

Supplementary materials for:

Increases in size and abundance of migratory fishes observed near the Athabasca oil sands

DOI: 10.1139/facets-2017-0028

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R scripts

```
## Tolerance Intervals
```

```
## mean
```

```
mu <- 0
```

```
## Standard deviation
```

```
sig <- 1
```

```
## sample size
```

```
n <- 20
```

```
## coverage probability (90%)
```

```
gamma <- 0.9
```

```
## percentiles of non-central  $t$  to attain desired coverage probability (gamma)
```

```
G1 <- (1 - gamma) / 2
```

```
G2 <- 1 - ((1 - gamma) / 2)
```

```
## upper limit of desired central (95% in this case) confidence interval
```

```
p <- 0.975
```

```
## Inner tolerance k-factor
```

```
k1 <- qt(G1, n - 1, sqrt(n) * qnorm(p)) / sqrt(n)
```

```
## Outer tolerance k-factor
```

```
k2 <- qt(G2, n - 1, sqrt(n) * qnorm(p)) / sqrt(n)
```

```
## Inner limit of tolerance
```

```
IT <- k1 * sig
```

```
## Outer limit of tolerance
```

```
OT <- k2 * sig
```

```
## Estimated percentile (i.e., 97.5)
```

```
med <- 1.96 * sig
```

```
## Tolerance limits for 2.5 percentile
```

```
OTL2.5 <- mu - OT
```

```
ptile2.5 <- mu - med
```

```
ITL2.5 <- mu - IT
```

```
## Tolerance limits for 97.5 percentile
```

```
ITL97.5 <- mu + IT
```

```
ptile97.5 <- mu + med
```

```
OTL97.5 <- mu + OT
```

```
## Parametric bootstrapping for estimating error of CPUE

## number of bootstrap samples
B <- 100000

## mean of observed of log10(x+1) transformed CPUE

mu<- 0.066

## standard deviation of log10(x+1) transformed CPUE
sd<-0.121

## resample size
n<-7

##generate B bootstrap samples
resamples <- lapply(1:B, function(i)
  rnorm(n,mu,sd))

## Calculate 95th percentile for B bootstrap samples from 'resamples'
UpperTail <- sapply(resamples, quantile, c(0.95))

## 2.5, 50, and 97.5 percentiles of distribution of B 95th percentiles (rounded to 3 decimals)
round(quantile(UpperTail, c(0.025,0.50,0.975)),3)
```

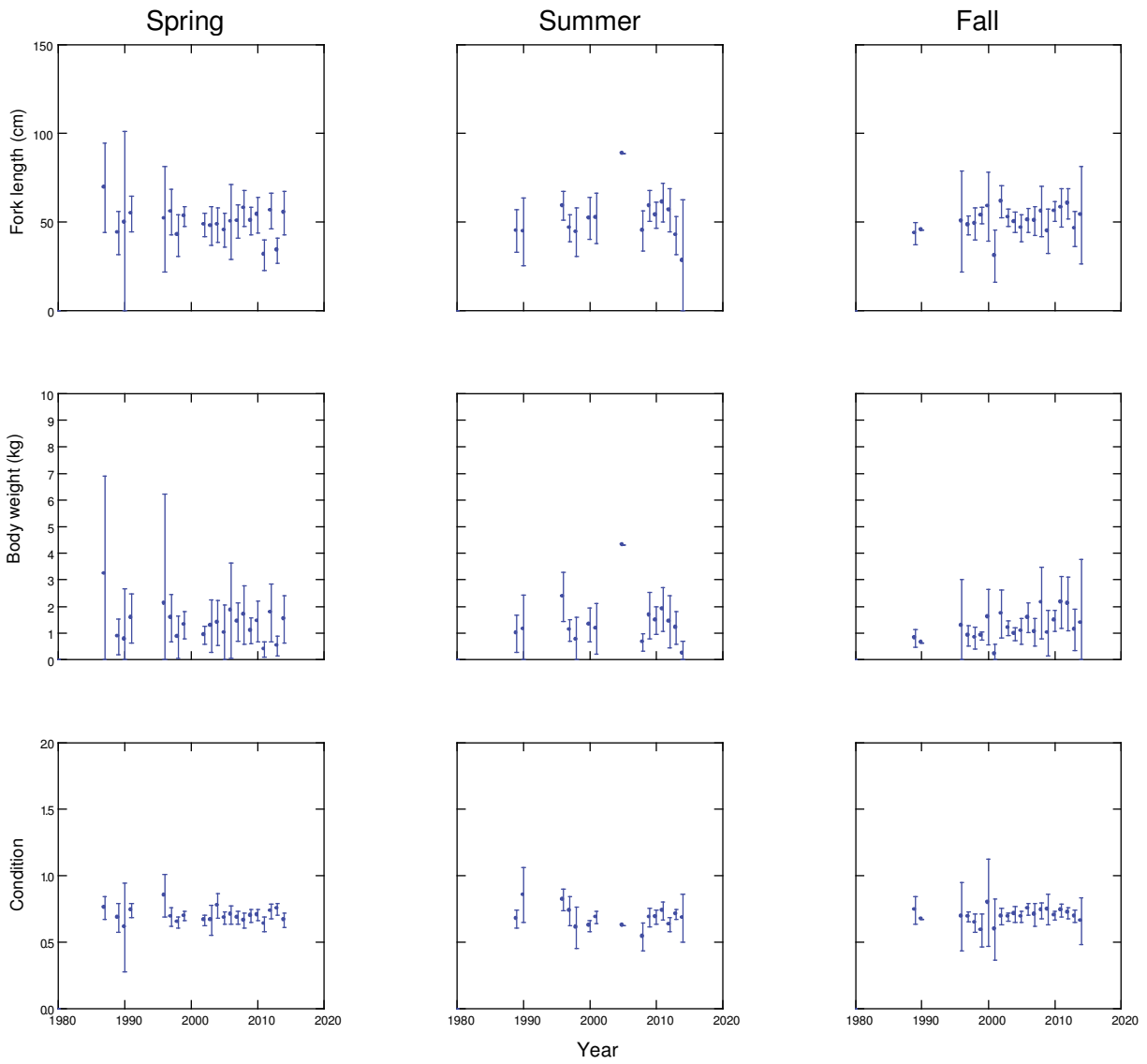


Fig. S1 Mean fork length (± 2 SE), body weight (± 2 SE), and condition (± 2 SE) of northern pike captured in the spring, summer, and fall inventories conducted in the mainstem Athabasca since 1987.

