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Kodiak Brown Bear-Sockeye Salmon Foraging Ecology in Southwest Kodiak Island, Alaska

2015 Progress Report

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Kodiak National Wildlife Refuge
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Polson, Montana
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The mission of the National Wildlife Refuge System is to administer a national network of lands and waters for the conservation, management and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans.

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Will Deacy[1] and William B. Leacock[2]

Abstract

Salmon are critically important to Kodiak brown bear (*Ursus arctos middendorffi*) productivity, body size, and fecundity. Salmon abundance in southwest Kodiak Island river-lake systems has been characterized by substantial fluctuations. Kodiak National Wildlife Refuge engaged researchers at the University of Montana (UM) in cooperative research of brown bear movements, distribution, and exploitation of anadromous streams utilized by sockeye salmon in southwestern Kodiak Island, Alaska, during June-September 2013-2015. Research goals included: (1) characterize the spatial and temporal variation of salmon runs in nine spawning streams using a novel time-lapse camera system; (2) determine how salmon abundance, run timing, and energy levels affect overall exploitation of salmon by Kodiak bears; (3) quantify the physical and biological characteristics of salmon runs that trigger bears to travel among streams; (4) and quantify the physical characteristics of preferred salmon foraging sites. Fieldwork occurred between mid-May and early November. Salmon abundance and bear density were monitored at nine streams using time-lapse camera monitoring systems. Calibrations relating time lapse counts of salmon to spawning escapement were developed for three streams. Total escapement in the nine streams was 448,082. There were a total of 22,769 bear detections along these streams. Temperature of streams was measured using waterproof loggers. Twelve female bears were captured; seven were fitted with new GPS collars while five were recaptures of already collared bears.

Introduction

Annually, hundreds of millions of salmon swim up the rivers and streams of the North Pacific Rim. These runs are critical to local economies and culture, and play a key ecological role by supplementing the nutrient budgets of freshwater, riparian, and terrestrial ecosystems and by serving as a food source for a variety of predators and scavengers. The Alaska Department of Fish and Game (ADF&G) recorded an average annual harvest of almost 157 million fish from 2000-2004, valued in excess of $230 million (ADF&G website, 2012). Because of this high economic value, the majority of early research into the interaction between salmon and their terrestrial predators focused upon the presumed detrimental effects to salmon populations (Gard 1971). More recently, however, research focused upon the role that spawning

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salmon play as a link between marine, freshwater, and terrestrial ecosystems (Schmidt et al. 1998, Schindler et al. 2005, Claeson and Li 2006, Piccolo et al. 2009). This linkage takes two forms: salmon are important nutrient vectors, injecting a relatively large subsidy of nutrients derived from the ocean into often nutrient limited systems (Ben-David et al. 1998), and they serve as a source of food for a variety of mammal, avian, and aquatic consumers (Willson and Halupka 1995). The overall effect is substantial: where salmon are abundant, they drive freshwater primary production (Schindler et al. 2005) and have a strong impact on nearby riparian and terrestrial ecosystems (Willson and Halupka 1995, Chaloner et al. 2002, Naiman et al. 2002, Helfield and Naiman 2006, Morris and Stanford 2011). In the Kodiak Archipelago, the most conspicuous salmon predator is the Kodiak brown bear (*Ursus arctos middendorffi*), which spends considerable time and energy locating, catching and consuming salmon through the summer and fall (Barnes 1990). Salmon have such a significant influence on coastal brown bear, including Kodiak brown bear, that they are considered ecologically distinct from the otherwise similar grizzly bear (*Ursus arctos horribilis*), which have limited access to salmon (Pasitschniak-Arts 1993, Hilderbrand 1999, Hilderbrand et al. 1999).

The annual diet of brown bear of Kodiak Island is composed primarily of herbaceous vegetation, fruits, and salmon, each of which varies substantially in quality and quantity throughout the year (Barnes 1990, Clark 1957). While each of these food contributes to individual and population productivity, meat plays a particularly important role in determining body size and population productivity (Hilderbrand et al. 1999). Kodiak bears occasionally predate on Sitka black tailed deer (*Odocoileus hemionus sitkensis*), but salmon is the most accessible, abundant, and utilized source of meat. Results from Van Daele et al.'s study indicated that salmon accounted for 68% of the assimilated diet of adult males, 48% of adult females, 43% of subadults, and 21% of dependent offspring. Average annual consumption of salmon ranged from 566 kgs/yr for subadult females and 1,364 kgs/yr for adult females to 2,788 kgs/yr for adult males. Additionally, the relative importance of salmon in the diet varied geographically. For example, assimilated dietary ratio of salmon was substantially greater in adult males of southwest Kodiak (75 ± 17%) compared to eastern Kodiak (59 ± 28%). Likely primary factors that dictate relative access of salmon in streams to bears include the abundance and timing of salmon runs; stream morphology, particularly depth; and bear reproductive status, body size, and social hierarchy position (Gende and Quinn 2004, Ben-David et al. 2004, Van Daele et al. 2013).

Escapement data collected by the Alaska Department of Fish and Game (ADF&G) indicate that highest salmon abundance is associated with three large lake-river systems of southwestern Kodiak Island (Van Daele et al. 2013). These drainages, the Karluk, Frazer, and Ayakulik, contain all five species of pacific salmon found in Alaska, but are dominated by pink (*Oncorhynchus gorbuscha*) and sockeye salmon (*Oncorhynchus nerka)*. Historically the Karluk sockeye run has been the most productive of the three drainages, yielding over 3 million fish at the turn of the century, one of the highest returns per unit area on earth (Schmidt et al. 1998). Analysis of nitrogen isotopes using sediment cores from Karluk Lake indicated large fluctuations in escapement levels into Karluk Lake during the last 500 years, including a marked decrease since commercial fishing started about 100 years ago (Finney 1998, Schindler et al. 2005).

Framework of Problem

Although previous studies have shown that brown bear population density, body size, and fecundity all strongly correlate with salmon consumption, we know surprisingly little about the factors that mediate the bear-salmon relationship. While one might expect overall salmon abundance to control the relationship between salmon abundance and consumption by bears, several other factors add complexity to this relationship. First, salmon are not passive prey and are only vulnerable to bears in certain habitat types. Second, bears compete for the best fishing locations, balancing the risks of competition with the benefit of increased salmon consumption. Perhaps the most significant factor is that spawning salmon are very patchily distributed across space and through time, and bears must navigate this resource mosaic to maximize their consumption of salmon. We are interested in *how bears respond to this complex salmon resource mosaic*.

Our primary goal is to understand patterns of brown bears foraging for salmon in light of the patchiness of salmon distribution across space, the ephemeral nature of salmon availability, and the underlying habitat template that controls the vulnerability of spawning salmon to predation by bears. We address this through three research elements that examine the movements and distribution of brown bears on southwest Kodiak Island, Alaska, an area where the three main drainages include many sockeye salmon spawning streams and several beach spawning areas (i.e., the resource mosaic).

Kodiak Island, and in particular the Karluk area, has long attracted the attention of researchers interested in the relationship between bears and salmon. Most relevant to this work is research completed by FWS biologist Victor Barnes in the 1980s. Barnes used brown bear telemetry and aerial surveys of salmon availability to investigate the relationship. He found that bears travel in reaction to changes in salmon availability (Barnes 1990). The main shortfall of Barnes' study was an inability to measure salmon abundance with high spatial and temporal resolution. While he did have rough measures of salmon availability from weir estimates, he had to rely on qualitative measures of salmon availability (aerial estimates of species and abundance) for individual spawning streams. This study has built upon Barnes' ground-breaking work by refining and expanding the scope work by using novel monitoring and analytical methods on multiple scales.

The success of bear salmon foraging is determined by many factors. Foremost is selection of streams where salmon are currently spawning, a potentially difficult task given the high variation in run timing and widely distributed spawning sites. Spawn timing is variable because it is influenced by abiotic conditions such as water temperature and groundwater flux (Olsen 1968). In the small streams, those most important to foraging bears, salmon presence can be relatively fleeting, sometimes as short as two weeks. A bear with access to only one stream may have a very brief window for consuming salmon. However, by integrating salmon foraging among multiple streams with asynchronous run timing, bears may be able to increase salmon consumption by spreading their effort over several weeks or months to maximize salmon intake (Barnes 1990, Ruff et al. 2011, Schindler et al. 2013).

