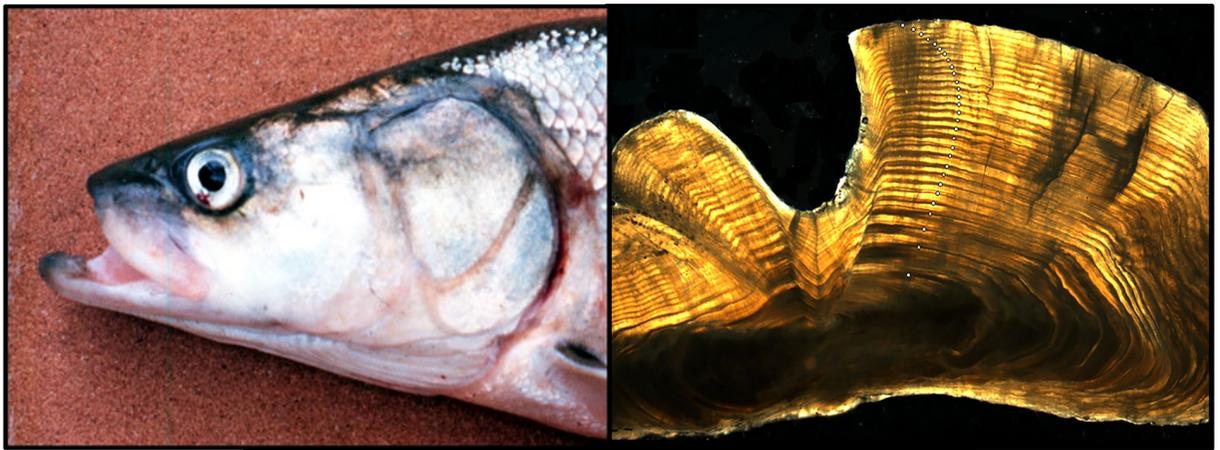


Selawik River Inconnu Spawning Population Age Structure Evaluation and Spawner Recruitment Response to a 2004 Permafrost Thaw Slump, Selawik National Wildlife Refuge, Alaska

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Cover photo: Inconnu depicting its distinctive protruding lower jaw; Inconnu otolith cross-section with white dots identifying age increments of a 29 year-old fish; The Selawik River retrogressive permafrost thaw slump in July 2009. All photos credit to USFWS.

Selawik River Inconnu Spawning Population Age Structure Evaluation and Spawner Recruitment Response to a 2004 Permafrost Thaw Slump

Raymond F. Hander, Randy J. Brown, and William K. Carter, III

Abstract

In 2004 a large permafrost thaw slump (slump) began emitting substantial volumes of fine sediment into the Selawik River upstream from the Inconnu *Stenodus leucichthys* spawning area. Following this event, the once clear-flowing river ran turbid for about nine summers before the slump stabilized and temporarily ceased emitting large amounts of sediment. To determine if sediment input had a negative effect on Inconnu spawner recruitment age cohorts, we investigated: 1) age and length data from male Inconnu from the Selawik River spawning population in 2023 and 2024; and for comparison, we obtained similar age structure data in 2024 from Inconnu preparing to spawn in the Kobuk River, a neighboring drainage without a slump; and 2) the effect of the slump on spawner recruitment based on the results of age structure tests. In the Selawik River in 2023 and 2024, we collected otoliths (age samples), fork length, weight, and identified sex from 202 and 210 spawning Inconnu, respectively. In the Kobuk River, 174 Inconnu samples were collected in 2024, but samples were unavailable in 2023. The proportion of females in sampled Inconnu from the Selawik River, 2023–2024 was 0.40 and 0.28 respectively. In 2024, mean fork lengths of males in the Selawik and Kobuk River samples were not significantly different ($t_{283} = -0.83$, $P = 0.407$). The median ages of Selawik (age-18) and Kobuk River (age-17) Inconnu were significantly different ($W = 42822.0$, $P = 0.004$). Age histograms for both populations indicated similar recruitment patterns. Ages 16–20 were more strongly represented in the Selawik and Kobuk rivers in 2024. All post-slump age cohorts were present in the Selawik River age samples from 2023 and 2024, thus allowing us to conclude that the slump had negligible effect on Selawik River Inconnu spawner recruitment. Selawik River Inconnu have consistently returned on an annual basis to spawn from 2004 to present. The negligible response of the Selawik River Inconnu spawning population to the slump's chronic and prolonged sedimentation events may be because of: 1) the reduced attenuation of sediment carried from the slump over the ~50 river kilometers to the spawning habitat and resulting sediment dilution; 2) the inherent spawning habitat's hydrological qualities, such as potential upwelling groundwater and interstitial flow, that promote successful reproduction under marginal water quality conditions. Subsequent age collections are recommended in approximate 5-year intervals as a management tool that may identify disruptions from anthropogenic and natural environmental stressors to Inconnu spawning populations in the Selawik and Kobuk rivers.

Introduction

Inconnu (Sheefish) *Stenodus leucichthys* are large, long-lived, iteroparous, coregonid fish found in several Arctic and sub-Arctic waters of Asia and North America (McPhail and Lindsey 1970; Scott and Crossman 1973). In the Kotzebue Sound region of northwest Alaska, two spawning populations have been identified, one in the upper Kobuk River (Alt 1969) and the other in the upper Selawik River within the Selawik National Wildlife Refuge (Refuge; Underwood 2000; Figure 1). The United States Congress identified Inconnu as a species of special interest in the Refuge, which was established in the Alaska National Interest Lands Conservation Act (ANILCA; USFWS 1993). In ANILCA, Congress mandated that Inconnu be maintained in their natural diversity and that opportunities for subsistence use continue. Inconnu is one of the most important food fishes in the Kotzebue region where 20,000 or more are harvested each year in subsistence, sport, and commercial fisheries (Georgette and Loon 1990; Taube and Wuttig 1998; Savereide 2002; Braem et al. 2018).

Inconnu from the Kobuk and Selawik River populations in northwest Alaska live their entire life cycle within those rivers and associated estuary habitat in eastern Kotzebue Sound, including Hotham Inlet and Selawik Lake. Mature Selawik and Kobuk River Inconnu preparing to spawn begin a slow migration up their respective natal river in early to mid-summer, initially feeding in the lower reaches with non-spawning fish and arriving at spawning areas by late summer or fall (Alt 1969; Underwood 2000). Non-spawning adults and immature Inconnu remain in the lower reaches of the rivers and estuary systems. By early September, Inconnu complete their migration to upstream spawning areas, where they remain until late September to early October when spawning takes place.

