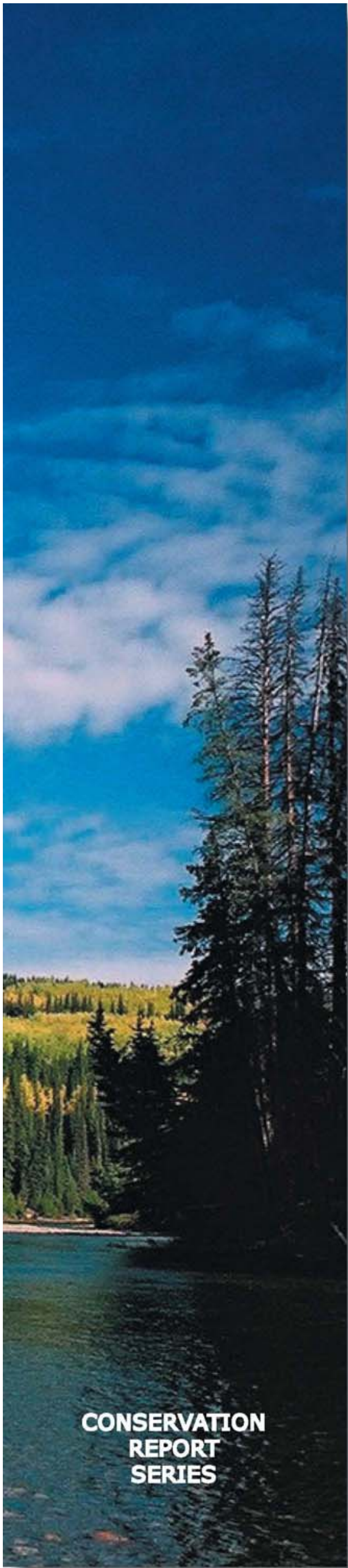

Abundance and Distribution of Bull Trout in the Muskeg River Watershed, 2014

Alberta Conservation Association
Conserving Alberta's Wild Side

The Alberta Conservation Association is a Delegated Administrative Organization under Alberta's Wildlife Act.

Abundance and Distribution of Bull Trout in the Muskeg River Watershed, 2014

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Conservation Report Series Type
Data

ISBN printed: 978-1-4601-2273-0
ISBN online: 978-1-4601-2274-7

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Suggested Citation:
Rodtka, M., and C. Judd. 2015. Abundance and distribution of bull trout in the Muskeg River watershed, 2014. Data Report, D-2015-002, produced by Alberta Conservation Association, Sherwood Park, Alberta, Canada. 18 pp + App.

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EXECUTIVE SUMMARY

The Muskeg River bull trout population is currently considered at *High Risk* of extirpation. The population is one of only a handful of bull trout populations in Alberta that has been assessed periodically since the 1960s. Our objective was to provide fisheries managers with an update on the abundance of bull trout in the Muskeg River and on their distribution throughout the watershed, information which can be used when determining species status in the Muskeg River watershed.

To assess abundance of adult (i.e., ≥250 mm fork length [FL]) bull trout in the Muskeg River, we sampled two reaches of the river established for population monitoring using angling and float electrofishing gear in 2013. Following unexpectedly low catches at both reaches, we returned to the watershed in 2014. We angled 4 and 5 km sections of the upper and lower reaches, respectively. In addition, we electrofished 4.5 km of the lower reach from July 3 to 6. We used Program MARK to estimate bull trout abundance, capture probability and associated 95% confidence limits (CL) using our 2014 catch from the first 2 km of the upper reach. Our bull trout catch in the lower reach was too low for a formal estimate of abundance. To describe bull trout distribution in the watershed, we sampled 25 sites distributed randomly throughout the upper Muskeg River and its larger tributaries upstream of Muskeg Falls using backpack electrofishing gear between July 7 and 29, 2014. We used occupancy estimation and modelling to quantitatively describe sport fish distribution, with an emphasis on the juvenile life stage of bull trout (i.e., ≤150 mm FL) because these fish may be more indicative of a local population than adults.

We captured 73 fish, including 56 individual bull trout, in the two reaches of the Muskeg River in 2014. The remainder of our catch was comprised of rainbow trout (n = 10) and brook trout (n = 7). Bull trout size ranged from 262 to 514 mm FL, with a mean (± standard deviation) of 381 ± 59 mm. All bull trout captured were ≥250 mm FL and were classified as mature. Despite capturing very few fish in the same reach in 2013 under comparable conditions, we estimated bull trout abundance in the first 2 km of the upper reach to be 50 (95% CL = 41 – 76) or 25 fish/km with an associated capture probability (p) of 0.47 (95% CL = 0.30 – 0.64). We captured 479 fish throughout the 7.8 km of stream sampled while backpack electrofishing, including 89 bull trout (42 of which were juveniles). The remainder of our catch included brook trout (n = 231) and rainbow trout (n = 159). Bull trout was the most widely distributed species and the only fish captured in the headwaters of the Muskeg River. Modelling identified moderate potential for false absences to bias estimates of bull trout occupancy. The naive estimate (i.e., assuming detection probability = 1) of juvenile bull trout occupancy was 0.24, whereas our model-averaged estimate (± standard error) was 0.34 (0.16) although our small sample size did not permit strong inference. Assuming an approximately average stream conductivity (i.e., 200 μS/cm) and fish availability of 0.85, our top-ranked model predicted cumulative conditional detection probability of bull trout exceeded 95% within the first 200 m of effort. Our study provides fisheries managers with an update on the abundance and distribution of bull trout in the Muskeg River watershed, which can be used when determining species status.

Key words: Alberta, Muskeg River, bull trout, distribution, abundance.

ACKNOWLEDGEMENTS

We thank Alberta Environment and Sustainable Resource Development staff George Sterling and Mike Blackburn for assisting with study design and Calvin McLeod for facilitating our work in Willmore Wilderness Park. We also appreciate project support from Jaymie Kugler and members of the Aseniwuche Winewak Nation. Alberta Conservation Association employees Kevin Fitzsimmons, John Hallett and Melissa Buchholtz assisted with data collection. Karen Hayduk (Alberta Justice and Solicitor General) arranged camp accommodations.