Relevance to Management

Because salmon are so important to coastal brown bears, changes in salmon abundance and distribution likely affect the resident bear population. These changes could be due to natural and/or anthropogenic factors, including salmon management policy. An ultimate goal of research focusing on the ecological link between salmon and bear should be to determine whether is it possible to integrate the management of these two species, and if so, how would integrated salmon-bear management function (Piccolo et al. 2009). Although we believe that salmon are critically important to maintaining historic bear densities on SW Kodiak Island, significant gaps remain in our knowledge of how variation in salmon abundance and spatio-temporal distribution affects bear population productivity, individual behavior, and habitat use, which may constrain the effectiveness of bear conservation and management efforts. In order to progress towards this ultimate goal we must develop innovative methods to monitor salmon and bears on appropriate spatial and temporal scales and use the resulting data to determine how individuals and populations of bears respond to variation in salmon abundance and distribution. This data may also help managers identify heavily used sites along anadromous streams and shoal-spawning areas for long-term monitoring and special protection.

Barnes (1990) described the importance of salmon to bears in southwest Kodiak Island and emphasized the need for more attention by resources managers. He cited the need for improved data on the timing and abundance of escapement into streams to advance our understanding of bear habitat use so that the needs of bears could also be taken into account in salmon management. He also emphasized the need to monitor bear use across anadromous streams and to identify areas that need protection from human disturbance.

The *Kodiak Archipelago Bear Conservation and Management Plan* (2002) recommended that management agencies evaluate “species-specific salmon escapement levels against drainage-specific bear use of salmon” through an ecosystems approach (p. 9-24). The USFWS’ *Revised Comprehensive Conservation Plan and Environmental Impact Statement: Kodiak National Wildlife Refuge* (2006) directs management to: “Monitor salmon escapement in streams on the refuge that are key seasonal feeding areas for brown bears and bald eagles, and work collaboratively with ADF&G to maintain escapement levels that reflect wildlife needs.” It goes on to stress that: “While wildlife needs are recognized in salmon escapement goals set by ADF&G as required by the Policies on the Management of Sustainable Salmon Fisheries and the Statewide Escapement Goals, the importance of brown bears and eagles and their dependence on the salmon resources require special attention. Documenting wildlife use of salmon resources and ensuring adequate fish abundance to meet these needs is an ongoing effort. The Refuge will continue to work with ADF&G to gather necessary data to update salmon escapement goals during their review cycle.” (p. 2-16)

We partly address these information needs by (1) developing and applying an accurate method for monitoring escapement in small salmon-spawning streams; (2) improving methods for monitoring bear distribution at fine temporal and spatial scales; and (3) evaluating brown bear responses to variability in salmon distribution and abundance across the landscape.

This report details progress made towards our goals and objectives during the summer 2015. It includes a summary of data collection and analytical methods, as well as preliminary results.

Study Area

This project focused on the Frazer, Ayakulik, and Karluk drainages of the southwestern part of Kodiak Island (Figure 1). The area is mountainous and topography is glacially influenced, consisting of broad valley floors, steep slopes, and mountain peaks up to approximately 950 meters. The region has a maritime climate characterized by cool temperatures, overcast skies, and moderate to heavy precipitation. Daily high temperatures usually range from 13-18 C in July and August and lowest temperatures normally occur during January and February. Data recorded by the National Weather Service at the Kodiak State Airport situated in northeastern Kodiak Island indicated a long-term (1981-2010) mean annual temperature of 2.08° C (-0.86° to 12.86° monthly mean range), mean monthly minimum temperature range of -1.84° to -3.17° between November and March, mean total annual precipitation of 198 cm, and mean total annual snowfall of 175 cm with measurable snow usually recorded between October and May. August tends to be the driest month (average = 11.6 cm) and December the wettest (average = 22.2 cm).

The study area encompasses three river-lake system study sites in southwestern Kodiak Island (Figure 1). In 2015, we monitored salmon abundance in, and bear activity along, nine streams collectively distributed among watersheds of the Karluk, Frazer, Red Lake basins (Figure 1). Criteria applied for selection of study focal streams included the relative efficiency of site access; documented extent and magnitude of brown bear bear use, as ascertained by Refuge monitoring surveys and previous studies (Troyer and Hensel 1964, Barnes 1990, Sorum 2012); and importance of streams to spawning sockeye salmon. In general, focal streams collectively represented many of the important stream foraging habitats of brown bear in southwest Kodiak Island.

Two Frazer streams, Stumble and Midway, were monitored in 2014 but not in 2015 because abundance of bears and returning salmon was minimal. North Karluk Lake sites (Moraine, Cottonwood, Grassy, and Halfway Creeks) were not monitored in 2014 or 2015 because access was prohibited by the landowner, Koniag Native Corporation . Karluk Lake is 19 km long by 0.8 km wide and has 11 tributaries, most of which are short and steep with only very short reaches accessible to spawning salmon (Berns et al. 1980). The exceptions are O'Malley and Thumb creeks, which have comparatively large flows and drain large valleys. Karluk Lake flows into the Karluk River, which is 39 km long and terminates at the ocean on the western side of the island. The Frazer drainage contains Frazer Lake which is 14 km long by 1.3 km wide, and has one primary tributary, Pinnell Creek. Dog Salmon Creek drains Frazer Lake and runs south 14 km to its terminus at Olga Bay. The Frazer drainage is unique among the three study sites because it supports an introduced sockeye salmon stock. Historically, there were no salmon in the Frazer Lake basin because a waterfall immediately downstream from the lake prevented salmon migration. In 1951, salmon were introduced to Frazer Lake, and in 1962, the Frazer Fish Pass was constructed, which permitted migration to the lake basin and establishment of a self-sustaining population of sockeye salmon. Currently, ADF&G operates the fish pass and a weir just upstream of the river's mouth in Olga Bay. Red Lake is 6 km by 1.3 km and has two significant tributaries, Connecticut Creek and Southeast Creek. Red Lake is drained by Red Lake River which flows into the Ayakulk River. Distance is 25 km between Red Lake and Ayakulik River-lagoon confluence on the west side of the island. The ADF&G operates another weir along the lower Ayakulik River.

Human use of the study area is dominated by recreationists such as hunters, anglers, and bear-viewers. Though public access is generally limited to air transport to floatplane-accessible lakes, recreational pressures have been increasing. Other human activities include management activities of the Refuge and the ADF&G, such as aerial wildlife surveys and salmon escapement monitoring. Development is restricted primarily to coastal areas including the villages of Larsen Bay, Karluk, and Akhiok, scattered, mostly seasonally occupied private residences and agency facilities. In the interior region, the ADF&G maintains facilities at Frazer Fish Pass on Dog Salmon Creek, the Refuge maintains an administrative site at Camp Island in Karluk Lake, and Koniag, Inc. maintains guided recreational use facilities at Karluk Lake and along Karluk River.

Methods

Salmon Monitoring Using Time-Lapse Photography

We measured salmon abundance on nine streams in the study area using "double sampling" time lapse and video camera systems. We monitored six Karluk tributaries, two in the Ayakulik system (Connecticut and Southeast Creeks), and Pinnell Creek in the Frazer drainage. These streams were chosen because they all have locally significant populations of spawning sockeye salmon and past GPS bear collar data has shown that bears routinely attend these locations when sockeye salmon are present and relatively abundant.

There are several tools for monitoring salmon, each with strengths and weaknesses. On the large rivers in Alaska and Canada, salmon monitoring is achieved using weirs, tower count, or sonar. These methods tend to be expensive and require a substantial labor input. Remote video recording have proven to be an effective measure of our variable of interest, salmon passage. In 2010, FWS biologist, William Leacock and University of Idaho graduate student, Mathew Sorum, began experimenting with remote video as a method for monitoring small tributaries (Sorum 2013). Video enumeration provides the accuracy of weir counts and observation towers without the associated disturbance of weir obstructions and human presence. Although video monitoring works well for monitoring a handful of small streams, the amount of time required to count passing salmon makes monitoring several streams prohibitively costly. To harness the advantages of remote camera systems without time-consuming video enumeration, we utilize a "double sampling" scheme, which is often used when the variable of interest is costly to measure (in time or money), but a related auxiliary variable is cheaper or more easily measured (Cochran 2007). We can measure the cheaper variable at a high frequency and only measure the expensive variable on a subsample of units. In this case, the expensive variable of interest is the video recorded salmon passage in each of 12 streams, and the related auxiliary variable is salmon counts from time-lapse images of each stream, recorded by wildlife "trail cameras."

Twelve double sampling camera systems were developed, deployed, and tested in 2012. These systems were the first to use time-lapse photography to monitor salmon. In response to pilot year performance, modifications were made, including increasing photo frequency and adding infrared lights for night monitoring. Nine of these improved camera systems were deployed in 2013, eleven in 2014, and nine in 2015.

