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Estimated Abundance of Adult Fall Chum Salmon in the Middle Yukon River, Alaska, 2004

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Abstract

Mark and recapture data were collected to estimate the abundance of fall chum salmon *Onchorhynchus keta* during 2004 in the middle Yukon River, above the Tanana River confluence. Weekly stratum estimates of migrating fall chum salmon were generated for a period of approximately eight weeks between 27 July and 21 September 2004. Fish were captured with a single fish wheel at the marking and recovery sites. Color-coded spaghetti tags were applied to 4,166 fish at the marking site. Throughout the season, 25,265 fish were examined for marks at the recovery site using video recordings. The tag status of 273 (1%) fish could not be determined and 197 (<1%) fish were tagged. Using a Darroch estimator, the estimated abundance of fall chum salmon migrating through the mainstem Yukon River in 2004 was 618,579 (SE 60,714) for the sampling period. Our estimate was 85% greater than the 2004 run reconstruction for fall chum salmon in the upper Yukon River. The run reconstruction included the combined total of tributary escapements (Chandalar, Sheenjek, and Fishing Branch rivers), harvest estimates above the study area, and Canadian border passage estimate of fall chum salmon. The difference between the Rampart-Rapids passage estimate and the run reconstruction may be partially attributed to unexpected biological and hydrologic factors during the 2004 field season.

Introduction

Since 1996, the U.S. Fish and Wildlife Service (USFWS) has generated weekly in-season estimates of adult fall chum salmon *Oncorhynchus keta* abundance in the middle Yukon River, above the Tanana River confluence. The tagging project is designed as a two-event, temporally stratified mark-recapture experiment. During the first two years of the study we established that the Darroch (1961) estimator could be successfully applied in the conditions found on the Yukon River (Gordon et al. 1998; Underwood et al. 2000a), and the Darroch estimator has been used in all subsequent years (except in 2000 when the project did not operate for the full season due to a low return).

Throughout the history of this project, we have worked to evaluate and reduce our impact on captured fish. Biologists associated with this project have raised concerns about the impact the Rampart-Rapids tagging study might have on the survivorship of Yukon River fall chum salmon (Underwood et al. 2002; Burek and Underwood 2002; Bromaghin and Underwood 2003, 2004; Bromaghin et al. 2004). As a result, during the past several years, we have worked to improve our protocol to reduce the impact we have on captured fish by: (1) upgrading the quality of fish wheel materials (padding on and around the chute and improved netting on the baskets); (2) reducing the amount of time fish are held in dip nets as they are landed and in the fish wheel live-box before and after they are marked; and (3) switching to a video recovery system. The video system has enabled us to eliminate holding fish at the recovery site. In previous years of

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this study, captured fish were held for varying amounts of time in the recovery wheel live-box during hours when the crew was not present (over-night and during crew breaks). Holding also occurred at the marking site, to varying degrees, between 1996 and 2002. Since 2003 we have eliminated holding at both the marking and recovery sites in an effort to minimize stress experienced by captured fish (Apodaca et al. 2004).

During the past several years, the in-season abundance estimates provided by the Rampart-Rapids tagging project have become an important component of the monitoring program for Yukon River fall chum salmon (JTC 2001). Due to low run sizes from 1997 to 2002, Yukon River fisheries managers and fishers have become increasingly concerned with in-season management of fall chum salmon. To prevent harvest-related population decline, fisheries managers have actively reduced harvest rates throughout the Yukon River drainage by restricting or closing commercial harvest of fall chum salmon and reducing subsistence opportunities when needed. To assess appropriate times to open and close fisheries, Yukon River fisheries managers rely upon available data on run timing and abundance throughout the drainage. The location of the Rampart-Rapids tagging study site makes this project particularly valuable for in-season management of the salmon fishery in the mid and upper regions of the Yukon River. Both state and federal fisheries managers use the Rampart-Rapids population estimate for making in-season decisions that are time-sensitive and could potentially affect the entire drainage (R. Holder, USFWS and F. Bue, Alaska Department of Fish and Game (ADF&G), personal communication). Additionally, fisheries managers with ADF&G use the Rampart-Rapids daily catch-per-unit-effort (CPUE) data as an index of run timing to the upper Yukon River. The mainstem abundance estimate has been used in conjunction with the Tanana River abundance estimate to evaluate the run distribution between the two major portions of the drainage and has had a significant influence on management decisions in recent years (F. Bue, ADF&G, personal communication). In this report we document the fall chum salmon population estimate generated by the mark-recapture study in 2004.

Study Area

The Yukon River is the fourth largest river basin in North America, with a drainage of more than 855,000 km^2 (Brabets et al. 2000). Three tributaries of the Yukon River, the Koyukuk, Tanana, and Porcupine rivers, are major waterways unto themselves with drainages of 91,000, 114,737, and 117,000 km^2, respectively (Brabets et al. 2000).

Our study site is located on the mainstem Yukon River, 58 km upstream from the Tanana River confluence (Figure 1). The site was selected to minimize capture of fall chum salmon returning to the Tanana River drainage, which constitutes the only known area of substantial fall chum salmon spawning downstream from the study area. The marking site was located at Rampart Rapids, a narrow canyon 1,176 km upstream from the mouth of the Yukon River that is locally known as “The Rapids”. The recapture site was 52 km upstream from the marking site near the village of Rampart, Alaska.

The middle Yukon River, upstream of the Tanana River, is almost 2 km wide at its widest point, and has a flow rate of 6 to 12 km per hour. Water height in the middle river fluctuates within and between years (Figure 2). Due to the glacial origins of some of its tributaries, the Yukon River is very silty during the summer but begins to clear during the fall. The region experiences a continental climate with long, cold winters and brief, warm summers. Air temperatures below freezing are common from September through April. Water temperature measured at the marking site in 2004 averaged approximately 15.5˚C between 12 June and 20 September 2004

(Figure 3). The river usually freezes by late October or November, and the ice remains until May of the following year.

