russell 1931; Beatty 1992). Overfishing occurs when fishing removes enough spawners from a population to cause it to decline. Overfishing reduces the production of salmon by reducing or eliminating the populations which have adapted to the habitat types and environmental conditions of the basin (Ricker 1972; Riddell and Legget 1981; Thorpe 1995). As it has developed from the experience of the last three generations of fisheries scientists, and as harvest regulations increasingly reflect, management of salmon ought to protect the productive capacity of salmon runs by pursuing the reasonable and essential objective of protecting the genetic diversity of Pacific salmon populations on which production ultimately depends (Paulik 1969; Lande and Barrowclough 1987).

Prior to 1941, excessive harvest exploitation and widespread habitat degradation (see discussion in Chapter 5) acted synergistically to reduce abundance of Columbia River Basin salmon stocks. As early as the 1870s, there are observations consistent with overfishing of the salmon runs by the commercial fishery of the lower Columbia River, when Native American harvesters, who fished up river from the commercial fisheries, found they could no longer meet their basic subsistence needs for salmon (Simms 1877). Seventeen years later, biologists were looking to the lower river fisheries to explain sharp declines in salmon (particularly spring chinook and sockeye) returns to the Yakima River in Washington State (McDonald 1894). Information collected from the commercial fisheries of the lower Columbia River which would have permitted a quantitative assessment of its impacts on the salmon populations of individual tributaries was not available during the time of Simms and McDonald. Putting numerical values on the roles of overfishing and habitat degradation in the decline of salmon productivity remains difficult. To do so requires estimating the mortalities in each life history stage throughout the life of the salmon cohort. Unfortunately, even now we have the capability to do this for only a relatively few life history types of only a few species, such as fall chinook.

As late as 1936, salmon fisheries were an important part of the economy of the region, employing 3,820 harvesters, and generating $10 million annually for the regional economy (Craig 1899). Although Craig and Hacker (1940) recognized that preventing overfishing was important, the authors emphasized that maintaining suitable spawning and nursery grounds was of paramount importance to the success of salmon fishing in achieving conservation. Craig and Hacker discuss in detail human population growth, logging, mining, hydroelectric power, and flood control and navigation as causes for the decline in salmon resources during the nineteenth and early twentieth centuries.

With regard to factors contributing to the first major Columbia River chinook salmon harvest declines from 1884 to 1889, Craig and Hacker cite the reduction of late spring and early summer chinook by fishing, and reductions in fishing effort as a result of falling demand for the relatively highly priced Columbia River salmon. They also note that species identification of the early landings was not particularly accurate, which opens the possibility that the largest reported landing of Columbia chinook in 1883 could have included species other than chinook.

A contemporary of Craig and Hacker, Willis Rich (1941), linked habitat declines to fishing pressure as a source of decline,

> *"The way in which the Chinook salmon runs have held up under the excessive exploitation and a constant reduction in the available spawning area is remarkable."* (p. 429).

In the same paper Rich issued a prophetic warning to fishermen, laymen and administrators about the futility of trying to replace lost salmon spawning and rearing habitats with hatcheries.

Other contemporaries of Craig and Hacker also recognized the interaction between habitat loss and the effects of fishing in determining salmon population size. Johnson et al. (1948) stated with regard to Columbia River blueback (sockeye) salmon,

> *"The blueback is ... in an advanced stage of depletion. ... A very intense fishery, coupled with elimination of the majority of the important spawning grounds, has reduced the populations to a fraction of their former abundance."* (p. 16).

Johnson et al. (1948) did not express concern about trends in escapement of chinook as of 1935. Such concerns emerged in the literature during the 1950s, especially with respect to spring chinook (Thompson 1951).

Since the time of Craig and Hacker (1940), a number of authorities have concluded that overfishing was a factor in the decline of Columbia River chinook. William Francis Thompson documented declines in nominal landings per unit effort of spring and summer chinook between 1876 and 1919 that were clearly associated with declines in actual chinook population size (Thompson 1951). In a comprehensive review of the historical evidence for overfishing of

Columbia River salmon, Chapman (1986) joined Thompson in concluding that overfishing was a factor in the decline of chinook.

Historian Anthony Netboy (1974) reported that the chinook salmon runs of the Columbia River were overfished, and in radical decline, after 1885 (pp. 282-283). In addition, Netboy recognized the role of habitat loses in salmon declines by citing the U.S. Army Corps of Engineers "308 Report" of 1948 which documented the existence of over 300 dams of all types in the Columbia River basin at that time (p. 285).

After 1941, the negative impact of fishing on Columbia River chinook salmon appears to be well grounded in observation. For example, Van Hyning (1973) documented the increase of ocean fishing as the main contributor to the decline of Columbia River fall chinook, 1938 - 1959. By this time, fall chinook were the dominant race of chinook in the Columbia River drainages, runs of spring and summer chinook having been reduced in abundance over the preceding 70+ years. The ocean fishery clearly had a negative effect on run sizes during the period of Van Hyning's database. It is noteworthy that Van Hyning's analysis included indirect measures of the effects of habitat degradation, in addition to measures of landings and fishing effort.

In order to summarize the history of the rise and fall of Columbia River Basin chinook salmon fishery, the five year moving average of the annual landings is used to remove the short term noise in order to make the trends easy to see (Figure 9.1). There are five eras with starting years of 1866, 1884, 1921, 1932 and 1953. From its inception to about 1883, the fishery was reaping the benefits of harvesting relatively lightly exploited populations of chinook salmon. Although Craig and Hacker (1940) estimated annual aboriginal harvest at 18.2 million pounds of chinook (about 900,000 individuals), and while other sources have estimated higher levels of aboriginal salmon harvests (Schalk 1986), many of the aboriginal peoples had perished in epidemics prior to the growth of the commercial fisheries.

