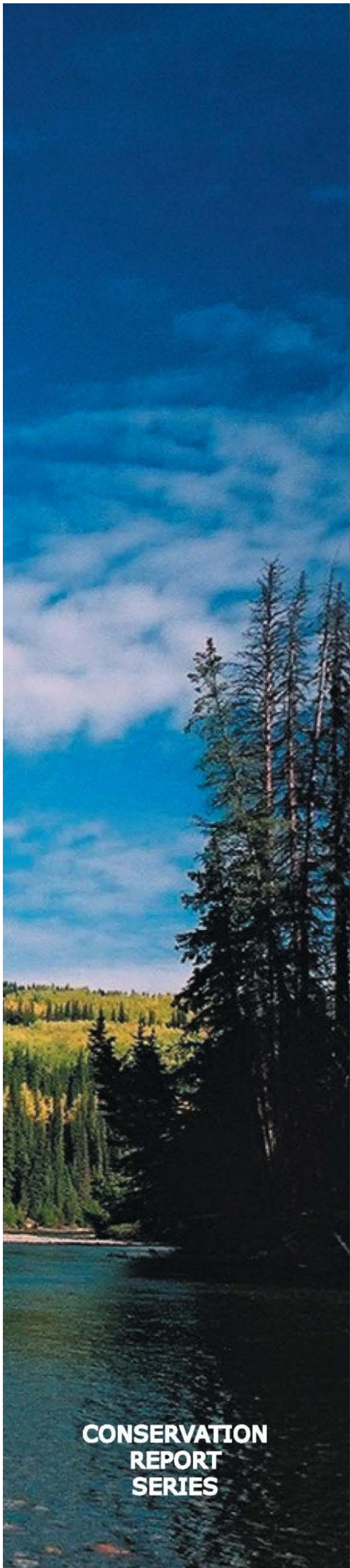

A Fish-based Index of Biological Integrity for Assessing Ecological Condition of the Beaver River Watershed

Alberta Conservation Association
Conserving Alberta's Wild Side

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EXECUTIVE SUMMARY

Urban development, agriculture and industrialization over the last century has resulted in land use modifications to Alberta's landscape that pose serious threats to the biological integrity of aquatic ecosystems in the province, including the Beaver River watershed. Developing management plans that are driven by a good understanding of the relationship between land use and aquatic ecosystem conditions are crucial to protecting these ecosystems.

In this study, we developed an index of biological integrity (IBI) for assessing the health of the Beaver River watershed (comprised of the Beaver, Sand, and Amisk rivers) using data collected on fish assemblages and a suite of physicochemical variables. We sampled 50 sites: 31 on the Beaver River, 17 on the Sand River, and 2 on the Amisk River. Fish sampling was completed using boat electrofishing. Physiochemical and GIS data were used to assess the level of disturbance of each site. White suckers represented 52% of the total catch, while the sportfish species, walleye and northern pike, represented less than 2% of the catch. Interviews with long-time anglers in the watershed indicate that sportfish have decreased in size and abundance over the past 30 years.

We developed 13 candidate metrics based on the fish community and screened them for responsiveness to disturbance using multiple regression and an information-theoretic approach. Five metrics (percentage of invertivorous cyprinids, percentage of benthic invertivores, percentage of omnivores, percentage of lithophils, and percentage of carnivores) were significantly related to human disturbance and were used to calculate the IBI. The resulting multi-metric IBI was highly sensitive to change in cumulative anthropogenic disturbances. Road density had the strongest relationships to the IBI and its metrics, particularly percentage of benthic invertivores, percentage of lithophils and percentage of carnivores. All three of these metrics decreased with higher road density, while percentage of omnivores metric increased with road density. Road density in the study area is mainly related to agricultural and petroleum activities, with agricultural activities accounting for the major land use within the watershed.

The upper Beaver and Amisk rivers had the lowest IBI values, reflecting poor aquatic health, characterized by high nutrient values, low flows, and a high number of fish species that are tolerant of habitat degradation. The Sand River had the highest IBI values and the lowest levels of human disturbance. The lower Beaver River showed intermediate IBI values despite having high levels of agricultural activities and bank disturbance. However, the lower Beaver River has high flows of good quality water (inflow from the Sand River) and more diversified habitat than the Sand River. The IBI we developed is a useful tool for assessment and biological monitoring of the Beaver River watershed. It could be used in the future to assess the effects of industrial development and remediation strategies on the health of the aquatic ecosystems throughout the watershed.

Key words: index of biological integrity, fish community, ecosystem health, biomonitoring, Beaver River watershed

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1.0 INTRODUCTION

Urban development, agriculture and industrialization over the last century have resulted in land use modifications to Alberta's landscape that pose serious threats to the biological integrity of the aquatic ecosystems in the province (Timoney and Lee 2001; Stevens et al. 2010). In order to ensure conservation of these ecosystems, it is crucial to establish management plans that are driven by a good understanding of the relationship between land use and aquatic ecosystem conditions (Allan 2004; Stevens et al. 2010).

For many years, the measurement of water quality (physiochemical) variables alone was considered sufficient to assess aquatic ecosystem health (Norris and Thoms 1999). However, water quality sampling is time consuming and costly and may not reflect changes in the aquatic ecosystem induced by human perturbation (Karr 1981). The index of biotic integrity (IBI), first presented by Karr (1981), has been widely used as an alternative to water quality to assess the biological integrity of aquatic ecosystems (Hughes et al. 1998; Karr 1999; Simon 1999; Ambasht and Ambasht 2002; Bramblett et al. 2005). The IBI is a multimetric index that reflects various components of biological assemblages, including taxonomic richness, habitat and trophic guild composition, as well as individual health and abundance (Hughes et al. 1998; Karr and Chu 1999; Stevens et al. 2010). The IBI is based on indicator organisms that cover different trophic groups, it integrates multiple effects and exposures, and it is responsive to a wide range of perturbations (Yoder and Smith 1999). The IBI uses functional metrics based on biological attributes, allowing for its use in different regions with a variety of taxa (Pont et al. 2006). Further, IBIs are cost and time effective, and provide a score that can be understood by the general public (Norris and Thoms 1999; Karr and Chu 1999). Fish communities are sensitive to ecosystem health and fish-based IBIs have been particularly successful as monitoring tools for the ecological condition and health of aquatic ecosystems (Karr et al. 1986; Lyons 1992; Hughes et al. 1998; Whittier et al. 2007).

Like many other systems in the province, the Beaver River watershed, located in northeastern Alberta, is experiencing rapid industrial and urban growth. A recent survey of long-time anglers indicates that there has been a decline in fishing opportunities in the Beaver River watershed, possibly due to declines in water quality and riparian condition, habitat fragmentation, and annual fluctuations in water levels (van Huystee and Furukawa 2009). Agriculture, road construction and industrial activities are prominent in the watershed, and the cumulative effects of these human activities on aquatic health, including fisheries resources, are largely unknown.

The purpose of this study is to develop a fish-based IBI for assessing the aquatic ecosystem health of the Beaver River watershed using data collected on fish assemblages and a suite of physicochemical variables. This study is part of the Aquatic Health Ecosystem Monitoring Program of the Beaver River Watershed Alliance. The goal is to provide an index that characterizes the aquatic health of the watershed, explore relationships between human disturbance and aquatic ecosystem health, and enable resource managers to not only assess current levels of health, but also forecast ecosystem health under various land use scenarios. Results of our study are intended to aid the Watershed Planning and Advisory Council in the development of sound policy recommendations for improved watershed management and the education of stakeholders. We also hope that our study will contribute to the application of IBI for assessing aquatic ecosystem health in Alberta. Multimetric indices based on fish communities have been used extensively in the United States but their use in Alberta is limited to a study on grassland streams (Stevens et al. 2006) and a study on the Battle River (Stevens and Council 2008; Stevens et al. 2010).

2.0 STUDY AREA

2.1 Description

The Beaver River originates in Beaver Lake and flows eastward, crossing the Alberta-Saskatchewan border northeast of Edmonton (Figure 1), eventually flowing into the Churchill River. The Alberta portion of Beaver River is approximately 240 km long, with a watershed size of over 15,500 km^2, covering approximately 2% of the province (Mitchell and Prepas 1990). The watershed has a low topographic gradient ranging from 500 to 750 m above sea level. The dominant vegetation communities are boreal forest and aspen parkland. The Beaver River has two major tributaries, the Amisk and Sand rivers, which drain Amisk, Wolf and Moose lakes. The mean annual discharge of Beaver River at the Alberta-Saskatchewan border is approximately 665,000,000 m^3 (Alberta Environment 2006b). Over the past three decades, the flow of Beaver River has changed considerably. Average flow at the city of Cold Lake has decreased 54% since 1976 (Figure 2). Similarly, peak flow has decreased 56% since 1976 and now tends to occur later in the year. The base flow of Beaver River has decreased 43% since 1979 (Komex International Ltd. 2003).

