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T. G. Brown, B. Munro, C. Beggs, E. Lochbaum,
and P. Winchell

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, B.C. V9T 6N7

2003

**Canadian Technical Report of
Fisheries and Aquatic Sciences 2459**

Fisheries and Oceans Canada   Pêches et Océans Canada

Canada

Canadian Technical Report of
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by

T. G. Brown[1], B. Munro[2], C. Beggs[2], E. Lochbaum[3], and P. Winchell[1]

[1] Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, British Columbia
V9T 6N7

[2] Fisheries and Oceans Canada
Habitat and Enhancement Branch
Puntledge River Hatchery
Courtenay, British Columbia
V9N 5N3

[3] Fisheries and Oceans Canada
Fisheries Management Branch, South Coast
3225 Stephenson Point Road
Nanaimo, British Columbia
V9T 1K3

Cat. No. Fs 97-6/2459/E ISSN 0706-6457

Correct citation for this publication:

Brown, T. G., B. Munro, C. Beggs, E. Lochbaum, and P. Winchell. 2003. Courtenay River seal fence. Can. Tech. Rep. Fish. Aquat. Sci. 2459: 55 p.

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Various methods were employed to reduce harbour seal predation upon declining salmon stocks in the Puntledge and Courtenay Rivers, Vancouver Island, British Columbia. A seal barrier fence was operated at the mouth of the Courtenay River from June to September 1998. It was hoped that pre-spawning chinook salmon after passing through the fence would be safe from harbour seal predation. The seal fence did limit upstream movement of seals from mid-June to August, but its effectiveness in reducing the number of salmon killed was questionable. The seal fence delayed salmon migration and seals were able to prey upon salmon holding below the fence. An acoustic deterrent device at the seal fence did not deter seal activity. A series of triads (cement interlocking columns) were placed along one side of the river downstream of the seal fence to provide refuge for adult salmon. The triads proved ineffective as adult salmon refuge.

Lethal removal of seals did not appear to reduce seal numbers at the fence for an appreciable period of time. Thirty-one seals were shot in 1997 and twenty-one more seals were removed in 1998 during the period of fence operation. We speculated that the influx of estuarine seals, attracted to the large numbers of returning pink salmon, maintained the number of seals in the lower river. The amount which the seal cull reduced predation on salmon is a difficult question that is not addressed in this report. However, in 2001-02 chinook returns to the Puntledge River increased substantially more than returns to neighboring rivers. The removal of habituated in-river seals and the corresponding reduction in both juvenile and adult salmon predation could have been one of many possible factors contributing to the increase in chinook returns.

In 1998, observers monitored seal and salmon behaviours for 24 hours/day from mid-June to mid-September. Assuming half of the total predation occurred in our observation area and assuming half of all the possible and probable kills were actual kills, seals killed 144 (38%) summer chinook, 700 (6.5%) pink, and 154 (33%) autumn chinook. Seal abundance corresponded to salmon abundance. Seal numbers were positively correlated to tide height ($P < .0001$), and seal numbers were significantly greater ($P < .01$) during flood tides. The number of seals varied diurnally, twice as many seals were counted at night and rate of salmon killed was 2 to 3 times higher at night than during the day. A significantly higher ratio of misses to kills occurred during the day ($P < .01$) which indicates that night pursuit was likely to be more successful then day pursuit. The distribution of salmon kills below the seal fence was different during day and night. More kills were recorded further down the river during the day ($P < .001$) and more kills were recorded during the day on one side of the river ($P < .01$). These differences in diurnal distribution of salmon kills may indicate either difficulties in our ability to observe foraging seals at night compared to day, or seal wariness.

Chinook salmon numbers were greater at mid-day than during morning or evening ($P < .01$), negatively correlated with tide height ($P < .05$), and more chinook were counted on flooding tides then on ebbing tides ($P < .001$). It is possible that the number of salmon counted below the fence is a reflection of seal presence. The number of chinook/hr was negatively correlated with the number of seals/hr during the daylight hours ($P < .05$).

The possibility of high water temperatures and low discharge as factors limiting chinook production was examined. The high water temperatures encountered by adult salmon in 1998 were a concern. Once salmon entered freshwater, no thermal refuge was available. In 1998 mean water temperatures exceeded 20^{o}C for 20 days and maximum temperatures exceeded 22^{o}C for 18 days. The introduction of summer cooling flows would be a major improvement in habitat conditions.

RÉSUMÉ

Brown, T. G., B. Munro, C. Beggs, E. Lochbaum, and P. Winchell. 2003 Courtenay River seal fence. Can. Tech. Rep. Fish. Aquat. Sci. 2459: 55 p.

Diverses méthodes ont été employées pour réduire la prédation exercée par les phoques sur les stocks affaiblis de saumons des rivières Puntledge et Courtenay, dans l'île de Vancouver (Colombie-Britannique). Une barrière àphoques a été mise en place àl'embouchure de la Courtenay de juin àseptembre 1998. On espérait qu'après avoir franchi la barrière, les quinnats en période de pré-fraye seraient àl'abri de la prédation par les phoques. La barrière a bien limité la remontée des phoques dans la rivière de la mi-juin àaoût, mais ne semble pas avoir réduit le nombre de saumons tués; elle avait plutôt pour effet de ralentir la migration des saumons, de sorte que les phoques ont pu se repaître des poissons retenus en aval de la barrière. Un dispositif acoustique destiné àéloigner les phoques s'est révélé inefficace. Une série de blocs de béton imbriqués a été installée le long d'une berge de la rivière, en aval de la barrière, pour créer un refuge àl'intention des saumons adultes, mais cette initiative n'a pas été fructueuse.

L'élimination des phoques par abattage ne semble pas avoir fait baisser le nombre de ces prédateurs àla barrière (cours inférieur de la rivière) pendant une période notable. En 1997, 31 phoques ont été abattus, et 21 autres en 1998 pendant la période de fonctionnement de la barrière. Nous pensons que l'arrivée de phoques provenant de l'estuaire, attirés par les grands nombres de saumons roses en remonte, a maintenu la présence des prédateurs dans le cours inférieur de la rivière. Toutefois, la remonte de quinnats dans la Puntledge a augmenté de façon remarquable en 2001-2002. L'élimination des phoques habitués àfréquenter la rivière et la réduction correspondante de la prédation exercée sur les saumons juvéniles et adultes peuvent être l'un des nombreux facteurs en cause dans cette augmentation.

En 1998, des observateurs ont surveillé le comportement des phoques et des saumons 24 heures sur 24, de la mi-juin àla mi-septembre. Nous avons estimé que sur le nombre total de chaque espèce de saumon en remonte, les phoques ont tué 144 (38 %) quinnats d'été, 700 (6,5 %) saumons roses et 154 (33 %) quinnats d'automne. L'abondance des phoques correspondait àcelle des saumons. L'effectif des phoques était positivement corrélé àla hauteur de la marée ($P < 0,0001$), et le nombre de phoques présents était nettement supérieur ($P < 0,01$) àla marée montante. Ce nombre variait àl'échelle diurne, les phoques étant deux fois plus nombreux la nuit, et le nombre de saumons tués était deux àtrois fois plus élevé la nuit que le jour. Le rapport des attaques manquées aux attaques mortelles était significativement plus élevé le jour ($P < 0,01$), ce qui indique que la chasse nocturne était vraisemblablement plus efficace que la chasse diurne. La distribution des mortalités de saumons au-dessous de la barrière différait entre le jour et la nuit. On a noté un plus grand nombre de morts de saumons en aval dans la journée ($P < 0,001$), et d'un côté de la rivière pendant la journée ($P < 0,01$). Ces

différences dans la distribution diurne des mortalités de saumons peuvent s'expliquer soit par le biais des observateurs soit par la méfiance des phoques.

L'effectif des quinnats était plus élevé au milieu de la journée que le matin ou le soir ($P < 0,01$) et corrélé négativement avec la hauteur de la marée ($P < 0,05$), et le nombre de quinnats dénombrés était plus élevé àla marée montante qu'àla marée descendante ($P < 0,001$). Il est possible que le nombre de saumons comptés au-dessous de la barrière donne une indication de la présence des phoques. Le nombre de quinnats àl'heure était négativement corrélé avec le nombre de phoques àl'heure pendant la journée ($P < 0,05$).

Nous avons aussi examiné la possibilité que les températures élevées de l'eau et le faible débit puissent être des facteurs limitant la production de quinnats. En 1998, les quinnats ont dû affronter des températures élevées. Une fois entrés en eau douce, les saumons n'avaient plus de refuge thermique. En 1998, les températures moyennes de l'eau ont dépassé 20 ^{o}C pendant 20 jours, et la température maximale a dépassé 22 ^{o}C pendant 18 jours. En intervenant en été par des lâchers d'eau qui refroidiraient les eaux des rivières, on pourrait remarquablement améliorer les conditions du milieu.

INTRODUCTION

In the mid-1990's, low escapements of anadromous fish to the Courtenay River, especially summer run chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*), were a concern. The reasons for this decline in escapement are complex. The watershed and estuary had been altered through various human activities (Asp and Adams. 2000). These include hydro generation, urbanization, agriculture, mining, and forestry. These activities have changed the natural hydrograph, altered water temperatures, produced acid mine drainage, increased sedimentation, and reduced access to upstream habitat. Poor ocean survival of salmon, increased fishing pressure, and climate change (warmer then average years) have also been considered as probable reasons for declining escapement. A salmon hatchery was established between 1974-77 on the Puntledge River to augment declining salmon stocks. Various enhancement and rehabilitation projects have been undertaken over the years with varied success.

The status of Puntledge River chinook salmon was viewed as precarious in the mid-90's. Chinook salmon escapement had dropped below 300 fish from a historic maximum estimate of 15,000 in 1954 (DFO Salmon Inventory System, Serbic 1991) and consistent annual returns of 6,000 (Trites et al. 1996). At the same time the Pacific harbour seal (*Phoca vitulina richardsi*) population in the Strait of Georgia had dramatically increased (Olesiuk and Bigg 1988; Olesiuk et al. 1990a; Olesiuk 1999a). Predation by Pacific harbour seals was viewed as having a potentially serious impact on specific salmon stocks, such as Puntledge River chinook (Bigg et al. 1990; Olesiuk et al. 1996a; 1996b). It was estimated that seals foraging in the Courtenay River could consume 13,000 adult salmon per year, including 1,500 chinook or 36% of the chinook returning to the system (Olesiuk et al. 1996b). It was debatable if depressed chinook stocks could survive at this level of seal predation. Summer run chinook salmon, which are viewed as a unique genetic stock, were considered to be at risk. However, the local community was polarized on the subject of lethal removal of seals (Hilliar 1997) and the effectiveness of culls was controversial (Olesiuk et al. 1996b). Other means of reducing seal predation on salmon need to be evaluated.

The Puntledge River Seal Program was initiated to reduce harbour seal predation on salmonids (Munro 1998). Two types of predation were occurring. First, seals were observed preying on out-migrating juvenile salmonids beneath bridges where artificial lights silhouetted the out-migrating young salmon (Olesiuk et al. 1996a ; Yurk and Trites 2000). Second, seals were preying on pre-spawning adult salmon from June through December (Bigg et al. 1990; Olesiuk et al. 1996b). An assessment of harbour seal predation on adult salmon and recommendations for reducing it were given by Olesiuk et al. (1996b). One of their recommendations was the construction of a barrier at the mouth of the river to block seals, while allowing passage of adult salmon, be considered.

Various methods were implemented in 1997 to reduce seal predation on adult and juvenile salmonids. Seals were captured, marked and tagged with tracking transmitters to study seal behaviour (DFO Puntledge River Committee 1997). It was hoped the tracking of seals would ascertain whether the same seals that had been identified as foraging on out-migrating fry and smolts were responsible for killing pre-spawning salmon. Acoustic deterrent devices were utilized and considered effective in reducing short-term, juvenile salmon mortality (Yurk and Trites 2000), but were considered ineffective as a barrier to seal passage (Olesiuk et al. 1996a). Strobe lights were installed in an unsuccessful effort to impair seal night vision and reduce feeding efficiency. A portion of channel was sectioned off with large nets designed to permit passage of adult salmon and exclude seals. It proved ineffective in excluding seals, required high maintenance, trapped debris and could not withstand high river flows (Munro 1998). Lethal removal of 31 seals did occur in 1997 and a 75% reduction in the number of seals foraging on juvenile salmon in the spring of 1998 was attributed to this removal (DFO Puntledge River Committee 1999).

A broomstick type, aluminium barrier fence was fabricated and installed under the 17th St. Bridge in 1998. The decision to install this fence was a major commitment of resources. It was anticipated that the barrier fence would protect endangered salmon stocks, while eliminating or reducing the need to kill seals. In this paper, we discuss the barrier fence's effectiveness in protecting adult salmon. During barrier fence operation, seal and salmon observations were recorded 24hr/day for 80 days. This provided us with a unique opportunity to examine seal and salmon behaviour and trends in abundance, relative to environmental factors such as; tide, light, discharge, and water temperature.

It was hoped that salmon would move easily through the fence on their upstream migration instead of being delayed by the fence. However, the possibility that salmon would congregate below the fence and fall prey to seals was considered. The river below the barrier fence had been dredged, its banks had been altered, and it lacked any natural complexity. Adult salmon had no physical refuge where they could hold on their upstream migration or into which they could escape when chased by seals. In previous years, seals were observed driving salmon onto the riverbanks below the 17th St. Bridge and killing them. An attempt to provide artificial "salmon havens" was initiated. Forty concrete triads were installed 200m below the 17th St. Bridge on the right side, looking downstream. In this paper, we examine the effectiveness of the triads in providing a refuge for salmon.

STUDY AREA

The Courtenay River is a 2.6 km section of river formed by the confluence of the Tsolum and Puntledge rivers (Figure 1). The total watershed drains an area of 858 km^2 and the river has a mean annual discharge of 51.3 m^3/sec (Riddell and Bryden 1996). The Courtenay River flows through the City of Courtenay and is considered a navigable river. The lower portion of the river has been dredged and portions of its channel have been confined by bank-works.

The Puntledge River drains an area of 608 km^2 (Riddell and Bryden 1996), is relatively high in elevation with over half of the watershed above 200 m (maximum elevation 2000 m). There are a number of glaciers and lakes in its headwaters. Natural discharge is highest in May and June (snow dominated). Lowest discharges occur during the months of July, August and September and these flows are augmented by water collected in winter and spring (Figure 2). The Puntledge River has been used for power generation since the early 1900's. Currently two dams operate on the river (an impoundment dam at Comox Lake and a diversion dam located 3 km downstream). The latter dam diverts some of the discharge through a penstock to just above the hatchery (4 km further down river). This reduces discharge in the natural channel above the hatchery and impedes salmon access to traditional holding and spawning areas. The freshwater salmon-spawning habitat has been degraded though sedimentation above and gravel depletion below the diversion dam. A summary of the impacts of hydroelectric development on Puntledge River chinook stock can be found in Trites et al. (1996).

The Tsolum River drains an area of 248 km^2, has a mean annual discharge of 10.3m^3/sec (Riddell and Bryden 1996), is relatively flat, is lower in elevation than the Puntledge, and highest flows are from November through May (rain dominated, Figure 3). The Tsolum River is “flashy” in nature (rainstorms generate rapid high discharge) and often contains high sediment loads due in part to human activities. During late summer, flows from the Tsolum are an insignificant contribution to the Courtenay River when compared to that of the Puntledge River (Figure 4). Acid drainage from an abandoned copper mine has been an environmental concern for years.

SALMON RESOURCE

The Courtenay River watershed supports anadromous populations of rainbow trout, summer and winter steelhead runs *(Oncorhynchus mykiss*), and cutthroat trout (*O*. *clarki*) as well as; coho *(O. kisutch)*, pink (*O*. *gorbuscha*), chum (O. *keta*), sockeye (*O*. *nerka*) and chinook summer and autumn (*O*. *tshawytscha*;) salmon. Resident populations of rainbow trout, cutthroat trout and Dolly Varden charr (*Salvelinus malma*) are also present. The average salmon runs (1986-95) were; sockeye 14, chinook 600, coho 7,000, chum 62,000, and pink 15,000 (Department of Fisheries and Oceans Salmon Inventory System; Serbic 1991). Chinook escapement estimates made by the Puntledge River Hatchery included broodstock captures after 1985 and were higher then records maintained by the Department of Fisheries and Oceans (Figure 5). The hatchery records were a better indication of total escapement and we used them in this report.

All summer run chinook salmon and the majority of autumn chinook return to the Puntledge River. Less than 20 autumn run chinook salmon may spawn in the Tsolum River some years. Historically, chinook spawned in the Puntledge River below Comox Lake and in the tributaries of Comox Lake. Historic access to the lake was especially important to summer chinook salmon as they could reside in cooler lake waters in summer until ready to spawn in autumn. The construction of a second dam eliminated the best natural spawning habitat below Comox Lake and restricted access into Comox Lake. Since 1991 “a reliable fishway” has been available (Griffith 2000) which would permit the upstream migration of chinook above the dams and into Comox Lake. However, the majority of summer chinook hold in the main river beside the hatchery until ripe enough to be taken for broodstock.

In the mid 1950’s summer chinook averaged over 3,000 returning adults. Returning adults declined to 300 in 1974 after the second dam was constructed. Following hatchery stock rebuilding efforts, the numbers of summer chinook increased through the 1980’s, peaked in 1990, and then declined through the 90’s (Figure 6). The numbers of returning summer chinook have recovered during the last four years (1999-02). Autumn-run chinook escapements have also declined after a peak in 1990, but numbers have increased dramatically during the last four years (1999-02). A positive correlation between summer chinook escapement and autumn chinook escapement does exist (Figure 7; Pearson Correlation; $P < .01$).

The stocks of summer and autumn chinook are considered to be genetically different and run timing as well as “Coded Wire Tags” (CWT) have been used to differentiate the two stocks. The cut off date for summer versus autumn chinook was September 1. All chinook arriving at the hatchery after September 1 were considered to be autumn-run unless the fish had a CWT that proved it was a summer chinook. Screens were dropped at the hatchery fence on August 1st to divert pink salmon into the hatchery. Chinook salmon above the hatchery fence before August 1st were considered to be summer-run stock. Any female chinook entering the hatchery between August 1 and August 15 was considered to be summer-run stock and spawned with males above the hatchery fence. Any chinook arriving at the hatchery fence between August 15 and August 31 was considered to be a separate group and was spawned as such.

SEAL POPULATION

Considerable research on harbour seal diet and foraging behaviour has been conducted in the Courtenay River and Courtenay Estuary (Bigg et al. 1990; Olesiuk et al. 1990b; Olesiuk et al. 1996b, Olesiuk 1999b). Seals use the estuary throughout the year and are often observed hauling out on log booms stored off Goose Spit and Royston, but numbers do fluctuate seasonally. Seal numbers range from 200-300 during January to June, rise to approximately 600 in October-November, and return to 200-300 by the end of December (Big et al.1990; Olesiuk et al. 1996b). Olesiuk (1999a) estimated that these counts of seals represented about 70% of actual abundance. Scats collected on the log booms indicated that the most important prey item during May-October was hake (Olesiuk et al. 1990b; Olesiuk 1993). In May the portion of salmon in the diet starts to increase and by November it is the most prevalent prey item.

A small number of seals foraged in the Courtenay River. In April-June seals congregated at night beneath the 5th Street Bridge and used the back-lighting cast from the bridge lights to feed on out-migrating salmon fry and smolts (Olesiuk et al. 1996a: Yurk and Trites 2000). Olesiuk et al (1996a) used the vantage provided by the bridge to photograph seals and identified individual seals based on their pelage. They estimated that 40-50 seals practised this feeding behaviour, and 20 seals accounted for 79-89% of the total juvenile salmon predation. Few seals foraged in the river from July-August, but coinciding with the return of adult salmon, in-river seal numbers increased peaking in November-December (Olesiuk et al. 1996b). Olesiuk et al. (1996b) estimated that seals foraging in the Courtenay River represented 2-17% of the total number of seals in the estuary and these seals accounted for 67% of the total pre-spawning salmon predation.

METHODS

SEAL FENCE

The seal fence design was a modification of floating broomstick type fences that had been successfully used to capture salmon broodstock. The seal fence was constructed under the 17th St. Bridge in a section of the river that was under tidal influence (Plate 1). Since the Courtenay River is considered a navigable river, a section of fence was designed to open and close to permit boats to pass. The river was approximately 75-m wide at this point. The spacing of the vertical aluminium bars in the floating panels was established by pushing and pulling seal carcasses through test panels. A spacing of 6.5 inches (16.5 cm) was used. This was considered the minimum opening necessary to block access to adult seals. The costs of constructing, installing, and removing the barrier fence was approximately $200,000 (DFO Puntledge River Committee 1999).

The Courtenay seal fence spanned the entire length of the 17th St. Bridge (261 ft or 79.6 m including three concrete bridge piers) and consisted of 335 ft (102.1 m) of floating and vertical aluminium panels (Hill 2003, personal communication). This seal barrier included five different sections. A vertical lumber broomstick type section spanned 88 ft (26.8 m) of the riverbank to pier #1 (the first concrete bridge pier on the right side looking downstream). This section contained a land gate for of kayak and canoe portage. The second 86 ft (26.2 m) section was constructed using 23 flexible floating aluminium panels, each 20 ft (6.1 m) long, anchored to the bottom with a steel rail, and free to rise and fall with the tide. The third section consisted of 39 ft (11.9 m) of vertical aluminium panels connected to the existing bridge piling. The fourth 45 ft (13.7 m) section between concrete pier #2 and #3 was termed the "navigation channel." This was the deepest part of the river and 14 floating aluminium panels, 22 ft (6.7 m) long were anchored to the bottom by a steel beam. The floating panels were designed to sink when a heavy beam was lowered by winch onto them, thus permitting passage of boats. The fifth fence section from pier #3 to the timber wall on the right bank completed the seal fence. This 77 ft (23.5 m) section was constructed using vertical aluminium panels.