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1.0 INTRODUCTION

1.1 Background

Historically, only bull trout (*Salvelinus confluentus*) inhabited the Muskeg River watershed upstream of Muskeg Falls, although brook trout (*Salvelinus fontinalis*) and rainbow trout (*Oncorhynchus mykiss*), introduced in the 1950s and 1970s respectively, have since become established (Boag and Hvenegaard 1993). The Muskeg River bull trout population is currently considered at *High Risk* of extirpation (Alberta Sustainable Resource Development [ASRD] and Alberta Conservation Association [ACA] 2009). Alberta Environment and Sustainable Resource Development's (ESRD) Fish Sustainability Index ranks adult bull trout density in the watershed as *Very Low* with a *Moderate* need of habitat protection (ESRD 2014). Classed as *Threatened* in Alberta (Saskatchewan – Nelson rivers populations) (COSEWIC 2012), bull trout are considered particularly sensitive to habitat change and are thought to reflect general ecosystem health (COSEWIC 2012). The widespread decline of bull trout in Alberta, including the Muskeg River population, is cause for concern.

Fisheries studies in the Muskeg River watershed have occurred since the 1960s (Boag and Hvenegaard 1993), and the Muskeg River bull trout population is one of only a handful of populations in Alberta that has been assessed periodically. Recent assessments have focused on two "index" reaches of the river upstream of Muskeg Falls (Mike Blackburn, ESRD Fisheries Biologist, pers. comm.). Our study provides fisheries managers with an update on the abundance of bull trout in the Muskeg River at the index reaches and on distribution throughout the watershed, which can be used when determining species status in the Muskeg River watershed.

1.2 Objectives

Our objectives for this study were to:

- assess adult bull trout abundance at two established index reaches of the Muskeg River upstream of Muskeg Falls
- describe sport fish distribution in the Muskeg River watershed upstream of Muskeg Falls with a focus on juvenile bull trout

2.0 STUDY AREA

The Muskeg River originates in the Persimmon mountain range within Willmore Wilderness Park and flows approximately 190 km to the confluence of the Smoky River. Muskeg Falls, an impassable barrier to fish, is located approximately 40 km upstream from the confluence. Main tributaries to the Muskeg River upstream of the falls include Mason Creek, Lone Teepee Creek, Mahon Creek and Douglas Creek (Figure 1). Land uses outside of Willmore Wilderness Park include forestry, oil and gas exploration, and recreational activities. Land use within Willmore Wilderness Park is restricted and primarily recreational. Our study area includes the Muskeg River and tributaries upstream of Muskeg Falls.

3.0 MATERIALS AND METHODS

3.1 Adult bull trout abundance

To assess the abundance of adult bull trout (i.e., ≥250 mm fork length [FL]) (ASRD and ACA 2009) in the Muskeg River, we sampled two reaches of the river previously established as index reaches for population monitoring (Figure 1). In 2013, we attempted to derive estimates of bull trout abundance from mark-recapture surveys from June 27 to July 1 using float electrofishing and angling gear. However, due to low catches, we could not use the catch data to derive abundance estimates. To assess abundance outside the index reaches, we angled a reach approximately 5 km upstream of the upper reach from June 28 to July 1, 2013, and experienced exceptionally high catch rates (9.7 fish/h), suggesting bull trout were aggregated near the headwaters of the river at the time of sampling. Suspecting fish movement had biased our 2013 results in the upper reach, we returned to the index reaches in 2014 to reassess adult bull trout abundance. We angled 4 km of the upper reach on July 3 and 5; low water conditions and obstructions prevented us from using electrofishing gear. At the lower reach, we angled 5 km and electrofished 4.5 km on July 4 and 6, respectively. Our results focus exclusively on the 2014 sampling effort, but the wide discrepancy between our 2013 and 2014 catch in the upper reach is considered when interpreting our 2014 results. Our 2013 catch information is summarized in Appendix 1.

