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A Habitat Based Evaluation of Okanagan Sockeye Salmon Escapement Objectives

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Abstract

Information from both historic and recent assessment activities has been assembled in this report to determine the current status of Okanagan sockeye. Subsets of the information are then used to: (i) evaluate the utility of historic escapement data, (ii) identify factors that may limit stock production within the Okanagan Basin and (iii) identify escapement objectives that are consistent with what is known about spawning and rearing habitat limitations in the Okanagan River and Osoyoos Lake.

Okanagan sockeye stock production is not large (average return of 56,147 sockeye per annum; range 1,666-199,832) compared to that found in other areas on the B.C. coast, but is very important locally to meet ceremonial and subsistence needs of First Nations people of the U.S. and Canadian portions of the Columbia and Okanagan River basins. Returns, averaging 18,148 adult sockeye per year in the current decade, are the lowest for any decade within the 45 year period of record for the stock. In addition, spawner abundance has declined to match record lows in 3 of the past 5 years and has stimulated expressions of concern by fisheries personnel and resource stakeholders about future prospects for long term persistence of Okanagan sockeye.

Analysis of spawning habitat capacity in terms of quantity and quality of gravel available for redds and egg incubation indicated that the Upper Okanagan River could accommodate several times the number of spawners that currently return annually. Similarly, analysis of rearing habitat in Osoyoos Lake based on both its nutrient status (total phosphorus load) and limits placed on sockeye use by changes in seasonal water quality parameters (temperature and oxygen levels) suggests that Osoyoos Lake has ample capacity to support good growth and survival of fry from no fewer than 58,730 spawners (as enumerated at Wells Dam). Analysis for possible associations between annual variations in spawner abundance and subsequent production variations of both smolt numbers and biomass also supports conclusions that neither spawning habitat in the Okanagan River or rearing habitat in Osoyoos Lake currently limit Okanagan sockeye population levels.

Recommendations supported by the paper are that: (1) minimum escapement objectives for Okanagan sockeye be set at 58,730 adults (in Wells Dam count units) or 29,365 adults as peak visual counts on the spawning grounds, (2) biological consequences of smolt size management of Osoyoos Lake sockeye be explored as a requisite to refining escapement objectives that might be adopted if Okanagan sockeye stock rebuilding is successful in future years, (3) annual sampling for size and age composition of Okanagan sockeye smolts be completed whenever feasible to facilitate future analysis of smolt-to-adult survival trends and smolt size management options in Osoyoos Lake, (4) annual sampling for age, size and sex composition of sockeye in catch and escapement be completed whenever feasible to facilitate future analysis of stock and recruit relations and to follow smolt-to-adult survival trends, (5) retrieval and review of source documentation pertaining to SEDS estimates of Okanagan sockeye escapement plus entry of supplemental comments describing methods used to generate escapement estimates be completed, (6) annual summary estimates of Okanagan sockeye escapement from Wells Dam counts be incorporated into SEDS as a formal alternative to relatively imprecise spawning ground counts and finally (7) given that neither spawning gravel capacity or lake rearing capacity appear to set the principal limits on Okanagan sockeye population size at current stock levels, additional effort should be expended by the Okanagan Basin Fisheries Working Group to determine the reasons for recent stock declines in the absence of any targeted exploitation of Okanagan sockeye.

Résumé

Des renseignements tirés d'évaluations récentes et historiques ont été réunis dans le présent rapport dans le but de déterminer l'état actuel du saumon rouge de l'Okanagan. Des sous-ensembles de données ont ensuite été utilisés pour : i) évaluer l'utilité des données historiques sur les échappées, ii) déterminer les facteurs pouvant limiter la production du stock dans le bassin de l'Okanagan et iii) identifier des objectifs d'échappée conformes aux connaissances sur les limites des habitats de frai et de croissance de la rivière Okanagan et du lac Osoyoos.

La production du stock de saumon rouge de l'Okanagan est peu importante (remontée moyenne de 56 147 par an ; étendue de 1 666-199 832) si on la compare à celle des autres stocks de la côte de la C.-B., mais elle est très importante localement car elle satisfait aux besoins rituels et alimentaires des Premières nations habitant les parties américaines et canadiennes des bassins du fleuve Columbia et de la rivière Okanagan. Les remontées annuelles moyennes de la présente décennie, de 18 148 adultes, sont les plus faibles de toute décennie de la période de 45 ans pour laquelle nous disposons de données. L'abondance des géniteurs a décliné pour atteindre des records minimum pendant trois des cinq dernières années et a donné lieu à des inquiétudes de la part des pêcheurs et des intervenants quant au maintien à long terme du saumon rouge de l'Okanagan.

L'analyse de la capacité de l'habitat en ce qui a trait à la quantité et la qualité du gravier pour la construction des nids et l'incubation des œufs a montré que le cours supérieur de l'Okanagan pouvait accommoder plusieurs fois le nombre actuel de géniteurs qui y reviennent à chaque année. De même, l'analyse de l'habitat de croissance du lac Osoyoos, fondée sur les teneurs en matières nutritives (charge totale de phosphore) et les limites de l'utilisation par le saumon rouge découlant des variations saisonnières des paramètres de la qualité de l'eau (température et teneurs en oxygène), porte à croire que ce lac peut facilement permettre une bonne croissance et une bonne survie des alevins produits par au moins 58 730 géniteurs (tel que dénombrés au barrage Wells). Une analyse portant sur des relations possibles entre les variations annuelles de l'abondance des géniteurs et les variations ultérieures de la production de saumoneaux (nombre et biomasse) appuie aussi les conclusions selon lesquelles ni l'habitat de frai de la rivière Okanagan ni l'habitat de croissance du lac Osoyoos ne limitent actuellement la population de saumon rouge de l'Okanagan.

Les recommandations suivantes sont formulées dans le document : 1) d'objectifs minimum des échappées établis à 58 730 adultes (unités de dénombrement du barrage Wells) ou à 29 365 adultes par dénombrement visuel maximum sur frayères ; 2) examen des conséquences biologiques de la gestion de la taille des saumoneaux dans le lac Osoyoos à titre de condition préalable d'une définition plus fine des objectifs des échappées qui pourraient être adoptés si le stock de saumon rouge de l'Okanagan se rétablissait au cours des prochaines années ; 3) réalisation, chaque fois que cela est possible, d'un échantillonnage annuel des saumoneaux du stock de l'Okanagan fondé sur la taille et l'âge afin de faciliter toute analyse future des tendances de la survie de saumoneau à adulte et des options de gestion de la taille des saumoneaux dans le lac Osoyoos ; 4) réalisation, chaque fois que cela est possible, d'un échantillonnage annuel fondé sur l'âge, la taille et le sexe des saumons rouges capturés et des échappées afin de faciliter toute analyse future des relations stock-recrutement et des tendances de survie de saumoneau à adulte ; 5) obtention et examen de documents de base sur les estimations du système de données sur la remonte des salmonidés (SDRS) des échappées de saumon rouge de l'Okanagan et ajout de remarques supplémentaires décrivant les méthodes utilisées pour générer les estimations ; 6) incorporation au SDRS des estimations résumées annuelles des échappées du saumon rouge de l'Okanagan obtenues par dénombrement au barrage Wells en remplacement formel des dénombrements relativement imprécis réalisés sur les frayères et 7) étant donné que ni la capacité du gravier des frayères ni celle de l'habitat de croissance du lac ne semblent être les principales limites à la taille de la population de saumon rouge de l'Okanagan aux valeurs actuelles, des efforts supplémentaires devraient être consentis par le groupe de travail des pêches du bassin de l'Okanagan afin de déterminer les raisons du récent déclin du stock en l'absence de toute exploitation visant directement le saumon rouge de l'Okanagan.

1.0 Introduction

At the turn of the century, more than a dozen anadromous populations of sockeye salmon (*Oncorhynchus nerka*) inhabited at least eight distinct river basins in the Columbia River system (Fryer 1995, Allen and Meekin 1980). Over the past century, dams, overfishing, and other habitat degradation have reduced the number to two, viable, populations of sockeye salmon that return to the Wenatchee River in Washington State and the Upper Okanagan River in the southern interior of British Columbia (Figure 1).

Adult sockeye salmon bound for their spawning grounds in the Okanagan River must migrate past ten hydroelectric or flood control dams (9 on the Columbia River mainstem plus one on the Okanagan River) equipped with fishways. Wells Dam is the last major dam that Okanagan sockeye must pass to reach the Okanagan River. Wells Dam is located at 829.6 km on the Columbia River and lies approximately 30 km downstream of the confluence of the Okanagan River (Figure 1). Zosel Dam is located at 117 km on the Okanagan River, just south of the Canada-U.S. border. The primary spawning areas for sockeye lie approximately 42 km upstream of Zosel Dam near the town of Oliver. Most of the Okanagan River is directly accessible from Highway 97 and side roads, which run parallel to the river. Osoyoos Lake lies within the drainage course of the Okanagan River and serves as the nursery lake for juvenile sockeye.

Okanagan sockeye typically arrive at Wells Dam the last week of June or the first week of July and migration past the dam continues into August. Sockeye migrate from the Columbia mainstem into the Okanagan River and then to Osoyoos Lake in the interval between July and early September as long as temperatures in the Okanagan River remain below 21 degrees Celsius. However migration may be impeded by as much as three weeks in some years by high, summer water temperatures in the Okanagan River (Major and Mighell 1966, Allen and Meekin 1980, Mullan 1986, Chapman et al. 1995 and Alexander et al. 1998). Once past Zosel Dam, sockeye hold in Osoyoos Lake until late September after which they move into portions of the Okanagan River above Osoyoos Lake to spawn (Figure 2). Spawning begins in early October and continues through to early November.

Okanagan sockeye stock production is not large compared to that found in other areas on the B.C. coast, but is very important locally to meet ceremonial and subsistence needs of First Nations people of the U.S. and Canadian portions of the Columbia and Okanagan River basins. Two native fisheries occur upstream of Wells Dam. The Colville Confederated Tribes have a ceremonial and subsistence fishery located at Chief Joseph Dam and in the U. S. portion of the Okanagan River (Figure 1.), and the Okanagan First Nation has a ceremonial and subsistence fishery on the Upper Okanagan River.

2.0 Report Objectives

This report has been assembled in response to requests from the Okanagan First Nation and Canada's Department of Fisheries and Oceans (CDFO) to review historic escapement objectives and to advise on current needs for management, rehabilitation and enhancement activities. We have assembled results from both historic and recent assessment activities to determine the current status of Okanagan sockeye. Specifically, we have attempted to assemble information on catch, escapement, harvest rate, juvenile production, biological traits of juveniles and adults of Okanagan sockeye between 1953 and 1998. The information assembled in this report is then used to: (i) evaluate the utility of historic escapement data, (ii) identify factors that may limit stock production within the Okanagan Basin and (iii) identify escapement objectives that are consistent with what is known about spawning and rearing habitat limitations in the Okanagan River and Osoyoos Lake.

3.0 Data Sources and Methods

3.1 Summary Catch and Escapement Records

Historic abundance trends and current status of Okanagan sockeye have featured prominently in several major reviews of Columbia Basin sockeye carried out by U. S. agencies (Mullan 1986, Chapman et al. 1995, Fryer 1995, Gustafson et al. 1997). Tabulations of summary catch and escapement information on Okanagan sockeye as presented by Chapman et al. (1995) are based on a systematic review of both published and unpublished source materials and are adopted for use in this paper, with some exceptions (see sections below), as "best" values.

3.2 Escapement Records

One to several, annual estimates of escapement based on different survey methods have been generated for Okanagan sockeye since approximately 1945. Currently, the abundance of adults returning to spawn in the Canadian portion of the Okanagan River are estimated at Wells Dam just downstream of the confluence of the Columbia and Okanagan rivers, at Zosel Dam south of Osoyoos Lake, and on the spawning grounds.

3.3 Escapement Estimates at Wells Dam

Wells Dam became operational in 1967 at which time annual enumeration of Okanagan adult sockeye passage rates through its fishways began. Annual counts have been tabulated by Chapman et al. (1995) and are also available from the Columbia River Fish Passage Center at "http://www.fpc.org/adlthist/weladult.htm".

Salmonids passing through fish ladders in all mainstem Columbia River dams are counted by experienced personnel stationed in front of viewing windows. Fish are counted for 50 minutes out of each hour over 16 hours per day during the seasonal periods when migration of particular salmon species occurs (e.g. sockeye pass Wells Dam primarily from mid-June to late August, Columbia River Fish Passage Center; Hatch and Schwartzberg 1991). Escapement estimates are multiplied by 1.2 to account for the 10 minutes per hour during which passage is not recorded. However, escapement estimates are not adjusted to correct for a small proportion of fish that may migrate at night (Hatch et al. 1992) or for double counts due to fallback where fish drop back over the dam after successfully ascending fishways and then ascend for a second time (Gibson et al. 1979). As part of their contract with the U. S. Army Corps of engineers, the Washington Department of Wildlife is required to provide counts that are accurate to within 5 % (Fryer 1995). Although it is possible that this accuracy level is exceeded, it is likely safe to assume that counting procedures used at Wells Dam produce a highly reliable annual estimate of escapement passing Wells.

3.4 Spawning Ground Escapement Estimates (SGE's)

Surveys to sample and enumerate sockeye spawning in the Okanagan River have been executed by several generations of fisheries personnel working on behalf of both government (*i.e. CDFO, Canada Department of the Environment, U.S. Fish and Wildlife Service*) and non government groups (*e.g. private sector consultants, Douglas County Public Utility Division, Chelan Public Utility Division, Okanagan First Nation, Columbia River Intertribal Fish Commission etc.*). Consequently, differences in annual SGE's may reflect either real differences in annual abundance of spawners or alternately variations in field survey methods, level of effort, or analyses used to convert raw observations into summary estimates.

The data and procedures used to generate SGE's over the full period of record for Okanagan sockeye exhibit a rich but variable history of documentation in the form of CDFO Stream Inspection Logs (SIL's), CDFO-BC16 summary forms, Environment Canada Okanagan Basin Study Reports, U.S. Fish and Wildlife Service Science Reports, and Consultant reports (see bibliographies in major reviews of Columbia River sockeye stocks by: Allen and Meekin 1980, Mullan 1986, Fryer 1995, Chapman et al. 1995, Gustafson et al. 1997). In the present report estimates of annual escapement based on visual enumeration during spawning ground surveys were summarized from CDFO's regional Salmon Escapement Database System (SEDS; Serbic 1991), from CDFO Stream Inspection Log (SIL) forms maintained in the Kamloops or Salmon Arm offices of CDFO (Barry Rosenberger, CDFO, Kamloops, pers. comm.) and from summary tables provided in a major review of the status of Mid-Columbia sockeye salmon stocks by Chapman et al. (1995).

Authors of several PSARC Working Papers have noted that reliable interpretation of the significance of apparent trends in SEDS summary estimates is often difficult given inconsistencies in both field survey and analytical methods that may occur over decades of escapement survey work. Further, difficulties encountered in resolving the utility of historic SEDS estimates are often complicated by the absence from SEDS electronic files of qualifying comments (from entries in diaries, BC16 or SIL forms) from data suppliers about year-to-year variations in procedures used to generate annual estimates. Types of information required to qualify SEDS estimates include: (i) dates on which surveys were completed, (ii) the survey method in use, (iii) supplemental observations to confirm the temporal position of a survey relative to peak time of spawning, (iv) records of raw counts on which summary estimates are based, (v) degree of completeness of spawning area spatial coverage provided by a given survey, (vi) changes between surveys in methods or procedures for obtaining raw counts or for estimating total escapement.

In our experience, retrieval of sufficient information of the type identified above can facilitate reconstruction of poorly qualified summary escapement estimates into relatively constant precision time series that may be interpreted more confidently than the escapement time series currently available from the SEDS database. Although sufficient time was not available to complete a systematic review of all of the documentation pertaining to SGE's noted above, we have:

(i) interviewed CDFO personnel (B. Rosenberger, CDFO Kamloops Office, Feb.10, 1999) regarding methods applied to execute Okanagan River sockeye escapement surveys,
(ii) performed a reconnaissance of the spawning ground survey area to obtain first hand information regarding viewing conditions that may influence spawner enumerations in the Okanagan River, and
(iii) reviewed a wide range of source materials (e.g. Stream Inspection Logs; paper BC16's; Washington State Department of Fisheries Progress Reports; Consultant reports) to provide insights into the likely influence of variations in assessment methods, results and documentation on the utility of annual escapement estimates derived from spawning ground surveys.

Specific elements of field surveys will be presented in the results and discussion section below. However, a general description of the survey approach used for annual SGE's of sockeye is presented here.

The major spawning area for Okanagan sockeye exists in a 2.4 km stretch of natural river channel that begins immediately downstream of McIntyre Dam at the outlet of Vaseaux Lake (Figure 2). The Okanagan River was channelized from about 1.4 km above the city of Oliver, B. C., downstream to Osoyoos Lake as part of a flood control project completed in 1957. Some sockeye spawning occurs in the channelized section of the river, in which water flow is influenced by 13 engineered, vertical-drop, structures (VDS1 - VDS13, Figure1), and a minor component of the population has been observed to spawn in Osoyoos Lake in some years (Meekin 1969). In a typical year, sockeye escapement enumeration involved the completion of one to several seasonal surveys (Allen and Meekin 1980; B. Rosenberger, CDFO, Kamloops, pers. comm., Feb. 10, 1999) during which visual counts were made either while floating the river in a rubber raft (generally sections from McIntyre Dam to VDS13) or from access points that permitted streamside inspection on foot (sections from VDS13 to Osoyoos Lake). Individual fish were counted if possible or when very abundant were estimated by 10's. Abundance data were recorded as peak live plus dead (PLD) counts and the peak count from multiple surveys, was used as the basis for the annual index of spawner abundance.