As an apparent response to exploitation, the decline of the populations to lower levels during the second era starting about 1884 appears also to have also coincided with declining salmon markets, reduced fishing effort, and substantial loss and degradation of spawning and rearing habitat. Annual landings during the last five years of this era were on the order of 1.5 - 2 million chinook, using a nominal average weight of 9.1 kg (20 lbs) per chinook. Note that Chapman (1986) used 10.45 kg for spring/summer chinook. Since the historical landings are reported in pounds, 9.1 kg per chinook was chosen for convenience in converting number of pounds to number of individuals. From 1884 until the end of the second era in 1920, the fishery was working at an apparent annual equilibrium landings level on the order of 1.25 million chinook. Although the total chinook landings oscillated about 1.25 million individuals, the stock composition of the landings was changing, with availability of spring and summer runs declining, and exploitation of fall chinook increasing to make up the difference (W.F. Thompson in Chapman 1986).

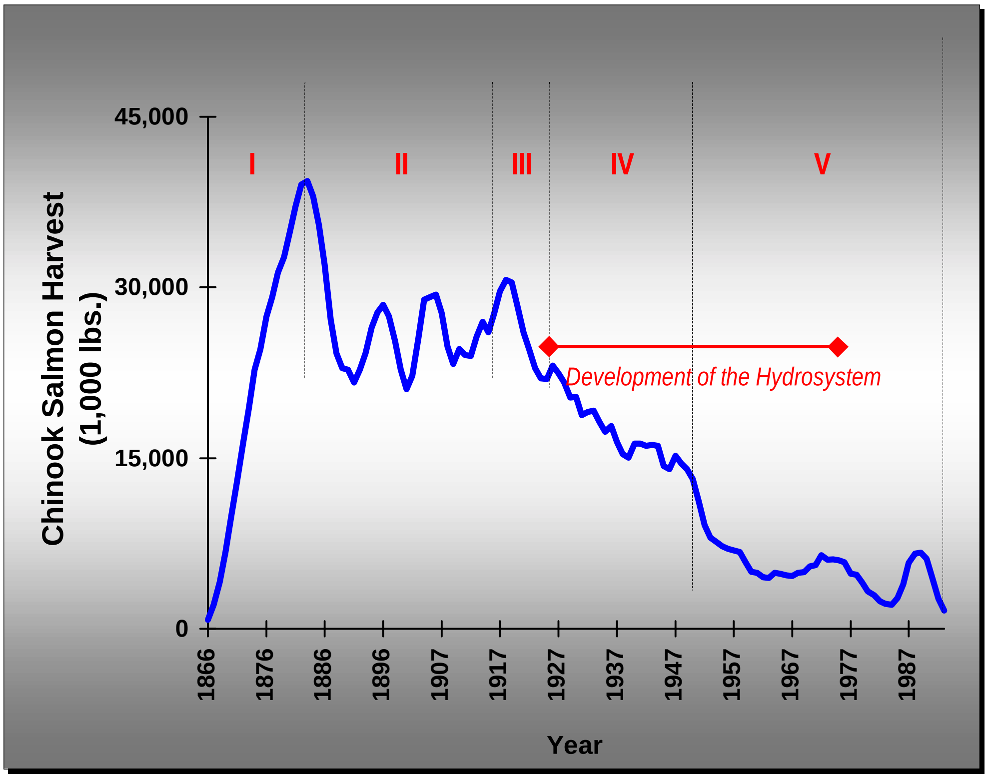

Figure 9.1. Five year moving average of landings of chinook salmon from the Columbia River in millions of pounds, 1866 to 1993.

The economics of World War I set in motion the events that closed out the second era with an increase in fishing effort both in the river, in the mouth of the river, and on the ocean (Craig and Hacker 1940). Increased demand for salmon products resulted in the final peak of the fishery. The year 1921, as fixed by the point where the five-year moving average of chinook landings last dropped below an annual harvest of 30 million pounds (1.5 million chinook, estimated), clearly marked the point where the Columbia River basin chinook populations started the slide toward extirpation, because it was at this point that the sum of the effects of accelerating habitat loss and degradation and ineffective harvest management regimes had converged to drive salmon population numbers below the critical point where they would have been able to replace their numbers from one generation to the next. Trends in marine productivity may have also been a factor exacerbating the effects of habitat loss and overfishing (Ware and Thompson 1991).

For the next three eras, from 1921 through the present, it is likely that overfishing joined forces with rapidly accelerating habitat degradation to cause lasting reductions in chinook population levels (Craig and Hacker 1940; Rich 1941; Van Hyning 1973). During the third era, 1921 - 1931, Columbia River chinook landings experienced a decline as sharp as that marking the beginning of the second era in 1884. The decline in landings in the third era is apparently related to decreased productive capacity of the populations, since there also appears to have been an increase in fishing effort during this time period (Craig and Hacker 1940). The five-year moving average of landings crossed the 20 million pound (1 million chinook, estimated) level at the beginning of the fourth era in 1932, a year which also witnessed the beginning of development of large hydroelectric dams in the main Columbia River. The first surge of big river dam building on the Columbia during this era brought operations at Rock Island in 1933, Bonneville in 1938, and Grand Coulee in 1941. Given the evidence of fishing being a primary factor in the decline of fall chinook salmon runs beginning in 1938 (Van Hyning 1973), the combination of big river hydroelectric development and fishing pressure led to the third collapse of chinook landings starting about 1941 (Figure 9.1).

In the year when McNary Dam went into operation on the Columbia River, 1953, at the start of the current, and fifth era, the five-year moving average chinook landings crossed the ten million pound mark (500,000 chinook, estimated), not to return to date. Although the Columbia River harvest of chinook in 1988 was 10.54 million pounds (489,000 chinook, actual), the five-year moving average was held down by the lower landing figures before and after 1988. The current era has seen most of the big river dam construction, with 15 dams being built on the Columbia and Snake Rivers from 1953 - 1975, a 500 percent numerical increase over the preceding era. Chinook salmon production during the current era would have probably fallen even more precipitously if salmon produced in hatcheries had not increased sharply after World War II, when a large number of federal and non-federal mitigative programs came into being.