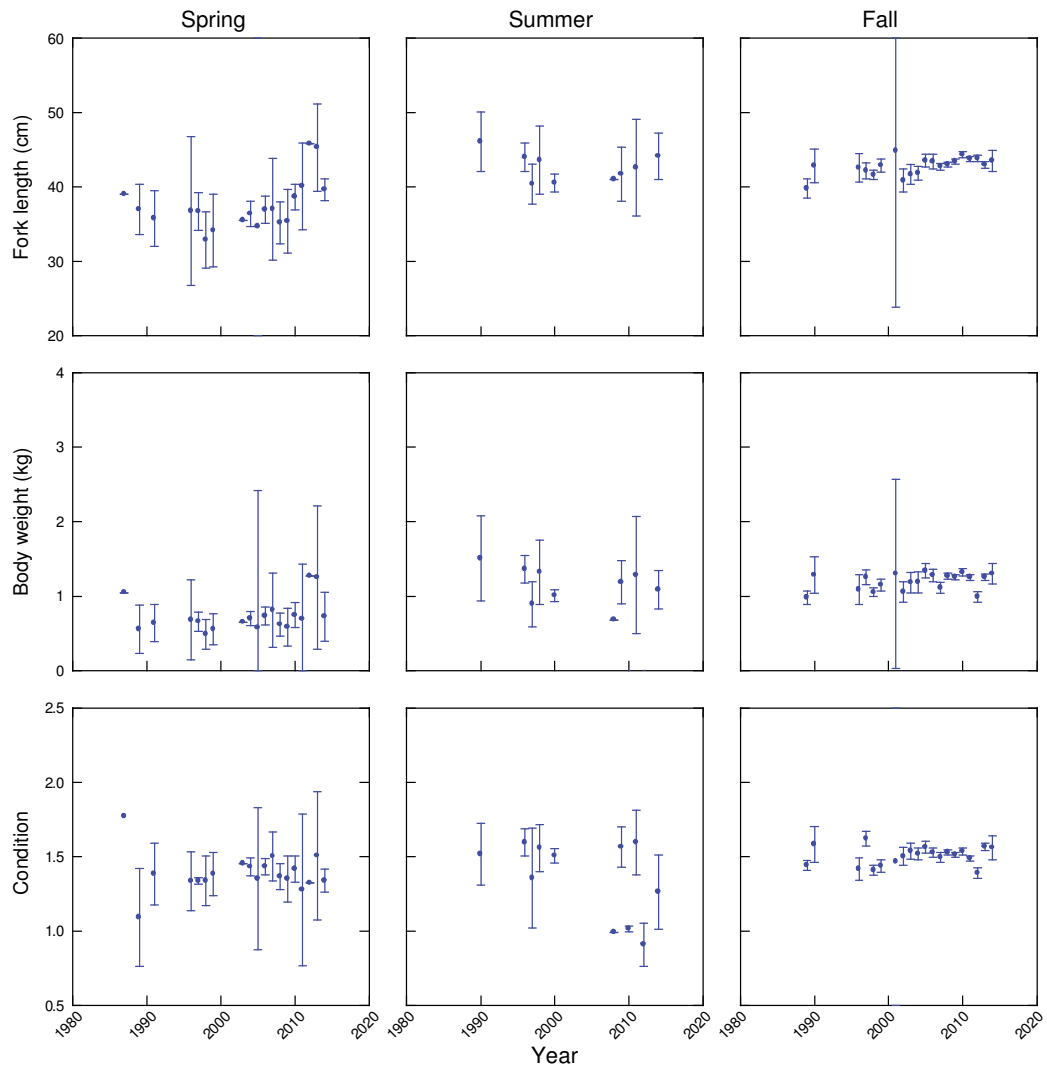


Fig. S2 Mean fork length (± 2 SE), body weight (± 2 SE), and condition (± 2 SE) of lake whitefish captured in the spring, summer, and fall inventories conducted in the mainstem Athabasca since 1987.