Methods

Fish Wheel Schedule and Placement

Under contract with the USFWS, Stan Zuray and Paul Evans operated and maintained fish wheels at the marking and recovery sites, respectively. At the marking site, a fish wheel was operated on the south bank (Figure 1) as needed to accommodate the marking schedule (Table 1). A single recovery wheel was operated 24 hours a day, seven days a week, at the Rampart recapture site (Figure 1).

Fish wheel placement relative to shore was determined by the basket depth of the dip on the shoreward edge of the baskets (Figure 4). This edge was positioned to sweep within 30 cm of the bottom. To maintain the same proximity to the bottom, fish wheels were moved relative to shore as the water level rose or fell. A lead, in the form of a submerged picket fence, was placed between the wheel and the shore to direct fish toward the dipping baskets. The river at the marking site was deeper than at the recapture site, so the fish wheels were sized accordingly. Baskets on the marking fish wheel were approximately 3.0 m wide and dipped to a depth of 4.5 m below the water surface, whereas baskets on the recapture fish wheel were approximately 2.5 m wide and dipped 3.0 m below the water surface.

Marking Site Sampling Procedures

Marking took place from 27 July to 20 September 2004. The marking strata schedule (Table 1) started on Saturdays and ended on Fridays, except for the beginning and end of the season. Sundays were not included in the weekly tagging schedule. To spread capture effort throughout the day, fish were tagged during four daily sessions (beginning at 0800, 1200, 1600, and 1900 hrs ADT). Following previous years (Apodaca et al. 2004) the maximum daily sample size goal was 300 fish. During each marking session the crew docked to the fish wheel and used a dip net to capture fish directly from the fish wheel chute. All marked fish were captured directly from the chute, tagged, and released back into the river without being held. Fish with major injuries thought to impede migration were released without processing. To tag fish an individually numbered and stratum-specific color-coded spaghetti tag (Table 2) was applied through the muscle at the posterior base of the dorsal fin with a hollow applicator needle. After application, the spaghetti tag was knotted 1.5 cm from the insertion point. The entire adipose fin was clipped with a pair of scissors as a secondary mark.. Care was taken to minimize handling time and trauma for all fish captured.

Recovery Site Sampling Procedures

At the recovery site, the fish wheel was operated 24 hours a day from 28 July to 21 September 2004 (Table 1), with exceptions for maintenance and fish wheel repair. A video image capture system was installed on the recovery fish wheel using equipment described by Daum (2004). A camera was mounted above the fish wheel chute and video images of fish passing through the chute were sent to a laptop computer for processing using Salmonsoft Fishcap 1.3.4 software. A light weight door with a magnetic switch was placed at the lower end of the chute. When the door was opened, the switch tripped and initiated video capture. The video system was set to take 15 video frames per each capture event (six before the trigger event, one during the event, and eight after the event). The crew visited the fish wheel in the morning, afternoon, and evening to back-up files on the laptop and transfer video files to a microdrive for transport to camp. Fish were tallied daily from the video files using Salmonsoft FishRev 1.3.5 software. Numbers of marked and unmarked chum salmon and tag colors for marked fish were recorded and compiled for each sampling day. All video files were reviewed at least twice during the season to ensure counting accuracy.

Analysis of Mark and Recapture Data

Abundance estimate—For abundance estimation we used SAS 8.2 software (SAS Institute, Inc. 1999) to process data files and SPAS software (Arnason et al. 1996) to compute Darroch estimates. The marking and recapture strata were lagged by one day to account for migration timing between the sites. For a detailed description of the estimator see Gordon et al. (1998).

Travel time—For travel time analyses, each captured fish was categorized according to the number of strata between marking and recapture. To investigate travel patterns among years we compared travel data from 2004 with travel data from 2002 and 2003.

Data comparisons—To investigate inter-annual trends in the estimated population of fall chum salmon in the upper drainage we plotted our annual point estimates and 95% confidence intervals (±1.96 x SE) from 1996 to 2004, except in 2000 when the project did not operate. We also compared these point estimates with run-reconstructions for all previous years that the project operated. The run reconstruction included the combined total of tributary escapements (Chandalar, Sheenjek, and Fishing Branch rivers), harvest above the study area, and Canadian border passage estimates of fall chum salmon. Additionally, to evaluate shifts in fish wheel efficiency we plotted the catch-per-unit-effort (CPUE) at both sites using a one day lag.

Results

Analysis of Mark and Recapture Data

Summary of Tagging and Recovery Fish Wheel Data—A total of 4,166 fall chum salmon were captured and released with color coded spaghetti tags (Table 3). Fall chum salmon captured at the recovery site totaled 25,265 fish. The tag status of 273 (1%) fish could not be determined and 197 (<1%) fish were recaptures (Table 3).

Abundance Estimate—Based on eight weeks of mark-recapture data (Table 4), we estimated that 618,579 (SE 60,714) fish passed through the mainstem Yukon River above the Tanana River confluence during the sampling period. Our weekly abundance estimates ranged from 17,381 (SE 7,725) to 241,301 fish (SE 52,640; Table 5).

Travel Time—In 2004, out of 197 tagged fish that were recaptured at the recovery site, 183 (93%) were recaptured within the same stratum in which they were marked, 14 (7%) were captured in the following stratum, and no fish were captured 2 or more strata later (Figure 5). Since 2002, this is the first year that no tagged fish were observed later than the stratum directly after their marking stratum.

Data Comparisons—The estimated population of Yukon River fall chum salmon in 2004 exceeded the annual point estimates for the past several years (Figure 6). This population resurgence began in 2003. Based on poor escapements in the primary parent years of 1999 and 2000 (JTC) the resurgence in the population during the past two years was not expected. The comparisons of our estimate (618,579; SE 60,714) with an upper Yukon River run reconstruction indicated that our estimate was approximately 85% higher (Table 6). A comparison of fish wheel data shows that the CPUE at the marking site fish wheel (Zuray 2004) was substantially lower than the CPUE at the recovery site fish wheel in the middle and late part of the season, especially during the fifth and eighth strata (Figure 7).