3.5 Other Sources of Spawner Abundance Information

Supplementary programs have been conducted to assess Okanagan sockeye escapements past Wells Dam or in the Okanagan River at various times. Supplementary studies (*e.g. mark recapture programs, Zosel Dam fishway counts, radiotagging studies*) of adult sockeye have been completed in recent years by fisheries personnel associated with the Douglas County Public Utility District No. 1 in Wenatchee, Washington (Alexander et al. 1998, Anonymous 1996, Swan et al. 1994, Hagen and Grette 1994, Hansen 1993, Hatch et al. 1993, Allen and Meekin 1980). However, as noted in an escapement cross calibration study conducted by Tschaplinski and Hyatt (1991), large differences in the magnitude of annual escapement estimates may occur as an inadvertent outcome of undocumented changes in annual assessment techniques. Thus, data from these supplementary surveys are identified and presented for comparison with longer time series estimates only where appropriate. All escapement values used in the current report are summarized in several tables (Tables 1-16) that document the origins of the data. Source documentation (e.g. paper "B.C.16's" forms, DFO - Stream Inspection Log forms and other unpublished reports) has been retrieved and examined in several instances to facilitate interpretation of poorly qualified summary estimates contained in summary tables of escapement estimates tabulated by other authors.

3.6 Biological Samples

Sampling for biological traits of sockeye in catches and escapements of Okanagan sockeye has not been routinely completed each year. Documentation of procedures for acquisition and processing of some of these samples is summarized by Allen and Meekin (1980) or Chapman et. al. (1995). Although information is known to be available for samples obtained from native food fisheries on the Columbia or Okanagan rivers in additional years (Columbia River Inter-Tribal Fish Commission, Portland, Oregon), most summary information requested was not available for inclusion in this report. It is important to retrieve this information in future. However, the absence of annual age-at-return information from both catch and escapement samples, precludes assessment of brood year specific production variations or stock and recruit analyses for Okanagan sockeye at present.

3.7 Juvenile Abundance Trends and Biological Traits

3.7.1 McNary Dam Smolt Indices

The relative abundance of sockeye salmon smolts migrating downstream in the Columbia Basin is assessed at the gatewells of each of several dams (e.g. Priest Rapids, McNary etc...). Index observations of annual variations in Okanagan smolt abundance considered in the present paper are completed annually at McNary Dam according to methods described by Fryer (1995) as follows. At McNary Dam (Figure 1), a portion of all downstream migrating smolts are diverted by screens from the upper portion of the water column into gatewells as water moves downwards towards the turbines. These smolts are then diverted into a bypass system where they are sent to the tailrace or collected for transportation via barge or truck to a point downstream of Bonneville Dam. An index of smolt abundance (Fish Passage Index or FPI) is made by counting the number of smolts using this system. Smolt indices are calculated as:

$$(FPI)_i = y_i/p_i$$

where y_i is the count of sockeye juveniles in the bypass system for day i, and p_i is the proportion of the flow passing through the turbines in day i (Pereira and Neeley 1990). Further details regarding the calculation of FPI and associated variances are available in Appendix 1. of Fryer (1995). Fryer notes that studies to estimate the efficiency of the smolt interception system to allow expansion of index numbers into total abundance estimates have not been completed for migrant sockeye. However, a series of studies focused on subyearling chinook have been completed (referenced in Raymond 1988) and suggest that cumulative FPI's for smolts will provide accurate estimates of annual variations in total smolt abundance.

McNary Dam is located far enough downstream on the Columbia River that annual assessments of sockeye smolt numbers and biological traits must also include procedures to separate smolts originating from the Okanagan system from those that compose the Wenatchee Lake sockeye stock. Details of the procedure used as the basis for this separation may be found in publications by Fryer (1994, 1995). The separation technique employs both smolt run timing differences (Wenatchee smolts generally pass McNary Dam prior to May 18 while the bulk of Okanagan sockeye smolts do not pass McNary Dam until after May 18th in any given year, Fryer 1995, Peven 1987) and scale pattern differences (Okanagan sockeye typically exhibit significantly higher circulus counts to the first annulus than do Wenatchee sockeye).

3.7.2 Acoustic and Trawl Surveys of Nerkid Abundance in Osoyoos Lake

Surveys to determine underyearling nerkid abundance (juvenile sockeye and kokanee), biological traits of underyearlings and general conditions in Osoyoos Lake that may influence sockeye production variations, have been completed in each of 1997 and 1998 (Rankin et al. 1998, Rankin et al. 1999). Sockeye smolts originating from lake rearing in these years are sampled at Rocky Reach Dam (Chuck Peven, Chelan Public Utility Division, pers. comm.). Sampling procedures vary depending on the nature of the sampling task assigned e.g. (i) execution of acoustic and trawl surveys in Osoyoos Lake to estimate distribution, abundance and biological traits of juvenile sockeye rearing there or (ii) sampling at the Rocky Reach Dam (Figure 1) bypass trap to obtain seasonal samples of Okanagan sockeye smolts migrating through the Columbia mainstem.

Detailed descriptions of standard procedures employed to survey sockeye nursery lakes have been fully documented in several published reports (Hyatt et. al. 1984, Hyatt and Stockner 1985, Gjernes et. al. 1986, Rutherford et al. 1986 and Hyatt et. al. 1989). Summary estimates and documentation at source (e.g. acoustics survey trip reports, trawl survey logs) are assembled and archived after each field survey and managed as electronic and paper records that constitute the Juvenile Sockeye Index Datasets (JSIDS) database maintained by Salmon Index Methods Unit personnel (K. Hyatt, P. Rankin) located at DFO's Pacific Biological Station in Nanaimo.

4.0 Results and Discussion

4.1 Adult Abundance Trends

Total returns of Okanagan sockeye have fluctuated greatly during the period of record (1953-1998) from an apparent high of over 200,000 fish in1967 to fewer than 5000 sockeye in each of 1963, 1994, 1995 and 1998 (Figure 3, Appendix Table 1). Precipitous declines in Okanagan sockeye returns in the early to mid 1960's coincided with the construction of five mainstem dams on the Columbia River (Chapman et al. 1995) which created severe passage problems for the fish. Completion of fishways and improvement in their operation facilitated stock recovery to levels that supported commercial and subsistence fisheries during the late 1960's to mid-1970's. However, for the past 26 years (1973-1998) returns of Okanagan sockeye have apparently been too low to support any significant harvest except in the 5 year interval between 1984 and 1988. Exploration of possible causes for alternating episodes of either high or low returns after the completion of the Columbia Dams in 1967 are beyond the scope of the present paper but have been considered in detail by others (i.e. Mullan 1986, Fryer 1995, Chapman et al. 1995).

4.2 Escapement Estimates at Wells Dam

Adult sockeye escapement estimates at Wells Dam reflect a pattern of annual variation that is similar, although not identical to changes in total returns (Figure 3). Variations in the numbers of adult sockeye passing Wells have fluctuated from a high of 113,000 potential spawners in 1967 to lows of fewer than 5000 potential spawners annually from 1961-1963 and again in each of 1994, 1995 and 1998. The 1985 -1998 decline in sockeye escapement following the 1984 peak count at Wells is no steeper than that observed during the 16 year interval following a similar escapement peak at Wells in 1967-68. However, in 3 of the past 5 years Okanagan sockeye escapements have been as low or lower than those estimated to have passed Wells during some of the worst years of returns (1960-65) associated with dam construction and passage difficulties.

Uncertainties regarding comparisons between depressed returns in the 1990's and those in the 1960's are related to the fact that Wells Dam fishway counts were not initiated until its completion in 1967. Prior to this, peak counts from escapement surveys of Okanagan River spawning areas have been expanded by a factor of two (Table 1) to roughly calibrate them to Wells passage equivalents (see results below). Some authors have suggested the expansion factor applied to the pre-Wells escapement estimates (1953-1966) should be closer to five (Mullan 1986, Gangmark and Fulton 1952), in which case the low escapement values from actual counts observed at Wells in recent years would take on even greater significance.

Given the absence of any significant catch, total returns of Okanagan sockeye in three of the past five years are among the lowest during the entire period of record (Figure 3) and have led to expressions of concern by fisheries personnel and resource stakeholders about future prospects for long term persistence of Okanagan sockeye.

4.3 Okanagan River Spawning Ground Escapement Estimates

Summary values from SEDS indicate that fall estimates of spawner abundance follow a similar pattern of annual variation to that observed earlier in the season at Wells Dam (Figure 4). However, fall abundance estimates from SEDS are much lower averaging only 43.08 % of the potential spawners enumerated at the Wells Dam (Table 2). Further, although covariation between SEDS and Wells annual estimates is significant ($p<0.01$, Figure 5a), the relation is highly variable with SEDS estimates spanning a multiyear range from 7.5 % to 107 % of Wells counts in 1979 and 1996 respectively.

Several authors have previously noted the discrepancies that exist between escapement estimates based on Wells Dam counts and those based on visual surveys of adult sockeye on the spawning grounds in the Upper Okanagan River (Gangmark and Fulton 1952, Allen and Meekin 1980, Chapman et al. 1995 and Peters et al. 1998). These differences have been variably attributed to: (i) inflated counts at Wells dam, especially in years of large volumes of spill during adult sockeye passage, causing an increase in the fallback rate and double enumeration of a proportion of adult migrants (Swan et al. 1994), (ii) inefficiencies of the spawning ground surveys due to the inability to make accurate counts given variable survey techniques, effort level and climatic limits on visual counting efficiency (Allen and Meekin 1980) and (iii) pre-spawning mortality, which may be a significant factor in the Okanagan Basin.

Chapman et al. (1995) summarized a considerable body of information regarding the magnitude and frequency of prespawning mortality of Okanagan sockeye. This author concluded that prespawning losses from all sources are likely to exceed 25 % in most years and much higher levels in some years when Okanagan River and Osoyoos Lake temperatures are high (> 21 degrees Celsius). Given the certainty and variable magnitude of prespawning mortality events, SEDS estimates have generally been considered to more closely represent annual variations in the number of sockeye that successfully survive to spawn in the Okanagan River each year (B. Rosenberger, CDFO Kamloops, pers. comm. March, 1999).

Application of unqualified SEDS estimates in analyses that require multiyear observations of relatively constant precision is of questionable utility. Consequently, we assembled and reviewed survey documentation from data suppliers to provide insights into the likely influence of variations in assessment methods, results and documentation on the utility of annual escapement estimates derived from spawning ground surveys.

4.4 Origins of Okanagan Sockeye SEDS Estimates

4.4.1 General Survey Procedures

Allen and Meekin (1980) note that extensive surveys of sockeye spawning in the Okanagan River were conducted between 1947 and 1974 by personnel of the U. S. Fish and Wildlife Service (1947-1964) or the Washington Department of Fisheries (1964-1974). Documents on file in the Kamloops Office of Canada's Department of Fisheries and Oceans indicate that CDFO personnel also conducted surveys in many of these same years and were the only source of most survey observations after 1974. Although the agencies and personnel conducting spawning ground surveys have changed over time, examination of CDFO-Stream Inspection Log forms, CDFO-BC16 entries and reports from a variety of sources indicate that throughout the period of record survey procedures were remarkably consistent involving: (i) visual counts of sockeye by rafting the upper river (McIntyre to VDS13), (ii) annual coverage of the upper river "index section" (McIntyre to VDS13) where the majority of sockeye spawn and (iii) visual counting on foot from streamside access points in the lower sections of the river whenever these were surveyed.

Raw counts of both living and dead sockeye were initially recorded by stream section for each seasonal survey. Start and stop points for stream sections were consistently defined by the location of 13 vertical drop structures (locations 1-13 in Figure 2) installed as permanent hydraulic control devices in 1954. Raw count data were summed among sections by survey date and the annual escapement estimate was then derived from "peak counts" selected from seasonal totals available from one to several survey dates per year.

4.4.2 Survey Effort and Timing

Examination of field notes from approximately 20 years of stream inspection logs (SIL's) generated by personnel from either CDFO or the U. S. Fish and Wildlife Service and summarized here (Tables 3 and 4), indicates that one to several seasonal surveys were executed each year to determine sockeye abundance on the spawning grounds. Peak abundance levels could be readily distinguished in years of multiple surveys (9 of 20 years) but in more than half of the years we examined, observations from single survey dates served as the only source of spawning ground numbers and were likely treated as the equivalents of peak counts from multiple survey years. The magnitude of bias in annual spawner abundance estimates based on single seasonal surveys that do not coincide with peak seasonal abundance may be approximated through reference to spawner abundance distributions from years of multiple surveys (Figure 6). These indicate that if single visual surveys had been completed during 1971-1974 and had missed the peak of spawner abundance by one week the resultant low bias would have ranged from as little as 3 % to as much as 65 % (mean 43 %).

Failure to time surveys to coincide with peak abundance of spawners in the Okanagan River has the potential to contribute considerably to the low bias of spawning ground versus Wells Dam escapement estimates noted above. This problem may have been especially severe due to reductions in fisheries patrol staff in 1986 after which Okanagan stream inspections consist of single-trip, surveys in 10 of 11 years (Table 3). Historic knowledge of the temporal distribution of peak spawning activity and year specific communication with local informants are employed by CDFO field staff in attempts to minimize this source of bias (B. Rosenberger pers. comm.). However, examination of additional information suggests these efforts have not always been successful.

Previous work (summarized in Chapman et al. 1995) suggests that on average, peak spawning activity takes place in mid-October. However, the range of peak spawning time spans an interval from the end of Sept. to as late as Oct. 23rd. (Figure 7), depending on annual variations in local climate (e.g. water temp., river flow etc...). Examination of CDFO survey dates (from Table 3) relative to this general timing information suggests that either surveys have been consistently biased to occur after the peak of spawning has passed or that the timing of peak spawning activity for Okanagan sockeye has shifted to a later date in the most recent decade (Figure 7). A clue to which of these alternatives is most likely may be extracted from information on the relative abundance of carcasses versus live fish for a given survey (Tables 3 and 4).

In years where the survey date of peak spawner abundance may be identified with certainty, carcass counts always represent less than 5 % of the total count for that date (Table 4). By contrast, sockeye carcasses constitute between 9.2 and 27.7 % of live plus dead survey counts that occur approximately one week after the occurrence of peak abundance (Table 4). Applying the criterion that surveys in which more than 10 % of the counts are composed of carcasses may be classified as being a week or more late, suggests that CDFO surveys occurred after the peak date of sockeye abundance in each of 1991, 1992 and 1997. If this were true, we might expect that surveys from these years would exhibit a greater degree of low bias relative to Wells Dam counts than surveys from years in which carcasses were present but as less than 3 % of the total suggesting the count was closer to the date of peak abundance. Although carcass counts were not recorded in all cases (Table 3), the available evidence suggests that survey years in which carcasses made up more than 10 % of the total do produce annual abundance estimates exhibiting a greater degree of bias relative to Wells counts than years when escapement estimates were based on single surveys in which carcasses made up less than 3 % of the total (Table 5). Thus, in 3 of 9 years in which carcass counts were available, surveys appear to have occurred after the peak of sockeye abundance which is approximately the proportion one would expect (as per Figure 7) given that most, recent year CDFO surveys were routinely scheduled to occur after Oct. 17th.

4.4.3 Survey Effort and Spatial Coverage

Observations assembled from 10 years of CDFO, stream inspection logs (Table 6) indicate that spawner enumeration surveys typically provided coverage of all sections of the river between McIntyre Dam and Osoyoos Lake (Figure 8). However, it is also clear that this was not invariably the case and that during some undetermined portion of years making up the period of record between 1953-1998, surveys covered only an "index section" of river between McIntyre Dam and VDS13. Observations of spawner distribution from years involving coverage of all sections of the river indicate that on average more than 90 % (range 63-98 %) of spawning sockeye were observed in the 2.4 km unchannelized "index" portion of the Okanagan River (Table 6). By contrast, only 9.3 % (range 0-27 %) of adult sockeye observed appeared to utilize the channelized portions of the river extending from VDS13 downstream to Osoyoos Lake (Figure 8). Thus, although survey effort may have varied with respect to spatial coverage in some years, it appears that the bias introduced into annual estimates by variable spatial coverage would have been small as long as counts in the index area between McIntyre and VDS13 were completed.

The level of certainty associated with the use of index section counts (either alone or combined with other counts) as a reliable annual abundance indicator has been called into question on the basis of 1997 assessments of sockeye spawner distribution based on two independent survey approaches. The first approach involved CDFO personnel who completed a routine survey for sockeye abundance by raft and streamside reconnaissance on Oct. 22, 1997. The second approach involved careful tracking by LGL Ltd. to determine the furthest point of upstream penetration of 219 sockeye that had been radio-tagged at either Bonneville or Wells Dam and which had subsequently entered the Lower Okanagan River (Alexander et al. 1998). Alexander et al. reasoned that the terminal distribution of radiotagged sockeye should approximate the distribution of spawning sites used by them. Comparison of results from these sources (Table 7) indicates that patterns of spawning site distribution differ depending on survey approach. Specifically, the radiotagging study results indicate much greater use (51 % of adult sockeye) of spawning habitat downstream of the upper river index section than suggested by CDFO visual counts (5 % of adult sockeye, DFO-SIL versus Rtags pooled results in Table 7).