Petroleum extraction and agriculture continue to change much of the landscape in the southern portion of the watershed, encompassing the Amisk and the mainstem Beaver rivers (Figure 1). In the past two decades, 12% of the watershed has been disturbed by anthropogenic activity, mainly cattle farming (Alberta Environment 2006b). Approximately 38,000 people live in the watershed (Statistics Canada 2001), with the majority of the population residing in Bonnyville and Cold Lake (Figure 1). There are seven First Nations reserves and four Métis settlements in the watershed. In contrast, human impact is minimal in the northern portion of the watershed, encompassing the Sand River (Figure 1). This area is characterized by low road density and little development, particularly within the Cold Lake Canadian Air Forces Weapons Range (CLAWR) as military restrictions exclude the general public. Hence, sites along the Sand River were identified as potential reference sites (i.e., minimally disturbed sites) prior to field work.

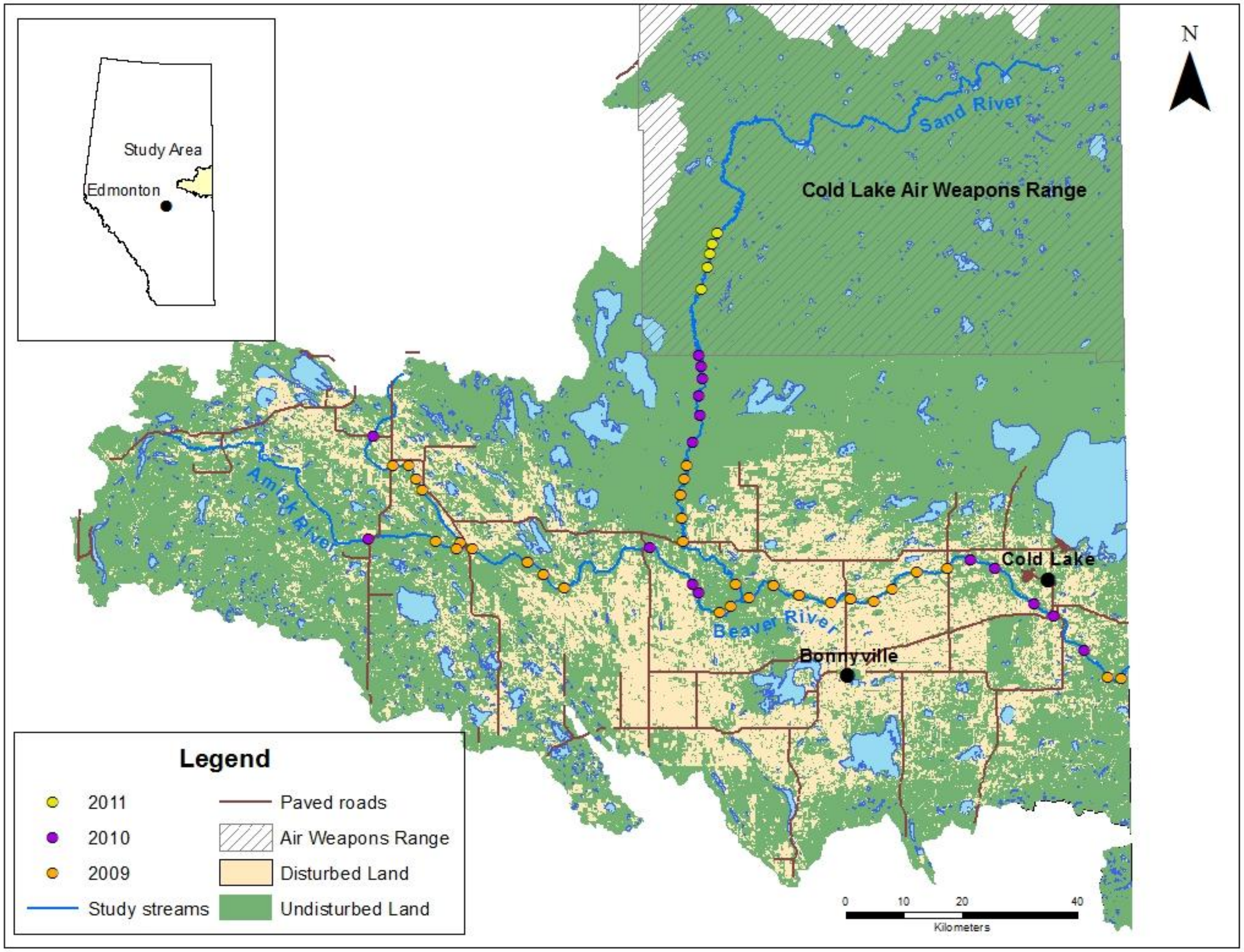

Figure 1. Map of the Beaver River watershed showing spatial and temporal distribution of IBI study sites (circles), 2009-2011.

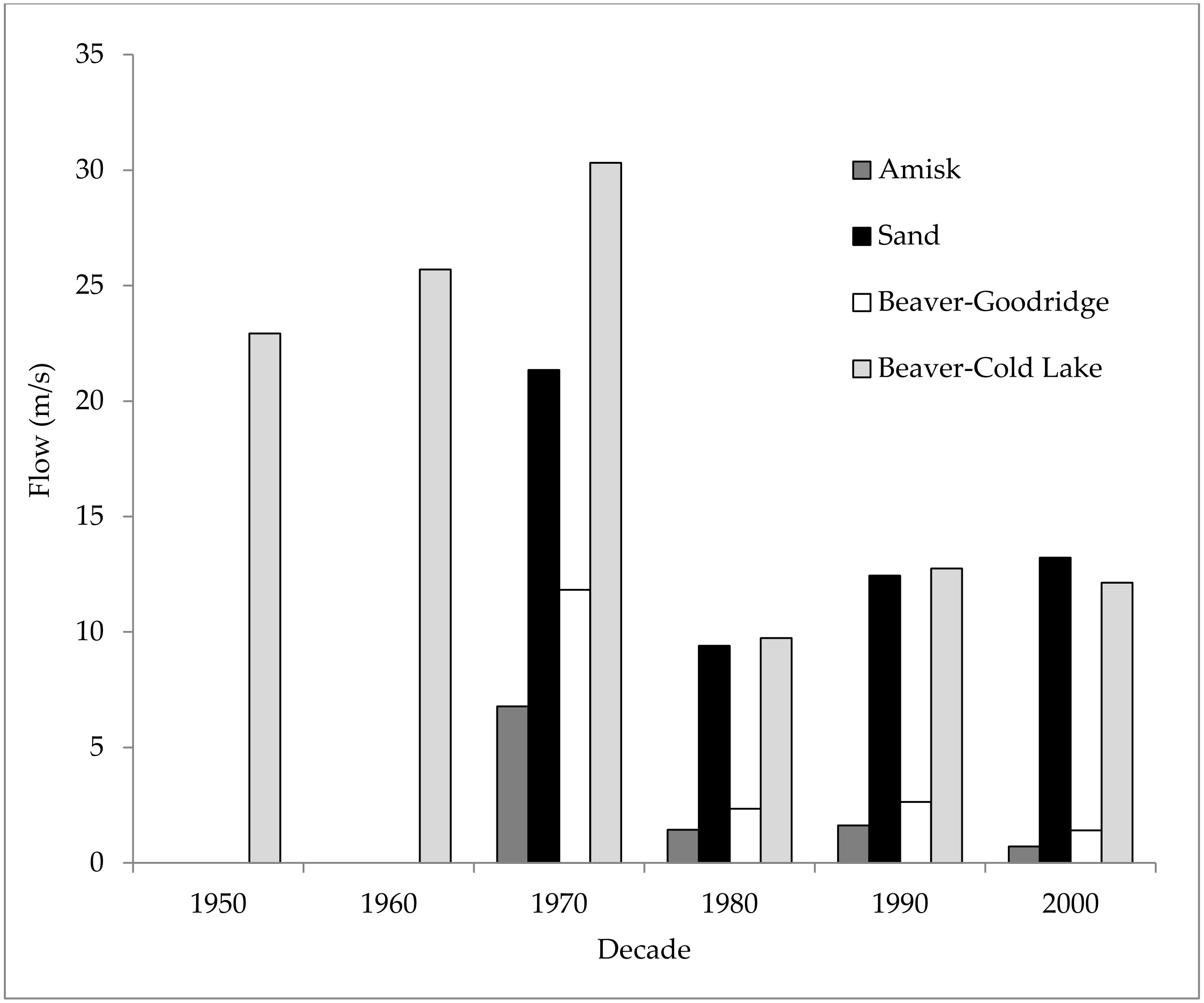

Figure 2. Average decadal flow at four locations in the Beaver River watershed. Data from the 1950s and 1960s were only available for the Beaver River at the Cold Lake gauging station (Environment Canada, Water Survey of Canada).

