RELATIONSHIPS BETWEEN BROWN BEARS AND CHUM SALMON AT

MCNEIL RIVER, ALASKA

By

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A

THESIS

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Abstract

Since 1967, the McNeil River State Game Sanctuary (MRSGS) has been managed by the Alaska Department of Fish and Game to "provide permanent protection for brown bears". Up to 144 bears have been identified in a summer at MRSGS, and 72 bears at once have been observed in the vicinity of McNeil Falls. In this study, 155 chum salmon were radio tagged as they entered McNeil River and monitored daily. In 2005 and 2006 bears killed 48% of pre-spawning tagged chum salmon and consumed 99% of all tagged chums below McNeil Falls where most of the run occurs. A retrospective analysis of 31 years of run data using a new stream life, and a correction for observer efficiency, revealed that the current escapement goal of 13,750-25,750 actually represents 34,375-64,375 chum salmon. Considering the large removal of pre-spawning chum salmon, I recommend an additional 23,000 chum salmon be added to the escapement goal. Additionally, an annual escapement of 4,000-6,000 chum salmon above McNeil Falls should be set as an objective. These recommendations should encourage increased chum salmon returns, providing both food for McNeil bears, as well as benefiting the commercial fishery with increased harvest opportunities.

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Acknowledgments

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General Introduction

McNeil River State Game Sanctuary (MRSGS) was created by the Alaska State Legislature in 1967 to "provide permanent protection for brown bears (*Ursus arctos*) and other fish and wildlife populations and their habitats, so that these resources may be preserved for scientific, aesthetic, and educational purposes" (Alaska Department of Fish and Game 1996). When compatible with this objective other human uses such as bear viewing, commercial fishing and temporary safe anchorage are permitted (Alaska Department of Fish and Game 1996).

Chum salmon (*Oncorhynchus keta*) provide the principal food source for the extraordinarily high number of brown bears that aggregate annually at McNeil River Falls and few places in the world provide such a dramatic example of how direct the relationship between bears (*Ursus spp.*) and pacific salmon (*Oncorhynchus spp.*) can be. As many as 144 individual bears have been identified at MRSGS during a single year, and up to 72 bears have been in view at one time in the vicinity of McNeil Falls (Meehan 2003).

Bear numbers have been in decline, however, over the past 9 years. Since 1988 chum salmon returns to McNeil River have been relatively poor. Despite annual closures to commercial fishing for the past 14 years, the current escapement goal (the number of salmon that enter a river) of 13,750-25,750 chum salmon has been met only sporadically over this time. In contrast, chum salmon returns to nearby streams in the surrounding commercial fishing districts have been strong for the past 7 seasons (Hammarstrom and

Dickson 2007), suggesting poor ocean survival is not the cause for the recent low returns to McNeil River.

Assurance of a predictable and continuous food resource is an important ecological factor in maintaining consistent bear use of an area (Aumiller and Matt 1994). Salmon are relatively high in energy compared to alternative foods (Welch et al. 1997; Rode et al. 2001), and the nutritional importance of salmon to bears has been well documented (Hilderbrand et al. 1999a, 1999b; Ben-David et al. 2004; Gende and Quinn 2004; Hilderbrand et al. 2004). Brown bears with access to salmon achieve heavier body weights, produce larger litters, and are found in higher population densities than bears without access to salmon (Hilderbrand et al. 1999a, 1999b). Conversely, in bears without access to high quality food resources, such as salmon, both the age at first reproduction, and the interval between litters are increased (Bunnell and Tait 1981; Rogers 1987; Stringham 1990a, 1990b).

The availability of high quality food resources such as salmon has also been shown to be an important factor in successful denning (McCarthy 1989; Farley and Robbins 1995; Barboza et al. 1998) and can impact the timing of den emergence (Kitchinksi 1972; Schoen et al. 1987; Van Daele et al. 1993). On the Kenai Peninsula, Alaska, salmon have been shown to be the single most important resource to female brown bears as they prepare to meet the demands of both hibernation and cub production (Hilderbrand et al. 1999a).

Establishing appropriate escapement goals for individual salmon stocks comprises the foundation of sustainable salmon fisheries management (Knudsen et al. 2003). It is important to have accurate and precise estimates of escapement in order to assess the health of salmon stocks (Lady and Skalski 1998; Manske and Schwarz 2000), set appropriate escapement goals (Bue et al. 1998), and manage salmon fisheries over the long term (Perrin and Irvine 1990; Bue et al. 1998).

Presently, annual escapement indices for McNeil River chum salmon are derived using the area-under-the-curve (AUC) method (Neilson and Geen 1981; Hill 1997; Bue et al. 1998; Hilborn et al. 1999). This method involves conducting periodic aerial surveys to count adult fish. The total fish days for the spawning season are then calculated and divided by the average number of days a live fish resides in the survey area. This trait, known as stream life, then accounts for repeat sightings of the same fish on consecutive surveys. Therefore, stream life is a key parameter in the AUC model, and, along with observer efficiency, it can have a tremendous effect on the accuracy of escapement indices (Bue et al. 1998).

While consideration of ecosystem needs is becoming increasingly recognized in the literature as an important factor in establishing sustainable escapement goals for salmon stocks (Cederholm et al. 2000; Knudsen et al. 2003; Michael 2003; Hilderbrand et al. 2004), it is difficult to find examples where this recommendation has been put into practice. Knudsen et al. (2000) argued that a shift in management is needed from a philosophy of managing individual parts to management of entire systems.

Fish stocks can not be managed successfully without taking into consideration the context of the watersheds they inhabit (Williams 2000). When the conservation of healthy ecosystems is the management objective, an allowance of salmon for wildlife should be considered (Hilderbrand et al. 2004). In this thesis I argue that effective management of the McNeil River chum salmon fishery should include the following considerations. First, brown bears represent a major source of mortality for pre-spawning chum salmon at MRSGS. Therefore, the escapement goal for McNeil River should explicitly incorporate this mortality, and a spawning escapement goal (the number of salmon that enter a river and spawn) should be established. Secondly, a minimum escapement of chum salmon above McNeil Falls is necessary to fully utilize available spawning habitat, and to encourage high stream-wide production of chum salmon.

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Chapter 1. Stream life of chum salmon and a retrospective analysis of escapement at McNeil River, Alaska[1]

1.1 Abstract

It is important to have accurate and precise estimates of escapement in order to assess the health of salmon stocks (*Oncorhynchus spp.*), determine spawning escapement, set appropriate escapement goals, and manage salmon fisheries over the long term. The area-under-the-curve (AUC) method is a common technique used to estimate escapement from periodic aerial surveys when more precise methods (e.g., weir or sonar) are not economically or logistically feasible. AUC calculations can provide accurate estimates of escapement; however, they are highly sensitive to errors in estimates of both stream life and observer efficiency. We used a new technique, radio telemetry, to determine the stream life of chum salmon (*Oncorhynchus keta*) at McNeil River, a high density brown bear (*Ursus arctos*) area in Alaska. Over two seasons 155 chum salmon were tagged and tracked from the time they entered McNeil River, until they died, or left the river. The average stream life for McNeil River chum salmon was 13.8 d, a 21% reduction from the old estimate of 17.5 d previously used in the AUC model. A retrospective analysis of 31 years of run data using the new estimate of stream life and an observer efficiency

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[1] Peirce, J.M., E.O. Otis, M.S. Wipfli and E.H. Follmann. 2007. Stream life of chum salmon and a retrospective analysis of escapement at McNeil River, Alaska. Prepared for submission in Transactions of the American Fisheries Society.

correction factor suggest that escapements at McNeil River have been underestimated by nearly 250%. These analyses indicate that the current escapement goal of 13,750-25,750 actually represents 34,375-64,375 chum salmon and provide important insight into the magnitude of pre-spawning mortality caused by bears.

1.2 Introduction

The term escapement has been used loosely in fisheries management. English et al. (1992) defined it as the number of mature salmon (*Oncorhynchus spp.*) that escape marine fisheries and enter a freshwater system. Lady and Skalski (1998) defined escapement as the number of salmon that return to a river and spawn. This is an important distinction, and is appropriate in situations where in-river mortality of salmon is high. While both definitions are important, the use of the term escapement is often meant to imply the number of successful spawners. However, as this is not always clear we will use the term escapement when referring to the total number of salmon which enter a river, and spawning escapement when referring to the total number of salmon which enter a river and successfully spawn.

Establishing appropriate escapement goals for individual salmon stocks comprises the foundation of sustainable salmon fisheries management (Knudsen et al. 2003) and requires an understanding of spawning escapement. It is important to have accurate and precise estimates of escapement in order to assess the health of salmon stocks (Lady and Skalski 1998; Manske and Schwarz 2000), determine spawning escapement, set appropriate escapement goals (Bue et al. 1998; Jones et al. 1998), and manage salmon fisheries over the long term (Perrin and Irvine 1990; Bue et al. 1998).

The most reliable estimates of escapement are derived from mark-recapture programs, counts at fish-ways and weirs (Neilson and Geen 1981) or using sonar. However, because of the large number of streams in Alaska, especially in remote areas, it is neither economically nor logistically feasible to count fish using these methods for every stream. Therefore, other techniques must be employed, and the abundance of salmon in many streams in Alaska is estimated using aerial counts (Bevan 1961; Neilson and Geen 1981).

During these aerial surveys salmon are enumerated on several occasions to obtain a series of counts (Su et al. 2001). Each count then represents an estimate of how many salmon were in a stream at the time of the survey and not the escapement for the entire season (Su et al. 2001). This is because some fish will have died before the survey, others will not yet have entered (Su et al. 2001), and still others may have been counted multiple times. Thus, a method must be used to convert these counts into escapement estimates (Su et al. 2001).

Gangmark and Fulton (1952) proposed a method to estimate total escapement based on multiple counts. They multiplied the total number of sockeye salmon (*Oncorhynchus nerka*) counted by the number of days in the spawning season and then divided this by the life expectancy in the stream of spawning sockeye salmon (Gangmark and Fulton 1952).

Neilson and Geen (1981) greatly improved upon this method and report plotting a curve of the number of salmon counted by date. The area under this curve was then integrated to arrive at total fish days. This number would be equal to total escapement if all salmon lived for one day. However, salmon live for more than one day, and Neilson and Geen (1981) divided total fish days by a life expectancy value. Neilson and Geen (1981) also demonstrated that life expectancy decreases with arrival date and early-run fish tend to live longer than late-run fish. Therefore, they attempted to further improve upon Gangmark and Fulton's (1952) methodologies by using two life expectancy values when calculating their escapement estimates.

Area-under-the-curve (AUC) estimates of escapement, as this method has become known, are well documented (Pirtle 1977; Ames 1984; English et al. 1992; Irvine et al. 1993; Hill 1997; Bue et al. 1998; Hilborn et al. 1999; Parken et al. 2003). Using the AUC method, the numbers of observable salmon in streams are counted during periodic aerial surveys to arrive at total fish days (English et al. 1992). The escapement curve typically starts at zero fish on day zero and ends at zero fish at some time later (English et al. 1992). The total escapement is then estimated by dividing cumulative fish days by the estimated mean number of days that an individual fish is thought to spend in the survey area (stream life) and a correction factor for observer efficiency (how many fish did the observer under- or over-count) (Bue et al. 1998; Hilborn et al. 1999).

The term "stream life" has been used in a variety of ways in the literature and with various definitions. Labels have included residence time, survey life, stream life, breeding life, turn-overtime and average lifespan (Perrin and Irvine 1990). Perrin and

Irvine (1990) preferred the term survey life because it had broad spatial limits and could apply to survey areas as small as a redd, or as large as an entire stream and then be termed stream life (how long an individual salmon was alive in the entire river after entering fresh water).

Most of the variations in the use of these terms refers to differences in survey designs, or are simply different names for the same approach (Perrin and Irvine 1990). The differences in definitions are not trivial, however. Therefore, it is important to define the survey area and select the appropriate measure of survey life (English et al. 1992). As we were able to survey the entire drainage, we will use the term stream life for this study and define it as the average number of days salmon were alive in McNeil River. Additionally, to avoid confusion we will use the term stream life when speaking generally of other research from this point forward.

Aerial surveys provide only an index of escapement when there is a lack of supporting data such as accurate estimates of stream life and observer efficiency (Otis and Hasbrouck 2004). Indices of escapement are therefore a measurement on a numeric scale that provides information only about the relative level of the escapement (Otis and Hasbrouck 2004). These measurements provide a ranking of escapement magnitude across years but in and of themselves provide no information on the total number of fish in the escapement (Otis and Hasbrouck 2004).

AUC models provide estimates of escapement from year to year, but can be highly biased based on observer efficiency, stream life and the number and periodicity of aerial surveys (Neilson and Geen 1981; Perrin and Irvine 1990; Hill 1997; Bue et al.