Discussion

Based on eight weeks of mark-recapture data, we estimated that 618,579 (SE 60,714) fish passed through the mainstem Yukon River above the Tanana River confluence during the sampling period. A comparison of the Rampart-Rapids fall chum salmon estimate with an upper Yukon River run reconstruction (Table 6) indicated that the Rampart-Rapids point estimate was 85% higher. The up-river assessments of abundance have not been finalized as of this writing, so this comparison should be viewed as preliminary. In addition, a measure of precision for the run reconstruction is not available, so it is difficult to determine how widely it might vary from the actual upper Yukon River fall chum salmon estimate. In previous years, our estimates have ranged from approximately 15% lower to 17% higher than run reconstructions, indicating that the Rampart-Rapids estimate had lined-up with other run indicators relatively well in the past. In contrast, the 2004 Rampart-Rapids estimate appeared to be an outlier. Several factors may have contributed to the difference between our passage estimate and the 2004 run reconstruction. Obvious factors that could affect this comparison include: (1) variation between monitoring project schedules and run timing of fall chum salmon; and (2) incomplete coverage of all possible spawning tributaries. The accuracy of this comparison is also dependent on the reliability of the Rampart-Rapids estimate, escapement assessments, subsistence harvest estimates, and the Canadian border passage estimate.

Because the final 2004 Rampart-Rapids estimate of fall chum salmon was considerably higher than expected (based on our run reconstruction) concerns have been expressed that the estimator was not stable throughout the entire 2004 field season. Similar to other models, the performance of the Darroch model is largely dependent on eliminating or at least minimizing departures from the assumptions of the model. For a detailed discussion of the model assumptions see Gordon et al. (1998). The assumptions of our model have been carefully tested over several years (Underwood et al. 2000a, 2000b, 2003, and 2004), and based on our findings we have little reason to believe that the model assumptions were not met during the 2004 field season. Despite our confidence that the model was not biased in the 2004 field season, we recognize that the following factors may have influenced the performance of the model: unusually low capture rates of tagged fall chum salmon throughout the field season (Table 3), low capture rates at the marking site, especially during the fifth and eighth strata (Figure 7), and unusually low water levels late in the season (Figure 2).

It is difficult to determine the range of site specific conditions and biological factors that may have contributed to the decreased capture probabilities at the marking and recovery sites in 2004. Based on a comparison of the catch-per-unit-effort (CPUE) data from the marking and recovery sites, it appears that the probability of capture at the marking site decreased irrespective of the run size late in the season. During the later part of the season the CPUE at the Rampart fish wheel was substantially higher than the CPUE at the Rapids fish wheel (Figure 7). This may indicate that shifts in site-specific environmental factors resulted in decreased capture probability at the marking site, even when the abundance of migrating fall chum salmon was still high. This drop in capture probability may have been influenced in-part by fish wheel spinning efficiency. In 2004 the water level in the Yukon River dropped below historic records (recorded between 1988 and 2003; Figure 2). During the extreme low water periods it was necessary to equip the fish wheel baskets at the marking site with multiple paddles to help propel them through the water with enough momentum to keep them turning. The unusually low water levels reduced the average number of daily wheel rotations and may have simultaneously influenced fish behavior.

The degree of bank-orientation in fall chum salmon may be influenced by water height and velocity. Yukon River fall chum salmon may become less bank-oriented during extremely low water periods when areas of reduced flow are not restricted to bank margins. Currently there is no available information on the behavioral response of fall chum salmon in differing hydrologic regimes within large rivers. However, it is widely hypothesized that movement behavior and bank orientation in salmon is largely influenced by hydrological conditions experienced during migration (Osborne 1961; Hinch and Rand 1998). For some salmon species, investigators have documented that river speed influences path selection during migration (Standen et al. 2004).

The hydrologic and behavioral factors mentioned above probably can not be prevented or controlled during any given year, although increasing the sample size may decrease the variance around the point estimate during times when unusual factors occur. To begin investigating the influence of sample size on the performance of the model, we ran simulations using SPAS software (Arnason 1996). Results from these simulations suggest that increasing the probability of capture at either the marking or recovery site will decrease the likelihood that the estimate variance will increase during times of low fish abundance (C. Apodaca, USFWS, unpublished data). Based on this information and a cost-benefit analysis, we plan to increase the capture probability at the marking site by increasing our sampling effort. To increase our sampling effort during the 2005 field season we plan to run a second fish wheel on the north-bank during times of low fish abundance, and add an additional tagging day to the weekly schedule. Sample size may be one of the only factors that we can attempt to control to improve the performance of the estimator in future years.

Due to the relatively low number of adult fall chum salmon that returned to the Yukon River between 1997 and 2002, the resurgence in the population size during the past two years (Figure 6) was unexpected based on poor parent year escapement. In 2004, despite a below-average preseason outlook on run size (JTC 2004), the number of fall chum salmon that entered the Yukon River (approximately 650,000 reported by the Pilot Station Sonar Project; ADF&G 2005) exceeded the upper management threshold of 600,000 fish (JTC 2004). This unexpected surplus resulted in a commercial fishery opening late in the season. The underlying factors that drive population trends for Yukon River salmon are not well understood. It is difficult to investigate the source of population fluctuations in anadromous salmon due to their complex life cycles that are split between marine, brackish, and fresh water environments during different life stages. Several investigators have suggested that climactic shifts influence productivity and in turn have a profound influence on the number of Pacific Salmon recruits (Beamish et al. 1999; Francis and Hare 1994). Additionally, interactions in the marine environment with hatchery-reared fish (Noakes et al. 2000; Meffe 1992) and harvest in both the marine and freshwater environments can have an effect on population trends for some Pacific Salmon species (Ricker 1954). Regardless of the primary factors that affect stock populations returning to the Yukon River, it is important to continue to monitor the population trends of Yukon River fall chum salmon in the freshwater environment. In-season abundance estimates provide mangers with crucial tools to make timely decisions on opening and closing the fall chum salmon fishery throughout the fishing season. The Rampart-Rapids project provides an in-season abundance estimate of fall chum salmon bound for Yukon River tributaries above the Tanana River confluence.