Why Harvest Controls Have Failed to Reverse Declines in Salmon Runs

Harvest management of Columbia River chinook populations remains ineffective because the two principal harvest control entities do not provide harvest regulations which explicitly provide for salmon spawning escapements to individual tributaries, i.e. they do not manage according to the productive capacities of the individual stocks (Paulik 1969). Salmon harvest regulations under the Columbia River Fisheries Management Plan, CRFMP, (United States Federal District Court, Portland, Oregon), is implemented through the Columbia River Compact by state and tribal fisheries managers. The management actions of the CRFMP, as coordinated through the Pacific Fishery Management Council, PFMC, Portland, Oregon (PFMC 1996) and Pacific Salmon Commission (Jensen 1986; Pacific Salmon Commission 1993) provide for aggregated spawning escapements to large river counting sites, such as hydroelectric dams, not to tributary spawning grounds (PFMC 1996).

In addition to the lack of watershed specific escapement objectives, the harvest management of Columbia River chinook salmon under the Columbia River Compact and its coordinating entities, the PFMC and the PSC, has two fundamental shortcomings relative to salmon recovery efforts. The first shortcoming is that the impacts of PSC and PFMC harvests on the overwhelming majority of naturally spawning Columbia River Basin salmon stocks are not directly measured. Prior to about 1985 only hatchery salmon were routinely annually tagged with coded wire in numbers sufficient to permit their identification in the landings of ocean fisheries. After 1985, routine annual tagging programs were extended to some natural stocks, so that contributions of several naturally spawning Columbia River chinook stocks to ocean salmon landings can now be measured. Unfortunately, contributions to ocean landings of most naturally spawning salmon populations are inferred from landings of other, mostly hatchery, stocks that have been tagged with coded wire.

Many salmon hatchery stocks, and some naturally spawning stocks, such as the Columbia River Hanford Reach fall chinook, are tagged as juveniles with coded wire and fin clipped so that they can be identified in samples of fishery landings. Although hatchery stocks may be appropriate biological entities from which to infer the impacts of PSC fisheries on some naturally spawning populations, it seems unlikely that hatchery salmon stocks can be valid proxies for each and every natural salmon population of concern. For example, annual variations in oceanic distribution and migratory timings of life history stages are but two attributes for which differences between hatchery and natural populations could render any indices of fishing mortality, which are based on hatchery populations, invalid for naturally spawning populations. Further, even for a population which is tagged, if the life cycle is such that the landings of the individuals of legal size are out of proportion to the actual catches of the population, then the indices of fishing mortality will also be invalid.

The second shortcoming, the disparity between catch and landings in the PSC salmon fisheries and PFMC non-PSC salmon and groundfish fisheries (Table 9.1), is relevant to the Columbia River salmon recovery because catch and bycatch of Columbia River chinook salmon populations in PSC and PFMC fisheries is not being estimated. Catch is a measure of the number of salmon actually killed, whereas landings measure the number of salmon actually kept on the vessel. Landings is a fraction of the number of fish killed in any fishery, and the difference between catch and landings is called bycatch, or incidental mortality. In the PSC hook and line fisheries, a regulation requires the release of fish under a minimum size limit (shakers), and in some hook and line and net fisheries, no chinook salmon of any size are allowed to be retained (chinook non-retention, legal sized and sublegal sized; Table 9.1). Not all of the fish so released are expected to live, so the reported number of salmon landed is necessarily an underestimate of the number of salmon actually killed.

Table 9.1. Annual estimates of total landings, incidental catch by fishery category; shaker, legal, sublegal, total catch, total incidental catch, total incidental catch per total landing, I/L, and percent of incidental catch in the total catch, of number of chinook salmon in adult equivalents, for all Pacific Salmon Commission fisheries, 1979 - 1992.

	Type of Fishery							
	Retention		*Non-Retention*			*Incidental Mortality*		
Year	*Landed*	*Shaker*	*Legal*	*Sublegal*	*Catch*	*Incident*	*Index I/L*	*Percent*
1979	2365600	301995	0	0	2667595	301995	0.127661	11.32
1980	2251730	294866	0	0	2546596	294866	0.130951	11.58
1981	2189445	303828	4076	3032	2500381	310936	0.142016	12.44
1982	2287289	368901	23770	18315	2698275	410986	0.179683	15.23
1983	2205210	352261	29489	22839	2609799	404589	0.183470	15.50
1984	2186297	337119	31160	23640	2578216	391919	0.179262	15.20
1985	1851845	233542	41140	57518	2184045	332200	0.179389	15.21
1986	1926438	276115	27723	35470	2265746	339308	0.176132	14.98
1987	2050465	304586	57044	62858	2474953	424488	0.207020	17.15
1988	2114972	291768	34880	66431	2508051	393079	0.185855	15.67
1989	1741698	274492	42939	50345	2109474	367776	0.211159	17.43
1990	1740361	300181	36512	52113	2129167	388806	0.223405	18.26
1991	1584825	314182	49235	61889	2010131	425306	0.268361	21.16
1992	1583080	358163	62216	70382	2073841	490761	0.310004	23.66

Source: Computed from data on pages K-1 through K-14 of Pacific Salmon Commission (1992)

To appreciate the magnitude of the potential impacts of ocean fisheries on salmon stocks of concern, and the disparities between catch and landings, some estimates are available from the 1992 report of the PSC Joint Chinook Technical Committee are useful. For example, in 1992 it is estimated that the PSC sports fishery in the Strait of Georgia caught the equivalent of 233,509 adult chinook salmon, however the number reported landed for this fishery, also in adult equivalents, was 126,922 (Pacific Salmon Commission 1993). Also in 1992, the PSC chinook troll fishery in Southeast Alaska reported landing the equivalent of 142,076 adult chinook, however the total catch in this fishery was estimated to be the equivalent of 276,310 adult chinook (Pacific Salmon Commission 1993). Note that the disparity between annual catch and landings figures will vary by fishery due to changes in the number of small salmon available to be caught. In the aggregate, annual incidental harvests of chinook in PSC chinook salmon fisheries in 1979 - 1992 ran from 294,866 to 490,761 which represented incidental harvests of 11 to 24 percent of total catch, with ratios of landings to incidental harvest ranging from approximately 9:1 to 3:1, as measured in adult equivalents. The 1979 - 1992 time trend in percent incidentally harvested chinook in PSC fisheries is decidedly positive.