Differences in sockeye distributions revealed by visual versus radiotag results suggest that the abundance of spawning sockeye was grossly underestimated by visual surveys in 1997 and possibly in other years. However, interpretation of these results is complicated by several factors including the potential influence of: (i) radiotag implantation on sockeye behaviour, (ii) climate events on sockeye distribution and (iii) climate conditions on visual survey efficiency. First, because very few sockeye containing radiotags were observed directly in the river during spawning it is not certain whether all or even most of these fish actually spawned in 1997. Second, 1997 was the coolest and wettest summer and fall experienced in the past 25 years with the result that high discharge levels occurred frequently in the Okanagan River during the spring and fall such that layers of silt that normally cover gravel in downstream sections of the river were scoured clear (B. Rosenberger pers. comm.) and may have attracted a larger proportion of spawners than would normally occupy these areas. Finally, higher than average discharge levels in the river during the visual count survey may have reduced counting efficiency greatly and especially in the areas of turbulent water immediately blow vertical drop structures favoured as holding locations by sockeye.

Further investigation is required to clarify the significance of these results. However, if radiotagging results obtained during 1997 do turn out to be representative of the true distribution of spawning areas, then low visual detection efficiencies on adult sockeye in river segments from VDS13 to Osoyoos Lake (rather than prespawning mortality) could account for a large proportion of the low bias in visual enumerations of sockeye on the spawning grounds relative to earlier season counts at the Wells Dam (Figure 4). This is not to say that annual counts of spawners in the index section from McIntyre Dam to VDS13 should be rejected as an indicator of sockeye abundance on the spawning grounds. Both radiotagging results and multiyear visual surveys confirm that the majority of sockeye prefer to spawn in the river section from McIntyre Dam to VDS13. Visual estimates of spawners in this section would be ineffective as an annual index of spawner abundance only if the proportion of the total run using this segment changed dramatically from year to year relative to lower river segments. This does not appear likely as visual enumerations indicate the proportion of spawners utilizing the index section (McIntyre to VDS13) versus other river segments (VDS13 to Osoyoos Lake) remains reasonably constant (Table 6) despite multiyear changes in peak abundance from fewer than 2000 sockeye to more than 34000 sockeye. Although it is conceivable that as many as 3000 spawners might be overlooked in lower river sections in high water years such as 1997, it is inconceivable that this would be the case in years of better viewing conditions when lower river sections would have to contain 20000 to 35000 sockeye (1984, 1985, 1988, Table 6; 1971 as per Allen & Meekin, 1980) to account for 50 % of the annual total.

4.4.4 Analysis and Reporting of Survey Results to SEDS

Summary estimates of annual escapement by salmon species, by stream and by run are archived in CDFO's regional SEDS database. Raw survey observations extracted from field diaries and SIL's are summarized on "BC16" forms (or their equivalent) and forwarded to CDFO Stock Assessment Data Systems personnel for verification and entry. Because verification activities have not routinely extended to confirmation of annual survey methods or analytical approaches used to convert raw observations into annual summary estimates of spawner abundance, it is advisable to check SEDS estimates against source data before attempting to apply them to resolve questions about habitat capacity or biological production trends as a basis for setting annual escapement objectives.

Comparison of SEDS summary estimates with records of peak counts of spawning sockeye from SIL's (Table 2) indicates the two are closely associated (Figure 9) but by no means identical. In general, SEDS entries involve inflation of peak SIL counts by an average factor of 1.65 (range 0.42 - 7.14). Although the basis for each year's expansion is not well documented, raw numbers are commonly inflated as attempts to account for survey years when either the peak period of abundance was missed, spawning habitat coverage was incomplete or visibility on the grounds was poor (B. Rosenberger, pers. comm.). In addition, some SEDS entries which are lower than peak field counts (Figure 9), are simply wrong (e.g. 1969 and 1970 SEDS estimates, Table 2.) due to either entries from incomplete survey information or transcription errors. Expansions of raw observations from SIL's of Okanagan sockeye are not restricted to only SEDS summaries. In their systematic review of data sources for Mid-Columbia sockeye populations Chapman et al. (1995) summarized what they referred to as peak spawning ground counts of sockeye for the interval 1945-1993 (their Table 2). However, comparison of their peak counts against original survey counts suggests that even their peak counts represent a mixture of unexpanded and expanded estimates (Table 8).

Given the results presented above, it is likely that annual counts of sockeye escapement past Wells Dam maintain a higher level of both accuracy and precision than annual estimates obtained through visual surveys on the spawning grounds. However, it is impossible to discount the view that, in spite of many sources of uncertainty, spawning ground counts may still serve as a useful index of annual variations in the number of sockeye that actually survive to deposit their eggs in the Upper Okanagan River.

Consequently, analyses to determine associations between spawner abundance and either spawning ground habitat utilization or production at subsequent life history stages should consider both Wells and Okanagan River escapement estimates. We suggest the value of the latter could be improved considerably through systematic assembly and analysis of raw counts from SIL's to provide a more reliable set of multiyear escapement estimates than currently contained in SEDS but have not been allotted the time to complete this task here.

4.5 Associations Between Annual Variations in Adult and Juvenile Sockeye Life History Stages

Annual changes in brood year abundance of adult sockeye spawners are positively associated with annual changes in relative abundance of Okanagan sockeye smolts monitored at the McNary Dam bypass (Figure 10). Brood year abundance at Wells provides a statistically superior prediction of smolt abundance at McNary ($r^2 = 0.45$, $p < .05$) by comparison to SEDS estimates ($r^2 = 0.24$, $p > .05$) although both data sets show the same trend. Thus, there is no evidence of any decline in smolt production per spawner across an escapement range from 2000 to approximately 80,000 spawners at Wells or from less than 1000 to approximately 38,000 spawners on the grounds in the Okanagan River (Table 9).

We were able to find only 12 years of samples taken at scattered intervals between 1957 and 1991 to characterize sockeye smolt size-at-age (Table 10). However, these observations do suggest that growth and size achieved by juvenile sockeye rearing in Osoyoos Lake are density dependent such that sizes attained at low fry abundance (as indexed by brood year escapements) are significantly larger than sizes attained at high abundance. In this case as well, indices of brood year escapement in the Okanagan River and at Wells Dam provide evidence of similar trends (Figure 11), but only the relationship between smolt size and brood year adult abundance at Wells Dam achieves statistical significance ($r^2 = 0.496$, $p < .01$).

The average size of sockeye smolts produced in Osoyoos Lake is consistently among the largest observed for the species throughout its geographic range (Mullan 1984, Chapman et al. 1995, Fryer 1995). This has been interpreted as evidence that Osoyoos Lake is one of the most productive sockeye nursery lakes in North America. However, virtually all previous comparisons of Osoyoos Lake smolt size relative to smolts from other populations have failed to take into account the potentially confounding influence of between-population, density differences on size-at-age. We wished to compare Osoyoos lake smolt size and abundance observations in a less biased way with the size-at-age of juvenile sockeye from other populations. Consequently, we have attempted to calibrate abundance measures of Osoyoos brood year escapement to fall fry abundance estimates measured in acoustic and trawl survey (ATS) units commonly employed by us for surveys of juvenile sockeye abundance in British Columbia lakes (Hyatt et al. 1984, Hyatt and Stockner 1985).

Acoustic and trawl surveys of juvenile sockeye (and kokanee) abundance in Osoyoos Lake have been completed on eight occasions in four separate calendar years (Table 11). The number of juveniles produced in ATS units per spawner varies greatly between 13 and 152. Given the limited number of years of observations, we have used the mean of all observations at 70 fry per spawner to provide a first approximation for an Osoyoos Lake smolt size to sockeye fry abundance relationship (Figure 12a). At this point in our survey work, there is still some uncertainty about what proportion of the juvenile “nerkids” in Osoyoos Lake are sockeye as opposed to kokanee underyearlings. However, our implicit assumption that the kokanee component is small is supported by observations that: (i) kokanee spawners for the years in question were not abundant enough to be explicitly included in annual spawning ground counts, (ii) a 7 fold decline in brood year sockeye escapements between 1997 and 1998 was accompanied by a 10 fold decline in total abundance of juvenile “nerkids” estimated via ATS work (Hyatt et al. unpublished survey observations) suggesting that the juvenile “nerkid” population is likely composed almost entirely of sockeye and (iii) significant associations exhibited among sockeye smolts indexed after departure from Osoyoos Lake, smolt size achieved through rearing in Osoyoos Lake and spawner abundance would all likely be undetectable given a large or variable contribution of juvenile kokanee to lacustrine nerkid populations. In addition, four years of mark and recapture estimates of Okanagan sockeye smolt abundance passing Priest Rapids Dam between 1984 and 1988 provide a second independent set of observations which suggest a mean value of 101 smolts per spawner (Table 12). The latter observations suggest that if there is a bias in our conversion from brood year escapement to ATS units of abundance in Osoyoos Lake it will likely lean towards underestimating sockeye fry abundance (and the productivity of Osoyoos Lake relative to other nursery lakes).

The smolt size to fall fry abundance relationship for the Sproat Lake sockeye population located on Vancouver Island is also presented for comparative purposes. These observations indicate that at equivalent rearing densities in both Sproat and Osoyoos lakes, juvenile sockeye rearing in Osoyoos Lake attain an average of more than twice the weight of Sproat sockeye by the end of a single year of lake residence (Figure 12a). This feat is even more remarkable in light of results from our ATS work on Osoyoos Lake during 1997 and 1998 which indicates that seasonal temperature and oxygen conditions in two of three basins of Osoyoos Lake preclude rearing there by juvenile sockeye for the majority of the growing season between June and November (Rankin et al. 1998, Rankin et al. 1999). Accordingly, we have also provided a version of the fry abundance and smolt size relationship to reflect the observation that virtually all Osoyoos Lake sockeye production is dependent on rearing habitat in the North Basin of the lake (Figure 12 b). The product of sockeye abundance and mean weight observations provides a simple, meaningful index of the relative capacities of Osoyoos and Sproat lakes (Tables 10 and 13) to support sockeye smolt production within the context of annual variations in fry recruitment. Average smolt production from Osoyoos Lake amounts to 14.5 kg per ha (range 10.2-21.1 , Table 10) versus 7.59 kg per ha (range 4.8-13.4, Table 13) at Sproat Lake.

4.6 Okanagan Sockeye Escapement Objectives

Significant numbers of Okanagan adult sockeye return after 1 or 2 years at sea (Chapman et al. 1995). Catches and escapements are known to exhibit very different age compositions but are not routinely sampled for age-at-return thus precluding credible assessment of production variations associated with specific brood years. Given the absence of brood year specific adult recruitment information, it has not been possible to complete a reliable stock-recruit analysis for Okanagan sockeye to define a potential escapement optimum to date. However, observations assembled in this paper may be employed to define escapement objectives for Okanagan sockeye in terms of either: (i) spawning habitat use by adults or (ii) associations between spawner abundance and juvenile sockeye recruitment as an alternative to more traditional analyses focused on recruitment of adults.

4.6.1 Spawning Habitat Capacity and Escapement Objectives

The Fisheries Service of Canada's Department of the Environment in collaboration with the Washington Department of Fisheries completed a detailed study and analysis of both the quantity and quality of gravel available for sockeye spawning in the unchannelized, index section of the Okanagan River immediately below Vaseaux Dam (Anonymous 1973). Surveys, including 26 channel cross sections and water surface profiles, were carried out at discharges of 540 cfs, 380 cfs and 210 cfs. At discharges of 540 cfs and 380 cfs areas of spawning gravel falling within the water depth and velocity parameters of 8-18 inches and 0.8 to 2.5 feet per second, and consisting of 1.5-4 inch diameter gravel,
were calculated. "Good" spawning gravel was designated as satisfying all three of the above parameters while "medium" spawning gravel satisfied only two. Interpolations from field data were also used to predict the area of spawning gravel available at discharges of 250 cfs, 125 cfs and 90 cfs in order to create spawning area versus discharge relationships restricted to either high quality (i.e. "good") areas alone or including both high and medium quality areas (Figure 13).

Calculations of habitat capacity for adult sockeye (Anonymous 1973, Appendix 2) suggested that high quality spawning areas could support approximately 38,900 spawners at discharges of 380 cfs. An extremely conservative approach was taken in the formulation of these calculations as they assumed that: (i) no spawning would take place in medium quality areas of gravel once high quality areas were fully occupied, (ii) each female sockeye would require 4.18 square meters (i.e. 5 sq. yd) of gravel. Amazingly, choice of the latter value was based on a wholly circular argument that use of a lower value would have produced spawning ground capacity estimates that were "in excess of recorded escapements" even given the artificial restriction of spawners to only high quality areas. Allen and Meekin (1980) suggested on the basis of their field observations that the index spawning area in the Upper Okanagan River was 80 % saturated given a peak abundance of 14,968 females in 1971. Following calculations in Anonymous (1973) that 108, 860 square meters of good spawning gravel are available at river flows of 325 cfs, this equates to an estimated requirement of 7.14 square meters of gravel for each female spawner (Table 14).

Several recent studies relate actual measures of fry output to spawning gravel requirements for female sockeye in various locations (Table 15). Results from these studies indicate, without exception, that previous calculations of Okanagan spawning ground capacity are biased low. Consequently, we have calculated new estimates based on: (i) the minimum as well as the mean number of females recent studies suggest a square meter of gravel will accommodate (i.e. 0.56 females.m^{-2} and 1.48 females.m^{-2}) plus (ii) continued adherence to the conservative assumption that spawning will only take place in the 108,860 m^2 of high quality habitat present in the Upper Okanagan "index section" at a river flow of 325 cfs (Anonymous 1973). These new estimates (Table 16) suggest that the Okanagan index area alone will have a minimum capacity to accommodate 67000 spawners (as SEDS units) and a mean capacity for approximately 179,000 spawners. These estimates are far in excess of observed escapements in all but a few years (Figure 14). Consequently, we suggest that the lower value of 67,000 spawners in SEDS units be set as the minimum escapement level required to "challenge" available spawning habitat in the Okanagan River (i.e. 135, 471 spawners if estimates were made as escapement past Wells Dam, Table 16, reference line a. in Figure 14).

4.6.2 Lake Rearing Capacity and Escapement Objectives

Both Mullan (1984) and Chapman et al. (1995) review a wealth of information to suggest that Osoyoos Lake is one of the most productive lakes occupied by juvenile sockeye throughout their geographic range. Rather than repeat their arguments here, we have attempted to place annual sockeye production from Osoyoos Lake into a broader context based on a known relationship between total phosphorus concentration and fish biomass maintained in a diverse suite of north temperate zone lakes. A large body of research supports the general view that phosphorus is an essential nutrient that commonly limits gross production in lakes from lower trophic levels on up through top consumers such as fish (Figure 15). More than two decades of research (Stockner and McIsaac 1996) also confirms that production levels of both primary producers and consumers such as sockeye are extremely low in the ultraoligotrophic sockeye nursery lakes of British Columbia. Production across trophic levels in these lakes is frequently controlled by the availability of limiting nutrients such as phosphorus, or less commonly, nitrogen (Stockner and Hyatt 1984, Hyatt and Stockner 1985, Johannes and Hyatt 1999).

Comparison of nutrient concentrations maintained throughout the growing season in Sproat and Great Central lakes (where the latter has received annual additions of inorganic fertilizers to stimulate nutrient limited production) with annual sockeye production estimates confirms the expectation that maintenance of extremely low seasonal mean nutrient levels is associated with levels of mean annual fish production that are among the lowest known for any set of north temperate zone lakes (Figure 15). By contrast, the North Basin of Osoyoos Lake maintains average seasonal phosphorus concentrations of 22 ug per liter (Mullan 1986, Pratt et al. 1991) which are an order of magnitude higher than the levels observed in Sproat or Great Central lakes (Hyatt and Stockner 1985, Johannes and Hyatt 1999). Thus, although not surprising, it is encouraging that average annual production levels estimated here for sockeye rearing in the North Basin of Osoyoos Lake (Table 10) correspond reasonably well with the level anticipated by the larger phosphorus to fish production datasets (Figure 15).

There have been several previous attempts to determine quantitative limits on the productive capacity of Osoyoos Lake to support juvenile sockeye and then to convert this into estimates of adult escapement levels required to match these limits. Pinsent et al. (1974), used plankton abundance to estimate that the lake could carry the progeny of 107,479 sockeye females. Pratt et al (1991) used the volume of the euphotic zone (Koenings and Burkett 1978) to determine that the lake could support 4 million sockeye smolts. Both of these approaches are based on an assumption that the entire volume of the lake is available as accessible habitat throughout the growing season. Extremes of high epilimnial temperature (>20 degrees Celsius) and low hypolimnial oxygen (<5 ug per liter) restrict Osoyoos sockeye to mid depths of the North basin of the lake for most of the growing season (Rankin et al. 1999). Consequently the approaches used by both Pinsent et al. (1974) and Pratt et al. (1991) are considered unreliable (Bull 1999).

Estimates of the capacity of Osoyoos Lake to support annual production of juvenile sockeye, as developed in the current paper, implicitly account for seasonal fluctuations in the environmental variables noted above. Thus, use of these values should provide a more reliable means of estimating adult escapement levels that will provide sufficient fry recruitment to fully utilize the average productive capacity of Osoyoos Lake. However, conversions from average yearly, levels of juvenile sockeye production (expressed as kg per ha) to adult escapement requirements involve one additional complication. This is related to the observation that the size of yearling smolts produced in Osoyoos Lake varies non-lineally with increases in fry rearing density (Figures 11 and 12). Consequently, relatively small changes in assumptions about what constitutes a desirable smolt size have major effects on determinations of desirable levels of both fry recruitment and adult escapement to be maintained in Osoyoos Lake.