Eggs and sperm are broadcast over gravel and cobble substrate (Alt 1969; Gerken 2009). The fertilized eggs are non-adhesive and negatively buoyant, so they drift downstream and settle into the interstitial spaces in the substrate where they incubate through the winter (Teletchea et al. 2009). Following spawning, adult Inconnu migrate downstream to the estuary to overwinter (Underwood 2000; Savereide and Huang 2016). Eggs are thought to hatch in the late winter or spring and larvae are then carried downstream to lake and estuary rearing areas during the spring runoff (Shestakov 1991; Bogdanov et al. 1992; Naesje et al. 1995). Thus, the two Inconnu populations in northwest Alaska share rearing, overwintering, and feeding habitats while using the unique habitat qualities of their respective natal drainages for spawning and egg development.

During the summer of 2004, a large retrogressive permafrost thaw slump (slump) began emitting copious amounts of sediment into the Selawik River approximately 50 river kilometers (rkm) upstream from the only known Inconnu spawning area in the river (Figure 1; Underwood 2000; Hander et al. 2008). Environmental conditions leading to the slump may have included warm air temperatures and increased precipitation that increase the soil active-layer beyond normal fluctuation, thawing of ice-rich soil, and creation of supersaturated soil that could flow downhill. Remote sensed imagery beginning in 2002 revealed pre-slump evidence of water ponding near the eventual evacuation channel breach of 2004 (Figure 2; Google Earth Web time lapse; Google Earth Web Version 10.88.0.2). Previous to 2004, the Selawik River flowed clear through the spawning area, a 12 rkm reach of gravel and cobble substrate (Underwood 2000). From approximately 2004 to 2011 the Selawik River flowed turbid through the spawning area during the summer months and at times the gravel bars in the spawning area became layered in fine

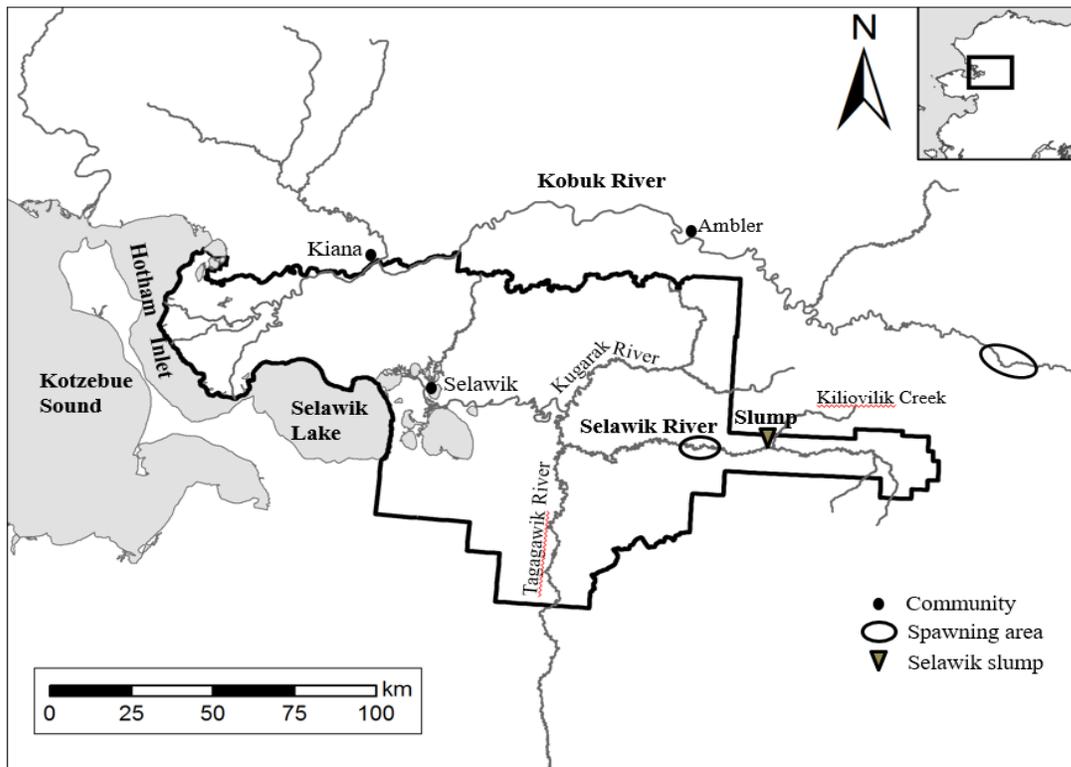


Figure 1.—Important Inconnu habitat in eastern Kotzebue Sound. The Selawik National Wildlife Refuge is outlined in bold, the Villages of Selawik, Kiana, and Ambler the blackened circle, locations of the Selawik and Kobuk River Inconnu spawning areas are the black ellipses, and the permafrost thaw slump the dark gray triangle. Ambler is near where the 2024 Kobuk River Inconnu samples were collected.



Figure 2.— Google Earth Web timelapse imagery 2001–2004 featuring pre-slump ponding evidence first noticeable in 2002 in the white circles near the evacuation channel breach that occurred later in 2004 (Figure 4).

sediment and mud. As of 2012, more than 580,000 m³ of sediment had thawed with approximately two-thirds of that volume mobilized into the Selawik River (Jensen et al. 2014).

Over the summers of 2009–2011, measured turbidity at the slump outflow averaged 34 times greater than a reference site upstream from the slump, and turbidity near the Inconnu spawning area was about 11 times greater than at the reference site (Calhoun 2012). Turbid water conditions had been observed at the mouth of the Tagagawik River, 150 rkm downstream from the slump (Figure 3), but were rarely observed in the Native Village of Selawik, about 100 rkm farther downstream. From these observations we deduced that the sediment released by the slump has been progressively and steadily deposited onto the riverbed. A September 2016 site visit to the slump and 2018 aerial images revealed that it had stabilized, and its floor and debris tongue had been almost completely vegetated with grasses and shrubs (Figure 4). Mid-July 2019 we discovered, via remote sensed imagery, that the slump was exhibiting polycyclic behavior (repeated reactivation), continuing lateral growth, and again delivering unknown amounts of sediment into the Selawik River (Figure 4). Aerial reconnaissance and photography in mid-October 2019 confirmed the slump’s renewed activity. The slump continues to erode at varying rates with unknown amounts of sediment delivery to the Selawik River. Sediment emission from the slump appears to be negligible although during heavy rain or high river discharge sediment may erode into the Selawik River from the toe of the debris tongue.