The seal fence was operational on June 19, 1998 and observers stationed at the fence started to record daylight seal and salmon observations on June 22, 1998. Uninterrupted 24 hr/day observations were initiated on June 24, 1998. The barrier fence was considered "seal proof" on June 29, 1998 after minor modifications. Prior to the installation of the seal fence, seals were seen in the river and four or five summer run chinook had been observed upstream at the Puntledge Hatchery. On September 13, 1998, the navigational section of panel was opened, creating a permanent gap in the seal fence. Observers continued uninterrupted monitoring of seal and fish movements until September 18, 1998. Observations of daylight seal activities continued until September 21, 1998. The barrier fence was removed by mid-October.

While the seal fence was in operation, various adjustments were made to the fence and changes were made to the fence's operating procedure. These minor adjustments and changes made the fence more impenetrable to seals. The river section below the fence supported an active lumber mill and the river above the fence was navigable. Disruptions to seal and salmon behaviour may have occurred for 4 or 5-day periods when the lower channel was dredged and when steel sheeting was added to the mill docks. Daily disruptions would have occurred when log booms were towed to the mill and a few times each day as boats passed up or down river. During the period of fence operation a total of 21 seals were shot.

An acoustic deterrent device (dB Plus II Acoustic Deterrent System manufactured by Airmar Technology Corp.) was installed below the seal fence and was operated continuously until mid-August when it was deemed to have been ineffective. Underwater cameras were also mounted directly below the fence. These proved to be of limited value due to short viewing distance, algae build up, and salt wedge optics. Algae and debris had to be continuously removed from the fence panels during summer to prevent the panels from sinking.

During each 24-hr period, six observers (two/shift) recorded seal numbers, seal behaviour, salmon numbers, and salmon behaviour. These observations were made from a platform under the 17th Street Bridge. This platform was positioned directly above the seal fence and provided an unobstructed view of the river for more than a kilometre downstream during the day (Plate 2). Observers used binoculars with a slight night enhancement feature and strong spotlights was used on a few occasions when appropriate. At night the lights from the 17th St. Bridge and the lights from the sawmill which bordered the river downstream of the 17th St. Bridge provided reasonable viewing of the river for approximately 400 m.

The maximum number of seals sighted per hour and the behaviour of the seals was recorded. The information recorded for each seal action included, type of action, time, location, and estimate of success. Types of actions included; attempts to circumvent the seal fence, chases of salmon, and salmon kills. For each salmon attacked by a seal, the species of salmon if identifiable was recorded and the likelihood of its demise was estimated. The success of each attack was listed as a positive kill (100% certain), probable kill (75% certain), possible kill (50% certain), or miss. Misses and chases were hard to differentiate. However, misses were assumed to be prolonged chases without any evidence of success.

When possible the salmon number, species, and behaviour were recorded. It was almost impossible to observe fish holding below the seal fence at night. Identification of specific fish and schools of fish over an extended period of time was difficult as fish were not marked (scars and deformities were used on three occasions). Individual fish and schools of fish would arrive at the fence, they might remain visible for a short period of time (e.g. 15 min), but would often disappear from view without their fate being discerned. It could not be assumed fish or groups of fish reappearing hours later were the same fish unless the fish group was similar in species, size, number, and behaviour. Thus, notes on the holding or delay time of salmon migration were difficult to interpret.

TRIADS

The banks of the Courtenay River below the seal fence lacked any physical refuge in which salmon could hold during their upstream migration or could escape from seals during a chase. In order to provide a physical refuge for salmon a series of 40 triads were placed from 253 m to 308 m below the seal fence on the right bank (looking downstream) of the river (Plate 3). These triads were put in place during spring 1998 and no data was collected prior to their placement. However, during previous years there were anecdotal reports of adult salmon being chased onto the shore by seals at this location.

Each triad consisted of three, 8 ft. (2.44 m) long, 8 inch (20.3 cm) in diameter, round cement columns, pinned together in the middle (Plate 4). A series of 40 triads provided complex refuge for 55 m of stream-bank, 2 m deep and 2-4 m wide (Plate 3). The triads were placed in tidal influence on the shallow side of the river. At low tide (< 4 m) the triads were dry and provided no refuge. At higher tides (> 6-7 m) the tops of the triads were just covered with water.

A series of 72 observations on seal activity were taken from the riverbank adjacent to the triads from June 11, 1998 to September 10, 1998 (Appendix A). All observations were made during daylight hours. The number and location of seals was noted and the position of each seal was described from two dimensions. Its position along the river was described as above, below or opposite the triads and its position across the river was described as far bank, mid river, or near shore. Any seal action which might relate to salmon predation (e.g. kills or chases) were recorded.

The possibility that salmon might use the triads for refuge during their upstream migration even when they were not being hunted by seals was considered. The riverbank bordering the triads was 3-5 m higher then the river channel and an observer could look down into the clear water and see adult chinook salmon if they were present. Observers quietly walked the riverbank with the purpose of recording the number of adult salmon and their position relative to the triads (above, within, and below). Counts of salmon use of the triads were attempted on 52 occasions ("Fish No." in Appendix A). We were confident that visibility was good on 40 of the occasions when salmon counts were made. On 12 occasions we were not adequately able to view the water column and assess fish presence due to water surface glare, when surface conditions were rough, or when the water column was murky. All observations were made during daylight hours. The first observation was made on June 11, 1998 and the last was made on September 10, 1998.

WATER TEMPERATURE AND DISCHARGE

In summer 1998, hourly water temperatures of the Courtenay River were continuously monitored with a data logger placed on the bed of the channel adjacent to the triads. This data logger remained submerged at low tide. Daily water temperatures (June to September 1998) for the Puntledge River and for the Courtenay River estuary (sea-surface site located in Comox Harbour) were provided by the Puntledge River Hatchery. The Courtenay River discharge is the combined flows of the Tsolum River and the Puntledge River. Water Survey of Canada lists the two stations as; Puntledge River Powerhouse (08HB006) and Tsolum River near Courtenay (08HB011). Forty years of discharge data with some measurements as early as 1914 were available.

A total of 12 surface and bottom water temperature profiles (bank to bank) were recorded on the Courtenay River (Appendix B). Measurements were taken on two days (July 29 and July 30, 1998) at high and low tides, and at three locations. The first profile was located adjacent to the triads, the second profile was located approximately 500 m downstream of the triads (adjacent to a marina), and the third profile was located approximately 1 km downstream of the triads. The water temperature profiles were completed on the days of the highest mean temperatures for the river.

RESULTS

SEAL ABUNDANCE

The maximum number of seals/hr observed below the seal fence increased from < 0.5 in late June, peaked at 3.5 in early August, declined to 1.0 in early September, and then increased to 1.5 for the remainder of the fence operation (Figure 8). Seal activity at the seal fence appeared to decline slightly in the days immediately following the lethal removal of seals. The removal of seals is likely responsible for the 3 day low number of seals/hr noted during the last 3 days in July (Figure 8). A total of 21 seals were shot at or near the seal fence during July and August 1998.

The degree to which the lethal removal of seals reduced seal activity below the fence is not measurable, as changes in seal abundance could be related to many factors. If a reduction in seal numbers at the seal fence did occur because of lethal removal then it appears the number of seals returned to pre-shooting levels within days. An examination of 10 seal carcasses (seals killed in July) indicated that only 3 seals were animals that habitually foraged in the river (Olesiuk, unpublished data). It is likely the other seals were from the estuary and were attracted into the river by the large pink run. Seal stomach analysis revealed that the seals had been feeding on pink and not chinook salmon. (Olesiuk, unpublished data). .

SEALS AT FENCE

Seals did attempt to pass through the seal barrier fence and some were successful (Figure 9). The number of attempts, intensity of the attempts, and the success of the seals in passing through the fence varied over the course of fence operation. Four different periods of fence operation and seal success at the fence can be postulated. These different periods relate to prey abundance, seal shootings, fence tightness, and seal size.

<u>June 22 to July 7, 1998</u>

In the first two weeks of the seal fence's operation the number of seals counted below the fence was low (0.8 seals/hr ± 0.2 C.I. 95%). Yet, individual seals were observed repeatedly attempting to pass through the fence, usually at night, and often with the expenditure of considerable effort (e.g. a single attempt could be over 15 minutes in duration). A total of 101 attempts on the fence were made (6.3 attempts/day) of which 11 were successful (11%). Minor adjustments were made to the fence, such as reinforcing horizontal bracing where seals were able to bend the bars apart and adding wire at some locations.

<u>July 8 to August 1, 1998</u>

Pink salmon were abundant below the fence and during this period 12 seals were shot. The number of seals counted below the fence was high (1.6 seals/hr ± 0.3 C.I. 95%). A total of 53 attempts on the fence were made (2.1 attempts/day) of which 2 were successful (4%). Notes taken during this period often describe the seals as "checking out the fence" rather then attempting to get through. The low numbers of attempts to get upstream through the fence, lack of intensity of seal attempts, and low success rate during the 2nd period; roughly corresponds to a period of seal culling and high prey abundance.

<u>August 2 to September 8, 1998</u>

The number of seals counted below the fence was highest (average 2.0 seals/hr ± 0.2 C.I. 95%) during this period. A total of 140 attempts on the fence were made (3.7 attempts/day) of which 64 were successful (46%). The size of the seals attempting to pass through the fence changed during late summer when younger, smaller seals were more abundant. Notes taken during this period often refer to the size of the seals passing successfully through the fence as being small. Also, the fence was difficult to maintain in proper working condition due to algae collecting on the floating fence panels and weighing them down (the fence did sink on one occasion). A total of 9 seals were lethally removed during this period. We suspect that the success of the seals in passing through the fence was due to a combination of seal size (smaller seals could squeeze through the bars), difficulties in maintaining the fence, and the attraction of the seals to salmon which had already moved up the river.

September 9 to September 17, 1998

The navigational panels at the fence were in an open position during this 9-day period allowing seals to easily pass through. The number of seals counted below the fence averaged 1.5 seals/hr ± 0.2 C.I. 95%. A total of 49 attempts on the fence were made (5.4 attempts/day) of which 48 were successful (98%). Despite the large opening, one seal tried unsuccessfully to pass through the fence elsewhere.

SEAL BEHAVIOUR

Seal numbers below the seal barrier fence were positively correlated with tide height (Linear Regression, $P < 0.0001$; Figure 10). The greatest numbers of seals/hr were observed on the highest tides. At lower tides the seals were more exposed and had to cross a shallow bar approximately 400 m below the fence. This bar became visible at tides of < 3 m. Bigg et al. (1990) estimated that a tide of > 2.25 m was required for seals to enter and forage in the Courtenay River. However, once above tidal influence the seals could forage as far upstream as the Puntledge hatchery.

The number of seals/hr varied diurnally (Figure 11). Fewer seals were seen below the fence during the day (1.2 seals/hr ± 0.1 C.I. 95%) than were counted at night (2.2 seals/hr ± 0.2 C.I. 95%). The number of seals declined from dawn (2.1 seals/hr ± 0.3 C.I. 95%) through the morning to a mid-day low (0.6 seals/hr ± 0.3 C.I. 95%) and then increased through the afternoon to dusk (2.7 seals/hr ± 0.4 C.I. 95%). Seals were often spotted well downstream of the fence at dusk and they moved up the river to the fence as night approached.

The two factors, tide height and time of day, interact (Figure 12). The majority of extremely low tides from June 22 to September 17 occurred during the day (tides less than 1.5 m, day = 82 and night = 23) while low tides were evenly distributed between day and night (tides between 1.5m and 2.5 m, day = 25 and night = 26). The number of hours of observation at tide heights greater than 2.5 was 845 hrs (day), 668 hrs (night) and 157hrs (dawn/dusk). However seals were not evident during either day or night at tides of less than 1.5 m and were rarely seen at tides below 2.5 m. For a given tide height more seals/hr were seen at night than during the day, except at a tide height of 5 m. At night the average number of seals/hr was similar (slightly greater than 2.0 seals/hr) for all tide heights greater than 3.0 m. During the day the number of seals/hr was correlated directly to tide height.

Seal numbers were significantly greater (Chi-square, $P < .01$) during flood tides than during ebbing tides (Figure 13). The greater the degree of change in tide height (m/hr) the more pronounced was the difference in seal abundance. During strong flood tides (> 0.6 m rise/hr) slightly more seals were seen. During strong ebb tides (> 0.6 m drop/hr) the least number of seals were observed (Figure 13). There was no noticeable difference in seal abundance when change in tide height was between + 0.6 m/hr and – 0.6 m/hr (Figure 13).

Although this study was not designed to examine the social interaction of seals or herd groupings if such exist, observers did record the maximum number of seals/hr. The frequency of seal numbers/hr can be compared for the three salmon runs (Figure 14). All three curves have a similar shape (a geometric depreciation) and we were more likely not to have seen any seals (31% of time) than to have seen 4 or more seals (23% of time). Slightly larger seal aggregations (4,5,6,7,8; Figure 14) were present during the pink salmon migration then during either the summer or autumn chinook migrations. Observers also recorded the number of seals within the immediate area of 158 salmon kills for which the species of salmon was known (Figure 15). In spite of the slightly larger aggregations of seals counted during the pink salmon run, less seals were involved in the killing and consumption of pink salmon (2.10 seals/kill ± 0.29 C.I. 95%) than chinook salmon (2.48 seals/kill ± 0.21 C.I. 95%). This difference was not significant (Mann-Whitney Rank Sum, P = 0.065). Forty-three percent of the known chinook kills (27/61) involved three or more seals, while 25% (27/97) of the known pink kills involved three or more seals.

LOCATION AND TIMING OF SALMON KILLS

The locations of 2447 seal actions, (kills, probable kills, possible kills, misses, and chases) are illustrated in Figures 16 and 17. More actions occurred on the “Old House” side of the river between the triads and the fence than at any other location. The Old House side of the river (Figure 1) accounted for 1106 actions (45%), the “Mill” side recorded 540 actions (22%), 448 actions (18%) were noted at mid-river, and the lateral positions of 353 actions (15%) were not recorded by observers. Thus, approximately twice as many seal actions took place on the Old House side of the river as on the Mill side. The majority of actions took place between the triads and the fence (1806 actions or 74%). A further 239 actions (10%) took place in or lateral to the triads, 49 actions (2%) were below the triads, 160 actions (7%) took place at the fence, and the longitudinal positions of 193 observations (8%) were not recorded. More actions took place in the area of the triads (148) than on the Mill side directly across from the triads (45).

The distribution of 414 salmon kills below the seal fence (Figure 18 and 19) was similar to the distribution of seal actions (Figure 16). More salmon kills (150 kills, 36%) were recorded on the Old House side of the river than on the Mill side (109 kills, 26%). A further 93 kills (23%) were listed as mid-river, while the lateral position of 62 kills (15%) were not recorded (Figure 18). The majority of kills took place between the triads and the fence (Figure 19; 280 kills, 68%). Fifty-two (13%) of the salmon were killed in or across from the triads, 19 (5%) of the salmon were killed at the fence, and 20 (5%) were killed below the triads. The longitudinal positions of 43 kills (10%) were not recorded.

There was a difference in the diurnal rate of seal actions and salmon kills (Figure 20). Salmon kill rates can be estimated from the representative number of hours of observation during day, night, and dawn/dusk. Observers at the seal fence recorded 148 salmon kills during the day for 1222 hrs of observation, 226 at night for 700 hours of observation 22 at dusk for 88 hours of observation and 18 at dawn for 87 hrs hours of observation. Kill rates were highest at night (0.32 kills/hr), lowest during the day (0.11 kills/hr), and intermediate at dawn (0.20 kills/hr) and dusk (0.25 kills/hr). If we include the 37 probable kills and 131 possible kills recorded below the seal fence and consider these to be actual kills, then kill rates become: 0.51 kills/hr during night, 0.17 kills/hr during day, 0.26kills/hr at dawn, and 0.38 kills/hr at dusk. If kill rates are calculated based on actual kills and the number of hrs of observation when tides are above 2.5 m then kill rates become; 0.17 kills/hr during the day (148 kills / 845 hrs), 0.34 kills/hr at night (226 kills / 668 hrs), and 0.25 kills/hr at dawn/dusk (40 kills / 157 hrs). Thus two to three times more salmon/hr were killed at night than during the day.

The ratio of misses to kills is an indication of the relative success of seals in capturing salmon under different light conditions at different locations (Figure 21). The following ratios of misses/kills were calculated: dark 0.84 (190/226), dawn 1.06 (19/18), day 1.27 (188/148), and dusk 0.84 (19/22). A significantly higher ratio of misses to kills occurred during the day than at night (Yates Chi-squared; P < .01). This indicates that either a night pursuit was more likely to be successful then a day pursuit or it was more difficult for observers to discern chases, misses and kills at night.

The location of the kills was different during day and night. In daylight more salmon kills were recorded on the Old House side of the river (71), than on the Mill side of the river (30), or mid-river (35), and the lateral position of 12 kills was not recorded (Figure 22). The majority of salmon kills in daylight were between the seal fence and the triads (82 kills, 55%), 36 (24%) were killed at or across from the triads, 20 (14%) were killed below the triads and the lateral position of 10 (8%) were not recorded (Figure 22). At night the location of salmon killed was evenly divided between the Old House side of the river (69) and the Mill side of the river (68), with another 48 kills mid-river, and 41 kills unknown (Figure 23). The majority of salmon kills at night (Figure 23) were recorded between the fence and the triads (184 kills, 81%), very few salmon kills were recorded at the triads (14 kills, 6%), no kills were noted below the triads, and the position of 28 kills (13%) was not recorded. Thus, more salmon kills were recorded further down the river during the day than during the night (Chi-squared, $P < .001$) and more kills were recorded on the Old House side of the river during the day than on the Mill side (Chi-squared, $P < .01$).

Observer bias may have accounted for some of the diurnal differences in longitudinal distribution of salmon kills as more salmon kills were recorded further downstream during the day (Figure 19). A total of 860 daylight seal actions were recorded from the seal fence and only 17 (or 2%) took place below the triads. In contrast, when the observers' day position was 200 m further downstream at the triads, more sightings (17 of 74, or 23%) were recorded below the triads.

SALMON ESCAPEMENT

The number of adult summer, autumn, and total chinook returning to the Puntledge River has increased dramatically from the low escapements recorded in 1997-1998, (Figure 5,6). The chinook return includes salmon taken for broodstock by the hatchery and the salmon that spawned naturally in the river. Returns of both summer and autumn chinook were significantly greater (Mann-Whitney Rank Sum, $P < .05$) in the 4 years (1999-2002) after the seal program than in the 4 years (1993-96) preceding it. Summer chinook increased from 346 to 1143, autumn chinook increased from 223 to 6252, and total chinook escapement increased from 646 to 7674.

Two neighbouring hatcheries, that only support autumn chinook and do not have summer chinook runs, have also shown an increase in chinook returns during the last few years. However their increases in autumn chinook returns relative to the Puntledge River have not been as great. From 1988 to 1998 Puntledge River autumn chinook returns, have been 11.3% ± 9.0% (95%C.I.) of the Big Qualicum River Hatchery and 11.2% ± 4.4% (95% C.I.) of the Quinsam River Hatchery returns. In 2001-02, Puntledge autumn chinook returns were 111.0% and 129.2% of the Big Qualicum returns and 85.5 and 70.8% of Quinsam River returns. Thus, it appears that following the seal program, the Puntledge autumn chinook returns have increased more than what we would have expected based on the historic between hatchery trends.

SALMON ABUNDANCE AT SEAL FENCE

The 1998 estimated escapement of summer chinook at the up-river hatchery was 236. There was no clear break between summer chinook and the autumn chinook runs. Chinook salmon which entered the river between August 15 - 31, could have been from either group. The first summer chinook was observed at the seal fence on June 23. Summer chinook were not abundant in 1998; the maximum number observed at the fence was six on July 14 and a total of 30 chinook were counted before July 16. Summer chinook and a very few summer steelhead (<12 total run) were the only salmon available to seals prior to July 16. A further 44 chinook were observed below the fence from July 17 to August 15 when the pink salmon run dominated the river.

The final count of autumn chinook salmon estimated at the up-river hatchery was 316. All chinook entering the river in September were counted as autumn chinook. Chinook entering the river between August 15 and August 31 were likely to be autumn chinook (they are examined for CWT tags at the hatchery). At the fence, 67 chinook were observed between August 15 – 31. Autumn chinook dominated the river after September 1 and a total of 96 were observed from the fence. Autumn chinook were more abundant than summer chinook.

The daily number and species of salmon available for seals to consume varied over the course of the fence operation (Figure 24). Three periods of salmon abundance can be noted; a) prior to July 16 when only summer chinook were available, b) from July 17 to August 31 when pink salmon dominated the river, and c) after September 1 when autumn chinook were most abundant. Seal abundance, patterns of seal activity, and number of salmon killed, roughly parallels the numbers of migrating salmon counted at the fence (Figure 8, 24, 25).

Before July 16 only summer chinook (41 seen from fence) were available to seals in the river. The number of seals (0.91 seals/hr), observed number of salmon killed (27 or 7% of total salmon killed), rate of salmon killed (1.03/day), and number of actions by seals (51 or 3% of total), were low. However, it does appear that seals consumed a high proportion of the summer chinook observed at the fence. During this period only 19 chinook were recorded as passing upstream through the fence.

In 1998, 98% of the pink salmon run occurred between July 17 and August 31 (Figure 24). The pink salmon migration dominated the salmon counts during this period as 95% of the salmon observed below the seal fence were pinks. Schools of pinks greater than 100 were noted circling below the fence. The number of seals (2.05 seal/hr), majority of salmon killed by seals (337 or 81%), rate of salmon killed (7.53/day), and majority of seal actions (1725 or 84%) occurred during this period. Although 31 chinook kills and 116 pink kills were observed (21% chinook), the only recognizable species of salmon found during analysis of 14 seal stomachs were pink salmon (DFO Puntledge River Committee 1999). It is therefore possible that the majority of the 190 unknown salmon killed during this period were pink salmon. The pink salmon migration (with the exception of a few stragglers) was over by the end of August (Figure 24) and seal activity declined (Figure 25). Total escapement of pink salmon in 1998 was estimated to be 10,000 (DFO Puntledge River Committee 1999).

After September 1, chinook salmon continued moving up the river and seal activity and salmon kills increased (Figure 25). The majority of fish (76%) observed from the seal fence and 58% of the identified salmon killed after September 1 were chinook salmon. The number of seals (1.52 seals/hr), observed number of salmon killed (50 or 12% of total salmon killed), rate of salmon killed (2.76/day), and number of actions by seals (282 or 14% of total actions) were less than during the pink migration.