The current average size of age 1.0 sockeye smolts exiting Osoyoos Lake is in excess of 100 mm (9.5 g). If 100 mm is chosen as the minimum size of smolt required to ensure "adequate" survival during the rigors of riverine migration, then escapement requirements may be specified from Figure 6b as Ln Escapement at Wells = (321.81 - 100)/20.20 which yields an escapement requirement of 58,730 sockeye at Wells (reference line c in Figure 14) or approximately 29,365 as peak count units in the Upper Okanagan index area. Limiting Okanagan sockeye escapement levels to maintain production of 100 mm smolts from Osoyoos Lake represents a highly conservative position. Yearling sockeye smolts produced in Wenatchee Lake average only 86 mm (6.2 g) in length. Further, observations reported in Fryer (1995) indicate no significant difference exists between Wenatchee and Okanagan sockeye smolt-to-adult survival rates. If the "threshold" size for Osoyoos Lake sockeye smolts is reduced to 86 mm, similar to those in Wenatchee Lake, then Okanagan sockeye escapement requirements increase to 117,453 spawners passing the Wells Dam (reference level b in Figure 14) or 58,727 sockeye as peak counts in the Upper Okanagan River.

Estimates of habitat based escapement objectives identified above provide a range of defensible values from as few as 58, 730 to as many as 135,471 spawners passing Wells Dam. Each of these values involves different assumptions about relationships between habitat capacity and subsequent levels of stock production that may be achieved. Further refinements to these objectives will be possible as additional information is gathered on associations between changes in terminal escapement, lacustrine fry recruitment and smolt size. However, the more pertinent observations at present may be that: (i) annual escapement levels have rarely exceeded even the most conservative escapement reference level of 58,730 identified here (reference level c in Figure 14.) and (ii) current escapement levels have trended downwards to alarmingly low levels in three of the past five years in the absence of any significant exploitation pressures on returning adults. A more in-depth examination of the causes for this recent decline would appear advisable.

5.0 Summary and Conclusions

Summary estimates of annual escapement have been assembled by various agencies to provide indications of annual abundance changes of Okanagan sockeye salmon over more than a 40 year period of record. Although the Regional Salmon Escapement Data System (SEDS) contains one version of these summary estimates, it is apparent from inspection of various years of source documentation on which SEDS estimates are based, that assessment methods and effort levels have changed at various times such that summary estimates in SEDS may be alternately biased high or low by varying degrees throughout the period of record.

Analysis presented above suggests that alternate estimates of sockeye enumerated passing the Wells Dam provide a more reliable index of annual changes in escapement of Okanagan sockeye than the current summary estimates in SEDS and should be considered for inclusion there.

Summary estimates of escapement currently contained in SEDS are largely devoid of accompanying commentaries concerning changes in assessment methods or effort levels applied annually to generate estimates. Resolution of the utility of historic estimates is more difficult than need be given the absence from SEDS electronic files of qualifying comments that correspond to CDFO-BC16 and Stream Inspection Log comment entries. Completion of information capture and transfer to the regional database (SEDS) from both summary forms (i.e. paper copies of the "B.C. 16's") and source records (e.g. "stream log" information periodically recorded in association with individual inspections) should be encouraged to improve the general utility of all entries, for stock assessment as well as other purposes.

We recommend the implementation of systematic retrieval and review of SEDS source documentation for key stocks that are likely to become a focus for future PSARC work. Specific information missing from SEDS that should be incorporated from paper copies of the "B.C.16's" or other source records wherever possible includes: (i) dates on which surveys for a given species were completed, (ii) the survey method in use, (iii) supplemental observations to confirm the temporal position of a survey relative to peak time of spawning, (iv) records of raw counts on which summary estimates are based, (v) degree of completeness of spawning area spatial coverage provided by each survey, (vi) changes between surveys in methods or procedures for obtaining raw counts or for estimating total escapement.

Development and application of standard techniques combined with documentation of procedures and observations-at-source to estimate juvenile abundance trends for Okanagan sockeye rearing in Osoyoos Lake (Rankin et al. 1998, 1999) have produced information of considerable utility to habitat based approaches to defining Okanagan sockeye escapement objectives by verifying that:

(i) growth and annual production variations for juvenile sockeye in Osoyoos Lake are density dependent,

(ii) most juvenile sockeye production is restricted to the North Basin of Osoyoos Lake,

(iii) unutilized potential to support production of additional sockeye exists in Osoyoos Lake given current fry recruitment and adult escapement levels,

(iv) defensible escapement objective may be provided on the basis of the relation between adult stock and size dependent recruitment variations of smolts.

We also recommend that the biological consequences of smolt size management for Osoyoos Lake sockeye be explored as a requisite to refining escapement objectives that might be adopted if Okanagan sockeye stock rebuilding is successful in future years. Generation of data sets to facilitate this will require more systematic retrieval of annual biosamples of smolts rather than the sporadic sampling that has apparently produced only 12 estimates of smolt size during the past 40 years.

Continued efforts to improve the documentation and reliability of escapement assessment methods applied to spawners in the Okanagan River is encouraged to resolve the issue of the extent to which differences in spawning ground versus Wells Dam estimates of sockeye are due to methodological or biological factors (e.g. prespawning mortality).

Examination of classical stock and adult recruit relationships was not possible for Okanagan sockeye stocks due to the general absence of annual estimates of the age composition of adult sockeye in food fishery catches and especially in escapement. The inability to assign stock specific returns to brood year of origin also precludes routine determination of annual smolt-to-adult survival rates for Okanagan sockeye. Because the latter information will be essential to the long term management of the stocks and lakes to determine combinations of smolt numbers and size that will optimize production, we recommend that annual sampling for age, size and sex composition of sockeye in catch and escapement be completed wherever feasible.

Our attempts to use habitat based approaches to objectively define escapement goals for Okanagan sockeye have, in our view, been reasonably successful in identifying a defensible set of <u>minimum</u> escapement objectives. Specifically, 58,780 sockeye enumerated at the Wells Dam or 29,390 as peak counts in the Upper Okanagan River escapement "index area" should be regarded as defensible, provisional escapement objectives. We have adopted conservative assumptions at each of several steps in our habitat based analysis of escapement needs. Thus, it is likely that existing spawning and rearing habitat in the Okanagan River and Osoyoos Lake will actually support a higher escapement objective than that specified here. However, it is also clear that all of the evidence examined by us supports the inference that neither spawning ground nor lake rearing capacity currently limits Okanagan sockeye population size. Accordingly, adoption of a provisional escapement goal of 59,000 Okanagan Sockeye passing the Wells Dam should suffice until such time as the stock rebuilds to levels that might actually challenge available habitat and warrant further refinement of escapement objectives.

6.0 Summary Recommendations

We recommend:

(1) Provisional escapement objectives for Okanagan sockeye be set at 58,730 adults (in Wells Dam units) or 29,365 adults as peak visual counts on the spawning grounds.

(2) Biological consequences of smolt size management of Osoyoos Lake sockeye be explored as a requisite to refining escapement objectives that might be adopted if Okanagan sockeye stock rebuilding is successful in future years.

(3) Annual sampling for size and age composition of Okanagan sockeye smolts be completed whenever feasible to facilitate future analysis of smolt to adult survival trends and smolt size management options in Osoyoos Lake.

(4) Annual sampling for age, size and sex composition of sockeye in catch and escapement be completed whenever feasible to facilitate future analysis of stock and recruit relations and to follow smolt to adult survival trends.

(5) Implementation of systematic retrieval and review of source documentation pertaining to SEDS estimates of Okanagan sockeye escapement as well as support for ongoing efforts to complete entry of supplemental comments describing methods used to generate both raw and summary escapement estimates.

(6) Annual summary estimates of Okanagan sockeye escapement from Wells Dam counts be incorporated into SEDS as a formal alternative to spawning ground counts.

(7) Given that neither spawning gravel capacity or lake rearing capacity appear to set the principal limits on Okanagan sockeye population size at current stock levels, additional effort should be expended by the Okanagan Basin Fisheries Working Group to determine the basis for recent stock declines in the absence of any targeted exploitation of Okanagan sockeye.

7.0 References

Alexander, R. F., K. K. English, B. L. Nass and S. A. Bickford. 1998. Distribution, timing and fate of radio-tagged adult sockeye, chinook and steelhead tracked at or above Wells Dam on the mid-Columbia River in 1997. Report prepared by LGL Limited Environmental Research Associates, 9768 Second street, Sidney, B. C. V8L 3Y8 for Public Utility District No. 1 of Douglas County, 1151 Valley Mall Parkway, East Wenatchee, WA 98802-4497. 29 p., 18 Tables, 20 Figures and 8 Appendices.

Allen, R. L. and T. K. Meekin. 1980. Columbia River sockeye salmon study, 1971-1974. Wash. Dep. Fish. Prog. Rep. 120, 75 p.

Anonymous. 1973. Fisheries Service Environment Canada. Canada-British Columbia Okanagan Basin Agreement: Task 162: Pacific salmon: population and habitat requirements. Preliminary report no. 16. 45 p., 3 appendices.

Anonymous. 1996. 1996 Okanogan River sockeye escapement study. Report prepared by Trumbley Environmental, Vernon, B. C. for the Douglas County Public Utility Districts.

Bijsterveld, L. and M. James. 1986. The Indian food fishery in the Pacific region: Salmon Catches, 1951-1984. Can. Data Rep. Fish. Aquat. Sci. No. 627. 12 pp., 4 appendices.

Bull, C. 1999. Fisheries habitat in the Okanagan River. Phase 1: Options for protection and restoration. Prepared by Glenfir Resources, Penticton, BC for Public Utility District No. 1 of Douglas County, 1151 Valley Mall Parkway, East Wenatchee, WA 98802-4497. 61 p., 9 Tables, and 17 Figures.

Chapman, D., C. Pevan, A. Giogi, T. Hillman, F. Utter, M. Hill, J. Stevenson, and M. Miller. 1995. Status of sockeye salmon in the Mid-Columbia region. Don Chapman Consultants, Inc., 245 p. plus 129 figs., 26 tables, and 1 appendix.

Cooper, A. C. 1977. Evaluation of the production of sockeye and pink salmon at spawning and incubation channels in the Fraser River system. International Pacific Salmon Fisheries Commission Progress Report. 36: 80 p.

Craddock, D. R. 1958. Spawning escapement of Okanagan River blueback salmon (Oncorhynchus nerka), 1957. U. S. Fish and Wildlife Service. Special Scientific Report: Fisheries. No. 275: 8 p.

Fyer, J. K. 1994. Identification of Columbia Basin sockeye salmon stocks using scale pattern analyses in 1993. Technical Report 94-2 of the Columbia River Inter-Tribal Fish Commission. Portland, OR 97232.

Fryer, J. K. 1995. Columbia Basin sockeye salmon: Causes of their past decline, factors contributing to their present low abundance, and future outlook. Ph.D. Thesis, Univ. Wash., Seattle, WA, 274 p.

Gangmark, H. A. and L. A. Fulton. 1952. Status of Columbia River blueback salmon runs, 1951. U.S. Fish and Wildl. Serv. Spec. Sci. Rept. Fish. No. 74: 29 p.

Gibson, G., R. Michimoto, F. Young, and C. Junge 1979. Passage problems of adult Columbia River chinook salmon and steelhead, 1973-1978. U. S. Army Corps of Engineers Contract No. DACW 57-78-C-0044 completed by the Oregon Department of Fish and Wildlife.

Gjernes, T. W., K. D. Hyatt and D. P. Rankin. 1986. Development of specifications for the use of an uncalibrated echo sounder to estimate populations of small limnetic fish. Can. Tech. Rep. Aquat. Fish. Sci. No. 1509: 35 p.

Gustafson, R. G., T. C. Wainwright, G. A. Winans, F. W. Waknitz, L. T. Parker and R. S. Waples. 1997. Status review of sockeye salmon from Washington and Oregon. U. S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-33, 282 p.

Hagen, J. E., and G. B. Grette. 1994. 1993 Okanogan River sockeye salmon spawning ground population study. Parametrix Inc. for Douglas County Public Utility District, East Wenatchee, WA. 19 p.

Hansen, J., 1993. Upper Okanogan River sockeye salmon spawning ground survey - 1992. Colville Confederated Tribes, Fish Wildlife Dept. 79 p.

Hatch, D. R. and M. Schwartzberg. 1991. Wenatchee River salmon escapement estimates using videotape technology in 1990. Columbia River Inter-Tribal Fisheries Commission Technical Report 91-3. Portland Oregon.

Hatch, D. R., A. Wand and M. Schwartzberg. 1992. Wenatchee River salmon escapement estimates using videotape technology in 1991. Columbia River Inter-Tribal Fisheries Commission Technical Report 92-3. Portland Oregon.

Hatch, D., S. M. Hagan and M. Schwartzberg. 1993. The feasibility of estimating sockeye salmon escapement at Zosel Dam using underwater video technology. 1993 Annual Progress Report. Columbia River Inter-Tribal Fish Commission.

Hyatt, K. D. , D. Rutherford, T. Gjernes, P. Rankin and T. Cone. 1984. Lake Enrichment Program: Juvenile Sockeye Unit survey guidelines. Can. Ms. Rep. Fish. Aquat. Sci. No. 1976: 84 pp.

Hyatt, K. D. and J. G. Stockner. 1985. Responses of sockeye salmon (Oncorhynchus nerka) to fertilization of British Columbia coastal lakes. Can. J. Fish. Aquat. Sci. 42: 320-331.

Hyatt, K. D., D. P. Rankin and E. Rome. 1989. Acoustic census of limnetic fish in a glacially turbid lake. Proc. Institute of Acoustics. Vol.11 Part3 pp. 238-246.

Johannes, M. R. S., and K. D. Hyatt. 1999 in prep. Trophic level interactions in two ultraoligotrophic B. C. lakes: The Great Central and Sproat Lake fertilization experiments revisited.

Koenings, J. P., and R. D. Burkett. 1987. Population characteristics of sockeye salmon (Oncorhynchus nerka) smolts relative to temperature regimes, euphotic volume, fry density and forage base within Alaksan lakes. Pages 216-234 in H. D. Smith, L. Margolis and C. C. Wood (eds.). Sockeye Salmon (Oncorhynchus nerka) Population Biology and Future Management. Can. Spec. Publ. Fish. Aquat. Sci. No. 96.

Major, R. L., and J. L. Mighell. 1966. Influence of Rocky Reach Dam and the temperature of the Okanogan River on the upstream migration of sockeye salmon. U. S. Fish. Wildl. Serv., Fish. Bull. 66(1):131-147.

Meekin, T. K. 1969. Fish passage problems at Wells Dam, 1968. Washington Department of Fisheries Report, Olympia, Washington.

Mullan, J. W. 1986. Determinants of sockeye salmon abundance in the Columbia River, 1880's-1982: A review and synthesis. U. S. Fish Wildl. Serv. Biol. Rep. 86(12), 135 p.

Peven, C. M. 1987. Downstream migration timing of two stocks of sockeye salmon on the Mid-Columbia River. Northwest Science 61: pp186-190.

Pereira, C. L. and D. Neeley. 1990. Report of Biometrician Group on a confidence interval for the cumulative passage index. Fish Passage Center, Portland Oregon.

Peters, C. N., D. P. Bernard and D. R. Marmorek. 1998. Should sockeye be re-introduced to Okanagan Lake? An exploration of potential benefits, impacts and uncertainties. Prepared by ESSA Technologies Ltd., Vancouver, BC for Participants of the Okanagan Sockeye Workshop (Okanagan Nation Fisheries Commission). 50 pp.

Pinsent, M. E., G. D. Koshinsky, T. J. Wilcocks and J. O'Riordan. 1974. Fisheries and Wildlife in the Okanagan Basin. Tech. Supp. IX, Okanagan Basin Study. 249 p.

Pratt, K. L., D. W. Chapman and M. Hill. 1991. Potential to enhance sockeye salmon upstream from Wells Dam. Don Chapman Consultants Inc. for Douglas County PUD, East Wenatchee, Washington.

Rankin, D.P., B. Hanslit and K. Hyatt. 1998. Acoustic and trawl surveys of Lake Osoyoos, 1997. Report to file JSIDS-SRe: 1-98. Salmon Index Methods Unit, Pacific Biological Station, Nanaimo, B.C. 8pp plus appendices.

Rankin, D.P., B. Hanslit and K. Hyatt. 1999. Acoustic and trawl surveys of Lake Osoyoos, 1998. Report to file JSIDS-SRe: 5-99. Salmon Index Methods Unit, Pacific Biological Station, Nanaimo, B.C. 9pp plus appendices.

Raymond, H. L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer chinook salmon and steelhead in the Columbia River Basin. North American Journal of Fisheries Management 8: 1-24.

Rutherford, D.K., K.D. Hyatt, J.E. Radziul and G.J. Steer. 1986. Physical parameters of sockeye salmon (Oncorhynchus nerka) rearing lakes under study by the Enhancement Assessment Unit. Can. Fish. Aquat. Sci. Ms Rep. No. 1878, 114p.

Rutherford, D. T., C. C. Wood, K. D. Hyatt, L. Margolis, T. E. McDonald, B. E. Riddell, and R. E. Withler. 1992. Biological characteristics of coastal populations of sockeye salmon (Ocorhynchus nerka) in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1849: 47 pp.

Serbic, G. 1991. The Salmon Escapement Database and Reporting System. Can. Tech. Rep. Fish. Aquat. Sci. 1791: 104 p.

Stockner, J. G. and K. D. Hyatt. 1984. Lake Fertilization: State of the Art after 7 years of application. Can. Tech. Rep. Fish. Aquat. Sci. No. 1324. 33 p.

Stockner, J. G. and E. A. McIsaac. 1996. Regulated Rivers: Research and Management 12:547-561.

Swan, G. A., L. K. Timme, R. N. Iwamoto, L. C. Stuehrenberg, E. E. Hockersmith, B. L. Iverson, and B. P. Sandford. 1994. Wells Dam radio-telemetry study, 1992. Nat. Marine Fish. Serv., Northwest Fisheries Science Centre, Report of research funded by Douglas County PUD and Nat. Marine Fish. Serv.