Although Columbia River stream type chinook (spring chinook and Snake River summer chinook) are only a very small proportion of PSC chinook landings based on recoveries of coded wire tags applied to hatchery populations, the proportion of these populations represented in the PSC chinook catch is unknown, as a matter of fact, as is also the case for non-PSC fisheries under the PFMC. Measurements of the stock composition by fishery of the PSC and PFMC chinook catches have not been taken. Juvenile chinook salmon, including spring chinook salmon originating in the Columbia River Basin, are known from tagging studies to be available for harvest in the areas of some of the present PSC fisheries. Given that the combined Canadian and United States PSC fisheries caught, but did not land, the equivalent of at least 294,866 to as many as 490,761 adult chinook between 1979 and 1992 (Table 8.1), if the Columbia River stream type chinook constitute even 0.5 percent of these incidental harvests, the annual loss in adult equivalents to the Columbia River Basin would be 1,500 to 3,000. Any such estimate of actual impacts of PSC fisheries on Columbia River stream type adult returns is necessarily speculative, due to the lack of stock composition data, and the impact of each fishery could be expected to vary substantially. The salmon bycatch in PFMC fisheries beyond the jurisdiction of the PSC for salmon and groundfish would add to the potential impacts of ocean fisheries on Columbia River which are not presently being addressed by assessment programs. However, given only the estimated magnitude of PSC incidental chinook harvests, the lack of stock composition information is a matter of serious concern to recovery of these types of salmon in the Columbia River Basin. Please note that the comments on PSC fisheries offered here do not apply to those salmon fisheries under the jurisdiction of the Fraser River Panel, which is a distinctly different management regime.

The relevance of incidental mortalities recovery of Columbia River stream type (spring/summer) chinook, is that the ocean fishery with the largest average catch has no stock identification based on sampling of the mortalities. For a very substantial portion, 12 – 24 percent, 1979-1992 (Table 9.2), of the total annual number of adult equivalent chinook salmon taken by PSC ocean fisheries there is no routine biological sampling at all. Hence any assumption that the ocean fisheries have no effect on the various spawning populations of Columbia River spring/summer chinook stocks is unwarranted.

Data on the ocean distributions of spring/summer chinook juveniles (Alverson et al. 1994) indicate that these stocks could be impacted by ocean fisheries (Table 9.2). The likelihood of such impacts would depend on the timing and location of the fishery in relation to the ocean distribution of chinook juveniles.

Table 9.2. Estimates of the percent of chinook salmon that die after being returned to the water by fishery type. Extracted from Alverson (1994).

Bycatch Species	***Area***	***Fishery***	***Mortality Percent***	
			Low/avg.	***Upper***
Chinook	North Pacific	Purse seine	50	90
Chinook	North Pacific	Troll	20	30
Chinook	Washington	Gillnet	2	28
Chinook, large	SE Alaska	Purse seine	24	
Chinook, medium	SE Alaska	Purse seine	68	
Chinook, small	SE Alaska	Purse seine	60	
Chinook, lillegal	SE Alaska	Purse seine	50	90
Chinook, legal	GOA	Troll	25	
Chinook, legal	GOA	Troll, coho	20	
Chinook, legal	SE Alaska	Troll	8	13
Chinook, sublegal	GOA	Troll	28	
Chinook, sublegal	GOA	Troll, coho	24	
Chinook, sublegal	SE Alaska	Troll	19	28

The known ocean distributions of juvenile chinook should put them at risk of being caught by any fishery operating in the right place at the right time. When small salmon are returned to the water, a certain percentage of them is expected to die (Table 9.2). Hence it is reasonable to expect that spring/summer chinook could be substantially affected by ocean fisheries.

It is our hypothesis that juvenile stream type (yearling emigrant) chinook originating in the Columbia River basin can be killed in ocean fisheries without being detected by current sampling programs. Present Compact, PFMC, and PSC management programs assume that juvenile stream type chinook occur at the same frequency in the incidental mortality (Table 9.2) as do the older, larger legal sized chinook that are sampled in current programs (see Table 9.3). Such assumptions in the absence of data to support them are not prudent when working with recovery of listed species. It is accurate to say that spring chinook of harvestable size are not often sampled from the landings of ocean fisheries, but the landings are widely geographically distributed from the coast of California to the Gulf of Alaska (Table 9.3). Unfortunately, data on fishery landings of salmon of harvestable size do not necessarily apply to understanding the effect of those fisheries on salmon of less than legal size.

Consequently, present information about the occurrence of legal-sized stream type (spring) chinook in the incidental harvests of the ocean fisheries (Table 9.2) does not support the present assumption of little or no impact on the smaller salmon. The degree to which ocean fisheries may affect stream type (spring/summer) chinook of all sizes has not been systematically studied. There are substantial gaps in understanding of stock composition of salmon that are killed but not landed in ocean fisheries. Available research on ocean distribution of spring chinook indicates that that it is not impossible for juvenile spring chinook to be killed by ocean fisheries. Coded wire tag recoveries of legal-sized spring chinook (Table 9.3) confirm that spring chinook are widely, if infrequently harvested in ocean fisheries. A discussion of the data and literature follows.

Data on the ocean distributions of spring/summer chinook juveniles indicate that these stocks could be impacted by ocean fisheries. The likelihood of such impacts would depend on the timing and location of the fishery in relation to the ocean distribution of chinook juveniles. The known ocean distributions of juvenile chinook should put them at risk to being caught by any fishery operating in the right place at the right time. When small salmon are returned to the water, a certain percentage of them are expected to die (Table 9.2). Hence it is reasonable to expect that Columbia River stream type, including Snake River spring/summer, chinook could be substantially affected by ocean fisheries.

Juvenile stream type (spring) chinook are found feeding in coastal ocean waters in April through October. Spring/summer juveniles are more oceanic than fall chinook, which are more prominent in inside marine waters such as Puget Sound and the Inside Passage (Milne 1957; Hartt 1980; Hartt and Dell 1986; Healey 1991). There is a review of ocean distribution of juvenile chinook (Healey 1991) that summarizes the geographically extensive catches of juvenile chinook in purse seining studies along the Pacific coast from the mouth of the Columbia River to Bay (Hartt 1980; Hartt and Dell 1986). The ocean distribution of juvenile chinook was based on 3,073 sets during the fifteen-year period, 1956 – 1970. The seining was conducted during April - October, but concentrated in the summer months. Most young chinook were caught during first year of ocean life along the coast.