Observers tried to identify the species of salmon killed by the seals. A total of 414 salmon kills were observed below the seal fence of which 73 (17%) were chinook kills, 127 (31%) were pink kills, and 214 (52%) of the fish killed were not identified. We assumed the ratio of known chinook to known pink kills during each of the three periods is applicable to the unknown kills during that period. All 27 salmon killed prior to July 16 were summer chinook. From July 17 to Aug 30 during the pink run, 21% of the known kills were chinook. Thus we can assume 40 of the 190 unknown kills were chinook (20 summer and 20 autumn) and 150 kills were pink salmon. After September 1, 58% of the known kills were autumn chinook. Thus, we can assume 14 of the 24 unknown kills were autumn chinook and 10 kills were pink salmon. We can partition the 414 known salmon kills into 63 summer chinook, 287 pink, and 64 autumn chinook. This may be considered a minimum number of kills as observed from the fence.

Further estimation of the number and species of salmon killed requires considerable speculation. First, an additional 170 possible and probable kills were also observed from the fence. If we assume half of these were kills and if we use the same species ratios for each of the three periods as above, then an additional 9 summer chinook, 13 autumn chinook, and 63 pink salmon would have been killed. Second, our observations were made from one location and must consider the salmon killed in the estuary. We could assume that for chinook, river kills are equal to estuary kills (1,487 estuary versus 1,489 river; Olesiuk et al. 1996b) and that pink salmon river kills represented 64% of the total pink kills (658 estuary versus 1,149 river; Olesiuk et al. 1996b). However, Bigg et al. (1990) estimated that pink salmon river kills were 65% of that recorded in the estuary. We will assume we saw the majority of river kills, probable kills and possible kills from the seal fence observation site and that the river kills represented half of the total number of kills for both chinook and pink salmon (other half killed in estuary). Therefore, the total estimated number of returning Puntledge River salmon killed by seals in 1998 would be: 144 summer chinook, 154 autumn chinook and 700 pink salmon. These estimates represent 38% of the summer chinook, 33% of autumn chinook and 6.5% of pink salmon.

The ratio of chinook kills relative to pink kills is likely to be high. Although less chinook salmon kills were recorded than pink salmon kills, the pink salmon run was an order of magnitude larger. We suspect that considerable bias towards identification of chinook salmon kills versus pink salmon kills occurred. The major criteria for distinguishing between a pink salmon and a chinook salmon kill was fish size. It is more likely that larger chinook salmon were brought to the surface to be eaten. More activity (splashing, chasing, and prey sharing) occurred when prey size was large. A large chinook salmon was easier to see from the fence then a smaller pink, and any large salmon observed being killed was recorded as a chinook while smaller fish could be of either species. Olesiuk et al. (1996b) also reported a disproportionately high number of pink kills compared to chinook kills based on recovery of scales and fish carcasses from kill sties.

Similar patterns are noted for seal abundance/day, the number of salmon killed/day, number of seal actions/day (chases, possible kills, probable kills), and salmon abundance/day (Figure 26). The graphs of each variable are bimodal in distribution, peaking during the first week of August and displaying a second, smaller peak in early September. It appears that seal abundance, actions, and kills correspond closely with the availability of salmon prey. The largest peak in seal activity corresponds to the large pink salmon run during the first week of August. The second smaller peak in seal activity corresponds to an increase in salmon abundance when the majority of autumn chinook entered the river. Although the timing of seal and fish abundance are the same, the magnitude of the seasonal change for seal numbers was much less pronounced than for fish. This might explain why the small chinook runs experienced a much higher predation rate than the larger pink run.

CHINOOK BEHAVIOUR

The time of passage of chinook through the seal barrier fence was recorded for 72 groups or schools, representing 203 chinook (Figure 27). This includes the time of passage for an additional 13 chinook (9 groupings) that were recorded without any indication of holding time. The time at which an observer noted the downstream disappearance was recorded 45 times for 108 chinook and an additional 9 times for 31 chinook chased downstream by seals. A large school of autumn chinook (128) passed through the fence in 5 groups between 14:30 and 16:30 on September 10. This large upstream migration (63% of total chinook) skews the graph of individual chinook behaviour (Figure 27) towards early afternoon. Figure 28 illustrates the distribution of chinook observations (schools) during the day, independent of the size of the school.

The greatest number of chinook salmon were recorded below the seal fence at mid-day. The majority of chinook (310/343; 90%; Figure 27) and the majority of chinook schools (114/139; 82%; Figure 28) counted below the fence were during a 9 hr, mid-day period (8:00 to 17:00). We could not count chinook holding below the fence during the 8 hrs of night with any certainty. The lack of night counts would reflect this bias (Figure 27 and Figure 28). However, visibility was excellent for 3 hrs after sunrise and for 3 hrs before sundown. The number of chinook schools observed (t-test, $P < 0.05$) and number of chinook counted (t-test, $P < .01$) were greater at mid-day than during the combined morning and evening periods.

It is possible that the number of salmon schools counted below the fence is a reflection of the number of seals observed (Figure 11, 28). The total number of chinook observations during daylight hours was negatively correlated with the number of seals/hr (Pearson Correlation, $P < 0.001$). The number of chinook holding during daylight hours was also negatively correlated with the number of seals/hr during daylight hours (Pearson Correlation, $P < 0.05$).

There was a relationship between tide-height and chinook counts below the fence (Figure 29). Less chinook were counted on high tides then on low tides. Significantly (Chi-squared, $P < .001$) more chinook (263, 77%) were counted on tides at or below 2.5 m than at tides above 2.5 m (80, 23%). Tides were at or below 2.5 m for 26% of the total fence observation time. It is possible the absence of chinook below the fence on high tides was due to the greater presence of seals on higher tides (Figure 30). Seal numbers and chinook numbers, relative to tide-height were negatively correlated (Peterson Correlation, $P < 0.05$).

There was a relationship between the number of chinook salmon below the fence and the direction of tide flow (Figure 31). Significantly (Chi-squared, $P < .001$) more chinook (249) were counted on flooding tides then on ebbing tides (94). Significantly (Chi squared, $P < .001$) more chinook passed through the fence on flooding tides (163) then on ebbing tides (40). Significantly (Chi-squared, $P < .001$) more chinook held below the fence on flooding tides (74) then on ebbing tides (35). This trend is similar to that noted for seals (Figure 13), as more seals were counted on flooding tides.

The delay in chinook salmon movement caused by the seal fence was difficult to estimate because individual salmon were hard to identify. In order to estimate the duration of holding a minimum of two observations on the same fish or fish group was required. Fish may have been holding below the fence prior to being first observed and may have been present after being last noted. Thus, duration of fish holding below the seal fence was estimated from 130 usable sets of observations on 330 chinook salmon (Figure 32). Only minimum holding times could be calculated. These observations were categorised as duration of holding prior to fish disappearing downstream (45 observations, 109 chinook), fish being chased downstream by seals (13 observations, 31 chinook), or fish moving upstream through fence (72 observations, 190 chinook).

The number of chinook holding below the fence (Figure 32) is negatively correlated with duration of holding (Pearson Correlation, $P < 0.01$). The average time for a chinook to hold below the fence was 80.5 min ± 9.6 min (95% C.I.) and 65% of all the chinook observed, held for less than 1 hr before either moving through the fence or disappearing downstream. Mean holding time for chinook salmon observed passing through the fence was 47.4 min ± 8.1 min (95% C.I.) and 83% of the chinook moving upstream did so within 1 hour of being sighted below the seal fence.

SALMON USE OF TRIADS

The triads were placed along the Old House Restaurant side of the river (right side looking downstream) approximately 250 m below the seal fence. It was hoped they would reduce salmon mortality. The triads could serve as a refuge for salmon on their upstream migration or could impede seals during a chase, thus allowing the chased salmon to escape. Although seals were observed killing salmon at this location the year prior to triad placement, a lack of a temporal control makes analysis of triad utility difficult.

The triads were totally exposed at tides of less then 1.5 m (16% of the time, June 23 to August 31) and thus useless as a refuge on low tides. Their possible use as a refuge from predation should increase as tides rise. At tides below approximately 2.5 m, the triads were only partially submerged and it is doubtful that migrating salmon would use this shallow water. From June 11 to September 10, 1998 a series of 52 daylight observations (Appendix A) were made from the banks above the triads of which 32 were made when fish were in the river and tides were greater then 2.5 m. No migrating salmon (chinook or pink salmon) were ever seen in the triads or holding near the shore directly above or below the triads during the day.

The location at which a seal initiates a salmon chase should be an indicator of where a salmon was holding. Chase observations were made both day and night from the seal fence. Observers at the fence recorded 9 of 1,313 chases (0.7%) originating in the location of the triads while 591 of 1,313 chases (45%) started on the Old House side of the river (below the fence and above the triads). Thus, as so few chases were initiated near the triads, it is unlikely salmon held in the triads either day or night.

It is possible that chases originating elsewhere in the river could end up in the triads. By impeding the seals during the chase, the triads might prevent a salmon kill. If the triads had reduced the number of kills, we could assume that the ratio of misses to kills would be higher at the triads then elsewhere in the river. This was not the case (Figure 21). The ratio of misses to kills was lower at the triads than at all but one other location. Thus, it appears that the triads were not effective in reducing the number of salmon kills.

WATER TEMPERATURE

Chinook salmon entering the Courtenay and Puntledge rivers in 1998 encountered high water temperatures. Mean water temperatures at the triads exceeded 20^{o}C for 20 days and maximum daily water temperatures exceeded 22^{o}C for 18 days in 1998 (Figure 33). Water temperatures in July 1998 were 2-3^{o}C warmer then the 30-year mean water temperature (Figure 33). Mean water temperatures 150 m downstream of Comox Dam exceeded 20^{o}C for the similar period of time (Griffith 2000).

There is considerable variation in annual summer water temperatures (Figure 34). In 1999, the maximum water temperature was 18.0^{o}C while in 1997, 1998, and 2000 water temperatures reached 20.8, 21.7, and 20.6^{o}C respectively. Thus, July maximum temperatures can vary annually by approximately 4^{o}C. Summer water temperatures were higher (1-2^{o}C; Figure 35) during the early 1990's than during any prior period. Six years of the lowest recorded escapements (< 350 summer chinook) occurred in the years following (1994-1999).

Courtenay River water temperatures below the seal fence (Appendix B) were examined during the 2 warmest days of the year (July 29-30, 1998). Surface and bottom water temperatures were measured at 1 meter intervals, at high and low tides, and at three river cross-sections. The cross sections were representative of approximately 1 km of river below the seal fence. Water temperatures ranged between 20^{o}C and 24^{o}C and for any given cross-section at a given depth, temperatures varied by less then 0.3^{o}C (Appendix B). Water temperatures were 1.9^{o}C warmer at low tide than at high tide (Anova, $P < .0001$) and 0.7^{o}C higher on the surface at high tide than on the bottom at high tide (Anova, $P < .0001$). However, at low tides there was no significant difference between surface and bottom water temperatures. At high tide, it is possible for cooler salt water to move up the river past the 17th St. Bridge resulting in cooler bottom temperatures. Adult salmon migrating up the river could use this slightly cooler salt water as a refuge as long as sea-surface temperatures were cooler than river temperatures (Figure 36). Sea surface temperatures recorded at the fish pens in Comox Harbour can exceed 20^{o}C in July and August.

DISCHARGE

The Puntledge River has a controlled discharge and during the period of fence operation (June 21 to September 21, 1998), discharge declined from 44 m^3/sec to 20 m^3/sec (Figure 24). A slight increase in flow started on July 12 (28 m^3/sec) and peaking on July 16 (49 m^3/sec) preceded an influx of pink salmon. It is possible that this slight increase in discharge may have triggered the upstream migration of pinks holding in the estuary. Pink salmon entered the river earlier in 1998 than in past years.

Discharge in 1998 was similar to historic mean discharge (Figure 37). Summer discharge varies annually and 1998 can be considered to be intermediate between a wet and a dry summer (Figure 38). Summer discharge is controlled at the dam and a minimum summer flow of 20 m^3/sec is prescribed. Maximum summer flows of greater than 120 m^3/sec occur and mean monthly discharge ranges from 20 m^3/sec to greater than 100 m^3/sec (Figure 39). Average discharge (1965 to 1999) for May-June and July-August are 49.3 m^3/sec and

27.2 m^3/sec respectively. There does not appear to be a trend towards dryer or wetter summers, although from 1988 to 1996 July-August discharges were less than the mean discharge.

A correlation between summer discharge and chinook escapements would be masked by many factors such as hatchery attempts to maintain the fish stocks (hatchery releases) and differences in ocean survival. Summer discharges and summer chinook escapements (Figure 40) were not significantly correlated (Pearson Correlation, $P = .33$). Summer discharge and release year escapement were not significantly correlated (Pearson Correlation, $P = .24$). Summer discharge and summer chinook brood year escapement (Figure 41) were significantly correlated (Pearson Correlation, $P < .05$). Autumn chinook escapements, release year escapements, and brood year escapements were not significantly correlated with summer flows. However, a correlation between summer discharges and autumn chinook brood year escapements can't be excluded (Pearson Correlation, $P = .06$).

DISCUSSION

WATER TEMPERATURE AND DISCHARGE

High temperatures (July-August) have been cited as a factor limiting chinook production in the Puntledge River (Rimmer et al. 1994). Long term exposure to temperatures above 20^{o}C can be detrimental to returning Puntledge River chinook (Guimond 2001). The Ministry of Water, Land and Air Protection (2001) water quality criteria considered water temperatures above 19^{o}C.for chinook migration and 13.9^{o}C for chinook spawning to be to high. Walthers and Nener (1997) established that the threshold of temperatures preferred by Nicola River chinook salmon during their spawning migration was less than 16^{o}C and the lower limit of lethal tolerance was 21^{o}C. Houston (1982) cites an LT_{50} for Chinook salmon of 21-22^{o}C. However, pre-spawning mortalities will occur at temperatures that are below lethal levels (Gilhousen 1990).

The water temperatures we measured in 1998 (>20^{o}C mean for 20 days, maximum 24^{o}C) were above acceptable thermal limits cited above. Griffith (2000) considered 1998 to be "the warmest year monitored to date". The summer chinook that entered the Puntledge River in June and July must remain in the Puntledge River until October when they spawn or are taken for broodstock by the hatchery. The stress on returning Puntledge River summer chinook due to high water temperatures would be compounded by seal chases and lack of any thermal refuge in the upper river. The introduction of summer cooling flows from a cold water release at the dam would be a major improvement.

Although summer flows seldom fall below a prescribed 20 m^3/sec, considerable annual variation in summer water levels does occur. The possible relationship between summer flows and chinook returns is a concern. Low discharges in the Courtenay River tend to be associated with higher water temperatures during summer (Guimond 2001). Low discharges may also be associated with increased predation by seals as reduced river width and depth implies less refuge for migrating salmon. Juvenile chinook reside in the lower river and estuary from May to July (MacDougall et al. 1999). Their survival could be affected when flows are reduced. Reduced summer flows would change the estuary conditions thus altering distribution, growth and survival rates of juveniles. However, we did not find a significant relationship between summer flows and chinook returns.

We did find a significant negative correlation between the mean water discharges (May-August) and summer chinook escapements 4 years later (P < .05). This implies a possible relationship between environmental conditions encountered by the returning adult chinook and the viability of the eggs they carry. The exact nature of this relationship, if one exists, should be further examined.

SEAL ABUNDANCE AND SALMON CONSUMPTION

Harbour seals are opportunistic feeders and their diet varies by region and season, depending on prey availability (Brown and Mate 1983; Bigg et al. 1990; Pierce et al. 1991; Harvey et al. 1995; Tollit and Thompson 1996; NMFS 1997; Carter et al. 2001). Harbour seals can consume considerable numbers of pre-spawning salmon during spawning migrations (Brown and Mate 1983; Bigg et al. 1990; Olesiuk et al. 1996b; NMFS 1997: Carter et al. 2001). Harbour seals fed seasonally on Atlantic salmon (*Salmo salar)* on the River Dee in Scotland (Carter et al. 2001). Spalding (1964) found that salmon represented 30% of the gut contents of seals collected near B.C. salmon spawning streams during the autumn. Zamon (2001) estimated that salmon accounted for 50% and 87% of observed prey captures of seals feeding in the San Juan Islands. An estimated 32% of the Puntledge River adult chinook salmon were killed by harbour seals in 1990 (Olesiuk et al. 1996b).

Large returns of spawning salmon attract seals to specific foraging locations. Seals move into estuaries and rivers to feed on seasonal increases in prey. In the Skeena River, a definite seasonal upriver movement of seals coincided with the salmon runs and seal numbers upriver steadily increased as the number of salmon increased (Fisher 1952). Bigg et al. (1990) found a strong relationship between abundance of seals and peak biomass of migrating salmon through Comox Harbour. Olesiuk et al. (1996b) noted that Courtenay River salmon predation rates varied in accord with the size and timing of salmon returns. They observed the highest salmon kill rate in November with the arrival of large chum runs. Peak seal abundance in the Rogue River, Oregon, coincided with seaward migration of steelhead and upriver migration of spring chinook salmon (Roffe and Mate 1984). At Netarts Bay, Oregon, peak seal abundance coincided with the chum salmon run (Brown and Mate 1983).

In this study, seal abundance, seal actions, and salmon kills all corresponded to prey availability in the Courtenay River. Seal abundance peaked when pink salmon numbers were greatest. A second smaller peak in seal abundance corresponded to the peak of the autumn chinook run. We did not continue the seal fence observations into the chum salmon run, but we suspect another peak in seal abundance would have occurred at the peak of the chum run, based on the findings of Olesiuk et al. (1996b).

All estimates of salmon killed made by earlier investigators (Bigg et al. 1990; Olesiuk et al. 1996b; Jurk et al. 1997; and DFO Puntledge River Committee 1997,1999) were dependent upon a number of sampling assumptions. The main assumptions were that all salmon kills were brought to the surface and observed, that predation was confined to the observation area, and that kill rates observed during the day were representative of kill rates at night. These assumptions were necessary because surface sightings and seal foraging behaviour could be observed for only a limited number of daylight hours and at a few specific locations. Despite these differences, the final estimates of salmon consumption are remarkably similar.

Estimates of the relative portion of salmon consumed by seals ranges from 23-35% for summer chinook, 3-4% for pink salmon, and 36-46% for autumn chinook. Bigg et al. (1990)

estimated that seals consumed 4% of the pink run and 46% of the autumn chinook in 1989. Olesiuk et al. (1996b) estimated that a total of 2,976 chinook salmon (1,486 in the estuary and 1,489 in the river) and 1,806 pink salmon (658 in the estuary and 1,149 in the river) were consumed by seals in 1990. This represented 35.6% of the chinook return (34.8% summer and 35.9% autumn) and 3.3% of the pink run in 1990. Summer chinook consumption in 1996 (Jurk et al. 1997) was considered to be < 50% of 1990, (90 kills with 294 escapement or 23%). This low estimate is likely due to the fact that their observations were limited to the river, study duration was limited (June 11 to July 19), and the return rate of summer chinook was very low. In 1997, between July 15 and July 29 (DFO Puntledge River Committee 1997), a chinook kill rate of about 0.246 kills/hr was recorded and approximately 124 chinook (32% of total run) were killed. In 1998 the number of summer chinook killed was roughly 70% of the number killed in 1997 (DFO Puntledge River Committee 1999).

We estimated that in 1998 a total of 144 (38%) summer chinook, 700 (7%) pink, and 154 (33%) autumn chinook were killed by seals. This estimate relies on the assumptions that half of all salmon killed were seen from the observation site at the seal fence and half of all possible and probable kills were kills. Our estimate of 38% of the summer chinook being consumed by seals is slightly higher then previous estimates (35%, Olesiuk et al. 1996b; 23%, Jurk et al. 1997; 32%, DFO Puntledge River Committee 1997; 33%, DFO Puntledge River Committee 1999). We suspect that the higher rate of night kills we observed would account for our slightly higher estimates. Our estimate of 6.5% of the pink run being consumed by seals is higher then a previous estimate of 3.3% (Olesiuk et al. 1996b). We suspect the high rate of night kills we observed combined with earlier and 20-50% fewer returning pink salmon in 1998 would account for our higher estimate of pink consumption. Our estimation of 33% of the autumn chinook being consumed by seals is slightly lower than previous estimates (46%, Bigg et al. 1990 and 36%, Olesiuk et al. 1996b). We suspect that the upstream migration of 63% of all the chinook observed below the fence within a two hour interval on September 10, 1998 may have simply swamped the seals and permitted a higher then expected escapement of autumn chinook.

SEAL BEHAVIOUR

Two distinctly different types of salmonid predation have been observed in the Courtenay River watershed. First, seals were observed swimming up the river and preying on out-migrating chum and pink fry, and coho and chinook smolts. This activity was conducted between dusk and dawn, from April through June, beneath bridges where artificial lights silhouetted the out-migrating young salmon. A description of seal feeding behaviour and various approaches used to reduce the loss of young salmon are presented in Olesiuk et al. (1996a) and Yurk and Trites (2000). Olesiuk et al. (1996a) concluded that 40-50 seals practised the specialized foraging behaviour on juvenile salmon and 20 seals accounted for 79-89% of the juvenile salmon consumption. This estimate was based on visual recognition of seals through photo-identification. Second, seals were preying on pre-spawning adult salmon in the Courtenay River Estuary, the Courtenay River, and the Puntledge River from June through December (Olesiuk et al. 1996b).

Olesiuk et al. (1996b) divided the seal population into two groups. A riverine group that habitually foraged in the river on both juvenile and adult salmon and a more opportunistic group that fed in the estuary and lower river during the upstream migration of large runs of adult salmon (e.g. pink and chum runs). Olesiuk et al. (1996b) felt that only 8% of the total seal population (riverine habituated group) was responsible for 67% of the total pre-spawning salmon consumption. However, they were unable to clearly establish if the same group of seals were also associated with pre-spawning salmon kills. In 1997 seals (in river and estuary) were captured and fitted with sonic transmitters (Olesiuk, personal communication). It was found that the same group of 40 to 45 riverine seals foraged in the river on pre-spawning salmon and on juvenile salmon. Seals captured in the estuary rarely entered the river until after the number of returning salmon had increased. The identification of the two distinct groups of seals and the possibility that the removal of members of the riverine foraging seal group could reduce salmon predation was a basis for the seal culls of 1997-1998. After the seal culls in 1997-98 it was estimated that 90% of the riverine habituated seals had been eliminated (DFO Puntledge River Committee 1999).