Tschaplinski, P. T. and K. D. Hyatt 1991. A comparison of population assessment methods employed to estimate the abundance of sockeye salmon (Oncorhynchus nerka) returning to Henderson Lake, Vancouver Island during 1989. Can. Tech. Rep. fish. Aquat. Sci. No.1798. 101 p.

Williams, I. V. and T. J. Brown. 1996. Ecosystem management for Pacific salmon; Integrating habitat into the harvest management, stock assessment loop. Unpublished Ms (PSARC Working Paper S96-15), Canada Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B. C. 77 p.

Figures

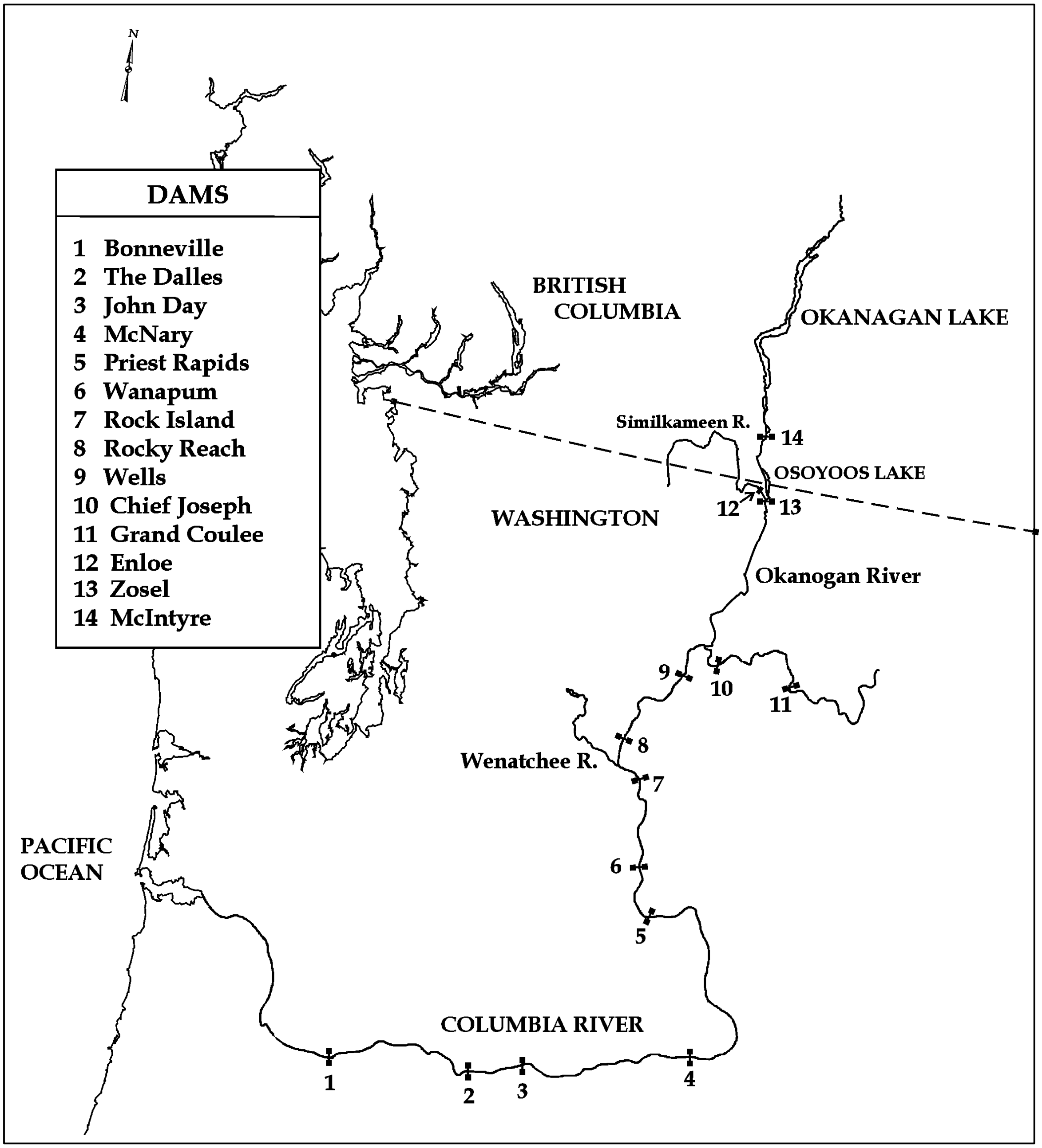

Figure 1. Location of Okanagan River and Osoyoos Lake study areas relative to the Columbia River sockeye migration corridor

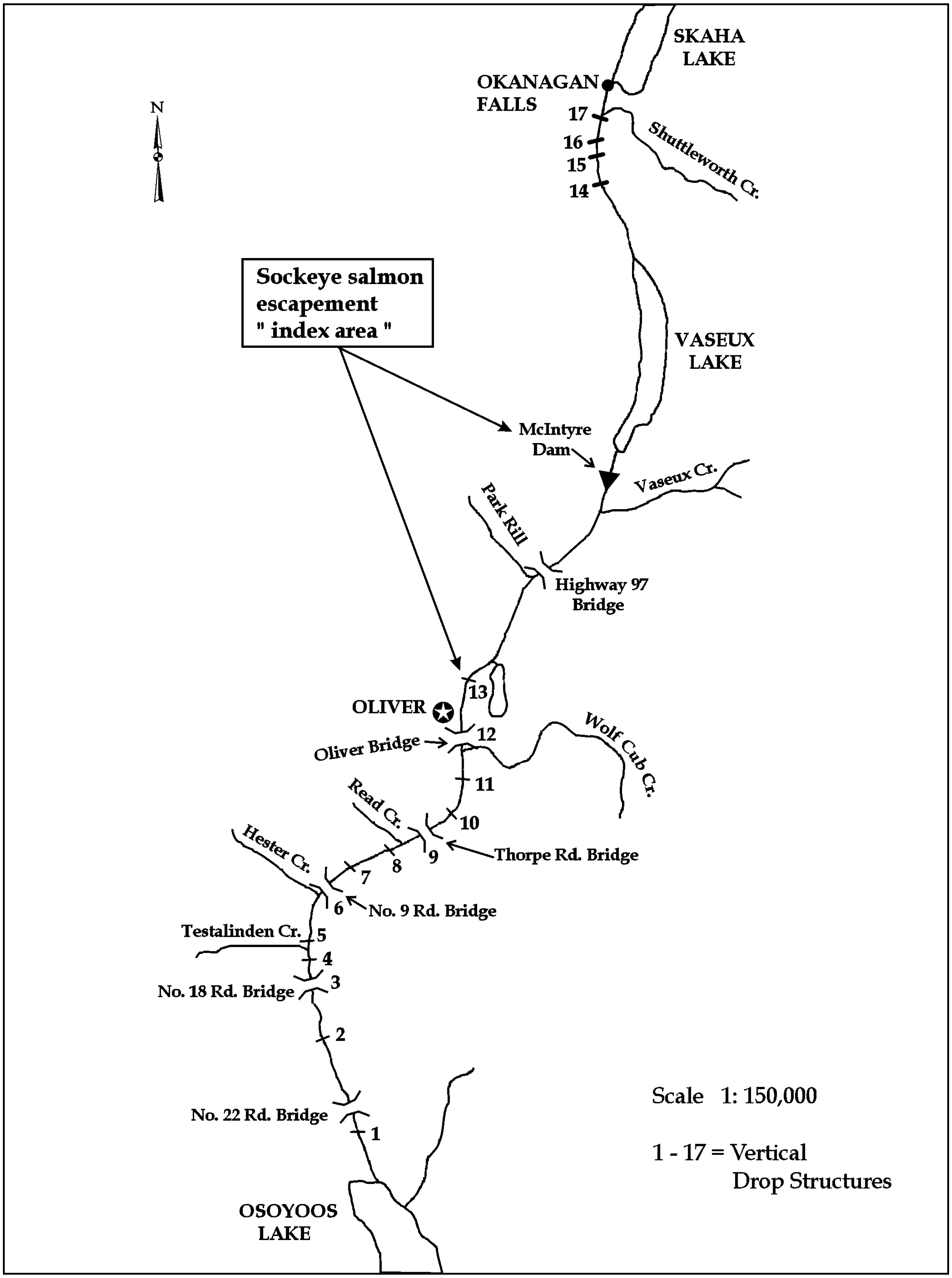

Figure 2. Upper Okanagan River from Skaha Lake to Osoyoos Lake

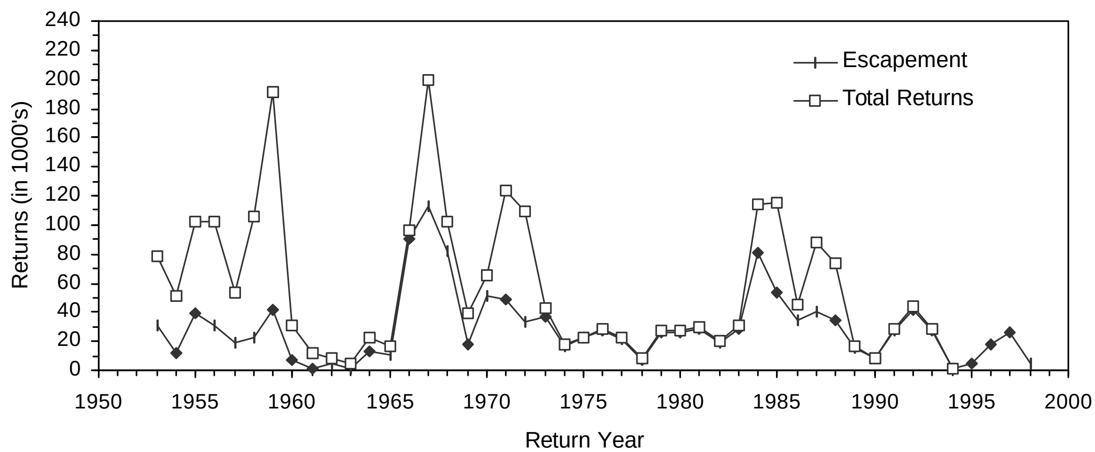

Figure 3. Total Returns and Escapement of Okanagan River Sockeye Salmon from 1953-1998

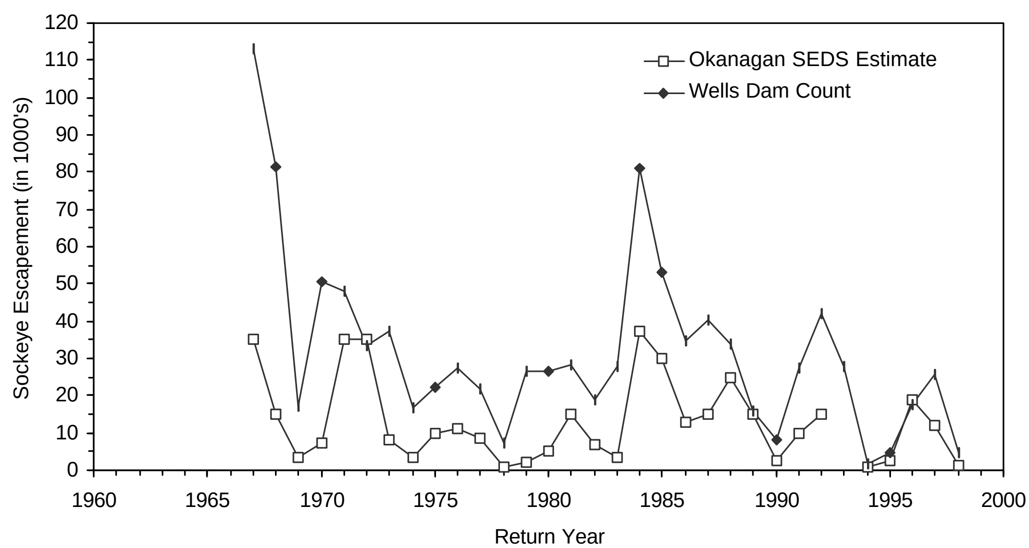

Figure 4. Trends in Okanagan River sockeye spawner abundance from 1967-1998 as per counts at Wells Dam or on the Okanagan River spawning grounds

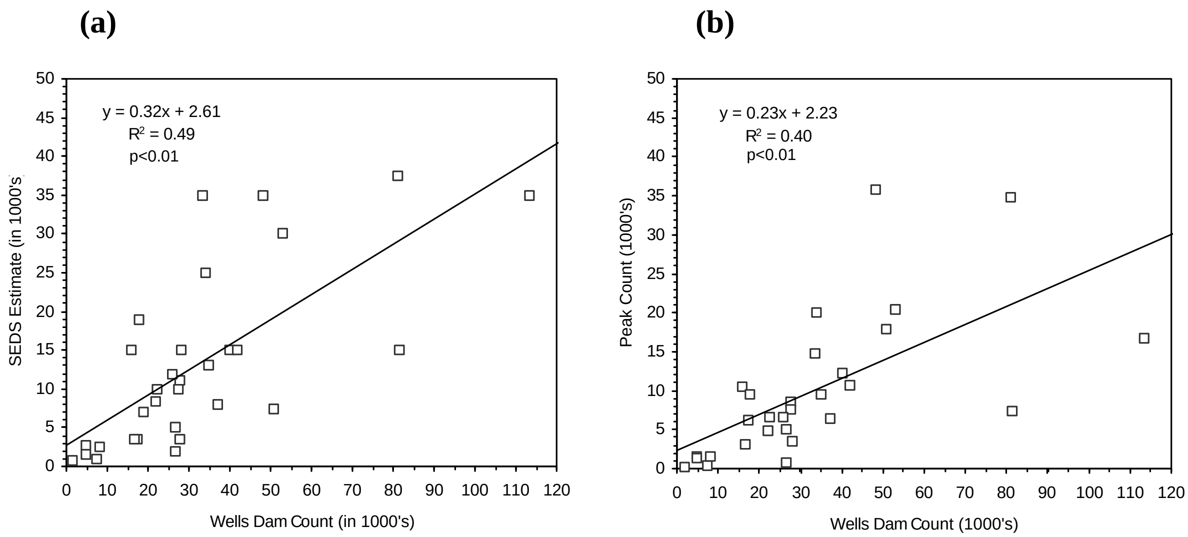

Figure 5. Escapement estimates at Wells Dam versus the Upper Okanagan River as indicated by either (a) SEDS estimates or (b) unadjusted peak live plus dead counts.

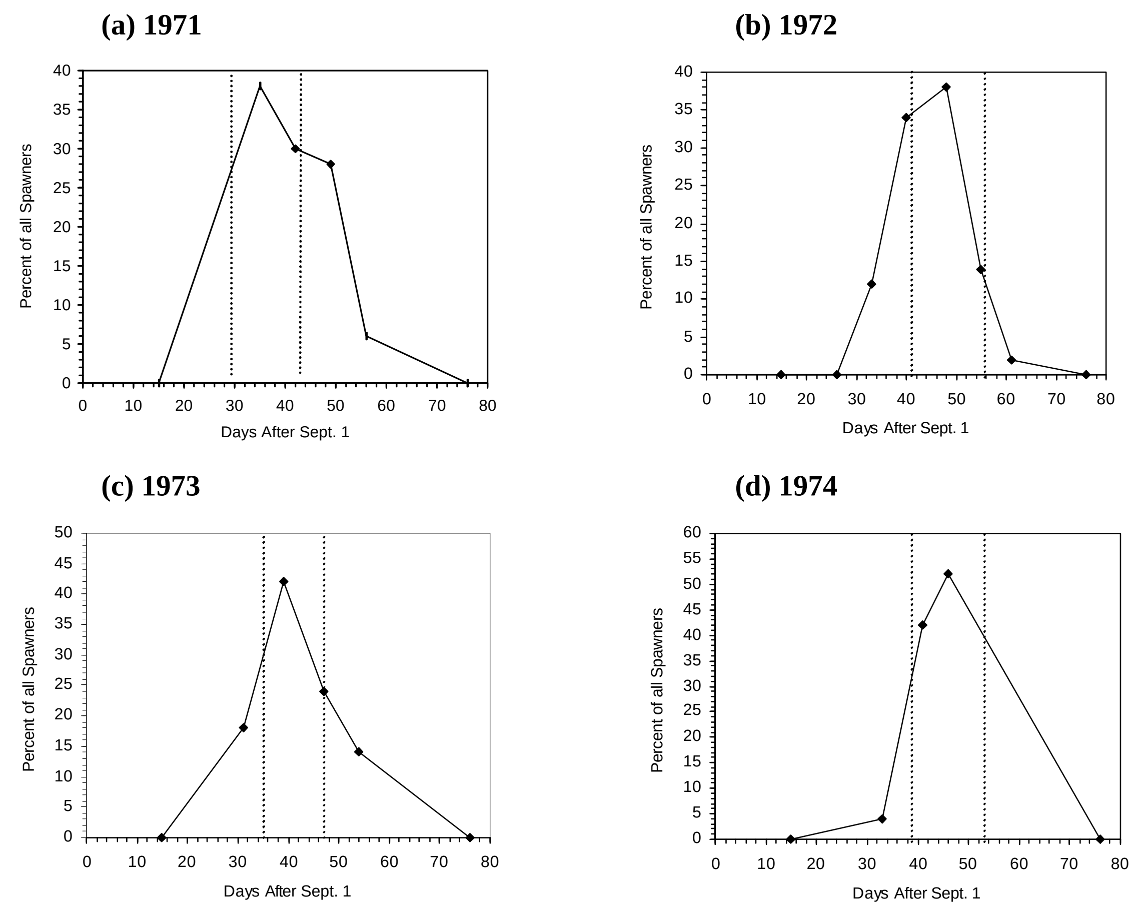

Figure 6. Seasonal abundance variations exhibited by sockeye salmon spawning in the Upper Okanagan River during the years 1971 – 1974. Dashed lines bracket a week before and after the occurrence of peak abundance (Source data modified after Allen and Meekin 1980).