The systems consisted of a small remote camera (*Reconyx XR6 UltraFire IR*) suspended over a stream at the end of a metal pole (Figure 2). White "contrast panels" were secured to the streambed below each camera to facilitate salmon observation (Figure 3). Time-lapse cameras were programmed to acquire a burst of three images every minute, 24 hours/day. Results from testing indicated that three image bursts adequately documented the number of sockeye salmon and their direction of movement. During nighttime hours, near infrared (IR) lights and/or a string of waterproof LED Christmas lights were used to illuminate the contrast panels in the streams.

Every 10-14 days a field crew visited each camera site to clear accumulated debris from the contrast panels, exchange data cards, replace camera batteries, and service the remote camera systems. Each system was powered by an arrangement of solar panels and batteries which were protected by a solar powered electric fence to prevent bears from disturbing the equipment. In four years of deployment, bears never disrupted or damaged equipment. At the Refuge administrative site at Camp Island, personnel reviewed each photo and recorded the number of sockeye salmon and their direction of travel, up or downstream. Time lapse counts were then aggregated by hour.

To relate time-lapse salmon counts (auxiliary variable) with video recorded salmon passage, we calculated a ratio estimator which was used to estimate spawning escapement of the remaining sampling units. For the ratio estimator, spawning escapement was measured for a sub-sample of 20-30 hours of video per stream, stratified across the range of salmon run intensities (the number of salmon passing the contrast panels in a given period of time). The use of the ratio estimator is contingent upon the time lapse camera detection rate being consistent across salmon run intensities. If the detection rate on a given stream differed depending on salmon run intensity, we used a regression estimator as an alternative. The ratio estimator, r, was represented as follows:

$$r = \frac{mean\ of\ video\ recorded\ salmon\ passage}{mean\ of\ time\ lapse\ salmon\ counts}$$

The SE of the ratio estimator was calculated by:

$$SE(r) = \sqrt{\frac{N-n}{N} * \frac{1}{\bar{x}^2} * \frac{s_r^2}{n}}$$

Where N is the total number of auxiliary samples, n is the smaller sample where we have measured both variables, $\bar{x}$ is the mean of time lapse counts, and s_r^2 is given by:

$$s_r^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - rx_i)^2$$

We estimated salmon passage for each hour by multiplying time lapse salmon count (recorded throughout the entire summer) by the ratio estimator. Subsequently, results were reorganized to yield hourly estimates of sockeye salmon abundance in each focal tributary.

To understand how bears respond to salmon abundance we must know how many salmon are *in* the stream, not just how many have passed into the stream. We modeled salmon abundance (the number of salmon in a stream at a given time) by computing corrected daily counts (e.g., upstream moving salmon minus downstream moving salmon), followed by computation of a modified estimate based on reported salmon mortality rates (Carlson et al. 2007). The three main sources of mortality for spawning sockeye salmon are senescent death, predation (mostly by bears), and stranding. Carlson et al. (2007) investigated the relationship between stream width and time to senescent death in streams morphologically similar to streams in this study. They found that salmon spawning in wider streams tend to have longer stream lives. Salmon in narrow streams experience higher predation rates, which apparently selects for a more rapid reproductive cycle and earlier death.

We used a normal distribution of stream life, with a mean and standard deviation derived by combining stream life estimates from the three sources of mortality (predation, stranding, and senescence) into a weighted mean and standard deviation of stream life. By simulating mortality we were able to estimate the number of sockeye in each focal stream on each day of the study period.

Bear Distribution and Movements

Time Lapse Photography

We measured bear density along each of the nine focal stream, and Red Lake River (where we did not monitor salmon) using time-lapse cameras. Three cameras were deployed and maintained on each stream (Figure 4), with the exception of Red Lake River and Connecticut Creek where 4 and 10 cameras were deployed, respectively. Each camera was programmed to take a photo every 5 minutes. Bears observed in photos were counted and classified as single adults, maternal females with young cubs (< one-year old), and maternal females with older cubs (> one year-old). Each family group (a maternal female with one or more cubs) was treated as one bear in analyses. The camera systems did not cover the entire length of each stream, and thus did not census the bears on a stream, but can provide an index for comparison throughout the day, over a season, and across years. Bear detections were pooled across cameras for each day, to derive the total daily detections on the stream. We assumed that rates of bear detections varied in proportion to the true number of bears using streams. We also assumed that salmon availability and abundance was the most important factor driving bear distribution during the primary period when sockeye salmon spawn in streams (July to mid-August), even though bears in Kodiak have access to a variety of other resources, most notably vegetation and berries. Other food resources, such as berries, may influence levels of exploitation of salmon resources. We did not include berry and herbaceous vegetation in our model for three primary reasons: availability of herbaceous food resources does not vary greatly during the salmon season; elderberry, the primary berry food resource, does not generally become available until late August (well after most stream-spawning sockeye have spawned) (Sorum 2013), and we currently have no logistically feasible way to quantify berry availability. As will be explained in the results section, our assumption that berry abundance does not have a large influence on bear use of salmon streams was not valid for summer 2014 or 2015 because of unusually early and productive berry crops.

Capture and Radio-collaring

Bears were captured in early June 2015 in accordance with US Fish and Wildlife Service permit number 2015-001. We fit seven adult female bears with Telonics GPS collars programmed to record locations every hour. We recaptured five adult females collared in 2014 to collect hair and take zoological measurements. Capture effort for new bears was distributed across the Frazer Lake and Red Lake basins.

We located bears for collaring with a small fixed-winged aircraft (Top Cub) and employed a helicopter (Hughes 500-D) to pursue and tranquilize them using a Cap-Chur rifle to fire Pneudart darts containing Telazol (1:1 mixture of tiletamine hydrochloride and zolazepam hydrochloride) at a concentration of 228.8 mg/ml. The dart was aimed at either the shoulder area or the hips, the safest places on the body for darting.

Bears were usually fully immobilized within 3 to 8 minutes following drug injection. If 10 minutes passed with little sign of effect, a second injection of a lower dosage was administered but total dosage never exceed 10 ml per bear. When necessary, supplemental doses were hand-injected intramuscularly. Dart wounds were cleaned with iodine per the DWC dart wound treatment protocol. Oxtetracycline 200mg/ml at a dosage rate of 4.5ml per 100 pounds body weight was administered IM with an 18g needle. No more than 10 ml were injected in a single location. We assessed the health of the bears by monitoring temperature, respiration, and pulse throughout the period of immobilization and maintained visual contact until the bears became responsive. All bears were tattooed with a unique identification number on the lingual side of upper and/or lower lips. The tattoo was applied with a special tattooing tool commonly used for livestock. Hair, tissue, blood, claw shavings, and fecal samples were collected for future diet studies.

Stream Temperature

Stream temperature is hypothesized to influence the timing of salmon spawning because of its influence on salmon egg development rates (Quinn 2005). In an effort to monitor the temperature of habitat important to salmon, we deployed temperature sensors in all focal streams in 2015 and monitored these between mid-June and early November. Temperature sensors, Onset® TidbiT v2 or Pro V2, were programmed to record temperature at hourly intervals.

Preliminary Results and Discussion

Salmon Run Monitoring

As expected, abundance of sockeye salmon differed among study sites in 2015 (Table 2). Escapement was greatest in Connecticut Creek (over 100,000 sockeye) and least in Falls Creek (8,700 sockeye) (Figure 5). The largest interannual difference in abundance was observed at Pinnell Creek, which decreased from over 90,000 salmon in 2014 to approximately 25,000 in 2015. Although this seems dramatic, salmon abundance in small streams tends to vary much more than whole watersheds; order of magnitude differences in abundance are normal at this spatial scale (Schindler et al. 2010). Although we observed similar densities of salmon spawning at most sites, the runs with more salmon were often of longer duration. This may explain the large difference between salmon run intensity among these sites. The overall spawning escapement in these eleven streams was 448,083 and spanned 116 days (Figure 6).

Bear Distribution and Movements

Time Lapse Photography

The frequency of bear detections varied greatly across stream sites. For example, detections were greatest at Red Lake River (> 5,000) and least at Pinnell Creek (96) (Table 2, Figure 7). . The abundance of bear detections observed at Red Lake river likely reflect a preference for un-morphed, comparatively high-fat, migrating sockeye salmon (Gende et al. 2001) coupled with the absence of alternate fishing sites during June - early July with exception of the lower falls of Dog Salmon Creek. The paucity of bears at Pinnell is hard to explain.