Harbour seals do feed at night. Various authors have questioned the relative proportion of nocturnal feeding to daytime feeding and reasons for it. Watts (1996) reported a diel pattern to haul-outs along the British Columbia coast (mid-day peak) and listed various authors who attributed this to nocturnal foraging. He felt this was plausible, but he questioned the relationship of haul-out time and feeding. Brown and Mate (1983) felt that seals were visual predators and may be less successful at capturing free-swimming salmon at night. In the Hood Canal more seals foraged at night than during the day, but the number of foragers was not significantly different (London et al. 2002). Although seals in Scotland did feed during both daylight hours and dark, the number of seals observed at night were generally lower than during daylight (Carter et al. 2001). Boulva and McLaren (1979) found more seals feeding at night in eastern Canada. They also noted blind-seals that were otherwise healthy and concluded that vision was not essential for successfully foraging. Olesiuk (1999a and 1999b) using time-depth recorders on seals in the Strait of Georgia found that seals tended to haul out during daylight hours and tended to forage more at night. This study was conducted where the seals fed mainly on hake and the results might reflect the nocturnal migration of hake to shallower depths. Marine mammals that forge in the dark may use fish-generated water movements detected by seal whiskers and can follow these hydrodynamic trails to locate prey (Dehnhardt et al. 2001).

Earlier studies in the Courtenay River assumed that the feeding rate at night was less than during the day (Bigg et al. 1990). This was attributed to the assumption that harbour seal foraging required vision and would be less affective at night. Olesiuk et al. (1996b) did observe feeding at night and recognized that seals were using some sense other then vision to capture salmon. However, they assumed night and day kill rates were the same.

In our study, we found that at night in the Courtenay River seals were more abundant, more kills took place, success rate per chase was higher, and distribution of kills differed from day distribution. Two to three times more seals were counted at night than during the day. The number of seals/hr was highest at dusk and lowest at mid-day. Two to three times more salmon were killed/hr at night than during the day. A higher ratio of misses to kills occurred during the day than at night. The distribution of kills changed diurnally. A higher proportion of salmon kills were recorded further down the river during the day than during the night and a higher proportion of kills were recorded on the Old House side of the river during the day than on the Mill side during the day.

Our results confirm the importance of nocturnal river presence, foraging, and feeding by seals. However, other factors should be considered. It is possible that the seal fence may have concentrated night seal activities immediately downstream of the fence by enhancing the opportunity of seals to feed. More salmon may have held directly below the fence at night but we were unable to observe them. Artificial lighting from the neighbouring streets, houses and mill may have aided hunting. Also, seals were being shot and they may have been wary of entering the lower river and approaching the fence during the day when more people were about.

Significantly more seals/hr were seen on floodtides then on ebb tides. London et al. (2002) also noted that the majority of seal predation on salmonids took place 4.5 to 0.5 hrs before high tide (flooding). In the Courtenay River seals required a tide of > 2.25 m to enter the river (Bigg et al. 1990) and have been reported to move further upstream with the tide (Olesiuk et al. 1996b). The opportunity for seals to enter a river mouth and feed on salmon has been correlated with high tides in other areas (Brown and Mate 1983) as have distribution, abundance and foraging success in the ocean (Zamon 2001). Seal numbers below the fence were positively correlated with tide height. We found a strong interaction between tide height and time of day. Seal numbers peaked at night when tide height was greater than 3 m, while during the day seal numbers continued to increase with tide height. Thus, the greatest number of seals would be seen at dusk, on a flooding tide, when tide height exceeded 3 m.

These results conflict with the findings of Olesiuk et al. (1996b), who concluded that time of day, tide height, and tide direction for the period when the river was accessible had no discernible effect on the overall kill rate in the river. We recorded twice the kill rate at night compared to the day for tides greater than 2.5 m (accessible period). We are uncertain as to why our results differ, but suspect this difference is due to the lack of night observations by Olesiuk et al. (1996b) and possible differences in feeding behaviour later in the year as Olesiuk et al. (1996b) extended their study into December. Other possible reasons for the differences in diurnal foraging may have been the artificial situation created by the fence and modified seal behaviours associated with seal culling.

Earlier investigators have examined the possibility of group foraging by seals. Bigg et al. (1990) reported that significantly more seals were involved in the killing of a chinook salmon (3.4 seals/kill) then a pink salmon (1.5 seals/kill). Olesiuk et al. (1996b) confirmed this difference with prey species and reported that seal group size was directly correlated with prey size. Our study was not designed to assess group foraging behaviour, however the number of seals within the immediate vicinity of a salmon kill was recorded on many occasions. The average number of seals in the immediate vicinity of a chinook kill was slightly greater then for a pink kill, but was not significantly different. The removal of habitual river foragers may have altered the dynamics of group feeding as these seals were the ones most likely to feed on chinook salmon (Olesiuk, personal communication).

We suspect that seal abundance and distribution was influenced by prey availability. Salmon abundance changed diurnally, with change in tide height, and with change in tide direction. These changes in prey availability could influence the distribution of seals below the fence. It is possible that the differences in observed location of day and night salmon kills was due to observer bias (difference in ability to see from the seal fence during day and night). It is also possible that seal behaviour was influenced by the lethal removal of seals and the behaviours we noted were specific to the Courtenay River during summer 1998. Seals may have been wary of entering the river and approaching the fence during the day on low tides when they would have been more visible and vulnerable to being shot. Support for this argument is limited to anecdotal reports. Observers at the seal fence would often joke that if they wore a bright yellow vest similar to the one worn by the seal shooter, the seals were more wary of approaching the fence. In the Columbia River, seals may have become conditioned to the sound of the boat used to hunt them and these seals would flee downstream when the boat approached (NMFS 1997).

SALMON BEHAVIOUR

The entry phase of salmon into freshwater is likely to be most important in short rivers (Banks 1969) such as the Puntledge and Courtenay rivers. The time of salmon entry and upstream migration could be queued by environmental factors such as rate of water discharge, tidal phase, and time of day. The rate of water discharge is an important, if not the dominant, stimulus to the upstream migration of salmon (Banks 1969) and freshets can induce salmon to enter rivers (Hayes 1953; Neave 1943). Salmon (chinook) will ascend on rising and falling stream levels, but often cease movement during peak floods (Shapovalov and Taft 1954). It is possible that a small freshet that peaked on July 16 at 49 m^3 triggered the July 17 start of the Puntledge River pink salmon run. However, this freshet was less than a doubling of flow and was not in the order of the seven-fold increases in discharge deemed necessary by authors cited by Ellis (1962).

Circatidal periodicity may influence salmon upstream movement from the sea into freshwater (Smith and Smith 1997) especially when associated with other factors such as wind, and high water (Hayes 1953; Banks 1969). Atlantic salmon "up-estuary movements" that led to river entry were predominantly nocturnal and tended to occur during the ebb tide, while penetration into the non-tidal reaches was at night, and was not significantly associated with tidal phase (Smith and Smith 1997). Other authors have noted salmon move through estuaries into rivers on flood tides (Stasko 1975; Brawn 1982; Potter 1988; Priede et al. 1988). In the lower Fraser River, sockeye salmon migrations were synchronized with the tidal cycle, maximum abundance and upstream orientation occurred during flood tidal periods (Levy and Cadenhead 1995). The most intensive entry of coho salmon into a river occurs at the beginning of a rising tide when "schools of coho stream into the mouth of the river" (Gribanov 1962). In the Courtenay River, significantly ($P < .001$) more chinook were counted below the fence and significantly more chinook passed upstream through the seal fence ($P < .001$) on flooding tides than on ebbing tides.

Significantly more chinook were counted on tides at or below 2.5 m ($P < 0.001$). This result is contrary to Atlantic salmon migrations observed by Hayes (1953) who noted entry coincided with high tides and dusk. We suspect that in the Courtenay River the number of salmon observed below the fence was strongly influenced by the presence of seals. Although both seals and chinook salmon were more abundant on flooding tides, relative to tide-height, seal numbers and chinook numbers were negatively correlated ($P < 0.05$).

Numerous researchers have reported that the majority of upstream migration of chinook salmon and rainbow trout occurred in the daytime and was often associated with a midday peak (Mottley 1938; Chapman 1941; Neave 1943; MacKinnon and Brett 1953; Shapovalov and Taft 1954). MacKinnon and Brett (1953) recorded 96% of chinook and coho salmon upstream movement at the Stamp Falls Fish Ladder between 8:00 and 20:00 (daylight). Researchers studying other salmon species have noted peak salmon movement at dusk or at night (Atlantic salmon, Smith and Smith 1997: Hayes 1953, kokanee (*Oncorhynchus nerka*), Lorz and Northcote 1965). In the Courtenay River, the number of chinook schools observed ($P < 0.05$) and number of chinook moving through the fence ($P < 0.01$) were significantly greater at mid-day than during the morning and evening. We were unable to assess night movement. This pattern for chinook salmon is opposite to that observed for seals. We observed that as dusk approached and more seals started to arrive at the fence, salmon that had held through mid-day and at lower tides would often disappear downstream. The number of chinook holding during daylight hours was negatively correlated with the number of seals ($P < 0.05$).

EFFECTIVENESS OF FENCES, TRIADS, AND LETHAL REMOVAL

Barrier fences and nets have been used to deter seal movement in other Pacific Northwest locations. Barrier structures proved effective in reducing seal predation at the Willamette Falls fish-way and were effective in excluding seals from a haul-out site on the Dosewallips River (NMFS 1997). Below the Ballard Locks, a physical barrier net tested in 1987/88 proved ineffective in reducing sea lion predation on adult steelhead as the sea lions shifted predation to areas downstream and the nets caused delays in adult salmon migration (NMFS 1996). In 1997, a portion of the lower Courtenay River was sectioned off with large nets designed to permit passage of adult salmon and exclude seals. This barrier net was ineffective in excluding seals as it trapped debris and could not withstand higher river flows (Munro 1998).

The effectiveness of the Courtenay seal fence in limiting upstream seal movement was mixed. The seal fence did impede the upstream movement of seals from June 22 to August 1, 1998. However, from August 1 to mid September some of the seals attempting to pass through the seal fence were able to do so. We suspect the success of seals in passing through the fence in August and September was due to a combination of factors. First, it is possible that as the population of salmon upstream of the fence increased, seals were more likely to attempt to pass through the fence and attempts were more vigorous. Second, it was difficult to maintain the floating sections of fence in proper working condition partly due to algae build-up on the fence. The floating sections of the fence did sink on one occasion. Third, seal pups are capable of looking after themselves within one month of birth (May-June) and the cows often abandon pups at this time (Spalding 1964). We noted an influx of smaller seals in July and August that were able to pass through the bars. We do not know the age of these smaller seals but suspect they were pups.

Despite the high cost of constructing, installing, operating, and removing the Courtenay seal fence, its effectiveness in reducing the number of salmon killed is questionable. The seal fence impeded the upstream movement of salmon. Chinook were observed holding for at least 80.5 min on average. This estimate is strongly biased by the rapid upstream movement of one group of 128 autumn chinook on September 10, 1998, by our incapacity to distinguish individual fish, and by our inability to count fish at night. Thus, the delay in fish passage created by the seal fence must be considered a minimum estimate. The delay in pink salmon migration caused by the fence was impossible to measure. However, Munro (1998) reported that pre-spawning pink salmon milled around for hours and he speculated that the delay in upstream migration might have been greater for pink salmon than for chinook. Seals were able to prey upon salmon below the seal fence and a major killing zone developed within 250 m downstream of the fence. Adult salmon holding below the seal fence lacked any refuge and it is likely that salmon concentrated below the fence were more vulnerable to predation than fish, which in previous years, would have moved up the river.

The acoustic harassment deterrent device (AHDs) associated with the seal fence did not appear to deter seal activity at or just below the seal fence. It appears seals quickly acclimated to it while foraging on pre-spawning salmon below the fence. In situations where a small number of “habituated” seals are responsible for the majority of salmon kills, lethal removal of seals followed by acoustic harassment devices may prove effective in the short-term (NMFS 1996; Yurk and Trites 2000).

It is questionable if the lethal removal of seals reduced the number of seals active below the seal fence when large numbers of salmon (pink and chum runs) were present in the river. During the first and second weeks of July, 1998, seal abundance in the lower river and estuary was less than half of 1997 levels, but by the third week of July and through August, seal numbers were similar to 1997 seal numbers (DFO Puntledge River Committee 1999). It appears the seal numbers in 1998 recovered from the 1997 cull. It appears the seal population that preys upon large adult salmon returns recovered within days following lethal removal of seals in July and early August of 1998. The replacement rate of removed seals by non-habituated estuary seals may be very high in the lower Courtenay River when salmon abundance is high. Many estuary seals are available to replace removed seals (200-250 in 1996, Jurk et al. 1997; 200-400 in 1989, Bigg et al. 1990). The location of estuary haul-outs is within 2 km of the lower river foraging area and the lower river is readily accessible at tides greater than 2.25 m (Bigg et al. 1990).

It is likely that the culling of habituated seals reduced predation on emigrating chinook juveniles in the spring. A total of 21 seals were removed (shot) during the period of seal fence operation in 1998 and 31 seals had been lethally removed the previous year (Munro 1998). It was estimated that the number of seals foraging on fry and smolts in spring 1998 was 65-70% less than in 1997 (Puntledge River Committee 1999). Prior to the cull as many as 26 seals were observed feeding on out migrating juvenile salmonids (Yurk and Trites 2000). Hatchery personnel from 1999-2002 have observed very few seals upriver since the seal culls of 1997-98. In 1998 no seals were observed at the two bridge sites most favoured during previous years (Munro 1998).

Following the seal program in 1997 and 1998, there was an increase in the number of summer chinook and a dramatic increase in the number of autumn chinook arriving upstream at the Puntledge River hatchery in 2001-2002. The increase in Puntledge chinook was greater than expected based on historic trends between neighbouring hatcheries. The seal cull and reduction in both juvenile salmonid and adult chinook in-river predation by habituated seals could account in part for this increase in chinook returns. However, a more complete and complex analysis is required before any clear relationships between the culling of seals and chinook returns can be seen. A number of other factors such as the number of smolts released, timing of releases, climatic trends, commercial fishery, recreational catches, and changes to hatchery procedures may have influenced chinook returns. Annual and seasonal differences in seal numbers, behaviours, and distributions should be considered. Also, two types of predation by seals were involved (juvenile salmonid predation and pre-spawning adult salmon predation) and it may prove useful to partition the relative contribution of each predation type.

The triads were not effective as a refuge for adult salmon and have been removed from the river. It is questionable if salmon would use a well-placed refuge if available. NMFS (1996) reported that there were no observations of steelhead using available cover (piers, pilings, etc) as a means of escaping predation. Adult salmon were never seen in or near the triads during the day. The triads were exposed at low tides when fish were most abundant. Few chases were initiated from the triads at night, thus night use was unlikely. They were ineffective as an impediment to a chase and kill. We suspect the triads were placed on the wrong side of the river. Ellis (1962) noted that migrating adult salmon follow the line of the deepest channel. We observed salmon moving upstream in the deeper water associated with the dredged Mill side and middle of the river, but not on the shallow triad side of the river.

ACKNOWLEDGMENTS

We would like to acknowledge the contribution that HRDC, working with the Community Fisheries Adjustment Center, has made. They contributed people and the funding of staff to make this project possible. The resources and staff of Puntledge Hatchery have also been utilized throughout the program. L. Flostrand assisted with observations made at the triads. We are grateful for the assistance provided to this project by Field Sawmills, Ministry of Highways, Parker Marine, and the communities of Courtenay and Comox. We appreciate the information on fence design supplied by N. Hill, temperature data supplied by T. Sweeten, and the dedication of D. Looy, G. Klimes, and F. Snelgrove. We would like to thank J. Zamon, B. Bravender, L. Nichol, C. Hilliar, P. Olesiuk, and T.J. Brown for reviewing this manuscript and technical input from C. Dragseth, J. Broome, D. Nagtegaal, J. Pringle, C. Hilliar, G. Ellis, S. Macdonald, R. Kadowaki, C. Levings, B. Hillaby, and K. Francis.

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PLATES

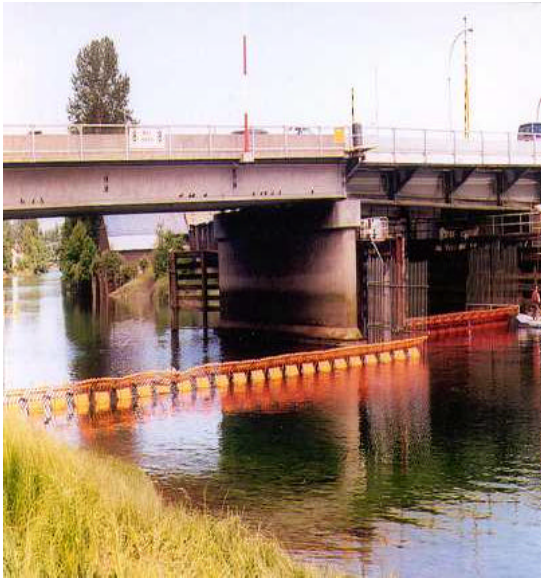

Plate 1. Seal fence (red panels and vertical bars) located under the 17th Street Bridge. Photo taken from the "Old House" side of the Courtenay River looking upstream.

Plate 2. Under 17th Street Bridge, seal barrier fence completed. Photo taken from observation platform looking across the river.

Plate 3. Triads at approximately 2.5 to 3 m tide. Looking downstream into Courtenay River estuary.

Plate 4. Two cement triads at low tide.

FIGURES

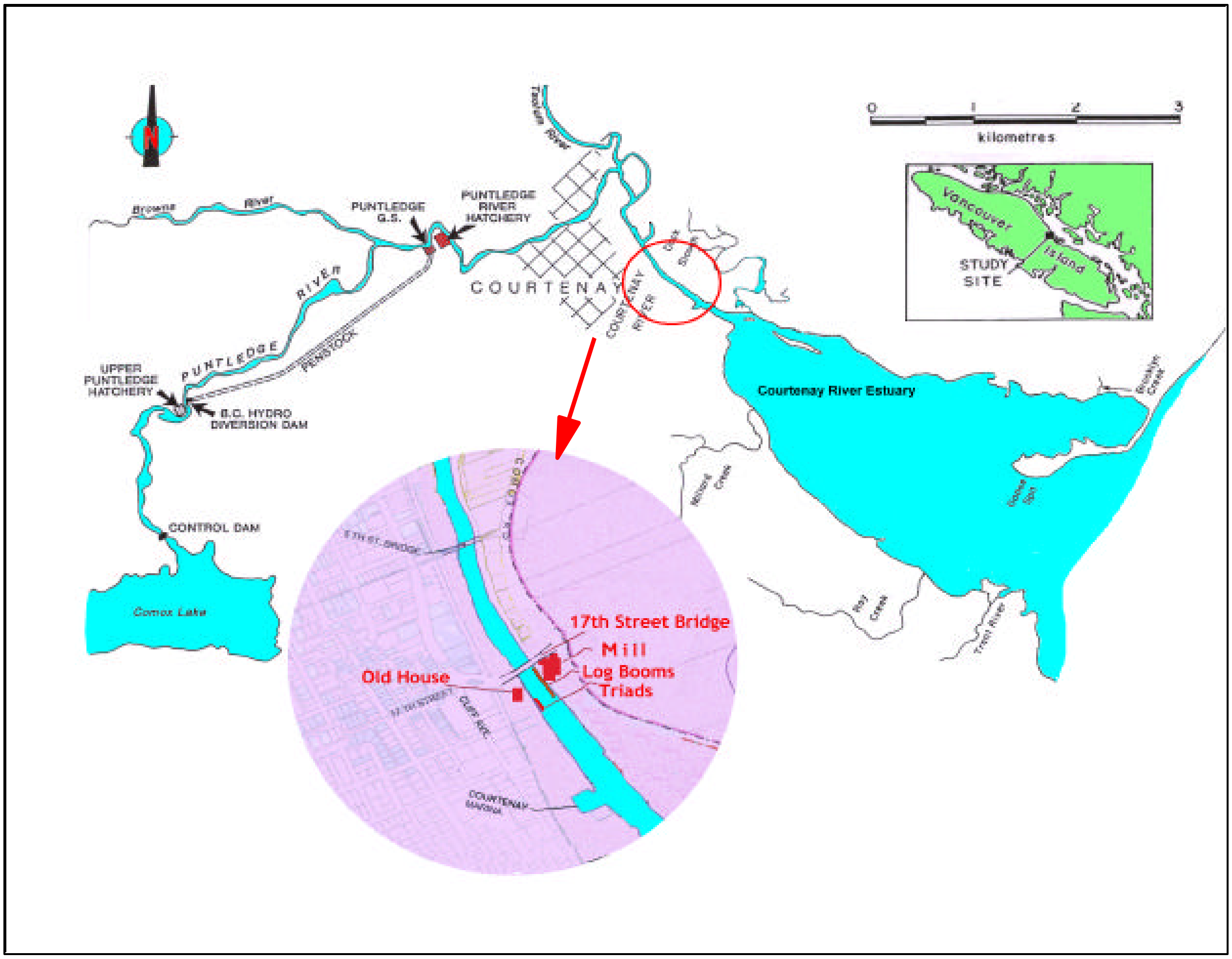

Figure 1. Map of Courtenay River and location of 17th Street Bridge (site of seal fence and triads).