Table 9.3. Number of years of marine fishery recoveries of coded wire tags by hatchery for stream type (spring) chinook salmon produced in the Snake River basin.
Fishery recoveries are from 1977 to 1996. For hatcheries producing more than one stock, the stock source is noted.

Hatchery	*Fishery*	*Years*
Dworshak	SEAK ocean troll	1
	OR ocean troll	1
Kooskia	CA ocean sport	1
Lookingglass	**Imnaha River**	
	CA ocean troll	1
	WA ocean troll	3
	WA ocean sport	1
	Non-Imnaha	
	SEAK ocean gill net	1
	No. BC ocean troll	1
	So. BC ocean troll	2
	OR ocean sport	1
	OR ocean troll	2
	CA ocean sport	1
Lyons Ferry	**Tucannon River**	
	No. BC ocean troll	1
	So BC mixed net	1
	WA treaty troll	2
Rapid River	No. BC ocean troll	1
Sawtooth	No. BC ocean troll	1
	Gulf AK groundfish	1

Catches were greatest from Columbia River to Southeast Alaska, with smaller catches being made to the North and West. No chinook were captured in the first year of ocean life in the central Gulf of Alaska or Bering Sea. Only 253 first year chinook were caught in their first year of ocean life over the fifteen year period, but peak catches were in June - August, and chinook appeared in the catches of the north later in the year than in the south. All but eight of the first ocean year chinook were stream type, and six of those were captured off Cape Flattery. From Cape Flattery northward the first ocean year chinook are overwhelmingly stream type, whereas those from inside waters were predominantly ocean type. First year ocean type chinook are more common in coastal ocean waters south of Cape Flattery (Fisher et al. 1983; Miller et al. 1983; Fisher et al. 1984).

Conclusions for Harvest

Based on the preponderance of evidence and experience of the past one hundred years, the key points relevant to understanding the relationship among harvest, habitat, and salmon productivity are as follows.

1. Harvest management played a role in the decline and extirpation of Pacific salmon populations. Unlimited exploitation incurred by the combination of fishing with other natural resource extraction activities on salmon contributed to reductions in the production of salmon in the Columbia River Basin.

2. Traditional harvest management, through imposition of limits on exploitation in directed salmon fisheries, has not been sufficient to allow salmon populations of the Columbia River to persist.

3. Traditional harvest management actions will not compensate for losses due to human activities other than directed harvest because estimates of salmon production from habitats that are constantly declining in productivity will always be too high. Overfishing results when estimates of harvestable surplus are too high. A new harvest management paradigm is needed which will take habitat productivity into account.

A Pacific Salmon Harvest Management Paradigm

The limits on salmon exploitation rates appropriate to conservation are ultimately dependent on the productive capacity of the habitat from which the populations originate, and on objectives for the magnitude and geographic distribution of spawners. Hence, salmon harvest managers need to look at the effects of degradation of the habitat on which spawners and juveniles depend for survival. The long-term persistence of all species of salmon throughout their ranges is dependent on the implementation of a salmon harvest management paradigm which applies exploitation rates consistent with the status of the salmon bearing ecosystems (i.e., production capability).

When combined with explicit recognition of the role of habitat in determining salmon productivity, the basic approaches to harvest regimes of the salmon fisheries of the Fraser River, Canada (Roos 1991) and Bristol Bay, Alaska (Mundy and Mathisen 1981; Eggers 1992) serve as the entry point to the paradigm. The effective harvest management paradigm for Pacific salmon may be defined in terms of its objectives and the information necessary to attain those objectives. Effective harvest management in an ecosystem context needs to retain some of the same objectives of traditional single species harvest management, such as conservation of population size, public safety, and product quality (Mundy 1985). In addition, the measure of performance for conservation needs to be extended beyond traditional measures of success, such as sustainable yield for a population of a single species, to include measures of ecological diversity (Pielou 1969) and of ecological processes (Mathisen 1972; Kyle et al. 1988).

The minimum information necessary to achieve these objectives under effective Pacific salmon harvest management (Fried and Yuen 1987; Hilborn 1987; Walters and Collie 1988; Eggers 1992; McAllister and Peterson 1992) go well beyond the information required to achieve these objectives under the old single species management. Information requirements are more intensive because the assumptions permitted by productive, stable habitat are no longer valid, because the sources of mortality are numerous, and because harvests are often not identified as such. In this paradigm, the inadvertent taking of salmon by humans is recognized as incidental harvest. Salmon are inadvertently taken by other human activities during the course of the salmon's life cycle, by activities such as logging, road building, agricultural cultivation and irrigation, many kinds of pollution, hydroelectric power generation, fishing for other species, and by directed fishing for the same, and for other life cycle stages of salmon.

The concept of stock-recruitment which holds that future spawning stock size is to some extent dependent on present spawning stock size (Ricker 1954b; Cushing 1983; Walters 1986; Hilborn and Walters 1992) needs to be enlarged to include other indicators of the status of the ecosystem (Ricker 1958). Although the relation between present and future spawning stock size can be highly variable for healthy salmon populations, the understanding of physical limits on future population growth posed by the number of eggs per female becomes extremely critical at the low population sizes common to salmon in the contiguous United States. Enlarging this concept will require new models to be developed which explicitly incorporate the role of habitat in determining salmon productivity. It is essential for harvest managers to find ways to establish salmon spawning escapements objectives for a watershed based on analyses of watershed attributes in addition to historical time series of the numbers of salmon spawning in the watershed. The parameters of a stock-recruitment function appropriate to effective harvest management in an ecosystem context should include information on habitat quality and quantity. Quantitative data on riparian vegetation and streambed condition in relation to surveys of spawning adults and rearing juveniles are generally lacking. Such information can be drawn from functions of the density and species composition of riparian vegetation, the percent of fine sediment in the spawning substrate, the abundance of critical life history stages of at least one prey, and one predator, species, and the abundance of one species utilized as an alternative by the salmon's predators. If it is possible to explicitly include one, or more, of the preceding habitat variables in the salmon stock-recruitment function, it would remind harvest managers of salmon originating from areas of high human population density of the ephemeral nature of the productive capacity of the environment.