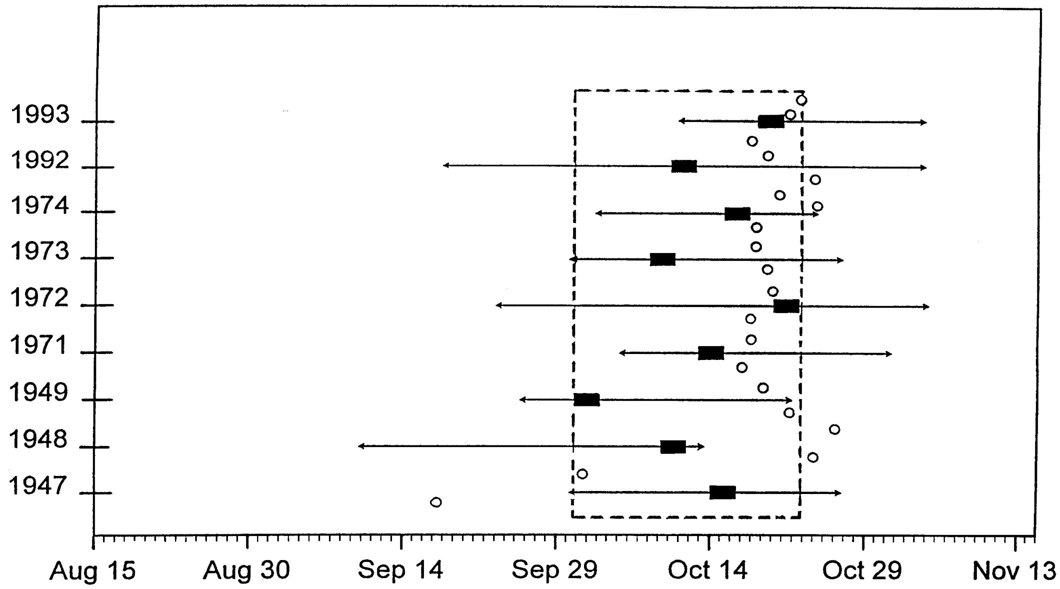

Figure 7. Relative timing of spawning activity of sockeye salmon from the Okanagan Basin (1947 1949 from Gangmark and Fulton 1952; 1971 – 1974 from Allen and Meekin 1980; 1992, 1993 from Hansen 1993 and Hagen and Grette 1994). These data show relative peaks of spawning activity since survey effort and total number of fish observed varied among years. Dates of recent year surveys by personnel from Canada's Department of Fisheries and Oceans (CDFO) are identified on the figure as O.

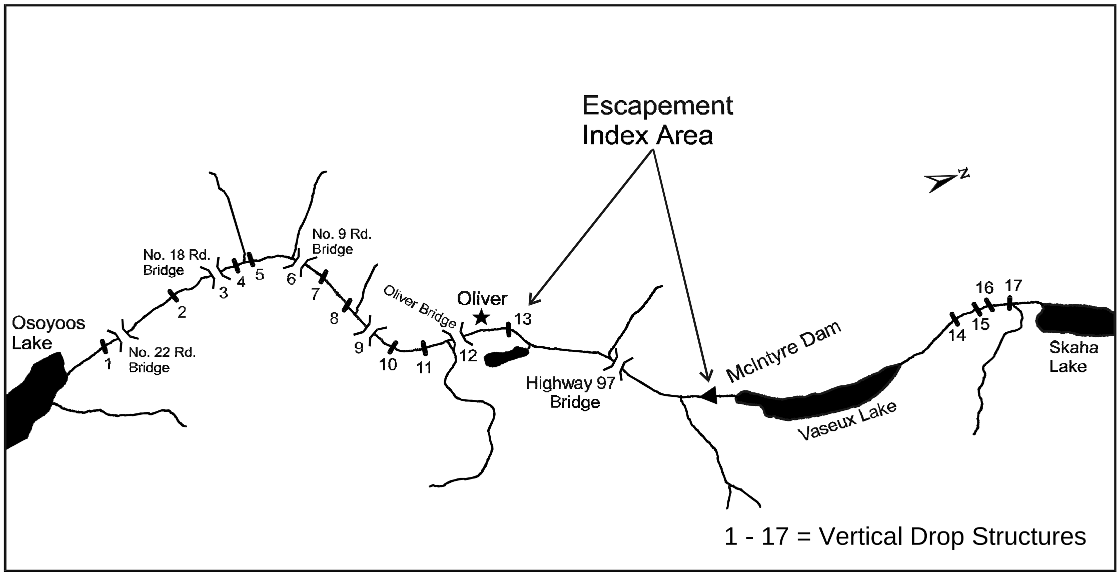

Figure 8a. Map of Upper Okanagan River spawner enumeration sections indicating the unchannelized “index area” as well as channelized sections

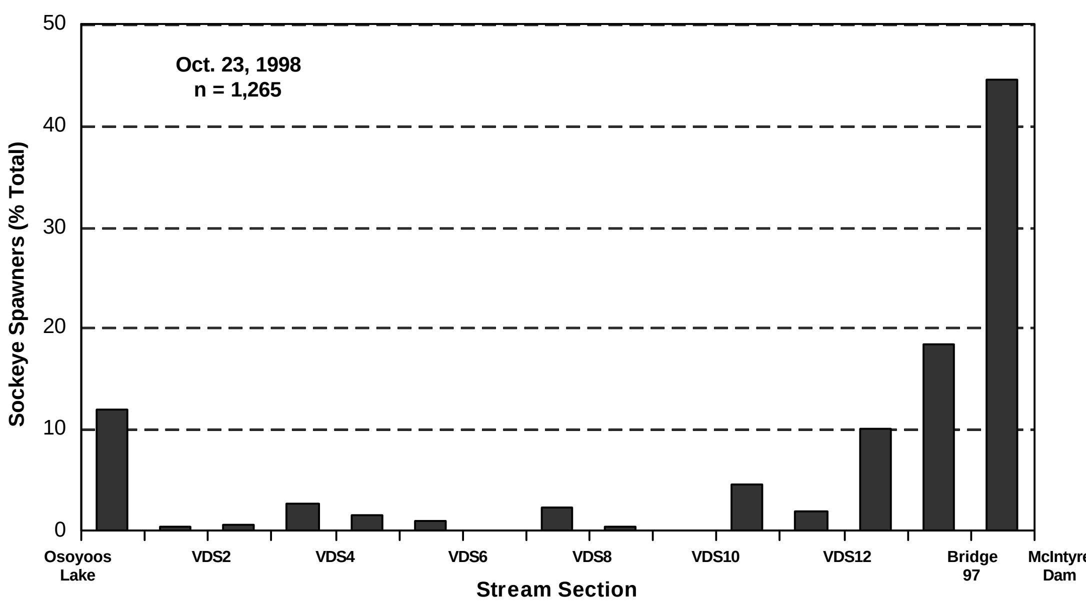

Figure 8b. Typical summary of the distribution of spawning sockeye in the Okanagan River observed during the survey of October 23, 1998 (observations extracted from the CDFO – Stream Inspection Log form for this date).

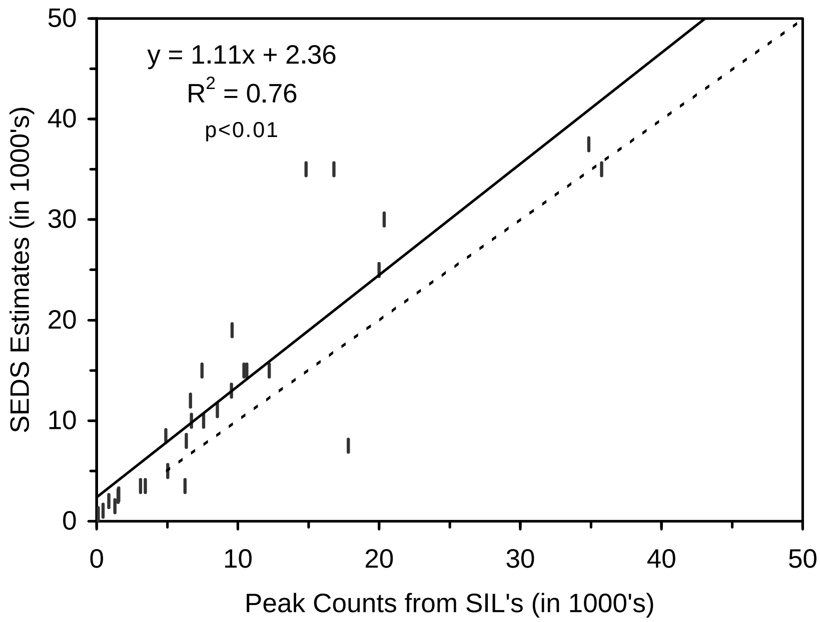

Figure 9. Peak annual count (live plus dead) of spawning sockeye from Stream Inspection Logs (SIL) versus summary estimates in the salmon escapement data system (SEDS)

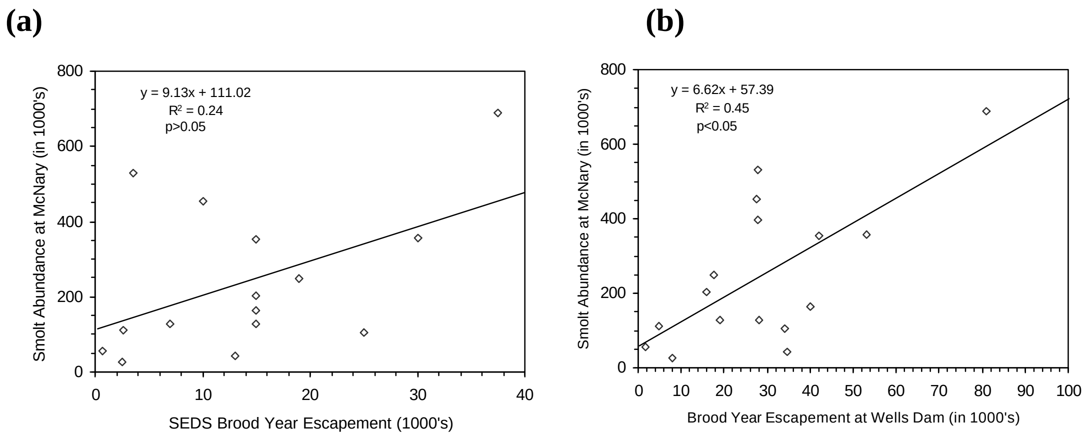

Figure 10. Annual production of Okanagan sockeye smolts (McNary bypass index) versus adult escapement from either (a) SEDS or (b) Wells Dam estimates

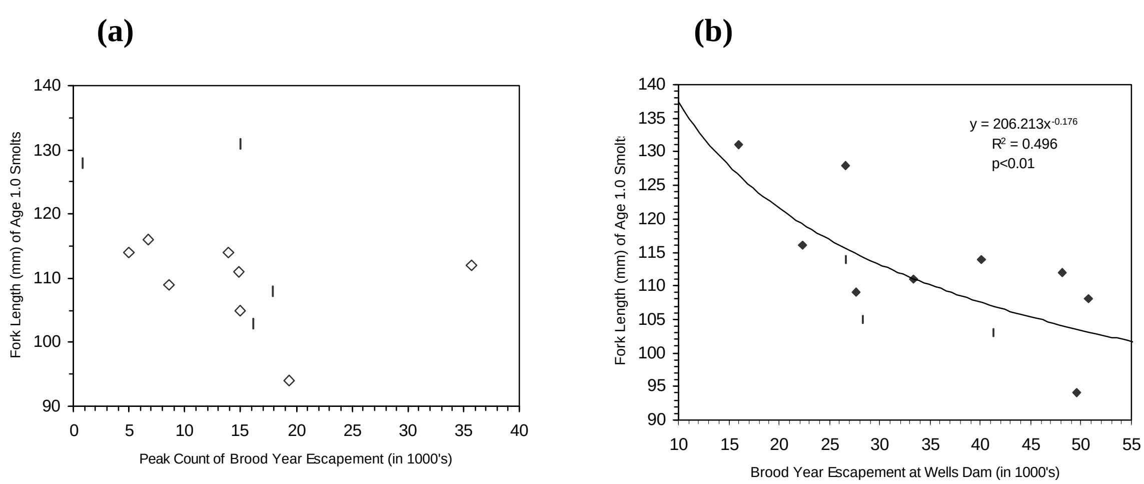

Figure 11. Okanagan sockeye smolt size versus escapement from either (a) SEDS or (b) Wells Dam estimates (data from Chapman et al. 1995)

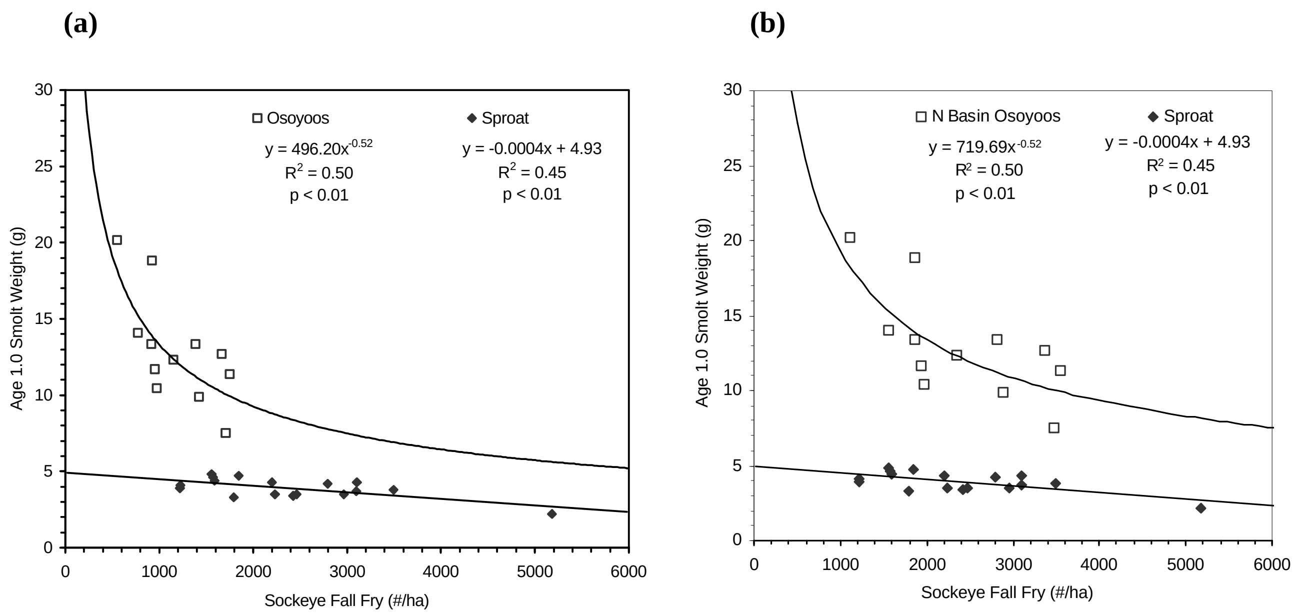

Figure 12. Relation between juvenile sockeye size and rearing density in (a) Osoyoos Lake and (b) North Basin of Osoyoos Lake, versus Sproat Lake

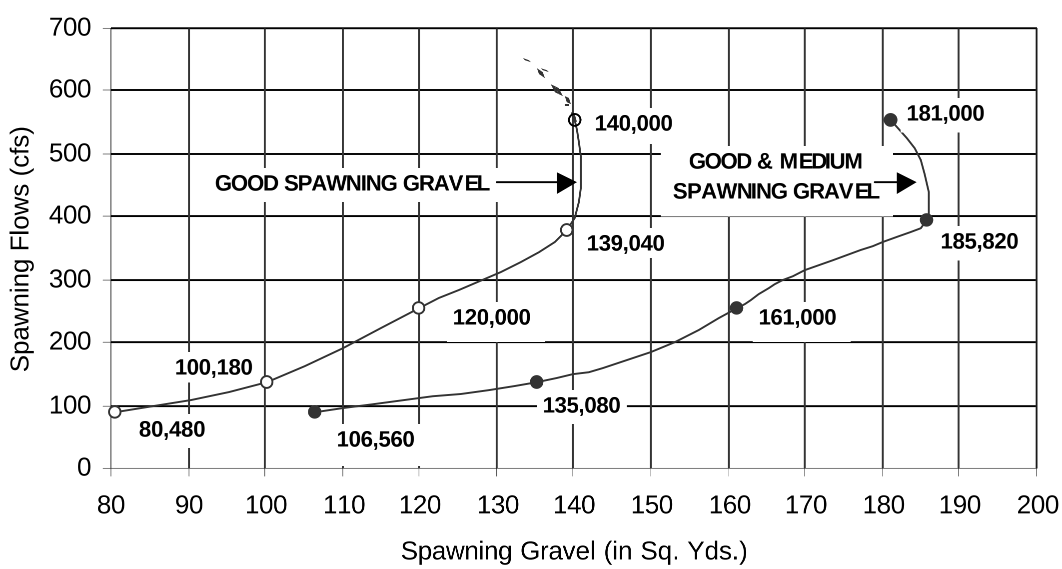

Figure 13: Summary observations of the relation between river discharge during the fall spawning period and surface area of “good” quality and good + medium quality gravels available for spawning sockeye in the unchannelized “index area” of the Upper Okanagan River (from Anonymous 1973)

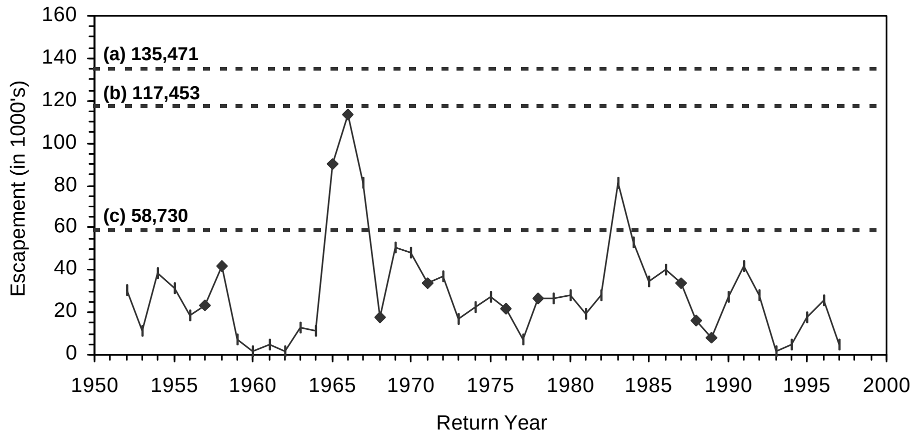

Figure 14. Annual escapement of Okanagan sockeye salmon (calibrated to Wells Dam counts) between 1953 and 1998. Dotted reference levels indicate (a) escapement required at Wells if "index area" spawning habitat will accommodate 0.56 female sockeye per m^{-2}, (b) sockeye escapement required at Wells in order to maintain production of 86 mm (6.2 g) yearling sockeye smolts from Osoyoos Lake, and (c) sockeye escapement required at Wells in order to maintain production of 100mm (9.5 g) yearling sockeye smolts from Osoyoos Lake.