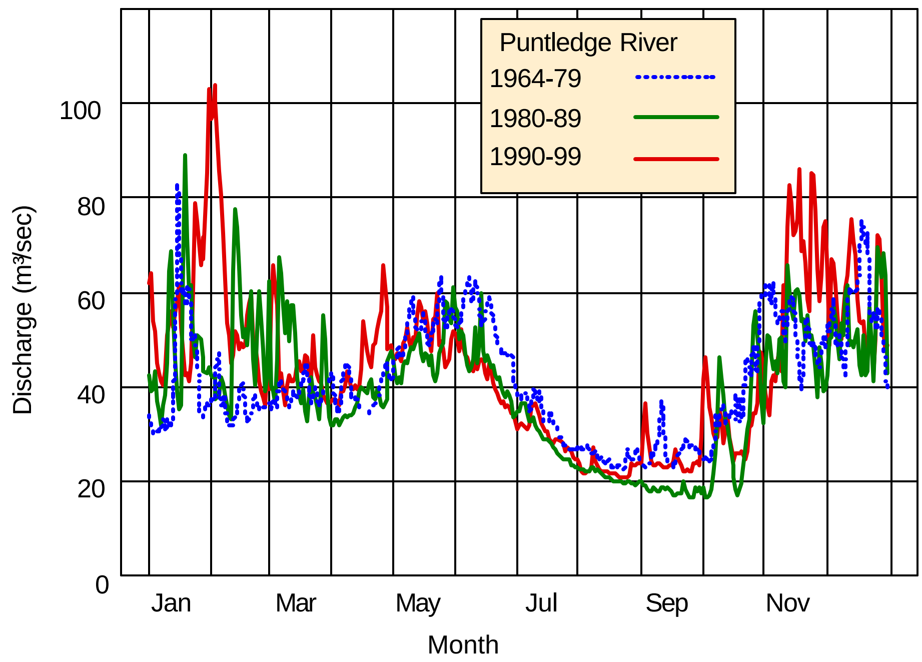

Figure 2. Courtenay River discharge (m^3/sec) for 3 periods of time.

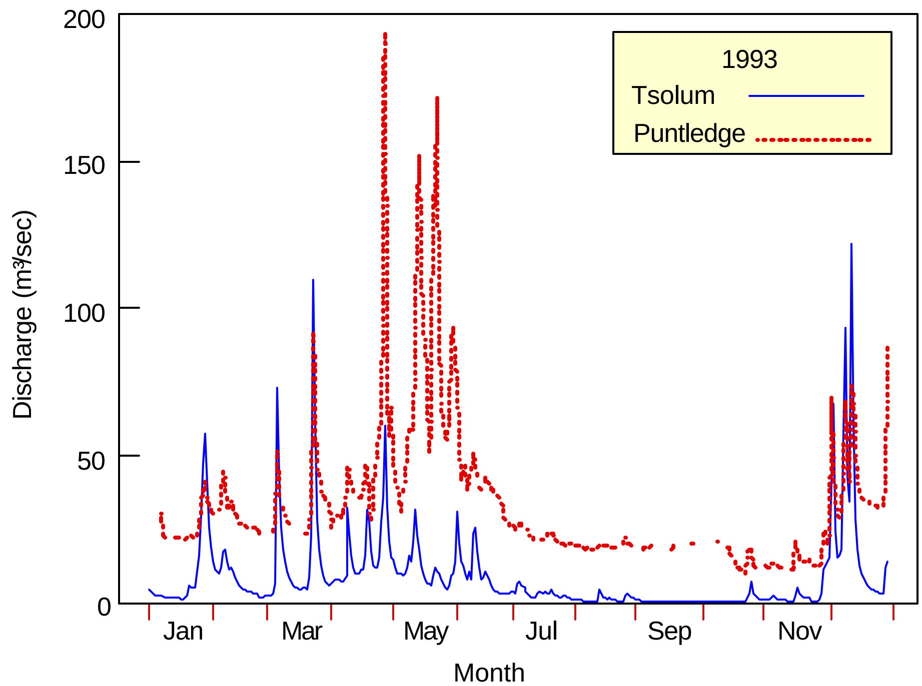

Figure 3. Discharge (m^3/sec) of Tsolum and Puntledge rivers for 1993.

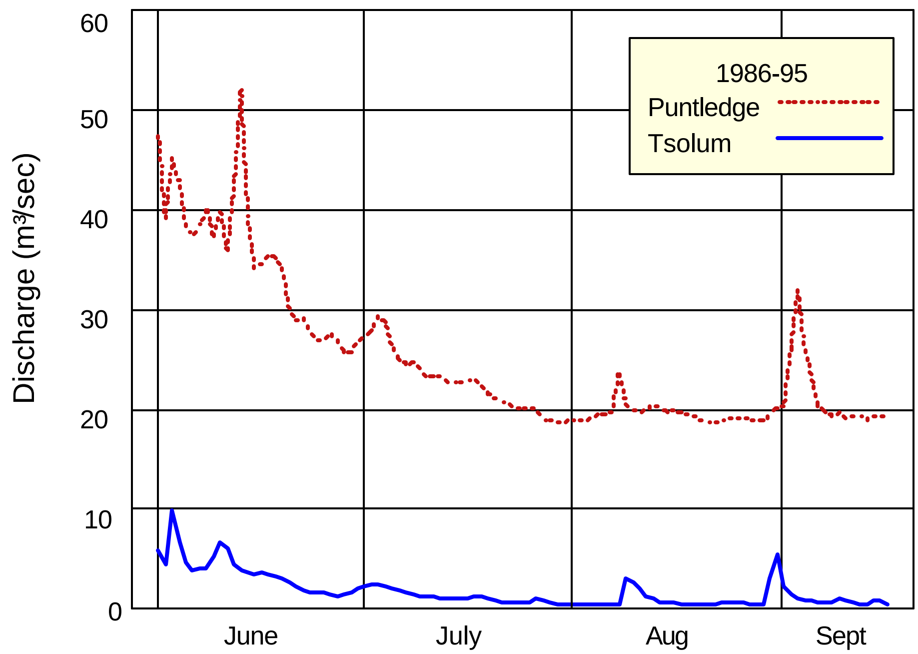

Figure 4. Mean summer discharge (m^3/sec) for Tsolum and Puntledge rivers (1986-95).

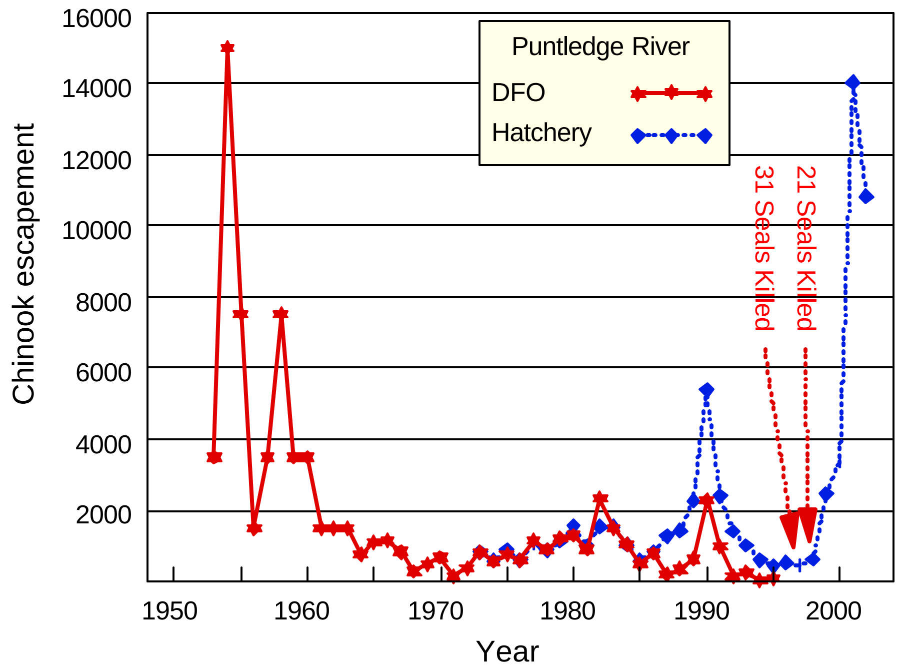

Figure 5. Total chinook salmon returns to Puntledge River (1954-2002).

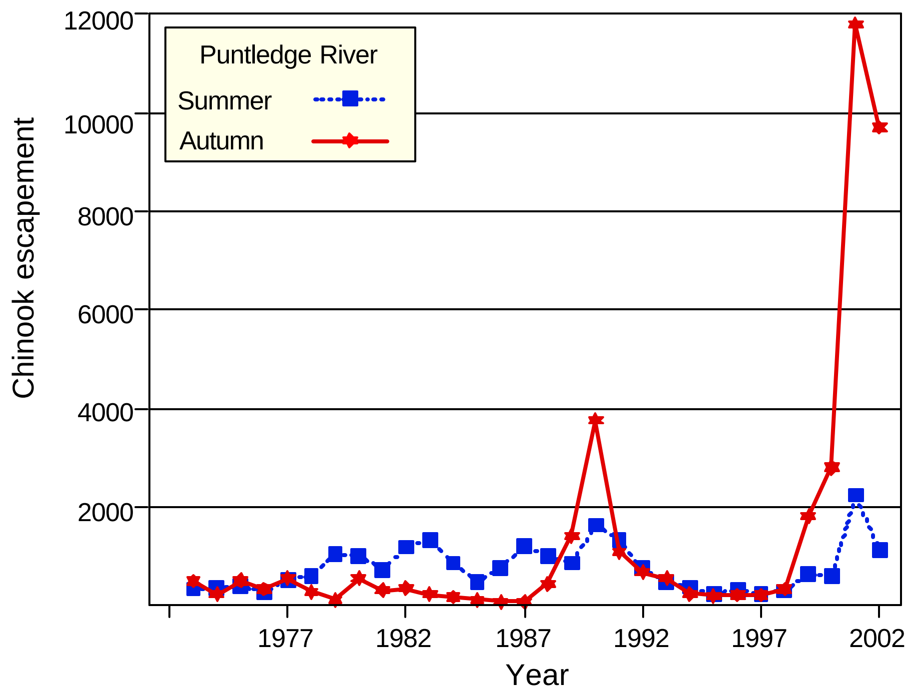

Figure 6. Chinook salmon, summer and autumn escapements (1973-2002).

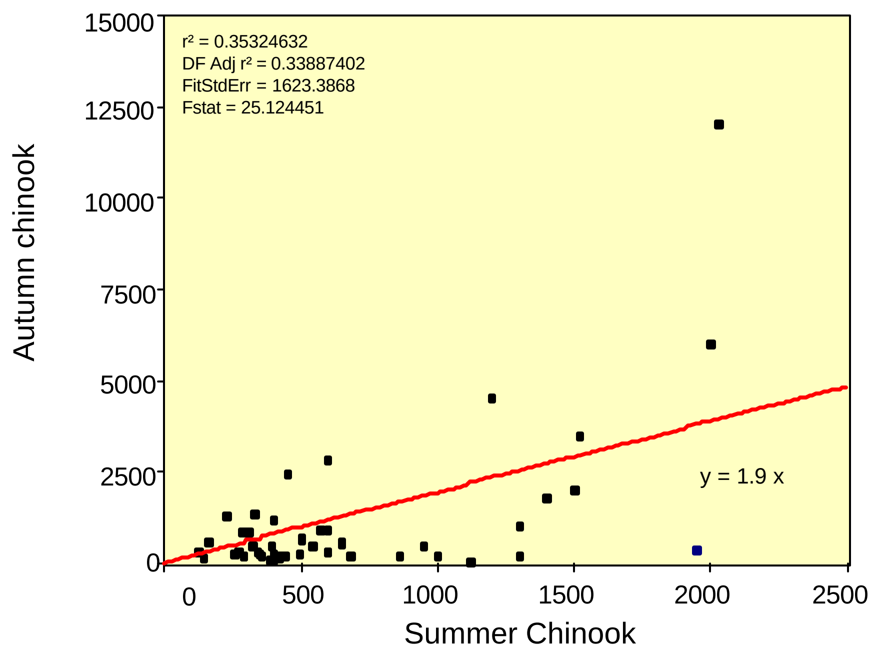

Figure 7. Relationship between autumn and summer chinook salmon escapements.

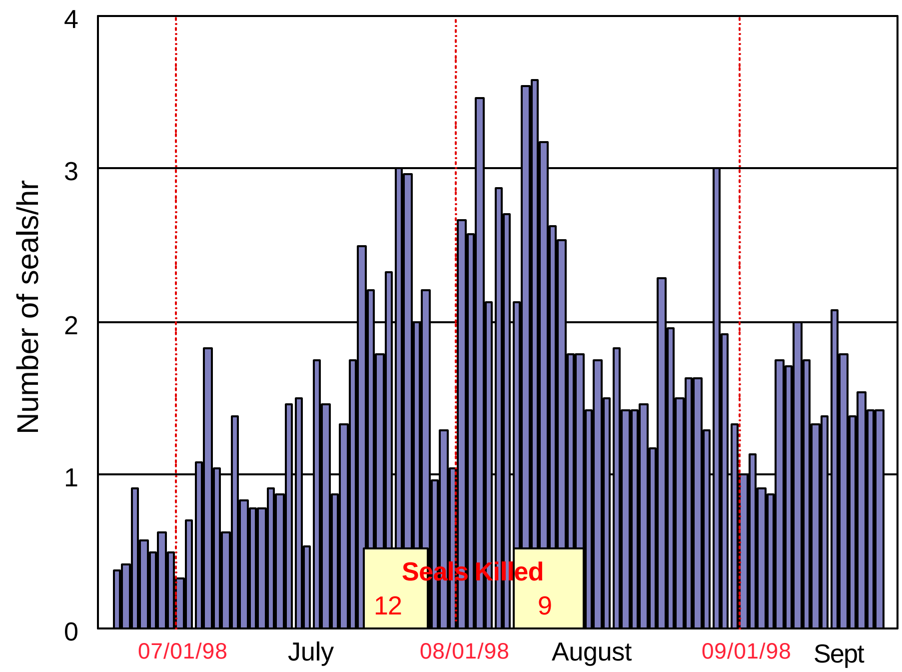

Figure 8. Mean daily number of seals sighted per hour below the seal fence. Periods of seal cull and number of seals killed are included.

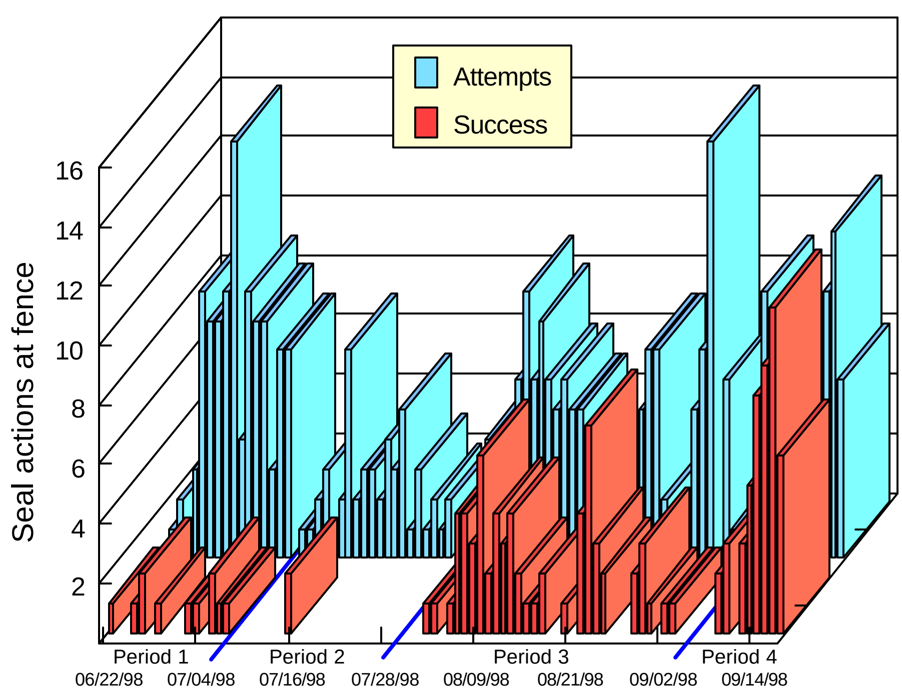

Figure 9. Daily number of seal attempts and successes in passing through the seal fence.

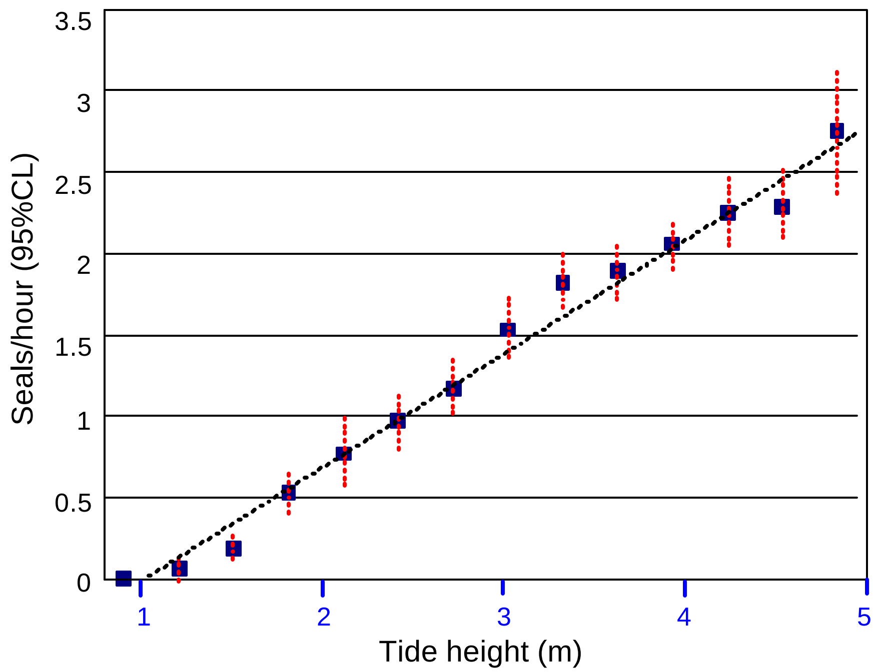

Figure 10. Relationship between tide height and seal abundance (mean number of seals/hour).

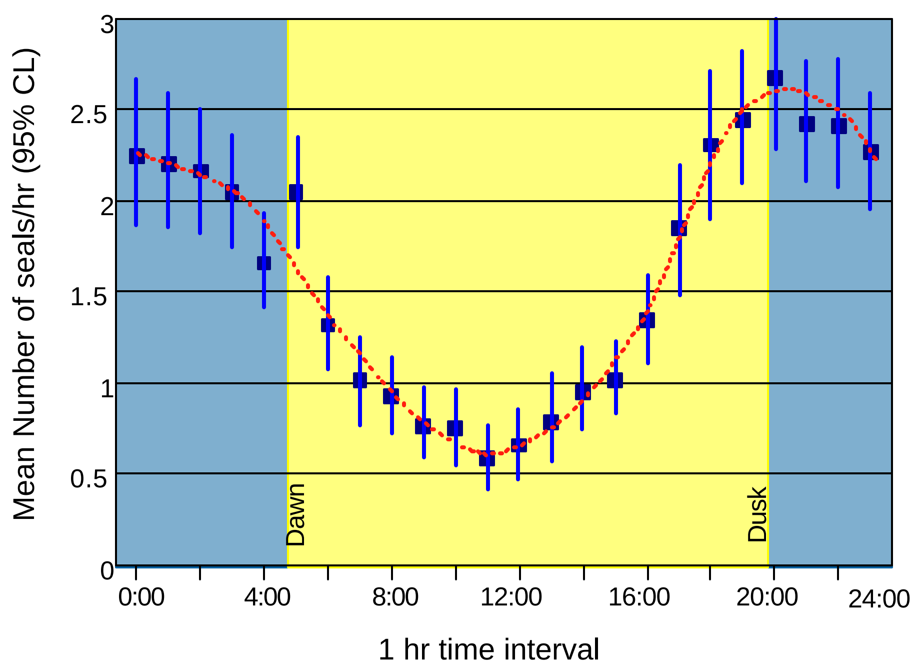

Figure 11. Diurnal abundance of seals below the seal fence relative to time of day.

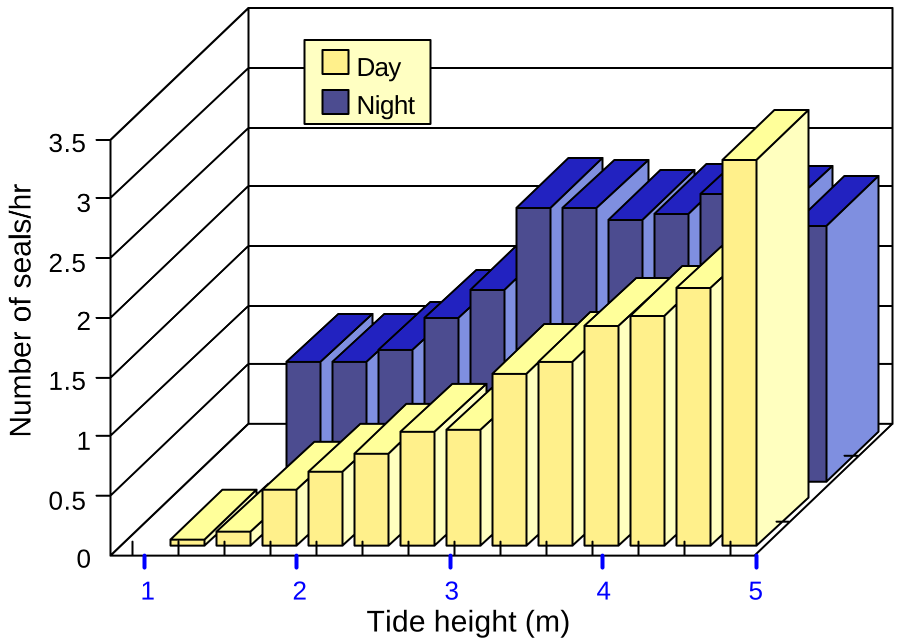

Figure 12. Day and night seal abundance relative to tide height.