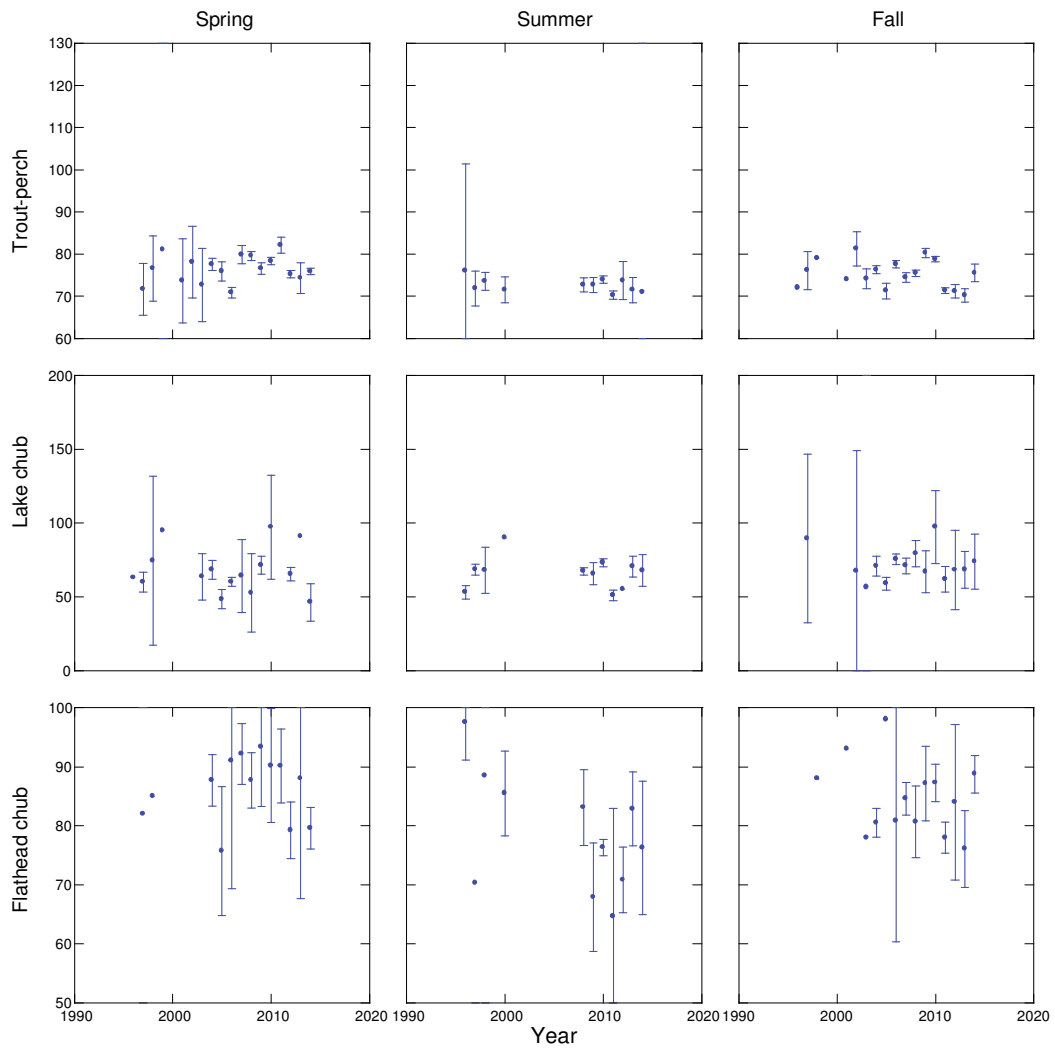


Fig. S3 Mean fork length ($\pm 2SE$) of trout-perch, lake chub, and flathead chub captured in the spring, summer, and fall inventories conducted in the mainstem Athabasca since 1987; weight and condition excluded: weight measured with imprecise resolution before 2008-2010.

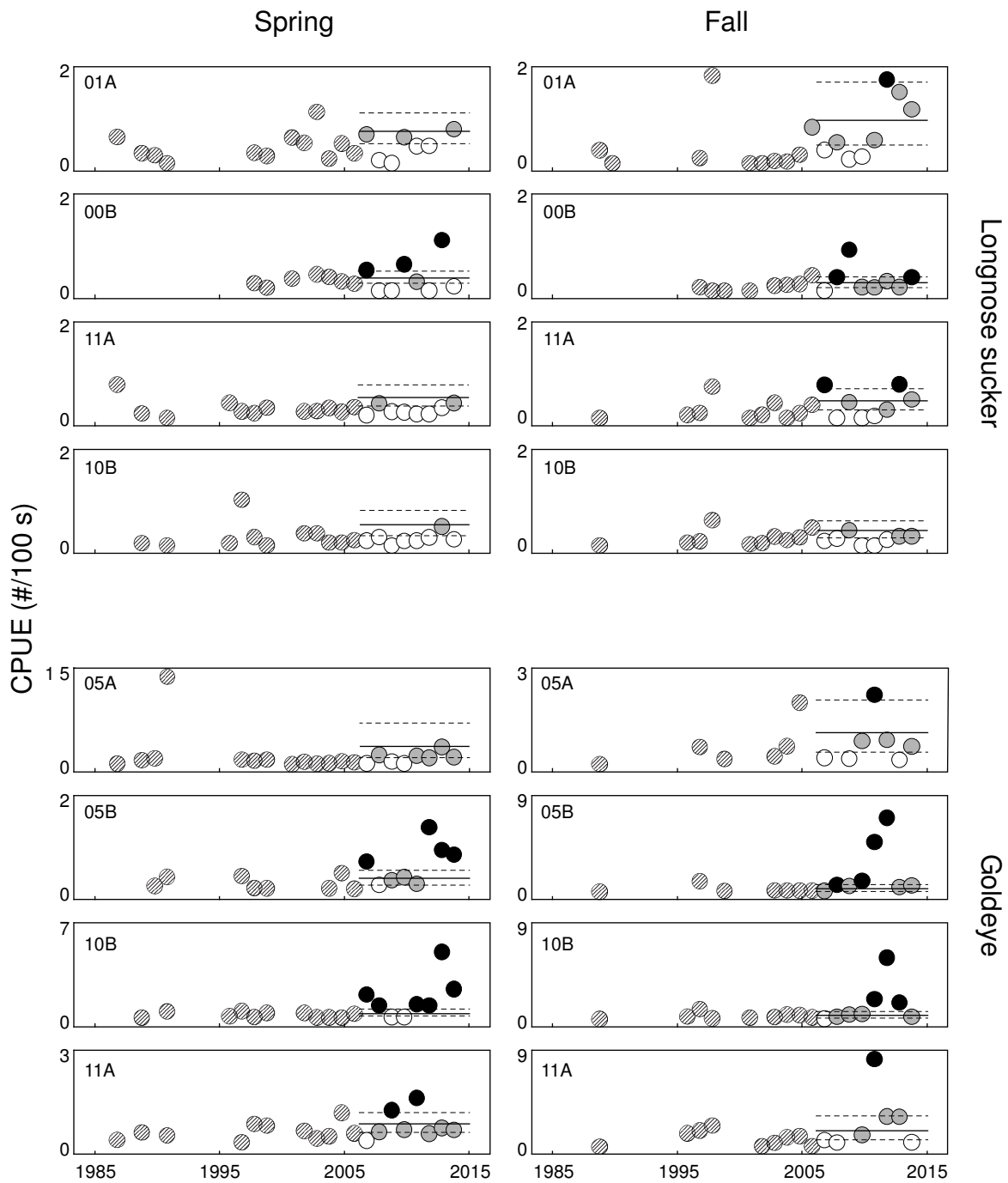


Fig. S4 Relative abundance (catch per unit effort; fish per 100 seconds of electrofishing) of longnose sucker and goldeye captured at representative locations in the Athabasca River inventories since 1987; circles with diagonal line shading are measurements done before 2007; open circle suggest no difference relative to before 2007; grey circle suggest a possible change relative to before 2007; black circles suggest a likely change relative to before 2007.