1998). Factors that can affect observer efficiency include water clarity, turbulence and depth, surveyor experience (English et al. 1992), riparian cover and light conditions. Factors that may affect stream life include water temperature, discharge, run timing, distance to spawning grounds, intra- and inter-specific competition at high spawner densities (Ames 1984; Perrin and Irvine 1990; English et al. 1992) and in-river mortality from predators such as bears (*Ursus spp.*). Factors that can affect periodicity of aerial surveys include weather constraints, aircraft availability and budgets for survey flights. Hill (1997) found the precision of AUC estimates decreased as the interval between flights increased due to the inability of limited surveys to capture the true shape of the escapement curve.

Bue et al. (1998) also investigated biases in the AUC model. They found that a correction factor for observer efficiency provided the single greatest improvement in AUC escapement estimates when compared to known weir counts. When observer efficiency was combined with a stream-specific stream life, AUC estimates were within 10% of known weir counts in Prince William Sound, Alaska (Bue et al. 1998). Irvine et al. (1993) also noted the importance of observer efficiency corrections in AUC calculations when fish were counted visually.

Stream life is important because it adjusts aerial surveys to account for fish that were counted in the previous survey and those that had died since the last survey (Thomas and Jones 1984). Stream life is often extrapolated across streams because of a lack of resources to conduct stream-specific estimates (Perrin and Irvine 1990). Studies have shown, however, that stream life can vary considerably not only among streams, but also within an individual stream from year to year (Thomas and Jones 1984; Bocking et al. 1988; Perrin and Irving 1990; Irving et al. 1993).

Values in the literature for stream life of chum salmon (*Oncorhynchus keta*) are highly stream-specific. Thomas and Jones (1984) reported an average stream life of 20.8 d for chum salmon in Traitors River in southeast Alaska with a range of 10-33 d. At Katlin Creek in southeast Alaska, chums had a stream life of 20.5 d (Thomas and Jones 1984). On two short creeks in southeast Alaska, Gende (2002) found chum salmon stream life averaged 10.1 d with a range of 8-21 d. Perrin and Irvine (1990) conducted a thorough review of other studies and estimated the average stream life for chums to be 11.9 d, but recommended stream life be determined on stream-specific basis.

McNeil River State Game Sanctuary (MRSGS) was created by the Alaska State Legislature in 1967 to "provide permanent protection for brown bears (*Ursus arctos*) and other fish and wildlife populations and their habitats, so that these resources may be preserved for scientific, aesthetic, and educational purposes" (Alaska Department of Fish and Game 1996). When compatible with this objective, other human uses, such as bear viewing, fishing, and temporary safe anchorage are permitted (Alaska Department of Fish and Game 1996). Chum salmon provide the principal food source for the extraordinarily high number of brown bears that aggregate annually at McNeil River Falls, and few places in the world provide such a dramatic example of how direct the relationship between bears and salmon can be. As many as 144 individual bears have been identified at MRSGS during a single year and up to 72 bears have been in view at one time in the vicinity of the falls in July (Meehan 2003).

Brown bear numbers at MRSGS have been in decline, however, over the past 9 years. Chum salmon returns to McNeil River have been relatively poor, and despite annual closures to commercial fishing, the current escapement goal of 13,750 – 25,750 chum salmon has been met only 6 times in the last 18 years (Hammarstrom and Dickson 2007). In contrast, chum salmon returns to nearby streams in the surrounding commercial fishing districts have been strong for the past 7 seasons (Hammarstrom and Dickson 2007), suggesting poor ocean survival is not the cause for the recent low returns to McNeil River.

Presently, annual escapement for McNeil River chum salmon is indexed using the AUC model, but with no correction for observer efficiency. Additionally, a generic 17.5 d stream life factor is currently being used for McNeil River, as well as all Lower Cook Inlet chum salmon systems. This stream life was thought to have been derived from studies of pink salmon (*Oncorhynchus gorbuscha*) conducted on Kodiak Island in the 1960's (A. S. Davis, Alaska Department of Fish and Game retired, personal communication). However, the true source of this stream life estimate is somewhat of an enigma. No matter what the source of this estimate of stream life, McNeil River represents a relatively unique situation with far higher in-river predation than other area streams. Therefore, in an attempt to better understand escapement at McNeil River we investigated the stream life for chum salmon there. In this paper we present a new technique for estimating stream life using radio telemetry. Finally, we retrospectively analyzed 31 years of escapement data using a new stream life value as well as an observer efficiency correction factor.

1.3 Study Site

MRSGS is located along the shores of Kamishak Bay on the Alaska Peninsula, approximately 340 km southwest of Anchorage and 160 km west of Homer (Figure 1.1). MRSGS encompasses both the McNeil River and Mikfik Creek drainages and is approximately 51,800 ha. Immediately to the north of MRSGS is the McNeil River State Game Refuge. To the south and west are Katmai National Park and Preserve, and to the east is the Kamishak Special Use Area.

Kamishak Bay is characterized by extreme tidal fluctuations ranging from +7 to -1.5 m in height. McNeil Lagoon is formed by a long spit which nearly separates it from McNeil Cove and the larger Kamishak Bay (Figure 1.2). A channel approximately 50 m wide enters the lagoon from the cove, and all salmon enter the system through this narrow point. McNeil River and Mikfik Creek both drain into the lagoon, which is flooded at high tide and channeled mud flats at low tide. The McNeil River run is primarily chum salmon and occurs in late June to early August, while the earlier Mikfik Creek run in June is composed almost entirely of sockeye salmon.

McNeil River is a fourth order stream which originates from two main branches. One branch is glacially-fed and the other lake-fed. From the confluence of these two branches, downstream to the lagoon, the river is 20.7 km long. The distance from the headwaters of the glacially-fed branch to the lagoon is 36.6 km. The distance from the outlet of McNeil Lake to the lagoon is 25.5 km. Discharge data are limited, but typical June flows are between 27-36 m^3 per second. There is high quality chum salmon spawning habitat available below the confluence of the two branches, in the lower 20 km of the river. However, virtually all of the chum salmon and bear activity occurs below the falls in the lowest 1.6 km of McNeil River and around the lagoon itself. A short series of steep rapids (McNeil Falls) impedes the upstream migration of chum salmon and during the peak of the run in July both chums and bears are concentrated in this area. The majority of the chum salmon do not successfully ascend the falls and instead drop into the lower river and tidally influenced areas to spawn. At this time in early August bear activity switches downstream to follow the movements of the spawning chums.

1.4 Methods

Chum salmon were captured, radio tagged and monitored from late June through mid August in 2005 and 2006. Advanced Telemetry Systems (ATS) Model #F1845 esophageal radio transmitters with mortality signals on frequencies between 150 and 153 MHz were used to tag 155 fish. Chum salmon were captured using rod and reel at the end of the spit and tagged as soon as they entered McNeil Lagoon. In order to ensure chum salmon were marked at the beginning of their stream life, only fresh chums were tagged, as determined by the presence of sea lice and minimal fresh water marking.

After a chum salmon was captured, it was briefly held in a rubber mesh landing net that was submerged in water for the duration of the handling. One person held the fish by the caudal peduncle and under the pectoral fins and rolled the fish onto its right side. A second person recorded length and sex and removed four scales from the left side for aging. If the chum salmon was determined to be fresh, a radio tag was inserted using a hollow 30 cm long piece of PVC tubing, with a 7 mm diameter (Eiler 1995). Each fish remained submerged during the entire handling process. No anesthesia was used, and after tagging all fish were immediately released into calm water (Eiler 1995). Capture times were approximately three minutes from the time of hooking until landing. Handling time, including tag insertion, lasted an additional three minutes on average. These procedures were reviewed and approved by the University of Alaska Fairbanks Institutional Animal Care and Use Committee (IACUC Assurance 05-40).

Salmon at different stages of the run have been shown to have different stream lives, with early-run fish living longer than late-run fish (Ames 1984; Thomas and Jones 1984; Perrin and Irvine 1990; McPhee and Quinn 1998). Therefore, an attempt was made to tag fish in proportion to historic run timing. Capture efforts were divided into five, 1-week periods, beginning 24 June and ending 28 July, with a tagging goal established for each week that was based on historic run timing (Table 1.1). Tags recovered in a serviceable condition from dead fish were redeployed as soon as possible to increase sample size. Each week equal numbers of males and females were tagged.

Radio-tagged fish were monitored via two remote data logger stations, daily manual ground tracking, and twice weekly (weather dependent) aerial tracking flights using ATS Model R4500 receivers.

Remote data logger stations were used to monitor for mortality signals 24 h every day. One was positioned at the end of the spit and the other 200 m upstream of McNeil Falls. Both data logger stations were constructed as follows. A 3.1 m high aluminum pole was attached to a custom-welded, water-proof and bear-resistant aluminum box measuring 0.6 x 0.5 x 0.3 m in size. Two, 4-element yagi antennas were attached to the pole with antenna #1 positioned in a downstream orientation and placed 1.7 m above the ground. Antenna #2 was oriented upstream and attached 3 m above the ground. Yarn was tied to the yagi elements to prevent bald eagles (*Haliaeetus leucocephalus*) from landing on them and causing damage.

Each aluminum box housed two absorbed glass mat (AGM) 12-volt batteries, an ATS Model R4500 receiver, associated wire connections and a solar charging regulator. Two solar panels (BP Model 275LLL, with 75W, 17V, 14.5 A, and 36 cells) were used to recharge the 12-volt batteries at each station. Finally, a 2-strand polywire electric fence (5 m x 4 m) was placed around each station to deter bears. The fences were electrified using 4-volt, solar charged units for power (Shock Inc. Model SS-440).

During daily ground tracking a 3-element folding yagi antenna and ATS Model R4500 receiver were used to locate all dead fish with transmitters below the falls. The transmitters were then recovered as soon as possible.

Aerial tracking flights were used to locate all chum salmon that successfully ascended the falls, and monitor them to determine live-dead status. Tracking flights were also used to help locate missing transmitters which were not detected in the survey area (McNeil River and Lagoon).

An individual chum salmon had to remain active (i.e. no mortality signal) for 24 h post tagging to be used in the analysis of stream life. The stream life for each individual fish that met this criterion was then determined by measuring the interval in hours between tagging and time of mortality, or when it permanently left the survey area. Time of mortality or permanent departure from the survey area was determined using all available telemetry data. For chum salmon above the falls, the time of mortality was interpolated as half way between the last flight in which an individual was alive and the first flight in which the fish was determined to be dead. Stream life data points were then averaged for all fish above or below the falls by year. An overall stream life for each year was determined by weighting the above and below falls stream life values based on aerial survey cumulative counts for each stream reach. A straight average was then taken between the two years to determine the overall stream life for McNeil River.

Escapement indices $(\hat{E})$ from 1976-2006 were retrospectively analyzed using aerial survey data from those years, our new stream life value, and an observer efficiency correction factor of 0.47. The observer efficiency correction factor was derived using known weir counts of salmon, compared to the counts of aerial surveyors (E. Otis, Alaska Department of Fish and Game, unpublished data). These same surveyors currently enumerate chum salmon at McNeil River. All AUC calculations followed Bue et al. (1998) methodologies as follows,

$$\hat{E} = \frac{\hat{A}}{\hat{S}\hat{B}}$$

where $\hat{A}$ is an estimate of the area under the escapement curve, $\hat{S}$ is an estimate of stream life, and $\hat{B}$ is an estimate of observer efficiency.

$$\hat{A} = \sum_{i=2}^{n} \frac{(t_i - t_{i-1})(C_i + C_{i-1})}{2}$$

where t_i was the survey date and C_i was the number of salmon observed on the i^{th} survey. When chum salmon were present on the first survey the parameter $\hat{A}$ prior to the first survey was estimated as,

$$\hat{A}_{first} = \frac{C_1 \hat{S}}{2}$$

When chum salmon were visible on the last survey $\hat{A}_{last}$ was estimated as,

$$\hat{A}_{last} = \frac{C_{last} \hat{S}}{2}$$

1.5 Results

All chum salmon were tagged fresh. In 2005 chums remained permanently in the survey area on average 7.1 h after tagging. In 2006 chum salmon remained permanently in the survey area 5 h after tagging. This strongly indicates that once chums enter McNeil Lagoon they remain in the system and do not move in and out for several days, which would have biased our estimates of stream life.

In 2005, 70 adult chum salmon were fitted with esophageal radio transmitters. Of those 70, 43 were active (i.e. no mortality signal) for more than 24 h and were used in the stream life analysis. Only three fish, or 7% of chums tagged, migrated above McNeil Falls in 2005. The stream life for these three fish ranged from 11.7-22.4 d and averaged 18.1 d (SE=3.25). The average stream life for fish that remained below the falls was 10.7 d (n=40, SE=0.63). Based on aerial survey cumulative counts by stream reach, 90% of the run remained below the falls and the overall weighted stream life in 2005 was 11.5 d (n=43).

In 2006, 85 adult chum salmon were radio tagged. Of those, 62 lived for more than 24 h and were used in the stream life analysis. A greater percentage of tagged fish (n=17, 27%) ascended the falls in 2006, and the stream life for these fish was 25.7 d (SE=1.40). The average stream life for fish below the falls (n=45) was 14.4 d (SE=1.09). Based on aerial survey cumulative survey counts by stream reach, 85% of the run remained below the falls, and the weighted average stream life for the entire river in 2006 was 16.1 d (n=62).