Figure 3.—An aerial view of the permafrost thaw slump in the upper Selawik River drainage in 2007 and its erosion progression 2004–2012 and lines at river level showing extents of sediment deposition (left image). The confluence of the Selawik and Tagagawik rivers in 2006 (right image), approximately 150 rkm downstream from the slump, illustrating the persistence of the turbid flow. Photo credits USFWS.

When sediment concentrations and rates of deposition exceed natural background levels, aquatic biota can be negatively affected resulting in shifts in community composition and reductions in abundance and diversity (Kemp et al. 2011). It is well documented that turbidity and the associated sedimentation of stream bottoms, whether by anthropogenic or natural causes, has profound negative effects on stream spawning fishes (Waters 1995; Wood and Armitage 1997; Birtwell 1999). Stream sedimentation can have three basic effects on spawning habitat: 1) sediments can penetrate gravel substrates and restrict interstitial water flow; 2) it can change the substrate surface from a rough to smooth by filling in the substrate’s interstitial spaces causing egg displacement to suboptimal habitats; and 3) sediment can cover eggs that settle into interstitial spaces (Chapman 1988; Birtwell 1999). Chapman (1988) provided a comprehensive review of the effects of sedimentation concentrations and interstitial flow, reporting that reduced

interstitial flow reduces dissolved oxygen levels available to eggs and leads to reduced egg survival. For example, Birtwell (1999) reported that survival of Chinook Salmon *Oncorhynchus tshawytscha* eggs declined from about 90% to <35% when fine sediment concentrations in the substrate increased from 10% to 40%. Fudge and Bodaly (1984) investigated egg survival in Lake Whitefish *Coregonus clupeaformis* spawning habitats that were experiencing elevated sediment deposition and found more than 10 times greater survival in control samples than in samples from habitats experiencing sedimentation.



Figure 4.— Aerial views of the permafrost thaw slump's growth, maturation, and reactivation. Note the gradual loss of the headwall height (slump's vertical perimeter wall), the onset of vegetation by 2009 and subsequent reduction of thaw discharge from the slump by 2018. An October 17, 2019 slump reconnaissance photograph shows newly exposed perimeter headwall bearing ice-rich soil that thawed and flowed down through a new evacuation channel just downstream of the original channel. The right-hand third of the slump persisted as evidenced by the established vegetation on the original slump floor. Permafrost thaw continued in 2020. All photos credit to USFWS.

They contended that direct exposure to flowing or upwelling water was required to facilitate egg respiration. When the eggs were covered by fine sediment or when interstitial flow was reduced, egg survival declined dramatically (Fudge and Bodaly 1984).

We observed that sediment input from the slump was reduced once freezing temperatures prevailed in the fall when spawning occurred and suspect that eggs are not being covered by sediment (Hander et al. 2019). However, given the magnitude of sediment input from the slump (Figure 3 and 4), and observation of sediment deposition in the spawning area, we expected the potential for restricted interstitial substrate water flow. Restricted water flow would reduce oxygen carried to developing eggs as well as reduced elimination of metabolic waste products. A change to smoother substrate from sedimentation causes eggs to be carried to suboptimal habitats that may put them at greater risk to predation.

Gravel and cobble substrate provides protection for eggs against predation by other fishes, which can be substantial (Hart 1930; Alt 1969; Letichevskiy 1981). Based on observations of exposed gravel bars in the spawning area it is likely that the substrate within the Selawik River became smoother as more sediment filled the cracks and crevices. This would have reduced its capacity to hold and shelter eggs. Inconnu are broadcast spawners and do not prepare redds for egg deposition, hence they have no mechanism to clean the substrate of sediments, and a smoother substrate may reduce egg survival in the Selawik River spawning habitat.

If egg survival was dramatically reduced because of sedimentation of the spawning substrate, then there would be a proportional reduction or elimination of recruitment for slump affected age cohorts relative to pre-slump unaffected age cohorts. There could be two basic sources of recruitment failure; one caused by a failure of egg development in the spawning area, which should affect only the Selawik River Inconnu population, and the other from environmental or predation effects in the shared rearing and overwintering habitat, which would affect both the Selawik and Kobuk River Inconnu populations (Smith et al. 2015).

If a recruitment failure was unique to the Selawik River population, it would indicate a problem on the Selawik River spawning area. If recruitment failure occurred on a single cohort only, it would be unlikely to have been caused by sedimentation of the spawning gravel, and more likely a problem in the shared lower river and estuary habitat. Because Inconnu are considered to be age-0 during their first summer, an age-10 fish would come from a brood year that spawned 11 years previously (see Appendix Table A.1). If egg development failed in 2004, the first year of the slump, recruitment failure should be noticed in the 2015 season for individuals maturing at age-10. If sedimentation of the spawning gravel were more gradual over time and the effects on egg development less extreme, recruitment failure or decline would take longer to detect. Age distribution data obtained prior to 2015 constitutes an unaffected (pre-2004 cohort) baseline.

Chronic sediment release from the slump in the upper Selawik River, and subsequent deposition in the Inconnu spawning area downstream, raised concern about potential negative effects to the population and the subsistence users that depend on it. In response to those concerns, Hander et al. (2019) compiled biological data from the Selawik River Inconnu spawning population and from the Kobuk River spawning population for comparison from 2011 to 2018. The primary goal of the research was to infer if the slump had an effect on spawner recruitment for Selawik River Inconnu. Because most Inconnu from spawning populations in the Selawik and Kobuk rivers appeared to mature between 10 and 15 years of age (Hander et al. 2019), several years older than other populations (Brown 2000; Howland 2005; Esse 2011), the sample did not include a sufficient number of age cohorts from post-slump cohorts to infer whether or not the slump

affected recruitment. However, their data provided the background necessary for this study with the addition of post-slump cohorts expected in the spawning population.

The primary objectives of our study were to: 1) collect age and length data from male Inconnu from the Selawik and Kobuk River spawning populations in 2023 and 2024; 2) use age structure tests to infer if there was a slump effect or no slump effect on spawner recruitment.

Study Area

The Selawik River drainage lies primarily within the Refuge in northwest Alaska. The main stem of the river flows from east to west along or adjacent to the latitude line of the Arctic Circle (Latitude 66.5569°) through a wide tundra valley for approximately 300 rkm, terminating in Selawik Lake (Figure 1). Two major tributaries join the Selawik River: the Tagagawik River flowing from the south and the Kugarak River flowing from the north.