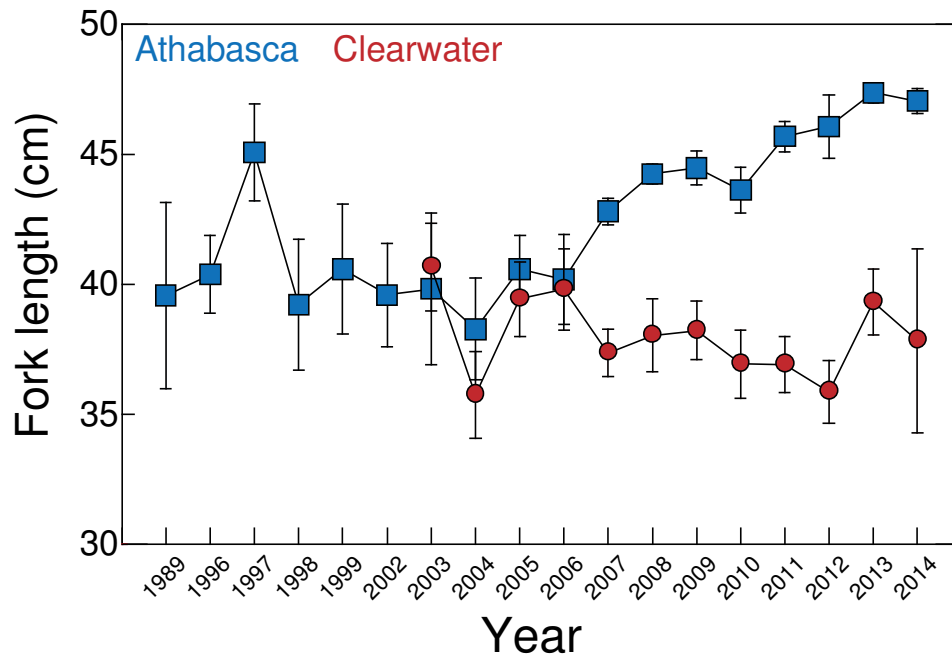


Fig. S5 Mean length ($\pm 2SE$) of white sucker captured in the Athabasca and Clearwater Rivers during the respective inventories; variability in Athabasca in 2008 and 2013 obscured by symbol size.

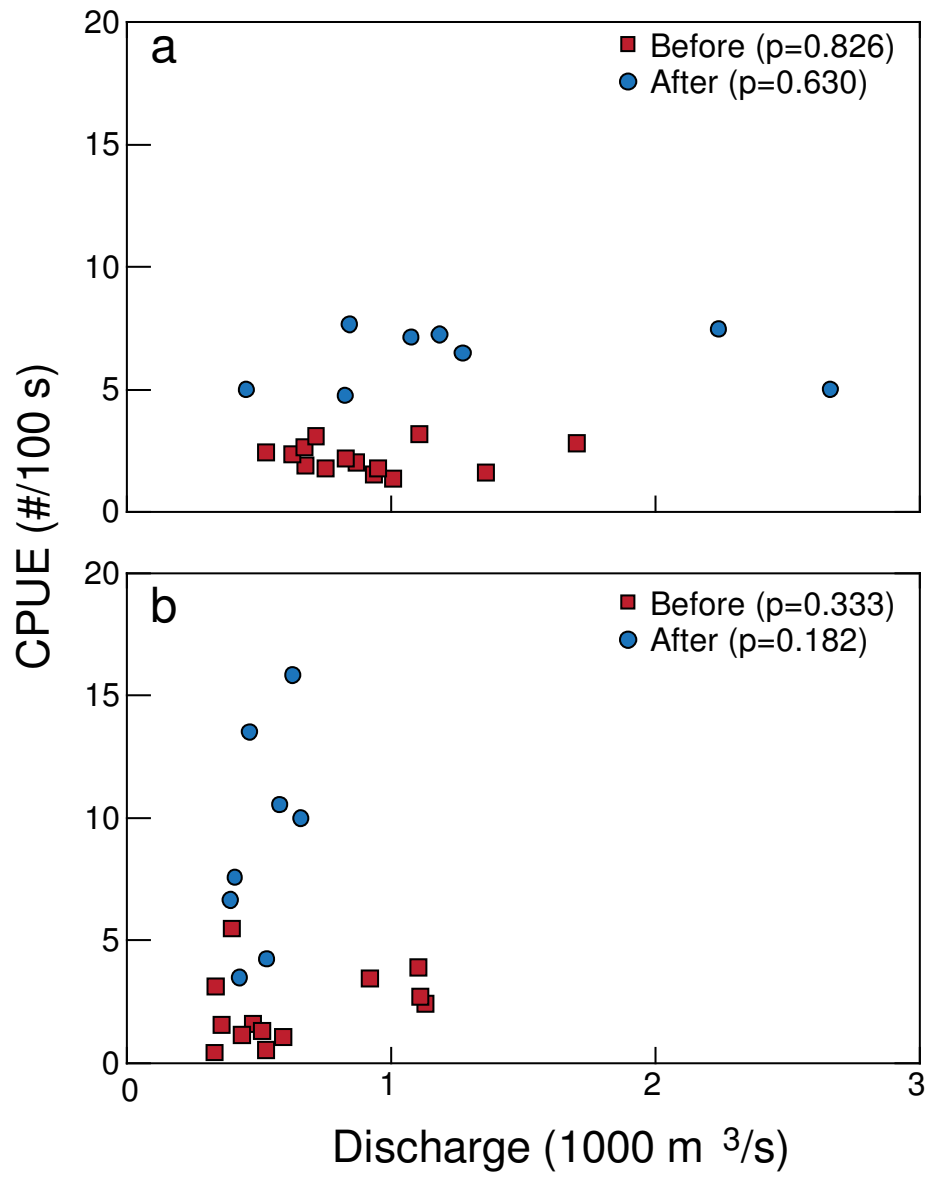


Fig. S6 Catch-per-unit-effort (CPUE; fish per 100s) vs discharge (1000 m³/s) during the Spring (a) and Fall (b) inventories in the Athabasca River for years before 2007 (■) and years after 2006 (●).