Effective harvest management must be transboundary in scope in order to sustain Pacific salmon and their ecosystems indefinitely. Columbia River chinook salmon, along with most other Pacific salmon populations, migrate through a range of harvest management regimes of differing capabilities in the course of their life cycles. Obviously having effective harvest management regimes in only those areas close to the spawning grounds is only likely to prevent extirpation in those cases where the spawning and rearing areas, as well as the migratory corridors, remain relatively pristine. In those cases where stocks from damaged freshwater habitats interact extensively with ineffective harvest management regimes, extirpation seems likely. The Pacific Salmon Treaty (Jensen 1986), and its predecessor, the International Pacific Salmon Fisheries Commission (Roos 1991), embody the principles, if not always the practice, of international cooperation in management for salmon conservation.

Effective harvest management requires interdisciplinary staffing beyond the disciplines of the biology of fishes and mathematics ordinarily found in the old single species harvest management. It is essential to develop, *" ... a framework for integrating predictable and observable features of flowing water systems with the physical-geomorphologic environment."* (Vannote et al. 1980, p. 135). The hydrology and geomorphology of the watersheds, as well as the consequences of riparian vegetation for salmon production, needs to be a part of Pacific salmon harvest management for salmon originating in all types of habitats. It is especially important for conservation of stocks originating from damaged habitat. As Willis Rich (1941), Joseph Craig, and Robert Hacker (1940) wrote more than half a century ago, understanding habitat is essential to sustainable salmon production.

Effective Harvest Management

The quantitative attributes of effective harvest management are escapement goals, geographic gradients in fishing mortalities, and zero-sum mortality allocation. Where there are effective management strategies, they are designed to provide adequate spawning escapements to all spawning grounds, and to accurately measure the attainment of these goals on an annual basis. Without monitoring, there is no effective harvest management of salmon, because salmon harvest management depends upon information (Walters 1986). Escapement goals under effective harvest management are quantifiable objectives, by locality and life history type, for spawning numbers, habitat, and associated species. Escapement goals must be accompanied by monitoring programs in order to be meaningful.

The concept that fishing mortalities need to decrease (be more conservative) as distance from the spawning grounds increases is essential to reduce the risk of extirpation for salmon populations originating in damaged habitat. The farther that harvest occurs from the spawning grounds, the less likely accurate stock identification becomes, and the lower the likelihood that effective harvest management can be achieved. Put another way, ineffectively managed fisheries should be low impact fisheries. The concept that the magnitude of salmon fishing mortality should be inversely proportional to the distance of harvest from the spawning grounds is an especially critical concept at places where distant mixed stock fisheries harvest populations from damaged habitat.

The concept of zero-sum mortality allocation holds that when one source of mortality increases, some other source of mortality must decrease in order to keep the population size from decreasing. Implementation of the zero-sum principle requires that survival be measured at each stage of the life history, that survivals be held to the standard in each life history stanza, and that controls be implemented on those sources of mortality that are controllable. A basic law of biology which is determined by the number of eggs per female among other physical and biological constraints, is that each Pacific salmon population can bear only a certain average total mortality before it starts to decline (e.g. Ricker 1954). As a conservative approximation, if the five year average total annual mortality from egg to spawner for a chinook salmon population reaches the level where one female chinook cannot be expected to produce two spawners in the next generation, the population will necessarily decline. When a population is in decline, the probability of extinction is 100 percent if the decline does not stop (Rieman and McIntyre 1993). For populations at critically low levels, such as those on the threatened or endangered species lists, when natural mortalities increase, anthropogenic mortalities need to decrease, and if they do not, the population will be extirpated.

Finally, harvest management cannot be effective unless there are consequences for the humans involved in salmon-consuming activities when survival standards and escapement goals for salmon are not met. Both Bristol Bay, Alaska, and the Fraser River, Canada, support thriving sockeye salmon populations today, because, since implementation of effective harvest management regimes, whenever spawning populations have reached critically low levels, fishing has been reduced, or stopped. For example, harvesters and processors in Bristol Bay lost an entire year's income in 1973 when biologists allocated nearly all of the adult return of 2.3 million sockeye to the spawning escapements. The sacrifice of the harvesters in 1973 led to large returns in the form of the sockeye migrations in the next generation in 1978.

In the Columbia River Basin by contrast, when the El Nino phenomenon reduces ocean productivity and drought reduces freshwater survival, it is business as usual for the hydroelectric system, the commercial barge transportation system, the irrigation systems, the timber industry, and for other sectors of the economy that cause mortalities to salmon as they operate. Until there are direct consequences to sectors of the economy in addition to harvesters when salmon populations dwindle, it is unlikely that the wide scale geographic effort necessary to prevent salmon from being extirpated can be mounted.

Mixed Stock Fisheries

In the face of mounting losses of Pacific salmon populations (Nehlsen et al. 1991; FEMAT (Forest Ecosystem Management Assessment Team) 1993), fisheries for mixtures of salmon stocks could be curtailed or eliminated in an attempt to protect damaged salmon populations, including federally threatened or endangered species (see PFMC 1996). Widespread losses of fishing opportunities might be necessary, if it is possible to identify and define successful concepts and approaches to sustainable salmon harvest management of mixed stock salmon fisheries. Such concepts and approaches are termed effective harvest management. The effective harvest management paradigm is distinctly different from the historical practice of salmon harvest management, yet it retains some familiar tenets. Scientific evidence and analysis support both the old and the effective paradigms, and both effective and historical approaches are based on the concept of sustainable yield. The effective paradigm differs sharply from the old in its criteria of success, in its objectives, and in the level of detail required in the scientific evidence and analysis on which its harvest actions are based.