The Refuge experiences a maritime climate during ice-free periods of the year (late May to early October) and transitions to more of a continental climate during winter months (Shulski and Wendler 2007). High temperatures during mid-summer average 15°C and average low temperatures during mid-winter are -23°C. The annual precipitation averages 25 cm. The Refuge is located in a discontinuous permafrost zone in the Selawik and Kobuk River watersheds (Jorgenson et al. 2008) with permafrost overlain by subarctic tundra vegetation or taiga occupying the majority of the area (USFWS 2011).

Sampling for this study was conducted on the Selawik River upstream from the Tagagawik River (Figure 1). The river in this area meanders through the valley in a series of pools and runs with an abundance of woody debris. The Inconnu sampling was conducted within their spawning area in the upper Selawik River (Figure 1; Underwood 2000) where substrate was primarily gravel and cobble.

Methods

Overview

This project involved components that established indicators of possible impacts of the Selawik River slump on egg survival and eventual recruitment to the Inconnu spawning population. In 2023 and 2024 we collected age, length, and weight data from male Inconnu from the Selawik River spawning population. Male and female Inconnu from the Kobuk River spawning population were sampled only in 2024 and served as a paired Inconnu sample from a non-slump affected river for comparison. Male Inconnu in the Selawik River were targeted as a conservative measure to minimize sacrificing egg bearing females and males are the greater proportion of the annual spawning population. We pooled male and female age data by river for age analysis.

This project relies on demographic data collected by Hander et al. (2019) on compared body condition (i.e., weight at length; Pope and Kruse 2007) and growth (i.e., length at age, Isely and Grabowski 2007), gonadosomatic index, and sex ratio from the two populations. Data from Hander et al. (2019) provides evidence that the Selawik and Kobuk River Inconnu exhibit relatively similar body condition and growth rates resulting from their common Selawik Lake and Hotham Inlet rearing environments. Their data also established that female Inconnu were preparing to spawn based on gonadosomatic indices. Thus, we were confident of sampling the

appropriate demographic group on their respective spawning grounds and that the greater proportion of spawners were male Inconnu, lessening the need to sacrifice spawning females.

Sampling and Otolith Collection

In 2023 and 2024 male Inconnu were sampled during September from the Selawik River spawning area, approximately 210 rkm upstream from Selawik Lake. Female Inconnu were immediately released unless seriously injured during capture. In 2024, male and female Inconnu were sampled late July to early August in the Kobuk River near the community of Ambler approximately 260 rkm upstream from Hotham Inlet. We used Bromaghin's (1993) statistical methods for determining appropriate sample sizes for estimating multinomial proportions at various levels of precision and accuracy. A sample size of 200 individuals provided proportion estimates of two different age classification levels to within 7% or less of their actual values at $\alpha = 0.05$. Selawik and Kobuk River Inconnu were captured by angling, which was shown to produce similar length distributions to those captured with beach seines during a previous mark-recapture project (Hander et al. 2008). The first 200 male Inconnu captured were sacrificed for age analysis. Each Inconnu captured was measured for fork length (FL) to the nearest 5 mm or less, weighed whole to the nearest 100 g, egg skeins of seriously injured and dispatched females were weighed to the nearest 10 g, and sagittal otoliths were retrieved from the head of each fish, rinsed clean, and stored dry in a coin envelope for later aging. Following otolith extraction, Inconnu filet meat was briefly hung to dry on a fish rack then transported downstream to Selawik residents for human consumption. Inconnu filet meat from the Kobuk River collection was distributed directly to residents of Ambler or donated to the Fairbanks Community Food Bank.

Otolith Preparation and Aging

Otolith preparation and age analysis took place at the U.S. Fish and Wildlife Service laboratory at Selawik National Wildlife Refuge in Kotzebue, Alaska. One otolith from each fish was thin-sectioned in the transverse plane through the core and mounted on a glass slide using thermal glue (Secor et al. 1992). Each otolith section was approximately 0.3-mm thick. Annuli were viewed with a compound microscope using polarized transmitted light. Annuli were identified and counted based on descriptions and illustrations in Chilton and Beamish (1982). Because egg incubation takes place during the winter following spawning, and the first annuli is produced during the first winter as a fish, Inconnu brood age in years is the number of annuli plus one.

Feeding Status and Gonadosomatic Index

The Kobuk River collection project was downstream from the spawning area and non-spawning Inconnu could potentially be sampled there. We tested our assumption that spawning fish were the predominant demographic group in the sample by examining captured fish for two indicators of spawning preparation. First, stomach fullness was evaluated for every captured fish because Inconnu are known to cease feeding during their spawning migrations (Alt 1969; Brown 2000; Esse 2011; Hander et al. 2019). Second, a gonadosomatic index ($GSI = [\text{egg weight/whole body weight}] * 100$) was created for all female Inconnu because non-spawning females rarely have GSI values greater than 3% (Brown et al. 2007, 2012). Therefore, fish without food in their stomachs and females with elevated GSI indices would provide support for our assumption of sampling the Kobuk River spawning population and that they would be comparable to the Selawik River collection. We included female spawners from 2011–2018, and 2023–2024 in our index (Hander et al. 2019).

Female Proportion of Spawning Sample

Inconnu were captured in the Selawik and Kobuk River sampling areas and externally examined to classify individuals as either male or female. This sex identification method was found to be reliable in the fall season to identify Inconnu preparing to spawn (Brown 2000). Selawik River Inconnu classified as females were counted and immediately released unless seriously injured during capture. Hander et al. (2008) found that a sample obtained using angling methods produced similar length distributions and sex composition to a sample obtained using beach seines, so we assumed that our angling samples were representative of the annual spawning populations. We estimated the mean proportion of female spawners in annual Selawik River spawning samples including those from 2004 and 2005, 2011–2018, and 2023–2024 (Hander et al. 2008; 2019).

Length Comparisons

Length data from male Inconnu from the 2024 Selawik and Kobuk River spawning populations were used to test length distribution similarity. The mean FL data for male Inconnu from the Selawik and Kobuk River populations were compared using a two-sample t-test of the null hypothesis that mean FLs were similar within the collections for the two populations. Statistical differences were considered to be significant at $\alpha = 0.05$. All statistical analyses were conducted using Minitab statistical software version 22.2.1.

Age Structure Analysis

Age data from male and female Selawik and Kobuk River Inconnu populations for 2024 were tested for similarity in median age. We reasoned that both populations may have comparable age structures since they experience a common rearing and overwintering environment in Selawik Lake and Hotham Inlet (Alt 1977; Underwood 2000; Smith et al. 2015). Additionally, if both populations were similarly distributed throughout this estuarine environment, they would also experience similar rates of natural and fishing mortality. Therefore, we hypothesized the 2024 age distribution of the two spawning populations would be similar in the absence of factors that affected one of the populations but not the other. We used a Mann-Whitney nonparametric test (Zar 1999) of the null hypothesis that median ages from both populations were similar, versus the alternative hypothesis that they were different.