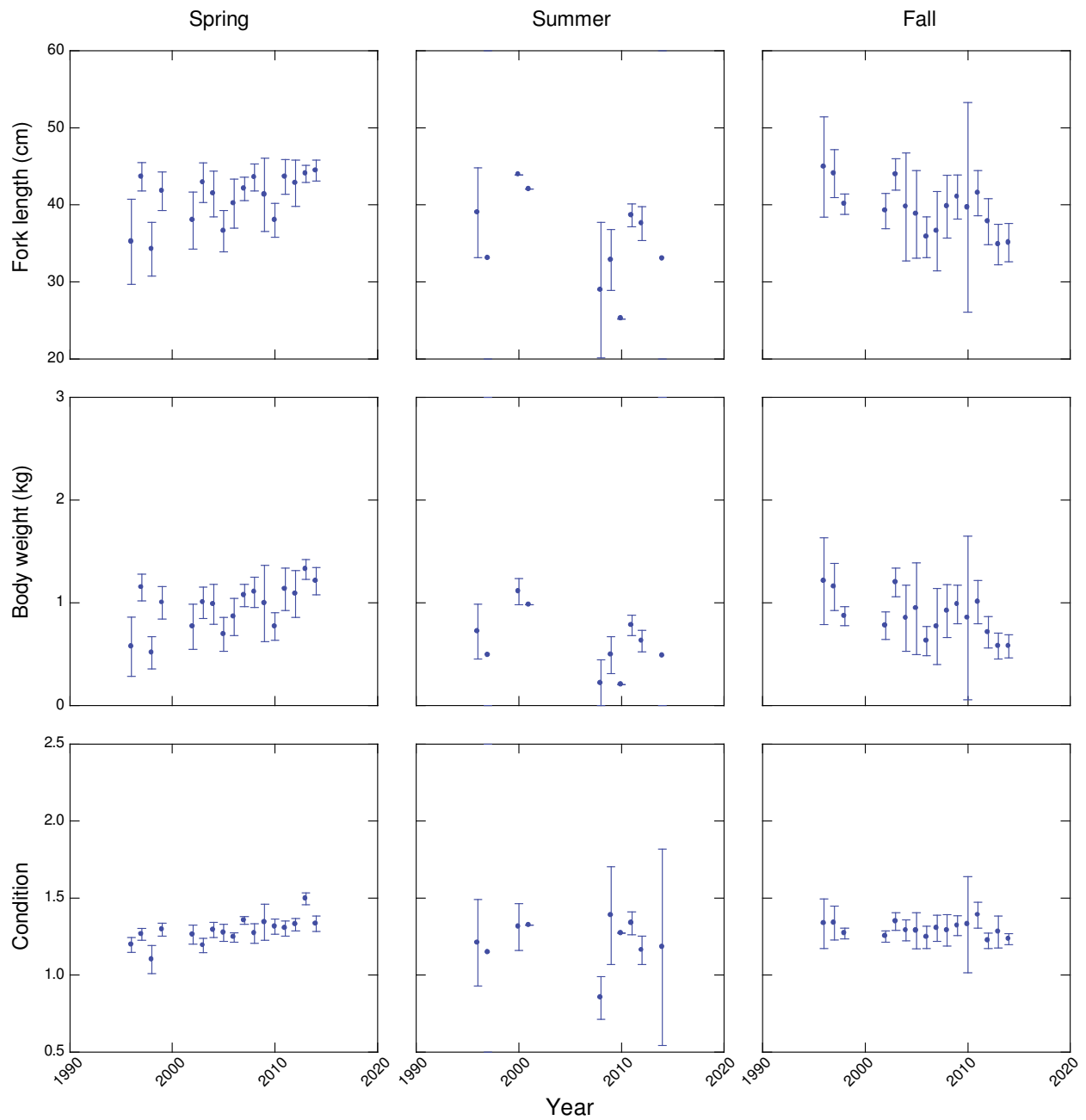


Fig. S9 Mean fork length ($\pm 2SE$), body weight ($\pm 2SE$), and condition ($\pm 2SE$) of longnose sucker captured in the spring, summer, and fall inventories conducted in the mainstem Athabasca since 1987.

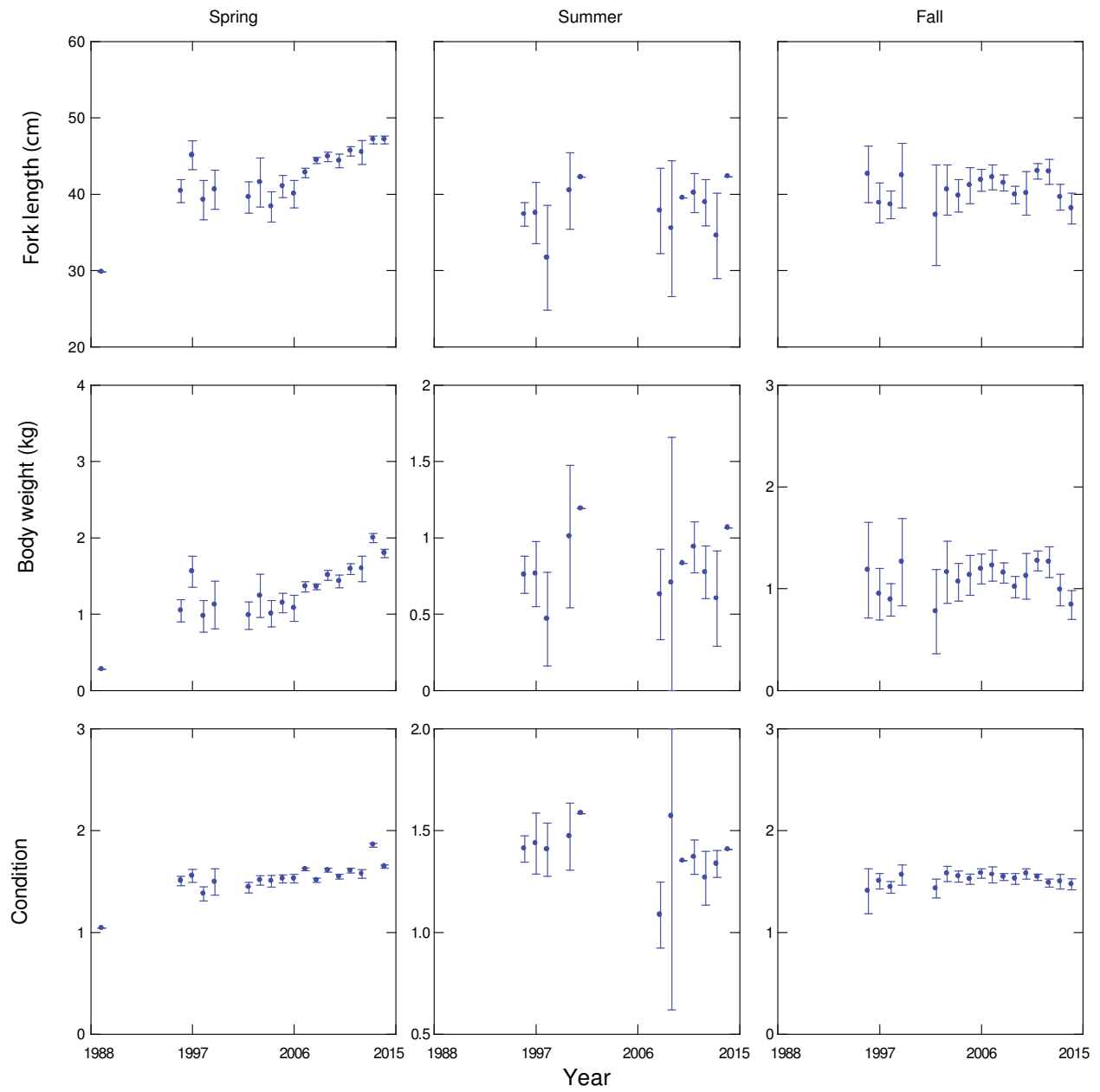


Fig. S10 Mean fork length ($\pm 2SE$), body weight ($\pm 2SE$), and condition ($\pm 2SE$) of white sucker captured in the spring, summer, and fall inventories conducted in the mainstem Athabasca since 1987.