Over both seasons a total of 155 chum salmon were fitted with radio transmitters. Of these only one salmon carcass was recovered before it had been consumed by bears or by harbor seals (*Phoca vitulina*). Seven tags went completely missing in 2005 and four in 2006. In 2005, 52 tags with no associated carcass were recovered, and 11 others were located but not recovered. In 2006, 49 tags with no associated carcass were recovered, and 32 others were located but not recovered. Tags which were located but not recovered were either in deep parts of the river, in areas where it was not safe to retrieve them, in areas where we would have displaced bears, or were too far above the falls to reach on foot.

The mean stream life for chum salmon above the falls for both years was 21.9 d (n=20). Below the falls, mean stream life was 12.6 d (n=85). Overall stream life for the two seasons was 13.8 d (n=105). We found no significant relationship between date of stream entrance and stream life for fish below the falls (2005, n=40, R^2=0.02, p=0.43;

2006, n=45, R^2=0.00, p=0.84) or above the falls (2005, n=3, R^2=0.27, p=0.65; 2006, n=17, R^2=0.00, p=0.98).

From 1976-2006, aerial survey counts were generally stratified by stream reach, and counts above the falls were recorded separately from counts below the falls. Therefore, we were able to retrospectively analyze above the falls escapements for 27 out of the 31 years of data available. Using a 21.9 d stream life and an observer efficiency correction factor of 0.47 over that period, escapement above the falls varied greatly, ranging from 117-10,931 chum salmon. Below the falls, escapement was retrospectively analyzed for all 31 years. Using a 12.6 d stream life, and an observer efficiency correction factor of 0.47, estimates of escapements below the falls ranged from a low of 5,034 to a high of 127,881 chum salmon. Stream-wide escapement estimates were also retrospectively calculated for all 31 years using an average stream life of 13.8 d and an observer efficiency correction factor of 0.47. Stream-wide escapement varied from 13,188-143,935 adult chum salmon. Using the old estimate of stream life (17.5 d) and no observer efficiency correction (as was previously being done) stream-wide estimates of escapement ranged from 5,269-54,219 chum salmon. These old values are approximately 39% of the new values implying that historic escapement has been underestimated by a factor of nearly 2.5 (Figure 1.3). Most of this difference is attributable to the use of the observer efficiency correction factor which nearly doubled all estimates of escapement.

1.6 Discussion

Radio telemetry provides a method of studying fish ecology, but the results are meaningless if the tags cause abnormal behavior (Gray and Haynes 1979). Therefore, radio tagging studies assume tags are retained for the duration of the study and that tagged individuals represent the population being studied (Ramstad and Woody 2003).

Transmitters may affect swimming performance and thus upstream migration rates (Thorstad et al. 2000). Gray and Haynes (1979) tested esophageal and external tags to look for differences in swimming performance in chinook salmon (*Oncorhynchus tshawytscha*). They found that while upstream movements were slightly faster with the esophageal tags, there was no significant difference between the two tag types (Gray and Haynes 1979). Thorstad et al. (2000) investigated swimming performance in Atlantic salmon (*Salmo salar*) using an untagged control group compared to fish tagged with dummy small and large external transmitters and dummy implants. When they placed fish in an artificial swim chamber, they found no significant difference in endurance among the groups. However in later work, Thorstad et al. (2001) cautioned that external tags may be prone to fouling which could significantly increase drag. In addition to concerns over swimming performance however, we were also concerned with the visual cue that an external transmitter may have presented to bears.

Esophageal radio transmitters require less handling time than external radio transmitters, but, they are also susceptible to loss through regurgitation (Ramstad and Woody 2003). However, salmon have been shown to have high retention rates of up to 98% (Ramstad and Woody 2003; J. H. Eiler, National Marine Fisheries Service, personal communication), and there is low associated tagging mortality with esophageal transmitters (Ramstad and Woody 2003). Because of these factors, esophageal tags are preferred in studies of adult salmonids (Eiler 1990; Burger et al. 1995; Ramstad and Woody 2003), and we feel confident our choice of esophageal transmitters minimized potential biases in our stream life estimates.

In general, capture and handling of fish has been shown to cause stress and alter behavior and migration (Bendock and Alexandersdottir; 1993; Bernard et al. 1999; Makinen et al. 2000). Additionally, studies have indicated if a salmon is going to regurgitate a transmitter it is likely to do so shortly after capture (Ramstad and Woody 2003; J. H. Eiler, National Marine Fisheries Service, personal communication). To avoid these biases many researchers do not include a fish in their data analysis unless it passes a data logger some distance upstream (J. H. Eiler, National Marine Fisheries Service, personal communication). However, this was not an option at McNeil River where most spawning occurs within 1.5 km of the ocean. Therefore, to avoid biasing our estimates of stream life, due to potentially increased vulnerability to predation from handling, as well as regurgitation of transmitters, a chum salmon had to remain active for 24 h post tagging to be used in our analysis.

The importance of stream life in AUC calculations is well recognized in the literature (English et al. 1992; Irvine et al. 1993; Hill 1997; Bue et al. 1998; Lady and Skalski 1998; Hilborn et al. 1999; Manske and Schwarz 2000; Parken et al. 2003), and a variety of techniques have been employed to estimate stream life. Neilson and Geen (1981) identified individual females visually based on redd position and distinctive markings. From these observations they estimated stream life on the spawning grounds. Eggers (1984) tried to address AUC biases by comparing the ratio of live to dead fish to estimate a correction factor for stream life.

Another common technique for estimating stream life has been to tag salmon with external visual tags, and then conduct regular foot surveys to recover tagged fish as they die (Ames 1984; Thomas and Jones 1984; Dangel and Jones 1988; Fukushima and Smoker 1997). However, this technique is not practical in many places where stream length or long upstream migrations would prevent tag recovery. At McNeil River, chum salmon moved into many inaccessible areas and migrated as far as 19.5 km upstream. Additionally, bears in the lower river ate almost every available fish, even post-spawning (Chapter 2). If only visual tags had been used, detection of dead fish would have been marginal at best and this technique would not have worked well at McNeil River or in other systems with high predation.

Stream life has also been estimated using mark-recapture models (Lady and Skalski 1998; Manske and Schwarz 2000). Using this technique fish are captured at distinct occasions and then recaptured until no more tagged fish are observed. Again this technique would not work well in rivers where salmon migrate any significant distance upstream because the recapture work required would be logistically unfeasible. In addition, in areas where bears are removing a large percentage of the salmon, such as at McNeil River, data would be highly biased because the probability of recapture would not be the same as the probability of capture.

Shardlow (2004) used time-lapse video equipment to determine stream life of sockeye salmon on their redds. However, this required a relatively small shallow area, conducive to video detection. In general most of the methods described above are restricted to small, shallow, short streams with limited removal of fish by predators. As this is not the case in many coastal streams, telemetry equipment then becomes a viable option to determine time of mortality and thus stream life.

The results of our retrospective analysis indicate current escapement indices for McNeil River are under representing actual escapement by approximately 250%. By refining the estimated stream life value and applying an observer efficiency correction factor in the AUC model, we have moved from an index closer to an actual estimate of escapement. Therefore, the current escapement goal of 13,750-25,750 should be recalculated and revised using our new estimates of historic escapement. Applying the same method used to derive the current escapement goal of 13,750-25,750 (Bue and Hasbrouck 1991) resulted in a new revised escapement goal of 30,000-64,000 chum salmon. It should be clearly pointed out here that this is not an increase in the suggested escapement goal, but only a more accurate reflection of the actual size of the chum salmon run in McNeil River. This new framework is important because it allows for a more complete analysis of the magnitude of bear predation at McNeil River and thus allows us to estimate an appropriate spawning escapement goal (Chapter 2).

Various techniques have been used to estimate stream life in order to improve escapement estimates using visual surveys. The methods presented in this paper demonstrate an effective technique for obtaining accurate estimates of stream life in large rivers with poor accessibility, and high removal of salmon by predators such as bears.

1.7 Acknowledgements

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1.9 Tables

Table 1.1. Tagging schedule of chum salmon at McNeil River, Alaska.

Date	# of Tags in 2005	# of tags in 2006	% of Tags Deployed	Cumulative Total
24–30 June	7	10	14%	14%
1-7 July	15	21	30%	44%
8-14 July	19	26	38%	82%
15-21 July	7	10	14%	96%
22-28 July	2	3	4%	100%

1.10 Figures

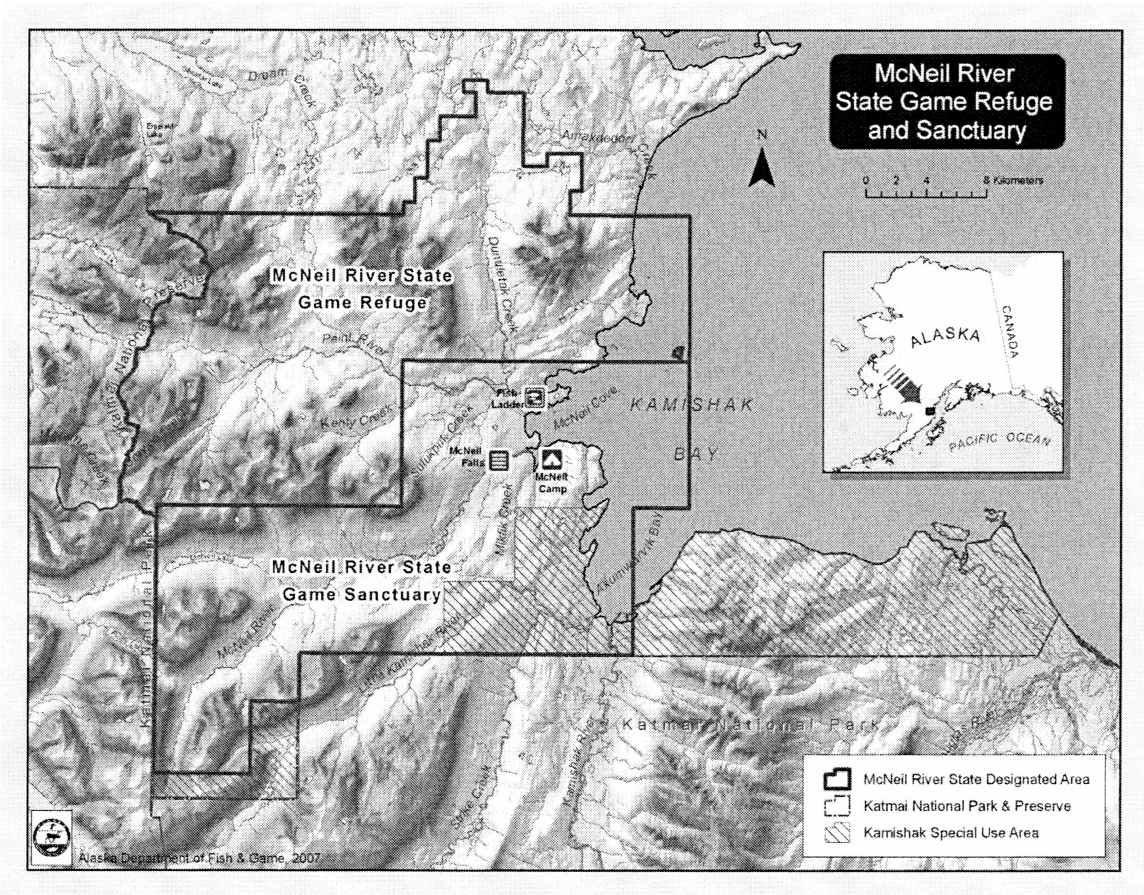

Figure 1.1. Area Map of MRSGS, Alaska.