Sustainable yield, or catch, is the idea that properly managed salmon populations can provide a harvest benefit to humans in perpetuity (Ricker 1954b; Cushing 1981). The meaning of “properly managed” is at the heart of the differences between the old and the effective salmon harvest management paradigms. In the effective paradigm, proper salmon harvest management means carefully defining yield to include, as harvest, all sources of human removals of salmon, wherever, and whenever, such harvests may occur. Under effective salmon harvest management, accounting for the actual yield from each stock would require not only counting the numbers caught in all directed, or intentional, salmon harvests from a population, as was often the case in the old salmon harvest management, but it also requires an accounting of incidental, or unintentional, harvest of the population. While most salmon harvest management regimes attempt to do such an accounting, few have achieved success at the level of resolution required for protection of damaged salmon populations. For example, although hydroelectric system mortalities of Columbia River chinook are accounted for in management models along with the effects of many other factors, in the past these effects were lumped into a single value called "natural mortality." Without explicit measurement and recognition of the relative magnitudes of controllable anthropogenic mortalities, management is unable to distinguish controllable effects from the effects of uncontrollable agents of mortality, which are truly natural, such as El Nino. Note that such accounting for harvests in effective salmon management practice need not require an exact count, or even a very precise estimate, of removals, in order to be useful to salmon harvest management decisions. For example, in responding to a conservation emergency, simply being able to identify sources of mortality which may be under human control is very useful information, even when precise estimates of the magnitudes of these may be lacking or difficult and expensive to obtain (National Research Council (NRC) 1996).

Approaches to management of mixed stock fisheries differ sharply between the old and the modern salmon harvest management. Since the "where" and "when" of salmon harvests could potentially span the thousands of miles of fresh and salt waters encompassed by the salmon's migrations, the modern concepts of how to achieve sustainability in salmon conflict sharply with the historical practice of uninformed mixed stock fishing. Mixed stock fishing occurs in areas where mixtures of fish populations, known as stocks, are harvested at the same time. Under uninformed mixed stock salmon fishing, the consequences of harvest to the sustainability of yield are unknown, and harvest management for sustained yield cannot properly be said to be occurring (Mundy 1985). Only when the annual yield, or catch, can be added to the spawning escapements, and the ages of the salmon estimated, can effective salmon harvest management attempt to achieve conservation objectives for salmon stocks. Without stock-specific catch, escapement, and age data, the salmon manager has no idea of the effect of the fishery on sustainability of the salmon populations in the fishery.

Nearly all directed salmon fisheries occur in areas where stocks are mixed to some degree, because harvest or capture takes place before the salmon reach their spawning grounds.

Only on the spawning grounds are all the salmon populations clearly separated consequently both the old and effective salmon harvest management must deal with mixed stock fisheries issues.

The effective approach to implementing modern sustained yield salmon management is informed mixed stock fishing. Informed mixed stock fishing uses information about migratory pathways, migratory timing of different populations, and other differences among salmon populations to determine the impact of fishing on the individual stocks. In an informed mixed stock fishery, catches taken in mixed stock areas can be assigned to their stock of origin in a process known as stock separation. Ideally, stock separation is quantitative with proportions of each stock in the harvest being estimated. In cases when only presence or absence of a stock in the harvest of a locality can be determined reliably, stock identification can still serve a useful purpose by determining whether fishing at that locality needs to be prohibited in the interest of protecting the stock whose presence has been ascertained.

Stock identification of catches has long been recognized by salmon managers as essential to determining impacts of salmon fisheries on stocks. As developed under conventional concepts of sustainable yield, it is assumed, as an ideal, that a fish population can be kept at a level of escapement through controlled harvests which, on average, produce the best long-term average production by the population. This is the theory as it applies for a single identifiable stock, which is essentially a Mendelian population, or a deme (National Research Council (NRC) 1996). However, in mixed harvest situations, the question of sustainable yield becomes more complex because stock identification is needed to distinguish among salmon stocks of differing productive capacities of in the mixed stock harvest.

The importance of informed mixed stock harvest to both long-term productivity and genetic diversity of salmon has long been established in the scientific literature. In addressing the consequences to long-term conservation of mixed stock salmon fisheries, Paulik et al. (1969) wrote:

> "*It is also apparent that different management strategies which result in similar sustained yields may have markedly different effects on the relative abundance of the individual stocks making up the total run of the fishery. Under such circumstances the desirability of preserving a broad genetic level of response to environmental change within a salmon run might mitigate against the application of those strategies which over-exploit small stocks to the level of extinction.*" (pp. 2535-2536).

Consequently, when a mixture of stocks is harvested at a common rate which permits them all to survive indefinitely, the sustainable yield is always lower, sometimes much lower, than the sum of the individual sustainable yields of the stocks, if harvested separately at rates appropriate to their individual productivities (Ricker 1954a; Paulik 1969; Ricker 1973). Correspondingly, the actual spawning population level, or escapement goal, which provides the greatest sustainable yield from a mixture of stocks is not the escapement goal which gives the theoretical maximum sustained yield from each stock from the mixture. This is because, in salmon management, yield, or catch, when subtracted from the total number of salmon transiting the harvest area equals escapement (Mundy 1985). Constraining harvest by the exploitation rate which permits each stock in the mixture to survive and produce could result in rates of escapement for the most productive stock that are higher than would be considered appropriate to maximize its yield.

When the preceding general principles of population biology are applied to salmon harvest management, it becomes very clear why informed mixed stock harvest is an essential part of the effective management paradigm. In mixed stock salmon fisheries, each identifiable collection of spawners from a watershed, called a stock, may have a different level of maximum sustained yield, due to differences in biological factors such as the number of eggs per female, the average size of the eggs produced, and the critical qualities of the spawning, rearing, and migratory environments. Within species of salmon there are differences in MSY for stocks, even if all the biological factors which determine productivity for each stock are the same. For example, sockeye salmon stocks coming from two lakes identical in every way except that one is smaller than the other, will have different MSY harvest levels. This is true because the population level at which the number of successful offspring per female is the highest is about one-half the carrying capacity of the environment. Populations of sockeye from larger lakes will have larger values of MSY than will smaller lakes of the same productivity. In general, big environment means big MSY, and conversely, all other factors being equal.