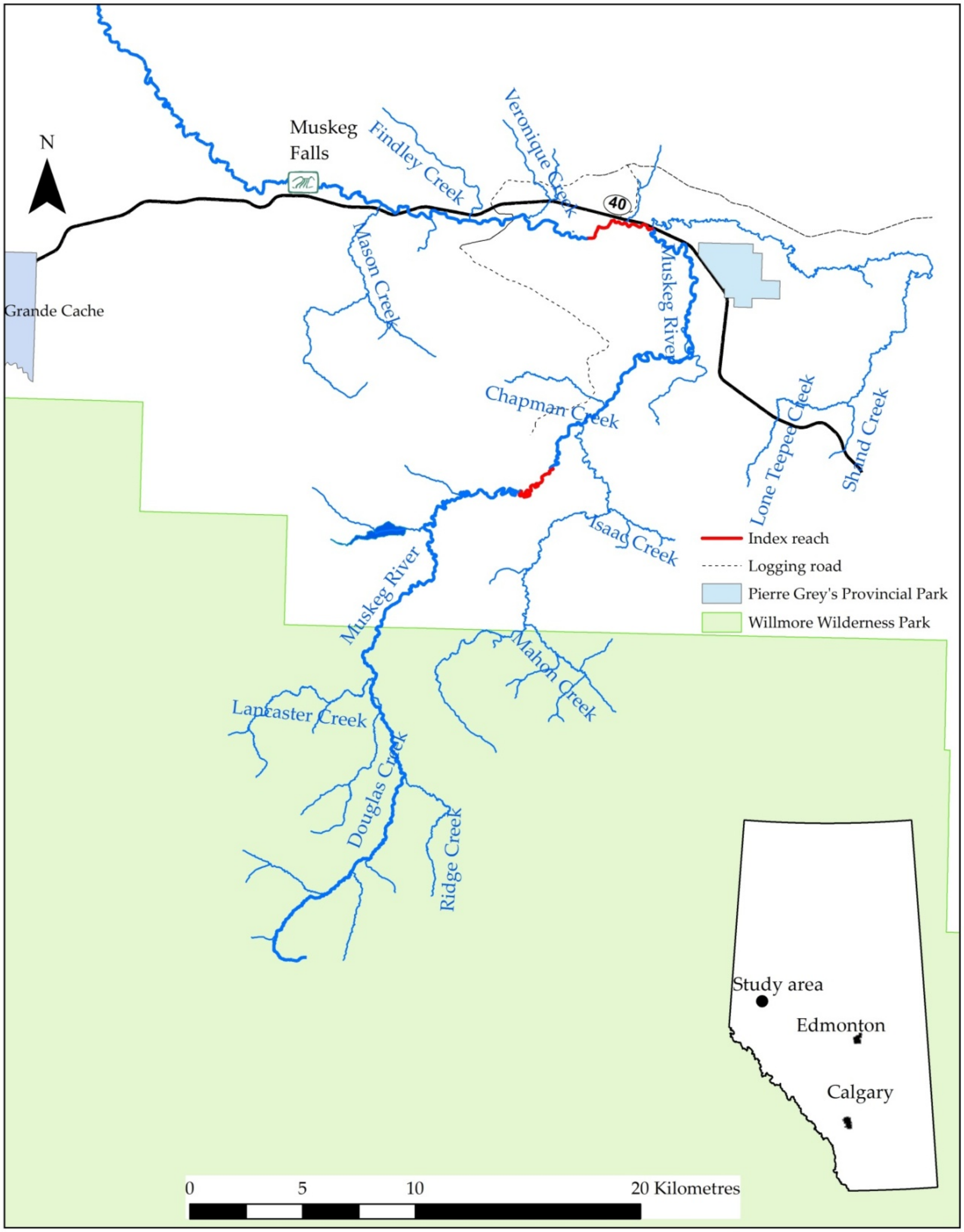

Figure 1. Location of the Muskeg River and major tributaries.

We angled at potential holding water locations (e.g., pools and flatwater) with a crew of two or three. Angling effort was measured by individual anglers using a stopwatch. Terminal tackle included jigs, spinners and crankbaits with baited hooks. All sampling was conducted in a downstream progression. We returned our angling catch to the river at point of capture after sampling. Our electrofishing gear included a 4.3 m inflatable raft equipped with a 2.5 GPP generator and single boom anode array. One person oared the raft while a second person applied power and dip netted from a platform mounted at the bow of the raft. We measured electrofishing effort in seconds; electrofisher settings were 60 Hz at 20% to 30% of low power range with output ranging between 3 to 6 amps. We held our electrofishing catch in a live well and sampled every 500 m.

Before sampling, fish were anaesthetized with a clove oil/ethanol solution added to the holding water (~0.5 ml/L). We measured FL (mm) of all fish. We took an adipose fin clip from bull trout (≥250 mm FL) and tagged them with a passive integrated transponder (PIT) tag in the dorsal musculature. The adipose fin clip allowed us to assess tag retention and provided a tissue sample for archival purposes.

We used Program MARK (White and Burnham 1999) to estimate bull trout abundance, capture probability and associated 95% confidence limits (CL) using our catch from the first 2 km of the upper reach; time constraints did not allow for complete sampling of the entire upper reach on the marking run. Estimates were calculated using the Huggins Closed Capture model, M_o, which assumes capture probability is constant (Hayes et al. 2007) in addition to the other assumptions of basic mark-recapture (reviewed in Hayes et al. 2007). Our bull trout catch in the lower reach was too low for a formal estimate of abundance.

We measured water temperature (1°C) and ambient conductivity (i.e., conductivity at ambient water temperature; 1 µS/cm) before sampling a reach (see Appendix 2). We collected field habitat measurements at 500 m transects along each index reach. Wetted and rooted widths (± 1 m) were measured at each transect. We also visually estimated the proportion of flow type, dominant substrate type and depth score between transects. A summary of our visual habitat assessment by reach, with definition of the various habitat classifications used, is presented in Appendix 3.

3.2 Sport fish distribution

From July 7 to 29, we sampled 25 sites distributed randomly throughout the upper Muskeg River and its tributaries to describe sport fish distribution. Emphasis was placed on the juvenile life stage (i.e., ≤150 mm FL) (ASRD and ACA 2009) of bull trout because bull trout is the only fish native to the upper watershed and juveniles may be more indicative of a local population than adults (Isaak et al. 2009). Given our focus, we monitored stream temperature of major tributaries to the Muskeg River in 2013 to assess their thermal suitability for bull trout. Based on our assessment, the entire watershed within the study area provided habitats considered thermally suitable (Isaak et al. 2009 and references therein) (summarized in Appendix 4) and was included in our sample frame.

We distributed prospective sample sites at 1,200 m intervals in an upstream progression along the length of third-order to fifth-order streams (1:20,000 scale) (Strahler 1952) in the study area using a geographic information system (GIS) (ArcGIS version 10.1) and the Government of Alberta Resource Management Information Branch hydro line data layer. A handheld Global Positioning System (GPS) was used to locate sample sites. All site sampling commenced at the head of riffle habitat. Sample sites were 300 m long (measured with a hip chain) or 50 times the mean wetted width (Reynolds et al. 2003) rounded to the nearest 50 m, whichever was greater. We set maximum site length at 500 m (mean site length ± standard deviation [SD]; 312 ± 42 m). Sites were sampled using a Smith-Root 12-B backpack electrofisher with pulsed DC (voltage 400 to 500 V, frequency 30 to 40 Hz, and duration 4 to 6 ms). Fish were identified to species, enumerated and measured (FL, mm), and electrofishing effort (seconds) was recorded at 50 m intervals within a site. We also measured the length of stream sampled to first capture of each species, including the juvenile life stage of bull trout.

At all sites, we measured water temperature (1°C) and ambient conductivity (1 μS/cm) before electrofishing. We measured stream depth (0.01 m) and wetted width (0.1 m), and we visually assessed dominant substrate along transects spaced every 50 m. Water depth and dominant substrate type were assessed at three stations per transect: one-quarter, one-half and three-quarters wetted width (one-half only where wetted width ≤1 m). Substrate categories were scored based on a modified Wentworth (1922) scale and included the following: fines (<2 mm; score 0), small gravel (2 to 16 mm; 1), large gravel (17 to 64 mm; 2), cobble (65 to 256 mm; 3), boulder (>256 mm; 4) and bedrock (5). Habitat data are summarized in Appendix 5.

Although bull trout use smaller streams, we focused on third-order to fifth-order streams because stream size is positively associated with bull trout occurrence (Rich et al. 2003; Ripley et al. 2005). Sites were randomly selected without replacement using a Generalized Random Tessellation Stratified (GRTS) design (Stevens and Olsen 2004). Our target sample size was intended to deliver an 80% probability of accurately detecting a 25% decrease in bull trout occupancy (Ψ) assuming a 200 m sample reach, Ψ = 0.45 and detection probability (p) of 0.72 (M. Rodtka, unpub. data). Sites were visited in the order in which they were drawn. A subset of sample sites were inaccessible (i.e., five sites were greater than 1 km from the nearest motorized access point using truck, off-highway vehicle or helicopter; one site was dry; and one site was too deep to safely wade). The GRTS sampling design allowed us to dynamically adjust our sample size to accommodate these nonresponse sites while maintaining a spatially balanced sample (Stevens and Olsen 2004).