2.2 Fish assemblages

Six families and 17 species of fish are known to occur in the Beaver River watershed (Nelson and Paetz 1992), including four sportfish species; northern pike (*Esox lucius*), walleye (*Sander vitreus*), yellow perch (*Perca flavescens*), and burbot (*Lota lota*). All species recorded are native to Alberta.

3.0 MATERIALS AND METHODS

3.1 Historical survey

Prior to field sampling, we conducted angler surveys and a literature review of the Beaver River watershed to provide historical fisheries information (i.e., species composition, abundance, and distribution) to aid in the development of reference condition criteria within the study area. We also solicited supplementary ecological information (e.g., water quality, flow levels) on the Beaver River watershed from retired fisheries biologists in the area. A full report of the historical survey is available online (van Huystee and Furukawa 2009) hence, only summary information is included here.

We collected data through in-person and phone interviews, and online surveys. We conducted interviews with any person who had experience with the fisheries in the study area since 1940. We sought anglers using posters (Figure 3) distributed throughout the study area, and through public service announcements in four local newspapers (the Bonnyville Nouvelle, the Courier, the Cold Lake Sun, and the Lac La Biche Post), and on four local radio stations (CHLW St. Paul, CILB Lac La Biche, CJEG Bonnyville, and CJXK Cold Lake). An online survey solicited information from the general public, and was available for more than four months, from 24 November 2008 to 31 March 2009.

We conducted a review of literature and photographs to obtain data on the fisheries and ecological characteristics of the study rivers. We searched for published reports, articles from local newspapers, and archival photographs from government, academic, and public libraries, as well as through numerous online databases.

Figure 3. Poster used to advertise the project and solicit fishery information from local anglers during the historical survey.

3.2 Field sampling

We collected fish abundance, water quality and habitat data at each study site. Sampling occurred during June and July of 2009, 2010 and 2011. We chose study sites systematically throughout the Beaver River watershed (Amisk, Beaver and Sand rivers) along a gradient of agricultural and industrial disturbance, with a 2 km buffer between sites (Figure 1). Some sections of the rivers could either not be accessed or not effectively surveyed with our electrofishing gear due to low water levels, rapids and fast moving water (upper Amisk, upper and middle Beaver, upper and lower Sand). The length of study sites were approximately 85 times mean wetted-width (Hughes et al. 2002).

In total, we sampled 50 sites: 31 on the Beaver River (14 upstream and 17 downstream of the confluence with the Sand), 17 on the Sand River and two on the Amisk River (Figure 1). In 2009, we sampled 21 sites on the Beaver River, six on the Sand River (downstream of the CLAWR border), and one on the Amisk River. In 2010, we sampled an additional ten sites on the Beaver River, six on the Sand River (downstream of the CLAWR border), and one on the Amisk River. We attempted to sample as far upstream as possible on the Amisk River, hoping to include minimally disturbed sites, but low water levels and numerous beaver dams made it impossible to sample this section of the river. Due to logistic difficulties, we were not able to sample the Sand River within the CLAWR in 2010 as planned. However, we sampled five sites within the CLAWR in 2011 (Figure 1).

3.3 Fish sampling

We used a boom-mounted electrofishing boat (Smith Root 5.0 GPP) to collect data on fish community composition at each site. We electrofished all habitat types to ensure that sampling adequately represented the fish assemblage of a reach. Fish were temporarily held in a livewell onboard, identified to species, counted, measured (fork length, FL) and examined for DELTS (disease, deformities, eroded fins, lesions, parasites, and tumors). We sampled sites in 500 m sections to minimize the time fish were held. Electrofishing seconds were recorded to calculate catch-per-unit-effort (CPUE), as the number of fish/100s.

3.4 Habitat

We collected site-specific habitat data by sampling cross-sectional transects at the beginning of each site and at 500 m intervals downriver to the end of the site. Data collected along each transect included; wetted and bankfull widths, bank erosion and angle, riparian width, vegetation cover and composition, soil exposure, littoral substrate composition and human-related disturbance along bank (Appendix 1). We measured water depth and dominant substrate at seven points evenly distributed along the transect. Bank erosion and human disturbance were assessed by ranking the severity from low to high (i.e., low = 0, high = 10; for bank erosion 0 = no erosion, 10 = completely eroded; for human disturbance 0 = natural bank, 10 = no natural vegetation). Composition of the riparian vegetation was assessed by estimating the percent cover of different classes of trees and shrubs in a 20 x 10 m riparian plot oriented parallel to the bank, following procedures in Wilhelm et al. (2005). We used a similar approach to estimate substrate composition in littoral plots of equal size. Longitudinal measurements of thalweg depth and dominant substrate within a site, were collected every 150 m. Appendix 2 presents the field data sheets used for recording habitat variables.

3.5 Water quality

We measured water temperature, dissolved oxygen, conductivity and pH in the field with a hand-held meter (YSI Professional Plus) and collected "grab" water samples at the beginning of each site according to Alberta Environment protocols (Alberta Environment 2006a). Water samples were sent to Maxxam Analytical Testing Laboratory for analysis of ions, nutrients and physical variables (Appendix 1). We used the nutrient data (total Kjeldahl nitrogen (TKN), pH, total dissolved solids, and concentrations of dissolved chloride, iron, manganese, nitrogen, oxygen, total phosphorus, sodium, and sulphate) to calculate a Water Quality Index (WQI) score, adopted from the Canadian Council of Ministers of the Environment (CCME 2001; Alberta Environment 2006a). WQI scores are based on the number of water quality variables that fail to meet the CCME guidelines, and provide a simplified value that can be compared to other sites in the same water body, and also to other watersheds.

3.6 GIS analysis

We used ArcGIS 9.2 and a number of government databases to calculate human-related disturbance measures. These databases included cattle census data (Alberta Agriculture, Food and Rural Development), human census data (Office of Statistics and Information, Alberta Employment and Immigration), Alberta road networks (Alberta Sustainable Resource Development, Resource and Information Branch, Spatial Data Warehouse Ltd.), town sites (Alberta Sustainable Resource Development, Resource and Information Branch, Spatial Data Warehouse Ltd.), and land cover data (Agriculture and Agri-Food Canada). Appendix 3 presents the associated metadata and assumptions.

We calculated watershed boundaries and upstream basin size for each study site using ArcHydro tools in ArcGIS 9.2 and a digital elevation model (DEM; 1:50,000) (Government of Canada, Natural Resources Canada, Earth Sciences Sector, Centre for Topographic Information 2000). The upstream start point for electrofishing and transect sampling was used as the drainage point for watershed delineation. We quantified human-related disturbance at various scales as, percentage cropland, cattle density, road density, urban cover and human density (Appendix 1).

3.7 Revisit sites

To assess annual variation in fish assemblage and environmental data, we sampled six sites in both 2009 and 2010. Revisited sites were selected randomly from three broad levels of disturbance (based on preliminary assessment of 2009 data). We used Wilcoxon signed-rank tests for between-year comparisons of the relative abundance (CPUE) of the six dominant fish species, candidate fish metrics and water chemistry variables at each site, using the R 2.11.0 statistical package (R Development Core Team 2010). Although abundance of white suckers and water temperature differed between years, there were no significant differences in candidate metrics suggesting these differences did not affect the IBI calculations. We used data from both years in developing the IBI; for the six sites, we used average values from the two years in IBI calculations.

3.8 Candidate metrics

To scale metrics appropriately, an estimate of the natural or minimally disturbed (reference) condition is needed (Mebane et al. 2003). Reference condition estimates are often obtained from the sampling of minimally disturbed rivers or from examination of historic natural conditions; other approaches include experimental lab data, paleoecological data, quantitative models and professional judgment (Hughes 1995; Reynoldson et al. 1997; Mebane et al. 2003). For our study, the Sand River was initially considered as a potential reference site, but in spite of the minimal disturbance in the surrounding landscape, fish abundances were low. Hence, we developed fish metrics based on; historical information and characteristics of our catch (Table 1), published information on species habitat requirements and life history (Nelson and Paetz 1992; Scott and Crossman 1998) and a review of metrics used in previous IBI studies (e.g., Karr 1981; Hughes et al. 1998; Bramblett et al. 2005; Stevens et al. 2006; Stevens and Council 2008).