Results

Feeding Status and Gonadosomatic Index

Our assumption that Inconnu sampled in the lower Kobuk River were preparing to spawn was confirmed. No food was found in the stomachs of fish sampled in either river, which is consistent with Inconnu spawning migration behavior. The GSI values from Kobuk River females collected 2011–2018 and 2024 ($n = 338$) revealed that all were $>3\%$ (GSI range 3.4–20.8) and increased through the season consistent with data from known spawners in other drainages (Figure 5).

Gonadosomatic indices are not particularly effective for assessing the spawning readiness in males during summer because the seasonal change in gonad mass between non-spawning and spawning Inconnu and other coregonid species can be an order of magnitude less for males than

for females (Lambert and Dodson 1990). However, the fact that no fish were feeding, and all females were preparing to spawn supported the inclusion for use of the Kobuk River samples as representative of annual spawning populations from the Kobuk River.

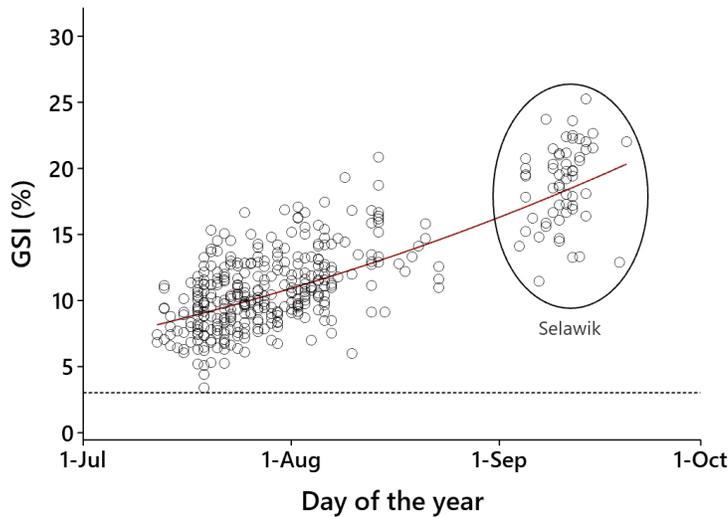


Figure 5.—Gonadosomatic index [GSI = (egg weight / whole body weight)*100] of female Inconnu from the Kobuk, $n = 338$, and Selawik, $n = 58$, River populations, 2011–2018 (Hander et al. 2019) and 2023–2024. Samples from the Selawik River (circled) were from Inconnu that were known to be preparing to spawn. The Kobuk River samples were collected downstream of the Kobuk River spawning area. The horizontal reference line at GSI = 3 indicates the separation of fish preparing to spawn and non-spawning fish. The regression equation is $\log_{10}(\text{GSI}) = -5.859 + 2.959 \log_{10}(\text{Day of the year})$ $R\text{-sq} = 47.93$.

Female Proportion of Spawning Sample

The proportion of females in sampled Inconnu from the Selawik River, 2004–2005, 2011–2018, and 2023–2024, varied annually from 0.21 in 2004 to 0.42 in 2012 (Figure 6). The weighted mean proportion of females when considering all 12 sample years was 0.30 (SE = 0.007). The consistency of these data suggest that males normally outnumber females in the spawning areas.

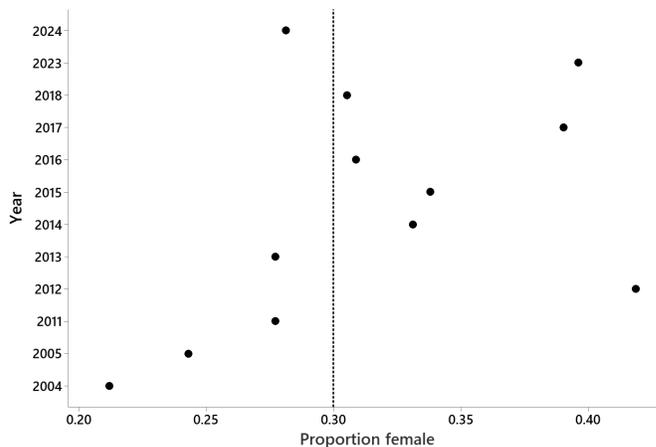


Figure 6.—Female proportions of spawning Inconnu from 12 different years of sampling on the Selawik River, 2004–2005 (Hander et al. 2008), 2011–2018 (Hander et al. 2019), and 2023–2024. The mean proportion female was 0.30 (vertical dashed line).

Length Comparisons

T-tests of null hypotheses that mean FL of male Inconnu were similar for the 2024 collections from the Selawik and Kobuk River spawning populations were not significantly different (Figure 7; $t_{283} = -0.83$, $P = 0.407$). Selawik ($n = 498$) and Kobuk ($n = 145$) River male mean FLs were 85.2 cm (range 69.0–100.0) and 85.5 cm (range 73.5–96.0) respectively.

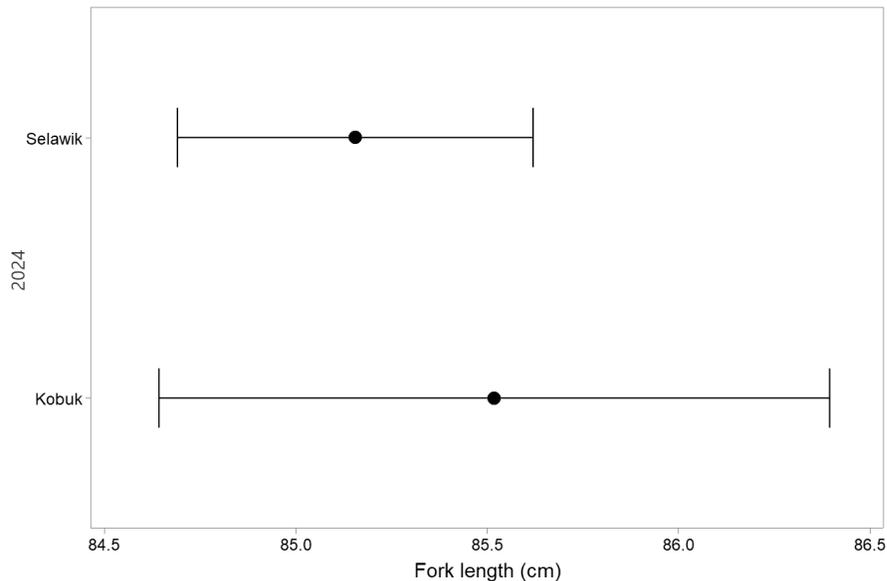


Figure 7.—Interval plot of mean FL with 95% confidence intervals for mature male Inconnu from the 2024 collections of Selawik and Kobuk River spawning populations. Comparison of mean male FL between the two populations were not significantly different ($p = 0.407$).