We used occupancy estimation and modelling to quantitatively describe the distribution of sport fish in the study area. Study designs for occupancy estimation require repeated surveys of a sample unit to estimate the probability of detection (MacKenzie et al. 2006). The repeated surveys may be represented by temporal replication at discrete time occasions, replication of different observers, or spatial replication at separate locations (MacKenzie et al. 2006). For logistical reasons, we used spatially replicated surveys exclusively, a common approach for large-scale studies such as ours (Pavlacky et al. 2012). However, estimating detection from spatially replicated surveys can result in biased estimates (Kendall and White 2009; Hines et al. 2010) because the models assume species detections between sites are independent (MacKenzie et al. 2006). To deal with this potential lack of independence, we used Hines et al.'s (2010) spatial-dependence model, which decomposes the observation processes into detection and availability probabilities. In addition to the independence of detections between sites, the model assumes that there is no un-modelled heterogeneity in the probabilities of detection and occupancy, that each sample site is closed to changes in occupancy over the sampling period, and that the target species are never falsely detected (MacKenzie et al. 2006). For a more detailed discussion of model assumptions and their relevance to studies like ours, see Rodtka et al. (2015).

Detection data from 50 m segments of each sample site were used as spatial replicates for the analysis. Model parameterization allowed us to estimate the probability a site is occupied and the probability of detection given the site is occupied and the species is present on the segment. Availability parameters θ (probability the species is present on a segment given the site is occupied and the species is not present on the previous segment) and θ' (probability the species is present on a segment given the site is occupied and the species is present on the previous segment) are also included in the model (Hines et al. 2010). Given our objective and the sparseness of our dataset, our initial model set was limited to models where Ψ, θ and θ' were held constant (.) and where *p* was either held constant or allowed to vary as a function of ambient stream conductivity (*cond*). We included this covariate of detection probability because a comparable analysis in the Clearwater River watershed identified stream conductivity as the most informative stream habitat variable for the prediction of backpack-electrofishing detection probability of juvenile bull trout (Rodtka et al. 2015). Finally, we included a simple, single-season (MacKenzie et al. 2006) occupancy model [Ψ(.) *p*(.)] in our set, which does not account for the possibility of spatial correlation between segments (Hines et al. 2010), to assess the relative utility of the spatial model given our low sample size. The resulting three models were run for juvenile bull trout, all bull trout, and rainbow trout. Brook trout were detected at only four sites and not included in our modelling. We added the model [Ψ(.), $\theta = \theta'$, *p*(*cond*)] to the bull trout model set based on the similarity of estimates of θ and θ' resulting from the [Ψ(.), θ(.), θ'(.), *p*(*cond*)] model. All modelling was performed using program PRESENCE (Hines 2006). For all spatial-dependence models, the option of estimating local presence before the first segment using θ and θ' was selected in program PRESENCE.

Stream conductivity was standardized to a mean of zero and SD of one (MacKenzie et al. 2006) before analysis. Models were ranked using Akaike's information criterion corrected for small sample size (AIC_c) (Burnham and Anderson 2002). Use of AIC provides a method of ranking models; to encourage parsimony, this method applies a penalty for the number of parameters in the model (Burnham and Anderson 2002). We considered models with an AIC_c score within two points (i.e., $\Delta_i \leq 2$) of the top-ranked model as receiving substantial support (Burnham and Anderson 2002). Criteria for determining effective sample size of any particular occupancy model have not been resolved (MacKenzie et al. 2006). We opted for a relatively conservative effective sample size defined as the number of sampling units included in the broadest scale analysis (i.e., n = 25). Following calculation of AIC_c, we estimated Akaike weights (w_i), which provide an approximate representation for the probability of a particular model fitting the data compared with the candidate set of models (Burnham and Anderson 2002). We used odds ratios (ORs) to examine the effect of stream conductivity on detection probability; OR 95% CLs were calculated using the delta method (MacKenzie et al. 2006). Odds ratios for a single unit of change were calculated as $\exp(\beta_i)$ (MacKenzie et al. 2006). An OR can range between zero and infinity; an OR less than one demonstrates that the response variable is less likely to occur, and an OR greater than one demonstrates that the response variable is more likely to occur (MacKenzie et al. 2006). Reported cumulative detection probability was made conditional on species availability; cumulative probabilities were calculated using the general equation $1 - (1 - a)^b$, where a is the estimated parameter of interest and b is the number of replicated units.

All fish and habitat information acquired in the field was submitted for inclusion into the ESRD Fisheries and Wildlife Management Information System (FWMIS) database.

4.0 RESULTS

4.1 Adult bull trout abundance

In 2014, we sampled 9 km in the two index reaches of the Muskeg River and captured 73 fish, including 56 individual bull trout (Table 1).

Table 1. Fish capture by species at two reaches of the Muskeg River, July 3 to 6, 2014.

Reach	Distance (km)	Effort	BLTR	BKTR	RNTR
Upper (Pass 1)	2	3.63 (h)	20	–	–
Upper (Pass 2)	4	5.97 (h)	21[1]	–	1
Lower (angling)	5	3.08 (h)	8	1	–
Lower (electrofishing)	4.5	1,911 (s)	7[2]	6	9

[1] Includes two BLTR recaptures from 2013.
[2] Includes one BLTR recapture from 2013.
Species codes: BLTR = bull trout, BKTR = brook trout, RNTR = rainbow trout.

Bull trout size ranged from 262 to 514 mm FL, with a mean ± SD of 381 ± 59 mm (Figure 2). All bull trout captured were ≥250 mm FL and were classified as mature. Brook trout size ranged from 232 to 328 mm FL, with a mean of 267 ± 38 mm, and rainbow trout size ranged from 163 to 502 mm FL, with a mean of 264 ± 99 mm.