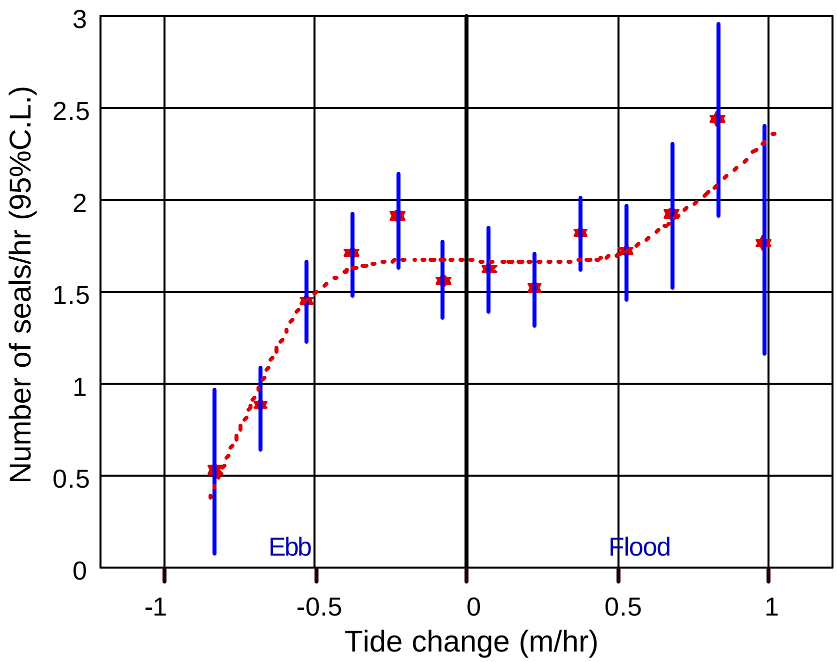

Figure 13. Relationship between tidal cycle and seal abundance.

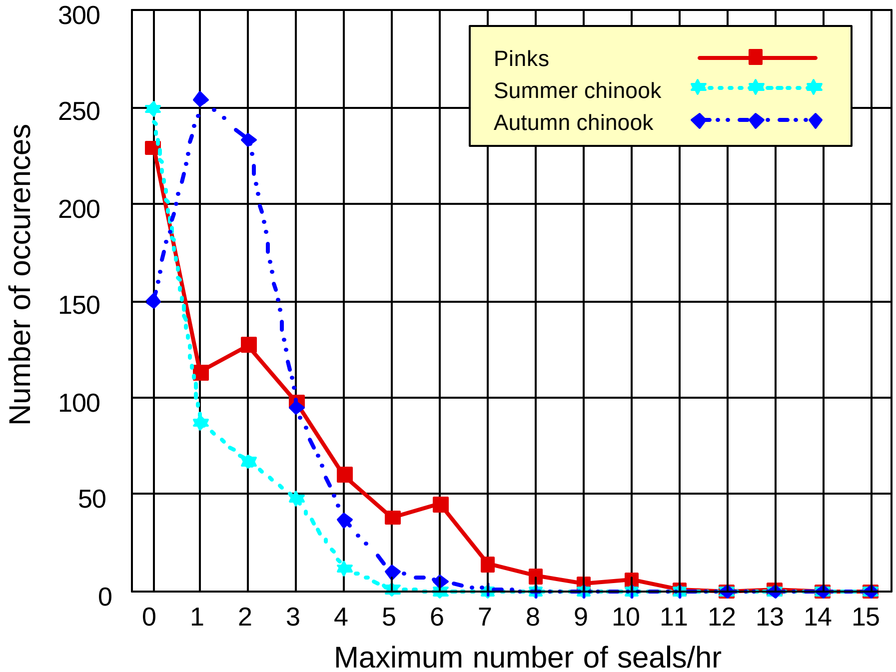

Figure 14. Frequency distribution of maximum number of seals/hr sighted below the fence relative to 3 periods of time, which represent summer chinook, autumn chinook, and pink salmon runs.

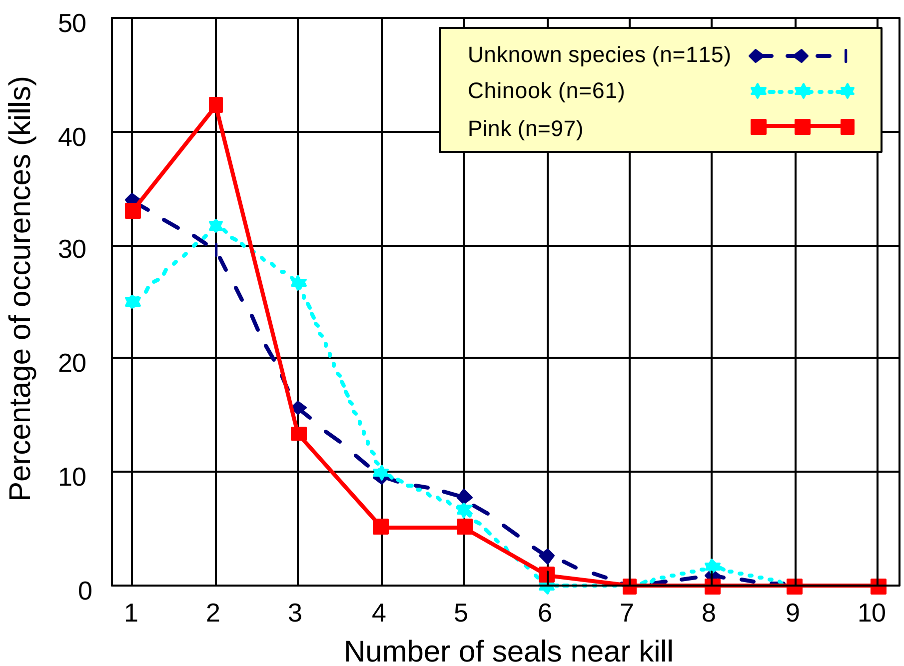

Figure 15. Frequency distribution of seal grouping sizes during the killing of chinook, pink, and unknown salmon.

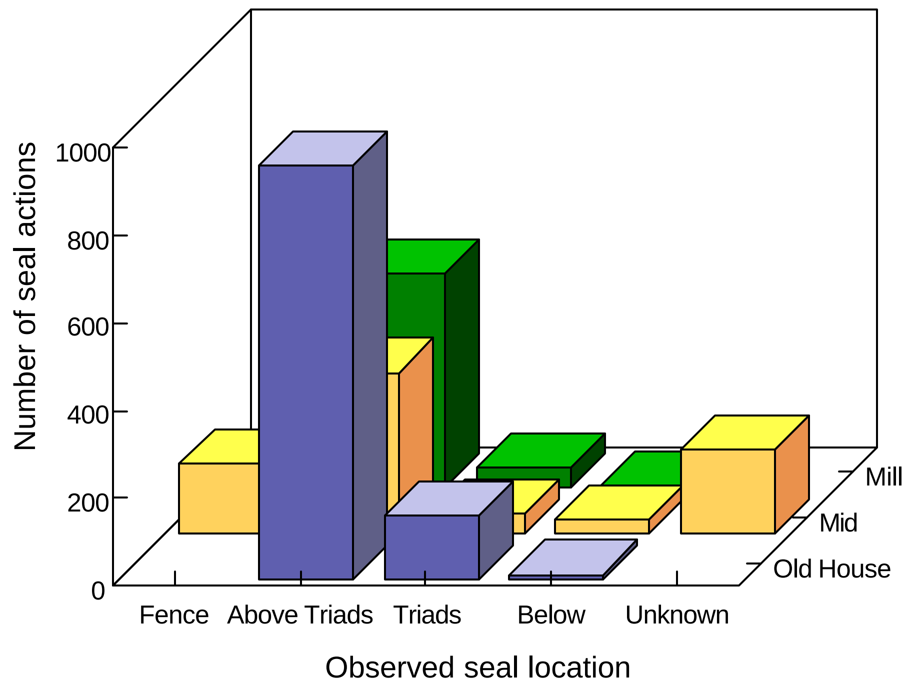

Figure 16. Longitudinal and lateral position of all seal actions below the seal fence.

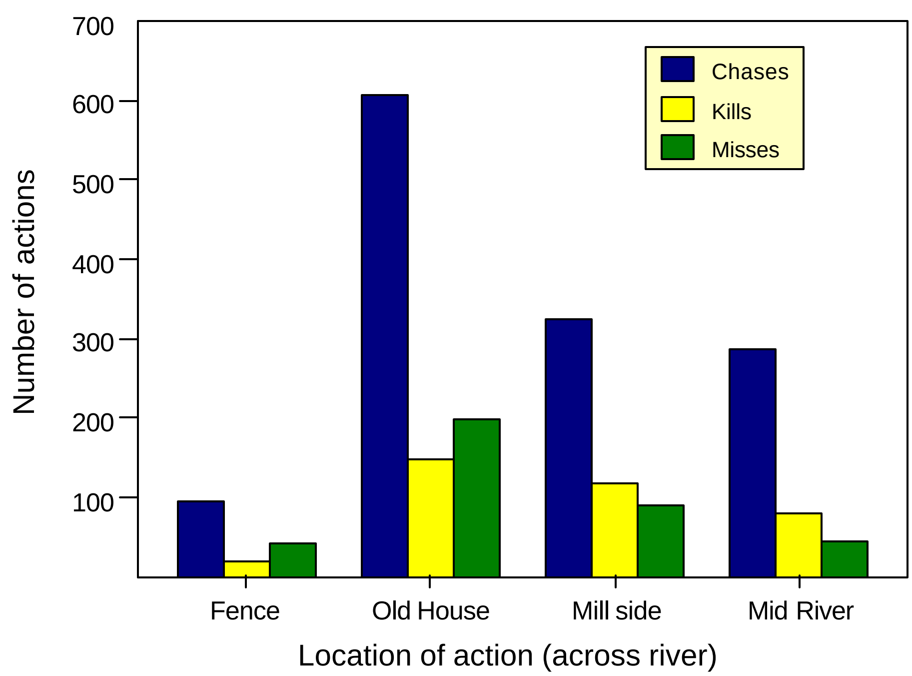

Figure 17. Location across the river of seal chases, kills, and misses.

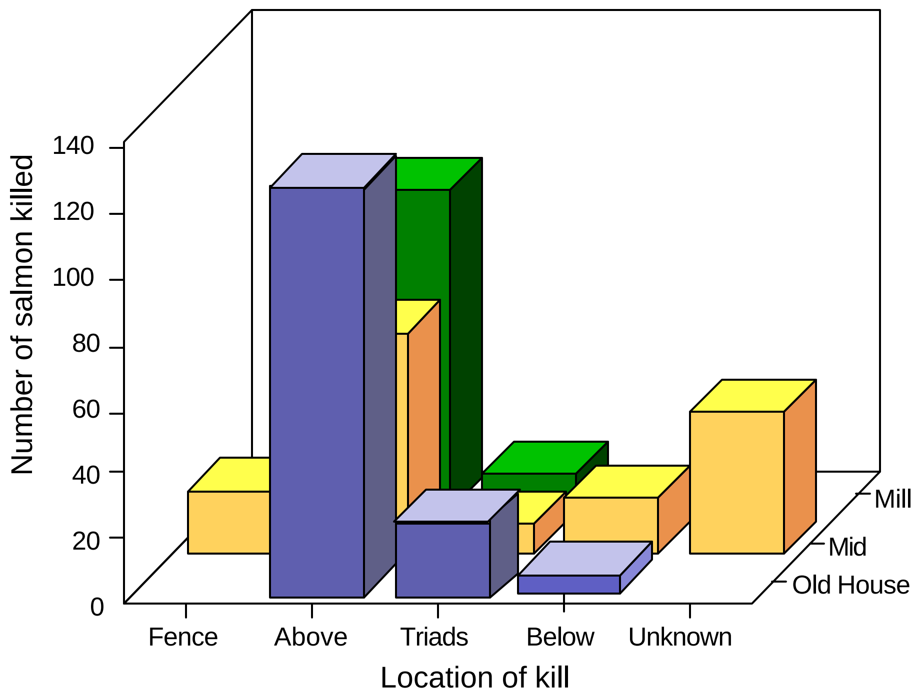

Figure 18. Longitudinal and lateral position of all salmon killed below the seal fence.

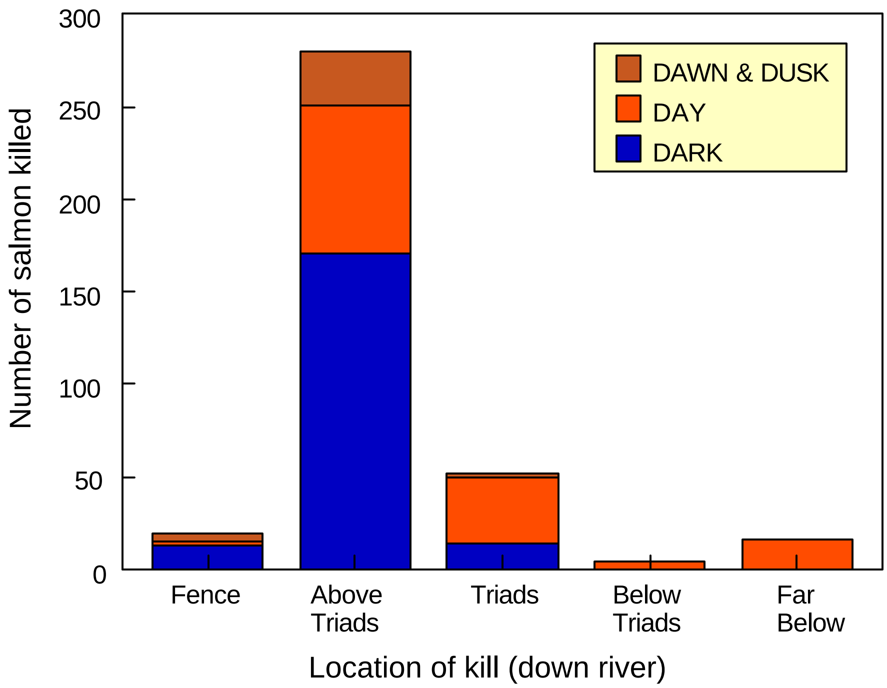

Figure 19. Longitudinal position of salmon killed relative to light conditions.

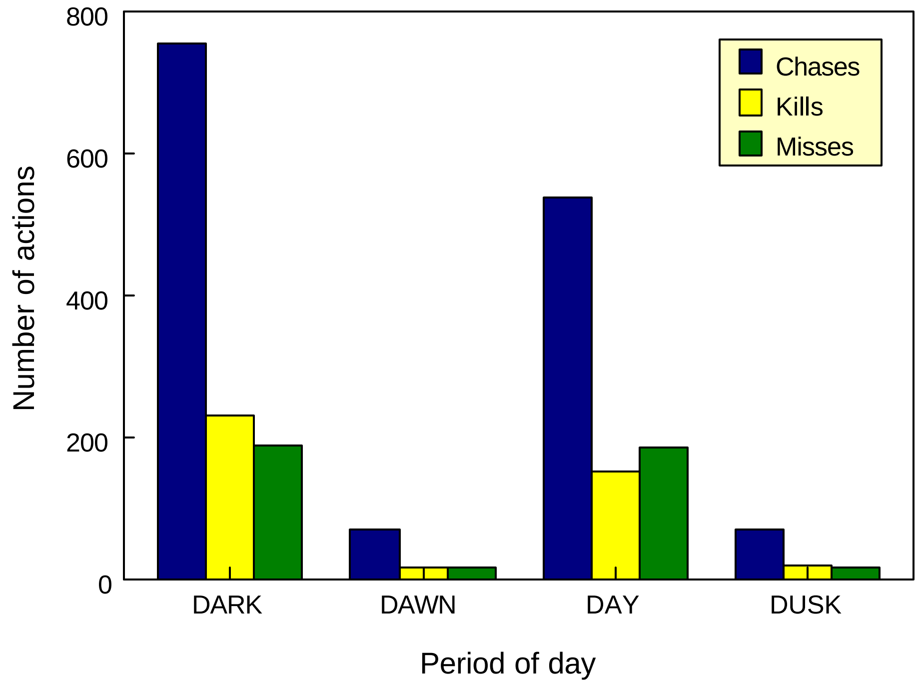

Figure 20. Chases, kills and misses relative to light conditions.

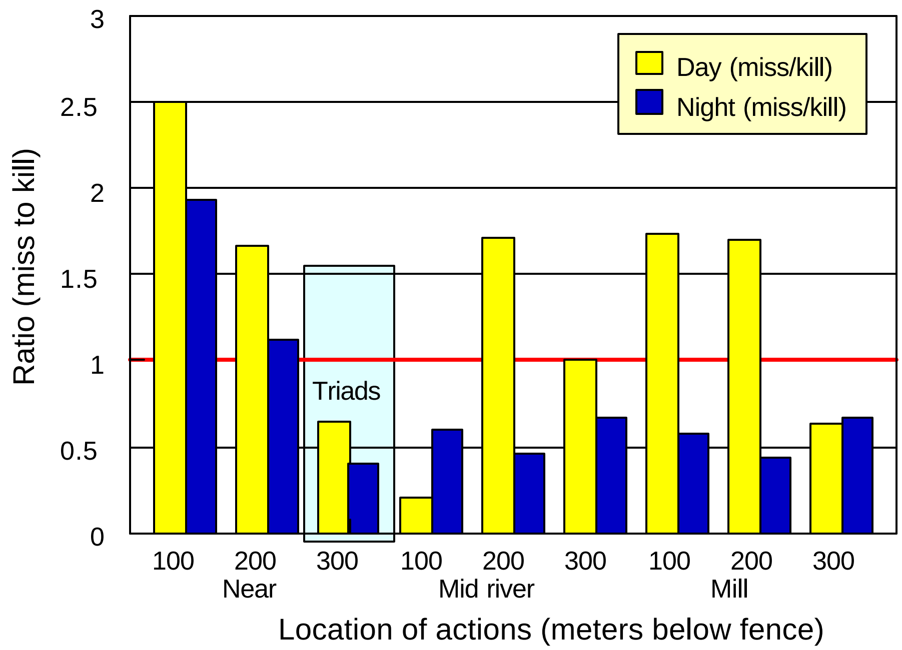

Figure 21. Ratio of misses to kills, during day and night, at 9 locations downstream of the seal fence.

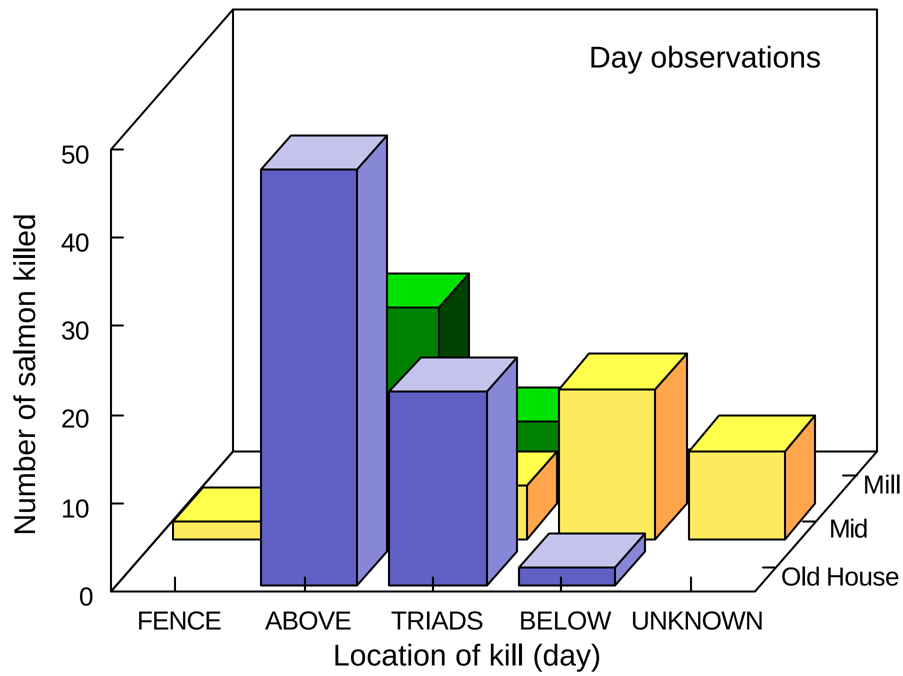

Figure 22. Longitudinal and lateral position of all day time salmon kills observed below the seal fence.

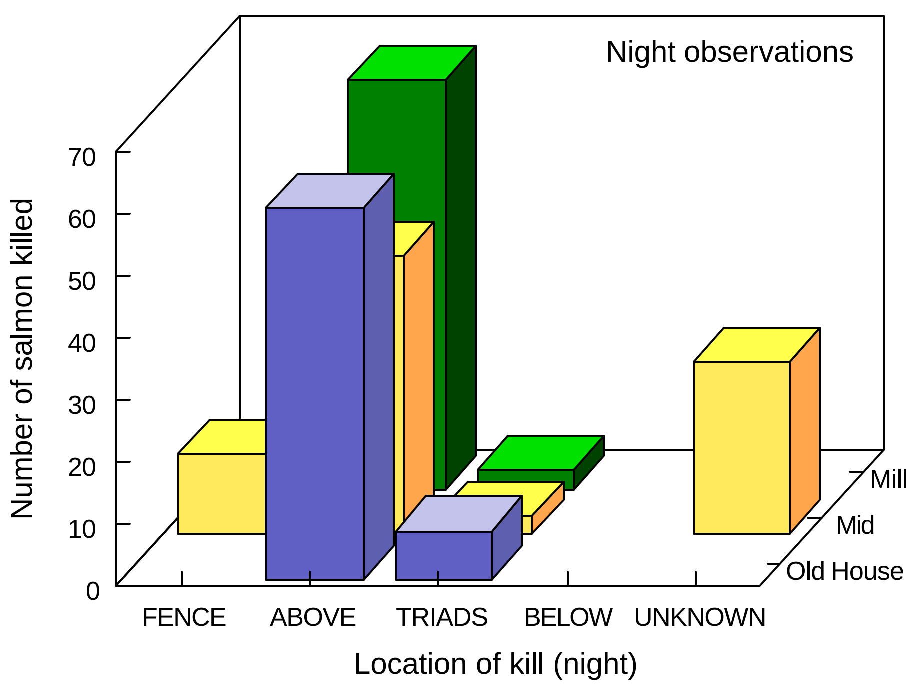

Figure 23. Longitudinal and lateral position of all night time salmon kills observed below the seal fence.