Median age samples from the Selawik and Kobuk River 2024 spawning populations were significantly different (median Selawik age = 18; median Kobuk age = 17; $W = 42822.0$, $P = 0.004$; Figure 8). For comparison, the median age of the Selawik River population was greater than that of the Kobuk River population during 2011–2018 sample years in which median ages were significantly different for five out of the eight years (Hander et al. 2019). The Kobuk River age sample contained one age-6, one age-7 and three age-8 Inconnu which are rare occurrences in the spawning population (Hander et al. 2019 and this study). These fish were excluded as outliers from the age analysis as they were a small fraction (~2%) of age samples and were beyond three SD from the mean age. There is only one other instance of age-8 Inconnu in the Kobuk River (2013) among Selawik and Kobuk River samples from sample years 2011–2018 and Selawik River 2023–2024 (Hander et al. 2019; Selawik total fish $n = 2,015$ and Kobuk total fish $n = 1,551$). Kobuk River age sample size was reduced from $n = 173$ to $n = 168$ from sample exclusions.

Age samples from the Selawik and Kobuk River Inconnu spawning populations indicated maturity was attained for most fish between age-12 and age-15, with a small number of individuals maturing as young as age-9 (Hander et al. 2019; Figure 9). Age-18 Inconnu in both rivers are dominant, and for the Selawik River age-19 fish mark the first post-slump age cohort that equates to the 2004 brood year. All post-slump age cohorts were present in 2023 and 2024 (Figure 9; Appendix Figure A.1.).

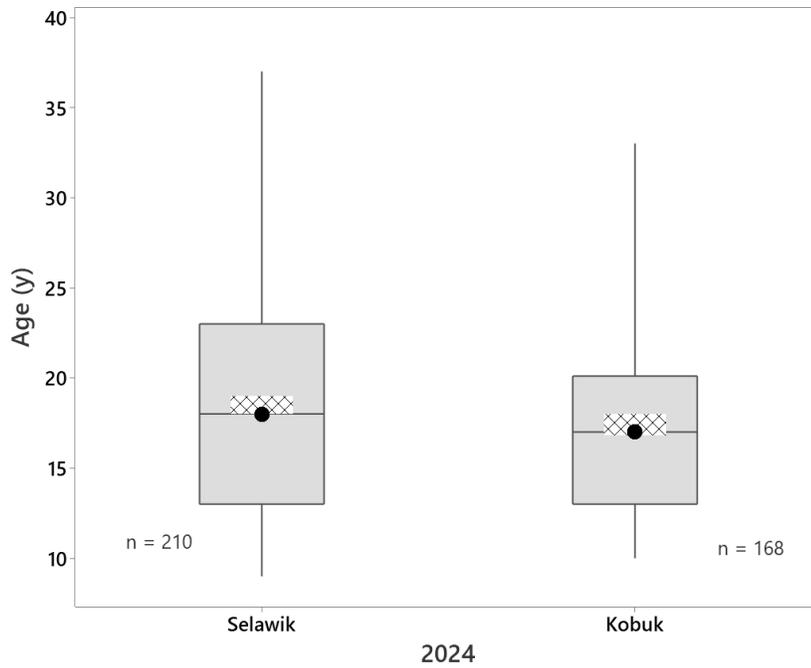


Figure 8.—Box plot of 2024 median age for Selawik and Kobuk River Inconnu populations. The 95% CIs are represented by the crosshatched region. The Mann-Whitney nonparametric test resulted in a significant difference in median ages ($P = 0.004$).

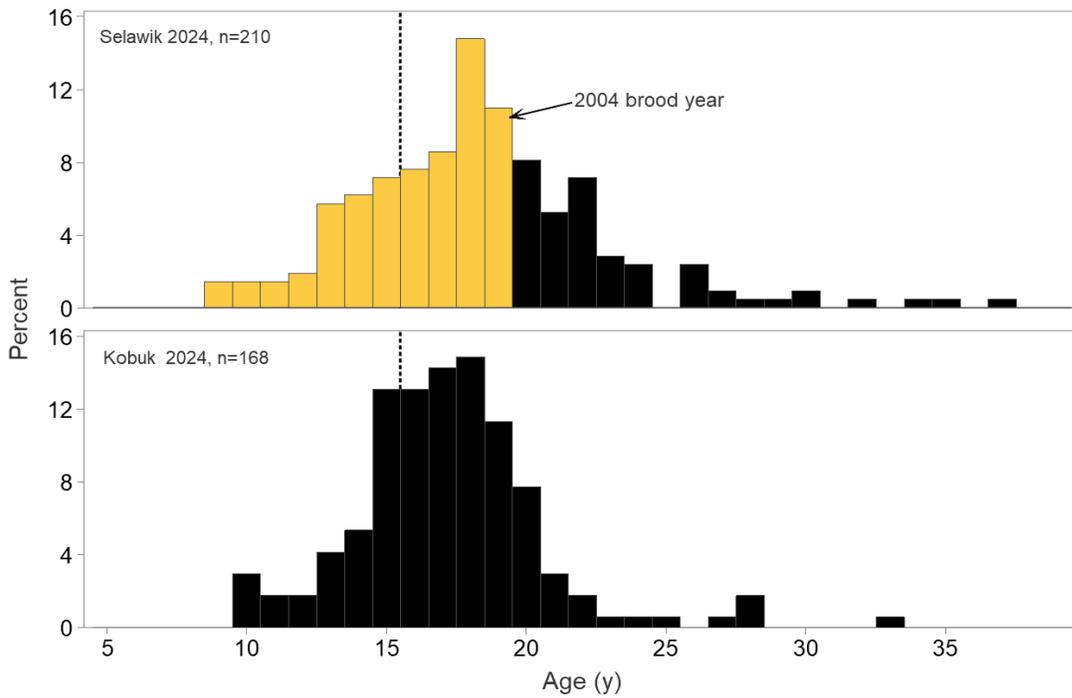


Figure 9.—Age histograms of mature Selawik River (top) and Kobuk River (bottom) Inconnu from 2024 illustrating major age structure features. The vertical dashed lines delineate the classification boundary between the recently recruited group that are 15 years of age and younger from the older group that are greater than 15 years of age. Note the observed post-slump (Selawik yellow bars) age cohorts are all present. Selawik and Kobuk River samples show reasonably similar age structure patterns although the Kobuk River sample appears to have a reduced older age component that may be attributed to in-river harvest.