Species composition from our catch generally corroborated that from the historical survey (Table 1). Functional and structural guilds (habitat guild, trophic guild, individual health and abundance) were the starting points of the IBI. Based on guild information we selected 13 candidate metrics (Table 2). Positive scoring metrics were hypothesized to increase with increasing biological integrity, while negative scoring metric were expected to decrease with increasing biological integrity (Karr 1981; Hughes et al. 1998; Whittier et al. 2007). We determined the habitat for each species according to Scott and Crossman (1998), and Nelson and. Paetz (1992).

Table 1. Fish species recorded in the Beaver River watershed and their ecological characteristics.

Taxon	Trophic category[a]	Feeding habitat[b]	Reproductive classification[c]	General tolerance[d]
Cyprinidae				
Lake chub	IN	WC	LO	MOD
Spottail shiner	IN	WC	LO	MOD
Pearl dace	IC	WC	LO	MOD
Fathead minnow	OM	GE	TR	TOL
Longnose dace	IN	BE	LO	INT
Emerald shiner	IN	WC	PEL	MOD
River shiner[1]	IN	WC	B	MOD
Finescale dace[2]	OM	BE	PHYTO	MOD
Northern redbelly dace[2]	OM	BE	PHYTO	MOD
Catostomidae				
Longnose sucker	IN	BE	LO	MOD
White sucker	OM	BE	LO	TOL
Esocidae				
Northern pike	CA	WC	PHYTO	MOD
Gasterosteidae				
Brook stickleback	IN	GE	TR	MOD
Percidae				
Iowa darter[1]	IN	BE	NA	INT
Yellow perch	IC	WC	PHYTOLITH	MOD
Walleye	IC	GE	LO	MOD
Log perch[2]	IN	BE	LO	NA
Gadidae				
Burbot	IC	BE	LO	NA
Salmonidae				
Lake whitefish	IC	BE	TR	NA

Sources: Nelson and Paetz (1992); Bramblett et al. (2005); Whittier et al. (2007); van Huystee and Furukawa (2009).

Abbreviations: [a]IN = invertivore; OM = omnivore; CA = carnivore; IC = invertivore-carnivore; [b]WC = water column; GE = generalist; BE = benthic;

[c]LO = lithophil; PEL = pelagophil; PHYTO = phytophil; TR = tolerant reproductive strategies; PHYTOLITH = phytolithophil; B = nest guarder;

[d]TOL = tolerant; MOD = moderate; INT = intolerant; NA = not available.

[1]Species present in historical survey that were not caught during IBI sampling;

[2]Species caught during IBI sampling that were not present in the historical survey.

Table 2. Candidate metrics for the IBI used in assessing the aquatic ecosystem health of the Beaver River watershed, Alberta, 2009-2011.

Candidate Metric	Description	Mean (range) of metric value
Positive Scoring	**Values increase with increasing biological integrity**	
Percentage of benthic invertivores (LNSC, LNDC, LGPR)	Expected to decrease when human disturbance results in river habitats that are excessively silty or dissolved oxygen is reduced.	14.9 (0-71)
Percentage of lithophils (LNSC, WHSC, LKCH, LNDC, SPSH, BURB, WALL, LGPR)	Expected to decrease when human disturbance results in higher sedimentation that reduces the availability of gravel substrate for spawning.	91.4 (0-100)
Percentage of intolerant individuals (LNDC)	Expected to decrease with increasing human disturbance.	0.1 (0-1)
Percentage of carnivores (WALL, NRPK)	Expected to decrease with increasing human disturbance. Viable and healthy populations of carnivores indicate a relatively healthy, diverse community.	2.2 (0-12)
Percentage of invertivorous cyprinids (LKCH, LNDC, SPSH)	Expected to decrease with increasing human disturbance. As the invertebrate food source decreases in abundance and diversity due to habitat degradation, there is a shift from insectivorous to omnivorous species.	22.2 (0-65)
Percentage of long-lived individuals (NRPK > 600 mm FL, WALL > 450 mm FL, WHSC > 400 mm FL)	Expected to decrease with increasing human disturbance. Older fish indicate suitable habitat, and river connectivity.	2.5 (0-31)
Relative abundance (CPUE, catch/100s)	Expected to decrease when human disturbance results in homogenous river habitats. Total relative abundance is comparable to the overall ability of the river to support an aquatic community.	5.0 (0-14)
Richness (number of species)	Expected to decrease when human disturbance results in homogenous river habitats.	4.2 (0-8)

Table 2. Continued

Candidate Metric	Description	Mean (range) of metric value
Negative Scoring	**Values decrease with increasing biological integrity**	
Percentage of tolerant reproductive guild (BRST, FTMN)	Expected to increase as habitat, water quality, and watershed conditions are degraded.	3.8 (0-50)
Percentage of tolerant individuals (WHSC, FTMN)	Expected to increase as habitat, water quality, and watershed conditions are degraded.	56.0 (0-100)
Percentage of FTMN	Expected to increase as habitat, water quality, and watershed conditions are degraded.	3.1 (0-46)
Percentage of omnivores (WHSC, FTMN, NRDC)	Expected to increase as habitat, water quality, and watershed conditions are degraded.	57.5 (0-100)
Percentage of individuals with DELTs (deformities, disease, fin erosion, lesions or tumors)	Expected to increase as water quality is degraded. These conditions occur frequently below point sources and in areas where toxic chemicals are concentrated and can reflect stress caused by pollution.	3.7 (0-22)

Sources: Karr et al. (1986); Karr and Chu (1999); Bramblett et al. (2005); Stevens et al. (2006); Stevens and Council (2008).
Abbreviations: BRST = brook stickleback; BURB = burbot; FTMN = fathead minnow; LKCH = lake chub; LNDC = longnose dace; NRDC = northern redbelly dace; WHSC = white sucker; LGPR = log perch; WALL = walleye; LNSC = longnose sucker; SPSH = spottail shiner; NRPK = northern pike).

3.8.1 Habitat guilds

Metrics representing the habitat guilds include feeding, reproductive, and specific habitat requirements (Table 1) and are used to evaluate fish assemblage components that are likely to decrease in response to habitat degradation (Hughes et al. 1998). These species are particularly sensitive to variations in water depth, water quality, velocity, substrate type and diversity (Karr et al. 1986).

The percentage of benthic invertivores metric represents species that are more abundant in clear, cool, unpolluted waters (Hughes et al. 1998). Abundances of these species are expected to decrease with human disturbance, such as when stream habitats become excessively silty or dissolved oxygen is reduced (Karr et al. 1986; McCormick et al. 2001; Bramblett et al. 2005). Other studies used darter species for this metric, but noted that other benthic species could be used (Karr 1981; Karr et al. 1986; Hughes et al. 1998; Bramblett et al. 2005). Although one darter species (Iowa darter) was reported in the historical survey, no individuals were captured during our field samplings. Hence, we used longnose sucker, longnose dace and logperch in our study.

The percentage of lithophils metric represents fish species that need rocky substrates for spawning and are negatively affected by sedimentation that reduces availability of cobble and gravel (McCormick et al. 2001; Bramblett et al. 2005). In our study this metric is composed of longnose and white suckers, lake chub, longnose dace, spottail shiner, burbot, walleye, and logperch.

In our study, the percentage of intolerant individuals metric is composed of only one species, longnose dace, which is known to be negatively affected by pollution (Bramblett et al. 2005; Jeffries et al. 2008).

Negative scoring metrics are used to evaluate fish assemblage components that are likely to increase in response to habitat degradation. The percentage of tolerant reproductive metric is characterized by species that can spawn on various substrates and are minimally impacted by reduced dissolved oxygen (Bramblett et al. 2005). In our study, this metric includes brook stickleback and fathead minnow.

The percentage of tolerant individuals and percentage of fathead minnows are negative scoring metrics as they comprise species that are tolerant to a wide range of water quality and habitat conditions (McCormick et al. 2001). There are two tolerant species present in our study; white sucker and fathead minnow.

3.8.2 Trophic guilds

Metrics representing the trophic guilds include percentage of invertivorous cyprinids, percentage of top carnivores, percentage of omnivores and percentage of benthic invertivores. Changes in water quality, habitat condition and land use in the watershed often result in changes in fish food resources (Karr et al. 1986). Species with specialized or restrictive dietary preferences tend to decrease in abundance when their prey base decreases, compared to generalist feeders that may have greater plasticity and may be more able to adapt (Karr et al. 1986; Hughes et al. 1998).

The percentage of carnivore metric evaluates the ability of a system to produce enough fish and large invertebrates to support relatively large predators (Hughes et al. 1998). In our study, this metric includes walleye and northern pike. Our historical survey suggested that both species were common occurrences in the watershed and attained relatively large sizes (van Huystee and Furukawa 2009).

The percentage of invertivorous cyprinids metric is affected by degradation of water quality and instream habitat that results in a decrease of aquatic invertebrate abundance (Karr et al. 1986). A scarcity of insectivorous fish species may reflect a disturbance that has reduced the production of benthic insects (Emery et al. 2003). Invertivorous cyprinids in our study are lake chub, longnose dace and spottail shiner.