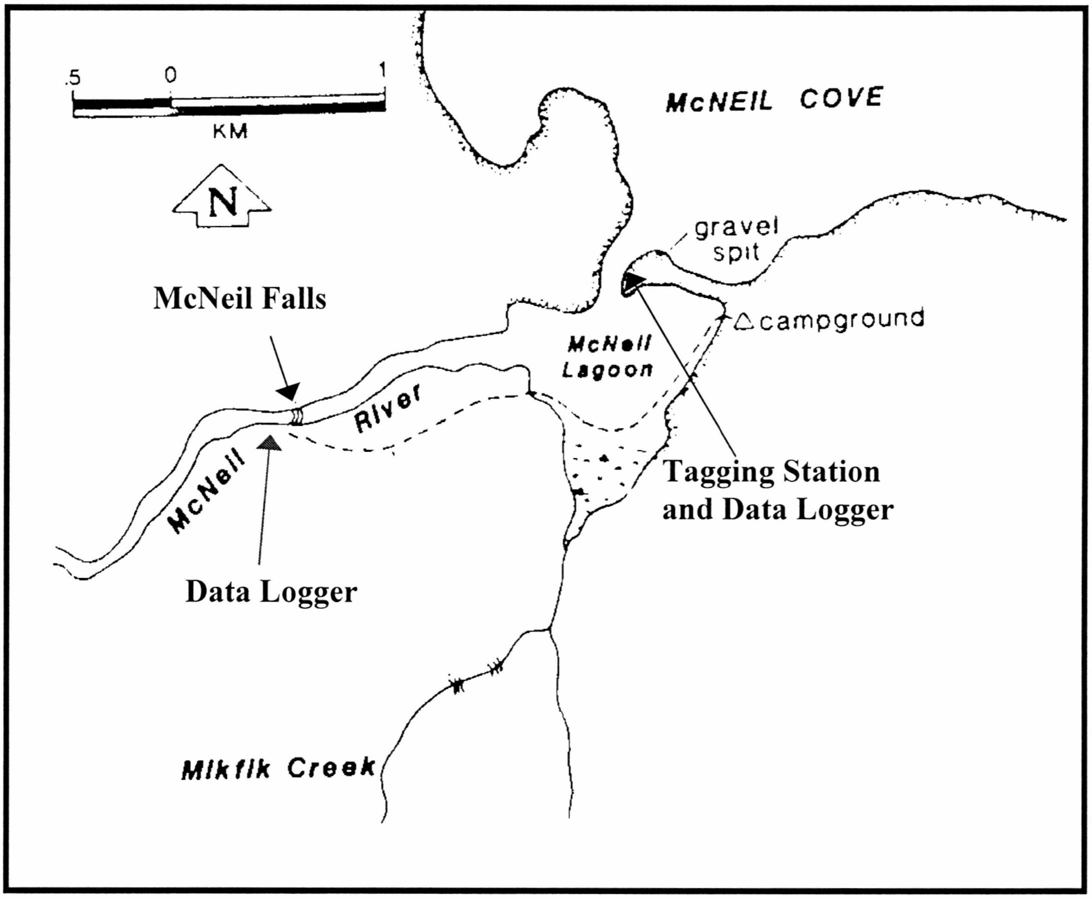

Figure 1.2. Detail of lower McNeil River and Lagoon, MRSGS, Alaska.

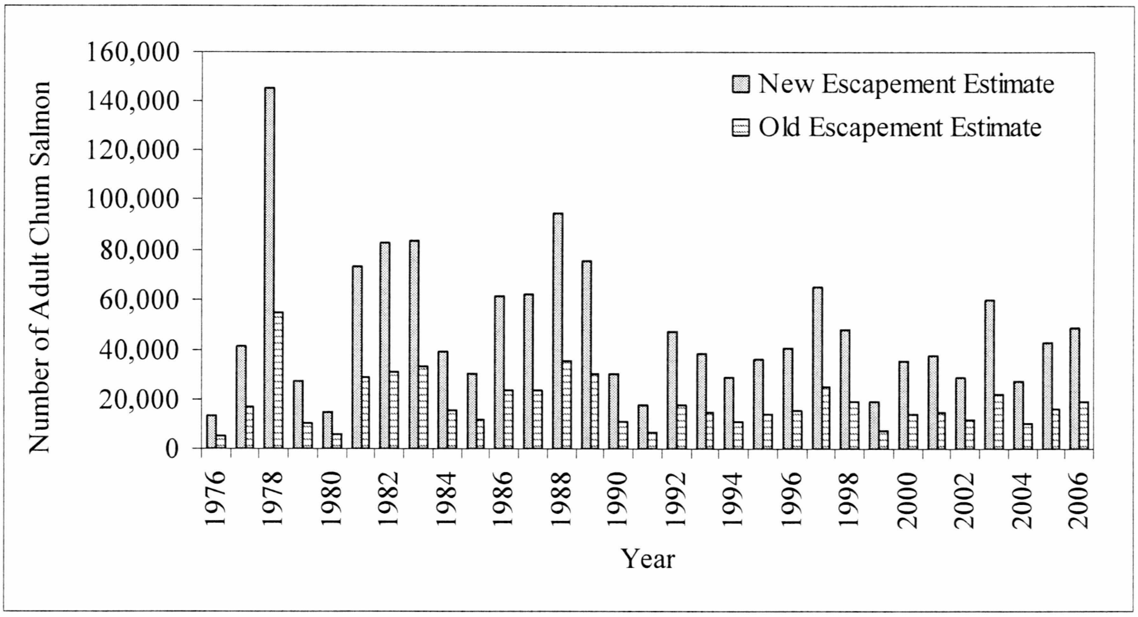

Figure 1.3. A comparison of chum salmon escapement at McNeil River, Alaska, 1976-2006.

Chapter 2. Management of chum salmon for brown bears and other fish and wildlife at McNeil River, Alaska[1]

2.1 Abstract

Salmon (*Oncorhynchus spp.*) are an important food resource for many wildlife species in Alaska, including bears (*Ursus spp.*). Since 1967, the McNeil River State Game Sanctuary has been managed by the Alaska Department of Fish and Game to provide permanent protection for brown bears (*Ursus arctos*). Few places in the world provide such a dramatic example of how direct the relationship between bears and salmon can be. Chum salmon (*Oncorhynchus keta*) provide the principal food resource for the extraordinarily large number of brown bears that gather annually along lower McNeil River. Up to 144 bears have been identified in one year and 72 have been seen at once in the vicinity of McNeil Falls. However, consistently low chum salmon escapements into McNeil River since 1988 have led to annual closures of the commercial fishery and are implicated as a factor contributing to a recent decline in bear numbers at McNeil Falls. In 2005 and 2006, 155 chum salmon were radio tagged and tracked daily to monitor time and cause of death. Chum salmon capture rates by bears at McNeil Falls were also recorded over the same time period. Below the falls, we estimated bears

[1] Peirce, J.M., E.O. Otis, M.S. Wipfli and E.H. Follmann. 2007. Management of chum salmon for brown bears and other fish and wildlife at McNeil River, Alaska. Prepared for submission in Ursus.

consumed 99% of all tagged fish, killing 48% of them before they spawned. We recommend an additional 23,000 chum salmon be added to the escapement goal at McNeil River to account for this pre-spawning mortality. Obtaining optimal spawning escapement should both ensure a reliable food resource for McNeil River bears as well as maintain high chum salmon productivity. Finally, this project may also serve as a model for other systems throughout Alaska where salmon escapement goals may not be adequately accounting for broader wildlife and ecosystem needs.

2.2 Introduction

McNeil River State Game Sanctuary (MRSGS) has gained fame because of its uniquely high concentration of brown bears (*Ursus arctos*) (Sellers and Aumiller 1994). MRSGS was created by the Alaska State Legislature in 1967 to "provide permanent protection for brown bears and other fish and wildlife populations and their habitats, so that these resources may be preserved for scientific, aesthetic, and educational purposes" (Alaska Department of Fish and Game 1996). When compatible with this objective, other human uses, such as bear viewing, fishing, and temporary safe anchorage are permitted (Alaska Department of Fish and Game 1996). For example, when human visitation in the early 1970's was found to be having an adverse effect on the number of bears, a permit system was established to limit visitation (Faro 1974). MRSGS is currently managed by the Alaska Department of Fish and Game (ADF&G) Division of Wildlife Conservation to maintain a high concentration of brown bears and provide for bear viewing opportunities (Aumiller and Matt 1994).

Chum salmon (*Oncorhynchus keta*) provide the principal food source for the extraordinarily large number of brown bears that aggregate annually at McNeil River Falls. Few places in the world provide such a dramatic example of how direct the relationship between bears (*Ursus spp.*) and salmon (*Oncorhynchus spp.*) can be. As many as 144 individual bears have been identified at MRSGS during a single year and up to 72 bears have been in view at one time in the vicinity of the falls in July (Meehan 2003).

Predator-prey relationships are fundamentally important ecological processes because of their consequences for community structure (Paine 1966, Sanford 1999), biodiversity (Henke and Bryant 1999), and life history evolution of both predators and prey (Stearns 1994, Gende 2002). The identification and understanding of such processes is of growing importance as anthropogenic pressure on ecosystems increases (Gende 2002).

Aquatic and terrestrial ecosystems are usually studied separately by different researchers (Willson and Halupka 1995). In some regions, however, it is clear that the ecological interactions between the two ecosystems are central to regional ecology (Willson and Halupka 1995). Willson and Halupka (1995) submitted that interactions between anadromous fish and terrestrial wildlife are important to regional biodiversity and deserve a far greater consideration in land management schemes, fisheries management practices, ecosystem management plans, and studies of ecosystems than they have received in the past.

When salmon migrate from the ocean to their natal streams to spawn they transport marine nutrients to freshwater and terrestrial ecosystems (Wipfli et al. 1998, Hilderbrand et al. 2004). Wipfli et al. (2003) found a positive relationship between the presence of salmon carcasses and growth rates of juvenile salmonids. Wipfli et al. (1998, 1999) also found increased spawner densities resulted in increased lower trophic level productivity which benefited juvenile salmonids and ultimately freshwater salmon production.

Food webs involving salmon and predators are complex and important (Willson et al. 1998). Salmon have been suggested as a keystone species (Willson and Halupka 1995, Knudsen et al. 2000), and the importance of the predator-prey relationship between bears and salmon in ecosystem processes is receiving increased study (Gende 2002).

Perhaps the most important mechanism for dissemination of salmon nutrients to terrestrial ecosystems is by bear predation (Gende 2002). Bears can distribute large amounts of salmon biomass throughout the riparian zone in 2 major ways. First, bears often carry them into the uplands, where the salmon may be only partially consumed, or second, via the deposition of digested fish in urine and feces (Gende 2002). Hilderbrand et al. (1999a) showed the importance of brown bears as a vector of marine derived nutrients to riparian areas and estimated that an average female brown bear on the Kenai Peninsula deposits 37.3 kg of marine derived nitrogen into the terrestrial ecosystem each year.

In addition to the ecological consequences of bear-salmon interactions, the functional importance of salmon to bears has been recently quantified (Gende 2002).

Salmon are relatively high in energy compared to alternative foods (Welch et al. 1997, Rode et al. 2001) and the nutritional importance of salmon to bears is well documented (Hilderbrand et al. 1999b and 1999c, Ben-David et al. 2004, Gende and Quinn 2004, Hilderbrand et al. 2004). The availability of high quality food resources, such as salmon, has been shown to be an important factor in successful denning (McCarthy 1989, Farley and Robbins 1995, Barboza et al. 1998) and can impact the timing of den emergence (Kitchinksi 1972, Schoen et al. 1987, Van Daele et al. 1993). On the Kenai Peninsula, Alaska, salmon have been shown to be the single most important resource to female brown bears as they prepare to meet the demands of hibernation and cub production (Hilderbrand et al. 1999b).

Brown bears with access to salmon achieve heavier body weights, produce larger litters, and are found at higher population densities than bears without access to salmon (Hilderbrand et al. 1999c). Conversely, in bears without access to high quality food resources, such as salmon, both the age at first reproduction, and the interval between litters are increased (Bunnell and Tait 1981, Rogers 1987, Stringham 1990a and 1990b).

Chum salmon returns to McNeil River have been poor and, despite annual closures to commercial fishing, the management goal for escapement (the total number of salmon that enter the river) has been met only 6 times in the last 18 years (Hammarstrom and Dickson 2007). The original decline of chum salmon at McNeil River in the late 1980's coincided with a general decrease of chum salmon in many Cook Inlet streams. These low returns persisted for a decade; however chum salmon escapements to nearby streams in the surrounding Kamishak District have now been strong for the past 7 seasons

(Hammarstrom and Dickson 2007). This suggests poor ocean survival is not the cause for the recent low returns to McNeil River.

Assurance of a predictable and continuous food resource is an important factor in maintaining consistent bear use of an area (Aumiller and Matt 1994, Peirce and Van Daele 2006). Concurrent with reduced chum salmon returns, bear numbers at MRSGS have also declined. In 2005 bear index counts fell below the minimum bear threshold criterion (MBTC) for the 7th consecutive season. The MBTC was established in 1993 (ADF&G 1993) to provide a systematic method to objectively measure and monitor bear activity at McNeil Falls.

Establishing appropriate escapement goals for individual salmon stocks comprises the foundation of sustainable salmon fisheries management (Knudsen et al. 2003) and requires an understanding of spawning escapement (the number of salmon that enter a river and spawn). Traditional approaches to establishing escapement goals rely on spawner-recruit models. These models generally focus on identifying escapement levels that produce a theoretical maximum sustainable yield (MSY) (Hilderbrand et al. 2004), and are based on the ratio of spawning adults to the number of recruits from the spawning cohort which return in subsequent years. While such models can be informative, their effectiveness relies on a long time series of accurate data (e.g., age data for brood tables, accurate measures of escapement, and pre-spawning mortality), which are not always available. Spawner-recruit models also may not adequately account for the potential nutrient feedback to juvenile salmon production made possible by escapements larger than MSY-based models recommend (Knudsen et al. 2003). Furthermore, traditional models do not directly account for the ecosystem benefits provided by surplus spawners (Cederholm et al. 2000, Quinn and Buck 2000).