Capture and Radio-collaring

A total of seven adult female bears were immobilized and fitted with GPS collars during early June. Capture locations were distributed throughout the southern Karluk, Frazer, and Red Lake basins (Figure 8). GPS relocations were downloaded from a Top Cub using an Ultra High Frequency (UHF) receiver on July 14, August 11, September 8, and October 3. The collars from three bears dropped early and were transmitting mortality signals. Upon recovery, it was discovered that one had slipped off the bear while three others had broken cotton spacers. The cotton spacers were advertised to work for two years.

Preliminary Among Year Comparison of Bear Space Use

Salmon and bears were monitored at four tributaries in 2013, 2014, and 2015 (Meadow, O'Malley, Canyon, and Thumb). Using this subset of streams, we can compare salmon abundance and bear activity among these years (Figure 9). Although the estimated salmon escapement was 24% higher in 2014 (197,930) compared to 2013 (159,454), bear detections were 46% lower (6,446 in 2014 vs. 11,983 in 2013). The largest difference in interannual patterns of bear detection occurred during late July and early August. The most likely explanation is that bears switched from foraging on salmon to foraging on berries, chiefly salmonberry (*Rubus spectabilis*) and red elderberry (*Sambucus racemosa*) earlier in 2014-15 compared with 2013. As in 2014, an early warm spring seemed to accelerate elderberry phenology in 2015. We first observed ripe elderberry berries on July 19 in 2015 compared to July 21 in 2014 and August 8 in 2013. The 2015 pattern of bear activity had similarities and differences with 2014. While there was a similar low period of bear detections in late July and early August in 2015, there were relatively high detections at the start and end of salmon spawning behavior. This suggested that bears shifted foraging to berries when they ripened, but were more responsive to salmon prior to and following berry season. This explanation is supported by telemetry data on movements of collared bears during late July and early August. Although counterintuitive, given the well documented relationship between bear fecundity and meat consumption (Hilderbrand et al. 1999), other work has shown bears select mixed diets that optimize protein intake at approximately 23% (Erlenbach et al. 2014). Our results underscore the importance of the salmon-berry interaction, and the need to develop methodologies to monitor berry phenology and abundance so we can better interpret habitat use patterns.

Stream Temperature

Stream temperature varied minimally among focal streams (Table 3, Figure 10). The warmest temperatures were recorded in O'Malley River, which flows out of O'Malley Lake while the coldest temperatures were recorded in Meadow creek. Temperature differed least at O'Malley River (CV=.14), likely because O'Malley Lake buffers temperature variation, and at Meadow Creek, which is well shaded along its entire length. In contrast, greatest temperature variation was observed in Southeast Creek and Connecticut Creek, perhaps because these streams are minimally shaded by riparian vegetation. The temperature at all of the sites varied across the season in rough synchrony with air temperature (Figure 11). Synchrony appeared weakest in the O'Malley River, likely because of the buffering effects of O'Malley Lake.

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Literature Cited

Alaska Department of Fish and Game. 2002. Kodiak Archipelago Bear Conservation and Management Plan. ADF&G, Division of Wildlife Conservation, Anchorage, Alaska.

Barnes, V. G. 1990. The Influence of Salmon Availability on Movements and Range of Brown Bears on Southwest Kodiak Island. Bears : Their Biology and Management 8.

Ben-David, M., T. a. Hanley, and D. M. Schell. 1998. Fertilization of Terrestrial Vegetation by Spawning Pacific Salmon: The Role of Flooding and Predator Activity. Oikos 83:47.

Ben-David, M., K. Titus, and L. R. Beier. 2004. Consumption of salmon by Alaskan brown bears: a trade-off between nutritional requirements and the risk of infanticide? Oecologia 138:465–74.

Berns, V., G. Atwell, and D. Boone. 1980. Brown bear movements and habitat use at Karluk Lake, Kodiak Island. Bears: Their Biology and Management 4.

Carlson, S. M., R. Hilborn, A. P. Hendry, and T. P. Quinn. 2007. Predation by bears drives senescence in natural populations of salmon. PloS one 2:e1286.

Chaloner, D., M. Wipfli, and J. Caouette. 2002. Mass loss and macroinvertebrate colonisation of Pacific salmon carcasses in southâ€ • eastern Alaskan streams. Freshwater Biology:263–273.

Cochran, W. 2007. Sampling Techniques. 3rd edition. John Wiley and Sons, New York, NY.

Van Daele, M. B., C. T. Robbins, B. X. Semmens, E. J. Ward, L. J. Van Daele, and W. B. Leacock. 2013. Indirectly Estimating the Diet of Brown Bears and the Intake and Importance of Abundant Salmon Across the Kodiak Archipelago, Alaska. FWS Report.

Erlenbach, J. a., K. D. Rode, D. Raubenheimer, and C. T. Robbins. 2014. Macronutrient optimization and energy maximization determine diets of brown bears. Journal of Mammalogy 95:160–168.

Finney, B. 1998. Long-term variability of Alaskan sockeye salmon abundance determined by analysis of sediment cores. North Pacific Anadromous Fish Commission Bulletin.

Gard, R. 1971. Brown bear predation on sockeye salmon at Karluk Lake, Alaska. The Journal of Wildlife Management 35:193–204.

Gende, S. M., T. P. Quinn, and M. F. Willson. 2001. Consumption choice by bears feeding on salmon. Oecologia 127:372–382.

Gende, S., and T. Quinn. 2004. The relative importance of prey density and social dominance in determining energy intake by bears feeding on Pacific salmon. Canadian Journal of Zoology 85:75–85.

Helfield, J. M., and R. J. Naiman. 2006. Keystone Interactions: Salmon and Bear in Riparian Forests of Alaska. Ecosystems 9:167–180.

Hilderbrand, G. 1999. Effect of seasonal differences in dietary meat intake on changes in body mass and composition in wild and captive brown bears. … Journal of Zoology 1630:1623–1630.

Hilderbrand, G. V, C. C. Schwartz, C. T. Robbins, M. E. Jacoby, T. a Hanley, S. M. Arthur, and C. Servheen. 1999. The importance of meat, particularly salmon, to body size, population productivity, and conservation of North American brown bears. Canadian Journal of Zoology 77:132–138.

Naiman, R. J., R. E. Bilby, D. E. Schindler, and J. M. Helfield. 2002. Pacific Salmon, Nutrients, and the Dynamics of Freshwater and Riparian Ecosystems. Ecosystems 5:0399–0417.

Pasitschniak-Arts, M. 1993. Mammalian Species: Ursus arctos. The American Society of Mammologists 439:1–10.

Piccolo, J., M. Adkison, and F. Rue. 2009. Linking Alaskan salmon fisheries management with ecosystem-based escapement goals: a review and prospectus. Fisheries:37–41.

Quinn, T. P. 2005. The Behavior and Ecology of Pacific Salmon and Trout. Pages 109–110.

Ruff, C. P., D. E. Schindler, J. B. Armstrong, K. T. Bentley, G. T. Brooks, G. W. Holtgrieve, M. T. McGlauflin, C. E. Torgersen, and J. E. Seeb. 2011. Temperature-associated population diversity in salmon confers benefits to mobile consumers. Ecology 92:2073–84.

Schindler, D., J. Armstrong, K. Bentley, K. Jankowski, P. Lisi, and L. Payne. 2013. Riding the crimson tide: mobile terrestrial consumers track phenological variation in spawning of an anadromous fish. Biology Letters 9:2–6.

Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. a Rogers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465:609–12.

Schindler, D., P. Leavitt, and C. Brock. 2005. Marine-derived nutrients, commercial fisheries, and production of salmon and lake algae in Alaska. Ecology 86:3225–3231.

Schmidt, D. C., S. R. Carlson, G. B. Kyle, and B. P. Finney. 1998. Influence of Carcass-Derived Nutrients on Sockeye Salmon Productivity of Karluk Lake, Alaska: Importance in the Assessment of an Escapement Goal. North American Journal of Fisheries Management 18:743–763.

Sorum, M. 2013. Behavior-Specific Resource Selection by Kodiak Brown Bears. University of Idaho.

Taylor, W., H. Reynolds, and W. Ballard. 1989. Immobilization of grizzly bears with tiletamine hydrochloride and zolazepam hydrochloride. The Journal of wildlife … 53:978–981.

Willson, M. F., and K. C. Halupka. 1995. Anadromous Fish as Keystone Species in Vertebrate Communities. Conservation Biology 9:489–497.