The percentage of omnivores metric refers to species that eat both plant and animal material allowing them to adapt easily to perturbation and alteration of river food webs (Karr 1981; Hughes et al. 1998). The percentage of omnivores is a negative scoring metric that has been used over the past 20 years (Karr et al. 1987; Hughes et al. 1998; Pont et al. 2006; Whittier et al. 2007). In our study, this metric is represented by white sucker, fathead minnow, and northern redbelly dace.

3.8.3 Individual health and abundance

Metrics in this group are related to attributes of the community (age structure, abundance, richness, and fish condition) that are linked to overall productivity and health of the aquatic ecosystem (Karr et al. 1986; Hughes et al. 1998).

The presence of long-lived individuals metric indicates a river's ability to support adult individuals, as minimally disturbed waters are frequently dominated by large, old individuals (Hughes et al. 1998). In the historical survey, anglers reported catching large walleye (380-610 mm FL) and northern pike (300-760 mm FL), suggesting that such long-lived individuals may have been present in the river naturally. In our study, walleye (>450 mm FL), northern pike (>600 mm FL), and white sucker (> 400 mm FL) were used to construct the percentage of long-lived individuals metric.

The relative abundance (CPUE, catch/100s) metric, and the richness (number of species) metric reflect the quality of the ecosystem. A severely degraded physical or chemical habitat would support a lower abundance and richness than a healthy habitat (Karr et al. 1986; Hughes et al. 1998).

The percentage of individuals with DELTS metric is a negative scoring metric that indicates severely degraded water or contaminants (Hughes et al. 1998; McCormick et al. 2001; Mebane et al. 2003; Bramblett et al. 2005). In our study, the main source of DELTS was the presence of fish lice and the lesions resulting from their attachment to fish.

3.9 IBI construction

3.9.1 Redundancy analysis

A criticism of the IBI multi-metric approach is that it includes redundant metrics (Minns et al. 1994; Hughes et al. 1998; Roset et al. 2007). To avoid redundancy, we screened the 13 candidate metrics using a Spearman's rank correlation test. We used a non-parametric test because the data were not normally distributed and were not normalized by basic transformations (i.e., log, square root, inverse). Highly correlated metrics (ρ > 0.80) were removed if the metric's inclusion was not supported by the IBI literature, if it was correlated with multiple metrics, or if its biological meaning was unclear. Redundant metrics were not included in the IBI development (Appendix 4). The IBI construction process is summarized in Figure 4.

Percentage of tolerant individuals was strongly correlated (ρ = 0.96) with percentage of omnivores, since all tolerant species were also omnivores. Similarly, percentage of tolerant individuals was negatively correlated with percentage of invertivorous cyprinids (ρ = -0.57). For this reason, and because percentage of omnivores and percentage of invertivorous species have been demonstrated to be sensitive metrics in previous studies (Karr et al. 1986; Hughes et al. 1998; Pont et al. 2006), we retained the omnivore and invertivorous cyprinids metrics and removed the tolerant species metric. The percentage of tolerant reproductive species metric was removed because of its strong positive correlation with the percentage of fathead minnows (ρ = 0.84) and its negative correlation with the percentage of lithophils (ρ = -0.62).

The percentage of individuals with DELTS metric was removed because of the confounding presence of fish lice in the watershed. Fish lice, *Argulus* spp., were present in the Sand (including the CLAWR) and lower Beaver rivers (Figure 5). Mechanisms of fish lice development (e.g., host attachment, off-host survival etc.) are known to be temperature-dependent (Hakalahti et al. 2005; Walker 2008). During our study, we found lice only after June 29 and at water temperatures over 16°C, suggesting the distribution we observed might be an artifact of the seasonality of lice development. In addition, because lice infestation may cause secondary infections (Walker 2008), it was difficult to dissociate their effect from other, independent, DELTS.

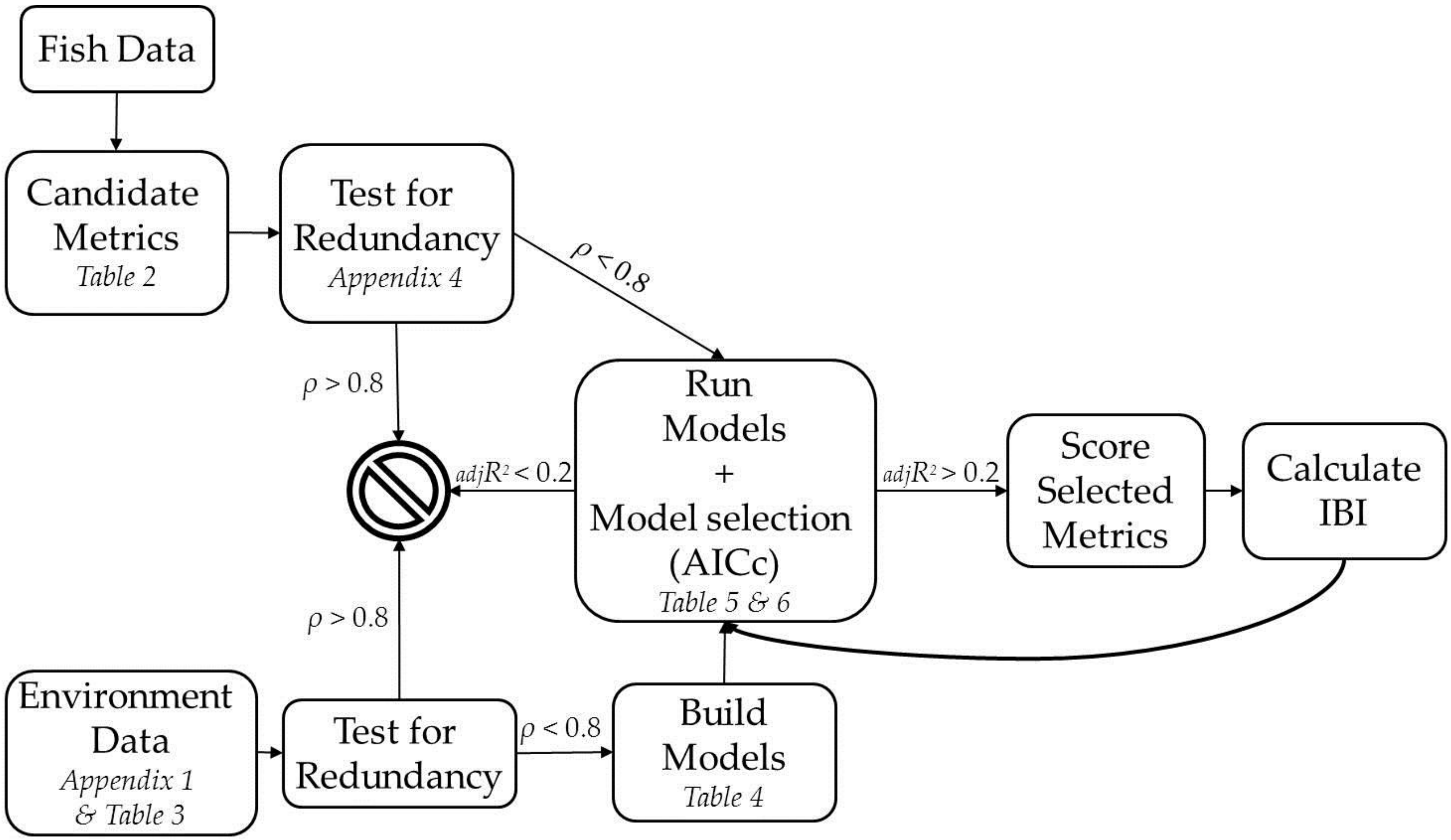

Figure 4. Flow chart representing the general steps of the IBI construction. The table and appendix number in italics provide the results of the various tests.