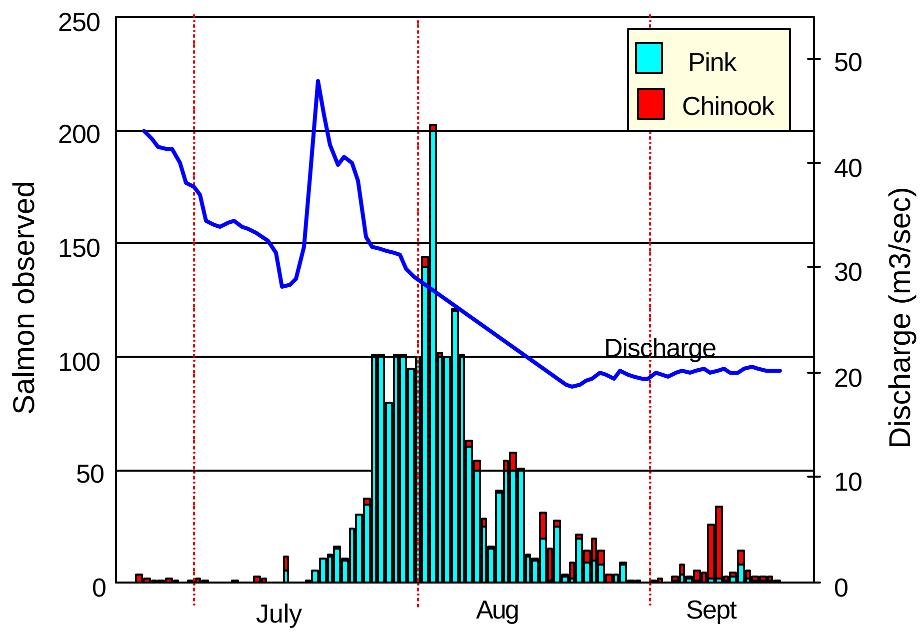

Figure 24. Daily number of salmon observed below the seal fence and daily mean water discharge during the 1998 period of observations.

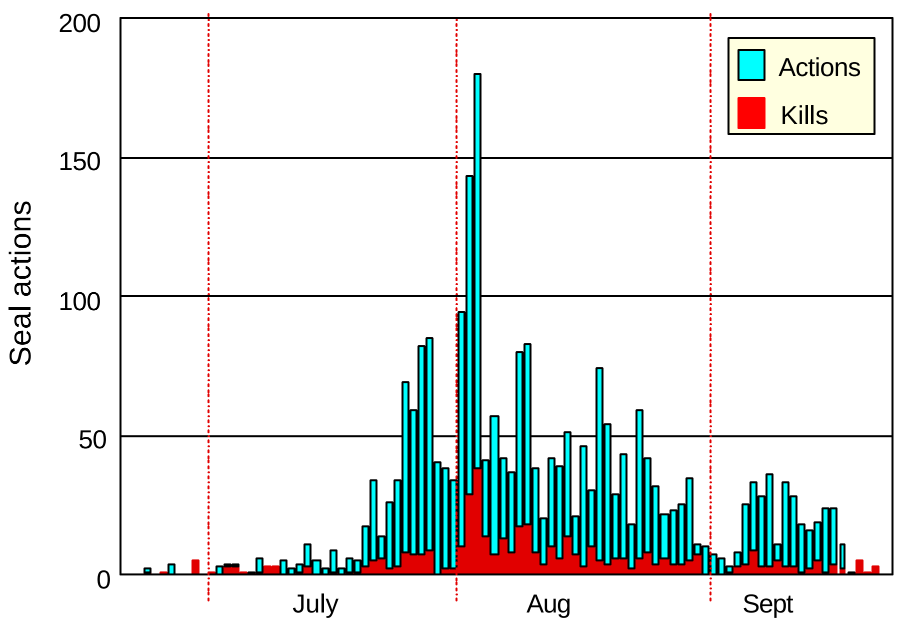

Figure 25. Daily number of seal actions and salmon kills observed below the seal fence.

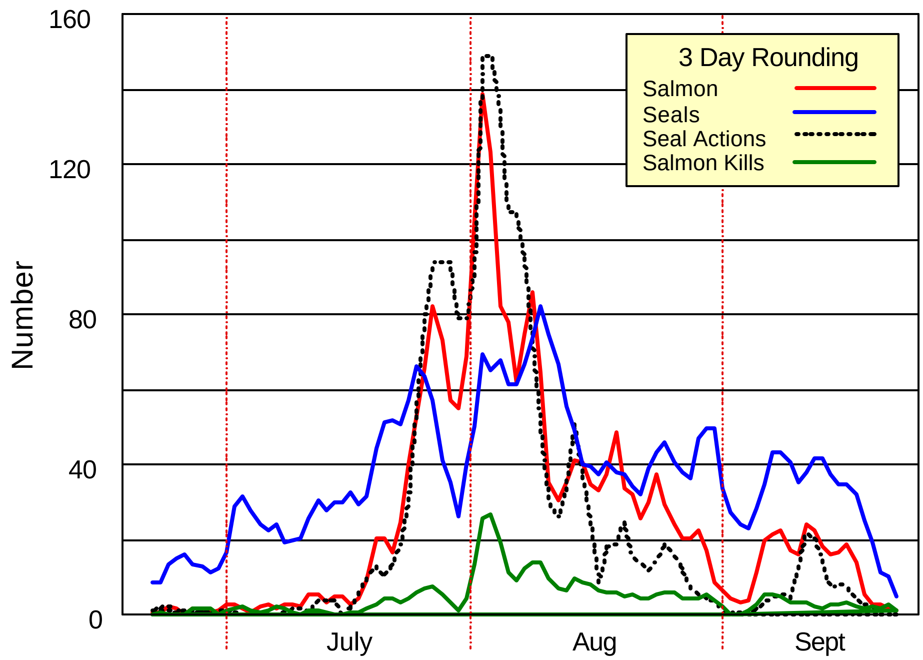

Figure 26. Relationship between seal actions, salmon kills, number of salmon, and number of seals. The numbers depicted in this figure were obtained by a 3-day rounding of mean daily counts.

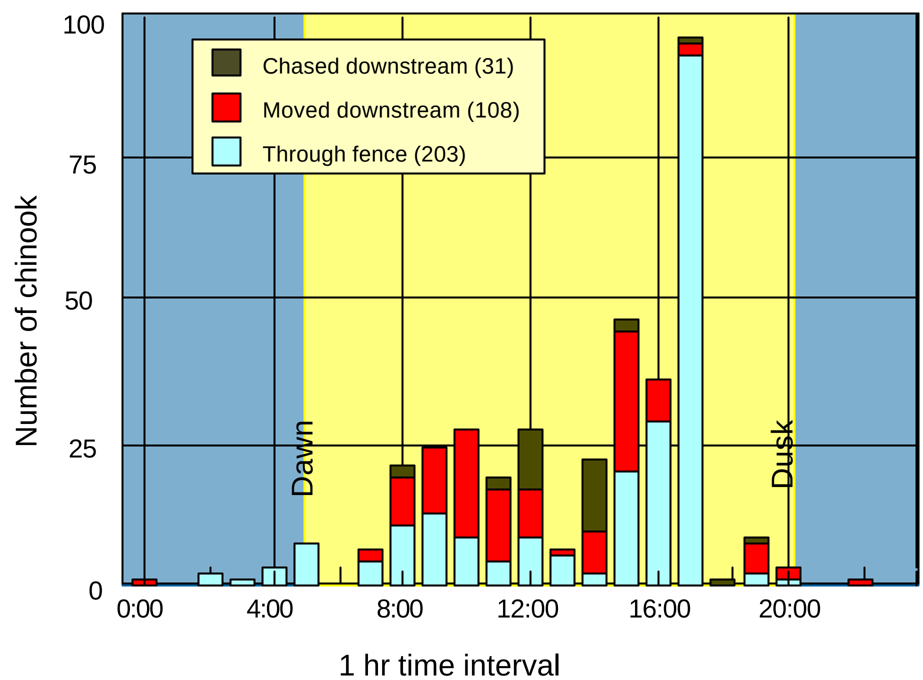

Figure 27. Hourly number of chinook salmon passing through the seal fence, being chased by seals downstream away from fence, or disappearing from view downstream.

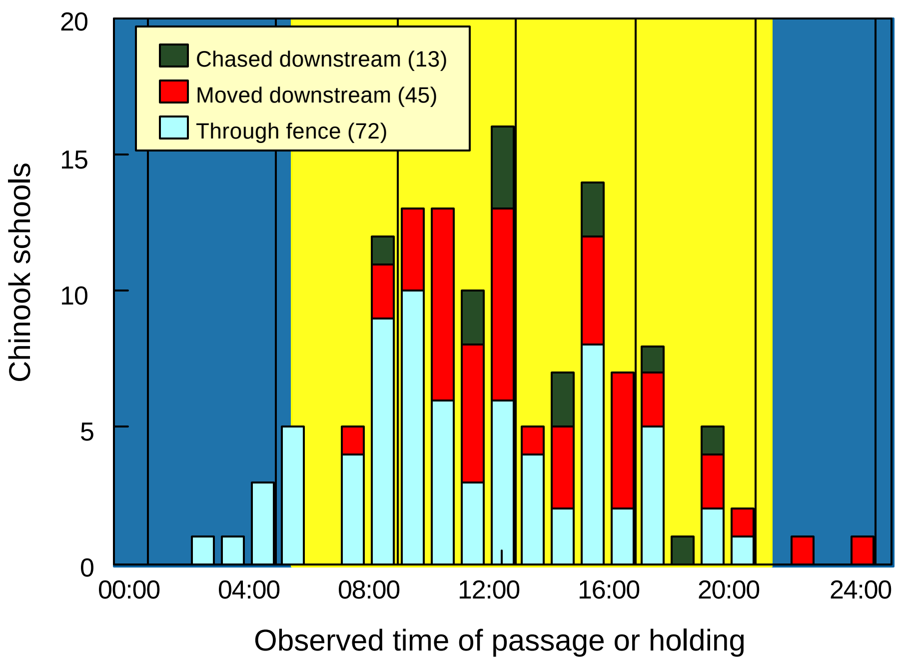

Figure 28. Hourly number of chinook schools (observations on groups) passing through the seal fence, being chased by seals downstream away from fence, or disappearing from view downstream.

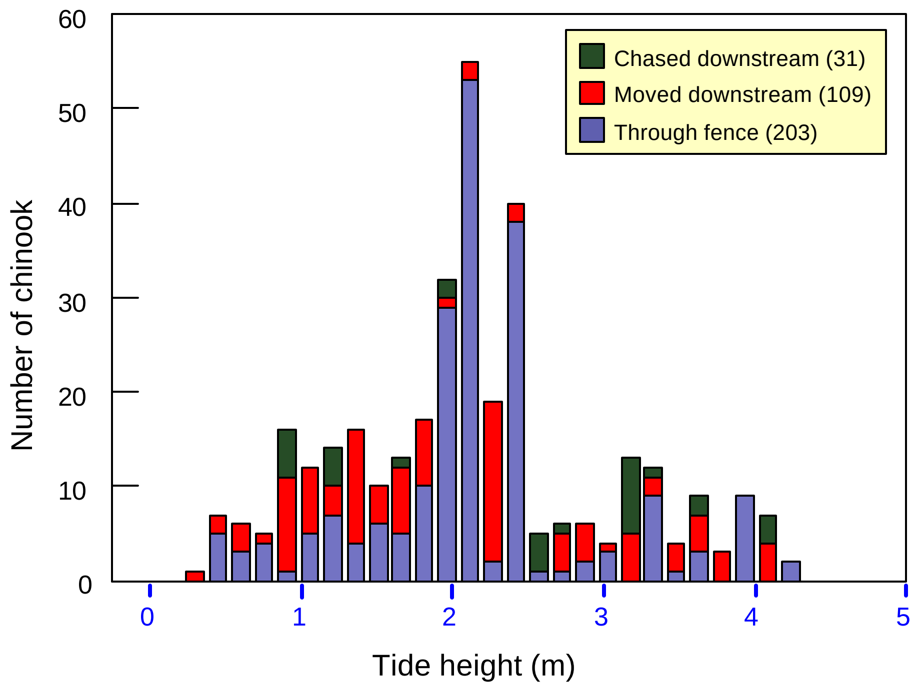

Figure 29. Relative to tide height; the number of chinook salmon passing through the seal fence, being chased by seals downstream away from fence, or disappearing from view downstream.

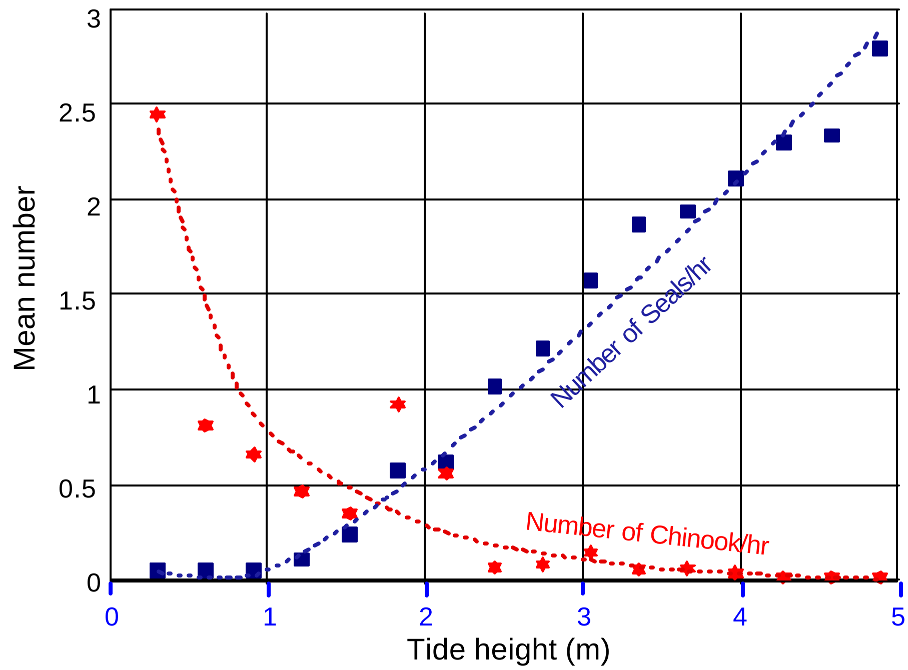

Figure 30. Relationship between number of seals/hr and number of chinook/hr relative to tide height.

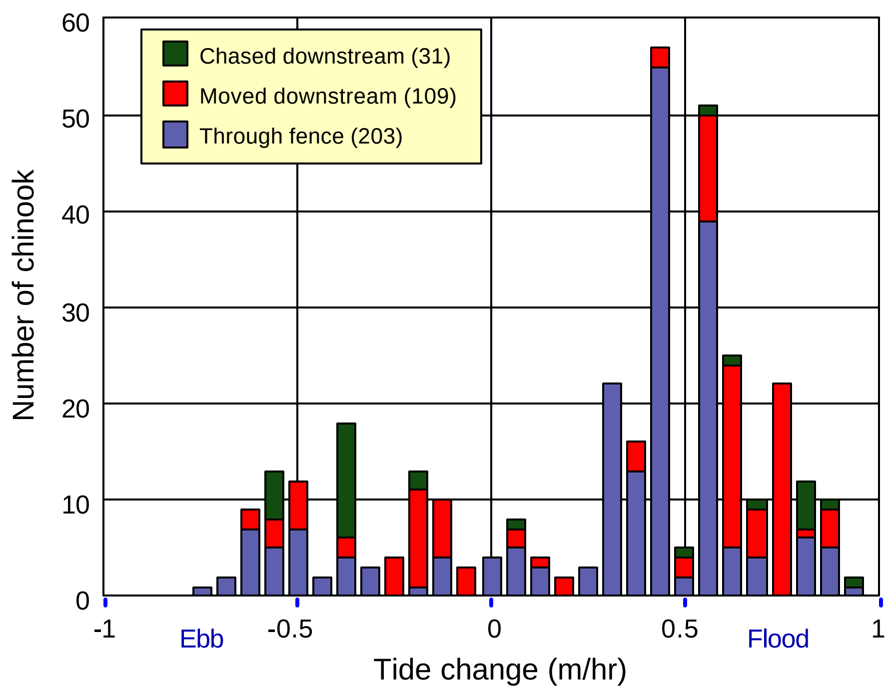

Figure 31. Relative to tide cycle, the number of chinook salmon passing through the seal fence, being chased by seals downstream away from fence, or disappearing from view downstream.

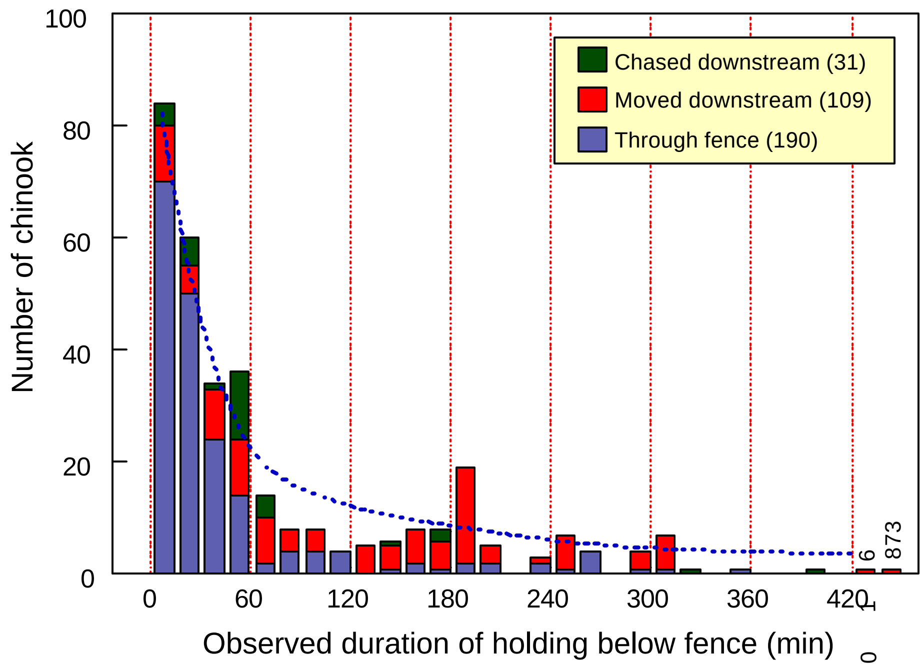

Figure 32. Duration of chinook salmon holding time below seal fence prior to; passing through the fence, being chased by seals downstream away from fence, or disappearing from view downstream.

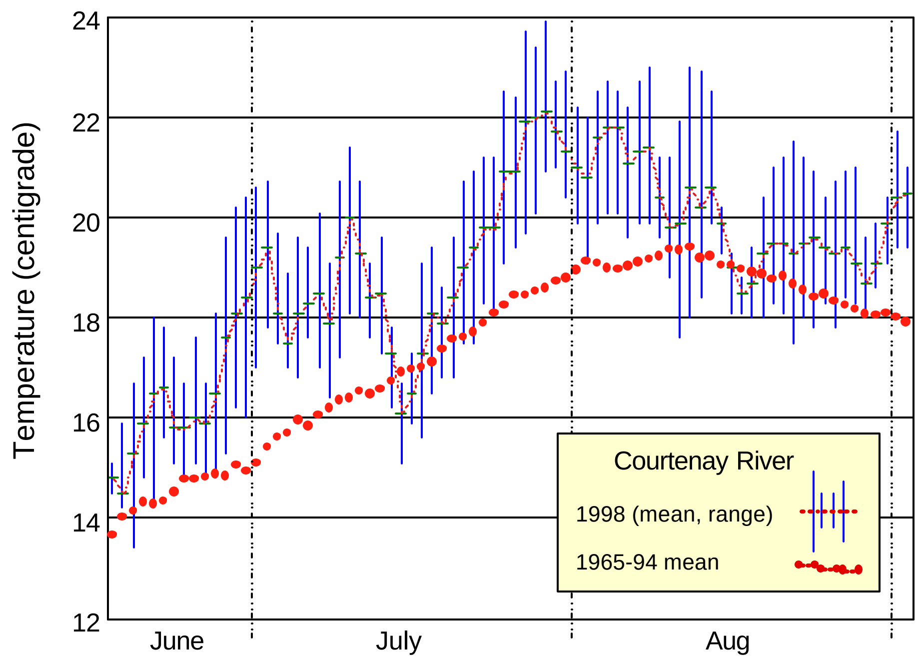

Figure 33. Relationship between 1998 daily summer water temperatures at triads (mean and range) relative to historic Puntledge River water temperature (1965-94).

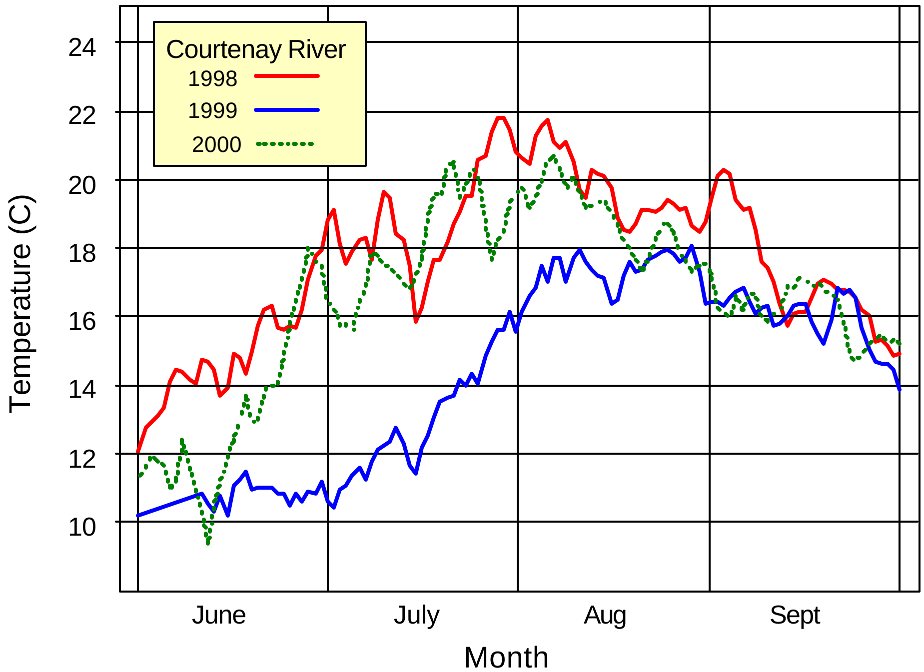

Figure 34. Courtenay River summer water temperatures for 1998, 1999,and 2000.