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Table 1. Sampling stratum schedule for Yukon River fall chum salmon tagging and recovery efforts, Alaska, 2004. No fish were tagged on Sundays.

Stratum	Dates
	Marking site
1	July 27 through July 30
2	July 31 through Aug 6
3	Aug 7 through Aug 13
4	Aug 14 through Aug 20
5	Aug 21 through Aug 27
6	Aug 28 through Sept 3
7	Sept 4 through Sept 11
8	Sept 13 through Sept 20
	Recapture site
1	July 28 through July 31
2	August 1 through Aug 7
3	Aug 8 through Aug 14
4	Aug 15 through Aug 21
5	Aug 22 through Aug 28
6	Aug 29 through Sept 4
7	Sept 5 through Sept 13
8	Sept 14 through Sept 21

Table 2. Color sequence of spaghetti tags used to mark Yukon River fall chum salmon, Rapids study site, Alaska, 2004.

Stratum	Color
1	Pink
2	Dark green with white band
3	White
4	Light green
5	Pink
6	Dark green with white band
7	White
8	Light green

Table 3. Marking and recovery wheel data for Yukon River fall chum salmon, 2004.

	Marking site	Recovery site				
Stratum	Number of tags deployed	Untagged catch	Tagged catch	Tag status unknown	Total	Percent tagged
1	213	403	5	2	410	1.23
2	226	674	5	7	686	0.74
3	363	2,137	31	30	2,198	1.43
4	457	1,975	15	29	2,019	0.75
5	832	6,822	25	90	6,937	0.37
6	811	5,115	38	42	5,195	0.74
7	432	3,196	26	26	3,248	0.81
8	832	4,473	52	47	4,572	1.15
Total	4,166	24,795	197	273	25,265	0.70

Table 4. Data from Yukon River fall chum salmon marking and recapture in 2004, and associated counts of unmarked fish with a one day lag time.

		Recapture stratum									
Marking stratum	Tags released	1	2	3	4	5	6	7	8	Total	Fish not captured
		Recapture data									
1	213	5	2	0	0	0	0	0	0	7	206
2	226	0	3	0	0	0	0	0	0	3	223
3	363	0	0	31	4	0	0	0	0	35	328
4	457	0	0	0	11	3	0	0	0	14	443
5	832	0	0	0	0	22	3	0	0	25	807
6	811	0	0	0	0	0	35	1	0	36	775
7	432	0	0	0	0	0	0	25	1	26	406
8	832	0	0	0	0	0	0	0	51	51	781
		Tagged and untagged fish captured in the recovery wheel									
Strata 1-8		408	679	2,168	1,990	6,847	5,153	3,222	4,525		

Table 5. Stratum and season estimates of abundance, the probability of capture, and associated measures of precision (SE= standard error, CV= coefficient of variation), for the 2004 run of Yukon River fall chum salmon. Dates for weekly strata are based on the marking site strata schedule.

		Abundance			Capture probability		
Stratum	Date	Estimate	SE	CV	Estimate	SE	CV
		Strata estimates					
1	July 27-30	17,381	7,725	0.44	0.012	0.005	0.42
2	July 31-Aug 6	38,875	24,594	0.63	0.006	0.004	0.67
3	Aug 7-13	25,387	4,527	0.18	0.014	0.003	0.21
4	Aug 14-20	71,053	22,217	0.31	0.006	0.002	0.33
5	Aug 21-27	241,301	52,640	0.22	0.003	0.001	0.33
6	Aug 28-Sept 3	99,241	20,820	0.21	0.008	0.002	0.25
7	Sept 4-11	53,562	10,884	0.20	0.008	0.002	0.25
8	Sept 13-20	71,797	10,204	0.14	0.012	0.002	0.17
		Season estimate					
1-8	July 27-Sept 20	618,579	60,714	0.10			

Table 6. Comparison of the annual Darroch estimate with measured components of the run (tributary escapement, harvest, and Canadian border passage) upstream of the tagging site from 1996 to 2004, except in 2000 when the project did not operate for the full season.

	Years							
Description	1996	1997	1998	1999	2001	2002	2003	2004
Escapement projects, border passage, and harvest above study area								
Chandalar River	208,170	199,874	75,811	88,662	110,971	89,847	198,897	130,221[b]
Sheenjek River	246,889	80,423[a]	33,058	14,229	53,932	31,856	38,321	37,877[b]
Fishing Branch River	77,278	26,959	13,564	12,094	21,635	13,300	24,841	19,664[b]
Mainstem border passage	143,758	94,725	48,047	75,541	38,908	91,808	140,000	134,266[c]
Sum of harvest	32,131	28,145	5,683	28,583	7,808	4,041	13,837	11,990[,e]
Comparison of Rampart-Rapids estimate with the sum of escapement, harvest, and border passage								
Rampart-Rapids estimate	654,296	369,547	194,963	189,741	201,766	196,186	485,102	618,579
Sum of escapement, harvest, and border passage	708,226	430,126	176,163	219,109	233,254	230,854	415,896	334,018[b]
Percent difference	-8	-14	11	-13	-14	-15	17	85

[a] Potentially incomplete estimate (B. Borba, ADF&G, personal communication).

[b] Preliminary estimate pending completion of final project reports.

[c] Preliminary estimate of border passage pending completion of final project reports (P. Milligan, Canada Department of Fish and Oceans, personal communication).

[d] Harvest figures not available at time report was written (B. Busher, ADF&G, personal communication).

[e] Sum of harvest above study area is based on a five-year average from 1998-2003, excluding 2000. Harvest data are from Rampart Village, Stevens Village, Beaver, Fort Yukon, Circle, and Central.