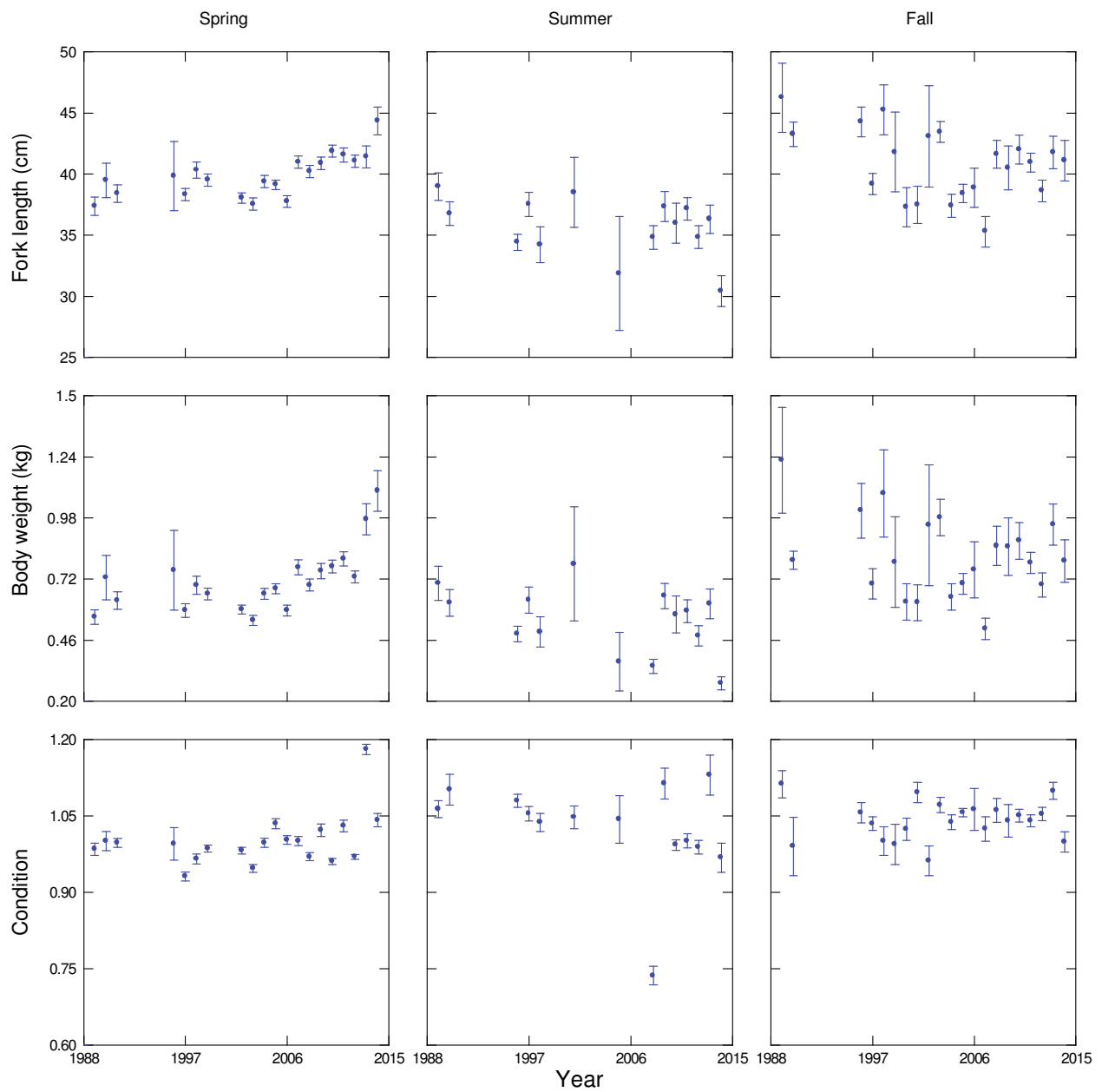


Fig. S11 Mean fork length ($\pm 2SE$), body weight ($\pm 2SE$), and condition ($\pm 2SE$) of walleye captured in the spring, summer, and fall inventories conducted in the mainstem Athabasca since 1987.

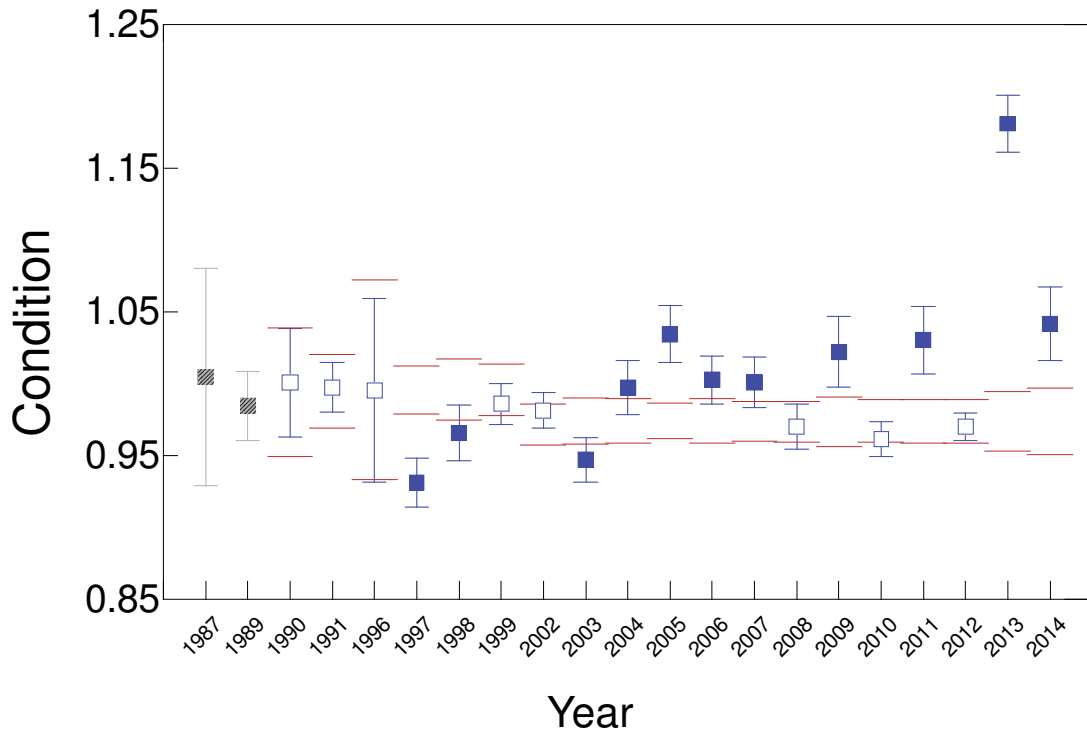


Fig. S12 Mean condition ($\pm 2SE$) of walleye captured in the spring evaluated using triggers derived from nonparametric bootstrapping; resample size (m) set to sample size (n) of test year; number of resampled means = 10,000; hatched symbols=baseline years; open symbols=no exceedance; closed symbols=exceedance.