While consideration of ecosystem needs is becoming increasingly recognized as an important factor in establishing sustainable escapement goals for salmon stocks (Cederholm et al. 2000, Knudsen et al. 2003, Michael 2003, Hilderbrand et al. 2004), it is difficult to find examples where this recommendation has been put into practice. Knudsen et al. (2000) argued that a shift in management is needed from a philosophy of managing individual parts to management of entire systems.

Fish stocks are unique and cannot be managed successfully without taking into consideration the context of the watersheds they inhabit (Williams 2000). Where the conservation of healthy ecosystems is the management objective, an allowance of salmon for wildlife should be considered (Hilderbrand et al. 2004). In this paper we argue that effective management of the McNeil River chum salmon fishery should include the following considerations. First, brown bears represent a major source of mortality to pre-spawning chum salmon at MRSGS. Therefore, the escapement goal for McNeil River should explicitly incorporate this mortality. Second, a minimum escapement above McNeil Falls may be necessary to ensure high production of chum salmon as well as provide a reliable food resource for brown bears and other fish and wildlife at MRSGS.

2.3 Study Area

Located along the shores of Kamishak Bay on the Alaska Peninsula, MRSGS is approximately 340 km southwest of Anchorage and 160 km west of Homer (Figure 2.1).

MRSGS encompasses both the McNeil River and Mikfik Creek drainages and is approximately 51,800 ha. Immediately to the north of MRSGS is the McNeil River State Game Refuge. To the south and west are Katmai National Park and Preserve, and to the east is the Kamishak Special Use Area.

McNeil River originates from two branches, one glacially-fed and the other lake-fed. From the confluence of these two branches, downstream to McNeil lagoon, the river is 20.7 km long. There is high quality chum salmon spawning habitat available below the confluence in the lower 20 km of the river. The distance from the headwaters of the glacially-fed branch to the lagoon is 36.6 km. The distance from the outlet of McNeil Lake to the lagoon is 25.5 km.

Virtually all of the human and bear activity occurs in the lower 1.5 km of Mikfik Creek, McNeil River and around McNeil Lagoon and Cove. McNeil Lagoon is formed by a long spit which nearly separates it from McNeil Cove and the larger Kamishak Bay (Figure 2.2). McNeil River and Mikfik Creek both drain into the lagoon which is flooded at high tide and channeled mud flats at low tide.

Bears begin to arrive at MRSGS in late May and concentrate their feeding activities on the protein rich sedge (*Carex lyngbeii*) flats until the Mikfik Creek run of sockeye salmon (*Oncorhynchus nerka*) begins in early June. In late June to early July bear activity gradually shifts to the larger McNeil River for the chum salmon run which lasts into mid August. During the peak of the chum salmon run in mid to late July, bears are concentrated in the vicinity of McNeil Falls, 1.6 km upstream of the lagoon. Here salmon are made vulnerable by a cascading series of rapids formed from eroded conglomerate rock as they rest in pools or attempt to ascend the falls. By late July to early August chum salmon which have not successfully ascended the falls begin to drop back to lower McNeil River, including the tidally influenced areas to spawn. The activity of bears follows the chums and they shift their fishing effort from the falls to the shallow spawning grounds. During both the sockeye and chum salmon runs, salmon are heavily preyed upon in the lagoon and cove by harbor seals (*Phoca vitulina*) at high tide, and bears at low tide. By late August most chum salmon have spawned and died, and bear activity at MRSGS substantially diminishes (personal observations).

2.4 Methods

Field work was conducted June through August in 2005 and 2006. Individual bears were visually identified by distinguishing characteristics and behavior, and bear use days at McNeil Falls were recorded. This included the total number of adult males, adult females, adult females with offspring and sub adults. Every individual bear observed on any given day represented 1 bear use day. For example, if the same bear was present at the falls 2 days in a row that would represent 2 bear use days.

From approximately 5 July to 5 August during both field seasons, daily observations were made at McNeil River Falls to estimate the number of chum salmon captured by bears at the falls. Chum salmon captured by bears were recorded during continuous half hour scans from approximately 12:00-19:00 hours daily. In total, the number of chum salmon captured by bears at the falls has been recorded for 16 of the past 31 years using similar methods (P. Hessing, ADF&G retired, unpublished data).

These data allowed us to estimate the minimum number of pre-spawning chum salmon captured at the falls for those years. For each year the average hourly catch rate was multiplied by 14 h to estimate a minimum number of fish removed per day. This was then multiplied by 30 days to provide a conservative, estimated seasonal total of chums removed at the falls. A long term average removal at the falls was then calculated for the 16 years of data available.

Chum salmon were captured at the end of the spit using rod and reel, and fitted with ATS esophageal radio transmitters with mortality signals (Chapter 1). All chums were tracked daily using a 3-element folding yagi antenna and an ATS R4500 receiver. Transmitters were recovered from dead fish as soon as possible. Only salmon that lived for > 24 h post tagging were used for analysis (Chapter 1). A high priority is placed on not disturbing bears at MRSGS and, when combined with safety issues, it was not always possible to recover transmitters immediately.

Whether a tagged chum salmon was eaten by bears or harbor seals, the radio transmitter was all that was recoverable (except in 1 case). Therefore, the cause of death for each radio tagged fish was based on the location of the transmitter when it was recovered, and any other available evidence. Cause of death was categorized as bear, unknown (bears or seals) or post-spawning senescence. In cases where only a transmitter was found, we used the following assumptions to determine whether or not the fish had spawned. The average stream life of McNeil chum salmon above the falls was 21.9 days (Chapter 1) and all fish above the falls that lived longer than 20 days were assumed to have spawned. All fish above the falls that lived at least 7 days and died after 15 July, the approximate date of the onset of spawning, were also assumed to have spawned. All other fish were considered to have been killed by a bear prior to spawning.

Chum salmon do not spawn at the falls, so all fish that died at the falls were assumed to be pre-spawning fish that were killed by bears. All chums below the falls that lived longer than 20 days were assumed to have spawned. All fish below the falls that died after 25 July, and lived more than 7 days were considered to have spawned. All other fish below the falls were considered to have been killed prior to spawning.

Individual bear identifications have been recorded at MRSGS since 1969, and data for bear use days were available from 1976 to 2006. Chum salmon escapement has been monitored since 1959, and consistently collected aerial survey data sufficient to estimate annual escapements were available from 1976 to 2006 (Chapter 1). To evaluate how important upriver spawning was to stream-wide production of chum salmon, we regressed the total number of chum salmon that escaped above the falls against stream-wide total returns in subsequent years. Stream-wide returns in subsequent years were based on 8 years of age composition data for McNeil River chum salmon, and we assumed that 40% of all fish return as 4 year olds, 57% as 5 year olds and 3% as 6 year olds. Finally, a Ricker stock recruit model was used as a comparison to the new recommended escapement goal for McNeil River. The stock recruit analysis used spawning escapement data (total escapement minus 48% pre-spawning mortality) from 1976-1992.

2.5 Results

Bear use days at McNeil Falls were similar in 2005 and 2006. In 2005 there were 804 bear use days at McNeil Falls during the month of July. Observations were recorded over 28 days for an average use of 29 bears per day. In 2006, 665 bear use days were recorded over 25 days for an average bear use of 27 bears per day. The last year average bear use days were this low was in 1983 (Figure 2.3).

In 2005, 2,332 adult chum salmon were observed being captured by bears at the falls in 167 h of observation (14 chums/hour). In 2006, 2,504 adult chum salmon were observed being captured by bears at the falls in 147.5 h of observation (17 chums/hour). Simple linear regression showed a positive relationship between catch rates and annual total escapement ($n=16$, $R^2=0.46$, $p<0.01$). A positive relationship was also found between catch rates and bear use days at the falls in July ($n=16$, $R^2=0.64$, $p<0.01$) (Figures 2.4 and 2.5). For the 16 years of data available at the falls the estimated number of pre-spawning chums captured ranged from 4,720-19,309 and averaged 23% of the total escapement.

In 2005, 97% of the tagged chum salmon that remained below the falls were consumed by bears and seals. In 2006, 100% of the tagged chum salmon that remained below the falls were consumed by bears and seals (Table 2.1). In the 2 seasons of this study, only 1 male chum salmon was found spawned out and the overall consumption rate of tagged fish below the falls was 99%. Except in 1 case it was not possible to determine if fish above the falls were also consumed, as we were not able to reach most upstream areas on foot. Therefore, using the aforementioned assumptions, we estimated what percentage of the total run was killed prior to spawning.

In 2005, we estimated that 60% of the tagged chum salmon (n=42) spawned. In 2005, we estimated that 100% of the tagged fish that ascended the falls (n=3) spawned whereas only 56% of tagged fish below the falls (n=39) spawned. In 2006 there was again an estimated 60% spawning success stream-wide for all tagged chum salmon (n=62), with 88% (n=45) and 49% (n=17) spawning success above and below the falls, respectively. For both years, the percentage of tagged chum salmon spawning successfully was 60% stream-wide, and 90% and 52%, above and below the falls, respectively (Table 2.1).

Stream-wide production of chum salmon showed a positive correlation with increased escapement above the falls (Figure 2.6), and escapement above the falls was positively correlated with increased in-river escapement (Figure 2.7).

A Ricker stock recruit model using estimates of spawning escapement showed a spawning escapement of 18,000-37,000 should result in the greatest production of adult chum salmon in McNeil River. The current revised escapement goal at McNeil River is 30,000-64,000 chum salmon (Chapter 1).

2.6 Discussion

Bears represent the largest and most widely distributed terrestrial predator of salmon (Reimchen 2000), and they can have a large impact on salmon returns (Shuman 1950) in local streams. Salmon consumption rates by bears vary greatly depending on the size of the stream and the numbers of bears and salmon (Reimchen 2000). For example, Shuman (1950) reported that bears killed 31% of pre-spawning salmon in Moraine Creek on Kodiak Island, Alaska. Clark (1959) estimated bear take of salmon from all Kodiak streams ranged from 1%-30% of the total escapement. Gard (1971) estimated 32%-79% of salmon were killed by bears, with 13%-17% of females killed pre-spawning in a tributary of Karluk Lake, also on Kodiak Island. Frame (1974) estimated that 18 black bears (*Ursus americanus*) ate 15% of all pre-spawning female chums in Olsen Creek, Prince William Sound, Alaska.

In more recent work, Quinn and Kinnison (1999) estimated 71% of the salmon they examined near Illiamna Lake, Alaska, were killed by bears, while only 29% had died of senescence. Quinn et al. (2001) found over 13 years, 46% of pre-spawning salmon were killed in Hansen Creek and over 12 years 37% were killed in Pick Creek, both in Bristol Bay, Alaska. Reimchen (2000) estimated 74% of the entire run in a small coastal stream in British Columbia was consumed by bears. Ruggerone et al. (2000) estimated 44%-54% of all female salmon in Hansen Creek, Alaska were killed by bears prior to spawning, and Dickerson et al. (2002) found that predation accounted for 97% of pre-spawning mortality on Himmel Creek, in Southeast Alaska.

Various techniques have been used in the past to investigate the pre-spawning mortality of salmon caused by bears. Shuman (1950) used data from a weir where all salmon were counted as they passed upstream. Salmon that died and washed back down to the weir were examined to see if they had been killed pre-spawning, or died post-spawning. If more than half the eggs were left in a fish then it was recorded as having died pre-spawning. If Shuman was unclear as to the cause of death it was recorded as "natural causes".

Frame (1974) was able to observe 98% of the entire salmon spawning area at Olsen Creek, and he could visually determine the sex and spawning status of each fish caught by bears. Gard (1971) conducted stream walks and investigated all dead salmon up to 100 m from the bank to determine cause of death. He defined an un-spawned sockeye female as one with more than 1100 eggs. Using egg count as a measure of spawning status is highly biased, however, as bears will often preferentially consume eggs.

Marking salmon and then recovering carcasses has also been a common technique for estimating bear-caused mortality. Hanson (1992) marked salmon with stainless steel jaw bands and then recovered carcasses to determine if they had spawned. Quinn et al. (2001, 2003) marked salmon with unique disc tags. Investigators then walked the streams daily to recover salmon and determine if each fish had died of senescence or been killed by bears.

These techniques were possible only because bears were high-grading (consuming only certain parts) salmon and leaving body parts. Additionally, it must be recognized that all of these techniques underestimated actual bear-related mortality because some of the salmon were completely eaten or carried into upland areas and not found. We faced an even greater challenge at MRSGS where, in the 2 years of this study, 99% of all tagged fish below the falls had been consumed entirely by the time we located them. Because there was usually no carcass to recover, we were not able to determine spawning status by physical examination. It was only through the use of radio telemetry that we were able to estimate each tagged salmon's final fate. Our tagged chums were typical of the situation along McNeil River where carcasses are rarely found. With the intensive fishing of the lower river by bears, and the limited salmon availability in recent years, pre- and post-spawning salmon alike were captured and consumed entirely.