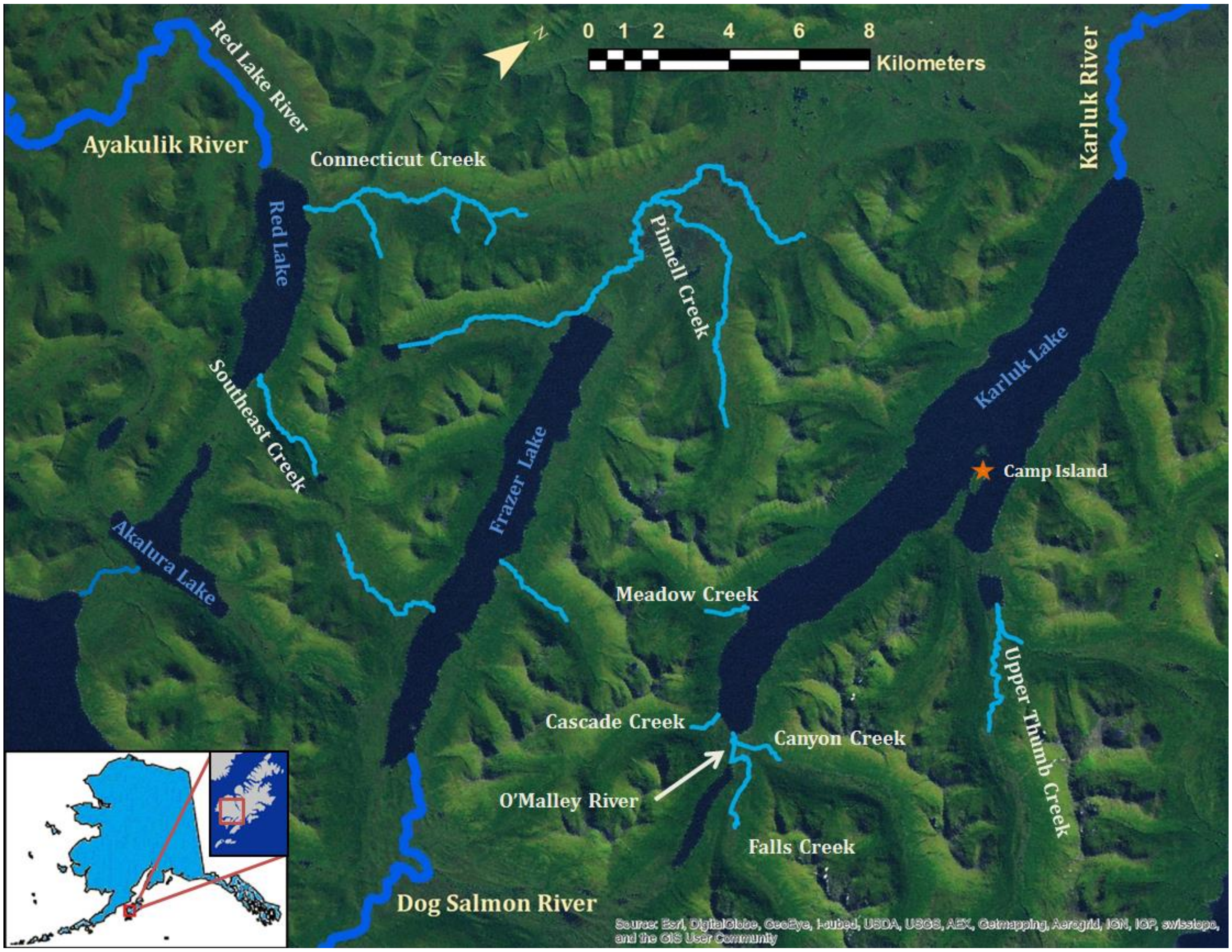

Figure 1. Bear project study area in southwest Kodiak Island. Streams monitored in 2015 are labeled.

Figure 2. Camera system at Moraine Creek. Note steel tripod and white contrast panels.

Figure 3. White substrate panels that highlight passing salmon. They are secured to a chain that spans the stream and is anchored to the bank with rebar or T-posts.

Creek	Creek Width (m)	Creek Depth (cm)	Reproductive lifespan (d)			Still alive at the end of the study
			mean±S.E. (N)			
			Senescent	Bear-killed	Other	N
A	1.4	10.0	12.65±0.23 (248)	4.36±0.12 (828)	6.02±0.55 (65)	294
Bear	5.1	19.3	13.43±0.31 (164)	8.40±0.19 (718)	7.29±0.81 (28)	19
C	2.1	10.0	12.9±0.24 (261)	7.36±0.17 (889)	5.57±0.75 (30)	518
Hansen	3.9	9.8	10.72±0.19 (226)	3.47±0.10 (753)	2.18±0.12 (258)	11
Pick	7.6	37.9	18.46±0.31 (276)	11.98±0.42 (263)	8.71±1.07 (31)	24
Yako	4.2	22.6	11.59±0.23 (152)	7.16±0.15 (771)	7.08±0.67 (24)	16

Table 1- Reproductive lifespan of sockeye (in days) in 6 Alaskan streams of various widths. Carlson et al. (2007).

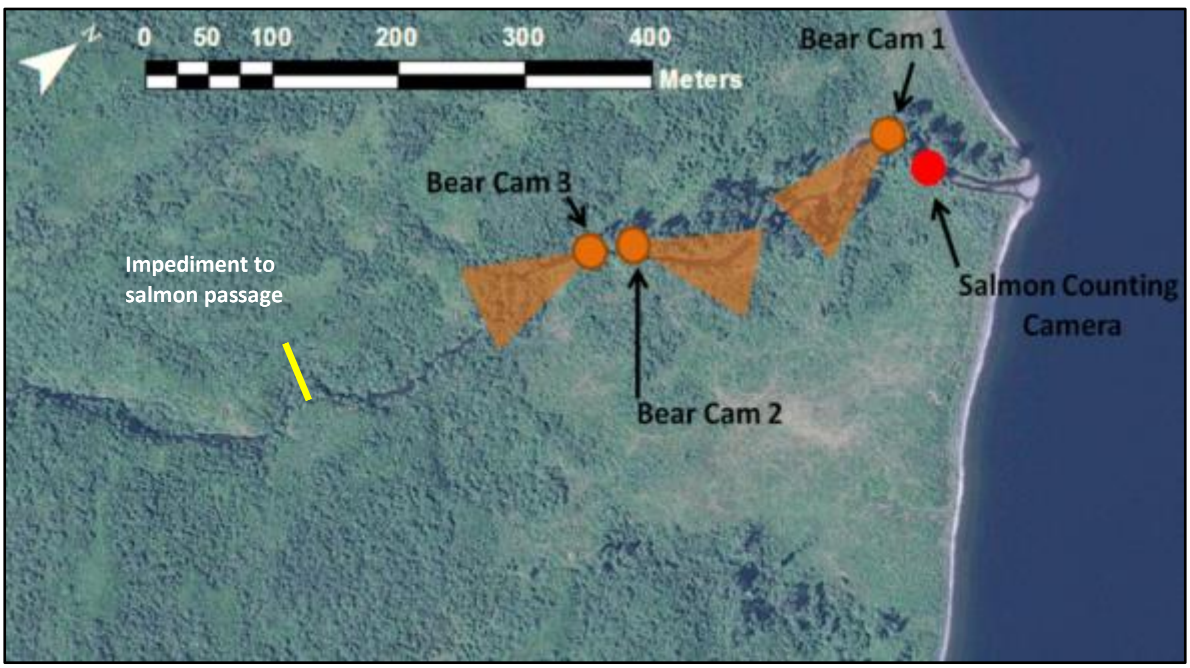

Figure 4. Example of orientation of salmon and bear counting cameras. Salmon cameras are located within 50m of stream mouths. Bear cameras are spaced along the portion of stream in which salmon spawn, in locations with large “viewsheds.” Random placement of cameras would result in many cameras placed in brushy locations with a poor rate of bear detection.