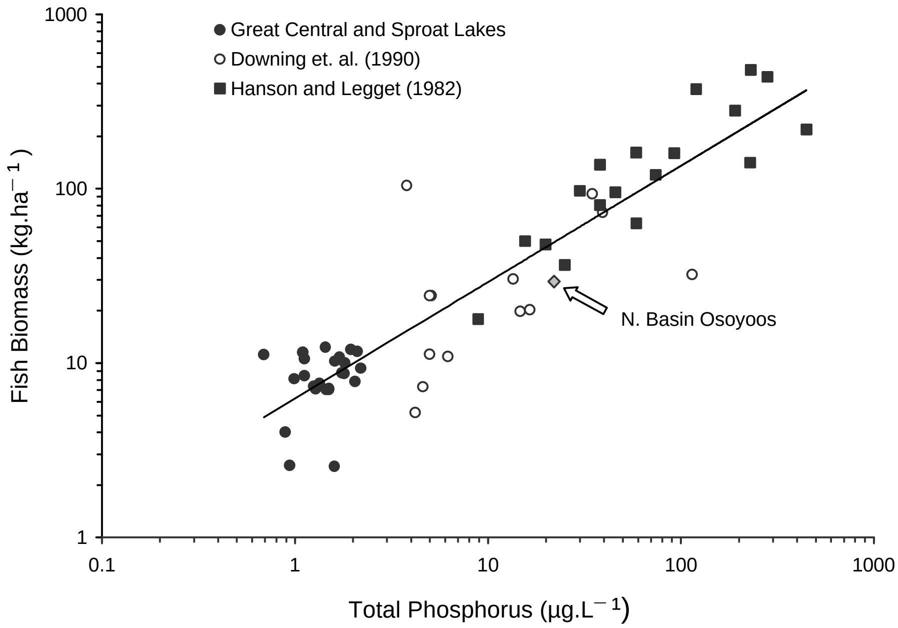

Figure 15. Annual yield of fish (as kg.ha↓≠) in North temperate lakes versus average concentration of phosphorus (∝g.l↓≠) maintained through the growing season. Value determined in present paper for sockeye production in the North Basin of Osoyoos Lake is highlighted (note the log scale used on both axes).

Tables

Table 1. Total Returns of Okanagan Sockeye

Return Year	Columbia Catch	Okanagan Catch	% Okanagan	Okanagan Escape.	Total Returns	Exploit. rate	% as 1.1	No. of 1.1's	% as 1.2	No. of 1.2's	Stock	Returns as 1.1's	Returns as 1.2's	Recruits	Stock
1953	63,011	48,077	76.3	30,330	78,407	61	0.87	68,214	0.13	10,193	30,330	25,679	37,503	63,182	30,330
1954	90,406	39,507	43.7	11,346	50,853	78	0.21	10,679	0.79	40,174	11,346	16,073	16,991	33,064	11,346
1955	119,206	63,656	53.4	38,640	102,296	62	0.13	13,298	0.87	88,998	38,640	89,204	162,812	252,016	38,640
1956	121,943	71,581	58.7	31,134	102,715	70	0.25	25,679	0.75	77,036	31,134	28,731	20,984	49,715	31,134
1957	70,017	35,009	50	18,566	53,575	65	0.3	16,073	0.7	37,503	18,566	10,336	2,405	12,741	18,566
1958	205,320	83,155	40.5	23,040	106,195	78	0.84	89,204	0.16	16,991	23,040	9,046	3,548	12,594	23,040
1959	188,965	149,849	79.3	41,694	191,543	78	0.15	28,731	0.85	162,812	41,694	5,105	2,128	7,233	41,694
1960	122,390	24,478	20	6,842	31,320	78	0.33	10,336	0.67	20,984	6,842	1,305	13,642	14,947	6,842
1961	41,435	10,069	24.3	1,382	11,451	88	0.79	9,046	0.21	2,405	1,382	8,361	10,596	18,957	1,382
1962	19,050	4,001	21	4,652	8,653	46	0.59	5,105	0.41	3,548	4,652	6,495	49,911	56,406	4,652
1963	24,345	3,433	14.1	1,402	4,835	71	0.38	1,305	0.62	2,128		46,072	101,914	147,986	
1964	37,572	9,431	25.1	12,572	22,003	43	0.38	8,361	0.62	13,642	12,572	97,918	87,958	185,876	12,572
1965	13,206	6,167	46.7	10,924	17,091	36	0.38	6,495	0.62	10,596	10,924	14,319	32,025	46,344	10,924
1966	10,250	6,253	61	89,730	95,983	7	0.48	46,072	0.52	49,911	89,730	7,030	4,613	11,643	89,730
1967	98,642	86,509	87.7	113,323	199,832	43	0.49	97,918	0.51	101,914	113,323	61,281	116,581	177,862	113,323
1968	30,200	20,747	68.7	81,530	102,277	20	0.14	14,319	0.86	87,958	81,530	7,441	53,508	60,949	81,530
1969	39,460	21,703	55	17,352	39,055	56	0.18	7,030	0.82	32,025	17,352	55,692	32,270	87,962	17,352
1970	22,829	15,227	66.7	50,667	65,894	23	0.93	61,281	0.07	4,613	50,667	10,757	10,432	21,189	50,667
1971	99,410	75,850	76.3	48,172	124,022	61	0.06	7,441	0.94	116,581	48,172	6,954	14,041	20,995	48,172
1972	105,280	75,802	72	33,398	109,200	69	0.51	55,692	0.49	53,508	33,398	8,605	17,759	26,364	33,398
1973	9,700	5,849	60.3	37,178	43,027	14	0.25	10,757	0.75	32,270	37,178	10,884	14,072	24,956	37,178
1974	1,450	670	46.2	16,716	17,386	4	0.4	6,954	0.6	10,432	16,716	8,625	4,986	13,611	16,716
1975	1,000	360	36	22,286	22,646	2	0.38	8,605	0.62	14,041	22,286	3,056	17,279	20,335	22,286
1976	1,200	1,024	85.3	27,619	28,643	4	0.38	10,884	0.62	17,759	27,619	10,591	17,284	27,875	27,619
1977	3,400	724	21.3	21,973	22,697	3	0.38	8,625	0.62	14,072	21,973	10,594	17,505	28,099	21,973
1978	975	584	59.9	7,458	8,042	7	0.38	3,056	0.62	4,986	7,458	10,729	11,783	22,512	7,458
1979	2,800	1,215	43.4	26,655	27,870	4	0.38	10,591	0.62	17,279	26,655	7,222	17,314	24,536	26,655
1980	1,833	1,305	71.2	26,573	27,878	5	0.38	10,594	0.62	17,284	26,573	10,612	50,253	60,865	26,573
1981	2,430	1,378	56.7	28,234	29,612	5	0.38	10,729	0.62	17,505	28,234	30,801	71,643	102,444	28,234
1982	1,440	816	56.7	19,005	19,821	4	0.38	7,222	0.62	11,783	19,005	43,911	27,780	71,691	19,005
1983	5,828	3,304	56.7	27,925	31,229	11	0.38	10,612	0.62	17,314	27,925	17,026	54,620	71,646	27,925
1984	58,473	33,154	56.7	81,054	114,208	29	0.38	30,801	0.62	50,253	81,054	33,476	21,066	54,542	81,054
1985	131,994	62,565	47.4	52,989	115,554	54	0.38	43,911	0.62	71,643	52,989	12,912	15,497	28,409	52,989
1986	13,894	10,018	72.1	34,788	44,806	22	0.38	17,026	0.62	27,780	34,788	479	3,598	4,077	34,788
1987	103,868	47,987	46.2	40,109	88,096	54	0.38	33,476	0.62	54,620	40,109	4,969	24,270	29,239	40,109
1988	79,525	40,160	50.5	33,978	74,138	54	0.38	12,912	0.62	21,066	33,978	4,623	35,941	40,564	33,978
1989	2,324	1,174	50.5	15,976	17,150	7	0.03	479	0.97	15,497	15,976	7,889	28,333	36,222	15,976
1990	2,621	595	22.7	7,972	8,567	7	0.58	4,969	0.42	3,598	7,972				7,972
1991	3,526	1,403	39.8	27,490	28,893	5	0.16	4,623	0.84	24,270	27,490				27,490
1992	2,505	1,879	75	41,951	43,830	4	0.18	7,889	0.82	35,941	41,951				41,951

Return Year	Columbia Catch	Okanagan Catch	% Okanagan	Okanagan Escape.	Total Returns	Exploit. rate	% as 1.1	No. of 1.1's	% as 1.2	No. of 1.2's	Stock	Returns as 1.1's	Returns as 1.2's	Recruits	Stock
1993	726	490	67.5	27,843	28,333	2	0		1	28,333	27,843				27,843
1994		0	10	1,666	1,666	0					1,666				1,666
Mean							**0.38275**		**0.61725**						

(1) Catch is the total of commercial catch in zones 1-5, Indian catch in zone 6 and by the Colville and Okanagan Tribes as per Table 1 of Chapman et al. (1995)

(2) Proportion of Okanagan sockeye in the catch is taken from data in Chapman et al. (1995) Tables 1 and 2 plus Figure 5.

(3) Okanagan catch as a proportion of total was not broken out in 81-84, 88 or 89 so the mean of catch for three year on either side of these years was used to crudely estimate Okanagan catch in each of these years.

(4) Escapement for the 1953-1966 return years has been set at twice the peak spawning ground count from Table 2 of Chapman et al. (1995) to account for the low bias in stream survey estimates relative to escapement counts at Wells Dam which are used as the preferred annual estimate of escapement in1967 and thereafter.

Table 2. Summary of peak live plus dead counts of adult sockeye on the spawning grounds in the Okanagan River and of adult sockeye passing Wells Dam.

Year	SEDS Entry or equivalent	Reconciled* Peak Counts (RPC's)	Counts @ Wells	SEDS as % of RPC's	RPC's as % of Wells	SEDS as % @ Wells	Peak Counts from CDFO-SIL's	PC's from Table 2 in Chapman (1995)
1967	35,000	16,786	113,323	208.51	14.81	30.89		16,786
1968	15,000	7,440	81,530	201.61	9.13	18.40		7,440
1969	3,500	6,235	17,352	56.13	35.93	20.17		6,235
1970	7,500	17,810	50,667	42.11	35.15	14.80		17,810
1971	35,000	35,728	48,172	97.96	74.17	72.66		35,728
1972	35,000	14,796	33,398	236.55	44.30	104.80		14,796
1973	8,000	6,328	37,178	126.42	17.02	21.52		6,328
1974	3,500	3,080	16,716	113.64	18.43	20.94		3,080
1975	10,000	6,684	22,286	149.61	29.99	44.87		6,684
1976	11,040	8,535	27,619	129.35	30.90	39.97		8,535
1977	8,475	4,870	21,973	174.02	22.16	38.57		4,870
1978	1,050	420	7,458	250.00	5.63	14.08		420
1979	2,000	839	26,655	238.38	3.15	7.50		839
1980	5,000	5,000	26,573	100.00	18.82	18.82		5,000
1981	15,000		28,234			53.13		
1982	7,000		19,005			36.83		
1983	3,500	3,430	27,925	102.04	12.28	12.53	3,430	
1984	37,500	34,832	81,054	107.66	42.97	46.27	34,832	
1985	30,000	20,342	52,989	147.48	38.39	56.62	20,342	16,246
1986	13,000	9,520	34,788	136.55	27.37	37.37	9,520	9,056
1987	15,000	12,190	40,109	123.05	30.39	37.40	12,190	13,867
1988	25,000	19,971	33,978	125.18	58.78	73.58	19,971	11,790
1989	15,000	10,419	15,976	143.97	65.22	93.89	10,419	
1990	2,500	1,498	7,972	166.89	18.79	31.36	1,498	2,028
1991	10,000	7,540	27,490	132.63	27.43	36.38	7,540	7,481
1992	15,000	10,618	41,951	141.27	25.31	35.76	10,618	22,587
1993	21,505	21,505	27,843	100.00	77.24	77.24		2,150
1994	700	98	1,666	714.29	5.88	42.02	98	226
1995	2,669	1,536	4,916	173.76	31.24	54.29	1,536	
1996	19,000	9,572	17,701	198.50	54.08	107.34	9,572	
1997	12,000	6,615	25,754	181.41	25.69	46.59	6,615	
1998	1,500	1,265	4,669	118.58	27.09	32.13	1,265	
Mean				164.58	30.92	43.08		
Range				42.1 - 714.3	3.15 - 74.17	7.5 - 107.3		

* Reconciled peak counts have been adopted from either Table 2 (estimates from 1967-1980) of Chapman et al. (1995) or from CDFO-SIL's (1983-1998).

Table 3. Okanagan River Escapement Survey Dates 1983-1998

Year	Inspection Dates	"Peak Count" Date	Peak Count	Carcasses as percent of count	Comments re: Peak Count
1998	Oct. 23, Oct. 27	Oct. 23	1,265	1.4	
1997	Oct. 22	Oct. 22	7,176	10.1	- possibly past peak.
1996	Oct. 18	Oct. 18	9,572	1.3	
1995	Oct. 20	Oct. 20	1,536	RNA	
1994	Oct. 24	Oct. 24	98	RNA	
1992	Oct. 19	Oct. 19	10,618	15.3	- possibly past peak.
1991	Oct. 24	Oct. 24	7,540	12.3	- possibly past peak.
1990	Oct. 17	Oct. 17	1,498	RNA	
1989	Oct. 17	Oct. 17	10,419	2.1	
1988	Oct. 18	Oct. 18	19,971	RNA	
1987	Oct. 20	Oct. 20	12,190	RNA	- fisheries patrol staff reduced to
1986	Oct. 17, Oct. 22	Oct. 17	9,520	0.8	a single survey per season for years
1985	Oct. 17, Oct. 24	Oct. 17	20,342	2.4	later than 1987.
1984	Sept. 16, Oct. 1, Oct. 1(	Oct. 16	34,832	2.7	
1983	Oct. 19	Oct. 19	3,430	RNA	

RNA = record not available

Table 4. Okanagan sockeye spawn timing

Date	Live	Dead	Total	% Dead	Days from Sept.1	% of Seasonal Total
15-Sep-57	0	0	0	0	15	0
25-Sep-57	985	0	985	0	25	4
01-Oct-57	3,207	4	3,211	0.12	31	13
08-Oct-57	8,499	34	8,533	0.4	38	36
15-Oct-57	6,719	680	7,399	9.19	45	31
22-Oct-57	1,858	1,848	3,706	49.87	52	16
15-Nov-57	0	0	0	0	76	0
Total	21,268	2,566	23,834	10.77		
15-Sep-71	0	0	0	0	15	0
05-Oct-71	21,731	36	21,767	0.16	35	38
12-Oct-71	13,750	3,363	17,113	19.6	42	30
19-Oct-71	9,543	6,777	15,320	44.2	49	27
26-Oct-71	3,208	1,000	3,208	31.2	56	6
15-Nov-71	0	0	0	0	76	0
Total	48,232	11,176	57,408	19.5		
15-Sep-72	0	0	0	0	15	0
26-Sep-72	36	0	36	0	26	0
03-Oct-72	3,285	0	3,285	0	33	13
10-Oct-72	9,213	8	9,221	0.09	40	36
18-Oct-72	9,152	289	9,441	3.1	48	37
25-Oct-72	2,489	952	3,441	27.7	55	13
31-Oct-72	361	0	361	0	61	1
15-Nov-72	0	0	0	0	76	0
Total	24,536	1,249	25,785	4.8		

Date	Live	Dead	Total	% Dead	Days from Sept.1	% of Seasonal Total
15-Sep-73	0	0	0	0	15	0
01-Oct-73	2,770	80	2,850	2.8	31	19
09-Oct-73	6,039	289	6,328	4.6	39	42
17-Oct-73	2,900	759	3,659	20.7	47	24
24-Oct-73	1,569	650	2,219	29.3	54	15
15-Nov-73	0	0	0	0	76	0
Total	13,278	1,778	15,056	11.8		
15-Sep-74	0	0	0	0	15	0
03-Oct-74	246	0	246	0	33	4
11-Oct-74	2,496	1	2,497	0.04	41	43
16-Oct-74	3,057	23	3,080	0.75	46	53
15-Nov-74	0	0	0	0	76	0
Total	5,799	24	5,823	0.41		

(1) Survey observations for 1957 are from Craddock (1958) and for other years are from Table 13 of Allen and Meekin (1980).