Complete consumption of carcasses by bears can be indicative of scarce salmon resources (Quinn and Buck 2000) or difficulty in capturing them due to river size (Gende et al. 2004). In many instances though, such as where there is easy access to salmon, the majority of carcasses are not fully consumed, and bears are highly selective (Quinn and Buck 2000, Gende et al. 2004). As the availability of salmon decreased, Gende et al. (2001) found that bears consumed larger portions of each fish they captured. Conversely, when availability was high they consumed less biomass per captured fish, but instead targeted energy rich fish (those that had not spawned) and energy rich parts (eggs in females and brains in males). In years of high salmon abundance, bears at McNeil River have also been commonly observed high-grading, and there are more salmon carcasses and parts scattered along the river (L.D. Aumiller, ADF&G retired, personal communication).

Even when feeding on a highly digestible and easily acquired food such as salmon, bears will modify their consumption choices to maximize lipid intake (Gende 2002). By selectively consuming high lipid body parts they are able to put on additional fat when salmon are abundant (Gende 2002). Gende (2002) speculated that high-grading may be due to gut fill; i.e. bears can only eat so much, and therefore they optimize foraging behavior by avoiding low energy parts.

Gende (2002) measured nutritional values of chum salmon and found eggs had the highest lipid content of any body part, followed by brains and finally muscle tissue. Skin, another high lipid content component of salmon, was not measured. Gende et al. (2004) showed that chum salmon contain up to 85% more lipid and 40% more protein when they enter a stream than at senescence. Collectively, the energy content of chum salmon at entrance into fresh water was 5.2 and 5.5 kj/g, but decreased to 3.2 and 3.5 kj/g at senescence (a loss of about 37%) for males and females, respectively (Gende 2002).

The maintenance cost of an active 160 kg female brown bear is 42,000 kj per day (Gende 2002). Assuming 95% of a salmon carcass is digestible and a conversion efficiency of 90% (Pritchard and Robbins 1990, Farley and Robbins 1995), Gende (2002) calculated consumption of a 3.6 kg female chum salmon just entering fresh water would yield 18,800 kj. An average senescent female chum with a mass of 2.8 kg would yield 9300 kj. Thus a bear would need to eat nearly twice as many senescent chums (4.2) as fresh chums (2.1) to meet daily maintenance needs (Gende 2002). McNeil River chum salmon are similar in size to those studied by Gende (2002), have a short migration and should therefore be similar in energy value.

Gende (2002) estimated selective consumption of chum roe from an average 4 kg female would yield 800 g of eggs, worth approximately 5608 kj. Considering a typical bear can consume 12-20% of its body weight daily (Hilderbrand et al. 1999b), Gende (2002) went on to estimate a 160 kg female could therefore consume 19-32 kg of biomass per day. If high-grading, and consuming only roe, this female would need to kill 23-40 female chums, and would realize an intake of 123,000 kj or almost 300% of maintenance (Gende 2002). At McNeil River large males weighing 450 kg are common. Using these same values a single large adult male eating only roe could consume 67-112 females per day. Observations of bears at the falls corroborate these calculations and, on 27 July 1987, 1 large male was observed killing and partially consuming 90 individual chum salmon (L.D. Aumiller, ADF&G retired, personal communication).

We used 3 approaches to estimate the number of pre-spawning chum salmon removed annually from McNeil River. The first was based on information collected on the Kenai Peninsula by Hilderbrand et al. (2004). In this study they estimated 1,003 kg of salmon were consumed by brown bears/year. This was then multiplied by the total number of bears in the study area to estimate the biomass (kg) of salmon consumed per season. The biomass consumed per season was divided by the average weight of a sockeye salmon to arrive at total fish. Total fish were then divided by 55% which Hilderbrand et al. (2004) assumed to be the average amount of each salmon consumed. From this they estimated a population of 262 bears could eat 128,000 3.7 kg sockeye with 92% of them being pre-spawning.

In the summer of 1997, 144 individual bears were identified at MRSGS. Using Hilderbrand et al.'s (2004) example, these bears at McNeil could have consumed 60,398, 4 kg pre-spawning chum salmon. Assuming no high-grading as has been the case in recent years at McNeil, this number would have been closer to 33,219, 4 kg pre-spawning chum salmon. Using historic bear use data and this approach, an average of 21,655 (range 13,380-33,219) pre-spawning chum salmon were removed from McNeil River from 1976-2006. These calculations provide a useful, but, coarse comparison as Hilderbrand et al.'s (2004) data were based entirely on females. At McNeil there are many large male bears who can consume considerably more biomass. Additionally, the McNeil season is only 1.5 months long compared to 2.5 months in Hilderbrand et al.'s (2004) work (G.V. Hilderbrand, ADF&G, personal communication).

The second approach to estimating the number of pre-spawning salmon removed annually was based on direct observations of chum salmon captured at McNeil Falls. In 2005 and 2006 an estimated 5,864 and 7,130 pre-spawning chums were captured respectively. Data were also available for 14 additional years, and the long term average removal of pre-spawning chum salmon at McNeil Falls over 16 years was 23% (range 13%-44%). This represents only a portion of the pre-spawning mortality, however, as a considerable number of chums were also removed from other areas of the lower river and lagoon. Using historic escapement data from 1976-2006 and an annual removal of 23%, we estimate bear-induced mortality at the falls alone averaged 11,081 pre-spawning chum salmon (range 3,033-33,335).

The third approach to estimate the number of pre-spawning chum salmon removed used the telemetry data collected as part of this research. This estimate encompassed the entire river, and suggests that 48% of the all chums below the falls were removed by bears prior to spawning in 2005 and 2006. At this level of removal an average of 23,127 pre-spawning chum salmon below the falls were removed per year from 1976-2006 (range 6,330-69,568).

Chum salmon are strong swimmers, but are not particularly strong leapers, and are usually found below the first barrier of any significance (Salo 1991). They prefer areas of upwelling for spawning (Salo 1991) and a preliminary investigation of spawning habitat in the lower 19 km of McNeil River revealed considerable suitable habitat is available above McNeil Falls (E. Otis, ADF&G, personal communication). While the vast majority of chum salmon are confined to the 1.6 km of river below McNeil Falls only about half of that area, ~860 m (52,000 m^2), is suitable for spawning. This represents only a small proportion of the spawning habitat available in McNeil River and the vast majority (~95%) of available spawning habitat exists above McNeil Falls.

Schroder (1973) investigated optimal spawner densities for chum salmon in a controlled channel and reported optimal densities of 1.7 m^2/female or 0.6 females/m^2. Given the estimated amount of spawning habitat available below the falls, this suggests that 31,200 chums may be the optimal density of spawners, and, with increasing densities there may not be an increase in successful egg deposition.

While the overall contribution of spawners above the falls vs. below the falls is difficult to determine with currently available data, it is quite clear that chum salmon spawning below the falls are faced with significant challenges. Although chum salmon regularly spawn in intertidal areas, survival of eggs and alevins has been shown to decrease from the upper to lower areas of the intertidal zone (Salo 1991). Chum and pink (*Oncorhynchus gorbuscha*) salmon both spawn in the same areas below McNeil Falls and because chums return earlier than pinks, there is likely considerable interspecific redd superimposition. Additionally, early-run chum salmon are more likely to have their redds reused by another female (McPhee and Quinn 1998), and at high spawner densities female chums have been shown to retain more eggs (Salo 1991). Even disregarding the substantially higher predation rates observed below the falls, these factors alone suggest that the potential production of salmon below the falls may be much lower than that above the falls.

There is heavy predation on chum salmon by bears in both freshwater and inter-tidal areas below McNeil Falls. Additionally, at high tide there is predation from seals in the lagoon and lower river. Spawning chums are disturbed nearly continuously by fishing bears in the shallow spawning areas below the falls, which may affect egg retention and spawning success. Finally, the mechanical disturbance of the gravel by bears fishing the spawning beds, as well as by other spawning females, may cause higher egg mortality.

It is difficult to tease out what percentage of the escapement in any year may have originated from above the falls vs. below the falls. However, our retrospective analysis of reach-specific escapement revealed a significant positive relationship between the number of chum salmon that escaped above the falls and subsequent returns associated with that brood year. In the 2 years of this study 90% of the tagged chum salmon (n=20) that made it above McNeil Falls lived long enough to spawn. In contrast we estimate that only 52% of all chum salmon (n=84) below the falls lived long enough to spawn.

When considering the high bear induced mortality, high densities of spawners and limited spawning areas below the falls, it appears likely that escapement above the falls may contribute disproportionally to the stream-wide production of chum salmon at

McNeil River. We found that in-river escapements that included more that 4,000 chum salmon above the falls resulted in the highest total returns in subsequent years. Therefore, we recommend that an escapement above the falls of this size be considered by fisheries managers on an annual basis when a commercial fishery opening is being considered.

Values in the literature for chum salmon stream life vary considerably (Thomas and Jones 1984, Perrin and Irvine 1990, Gende 2002). Because of this, considerable efforts were invested into refining the stream life value used at McNeil River to improve escapement estimates (Chapter 1). However, at McNeil average stream life does not indicate spawning success because of high predation. Because of the high variability in stream life of chum salmon among stocks (Thomas and Jones 1984, Gende 2002, Perrin and Irvine 1990), to simply use a value from the literature to determine if a salmon at McNeil River spawned or not is inappropriate. The stream life of chums above the falls was 21.9 days (Chapter 1). Two factors likely contributed to average stream life being much higher for fish above the falls compared to fish below the falls: 1) most of the chum salmon above the falls were early-run fish which tend to live longer, and 2) predation above the falls was very low. Because so few fish above the falls were killed by bears, their average stream life may best represent the potential spawning stream life at McNeil River. Therefore, our criterion of a fish with a stream life of at least 20 days having spawned is appropriate.

Late-run salmon have been shown to have a shorter stream life than early-run salmon (Ames 1984; Thomas and Jones 1984; Perrin and Irvine 1990; Manske and

Schwarz 2000) and to just use a 20 day cut off would likely over-inflate our estimates of pre-spawning mortality. Anecdotal data from hatcheries suggest chum salmon ripen and spawn within 1-2 weeks of arriving in fresh water. Therefore, we assumed all fish that lived at least 7 days, and died after the peak of spawning, spawned. While our estimates of pre-spawning mortality are based on assumptions, they are conservative assumptions. Therefore, we are confident this approach still represents a minimum level of pre-spawning mortality and does not over-state the extent of predation from bears.

Many of the same bears return year after year to fish at McNeil River (Luque and Stokes 1976). Not surprisingly, as escapement goes up so do catch rates, and as bear use days go up so do catch rates. The dynamics involved in forage rates, however, are more complex than this and factors such as social dominance can play an important role (Stonorov and Stokes 1972, Gende and Quinn 2004, personal observations). Therefore, estimating an upper limit of the number of salmon that can be captured by McNeil bears is difficult to do.

The relationship between bear use days and capture rates appears linear at McNeil. However, it is unlikely that there is an unlimited number of chum salmon that could be consumed as there are likely other ecological and social factors driving maximum bear densities at MRSGS. It remains to be seen what level of escapement would result in the number of chum salmon killed at McNeil by bears becoming asymptotic. It is clear, however, that this point has not been reached in recent years.

Of the 155 chum salmon tagged we recovered only 1 spawned out fish in 2 years. During extensive daily surveys on foot in the lower river and lagoon we found very few spawned out salmon in general. If we did find a spawned out fish it had likely just died and it was always gone the next time we passed the site. That 99% of tagged fish below the falls were consumed pre- or post-spawning is to be strongly emphasized. Based on optimal foraging theory for bears reported by Gende (2002) and observations of high-grading in many other areas (Shuman 1950, Frame1974, Quinn and Buck 2000, Gende 2002), the lack of salmon carcasses in recent years strongly suggests that the current level of escapement is insufficient to meet bear use at McNeil.

The traditional Ricker stock recruit model resulted in a spawning escapement range of 18,000-37,000. The telemetry data collected during this study suggest that 23,000 chum salmon have been removed annually at McNeil River (95% CI 18,400-27,800) over the past 31 years. Therefore, to achieve this level of spawning escapement would require a total escapement of 41,000-60,000. We feel however, this level of escapement is still insufficient to meet bear use at McNeil. For instance the total escapement in 2005 and 2006 was 42,588 and 48,500, respectively, and both of these years would have fallen within this range. However, we know from our telemetry data that during these 2 years 99% of all chum salmon below the falls were consumed and high-grading did not occur. This would suggest that bears potentially could remove an even much greater number of chum salmon as run size increased.

Stock recruit analyses are highly dependent on accurate estimates of spawning escapement. While we are confident in our estimate of 48% pre-spawning mortality in 2005 and 2006, escapement and bear use were similar in both these years. Therefore, incorporating our telemetry data with the 16 years of data collected at the falls into a predation model is recommended before the Ricker approach is used. This would account for pre-spawning mortality over a broader range of escapements and wider range of bear use.