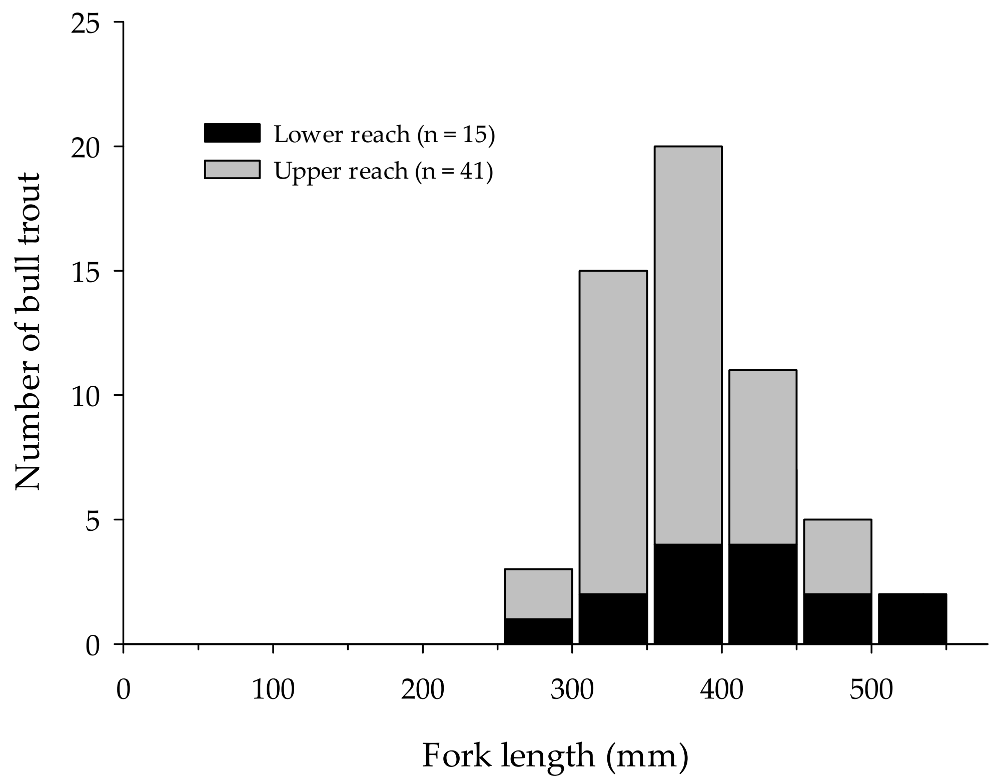

Figure 2. Length frequency distribution for bull trout captured at two reaches in the Muskeg River using angling and float electrofishing gear, July 3 to 6, 2014.

Based on the 2014 catch, we estimated bull trout abundance in the first 2 km of the upper reach was 50 (95% CL = 41 – 76) or 25 fish/km with an associated capture probability (*p*) of 0.47 (95% CL = 0.30 – 0.64) (Table 2). No tags were lost between recapture events.

Table 2. Number of bull trout marked (M), captured in Pass 2 (C) and recaptured (R) during abundance estimates at two reaches of the Muskeg River, July 3 to 5, 2014.

Reach	Pass 1	Pass 2			Total
	M	M	C	R	individuals
Upper	20	16	27	11	36
Lower	8	7	7	0	15

4.2 Sport fish distribution

We captured 479 fish throughout the 7.8 km of stream sampled with backpack electrofishing gear. Bull trout was the most widely distributed species and the only fish captured in the headwaters of the Muskeg River (Figure 3). Rainbow trout were captured in Mahon Creek and downstream tributaries, whereas brook trout appear to be confined to Lone Teepee Creek and surrounding waters. A summary of our backpack electrofishing catch is presented in Appendix 6.

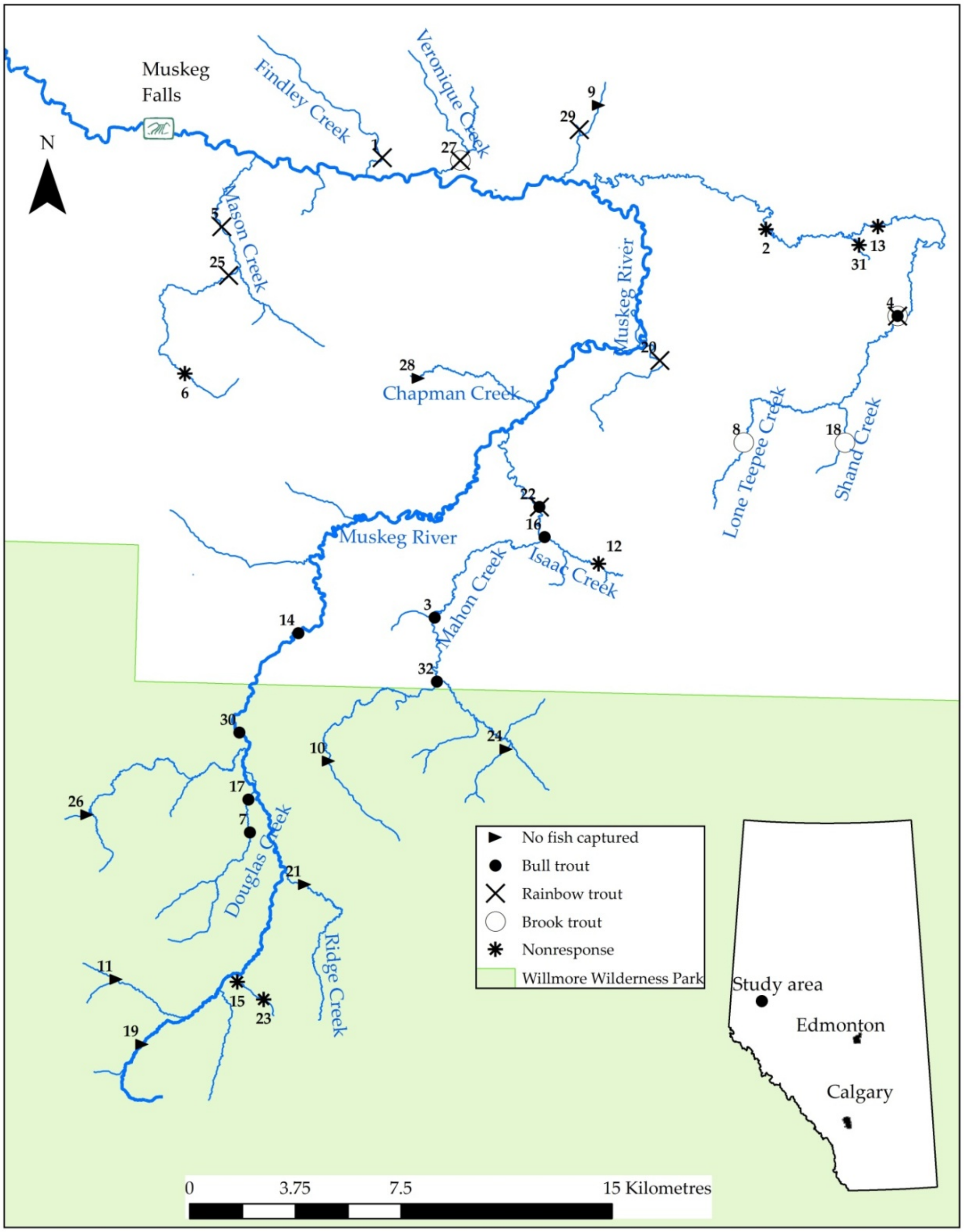

Figure 3. Electrofishing site identification and distribution of sport fish in the Muskeg River watershed upstream of Muskeg Falls captured using backpack electrofishing, July 7 to 29, 2014.