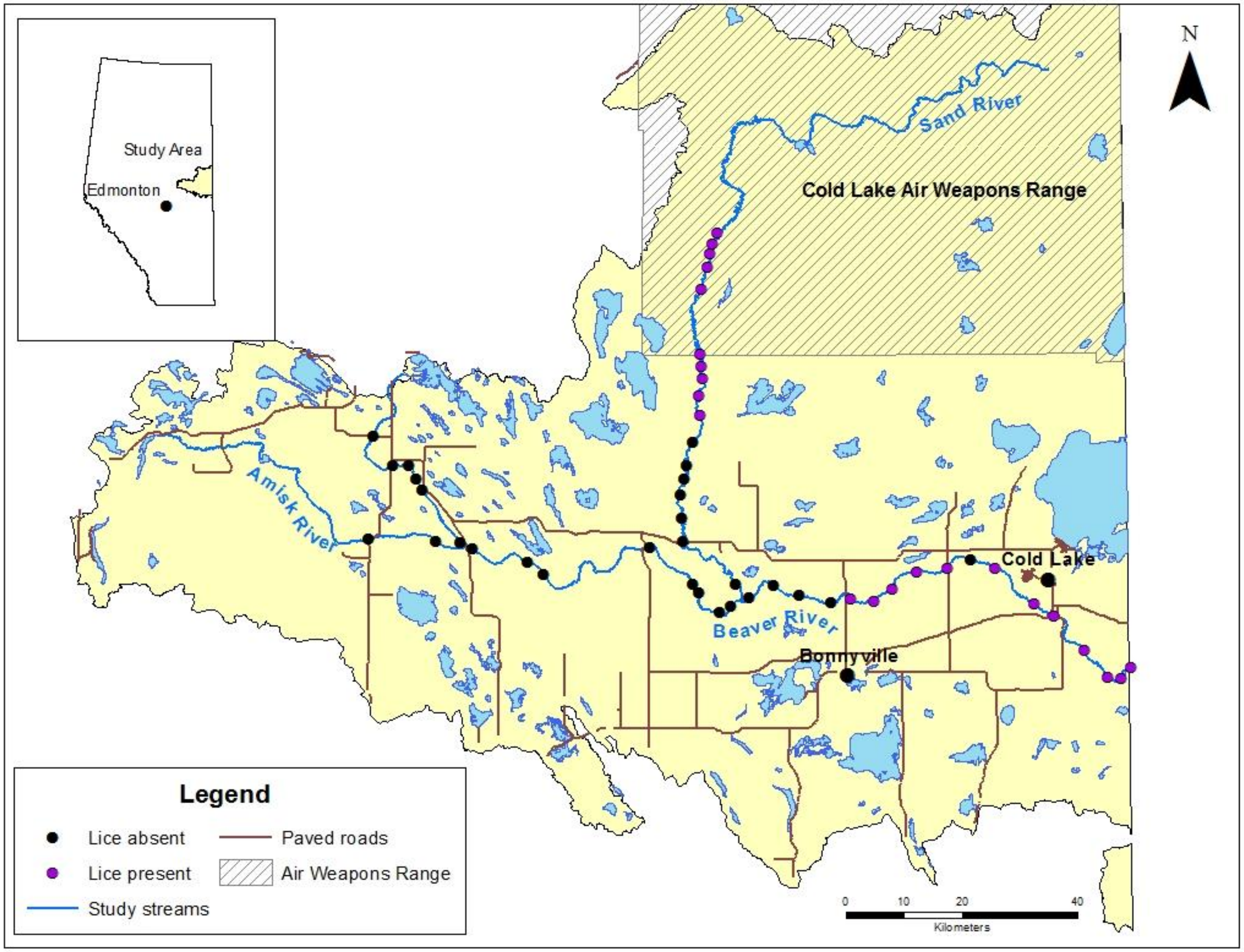

Figure 5. Distribution of lice in the Beaver River watershed IBI study sites, Alberta, 2009-2011.

3.9.2 Model construction

Similar to the approach used by Stevens et al. (2010), we used the environmental variables (habitat, water chemistry and land-use) to screen biological responsiveness to human disturbance using multiple regression and an information-theoretic approach that ranked *a priori* models (Burnham and Anderson 2002). The first step was to remove environmental variables that presented extremely low values or had insufficient variation between sites; the variables we retained are presented in Table 3. We then conducted a redundancy test (Spearman's rank correlation) to select the environmental variables to build *a priori* models (Table 4) representing different human disturbance categories. To ensure that responsiveness to human disturbance was not confounded by the relationship between fish assemblage composition and watershed size, all models included basin size as a proxy of stream size and position (Karr and Chu 1999; Bramblett et al. 2005; Stevens et al. 2010).

The *a priori* models were selected for each metric using Akaike's Information Criterion corrected for small sample sizes (*AICc*) (Burnham and Anderson 2002). Primary inferences were drawn from the model presenting the best fit (lowest *AICc*) and others within two units of *AICc* (Burnham and Anderson 2002; Anderson 2008). We also calculated the Akaike weights, which represents the probability that the candidate model is the true model, given the entire subset of potential models. Metrics were selected if regression analyses showed the anticipated response to human disturbance and if the direction of the relationship was consistent between variables. Additionally, we considered the adjusted coefficient of determination (${}_{adj}R^2$) in our metric screening. If the best model showed an ${}_{adj}R^2$ of less than 0.2 (i.e. the model explained less than 20% of the metric's variation) the metric was considered "insensitive" to human disturbance and rejected (Stevens et al. 2010). Post-estimation included the Breush-Pagan test for heteroscedasticity and the Durbin-Watson test of multi-colinearity. The variance inflation factors were also generated to assess multi-colinearity.

Of the environmental variables collected, 15 were retained to build five *a priori* models (Riparian and instream conditions; Water chemistry; Human disturbance; Water quality index; Global) that tested the relationship between the metrics and human disturbance (Tables 3 and 4). We rejected some environmental variables because they were redundant and others because they did not show sufficient variation between sites. The vegetation cover variable was strongly correlated to both exposed soil (ρ = -0.95) and bank erosion (ρ = 0.77) and was used as a surrogate for both variables in the riparian and instream conditions model. In the water chemistry model, total suspended solids was removed because it was strongly correlated with turbidity (ρ = 0.81). In the human disturbance model, urban and road densities were the only variables retained, because both agricultural variables (cropland and cattle density) were correlated to road density (cropland ρ = 0.89; cattle ρ = 0.84). Basin size was not highly correlated with any of the metrics or environmental variables.

Table 3. Environmental variables used in deriving the Beaver River watershed IBI.

Variables	Mean	SD	Min	Max	CV (%)
Riparian					
% mean vegetative cover	91.6	5.6	78.4	100	6.1
% mean exposed soil	7.6	5.4	0	21.2	71.5
Bank erosion (semi-quantitative 0-10)	1.6	1.1	0	4.9	72
Bank disturbance (semi-quantitative 0-10)	1.1	1.5	0	5.3	130.8
Mean riparian width (m)	9.8	12.6	2.2	71.5	129.2
Water Quality					
Dissolved oxygen (mg/L)	8.8	1.8	6.2	20.2	20.6
Nitrate-nitrite (mg/L)	0.01	0.02	0.003	0.1	165.5
pH	8.1	0.3	7.6	8.7	3.1
Conductivity (us/cm)	337.7	192.9	140.0	840	57.1
Total phosphorus (mg/L)	0.1	0.1	0.03	0.5	93.3
Ammonia (mg/L)	0.1	0.1	0.05	0.7	136.3
Total Kjeldahl nitrogen (mg/L)	1.5	2.9	0.6	23	190.4
Total suspended solids (mg/L)	30.5	29.1	1	110	95.2
Turbidity (NTU)	13.2	9.4	1.1	37	71.3
WQI	91.2	10.9	60.2	100	11.9
Landscape					
% cropland in basin	16.7	12	0	34.5	72.1
% cropland 1 X 5km upstream	20.6	18.4	0	61.3	89.6
% cropland 2 X 10km upstream	26.1	21.3	0	65.2	81.7
Road density in basin (m/ha)	3.6	2.4	0.2	6.6	66
% urban in basin	0.1	0.2	0	0.7	178.2
Human density in basin (pop/ha)	0.008	0.004	0.004	0.02	41.6
Cattle density in basin (cattle/ha)	0.09	0.06	0	0.2	69.7
Basin size (ha)	669,960	463,762	78,010	1,501,057	69.2
Mean wetted width (m)	35.8	11.2	9.7	54.7	31.3
Mean bankfull width (m)	47.7	20.1	15	161.5	42.1
Maximum depth (m)	1.5	0.7	0.3	4.3	44.7

Table 4. Description of the five *a priori* models used to select the metrics for the Beaver River watershed IBI.

Model	Variables
Riparian and instream conditions	basin size, percentage of vegetation cover, human disturbance on bank, wetted width, riparian width
Water quality	basin size, dissolved oxygen, total dissolved phosphorus, total ammonia-nitrogen, total Kjeldahl nitrogen (TKN), pH, conductivity, turbidity
Human impact	basin size, urban density in basin, road density in basin
Water quality index (WQI)	basin size, WQI
Global	basin size, percentage of vegetation cover, human disturbance on bank, wetted width, riparian width, dissolved oxygen, total dissolved phosphorus, total ammonia-nitrogen, total Kjeldahl nitrogen (TKN), pH, conductivity, turbidity, urban density in basin, road density in basin, WQI

3.9.3 Responsiveness analysis

We used a two-step process to evaluate the relationship between human disturbance and the remaining ten IBI metrics (percentage of benthic invertivores, percentage of lithophils, percentage of fathead minnows, percentage of intolerant individuals, percentage of carnivores, percentage of invertivorous cyprinids, percentage of omnivores, percentage of long-lived individuals, relative abundance and richness). First, we ran each metric through the five *a priori* models (Table 5). We selected the top model for each metric; the one with the lowest value of *AICc* (models within 2 values were also selected). Following model averaging, percentage of long-lived individuals, percentage of intolerant individuals and percentage of fathead minnow metrics were rejected because they showed weak relationships to human disturbance ($_{adj}R^2 < 0.2$).