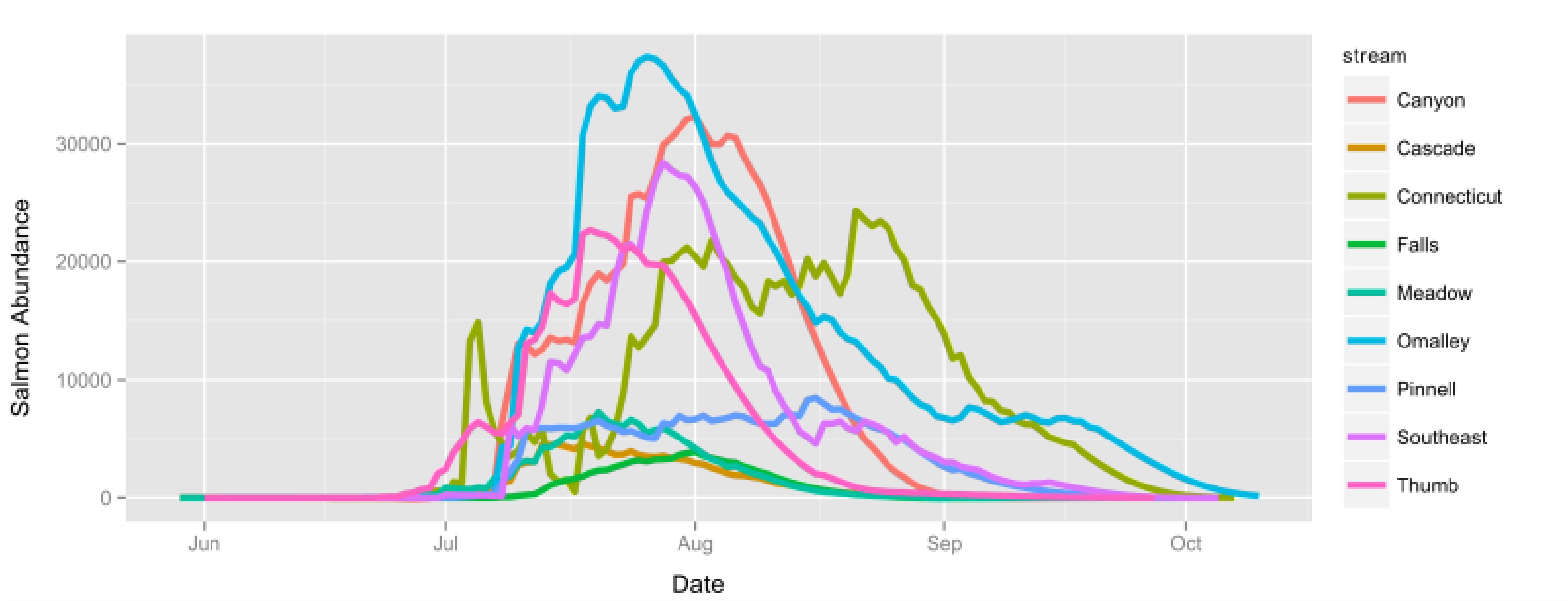

Figure 5. Salmon abundance in nine SW Kodiak tributaries during summer 2015.

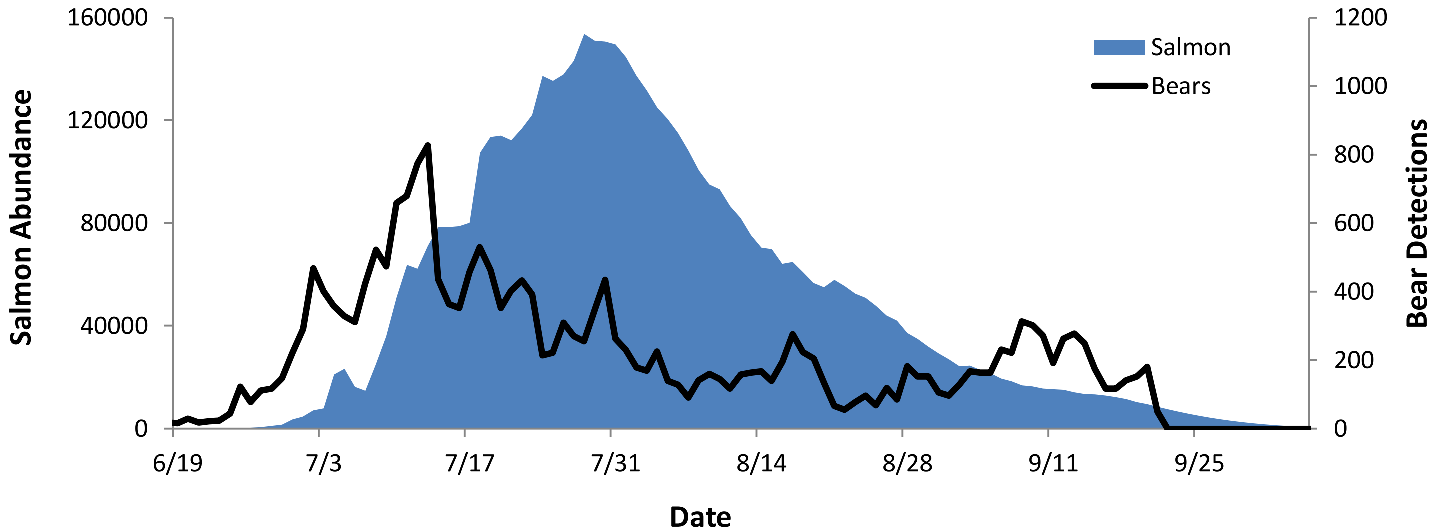

Figure 6. Salmon abundance in, and bear detections along, nine focal streams during summer 2015.

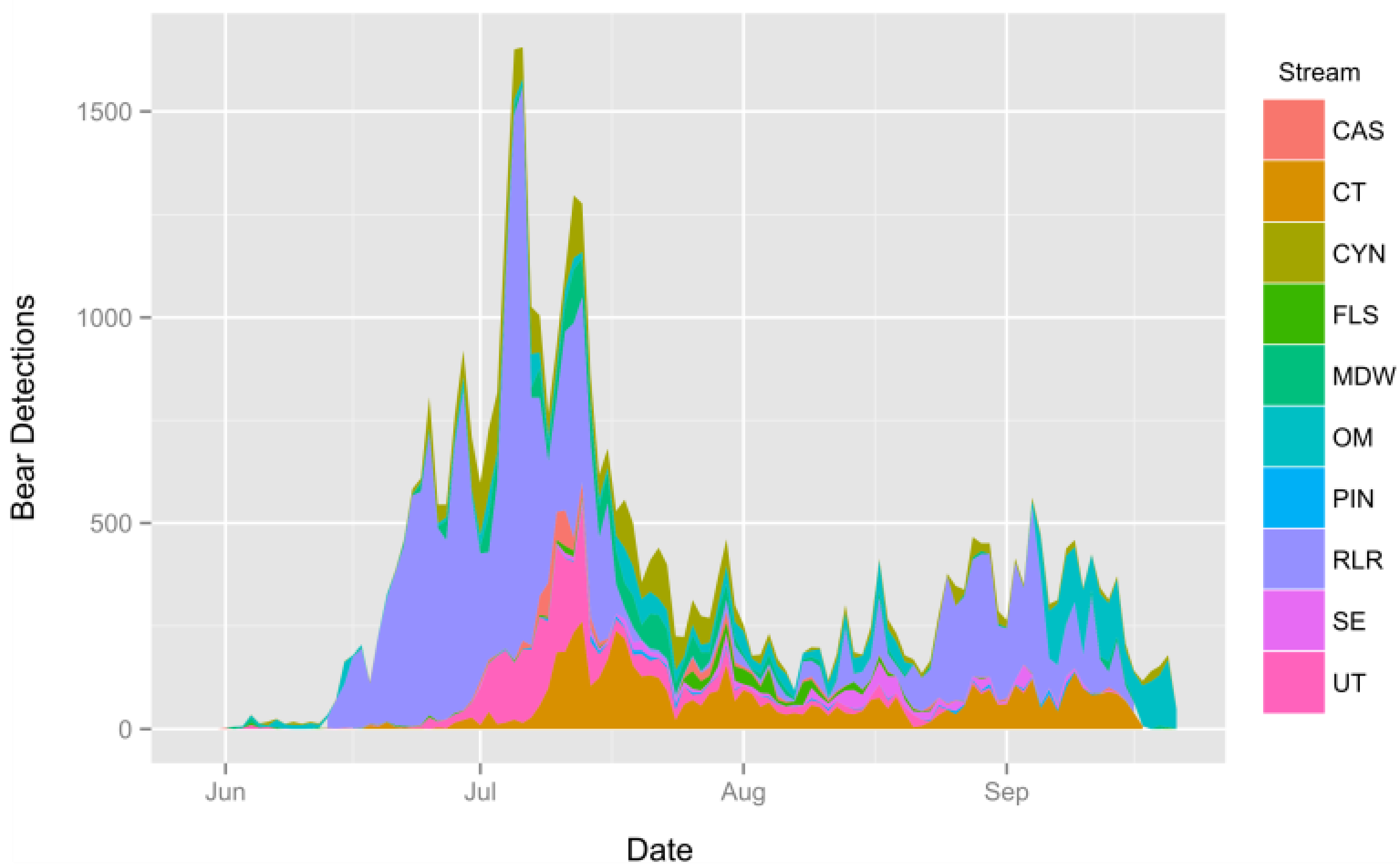

Figure 7. Bear detections during summer 2015. Data from time lapse cameras placed along salmon streams. Data is stacked so that the height of each color on any day is the number of detections on a single stream, while the overall shape is the number of bears detected across all streams. There were 43,713 total detections in 2015.