Discussion

Overview

The primary goal of this study was to infer if the slump's multiple years of sediment release had an effect on recruitment for Selawik River Inconnu. Since publication of Hander et al. (2019), six additional post-slump age cohorts were expected to be present in the Selawik River spawning population as of 2024. The additional years provided a sufficient number of post-slump age cohorts to infer whether or not the slump affected recruitment. All post-slump spawned age cohorts were present in the Selawik River in 2023 and 2024 (Appendix Figure A.1.) and fulfilled our objective of inferring the slump's negligible effect on recruitment. High stream discharge in the Kobuk River in 2023 prohibited sample collection and limited our sample comparison. We used basic statistical analyses to characterize the comparisons of Selawik and Kobuk river's spawning populations based on the limited 2024 sample collections.

The conclusion of a negligible slump effect on Inconnu spawner recruitment in the Selawik River is likely because of their innate ability to navigate and spawn in turbid glacially influenced rivers (Brown et al. 2025). The onset of autumn freezing air temperature begins mid-September in the Selawik River basin and Inconnu spawning occurs in late September to early October. With freezing conditions there is a dramatic reduction of runoff generated sediment input (e.g., eroding riverbanks and the slump). Inconnu have high spawning site fidelity to a discreet section the Selawik River (Underwood, 2000; Hander et al. 2008) and have returned annually to spawn since the slump's initiation in 2004 to present. The dilution of slump sediments over the approximate 50 rkm to the spawning area may have resulted in low levels of sediment accumulation.

Hyporheic water exchange has been shown to be an important variable in spawning site selection in salmonids (Baxter and McPhail 1999; Mueller and Geist 1999; Geist et al. 2002) but has not been linked to spawning habitat in Inconnu or other whitefish species (Gerken 2009). At a minimum, these factors work in favor of the Selawik River Inconnu spawning population's reproductive success related to the 2004 Selawik River slump.

Feeding Status and Gonadosomatic Index

Consistent with Inconnu preparing to spawn, no food was found in the stomachs of fish sampled in the Selawik and Kobuk rivers. Additionally, all Selawik and Kobuk River female Inconnu had GSI values >3%, indicating they were preparing to spawn. The difference in Selawik and Kobuk River Inconnu GSI grouping can be explained by the seasonal timing of data collection events and the energetic cost of fasting and egg development (Hander et al. 2019). Most of the Kobuk River samples were collected in July and August in the lower Kobuk River where Inconnu were in the early stages of their spawning migration. Selawik River samples were collected within their spawning area from early to mid-September within two weeks prior to spawning.

Female Proportion of Spawning Sample

The greater proportion of males in the spawning population of Inconnu in the Selawik River was first documented from a mark-recapture project in 2004 and 2005 (Hander et al. 2008). The proportion female in the spawning population was 0.21 in 2004 and 0.24 in 2005. We continued to observe the same pattern during this project with an overall annual average proportion female from all 12 sampling years of 0.30 (range 0.21–0.42). Others have documented similar findings

from spawning populations sampled in the upper Yukon Flats (0.41, one sample year; Brown 2000), the Sulukna River (0.41, one sample year; Esse 2011), the Alatna River (0.28, one sample year; McKenna et al. 2015), and the Peel River (mean = 0.38, five sample years; VanGerwen-Toyne et al. 2008). These data suggest that lower proportions of females are common for populations of spawning Inconnu.

Fork Length Comparisons

Selawik and Kobuk River male Inconnu spawners mean FL in 2024 was not significantly different (Figure 7). During seven of eight years of the project, 2011–2018 (Hander et al. 2019), annual mean FL values of males from the Inconnu population in the Kobuk River were significantly smaller than those of male Inconnu from the Selawik River population. It is not clear why mean FL values from males in the two populations in 2024 were similar, although it may be attributed to the relatively large group of older fish, age 15 and older, in both spawning populations. This would indicate a series of strong recruitment years 15 and more years ago.

Age data and analyses

Our data indicated that most Selawik and Kobuk River Inconnu matured between age 12 and 15 (Figure 9) with a small number of precocious individuals, mostly males, maturing as young as age-9 and 10 (Hander et al. 2019). While the 2024 median age was significantly different between Selawik and Kobuk River Inconnu, the difference was only one year older for Selawik River Inconnu at age-18. In 2023 and 2024 the most prominent age cohorts align with brood years 2004 and 2005 (Figure 9). These were the first two post-slump years when downstream slump sediment load led to visually observed glacial stream equivalent turbidity (Hander et al. 2008) and observed sediment deposition in the spawning habitat. Stream turbidity from the slump during open-water season persisted from 2004 to about 2012 and gradually lessened as the slump was vegetated and stabilized, delivering less sediment to the Selawik River even with bouts of slump reactivation.

The prevalence of “middle-age” Inconnu in both rivers and fewer fish in the young component (\leq age-15) conforms with the periodic recruitment characteristic reported by Hander et al. (2019). Both populations experience harvest in their common wintering environments of Hotham Inlet and Selawik Lake. The reduced older age components in the Selawik River are thought to be mainly from age-related mortality and harvest that occur near the community of Selawik in the lower river and Selawik Lake where both populations are present (Alt 1977; Underwood 2000; Smith et al. 2015). The Kobuk River population experiences greater in-river harvest from five communities between the river’s mouth and their spawning area that contributes to the more rapid decline in age beginning after age-20 in 2024 (Georgette and Loon 1990; Taube and Wuttig 1998; Braem et al. 2018). Additionally, harvest on the Kobuk River is primarily on mature fish migrating upstream to spawn (Georgette and Loon 1990; Taube and Wuttig 1998). The fewer recruits observed in 2023 and 2024 will be expected to give way to increased recruitment based on the periodic recruitment phenomenon observed in the Selawik and Kobuk River spawning populations, barring significant harvest and environmental changes.

Recommendations

The effects of sediment deposition, if any, on the Selawik River Inconnu spawning population appear to be negligible on post-slump recruitment as 2023 and 2024 samples included all post-slump age cohorts.

It is recommended that future age collections occur about every five years on the Selawik and Kobuk river's Inconnu spawning populations to determine if there are changes to population age structures. Changes to Inconnu spawning population age structure, whether caused by anthropogenic or natural processes, may inform land management agencies on appropriate measures to protect Selawik and Kobuk River Inconnu and their aquatic habitat requirements.