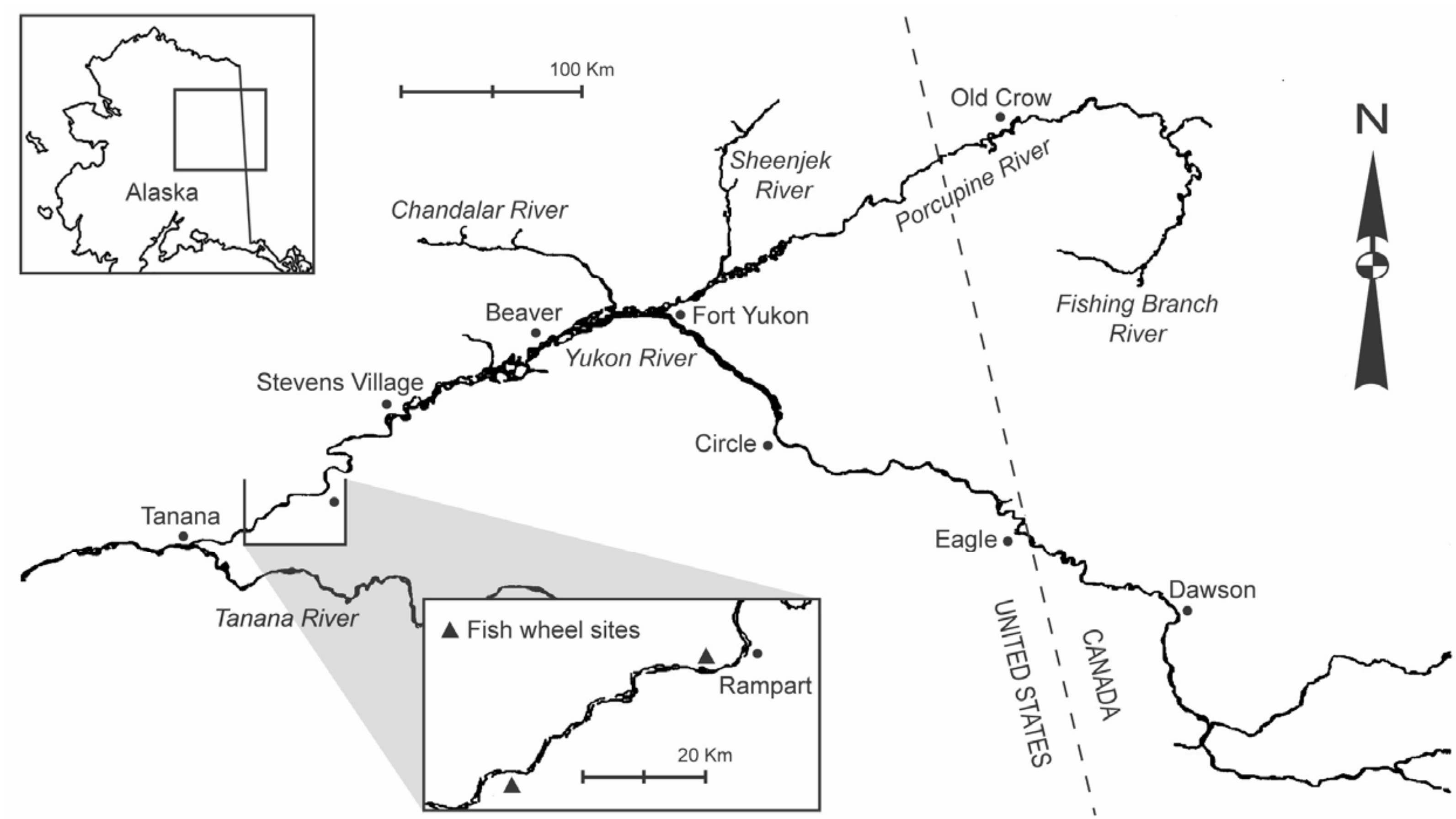

Figure 1. Map of the Yukon River drainage with an inset of the study area. The marking and recapture fish wheels are indicated with triangles.

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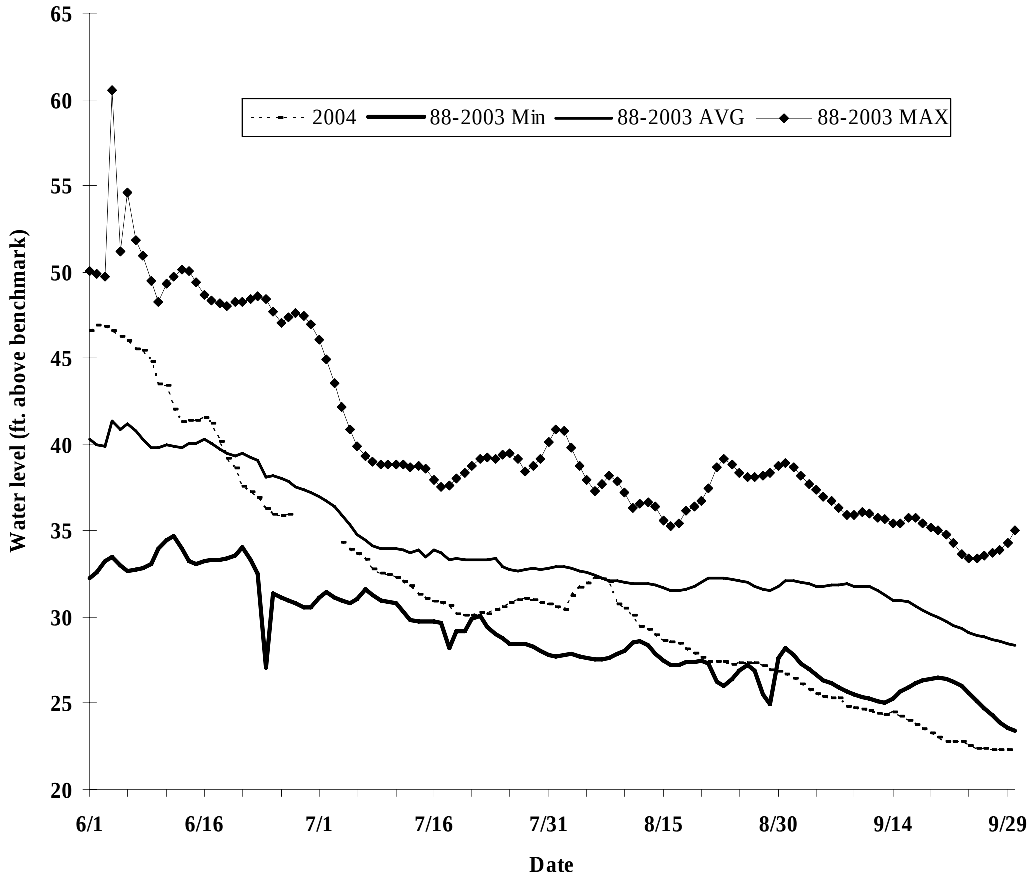