All existing salmon escapement goals are likely to be based on data collected from mixtures of stocks (see PFMC 1996), so the escapement goal and the corresponding levels of allowable harvest depend on which stocks have been considered to be part of the mixture. For most salmon management agencies, the most economically prominent group of fish stocks were the stocks most often included in the mixture that subsequently defined MSY and escapement goals. Disaggregation of escapement goals to something approaching the watershed level may be necessary to support efforts to increase productivities of salmon populations, to enhance salmon life history diversity, and to broaden the geographic distribution of salmon in the Columbia River Basin.

Informed Mixed Stock Fishing

The scientific principles which form the basis for the concept of informed mixed stock harvest have been developing in the fisheries literature for more than a century, although their specific application to salmon management is somewhat younger (see Roos 1991). This literature makes it clear that accounting for sources of removals, or mortalities, is absolutely essential to effective fisheries management (Ricker 1954b; Beverton and Holt 1957; Cushing 1981; Hilborn and Walters 1992). Without an accounting of all sources of mortality potentially under human control, the managers do not have a full range of options available to them when trying to implement conservation measures.

Accounting for all sources of mortality, in addition to directed harvest, is an extremely important part of informed mixed stock harvest. For example, not all fish caught (the catches) are necessarily landed and reported (the landings). Consequently, landings may be only a fraction of the number of salmon actually killed in a fishery. Informed mixed stock fishing requires stock composition information on catch, as well as on landings.

Informed mixed stock harvest has long been accepted in salmon management (see Roos 1991). Accordingly, the history of exploitation of salmon fisheries has been one of seeking increasingly detailed stock composition information on all species of salmon through a variety of means including visible tags (Gilbert and Rich 1925, Aro et al. 1971, Aro 1972, Gray et al. 1978, Meyer 1983, Brannian 1984, Robertson 1984, Lynch and Edginton 1986, Eggers et al. 1991), coded-wire tags (Clark et al. 1985, Shaul et al. 1986), scale patterns analysis, (Wright 1965, Krasnowski and Bethe 1978, McGregor and Marshall 1982, Marshall et al. 1987), and genetic characteristics (Seeb et al. 1986, Seeb et al. 1995). The many thousands of hours and millions of dollars spent on stock identification in North American salmon fisheries attests to the importance attached to stock composition information by scientists concerned with management.

The best example of how stock identification functions with appropriate monitoring to provide the information necessary to manage sustainable yields from salmon populations is found in the current management of the sockeye salmon fishery in Bristol Bay, Alaska (Fried and Yuen 1987). When accompanied with adult spawning escapement enumeration, stock identification of the catches makes it possible to annually determine the status of individual salmon stocks. Knowing the annual status of each stock makes it possible to formulate fishing regulations, which protect the diversity and productivity of each stock. For example, as annual landings records attest, the sockeye salmon of Bristol Bay, Alaska, have been intensively commercially harvested since the third quarter of the 19^{th} century (Mundy in press). Under virtually unrestricted fishing from 1884 to 1927, annual Bristol Bay sockeye catches rose rapidly to average 15 million adults per year. Annual catches fluctuated greatly, occasionally exceeding 20 million, but otherwise steadily declined under a limited federal management regime, until the fishery was put under a management-by-escapement-objective program in 1954. Under the new regime, stock identification was accomplished by limiting the harvesters to "terminal areas" in the marine waters near the mouths of the major rivers where returning stocks of spawners were thought to be separated.

Nonetheless, the declines in catches of Bristol Bay sockeye in the terminal areas continued down to a level of only 2.3 million in 1973 in the face of indiscriminate and uncontrolled harvests of the sockeye on the high seas by Japanese fishing vessels (Fried and Yuen 1987). After the Japanese government agreed to cease catching returning adult salmon in 1974, annual sockeye catches rose steadily to routinely exceed 20 million during the 1980s, with a catch in excess of 40 million sockeye recorded in 1995. Since 1985, the five-year moving average of annual catches of Bristol Bay sockeye has exceeded the largest single annual catch recorded prior to 1927 during the era of uncontrolled fishing. Bristol Bay is the largest of a substantial number of sockeye salmon fisheries, which are successfully sustainably managed using stock identification information. For example, the management of sockeye salmon under the Fraser River Panel of the Pacific Salmon Commission (Roos 1991) is exemplary.

Conclusions for Harvest and Harvest Management

Harvest regulation is a sufficient means of protecting and increasing salmon production only in the presence of reasonably pristine habitat. Harvest management has failed to consider the relation of salmon abundance to other components of the ecosystem, which are connected by the life cycle of the salmon.

Conclusions (and Levels of Proof)

1. Directed (intentional) and incidental (unintentional) harvest of CRB salmon has occurred in the absence of knowledge of harvest impacts on the abundances and viabilities of the majority of the individual native spawning populations. Viability means having a reasonable probability of survival within an arbitrary time horizon. (1)

2. Harvest rates on native spawning populations of CRB salmon from incidental and direct sources have increased since development of the Columbia River basin by western civilization in the early nineteenth century. (3)

3. Both directed and incidental harvests exert levels of mortality on salmon spawning populations that are large enough to influence their annual abundances and viabilities. (2)

4. Harvest, both incidental and intentional, has contributed to the decline in abundance of CRB salmon and it is a factor limiting their recovery. However, harvest restrictions in the absence of habitat restoration is not sufficient to permit recovery. (2)

5. Interactions between mortality associated with habitat degradation (incidental harvest) and directed harvests by fisheries have led to the extirpation of many CRB salmon populations. (3)

6. All Columbia River stocks, with the possible exception of Hanford fall chinook, are at such low levels that harvest in the ocean will have to be very low or non-existent to allow the habitat restoration proposed herein to have a reasonable chance to succeed. (2)

Recommendations for Harvest and Harvest Management

1. Harvest management needs to recognize the relation of salmon abundance to other components of the ecosystem which are connected by the life cycle of the salmon.

2. Sustained yield management of a salmon population, or *deme (see NRC 1995 and 1996)*, needs to be based on numerical spawning escapement goals at the watershed level which represent both the productive capacities of the habitats for the salmon population and all related salmon populations, geographic gradients in fishing mortality appropriate to the nature of the stock composition information for each fishery, and a zero-sum mortality allocation across all fisheries.

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