Table S1 Approximate upstream and downstream limits (latitude (°N) and longitude (°W)) for RAMP fish inventory reaches emphasized in this study.

Reach	Upstream limit		Downstream limit	
	Latitude	Longitude	Latitude	Longitude
00B	56.892	111.416	56.916	111.428
01A	56.914	111.436	56.938	111.442
04A	56.990	111.446	57.007	111.472
05A	57.007	111.472	57.027	111.500
05B	57.027	111.500	57.049	111.512
10B	56.993	111.442	57.010	111.463
11A	57.120	111.592	57.152	111.618
16A	57.147	111.624	57.183	111.628
17A	57.292	111.673	57.321	111.682

Table S2 Sample sizes (n) for fish collected in Spring Inventory after subsection to outlier/juvenile removal; *single fish weight and condition of fish included in estimate for 1996.

Species	Year	Fork length	Body weight	k
White sucker	1989	15	1*	1*
	1996	38	38	38
	1997	48	48	48
	1998	41	41	41
	1999	24	24	24
	2002	35	35	35
	2003	29	29	29
	2004	72	71	71
	2005	76	76	76
	2006	53	55	53
	2007	310	310	309
	2008	448	445	445
	2009	202	200	200
	2010	159	159	159
	2011	223	223	223
	2012	69	69	69
2013	275	273	273	
2014	396	396	396	
Walleye	1987	93	29	29
	1989	72	65	65
	1990	36	36	36
	1991	97	97	97
	1996	11	11	11
	1997	180	180	180
	1998	108	107	107
	1999	153	151	151
	2002	224	223	223
	2003	162	162	162
	2004	177	175	175
	2005	339	339	339
	2006	192	192	192
	2007	227	225	225
	2008	231	230	230
	2009	147	146	146
	2010	215	213	213
	2011	196	196	196
2012	205	203	203	
2013	106	104	104	
2014	81	81	81	

Table S3 Catch (n) per species and effort (electrofishing seconds) recorded in the Spring Athabasca Inventories at focal (00B, 01A, 04A, 04B, 05A, 05B, 10B, 11A, 16A, 17A) locations sampled in 1987-2014.

Year	Effort (seconds)	Species and catch (n)																												
		ARGR	BLTR	BRST	BURB	CISC	EMSH	FLCH	FNDC	FTMN	GOLD	LKCH	LKTR	LKWH	LNDC	LNSC	MNWH	NNST	NRDC	NRPK	PRDC	SLSC	SPSC	SPSH	TRPR	UNK	WALL	WHSC	YLPR	sum
1987	14,900	0	0	0	0	0	0	26	0	0	27	0	0	1	0	139	0	0	0	5	0	0	0	0	0	0	95	7	0	300
1989	27,100	0	0	0	2	0	2	51	0	0	102	0	0	3	0	19	1	0	0	28	0	0	0	0	1	0	122	31	0	362
1990	7,705	0	0	0	1	0	0	2	0	0	41	0	0	0	0	3	0	0	0	3	0	0	0	0	0	0	36	3	0	89
1991	26,790	0	0	0	7	0	0	5	0	0	157	0	0	3	0	6	0	0	0	21	0	0	0	0	2	0	171	6	0	378
1996	4,405	0	0	0	0	0	0	4	0	0	4	1	0	3	0	9	1	0	0	5	0	0	0	0	0	0	12	38	0	77
1997	20,056	0	0	0	3	0	1	72	0	0	110	11	0	2	0	68	10	0	0	11	0	0	0	2	26	0	185	54	2	557
1998	18,507	1	0	0	0	0	4	45	0	0	66	2	0	5	0	34	0	0	0	14	0	0	0	1	10	0	117	47	2	348
1999	16,270	0	0	0	3	0	1	26	0	0	74	1	0	4	0	31	2	0	0	26	0	0	1	0	6	0	155	27	0	357
2001	6,430	0	0	0	0	0	34	25	0	0	17	0	0	0	0	16	0	0	0	7	0	0	0	4	8	0	20	19	0	150
2002	18,271	1	0	0	0	0	2	65	0	0	63	0	0	0	0	26	3	0	0	21	0	1	1	0	14	0	237	45	0	479
2003	22,529	0	0	0	0	1	3	41	0	0	49	3	0	1	0	53	4	0	0	20	0	0	1	0	13	0	168	32	0	389
2004	25,783	1	0	1	0	0	18	75	0	2	51	12	0	13	0	33	1	0	0	20	0	0	1	15	120	0	181	81	2	627
2005	24,324	0	1	0	6	0	2	60	0	0	98	31	0	2	0	31	2	0	0	13	0	0	0	1	83	0	347	89	0	766
2006	22,869	0	0	0	0	0	13	150	0	4	49	13	0	9	0	32	0	0	0	10	0	0	1	1	168	0	196	61	0	707
2007	24,629	0	0	1	8	0	5	65	0	0	134	4	0	5	1	69	0	0	0	23	0	0	1	4	190	0	232	328	0	1,070
2008	18,924	0	0	1	5	0	39	35	5	1	99	4	0	11	0	37	3	0	0	15	0	0	1	0	294	1	236	467	1	1,255
2009	18,233	0	0	0	1	0	6	43	0	0	91	13	0	10	0	12	0	0	1	14	0	3	0	0	249	0	150	205	0	798
2010	21,041	0	0	0	5	0	65	44	1	0	59	9	0	15	0	57	1	0	0	15	1	0	0	13	403	1	217	167	1	1,074
2011	18,612	0	0	0	2	0	7	43	1	0	212	0	0	4	0	23	13	0	0	19	2	3	0	0	390	0	208	227	0	1,154
2012	15,265	0	0	0	3	0	8	155	0	0	125	12	0	1	0	22	0	0	0	17	0	0	0	7	354	0	207	80	0	991
2013	15,371	1	0	0	10	0	4	101	4	0	320	4	0	1	0	112	0	0	0	28	0	0	0	3	46	0	134	342	4	1,114
2014	13,798	0	0	0	8	0	3	67	0	0	190	5	0	6	0	38	0	0	0	16	2	0	0	7	249	0	81	402	0	1,074