Figure 2. Average daily water height measured in feet at a fixed USGS gauging station on the Yukon River, near the Dalton Highway. Daily measures are presented for 2004 in comparison with the averages for historical data from 1988-2003 (Data compiled by Bonnie Borba, ADF&G).

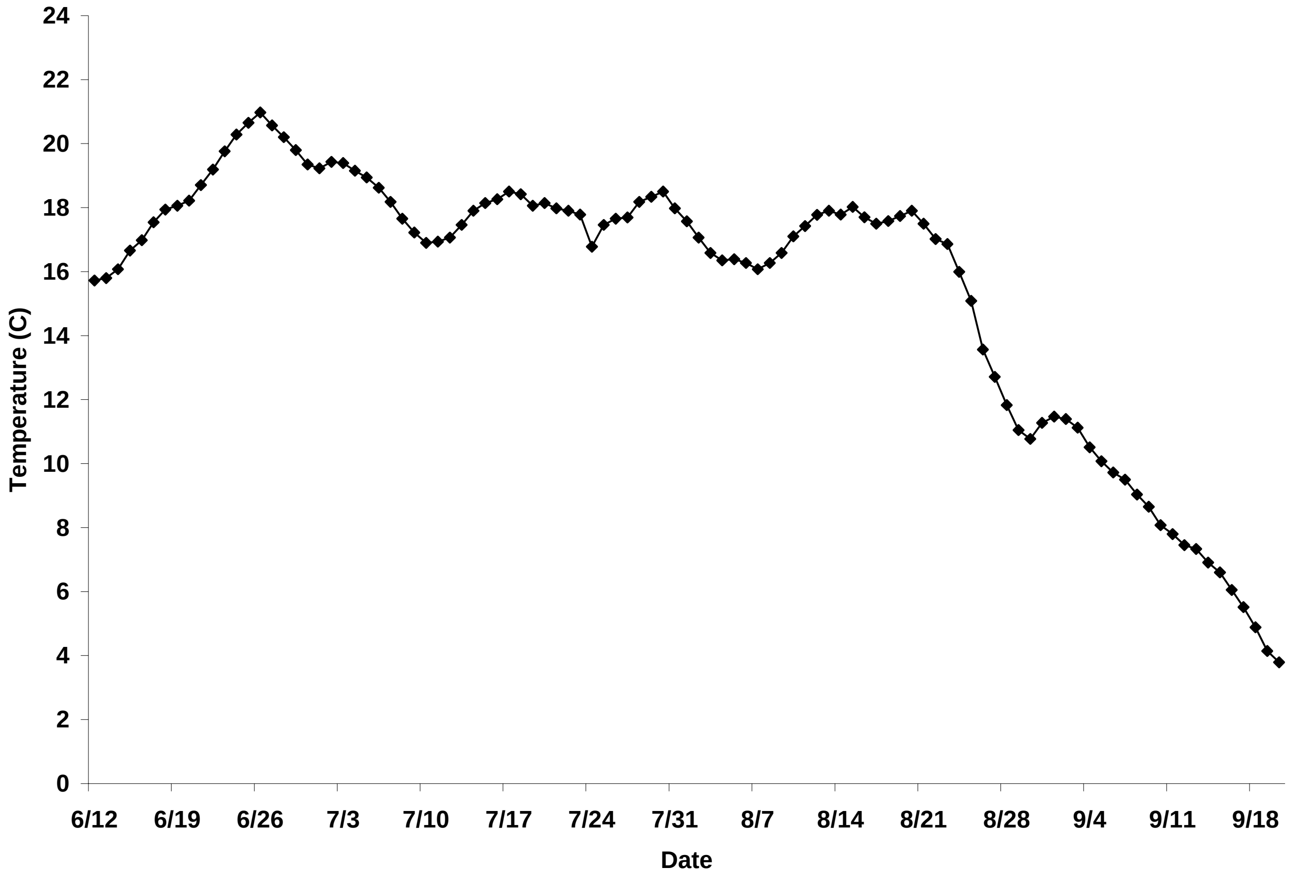

Figure 3. Average daily water temperature measured with an Onset Stow Away TidbiT© water temperature data logger from 12 June to 20 September 2004, Rapids south-bank fish wheel, middle Yukon River, Alaska.