The second step was to compare 95% confidence intervals of the regression coefficient for each variable, for each metric (Table 6). Richness was removed because it was positively related to urban density. This is not consistent with established theory which predicts an inverse relationship: high urban density should decrease biological integrity and thus, decrease the number of species present (Karr 1981). Relative abundance was also removed because it showed contradictory results to human disturbance (negatively linked to urban density and positively linked to road density). It was also removed to avoid underestimating ecosystem health at undisturbed sites with low fish abundances (Rankin and Yoder 1999b). The percentage of benthic invertivores was positively linked to nitrogen concentration, the percentage of lithophils was negatively linked to WQI, the percentage of omnivores was negatively linked to total Kjeldahl nitrogen (TKN) and the percentage of carnivores was positively linked to urban density. Although these relationships are contrary to what was expected (Karr et al. 1986; McCormick et al. 2001), the metrics were kept because they were meaningfully linked to other variables in our study and previous IBIs (Pont et al. 2006; Stevens et al. 2010).

The remaining metrics were scored on a 0 to 8 continuous scale (Hughes et al. 1998; Bramblett et al. 2005). For a positive metric, the upper expectation (ceiling) was the value corresponding to the 95th percentile of the distribution of the metric for all study sites. Sites with a metric value above the ceiling received a score of 8. The lower expectation (floor) was the value corresponding to the 5th percentile of the distribution of the metric for all study sites. Sites with a metric value below the floor received a score of zero. Regression was used to linearly scale all other values along the range so that the metric score ranged from 0 to 8. For a negative scoring metric, value attribution was reversed. For both type of metrics, higher scores mean higher ecological integrity. The total IBI score per study site was the sum of standardized scores of the screened metrics, yielding a possible range of 0 to 40.

The IBI was validated for responsiveness to human disturbance using the same methods (i.e. multiple regression and information-theoretic approach) as for selecting the metrics.

Table 5. Model rankings (according to Akaike's Information Criterion corrected for small sample sizes; *AICc*), as well as the adjusted coefficient of determination ($_{adj}R^2$), predicting scores of IBI metrics for the Beaver River watershed. Models presenting the lowest *AICc* value (or within a value of 2) for each metric are shaded.

Metric	Model	n	df	LL	*AICc*	$\Delta AICc$	Akaike weight	R^2	$_{adj}R^2$
% benthic invertivores	Riparian	50	5	-6.5	421.7	29.9	3.1E-07	0.44	0.37
	Water quality	50	8	-1.91	400.6	8.8	1.2E-02	0.69	0.63
	Human impact	50	3	0	391. 8	0	0.99	0.66	0.63
	WQI	50	2	-6.57	422.1	30.3	2.6E-07	0.34	0.31
	Global	50	15	-5.97	419.3	27.5	1.1E-06	0.74	0.63
% lithophils	Riparian	50	5	-1.65	430.6	7.6	0.02	0.43	0.37
	Water quality	50	8	0	423	0	0.97	0.59	0.51
	Human impact	50	3	-3.28	438.1	15.1	5.1E-04	0.27	0.22
	WQI	50	2	-4.04	441.6	18.6	8.9E-05	0.17	0.14
	Global	50	15	-2.14	432.9	9.9	0.01	0.71	0.59
% fathead minnows	Riparian	50	5	-1.51	363.4	6.9	0.03	0.21	0.12
	Water quality	50	8	-3.93	374.5	18.1	0.00	0.17	0.01
	Human impact	50	3	0	356.4	0	0.93	0.23	0.18
	WQI	50	2	-1.31	362.4	6	0.05	0.09	0.05
	Global	50	15	-5.64	382.4	26	0.00	0.44	0.19
% intolerant	Riparian	50	5	-1.74	-6.7	8	0.01	0.06	-0.05
	Water quality	50	8	-3.41	1	15.7	2.9E-04	0.09	-0.09
	Human impact	50	3	-0.47	-12.5	2.2	0.25	0.07	0.01
	WQI	50	2	0	-14.7	0	0.74	0.07	0.03
	Global	50	15	-8.74	25.5	40.2	1.4E-09	0.14	-0.24
% carnivores	Riparian	50	5	-2.39	256.7	11	4.0E-03	0.2	0.11
	Water quality	50	8	-2.7	258.1	12.4	1.9E-03	0.31	0.18
	Human impact	50	3	0	245.7	0	0.96	0.29	0.24
	WQI	50	2	-1.52	252.7	7	0.03	0.14	0.1
	Global	50	15	-4.44	266.2	20.4	3.5E-05	0.54	0.33
% invertivorous cyprinids	Riparian	50	5	0	416.4	0	0.66	0.59	0.55
	Water quality	50	8	-23.9	420.5	4.1	1.3E-24	0.63	0.56
	Human impact	50	3	-23.3	417.8	1.4	4.8E-24	0.53	0.5
	WQI	50	2	-24.8	424.6	8.2	1.6E-25	0.44	0.42
	Global	50	15	-28.6	442.3	25.9	2.3E-29	0.67	0.53

Table 5. Continued

Metric	Model	n	df	LL	*AICc*	*ΔAICc*	Akaike weight	R^2	$_{adj}R^2$
% omnivores	Riparian	50	5	-6.97	449.8	32.1	1.1E-07	0.54	0.49
	Water quality	50	8	0	417.7	0	0.99	0.8	0.76
	Human impact	50	3	-5.87	444.7	27	1.4E-06	0.54	0.51
	WQI	50	2	-11.3	469.8	52.1	5.0E-12	0.2	0.16
	Global	50	15	-2.68	430.1	12.4	2.1E-03	0.85	0.78
% long-lived	Riparian	50	5	-1.05	315.2	4.8	0.06	0.06	-0.04
	Water quality	50	8	-1.95	319.3	9	0.01	0.15	-0.01
	Human impact	50	3	-0.37	312.1	1.7	0.28	0.02	-0.04
	WQI	50	2	0	310.4	0	0.66	4.4E-	-0.03
	Global	50	15	-2.95	324	13.6	7.3E-04	0.46	0.23
CPUE (catch/100s)	Riparian	50	5	-2.45	250.9	11.3	3.6E-03	0.42	0.35
	Water quality	50	8	-3.81	257.2	17.6	1.5E-04	0.45	0.34
	Human impact	50	3	0	239.7	0	0.99	0.49	0.45
	WQI	50	2	-2.58	251.5	11.9	2.6E-03	0.32	0.29
	Global	50	15	-5.44	264.7	25	3.6E-06	0.63	0.47
Richness (n)	Riparian	50	5	-0.36	186.8	1.7	0.2	0.35	0.27
	Water quality	50	8	-1.42	191.7	6.6	0.02	0.4	0.28
	Human impact	50	3	0	185.2	0	0.47	0.3	0.25
	WQI	50	2	-0.18	186	0.8	0.31	0.25	0.22
	Global	50	15	-5.68	211.3	26.2	9.8E-07	0.49	0.26
IBI	Riparian	50	5	-5.61	296.8	26	2E-06	0.72	0.69
	Water quality	50	8	-0.91	274.9	4.2	0.11	0.85	0.82
	Human impact	50	3	0	270.8	0	0.89	0.82	0.81
	WQI	50	2	-11.2	322.3	51.5	5.7E-12	0.46	0.44
	Global	50	15	-2.83	283.5	12.8	1.5E-03	0.9	0.85

Table 6. Summary of model-averaged regression coefficients for predicting candidate metrics and the five-metric IBI for the Beaver River watershed. Significant values (confidence interval not overlapping zero) are shaded.