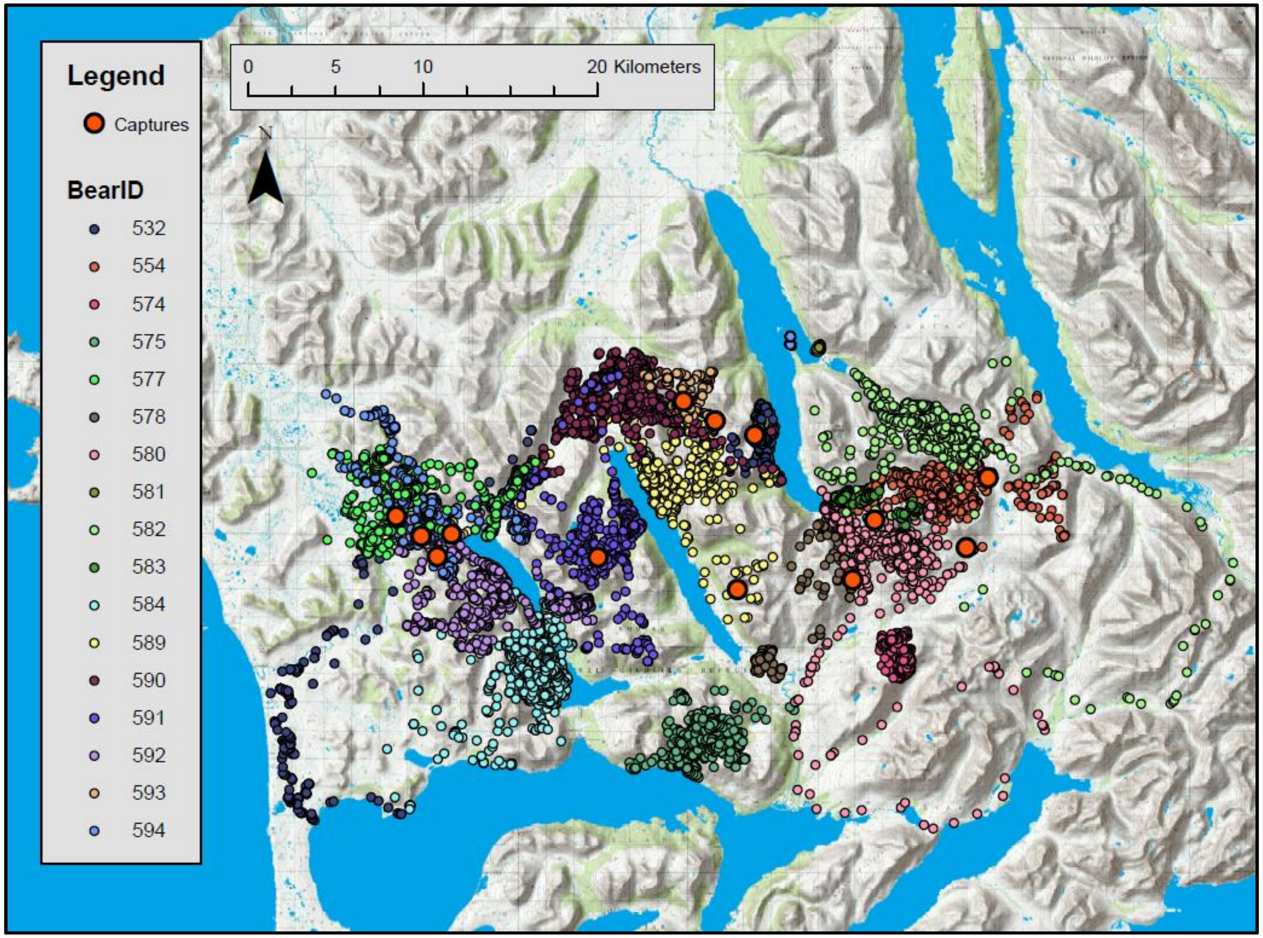

Figure 8. Capture locations and relocations up to August 11th, 2015.

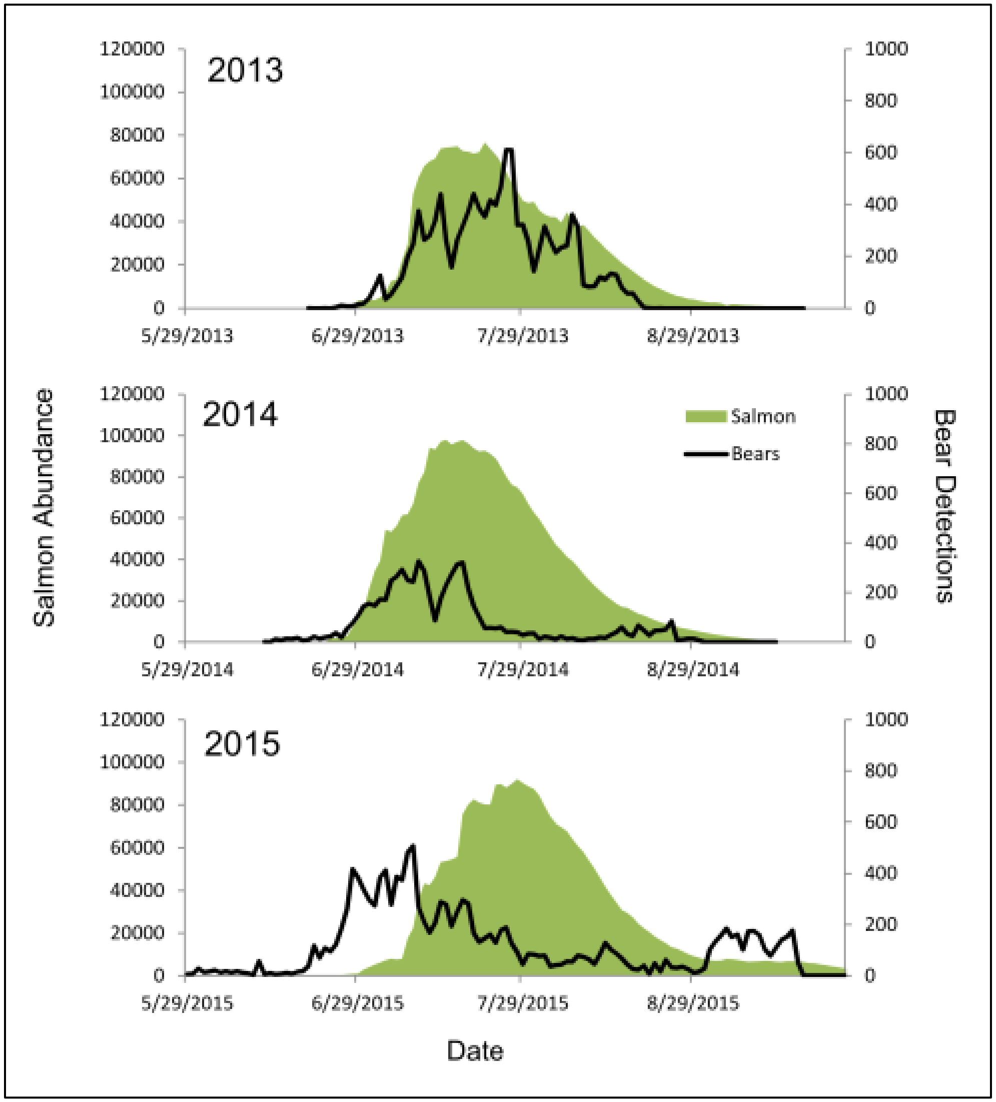

Figure 9. Comparison of salmon abundance and bear detections in four Karluk tributaries in 2013, 2014, 2015. The large difference in bear activity in July/August 2014 and 2015 is likely due to an early and abundant elderberry crop.