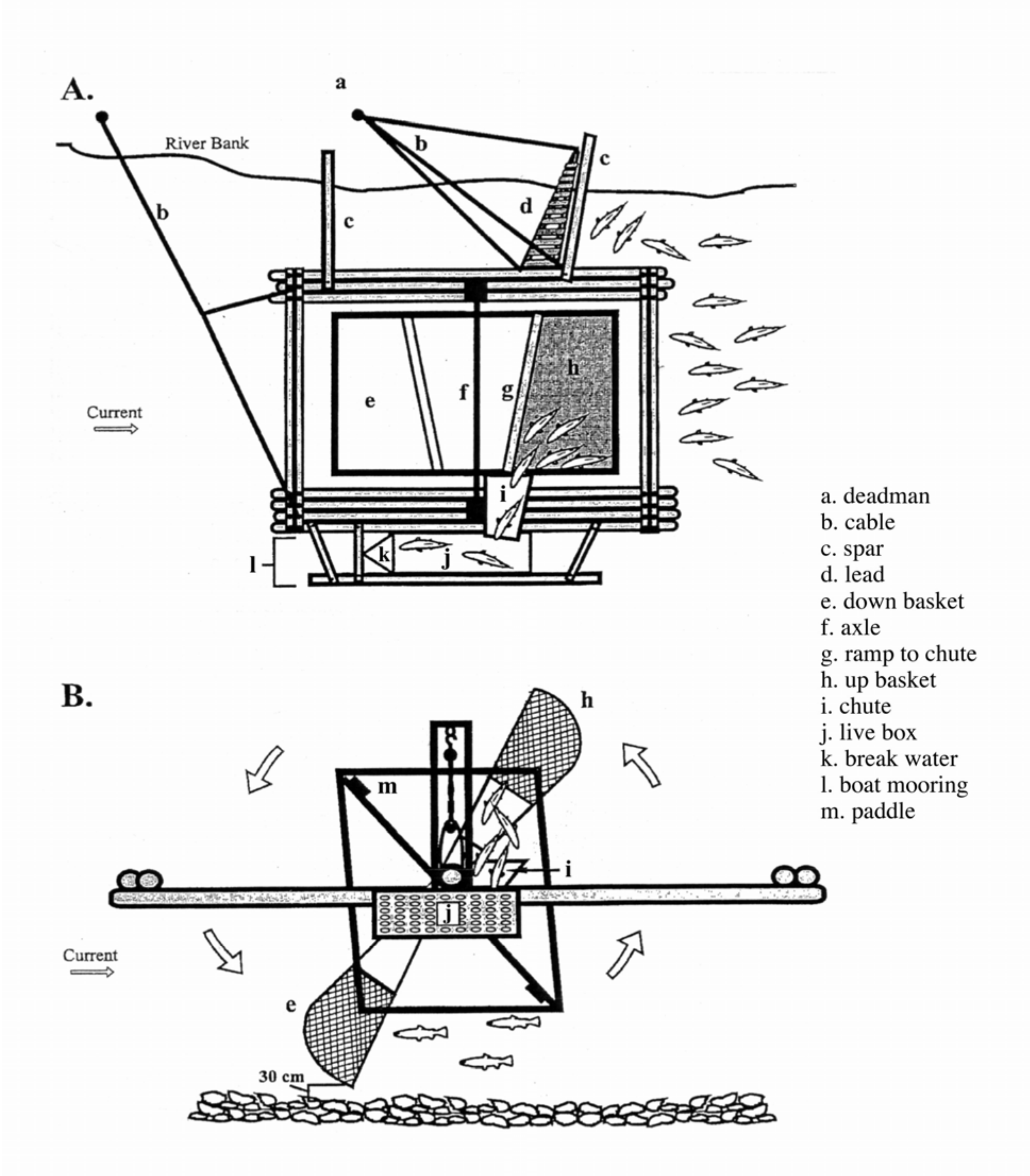

Figure 4. Two-basket fish wheel equipped with padded chute. A. Aerial view. B. Side view with arrows indicating the direction of wheel movement in response to the current.

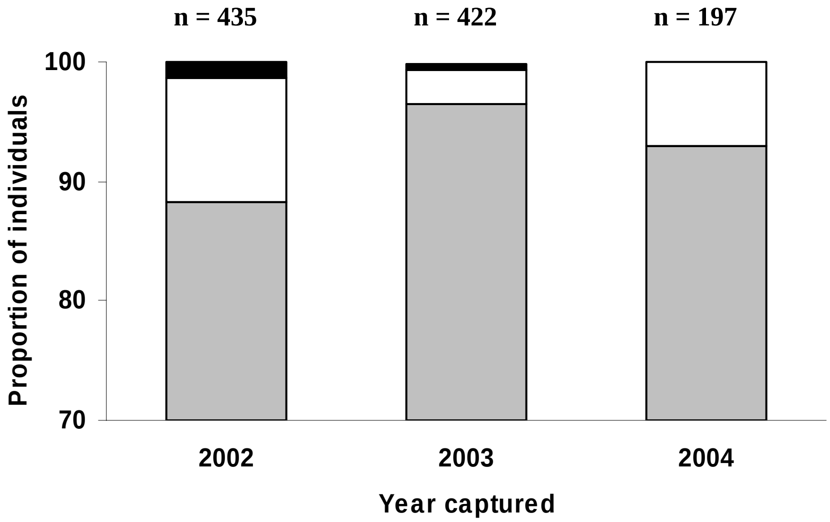

Figure 5. Proportion of Yukon River fall chum salmon recaptures in Rampart, Alaska in 2002, 2003, and 2004 within the same weekly stratum (gray), recaptured in the stratum following their marking stratum (white), and recaptured in a stratum two weeks after their marking stratum (black).