(2) Survey observations above have been "altered" here by closing off spawn start and stop dates with counts of zero assumed for each year on Sept. 15th and Nov. 15th.

(3) Note that additional years of spawn timing observations are available for other years in a variety of reports that were not summarized here. Completion of these summaries will yield additional data re: peak and mean spawn times to check for associations with bias on single surveys or peak timing and annual temperature variations.

Table 5. SEDS as % of Wells sockeye escapement estimates from survey dates with an abundance (>10% of counts) or scarcity (<3%) of carcasses.

Survey years @ carcasses > 10 %	SEDS as % of Wells	Survey years @ carcasses < 3%	SEDS as % of Wells
1997	47	1998	32
1992	36	1996	107
1991	36	1989	94
		1986	37
		1985	57
		1984	46
Mean	39.67		62.17
Range	36 - 47		32 - 107

Table 6. Distribution of sockeye spawners by year and river section from McIntyre Dam to Osoyoos Lake.

Start Point	McI. Dam	Hwy 97 Bridge	VD13	VD12	VD11	VD10	VD9	VD8	VD7	VD6	VD5	VD4	VD3	VD2	VD1	
End Point	Hwy 97 Bridge	VD13	VD12	VD11	VD10	VD9	VD8	VD7	VD6	VD5	VD4	VD3	VD2	VD1	Lake	
Section	S-15	S-14	S-13	S-12	S-11	S-10	S-9	S-8	S-7	S-6	S-5	S-4	S-3	S-2	S-1	
Year	**Percent of all Sockeye Observed**															**N**
1998	45	18	10	2	5	0	0	2	0	1	2	3	0	0	12	1,265
1997	32	59	4	1	1	0	1	1	1	0	0	0	0	0	0	6,615
1992	26	68	5	0	0	0	0	0	0	0	0	0	0	0	0	10,618
1991	27	68	1	1	0	0	0	1	0	0	0	1	0	0	0	7,540
1990	34	64	0	1	0	0	0	0	0	0	0	0	0	0	0	1,498
1989	16	82	1	0	0	0	0	0	0	0	0	0	0	0	0	10,419
1988	20	66	9	0	0	1	1	0	0	2	0	0	0	0	0	19,971
1986	15	73	2	1	0	4	1	1	3	0	0	0	0	1	0	9,520
1985	17	79	0	0	0	0	0	0	0	0	0	1	0	0	0	20,342
1984	18	80	0	0	0	1	0	0	0	0	0	0	0	0	0	34,832
Mean	25	65.7	3.2	0.6	0.6	0.6	0.3	0.5	0.4	0.3	0.2	0.5	0	0.1	1.2	12,262
1952	52	40	3	1	1	1	1	1	1	0	0	0	0	0	0	24,714
1953	38	41	8	2	2	2	2	2	2	0	0	0	0	0	0	34,284

VD = vertical drop structure as per Figure 2

Raw counts of sockeye taken from DFO stream inspection log (SIL) summaries.

Table 7. Spawning ground distribution of sockeye in 1997 from visual (CDFO-SIL) versus radiotag (DCPUD-LGL) observations.

Start Point	McIntyre Dam	VD13	VD12	VD11	VD10	VD9	VD8	VD7	VD6	VD5	VD4	VD3	VD2	VD1	
End Point	VD13	VD12	VD11	VD10	VD9	VD8	VD7	VD6	VD5	VD4	VD3	VD2	VD1	Lake	
Section	S15 + S14	S-13	S-12	S-11	S-10	S-9	S-8	S-7	S-6	S-5	S-4	S-3	S-2	S-1	
Survey Method	**Percent of all Sockeye Observed**														**N**
DFO/SIL	91	4	1	1	0	1	1	1	0	0	0	0	0	0	6,615
Rtags pooled	37	12	8	5	2	3	3	1	3	2	7	2	6	9	219
Rtag1 from Bonneville	37	13	10	4	2	2	2	2	3	2	7	2	6	10	178
Rtag2 from Wells Dam	42	7	2	7	2	5	7	0	2	2	5	5	7	5	41

(1) VD = vertical drop structure as per Figure 2

(2) DFO/SIL - raw counts from DFO stream inspection log summary of Oct.22, 1997 survey.

(3) Rtag1 and Rtag 2 - spawning ground "recoveries" of sockeye adults radiotagged at Bonneville Dam as per results in Figures 9 and 10 respectively of Alexander et al. (1998).

Table 8. Comparisons of Peak Counts of Spawner Abundance by Year from Various Sources

Year	"Raw" Peak Counts*	Chapman Peak Counts**	SEDS	Chapman Peak as % of Raw	SEDS as % of Raw	Comments
1971	21,767	35,728	35,000	164.14	160.79	* 1971-1974 raw survey observations from
1972	9,441	14,796	35,000	156.72	370.72	Allen and Meekin (1980); 1983-1998 raw
1973	6,328	6,328	8,000	100.00	126.42	survey observations from CDFO-SIL's obtained
1974	3,080	3,080	3,500	100.00	113.64	from the Salmon Arm Office and summarized here.
1983	3,430		3,500		102.04	** "peak counts" tabulated in Table 2. of Chapman
1984	34,832		37,500		107.66	et al. (1995).
1985	20,342	16,246	30,000	79.86	147.48	
1986	9,520	9,056	13,000	95.13	136.55	On the basis of these limited observations, the
1987	12,190	13,867	15,000	113.76	123.05	Chapman et al. "peak counts" represent a range of
1988	19,971	11,790	25,000	59.04	125.18	raw count expansions from 1.0 to 2.3 and a mean
1989	10,419		15,000		143.97	expansion of 1.29 times peak survey counts
1990	1,498	2,028	2,500	135.38	166.89	to generate mean annual escapement estimates.
1991	7,540	7,481	10,000	99.22	132.63	
1992	10,618	22,587	15,000	212.72	141.27	
1993		2,150	2,150			
1994	98	226	700	230.61	714.29	SEDS estimates utilize a wider range (1.02- 7.14)
1995	1,536		2,669		173.76	and a higher mean (1.83) expansion factor than
1996	9,572		19,000		198.50	Chapman et al. to generate annual escapement
1997	6,615		12,000		181.41	estimates from raw counts.
1998	1,265		1,500		118.58	
Mean				128.88	183.41	

Table 9. Summary of escapement by brood year (either as SEDS spawning ground units or as Wells Dam counts) and of sockeye smolt abundance at McNary Dam.

Brood Year	Smolt Year	Adult Sockeye Rsnbrgr Excel	Adult Sockeye Wells Dam	McNary Smolt Index
1981	1983	15,000	28,234	126,493
1982	1984	7,000	19,005	127,272
1983	1985	3,500	27,925	529,673
1984	1986	37,500	81,054	689,110
1985	1987	30,000	52,989	356,857
1986	1988	13,000	34,788	41,148
1987	1989	15,000	40,109	163,889
1988	1990	25,000	33,978	105,627
1989	1991	15,000	15,976	202,123
1990	1992	2,500	7,972	26,571
1991	1993	10,000	27,490	454,041
1992	1994	15,000	41,951	352,539
1993	1995		27,843	397,070
1994	1996	700	1,666	55,009
1995	1997	2,669	4,916	110,659
1996	1998	19,000	17,701	248,551
1997	1999	12,000	25,754	
1998	2000	1,500	4,669	

Table 10. Osoyoos age 1.0 sockeye smolt size, in-lake fry abundance (in ATS units) and annual production estimates (in kg per ha).

Smolt Year	Size FL (mm)	Size (g)	North Basin # as ATS Equivalent	Ann.prod. North Basin (kg.ha)	Whole Lake # as ATS Equivalent	Ann.prod. Whole Lake (kg.ha)	"SEDS" Escapement	Escapement @Wells
1957	94	7.53	3467.8	26.12	1710	12.88	19,320	49,538
1958	103	9.88	2884	28.50	1422	14.05	16,067	41,197
1972	108	11.38	3546.69	40.35	1749	19.90	17,810	50,667
1973	112	12.68	3372.04	42.74	1663	21.08	35,728	48,172
1974	111	12.34	2337.86	28.85	1153	14.23	14,796	33,398
1977	116	14.07	1560.02	21.95	769	10.82	6,684	22,286
1978	109	11.69	1933.33	22.61	953	11.15	8,535	27,619
1981	128	18.84	1865.85	35.16	920	17.34	839	26,655
1982	114	13.36	1860.11	24.85	917	12.25	5,000	26,573
1983	105	10.46	1976.38	20.68	975	10.20	15,000	28,234
1989	114	13.36	2807.63	37.51	1384	18.49	13,867	40,109
1991	131	20.19	1118.32	22.58	551	11.13	15,000	15,976
Mean				29.32		14.46		
Range				20.7 - 42.7		10.2 - 21.08		

Table 11. Summary of acoustic and trawl based surveys of nerkid abundance in Osoyoos Lake.

Basin Area (ha)	North 937	Central 208	South 883	Total 2028	No. ha North 937	No. ha All 2028	Trawl #	Hailed Catch	By Aults @ Wells	Nerkids . spwnr via ATS	Nerkid Production North basin	kg per ha All Basins
ATS Date												
Jul-97	1.45	0.00	0.00	1.45	1,551	706	2	12	17,701	82		
Sep-97	1.24	0.03	0.07	1.33	1,320	648	7	258	17,701	75		
Nov-97	0.94	0.08	0.15	1.16	1,001	563	5	480	17,701	65		
Mean 1997	1.21	0.03	0.07	1.31	1290.67	639			17,701	74	17.42	8.63
May-98	3.04	0.16	0.38	3.57	3,813	1,762	9	485	25,754	139		
Jul-98	2.50	0.08	0.00	2.58	2,756	1,273	5	268	25,754	100		
Oct-98	3.77	0.00	0.16	3.93	4,195	1,938	10	250	25,754	152		
Mean 1998	3.10	0.08	0.18	3.36	3,588	1,657.67			25,754	130	48.44	22.38
Mean 1973				2.10	2,241	1,035.50			33,398	63	30.25	13.98
Mean 1974				0.50	534	246.55			37,178	13	7.21	3.33

(1) Nerkid per spawner calculation will be potentially confounded by unknown contributions of kokanee.

(2) Assume smolts produced in ATS lake survey years will achieve 13.5 g as 1.0 (i.e. an average FL of 112 mm) as per Table 30 of Mullan. Note, this value is conservative because given escapement abundance in brood years of origin smolts should always end up larger than 112 mm FL (as per Figure 11b).

(3) Table 30 of Mullan (1984) indicates that wild age 1.0 smolts leaving Lake Wenatchee average only 6.2 g (range 5.2-6.0, n=5) and 8.6 mm FL (range 8.1-8.8, n=5).

Table 12. Mark recapture estimates of sockeye salmon smolts (in thousands) at Priest Rapids Dam 1984-1988 (from Table 4.7 of Fryer 1995).

	Total run *		Wenatchee		Okanagan		Okanagan Brood Year Escapement @ Wells	Smolts per Spawner from Priest MRP Estimates
Year	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.		
1984	11361	2763	5992	2280	6143	1901	19,005	323.231
1985	7949	806	2602	361	5529	860	27,925	197.995
1986	19067	3480	25104	13642	6349	1064	81,054	78.330
1987	7014	1278	2306	536	3959	1187	52,989	74.714
1988	4703	1152	2106	291	1843	1093	34,788	52.978
					Mean (excluding1984)			101.004

* Total smolt run estimates do not equal the sum of the Wenatchee and Okanagan population estimates as different simulations were conducted for each of the three population estimates.

Table 13. Annual summary of Sproat Lake sockeye yearling size, abundance and production.

Brood Year	Fork Length (mm)	SE	Lake Year	PSARC ATS no. (millions)	No. per ha	Fresh Std. Weight(g)	Ann. prod. (kg.ha)	Standard Error	Sample Size
1975	70	0.3	1976			2.7	0.00	0.04	243
1976	81	0.6	1977			4.6	0.00	0.11	168
1977	70	0.2	1978			2.9	0.00	0.03	639
1978	77	0.3	1979	4.62	1224	4.1	5.02	0.05	439
1979	81	0.3	1980	5.84	1574	4.6	7.24	0.05	549
1980	73	0.3	1981	11.19	2964	3.5	10.37	0.04	382
1981	74	0.3	1982	8.43	2233	3.5	7.82	0.04	394
1982	79	0.2	1983	11.72	3105	4.3	13.35	0.04	483
1983	64	0.2	1984	19.56	5181	2.2	11.40	0.03	313
1984	83	0.5	1985	6.97	1846	4.7	8.68	0.09	211
1985	77	0.3	1986	8.3	2199	4.3	9.46	0.04	497
1986	73	0.2	1987	9.3	2464	3.5	8.62	0.02	1150
1987	75	0.1	1988	13.2	3497	3.8	13.29	0.02	1099
1988	77	0.2	1989	10.55	2795	4.2	11.74	0.04	581
1989	72	0.2	1990	9.16	2426	3.4	8.25	0.03	972
1990	82	0.3	1991	5.88	1558	4.8	7.48	0.05	412
1991	76	0.2	1992	4.6	1219	3.9	4.75	0.04	909
1992	78	0.3	1993	5.99	1587	4.4	6.98	0.04	982
1993	72	0.2	1994	6.77	1793	3.3	5.92	0.04	1019
1994	74	0.2	1995	11.7	3099	3.7	11.47	0.03	1301
Mean							7.59		
Range							2.23 - 10.03		

Table 14. Summary of Okanagan spawning area utilization in 1971 (adapted from Allen and Meekin 1980).

Year	Location	No. at Peak	Wells Equivalent (Peak X 2)	
1971	Index Section (IS)	21,767	43,534	No. at peak count from Allen and Meekin (1980) surveys.
	VDS13-Lake	3,761	7,522	Index section is from McIntyre Dam to VDS13.
	Lake	1,200	2,400	
	Total	26,728	53,456	
	Proportion females	0.560	0.560	Samples for sex composition from spawning grd. surveys.
	Sample size	626		
	Total females	14,968	29,936	
	Tot. egg deposition (millions)	37.420	74.840	Assuming an average fecundity of 2500 eggs for female
	Index females	12,190	29,935	sockeye that average 48 cm in length.
	Index egg deposition (millions)	30.475	74.838	
	m² per female	8.930	3.637	Assumes index area has 108,860 square meters of useable
	% of spawn area used	80.0%		spawning gravel at river flows of 325 cfs (from Anonymous
	Females req'd. to fill index area	15,237.50	37,418.75	1973).
	IS m² per female at saturation	7.144	2.909	Expanded to 100 % use based on no. of females at 80 % and
				assuming a multiyear proportion of 41 % females.

Table 15. Summary of sockeye females per m² required to utilize available spawning habitat in various spawning areas.

Spawning Location	Spawning Area (m²)	Max. Females per m²	Source
Chilko River	359,000	0.56	- for efficient spawning and a high rate of egg-to-fry
			survival
Weaver Creek			
Spawning Chann	NA	0.84	Cooper (1977)
Babine Spawning			
Channel	NA	2	Groot in Williams (1996)
Adams River	NA	2	Williams (1996)
Horsefly River	302,689	2	Williams (1996). Extensive measures from air
			photo interpretation plus highly significant relation
Mean of all		1.48	between measured egg-to-fry surv. and abundance of
Range of all		0.56 - 2.0	spawners in the 1985, 86, 89 and 90 brood years.
Okanagan			Calculations based on 1971-1974 surveys in
Index			Table 14
Section			
(OIS)			
1971	108,860	0.14	Based on SEDS annual escapement units.
1971	108,860	0.34	Based on Wells annual escapement units.
1973	108,860	0.08	Based on SEDS annual escapement units.
1973	108,860	0.25	Based on Wells annual escapement units.

Table 16. Estimates of annual escapement required to fully utilize the area of spawning gravel available in the Okanagan River between McIntyre Dam and VDS13.

"Optimal" no. of female sockeye per m²	Source of female sockeye per m² values	Estimate of annual escapement required to fully utilize * all spawnable area in the Okanagan River Index Section		
		Escapement req'd. as females (in "Wells count units")**	Total escapement*** required (in "Wells count units")	Total escapement required (in "SEDS count units")****
0.34	1971 Okanagan R. surveys (Allen and Meekin 1980)	37,012	82,248	41,124
1.48	Mean from non-Okanagan stocks (NOS) cited in Williams (1996)	161,113	358,028	179,014
0.56	NOS minimum	60,962	135,471	67,736
2	NOS maximum	217,720	483,822	241,911

* Assume Okanagan River Index Section between McIntyre Dam and VDS13 has 108,860 square meters of useable spawning gravel at a river flow of 325 cfs (Anonymous 1973).

** Calculations have been identified as equivalent to Wells count units because spawning ground estimates for non Okanagan stocks are based on mark and recapture or fence count estimates which are more comparable to Wells Dam counts of Okanagan sockeye than to peak visual counts in the Okanagan R. index section.

*** Assumes the multiyear proportion of females is 0.45 as per Allen and Meekin (1980).

**** Assumes SEDS estimates are one half of the counts obtained at the Wells Dam.