Despite being detected at only four sites, brook trout comprised 48% of our total catch, followed by rainbow trout (33%) and bull trout (19%) (Table 3). Appendix 7 summarizes size information for our backpack electrofishing catch. All species were typically detected within the first 50 m of sampling, although initial detections beyond 200 m were observed.

Table 3. Catch information and naive (i.e., assuming p = 1.0) estimates of sport fish occupancy in the Muskeg River watershed upstream of Muskeg Falls captured using backpack electrofishing, July 7 to 29, 2014.

Species	Site detections	Total catch	Mean (± SE) catch per 300 m site	Median distance (m) to first detection (range)	Naive $\hat{\Psi}$
Juv. BLTR	6	42	1.6 (± 0.8)	55 (7 – 140)	0.24
All BLTR	9	89	3.4 (± 1.3)	33 (7 – 214)	0.36
BKTR	4	231	8.9 (± 5.5)	1.5 (1 – 210)	0.16
RNTR	8	159	6.1 (± 2.8)	24.5 (5 – 377)	0.32

Juv = juvenile; SE = standard error

Occupancy modelling confirmed the general pattern of species distribution we observed while in the field, although our small sample size limits this inference. Although spatial models were top ranked in every analysis, the single-season model also received modest support in the juvenile bull trout and rainbow trout analyses (model weights of 0.38 and 0.26, respectively) (Table 4). Given this uncertainty, we recommend the model-averaged estimates reported in Table 4 be used when evaluating occupancy for these groups.

Table 4. Model structure and summary statistics for models of sport fish occupancy (Ψ) in the Muskeg River watershed upstream of Muskeg Falls including stream conductivity (*cond*) as a covariate of electrofishing detection probability (*p*), θ = probability the species is present on a 50 m stream segment given the site is occupied and the species is not present on the previous segment, θ′ = probability the species is present on a segment given the site is occupied and the species is present on the previous segment. Model weights may not add up to 1 due to rounding error.

Model	AIC_c	Δ_i	w_i	-2 log(*L*)	*K*	$\hat{\Psi}$ (± SE)
Juvenile BLTR						
Ψ(.), θ (.), θ′(.), *p*(*cond*)	90.15	0.00	0.50	76.99	5	0.42 (0.16)
Ψ(.) *p*(.)	90.72	0.57	0.38	86.17	2	0.25 (0.09)
Ψ(.), θ (.), θ′(.), *p*(.)	93.15	3.00	0.11	83.15	4	0.31 (0.17)
Model averaged	—	—	—	—	—	0.34 (0.16)
BLTR						
Ψ(.), θ = θ′, *p*(*cond*)	103.72	0.00	0.82	93.72	4	0.48 (0.12)
Ψ(.), θ (.), θ′(.), *p*(*cond*)	106.80	3.08	0.18	93.64	5	0.48 (0.12)
Ψ(.) *p*(.)	118.92	15.20	0.00	114.37	2	0.36 (0.10)
Ψ(.), θ (.), θ′(.), *p*(.)	119.02	15.30	0.00	109.02	4	0.37 (0.10)
Model averaged	—	—	—	—	—	0.47 (0.12)
RNTR						
Ψ(.), θ (.), θ′(.), *p*(*cond*)	99.92	0.00	0.49	86.76	5	0.38 (0.11)
Ψ(.), θ (.), θ′(.), *p*(.)	101.18	1.26	0.26	91.18	4	0.33 (0.10)
Ψ(.) *p*(.)	101.20	1.28	0.26	96.65	2	0.32 (0.09)
Model averaged	—	—	—	—	—	0.35 (0.11)

There appears to be moderate potential for false absences to bias naive estimates of bull trout occupancy, especially when stream conductivity is relatively low. Models including stream conductivity as a covariate of detection probability were top ranked in all three analyses. Unfortunately, our sample size did not permit strong inference regarding the impact of conductivity on electrofishing capture probability. Results of the top-ranked model for bull trout, the most precise estimate generated during our analyses, indicate detection was 40 times more likely (95% CIs = 3 – 600) for each SD (i.e., 49 μS/cm) increase in conductivity. Assuming an approximately average stream conductivity (i.e., 200 μS/cm) and fish availability of 0.85 (Table 5), our top-ranked model predicts cumulative conditional detection probability of bull trout exceeded 95% within the first 200 m of effort.

Table 5. Model-averaged estimates (± standard error) of detection probability (p) and availability (θ) of sport fish in the Muskeg River watershed upstream of Muskeg Falls sampled using backpack electrofishing gear.

Species	Single season $\hat{p}(.)$	Spatial model $\hat{p}(.)$	Spatial model $\hat{p}(cond)$	$\hat{\theta}(.)$	$\hat{\theta}'(.)$
Juvenile BLTR	0.43 (0.08)	0.76 (0.17)	0.82 (0.42)	0.33 (0.14)	0.63 (0.14)
BLTR	0.61 (0.06)	1.0 (undefined)	0.68 (0.16)	0.86 (0.09)	0.85 (0.08)
RNTR	0.64 (0.07)	0.91 (0.12)	1.0 (undefined)	0.40 (0.14)	0.85 (0.10)

Not surprisingly, the single-season model greatly underestimated our probability of detecting juvenile bull trout and rainbow trout as both groups exhibited strong dependence of availability for detection between segments, which is not accounted for by the model (Table 5). The $p(.)$ and $p(cond)$ models estimated perfect detection of bull trout and rainbow trout, respectively, with undefined error. We suspect the $p(.)$ model estimate of bull trout detection is unreliable; the estimate is unusually high, the model received essentially no support in our candidate set and it only converged after we used alternative starting values of p in our analysis (Hines et al. 2010). The rainbow trout $p(cond)$ model, however, exhibited none of these behaviours, and it is possible detection probability for the species actually approached 1. Although a lack of detections precluded modelling of brook trout occupancy, the potential for false absences should be slight if the densities we observed (Appendix 6) are typical of the species within the study area.