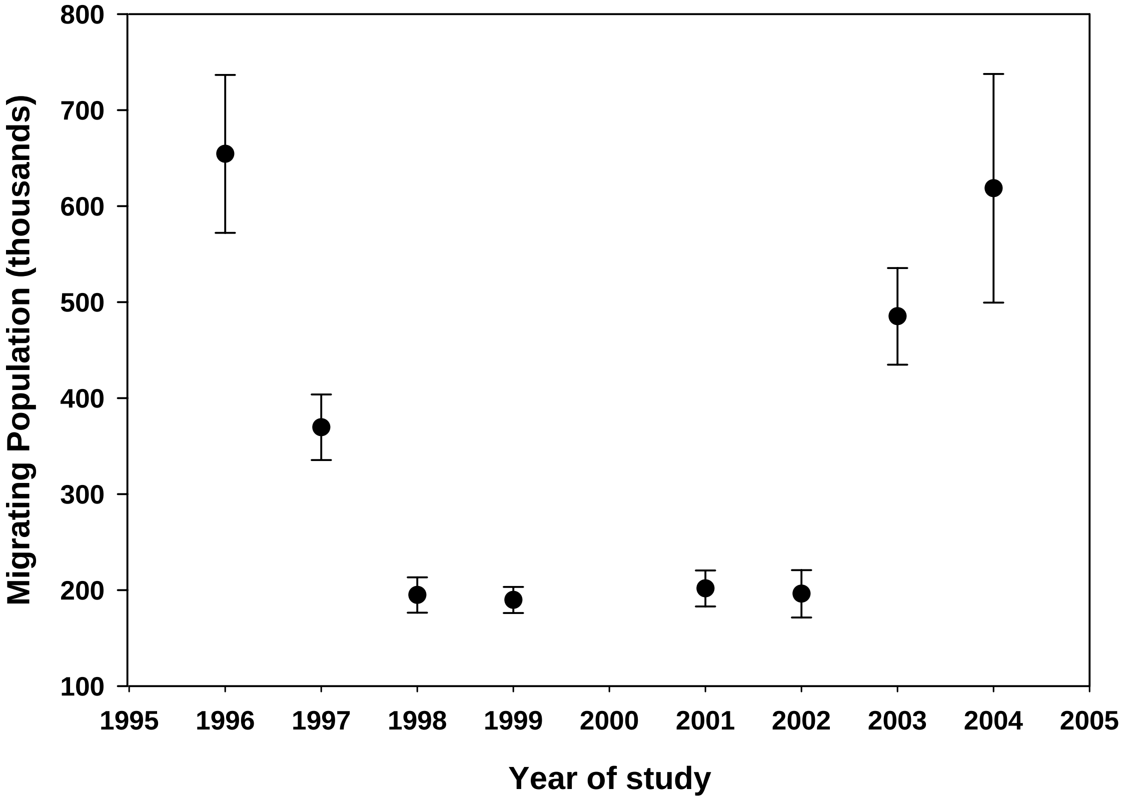

Figure 6. Population estimates of Yukon River fall chum salmon and 95% confidence intervals (±1.96 x SE) from 1996 to 2004, excluding 2000. A seasonal estimate was not generated in 2000 because the project did not operate for the full season due to a low return.

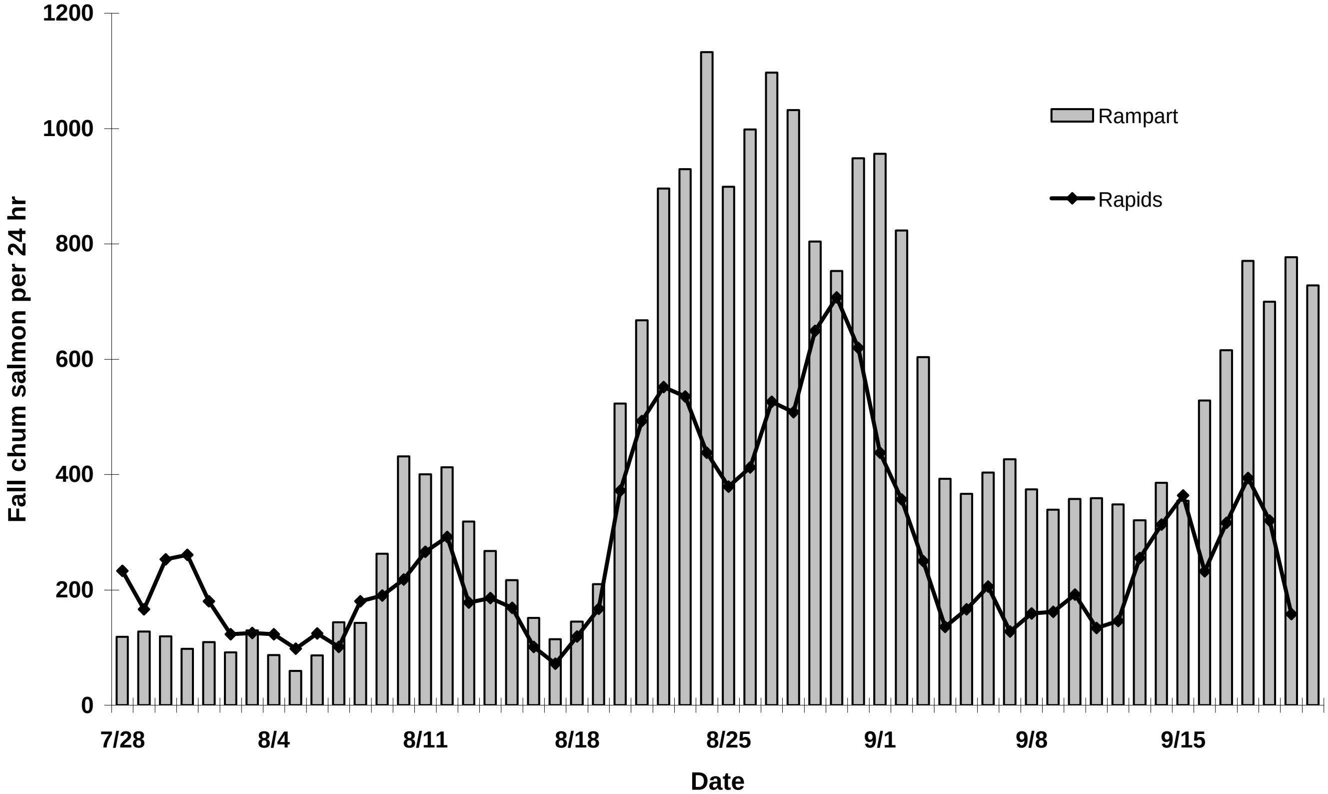

Figure 7. Yukon River fall chum salmon CPUE data collected at the Rampart and Rapids fish wheels, middleYukon River, Alaska, 2004.