ARGR: Arctic grayling (*Thymallus arcticus*); **ARLM:** Arctic lamprey (*Lampetra japonica*); **BKTR:** brook trout (*Salvelinus fontinalis*); **BRMN:** brassy minnow (*Hybognathus hankinsoni*); **BRST:** brook stickleback (*Culaea inconstans*); **BLTR:** bull trout (*Salvelinus confluentus*); **BURB:** burbot (*Lota lota*); **CISC:** cisco (*Coregonus artedii*) **EMSH:** emerald shiner (*Notropis atherinoides*); **FLCH:** flathead chub (*Platygobio gracilis*); **FNDC:** finescale dace (*Phoxinus neogaeus*); **FTMN:** fathead minnow (*Pimephales promelas*); **GOLD:** goldeye (*Hiodon alosoides*); **LKCH:** lake chub (*Couesius plumbeus*); **LKTR:** lake trout (*Salvelinus namaycush*); **LKWH:** lake whitefish (*Coregonus clupeaformis*); **LNDC:** longnose dace (*Rhinichthys cataractae*); **LNSC:** longnose sucker (*Catostomus catostomus*); **MNWH:** mountain whitefish (*Prosopium williamsoni*); **NRPK:** northern pike (*Esox lucius*); **NNST:** ninespike stickleback (*Pungitius pungitius*); **NRDC:** northern redbelly dace (*Phoxinus eos*); **PRDC:** pearl dace (*Semotilus margarita*); **SLSC:** slimy sculpin (*Cottus cognatus*); **SPSC:** spoonhead sculpin (*Cottus ricei*); **SPSH:** spottail shiner (*Notropis hudonius*); **RVSH:** river shiner (*Notropis blennioides*); **RNTR:** rainbow trout (*Oncorhynchus mykiss*); **TRPR:** trout-perch (*Percopsis omiscomaycus*); **WALL:** walleye (*Sander vitreus*); **WHSC:** white sucker (*Catostomus commersoni*); **YLPR:** yellow perch (*Perca flavescens*) ; **UNK:** Unknown.

Table S4 Catch per species (n) and effort (electrofishing seconds) recorded in the Spring Athabasca Inventories at focal (00B, 01A, 04A, 04B, 05A, 05B, 10B, 11A, 16A, 17A) locations sampled in 1987-2014.

Year	Effort (seconds)	Species and catch (n)																								sum				
		ARGR	BLTR	BRST	BURB	CISC	EMSH	FLCH	FNDC	FTMN	GOLD	LKCH	LKTR	LKWH	LNDC	LNSC	MNWH	NNST	NRDC	NRPK	PRDC	SLSC	SPSC	SPSH	TRPR		UNK	WALL	WHSC	YLPR
1989	12,198	35	0	0	0	0	0	0	0	0	4	0	0	37	0	3	0	0	0	40	0	0	0	0	0	10	1	0	130	
1990	1,189	1	0	0	0	0	0	0	0	0	1	0	0	13	0	0	0	0	0	1	0	0	0	0	0	0	3	0	19	
1996	4,864	0	0	1	0	0	0	3	0	0	44	0	0	21	0	3	0	0	0	4	0	0	0	0	1	0	32	9	0	118
1997	13,416	4	0	0	0	0	0	32	0	0	134	2	0	47	0	10	2	0	0	15	0	0	0	0	14	0	86	19	0	365
1998	10,381	12	0	0	0	0	6	8	0	0	41	0	0	116	0	60	3	0	0	10	0	0	0	0	2	0	28	36	0	322
1999	4,786	0	0	0	0	0	3	3	0	0	9	0	0	35	0	1	0	0	0	9	0	0	0	0	0	0	5	8	0	73
2000	10,270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	13	0	0	17
2001	14,144	0	0	0	0	0	4	4	0	0	5	0	0	2	0	1	0	0	0	3	0	0	0	0	3	0	19	1	0	42
2002	13,002	0	0	0	2	0	21	1	0	0	2	4	0	25	1	28	0	0	0	6	0	1	2	2	33	0	29	11	4	172
2003	29,527	3	0	0	1	2	3	11	0	0	41	2	0	43	0	36	12	0	0	30	2	0	0	0	40	0	84	24	4	338
2004	25,344	0	0	0	0	0	11	168	0	4	210	14	0	56	0	13	3	0	0	32	0	0	0	2	313	0	117	41	8	992
2005	22,248	0	0	0	0	34	7	128	0	0	172	20	0	105	0	27	5	0	0	27	0	1	2	0	84	0	137	31	3	783
2006	21,260	2	0	0	2	0	33	32	0	0	25	59	0	69	0	67	9	0	0	39	0	0	2	11	574	0	145	48	31	1,148
2007	21,047	0	0	0	2	1	4	48	0	4	29	33	0	259	1	38	0	1	0	18	3	0	0	3	265	0	85	49	17	860
2008	17,944	0	0	0	1	0	7	40	0	0	214	13	0	395	0	24	2	0	0	14	0	0	0	0	425	0	92	83	1	1,311
2009	13,607	0	0	0	2	0	13	33	0	0	86	8	0	342	0	42	1	0	0	10	0	0	0	7	193	0	83	60	0	880
2010	19,090	17	0	0	1	0	13	36	0	0	143	8	0	282	0	4	8	0	0	29	2	0	2	1	1293	0	90	33	28	1,990
2011	16,654	4	0	0	1	0	40	138	0	0	745	5	0	290	0	33	5	0	0	20	6	1	4	2	371	0	117	76	9	1,867
2012	14,873	0	0	0	0	1	216	270	0	0	843	5	0	278	0	46	2	0	2	19	0	0	0	15	307	0	173	52	5	2,234
2013	16,853	0	0	0	1	0	605	73	0	0	296	14	0	188	0	72	1	0	0	19	0	3	0	184	63	0	81	30	12	1,642
2014	16,167	0	0	0	4	0	18	167	0	0	38	5	0	16	0	50	0	0	0	4	0	0	0	6	140	0	114	13	16	591

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