4.3 Summary

We angled and electrofished 9 km in two index reaches of the Muskeg River in July 2014, capturing 73 fish including 56 bull trout. All bull trout caught in these reaches were classified as mature. We estimated bull trout abundance in the first 2 km of the upper reach to be 25 fish/km. Low catch rates of bull trout in the lower reach prevented us from formally estimating abundance. Although we suspect bull trout abundance in the river upstream of the confluence of Mahon Creek is relatively high, anecdotal evidence collected over the course of our study suggests fish movement within the river in summer is substantial and has considerable potential to bias abundance estimates based on sampling fixed reaches.

We captured 479 fish including 89 bull trout (42 of which were juveniles) in the 25 sites sampled in the Muskeg River watershed with backpack electrofishing gear. Bull trout was the most widely distributed species and the only fish we captured in the headwaters of the Muskeg River. Most fish were detected within the first 50 m of electrofishing effort. Occupancy modelling identified moderate potential for false absences to bias estimates of bull trout occupancy. Naive occupancy of juvenile bull trout was 0.24, whereas our model-averaged estimate (± standard error) was 0.34 (0.16) although our small sample size did not permit strong inference. Our study provides fisheries managers with an update on the abundance and distribution of bull trout within the Muskeg River watershed, which can be used when determining species status.

5.0 LITERATURE CITED

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6.0 APPENDICES

Appendix 1. Bull trout catch and effort at three reaches of the Muskeg River, 2013.

Reach	Length (km)	Angling effort (h)	Electrofishing effort (s)	BLTR catch
Upper	5	1.67	2,819	9
Lower	9	2.52	–	1
Above	1.7	3.30	–	32

Appendix 2. Summary of visually assessed river habitat by sample reach on the Muskeg River, July 3 to 5, 2014.

Habitat variable	Upper reach	Lower reach
Transects	9	11
Width (m; mean ± SE)		
Wetted	14 ± 1	20 ± 2
Rooted	18 ± 2	50 ± 5
Percentage flow type (mean (min – max))[1]		
Pool	4 (0 – 5)	1 (0 – 5)
Riffle	39 (5 – 70)	58 (40 – 75)
Flatwater	54 (20 – 80)	24 (0 – 50)
Cascade	3 (0 – 10)	18 (0 – 40)
Substrate (dominant/secondary)[2]	Cobble/large gravel	Cobble/large gravel
Depth score (median (min – max))[3]	0.5 (0 – 2)	1 (0 – 1)

[1] Flow type classification: pool (<0.3 m/sec flow, low turbulence, slow water), riffle (>0.3 m/sec flow, moderate turbulence, little whitewater), flatwater (>0.3 m/sec flow, low turbulence) and cascade (>0.3 m/sec flow, high turbulence, whitewater); percentages may not add up to 100 due to rounding error.

[2] Substrate classified according to Bain et al. (1985): fines (sand, silt, clay), small gravel (marble sized), large gravel (tennis ball sized), cobble (basketball sized) or boulder (basketball+).

[3] Depth score: 0 = mostly shallow (<0.5 m), 1 = mostly moderate (0.5 – 1.0 m), 2 = mostly deep (>1.5 m).

Appendix 3. Location of reaches sampled (NAD 83, Zone 11) and beginning and end temperature and conductivity measurements on the Muskeg River, 2013 to 2014.

Reach	Date	Start				Stop			
		UTM		Temp.	Cond.	UTM		Temp.	Cond.
		Easting	Northing	(°C)	(µS/cm)	Easting	Northing	(°C)	(µS/cm)
Upper	June-27-2013	385782	5964362	7	192	387441	5966091	11	226
Lower	June-30-2013	391533	5976009	11	187	385397	5976427	14	217
Above	July-01-2013	381482	5962867	10	214	381782	5961620	15	232
Upper	July-03-2014	385772	5964363	10	212	387176	5965338	12	231
Lower	July-04-2014	391528	5976010	11	225	388392	5975630	15	257

Appendix 4. Location of temperature loggers (NAD 83, Zone 11) and summer stream temperature (June 13 – August 31) measurements in the Muskeg River watershed, 2013.

Logger number	Drainage	UTM		Stream temperature (°C)		
		Easting	Northing	Mean	Min	Max
M1	Muskeg River	387363	5966113	8.7	4.8	13.4
M2	Mahon Creek	389309	5964925	8.1	4.6	12.6
M3	A la Peche Creek	381152	5962663	15.8	10.4	23.0
M4	Muskeg River	381672	5962915	9.2	4.3	14.3
M5	Chapman Creek	388902	5968514	8.6	4.0	13.5
M6	Shand Creek	400055	5966127	6.3	3.0	9.5
M7	Lone Teepee Creek	396514	5968038	6.3	3.0	9.5
M8	Lone Teepee Creek	397138	5967512	9.4	5.7	14.0
M9	Burleigh Creek	395191	5968887	9.5	4.8	15.5
M10	Lone Teepee Creek	391607	5976043	11.9	7.2	16.2
M11	Plante Creek	403146	5976340	8.0	5.0	10.8
M12	Muskeg River	385411	5976455	10.7	5.9	16.1
M13	Findlay Creek	383513	5976629	11.9	6.2	18.2
M14	Mason Creek	379385	5976832	9.4	4.5	15.9

Appendix 5. Summary of habitat measurements at backpack electrofishing sites in the Muskeg River watershed, 2014.