The geologic history and permafrost distribution in the Selawik River basin and northwest Alaska predisposes the region to thermokarst disturbance. The abrupt increase in the extent and rate of permafrost degradation for at least the last three decades has significant ecological implications for tundra ecosystems (Jorgenson et al. 2006; Kokelj et al. 2021). Along the Selawik River corridor there is ample evidence of active erosion from elevated banks. Observational analysis of the slump in 2007 compared to pre-slump high altitude aerial imagery (K. Yoshikawa, University of Alaska Fairbanks, personal communication; Brooks 1988) indicated that the slump had encroached on a historic slump scar. We recommend monitoring of the Selawik and Kobuk River corridors for permafrost failure features that may directly affect fish populations and their habitat. Age data from this study and Hander et al. (2019) can serve as a valuable baseline to detect relative changes in the spawning population age structure.

The significant cultural and subsistence value of Selawik and Kobuk River Inconnu merit a more complete understanding of their population dynamics. That requires combined efforts of resource management agencies and resource users to continue efforts to fill information gaps by collecting harvest data, spawner abundance, spawner age structure, and stock identification. The most recent comprehensive Kotzebue District subsistence fish harvest surveys including whitefishes was during 2012–2014 (Braem et al. 2018). Sonar derived Inconnu abundance estimates in the Selawik (Hander et al. 2019) and Kobuk River are possible and should be considered an additional spawning population assessment tool. Continued collection of spawning population age structure and recruitment variability characteristics for Selawik and Kobuk River Inconnu are essential components for resource management applications. Mixed-stock genetic analysis was unable to differentiate between Selawik and Kobuk River Inconnu (Hander et al. 2017). Otolith micro-chemistry may offer the ability for stock differentiation based on water chemistry qualities of the Selawik and Kobuk River basins (Brennan et al. 2014; Padilla et al. 2015).



Figure 105.—Comparison of a historic slump scar identified by the black outline, K. Yoshikawa (unpublished) and encroachment on to the scar by the current slump. The historic slump may have predisposed the 2004 Selawik River slump's ground failure. Left image reference, Brooks (1988), right image credit USFWS.

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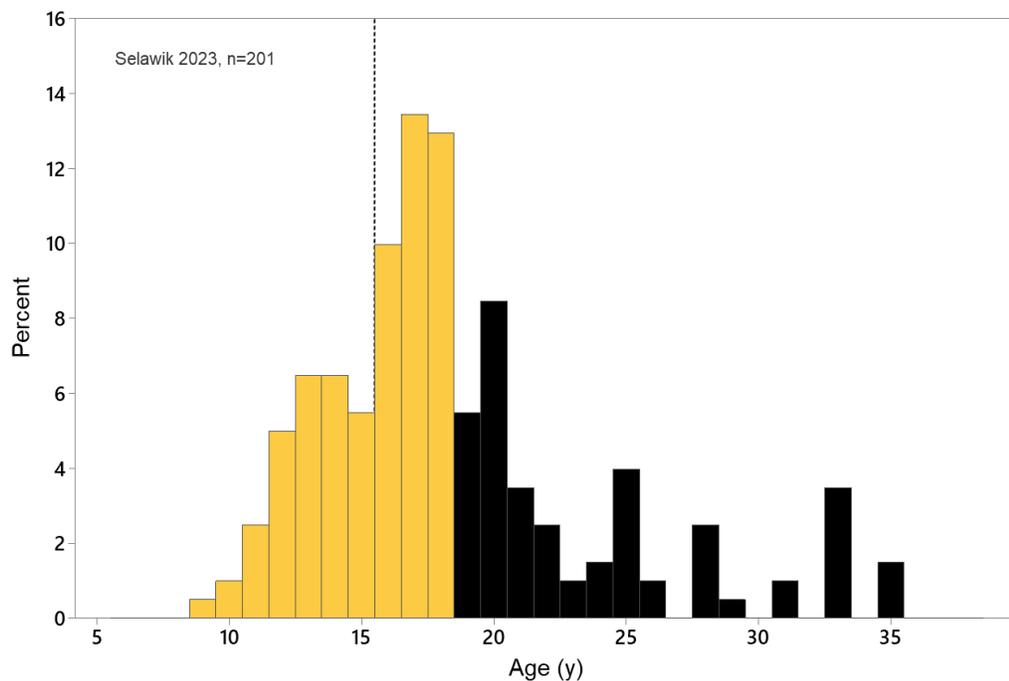
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Appendix Table A.1.—Brood year specific ages and expected research year at maturity for a selection of pre-slump and post-slump brood years. Minimum age at maturity is thought to be 9 years. Age cohorts expected to be mature on a given research year are in bold. The shaded region in the lower right represents the age cohorts that could potentially be affected by the thaw slump.

Research Year	Brood year specific ages and expected research year at maturity										
	Pre-slump brood years				Post-slump brood years						
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
2004	3	2	1	0							
2005	4	3	2	1	0						
2006	5	4	3	2	1	0					
2007	6	5	4	3	2	1	0				
2008	7	6	5	4	3	2	1	0			
2009	8	7	6	5	4	3	2	1	0		
2010	9	8	7	6	5	4	3	2	1	0	
2011	10	9	8	7	6	5	4	3	2	1	0
2012	11	10	9	8	7	6	5	4	3	2	1
2013	12	11	10	9	8	7	6	5	4	3	2
2014	13	12	11	10	9	8	7	6	5	4	3
2015	14	13	12	11	10	9	8	7	6	5	4
2016	15	14	13	12	11	10	9	8	7	6	5
2017	16	15	14	13	12	11	10	9	8	7	6
2018	17	16	15	14	13	12	11	10	9	8	7
2019	18	17	16	15	14	13	12	11	10	9	8
2020	19	18	17	16	15	14	13	12	11	10	9
2021	20	19	18	17	16	15	14	13	12	11	10
2022	21	20	19	18	17	16	15	14	13	12	11
2023	22	21	20	19	18	17	16	15	14	13	12
2024	23	22	21	20	19	18	17	16	15	14	13
2025	24	23	22	21	20	19	18	17	16	15	14
2026	25	24	23	22	21	20	19	18	17	16	15



Appendix Figure A.1.—Age histogram of mature Selawik River Inconnu from 2023 illustrating major age structure features. The vertical dashed line delineates the classification boundary between the recently recruited group that are 15 years of age and younger from the older group that are greater than 15 years of age. Note the observed post-slump (yellow bars) age cohorts are all present. Age-18 fish are from the 2004 brood year.