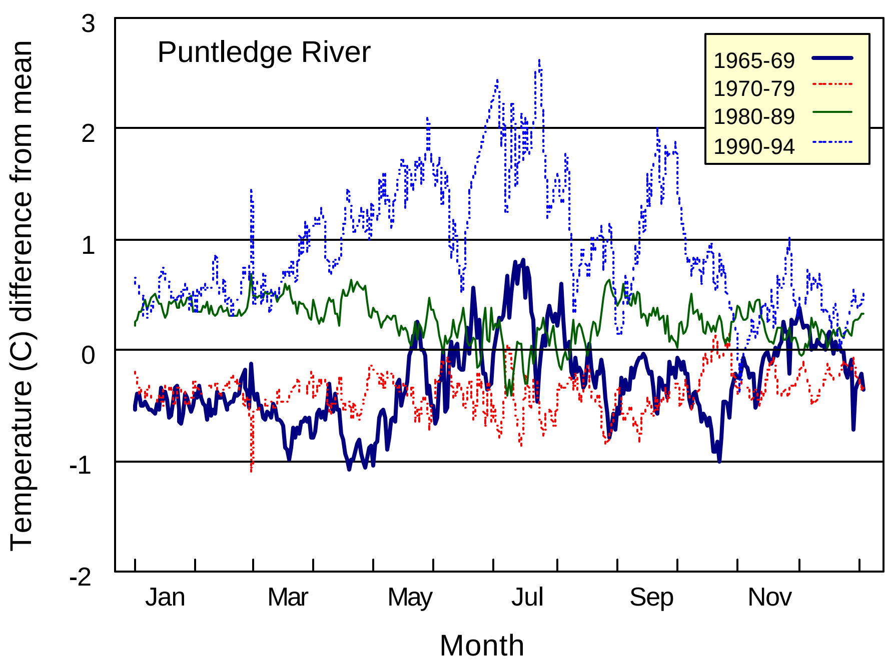

Figure 35. Daily difference from mean water temperature for 4 periods of time (1965-69, 1970-79, 1980-89, and 1990-94).

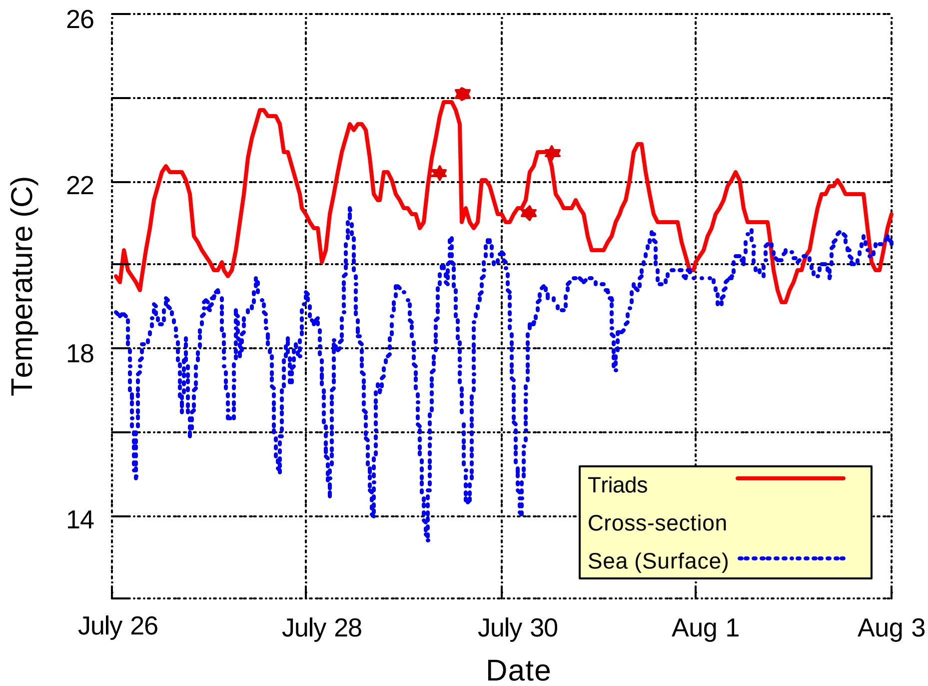

Figure 36. Relationship between sea surface water temperature (measured in Comox Harbour) and water temperature at triads for warmest summer week. Date and time of 4 temperature cross-sections located below the seal fence are illustrated.

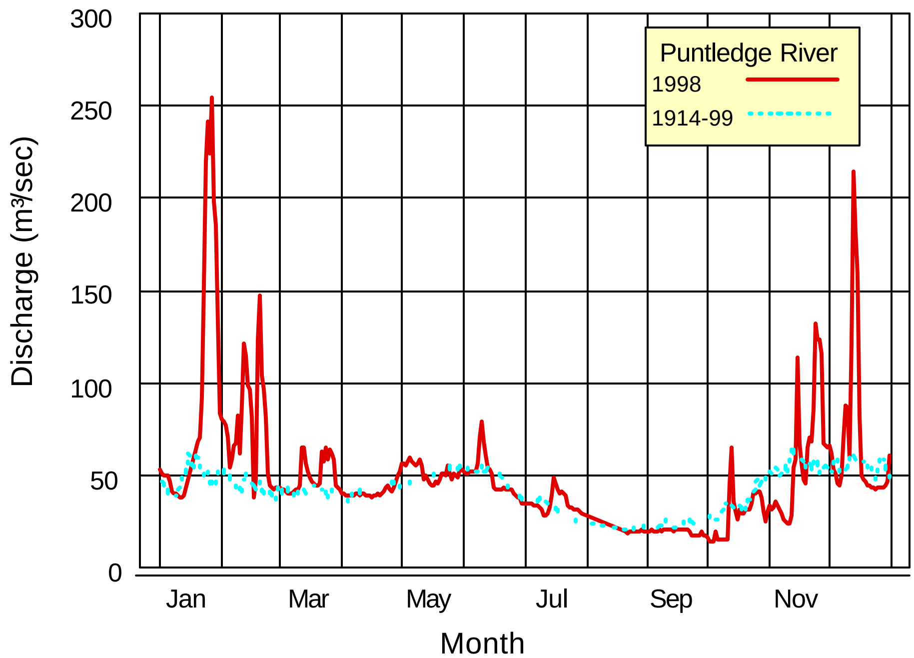

Figure 37. Comparison of annual historic mean discharge (1914-99) with Puntledge River discharge (m^3/sec) for 1998.

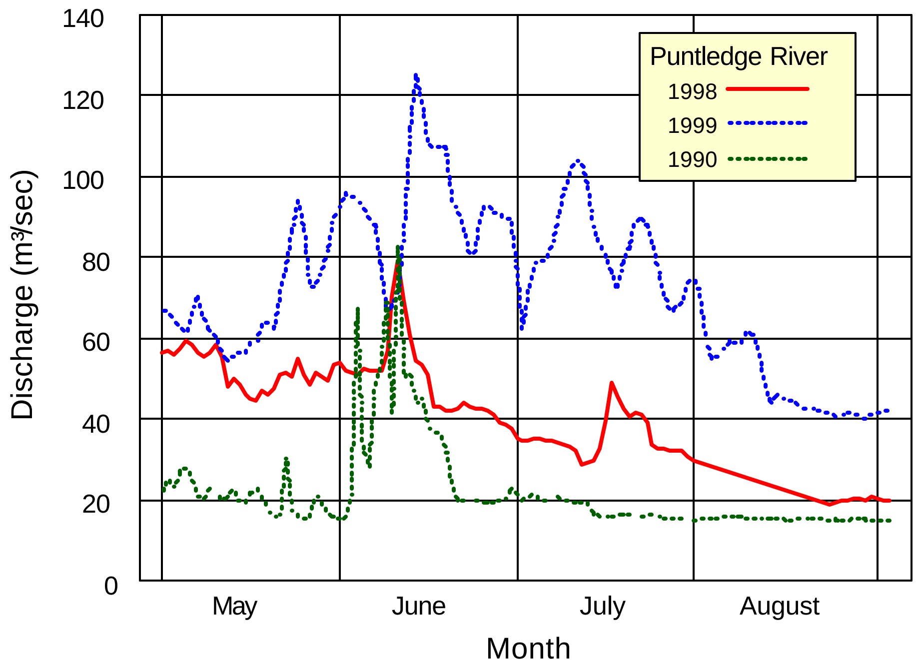

Figure 38. Puntledge River summer water discharge (m^3/sec) for 1998, 1999,and 1990.

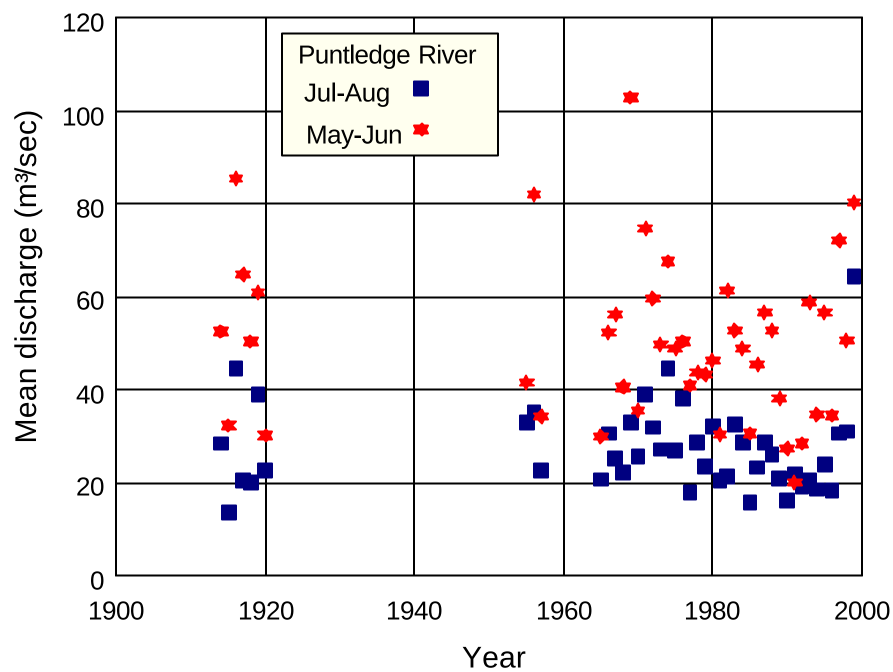

Figure 39. Puntledge River May-June and July-August mean summer water discharge (m^3/sec) for all recorded years between 1914 and 2000.

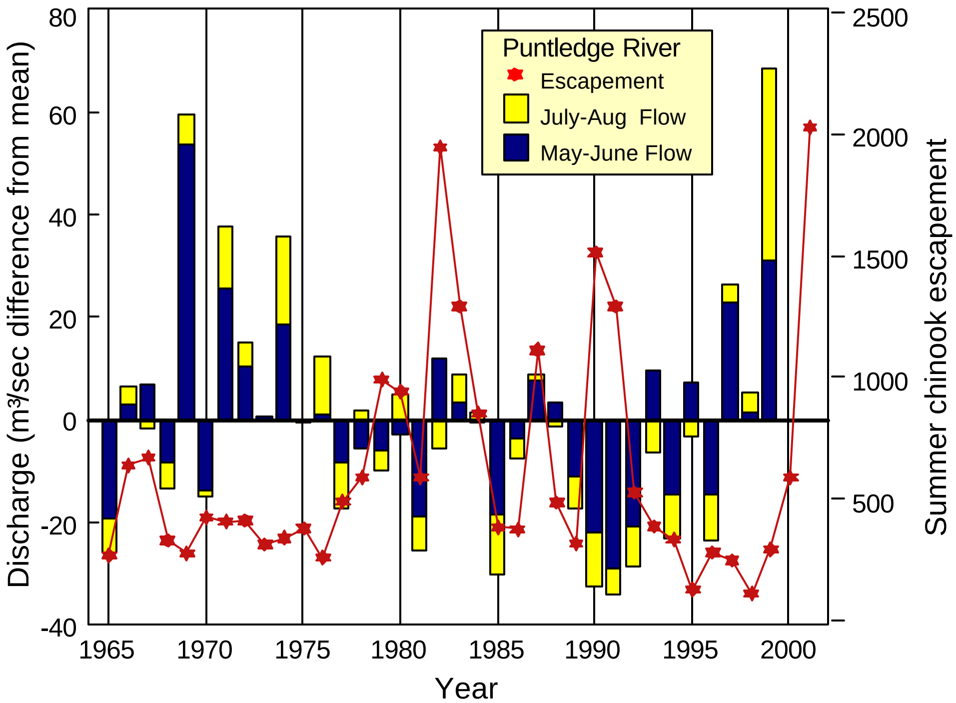

Figure 40. Relationship between summer water discharge and summer chinook escapement. Discharge (m^3/sec) is represented as annual difference in mean summer water discharge from historic May-June and July-August mean water discharges.

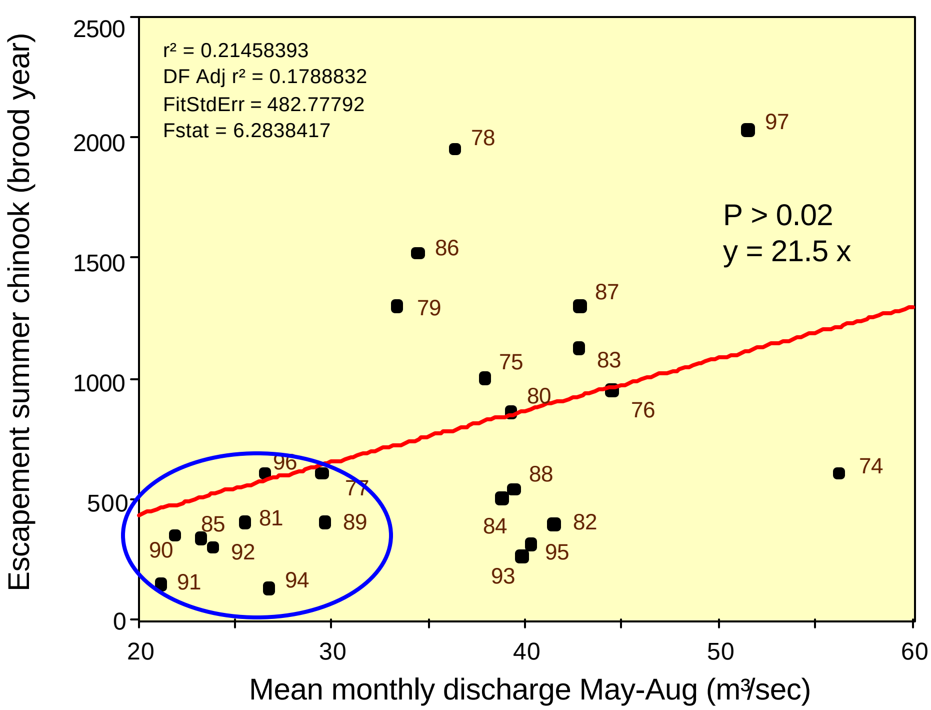

Figure 41. Correlation between mean monthly discharge (m^3/sec) for the summer months (May to August) and chinook escapement 4 years later (brood year).

APPENDICES

Appendix A. Observations of adult salmon and seals from the triads.

Obs.	Date	Time	Visibility	Tide		Fish	Seals			
				Height (ft)	Cycle	No.	No.		Long	Across
1	June 11/98	10:30	good	4.8	ebb	0	0	0		
2	June 16/98	11:05	good	10.6	slack	0	0	0		
3	June 16/98	14:45	good	5.0	ebb	0	0	0		
4	June 19/98	11:00	good	6.5	flood	0	0	0		
5	June 19/98	14:40	good	11.2	slack	0	0	0		
6	June 26/98	14:00	good	0.4	slack	0	0	0		
7	June 30/98	17:50	good	4.6	slack	0	0	0		
8	June 30/98	18:50	good	7.0	flood	0	2	1	Triads	mid
								1	Below	mid
9	June 30/98	19:30	good	8.1	flood	0	2	1	Above	far
								1	Below	mid
10	June 30/98	20:15	good	9.5	flood	0	1	1	Triads	mid
11	June 30/98	21:20	good	12.0	flood		3	3	Triads	mid
12	June 30/98	21:45	glare	12.4	flood	0	3	3	Above	
13	July 1/98	09:30	rough	8.3	flood	0	0	0		
14	July 1/98	12:30	rough	9.7	slack	0	1	1	Below	mid
15	July 1/98	13:22	rough	9.0	ebb	0	0	0		
16	July 1/98	18:20	good	6.2	slack	0	0	0		
17	July 1/98	20:00	good	8.2	flood	0	0	0		
18	July 1/98	21:48	poor	10.9	flood		4	2	Above	
								1	Triads	mid
								1	Above	near
19	July 2/98	09:00	good	6.1	flood	0	0	0		
20	July 2/98	19:30	good	7.5	flood	0	0	0		
21	July 2/98	20:00	good	7.9	flood	0	0	0		
22	July 2/98	20:56	good	9.2	flood	0	1	1	Below	mid
23	July 2/98	21:30	poor	10.0	flood		3	1	Below	
								2	Above	
24	July 2/98	23:59	night	13.2	flood		1	1	Above	near
25	July 3/98	19:40	rough	7.9	slack	0	1	1	Above	far
26	July 3/98	23:13	night	11.3	flood		3	3	Above	
27	July 3/98	23:43	night	11.9	flood		4	4	Above	
28	July 4/98	18:30	good	9.9	ebb	0	2	2	Triads	far
29	July 4/98	19:24	good	9.0	ebb		3	3	Above	mid
30	July 5/98	20:00	rough	9.1	ebb	0	0	0		
31	July 6/98	21:10	good	10.0	ebb	0	1	1	Triads	mid
32	July 7/98	21:00	good	11.3	ebb		2	2	Below	
33	July 7/98	21:30	good	10.6	ebb	0	1	1	Below	far
34	July 8/98	09:00	good	4.9	ebb	0	0	0		
35	July 9/98	11:10	good	1.8	ebb	0	0	0		
36	July 9/98	15:40	good	6.5	flood	0	0	0		

Obs.	Date	Time	Visibility	Tide		Fish	Seals			
				Height (ft)	Cycle	No.	No.		Long	Across
37	July 11/98	13:36	poor	8.8	slack	0	0	0		
38	July 13/98	08:00	murky	12.2	slack	0	0	0		
39	July 13/98	16:50	poor	5.7	flood	0	0	0		
40	July 13/98	17:25	poor	5.7	flood	0	0	0		
41	July 13/98	19:10		9.9	flood		1	1	Triads	near
42	July 13/98	19:24		11.3	flood		4	3	Triads	far
								1	Above	mid
43	July 14/98	09:50	good	11.4	slack	0	0	0		
44	July 15/98	20:10		4.9	flood	0	0	0		
45	July 15/98	15:40		9.1	flood	0	0	0		
46	July 15/98	11:00	good	10.0	flood	0	0	0		
47	July 16/98	16:00	good	6.8	ebb		1	1	Triads	near
48	July 16/98	15:52		12.8	slack		1	1	Triads	near
49	July 20/98	15:40	good	2.1	flood		4	4	Triads	mid
50	July 22/98	12:00	good	10.1	flood		3	3	Triads	mid
51	July 22/98	12:30	good	8.7	flood	0	1	1	Above	near
52	July 29/98	10:30	good	10.7	slack	0	1	1	Below	mid
53	July 30/98	14:37	good	8.0	ebb	0	0	0		
54	July 30/98	19:10	good	8.7	flood	0	3	3		
55	Aug 5/98	18:05	good	13.4	slack		0	0		
56	Aug 5/98	18:30	good	13.3	slack	0	2	2	Above	
57	Aug 7/98	17:00	poor	11.7	flood	0	1	1		
58	Aug 7/98	18:04		13.5	flood		3	3		
59	Aug 7/98	18:30	murky	14.0	flood	0	1	1	Triads	mid
60	Aug 10/98	17:45	good	8.2	flood	0	2	2	Triads	far
61	Aug 10/98	18:15	good	10.3	flood		6	1	Triads	mid
	Aug 10/98			10.3	flood			5	Below	
62	Aug 10/98	18:40	good	11.6	flood		5	2	Above	
								3	Below	
63	Aug 10/98	18:42		12.5	flood		7	7		
64	Aug 11/98	18:30	good	10.3	flood	0	2	2	Triads	mid
65	Aug 11/98	19:45		12.8	flood		5	5		
66	Aug 12/98	18:00		7.9	flood	0	1	1	Above	
67	Aug 19/98	15:15	good	10.5	flood	0	1	1	Triads	mid
68	Aug 21/98	09:50	good	4.3	ebb	0	0	0		
69	Aug 27/98	11:30	good	10.3	ebb	0	0	0		
70	Sept 3/98	10:05	good	2.5	slack	0	0	0		
71	Sept 3/98	10:40	good	2.7	slack	0	0	0		
72	Sept 10/98	10:45	good	11.9	ebb	0	0	0		

Appendix B. Courtenay River water temperatures below the seal fence at 3 locations. Cross sections at; a) top of triads, b) top of Marina, c) at range markers 1km below triads.

				Temperature (^{0}C)			
Tide	Site	Date	Time	Top	CL(95%)	Bottom	CL(95%)
High	Triads	July29/98	12:15	22.22	0.11	21.08	0.61
	Marina	July29/98	13:10	22.28	0.08	20.41	0.57
	Range	July29/98	13:43	22.74	0.29	21.37	0.6
Low	Triads	July29/98	16:20	24.01	0.05	23.97	0.59
	Marina	July29/98	16:45	24.06	0.03	23.60	0.59
	Range	July29/98	17:10	24.32	0.17	24.00	0.13
High	Triads	July30/98	10:00	21.25	0.04	21.13	0.06
	Marina	July30/98	10:25	21.29	0.09	20.56	0.31
	Range	July30/98	10:50	21.37	0.05	20.40	0.25
Low	Triads	July30/98	15:41	22.67	0.03	22.51	0.11
	Marina	July30/98	16:03	22.72	0.02	22.20	0.33
	Range	July30/98	16:30	22.80	0.08	22.30	0.48

Tide	Site	Date		Top Summary	Bottom Summary
High	Combined	July29/98	13:00	22.40	21.00
Low	Combined	July29/98	16:45	24.10	23.90
High	Combined	July30/98	10:25	21.30	20.70
Low	Combined	July30/98	16:00	22.70	22.30
			Mean	22.60	22.00