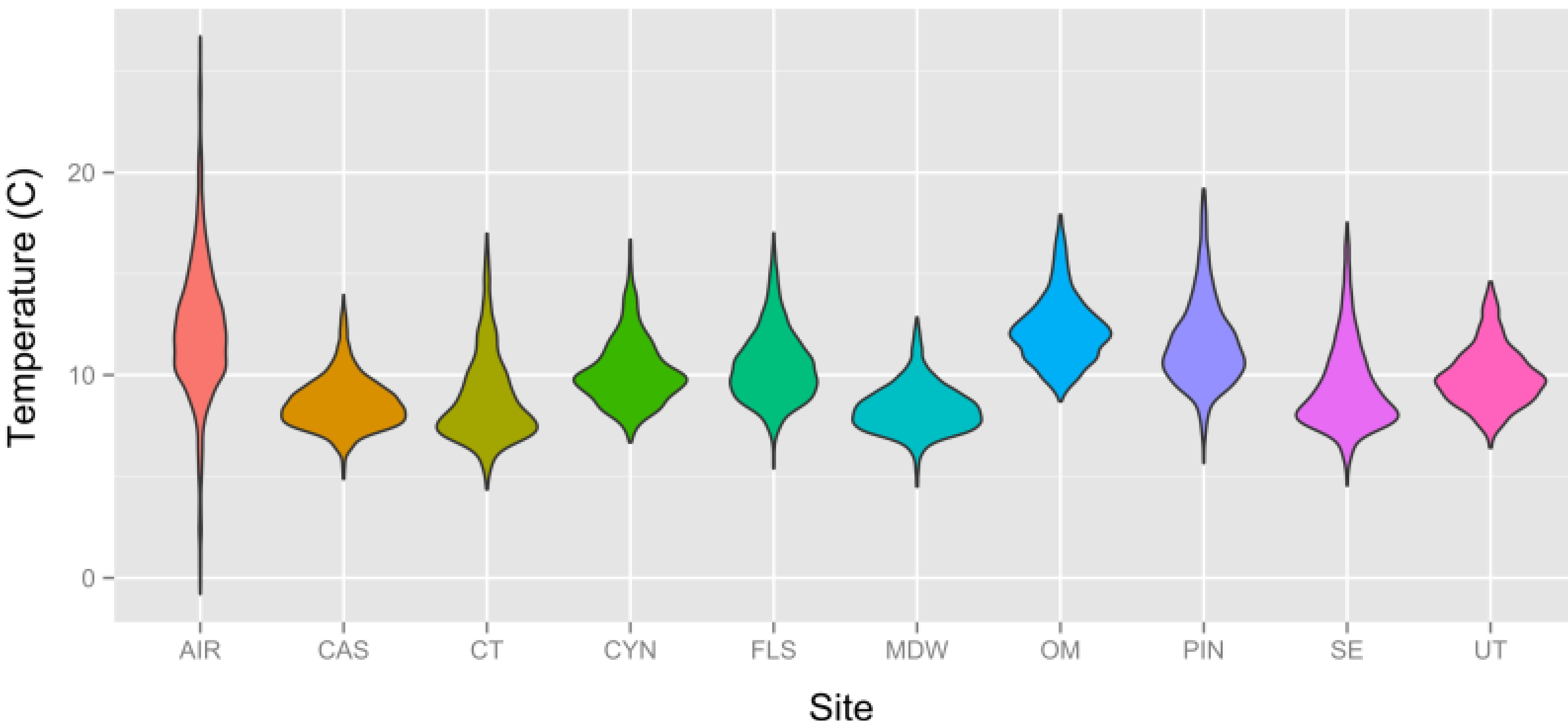

Figure 10. Violin plots of temperature distribution in nine focal streams and air temperature at North Frazer Lake.

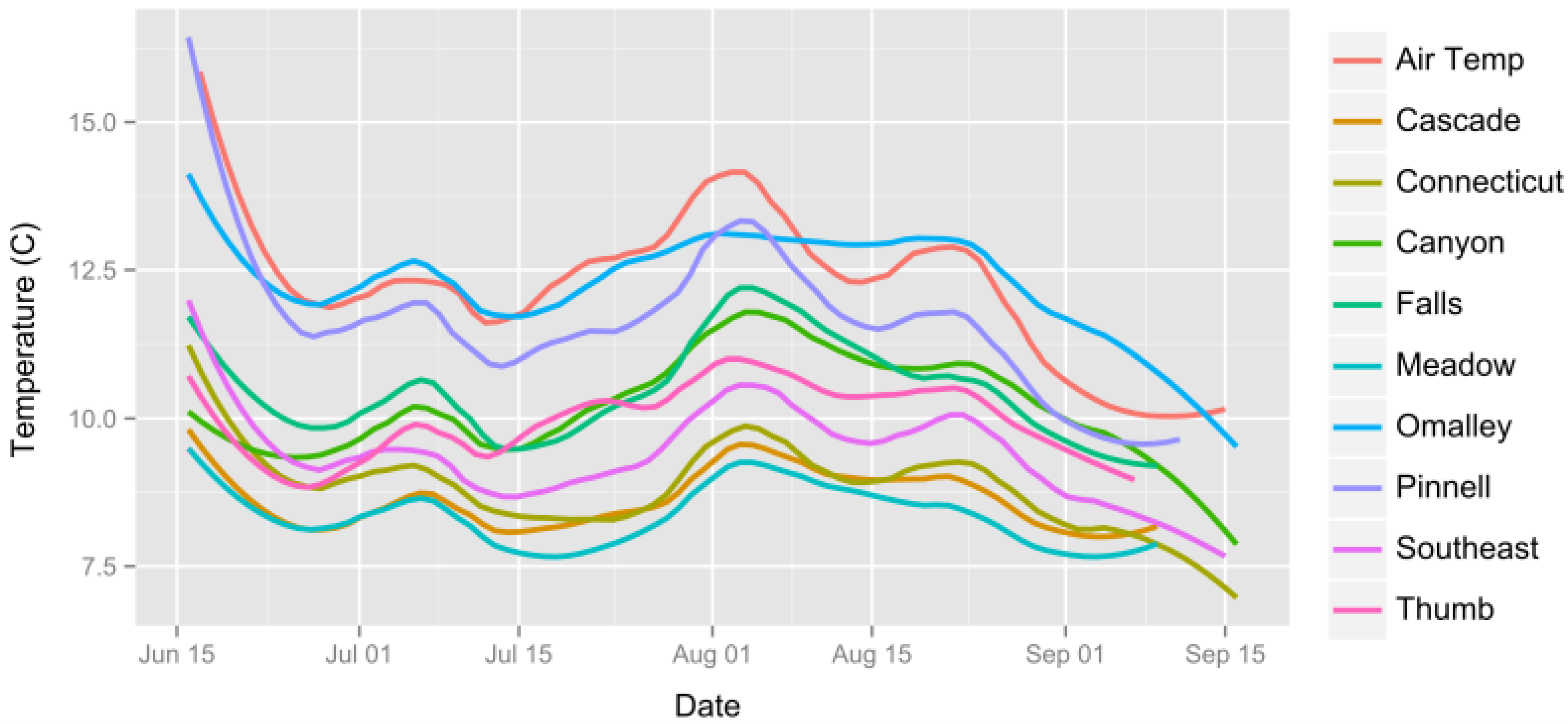

Figure 11. Smoothed daily temperature data from 9 focal streams and air temperature at North Frazer Lake.

Creek	Creek Width (m)	Creek Depth (cm)	Reproductive lifespan (d)			Still alive at the end of the study
			mean ± S.E. (N)			
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A	1.4	10.0	12.65 ± 0.23 (248)	4.36 ± 0.12 (828)	6.02 ± 0.55 (65)	294
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Table 1- Reproductive lifespan of sockeye (in days) in 6 Alaskan streams of various widths. Carlson et al. (2007).

Stream	Salmon Escapement	# of Bear Cams	Bear Detections	Bear Detections/ Cam
Canyon	65,747	3	3900	1300
Cascade	13,628	3	733	244
Connecticut	101,216	10	6374	637
Falls	8,766	3	679	226
Meadow	19,078	3	2220	740
O'malley	88,381	3	3992	1331
Pinnell	24,715	3	288	96
Southeast	89,431	3	975	325
Thumb	37,122	3	3608	1203
Red Lake River		4	20944	5236

Table 2- Salmon escapement and bear detections on 10 streams. Salmon were not monitored on Red Lake River.

Site	mean	sd	CV
Air	12.3	3.4	0.28
Cascade	8.6	1.3	0.15
Conn	8.8	2.1	0.24
Canyon	10.2	1.6	0.16
Falls	10.5	1.8	0.17
Meadow	8.3	1.2	0.14
O'malley	12.3	1.7	0.14
Pinnell	11.6	2.1	0.18
Southeast	9.4	2.1	0.23
Thumb	10.0	1.5	0.15

Table 3- Summary temperature data for focal streams and air temperature at North Frazer. Temperature was measured in Celsius. Coefficient of Variation (CV) is the mean/sd and allows us to compare variation in temperature among sites with different means.