Site ID	Temp. (°C)	Cond. (µS/cm)	Mean wetted width ± SD (m)	Mean depth ± SD (m)	Dominant/secondary substrate	Percentage pool (mean (min – max))	Percentage riffle (mean (min – max))	Percentage run (mean (min – max))
1	11	158	2.9 ± 1.0	0.21 ± 0.05	Cobble/small gravel	13 (0 – 20)	32 (20 – 50)	55 (30 – 80)
3	9	280	6.3 ± 1.3	0.34 ± 0.07	Large gravel/large gravel	0 (0 – 0)	73 (20 – 90)	28 (10 – 80)
4	8	202	5.1 ± 1.5	0.48 ± 0.16	Cobble/boulder	5 (0 – 20)	47 (35 – 70)	48 (20 – 60)
5	9	256	4.6 ± 0.4	0.22 ± 0.03	Cobble/large gravel	0 (0 – 0)	92 (70 – 100)	8 (0 – 30)
7	6	188	3.2 ± 0.9	0.29 ± 0.10	Cobble/boulder	1 (0 – 5)	96 (90 – 100)	3 (0 – 5)
8	11	180	3.0 ± 1.0	0.29 ± 0.13	Cobble/large gravel	7 (0 – 15)	73 (60 – 85)	18 (10 – 40)
9	8	121	0.7 ± 0.3	0.10 ± 0.04	Fines/cobble	24 (10 – 50)	54 (30 – 70)	22 (20 – 30)
10	8	263	2.6 ± 0.9	0.31 ± 0.16	Large gravel/small gravel	5 (0 – 10)	58 (35 – 75)	38 (20 – 60)
11	9	193	4.4 ± 1.9	0.24 ± 0.04	Boulder/cobble	0 (0 – 0)	94 (85 – 100)	6 (0 – 15)
14	8	242	11.2 ± 2.8	0.67 ± 0.18	Large gravel/cobble	2 (0 – 15)	33 (0 – 70)	65 (30 – 100)
16	10	219	4.6 ± 2.0	0.34 ± 0.09	Cobble/large gravel	0 (0 – 0)	82 (10 – 100)	18 (0 – 90)
17	6	179	3.1 ± 0.7	0.26 ± 0.02	Cobble/boulder	1 (0 – 5)	94 (90 – 100)	5 (0 – 10)
18	7	180	2.2 ± 0.2	0.20 ± 0.07	Cobble/large gravel	8 (0 – 25)	48 (30 – 60)	43 (20 – 70)
19	5	264	2.0 ± 0.7	0.28 ± 0.05	Cobble/large gravel	0 (0 – 0)	100 (100 – 100)	0 (0 – 0)
20	8	119	1.9 ± 0.4	0.39 ± 0.12	Fines/large gravel	29 (10 – 50)	20 (10 – 30)	51 (40 – 65)
21	14	271	2.7 ± 0.5	0.28 ± 0.11	Cobble/large gravel	0 (0 – 0)	95 (90 – 100)	5 (0 – 10)
22	8	218	8.1 ± 1.2	0.49 ± 0.23	Cobble/large gravel	3 (0 – 5)	79 (35 – 95)	19 (5 – 60)
24	5	226	1.8 ± 0.4	0.16 ± 0.03	Cobble/large gravel	0 (0 – 0)	94 (90 – 95)	6 (5 – 10)
25	9	264	4.5 ± 1.7	0.26 ± 0.04	Cobble/boulder	2 (0 – 10)	86 (75 – 100)	12 (0 – 20)
26	5	201	2.3 ± 0.5	0.31 ± 0.07	Cobble/boulder	0 (0 – 0)	100 (100 – 100)	0 (0 – 0)
27	9	176	4.5 ± 2.3	0.27 ± 0.05	Cobble/boulder	5 (0 – 20)	42 (20 – 60)	53 (40 – 80)
28	10	143	3.0 ± 1.2	0.19 ± 0.09	Cobble/boulder	1 (0 – 5)	53 (35 – 95)	46 (5 – 65)
29	7	164	1.5 ± 0.3	0.18 ± 0.08	Large gravel/cobble	0 (0 – 0)	52 (30 – 70)	48 (30 – 70)
30	14	290	8.5 ± 1.6	0.48 ± 0.12	Cobble/large gravel	0 (0 – 0)	86 (25 – 100)	14 (0 – 75)
32	11	173	5.3 ± 1.7	0.31 ± 0.08	Cobble/large gravel	1 (0 – 5)	74 (60 – 90)	25 (10 – 40)

Appendix 6. Backpack electrofishing site locations (NAD 83, Zone 11) and fish capture by species in the Muskeg River watershed, 2014.

Site ID	Date	UTM		Distance (m)	Effort (s)	Species			
		Easting	Northing			Juvenile BLTR	BLTR	BKTR	RNTR
1	July-07-14	384048	5977006	300	962	0	0	0	23
3	July-29-14	385911	5960675	300	750	16	21	0	0
4	July-18-14	402342	5971392	300	1,430	0	2	107	5
5	July-28-14	378357	5974566	300	1,043	0	0	0	22
7	July-29-14	379351	5953049	300	668	0	2	0	0
8	July-08-14	396878	5966900	300	914	0	0	97	0
9	July-09-14	391733	5978875	250	272	0	0	0	0
10	July-29-14	382143	5955584	300	481	0	0	0	0
11	July-28-14	374605	5947837	300	569	0	0	0	0
14	July-22-14	381069	5960129	450	1,286	5	15	0	0
16	July-29-14	385911	5960675	300	770	3	9	0	0
17	July-29-14	379296	5954220	300	766	1	1	0	0
18	July-08-14	400469	5966890	300	915	0	0	26	0
19	July-28-14	375517	5945526	300	423	0	0	0	0
20	July-10-14	393908	5969814	300	668	0	0	0	1
21	July-28-14	381297	5951205	300	520	0	0	0	0
22	July-19-14	389624	5964603	400	1,142	12	23	0	2
24	July-29-14	388449	5956007	300	593	0	0	0	0
25	July-28-14	378595	5972835	300	596	0	0	0	7
26	July-28-14	373570	5953683	300	685	0	0	0	0
27	July-10-14	386816	5976913	300	1,315	0	0	1	54
28	July-20-14	385331	5969184	300	485	0	0	0	0
29	July-21-14	391041	5978014	300	942	0	0	0	45
30	July-29-14	378973	5956592	400	682	5	14	0	0
32	July-29-14	385993	5958402	300	500	0	2	0	0

Appendix 7. Size of fish caught at backpack electrofishing sites in the Muskeg River watershed, 2014.

Species	Mean fork length ± SD (mm)	Range fork length (mm)	n
Bull trout	176 ± 100	41 – 440	89
Brook trout	102 ± 33	42 – 245	231
Rainbow trout	87 ± 51	45 – 244	159

Alberta Conservation Association acknowledges the following partner for its generous support of this project:

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