In streams with high predation, such as the McNeil River, total in-river escapement does not represent spawning escapement. Based on a retrospective analysis of historic escapement in McNeil River the current escapement goal is 30,000-64,000 chum salmon (Chapter 1). To achieve a spawning escapement of this size an additional 23,000 chum salmon should be allowed to enter the river to explicitly account for pre-spawning mortality and our new recommended escapement goal is 53,000-87,000. Escapements of this size may also help seed upriver spawning areas and have historically resulted in escapements above the falls of 2,000-5,000 chum salmon.

On the human side of the equation there are 2 major ways in which we can affect wildlife/salmon interactions: (1) by changing the availability of salmon and (2) by changing accessibility to salmon (Hilderbrand et al. 2004). Human use at McNeil River has been highly regulated since the early 1970's (Faro 1974), and as such, most bears are not prevented by humans from accessing McNeil River chum salmon. The availability of salmon then is the one major impact that humans can potentially have at MRSGS. Salmon availability at McNeil River, however, is not at all entirely within management control as other factors such as ocean conditions, river levels, and bear activity can play a significant role in year-to-year returns. There has not been a commercial fishery in 14 years at McNeil River, and our recommended escapement goal can only be achieved once runs rebuild to higher levels.

Pre-spawning mortality in streams throughout Alaska and British Columbia due to predation is common (Quinn et al. 2001). Therefore, salmon and wildlife must be viewed as integral components of the same system (Willson and Halupka 1995, Willson et al. 1998, Hilderbrand et al. 2004). In this paper we have attempted to explicitly incorporate predation of chum salmon by brown bears into a revised escapement goal at McNeil River. We have provided a conservative estimate of pre-spawning mortality and recommend this be added to the current escapement goal. This will help ensure sufficient spawning escapement in McNeil River and encourage use of available spawning habitats by chum salmon above McNeil Falls. Future work on the relative contribution that spawning habitats above, and below the falls have on stream-wide chum salmon production at McNeil River, as well as factors influencing escapements above the falls, would be highly beneficial. These data would help refine the McNeil River escapement goal even further. Finally, this approach to fisheries management is not only important to the MRSGS ecosystem, but will hopefully serve as a model for similar systems throughout Alaska where escapement goals may not be adequately accounting for ecosystem needs.

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2.9 Tables

Table 2.1. Chum salmon mortality at McNeil River, Alaska.

2005	**Stream Wide**	**Above Falls**	**Below Falls**
Total number of fish tagged:	42	3	39
Number of tagged fish eaten by bears:	22	1	21
Number of tagged fish eaten by bears or seals:	17	0	17
Proportion of tagged fish that were eaten:	93%	33%	97%
Number of tagged fish found spawned-out:	1	0	1
Number of pre-spawning fish killed:	17	0	17
Proportion of tagged fish killed before spawning:	40%	0%	44%
Total tagged fish assumed to spawn:	25	3	22
Proportion of tagged fish assumed to spawn:	60%	100%	56%
2006	**Stream Wide**	**Above Falls**	**Below Falls**
Total number of fish tagged:	62	17	45
Number of tagged fish eaten by bears:	43	2	41
Number of tagged fish eaten by bears or seals:	4	0	4
Proportion of tagged fish that were eaten:	76%	12%	100%
Number of tagged fish found spawned-out:	0	0	0
Number of pre-spawning fish killed:	25	2	23
Proportion of tagged fish killed before spawning:	40%	12%	51%
Total tagged fish assumed to spawn:	37	15	22
Proportion of tagged fish assumed to spawn:	60%	88%	49%
2005-2006	**Stream Wide**	**Above Falls**	**Below Falls**
Total number of fish tagged:	104	20	84
Number of tagged fish eaten by bears:	65	3	62
Number of tagged fish eaten by bears or seals:	21	0	21
Proportion of tagged fish that were eaten:	83%	15%	99%
Number of tagged fish found spawned-out:	1	0	1
Number of pre-spawning fish killed:	42	2	40
Proportion of tagged fish killed before spawning:	40%	10%	48%
Total tagged fish assumed to spawn:	62	18	44
Proportion of tagged fish assumed to spawn:	60%	90%	52%

2.10 Figures

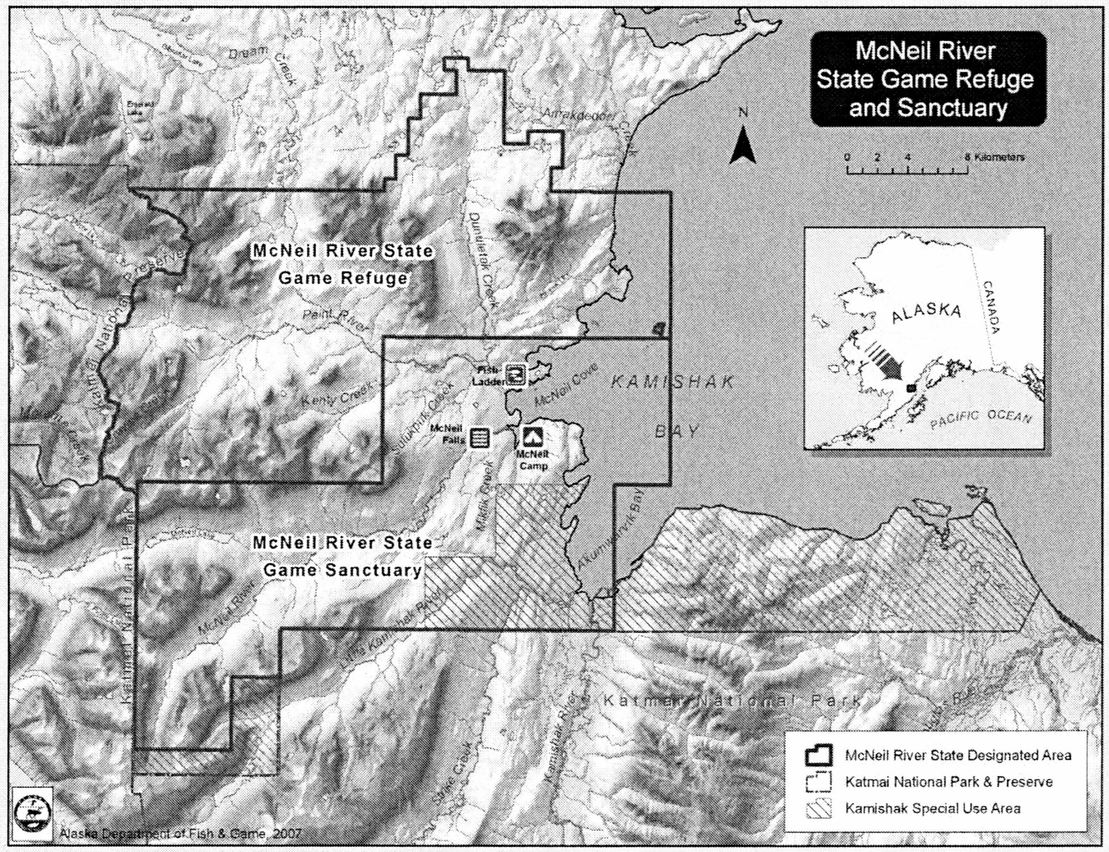

Figure 2.1. Area Map of MRSGS, Alaska.

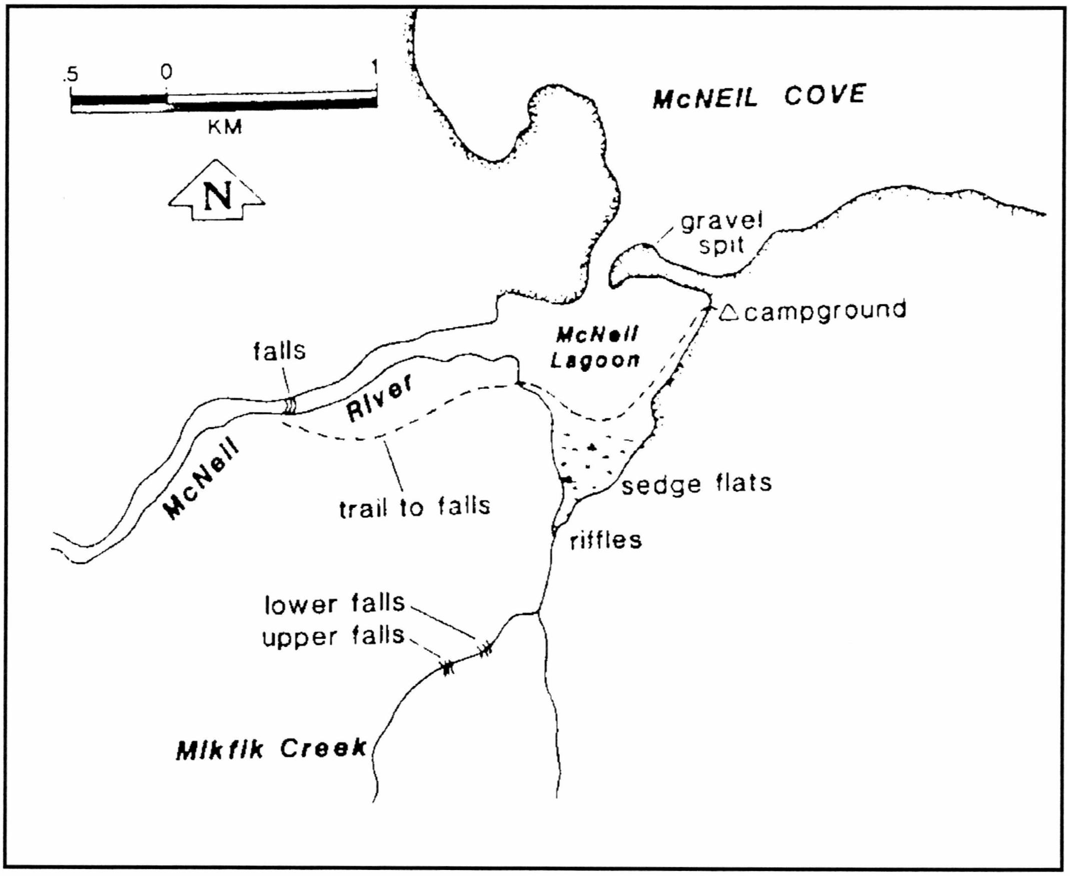

Figure 2.2. Detail of lower McNeil River and Lagoon, MRSGS, Alaska.

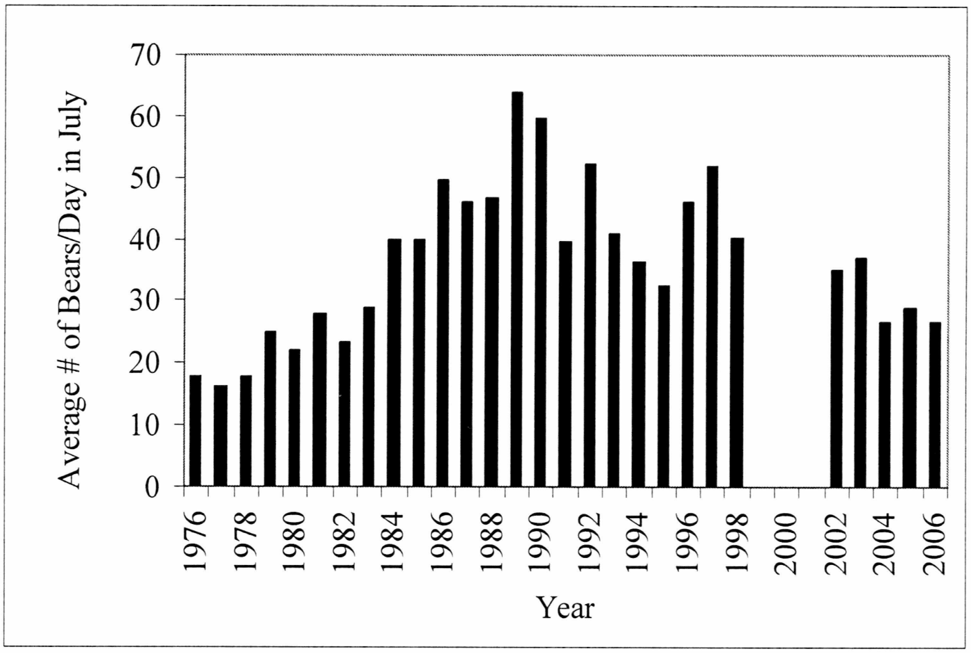

Figure 2.3. Average number of bears per day in July at McNeil Falls, Alaska. No daily bear use data were collected in 1999-2001.

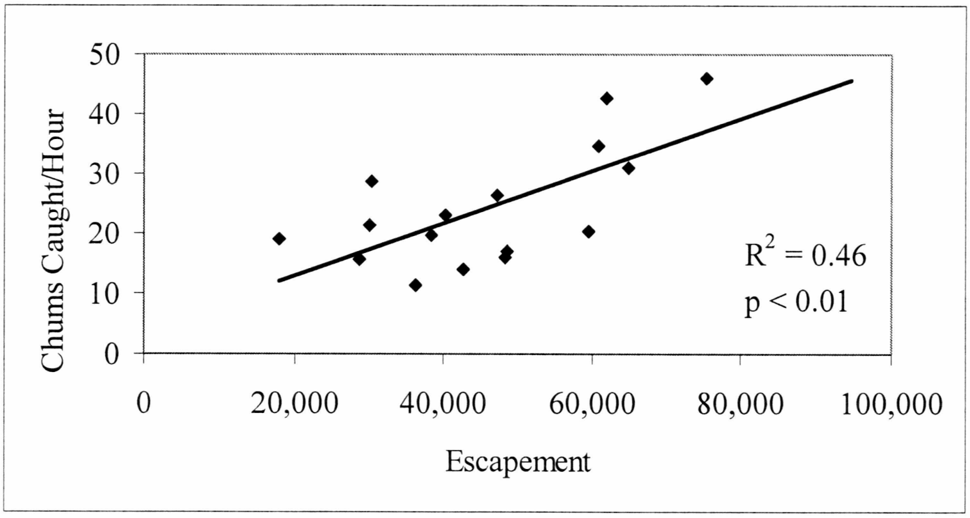

Figure 2.4. Chum salmon capture rates at McNeil Falls with increasing annual escapement, MRSGS, Alaska.

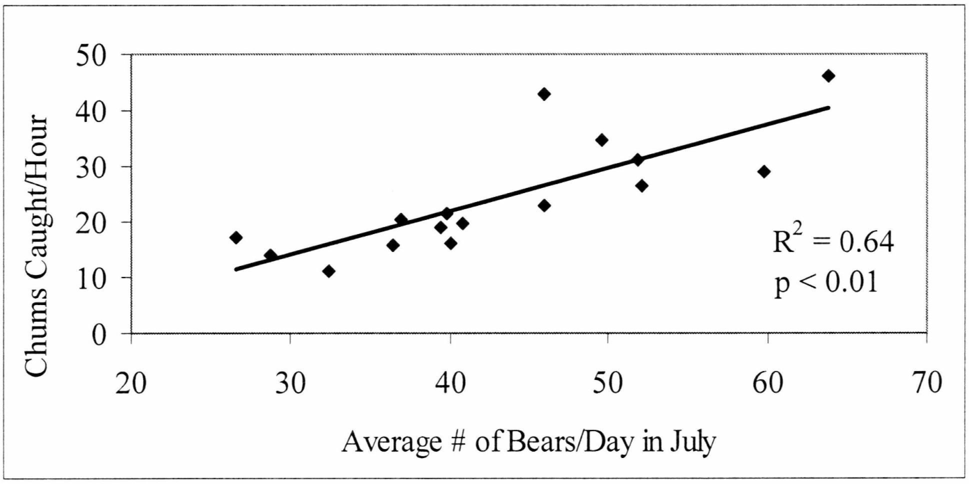

Figure 2.5. Chum salmon capture rates at McNeil Falls with increasing bear use days, MRSGS, Alaska.

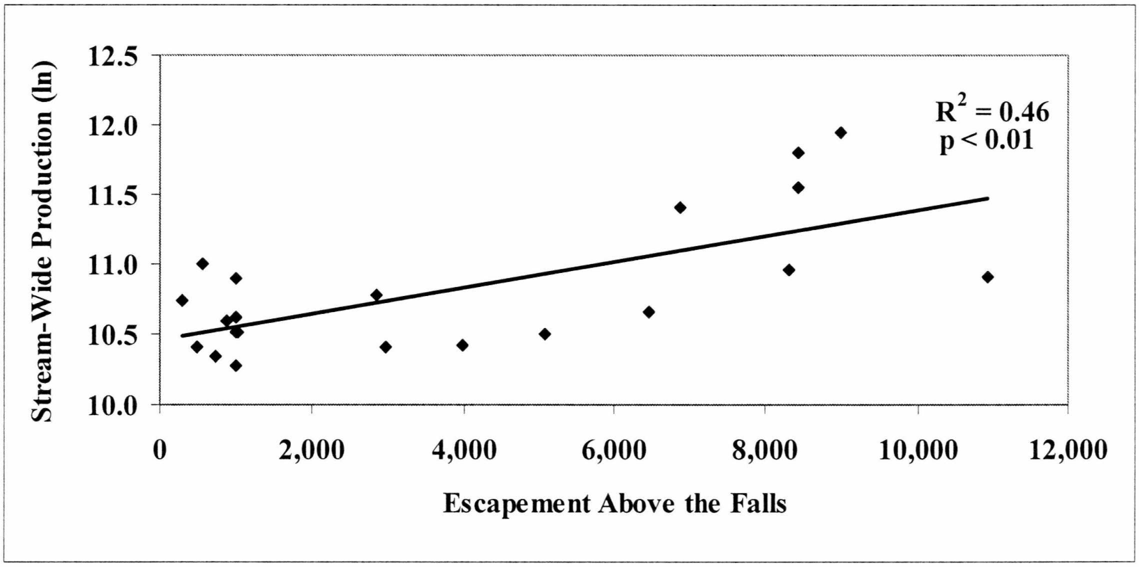

Figure 2.6. Stream-wide production (ln) of chum salmon with increasing escapement above McNeil Falls, MRSGS, Alaska.

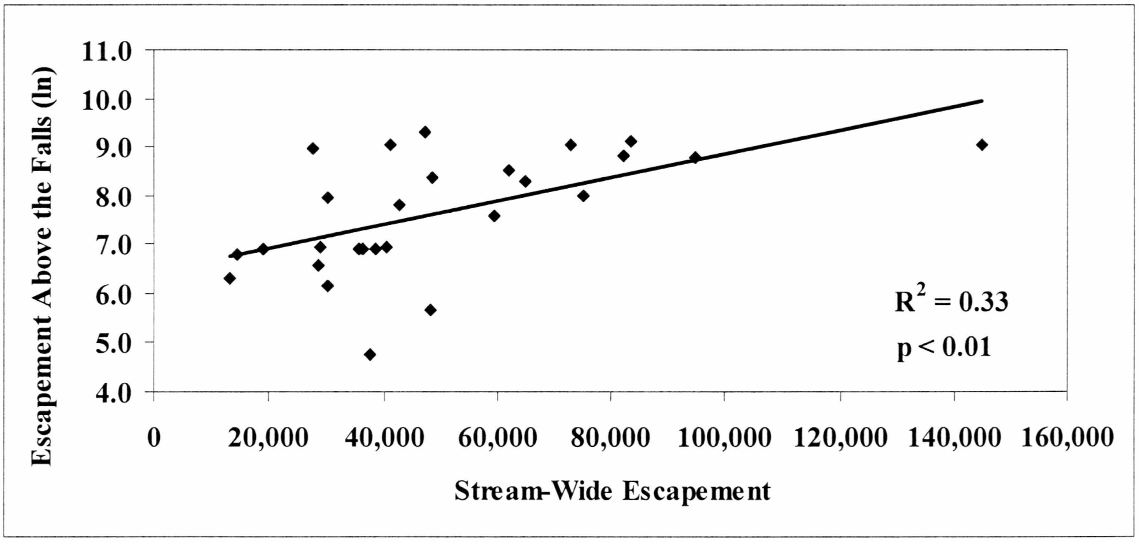

Figure 2.7. Escapement above McNeil Falls (ln) with increasing stream-wide escapement, MRSGS, Alaska.

General Conclusions

The importance of stream life (the average number of days salmon live in a river) in area-under-the-curve (AUC) calculations is well recognized in the literature (English et al. 1992; Irvine et al. 1993; Hill 1997; Bue et al. 1998; Lady and Skalski 1998; Hilborn et al. 1999; Manske and Schwarz 2000; Parken et al. 2003). Values in the literature for the stream life of chum salmon are highly site-specific (Thomas and Jones 1984; Perrin and Irvine 1990; Gende 2002). Therefore, determining the stream life of chum salmon at McNeil River was a key component of the retrospective analysis of historic escapement. Many techniques which have been used in the past to estimate stream life would not have worked at MRSGS. Chum salmon in McNeil River move into many inaccessible areas and migrate as far as 20 km upstream. Additionally, bears in the lower river eat almost every available fish, even post-spawning. If radio tags had not been used, daily detection of dead fish would have been marginal at best. The methods presented in this thesis demonstrate an effective technique for obtaining estimates of stream life in larger rivers with poor accessibility and high removal of salmon by predators such as bears.

The results of the retrospective analysis indicate current escapement indices are under-estimating actual escapement by approximately 250%. Therefore, the current escapement goal of 13,750-25,750 should be revised to 30,000-64,000. This is not an increase in the escapement, only a more accurate reflection of actual escapement.

Bears can have a large impact on salmon spawning escapement (Shuman 1950) in local streams. Techniques used to investigate mortality of pre-spawning salmon by bears have all relied on short, highly accessible streams, with carcasses available for examination. These techniques are possible, however, only when bears high-grade salmon and leave body parts. In the two years of this study at MRSGS, 99% of all tagged chum salmon below the falls were consumed entirely. It was only through the use of radio telemetry that each salmon's final fate was determinable. Because there was usually no carcass to recover we were not able to assess spawning status by examination and had to make a determination based on stream life, and time of death, relative to the peak of spawning. Our tagged chum salmon sample was highly representative of the overall situation along McNeil River, where carcasses are rarely found.

We estimated the number of pre-spawning chum salmon removed each year from McNeil River using three different techniques. Using the example from Hilderbrand et al. (2004) we estimated fish removals ranged from 14,543-36,108 with an annual average removal of 23,538 chum salmon. Using actual count data of chums captured just at the falls, average annual removal was 23%. Annual captures at the falls ranged from 3,033-33,335 and the average annual removal was 11,081 chum salmon. Using the estimate of pre-spawning mortality below the falls suggested by telemetry data (48%), resulted in a range of 6,330-69,568 with an average of 23,127 pre-spawning chum salmon removed per year.

While the area below the falls is heavily used by chum salmon there are only ~860 m of linear river where spawning actually occurs. This represents only a small proportion of the habitat available in McNeil River, and therefore small escapements above McNeil Falls may be limiting total chum salmon returns at McNeil.

Chum salmon production at McNeil River is difficult to assess, however, it is clear that fish spawning below the falls are faced with greater challenges than those spawning above the falls. We found a significant positive relationship between the numbers of chum salmon which escaped above the falls and total returns in subsequent years. In the two years of this study, we estimated that 90% of tagged chum salmon that made it above McNeil Falls lived long enough to spawn, while only 52% of chums below the falls spawned. When considering the high mortality, high densities of spawners, and limited spawning areas below the falls, it appears that encouraging above the falls escapement may be a key component to restoring and maintaining strong chum salmon runs at McNeil River.

Many of the same bears return year after year to fish at McNeil River (Luque and Stokes 1976). Not surprisingly, our data showed as escapement increased so did catch rates, and as bear numbers increased so did catch rates. However, the dynamics involved in forage rates are more complex than this, and factors such as social dominance among bears can play an important role (Stonorov and Stokes 1972; Gende and Quinn 2004; personal observations). Therefore, putting an upper limit on the number of salmon that can be captured by McNeil bears is difficult to do.

Quinn et al. (2003) found that the number of salmon killed by bears was asymptotic as salmon densities increased. At what escapement level salmon killed at McNeil River would become asymptotic still needs to be more thoroughly investigated. It is clear, however, that this point has not been reached in recent years.

Of the 155 chum salmon tagged, only one spawned out chum salmon in two years was recovered. In general, during extensive telemetry tracking in the lower river and lagoon very few spawned out salmon were found. That 99% of tagged fish below the falls were consumed is to be strongly emphasized, and the lack of salmon carcasses strongly suggests that the current level of escapement is insufficient for bears at McNeil.

The telemetry data collected during this study suggest that 23,000 chum salmon have been removed annually by bears at McNeil River (95% CI 18,400-27,800) over the past 31 years. To achieve a spawning escapement of 30,000-64,000 it is recommended the new escapement goal be set at 53,000-87,000 to explicitly account for pre-spawning mortality. This goal will help ensure sufficient spawning escapement in McNeil River and encourage the use of available spawning habitats above the falls. There has not been a commercial fishery in 14 years at McNeil River and our recommended escapement goal can only be managed for once runs rebuild on their own to higher levels.

In this thesis I have attempted to explicitly incorporate predation of chum salmon by bears into a revised escapement goal at McNeil River. Future work on the relative contribution above and below the falls spawning habitats have on stream-wide chum salmon production at McNeil River needs to be more thoroughly investigated. Additionally, stream flow gauges should be established on McNeil River to help elucidate the relationship between water levels, bear use, catch rates and total escapement on escapement above the falls. Knowing what influences escapement above the falls would be very useful to fisheries managers as they make decisions related to commercial fishery openings. As data become available a more complete predation model which encompasses wide ranges of escapement and bear use should be developed. Using this as a framework will allow the escapement goal at McNeil River to be refined even further using a Ricker stock recruit analysis. Finally, the escapement goal for Mikfik Creek should be addressed in a framework similar to this research. There is high pre-spawning mortality of sockeye salmon in this creek, and the current escapement goal there does not explicitly incorporate this mortality.

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