Variables	Coeff	Lower CI	Upper CI	Coeff	Lower CI	Upper CI
	% benthic invertivores			**% lithophils**		
y-intercept	17.4	-40.2	75	89.6	2.08	177
Basin size	-7E-07	-4E-06	2E-06	3E-05	1E-05	4E-05
Conductivity	-3E-03	-0.02	0.01	8E-04	-4E-03	0.01
Dissolved oxygen	0.03	-0.17	0.24	7.11	2.61	11.6
Human disturbance	-0.1	-0.59	0.39	-4.3	-7.77	-0.84
Nitrogen	164	27.9	300	-0.57	-11.3	10.1
pH	0.81	-2.94	4.55	1.63	-5.27	8.54
Riparian width	-2E-03	-0.02	0.01	3E-03	-0.04	0.04
Road	-5.45	-7.25	-3.65	-3.77	-6.45	-1.09
TKN	-0.01	-0.08	0.06	-3.48	-4.85	-2.1
Total phosphorus	-0.01	-2.94	2.92	3.56	-13.2	20.3
Turbidity	8E-04	-0.01	0.01	-0.61	-1.36	0.14
Urban density	-0.66	-3.76	2.45	-0.47	-3.33	2.4
Vegetation cover	0.09	-0.25	0.42	0.01	-0.06	0.07
Wetted width	3E-03	-0.02	0.02	-1E-03	-0.05	0.04
WQI	0.03	-0.09	0.14	-0.65	-1.2	-0.1
	% carnivores			**% invertivorous cyprinids**		
y-intercept	-13.5	-41.00	14	124	-73.3	321
Basin size	4E-08	-2E-07	3E-07	2E-05	4E-06	4E-05
Conductivity	5E-03	-6E-03	0.02	-2E-04	-3E-03	3E-03
Dissolved oxygen	0.02	-0.09	0.14	-0.16	-0.91	0.6
Human disturbance	0.04	-0.15	0.23	-0.09	-0.65	0.46
Nitrogen	-34.4	-71.4	2.65	-18.9	-94.1	56.2
pH	0.68	-1.68	3.03	-17.2	-40.1	5.76
Riparian width	-5E-03	-0.02	0.01	-2E-03	-0.02	0.02
Road	-0.79	-1.39	-0.18	0.06	-0.25	0.36
TKN	-0.02	-0.09	0.05	-0.02	-0.13	0.09
Total phosphorus	-0.28	-1.79	1.23	-1.53	-10.4	7.39
Turbidity	0.02	-0.05	0.09	0.01	-0.07	0.09
Urban density	9.98	5.07	14.9	-11	-39.4	17.5
Vegetation cover	0.09	-0.11	0.3	0.01	-0.08	0.11
Wetted width	0.04	-0.07	0.15	0.69	0.07	1.31
WQI	1E-03	-5E-03	8E-03	-4E-04	-0.02	0.02

Table 6. Continued

Variables	Coeff	Lower CI	Upper CI	Coeff	Lower CI	Upper CI
	% omnivores			**CPUE (catch/100s)**		
y-intercept	112	8.72	215.00	2.66	-4.37	9.68
Basin size	-7E-06	-2E-05	1E-05	5E-06	2E-06	8E-06
Conductivity	0.02	-0.03	0.07	-2E-03	-0.01	4E-03
Dissolved oxygen	0.6	-1.66	2.87	2E-03	-0.03	0.03
Human disturbance	0.16	-0.6	0.93	-0.12	-0.55	0.31
Nitrogen	-12.7	-66.1	40.7	-2.89	-14.8	9.05
pH	1.41	-4.64	7.46	-0.02	-0.16	0.13
Riparian width	-0.01	-0.07	0.05	-0.06	-0.13	0.01
Road	4.26	0.54	7.98	0.74	0.24	1.25
TKN	-4.51	-6.01	-3.02	-3E-03	-0.02	0.02
Total phosphorus	-1.48	-11.3	8.37	-0.09	-0.98	0.8
Turbidity	-0.11	-0.51	0.28	0.01	-0.02	0.03
Urban density	0.6	-2.9	4.09	-5.59	-10.90	-0.31
Vegetation cover	-0.23	-0.94	0.49	-3E-03	-0.02	0.01
Wetted width	-1.08	-1.77	-0.39	-0.03	-0.13	0.07
WQI	-0.23	-0.78	0.32	-1E-03	-0.01	0.01
	Richness			**IBI**		
y-intercept	4.09	0.05	8.14	-2.26	-25.8	21.2
Basin size	-2E-08	-2.E-07	2E-07	6E-06	2E-06	1E-05
Conductivity	-5E-04	-2E-03	1E-03	-0.01	-0.02	0.01
Dissolved oxygen	3E-03	-0.03	0.04	-0.02	-0.11	0.08
Human disturbance	-2E-03	-0.03	0.03	-0.01	-0.07	0.06
Nitrogen	-11.8	-32.2	8.6	-0.11	-1.98	1.77
pH	-0.01	-0.15	0.14	0.01	-0.31	0.33
Riparian width	-0.02	-0.06	0.02	-8E-04	-0.01	0.01
Road	-0.02	-0.09	0.06	-1.62	-2.45	-0.79
TKN	-0.07	-0.25	0.1	-5E-04	-0.03	0.03
Total phosphorus	-0.47	-2.41	1.47	-5.71	-19.00	7.58
Turbidity	0.01	-0.03	0.05	0.14	-0.04	0.31
Urban density	2.84	0.73	4.94	0.11	-0.54	0.76
Vegetation cover	-1E-03	-0.01	0.01	0.22	-0.04	0.48
Wetted width	0.01	-0.03	0.06	0.12	-0.07	0.31
WQI	-5E-04	-0.01	0.01	5E-03	-0.02	0.03

4.0 RESULTS

4.1 Distribution and abundance

At the 50 sites we sampled for this study, we caught 17 fish species from 6 families (Table 7). Effort ranged from 659 to 2,855 seconds-per-site and the CPUE ranged from 0 to 14 fish/100s (Figure 6). Species richness within sites ranged from 0 to 8 species. We captured a total of 5,719 fish; 52% were white sucker, 31% lake chub, 9% longnose sucker, 3% fathead minnow and 1% walleye; the remaining species represented less than 1% of the total catch. The highest fish catches occurred in the middle section of the Beaver River (between the Sand River confluence and Cold Lake), while the lowest catches occurred on the Sand River, particularly within the CLAWR. Fathead minnows were most abundant in the Amisk and Beaver rivers, upstream of the San River confluence. Lake chubs, longnose suckers and walleye were more abundant in the Sand River and the lower section of the Beaver River, than in the upstream section of all three rivers. Summary information on size of fish caught is provided in Table 7.

Differences between our study and studies presented in the historical survey preclude quantitative comparisons. Some of the studies presented in the historical survey (Table 8) used different sampling methods and focused on a limited number of species, therefore we made qualitative comparisons between our data and the historical data. In general, the pattern of species composition we observed in 2009 to 2011 was similar to those reported during the 1970s and 1980s (Table 8). Sucker species (white sucker and longnose sucker) dominated the catch and longnose suckers were reported in the Sand River and lower sections of the Beaver River (Tables 7 and 8; for full report see van Huystee and Furukawa 2009). However, historically the relative abundances of walleye and northern pike were as high as 7% and 23%, respectively (Table 8), much higher than recorded during the 2009-2011 surveys. Two species, river shiner and Iowa darter were reported in the historical survey, but not found during the 2009-2011 sampling. We captured three species, northern redbelly dace, finescale dace, and log perch in 2009-2011 sampling that were not reported in the historical survey.

Table 7. Species composition and length of fish captured using electrofishing during development of the IBI for the Beaver River watershed, Alberta, 2009-2011.

Taxon	Mean FL (mm)	SD	Min (mm)	Max (mm)	n
Cyprinidae					
Lake chub (*Couesius auratus*)	73.1	18.5	23	160	1,763
Emerald shiner (*Notropis atherinoides*)	84.3	9.0	75	93	3
Spottail shiner (*Notropis hudsonius*)	73.0	2.8	71	75	15
Northern redbelly dace (*Phoxinus eos*)	49.1	6.8	32	61	30
Finescale dace (*Phoxinus neogaeus*)	50.5	4.9	47	54	2
Fathead minnow (*Pimephales promelas*)	51.8	14.0	21	131	188
Longnose dace (*Rhinichthys cataractae*)	87.5	38.9	60	115	15
Pearl dace (*Semotilus margarita)*	51.0	-	51	51	1
Catostomidae					
Longnose sucker (*Catostomus catostomus*)	262.6	118.2	51	434	530
White sucker (*Catostomus commersonii*)	233.4	112.5	20	496	2,966
Esocidae					
Northern pike (*Esox lucius*)	361.1	163.4	111	670	38
Gadidae					
Burbot (*Lota lota*)	299.0	112.7	270	352	3
Gasterosteidae					
Brook stickleback (*Culaea inconstans*)	43.8	6.3	33	55	17
Percidae					
Yellow perch (*Perca flavescens*)	89.1	48.1	27	201	30
Walleye (*Sander vitreus*)	356.7	134.4	42	606	76
Log perch (*Percina caprodes*)	89.1	21.9	30	120	39
Salmonidae					
Lake whitefish (*Coregonus clupeaformis*)	50.7	19.3	39	73	3

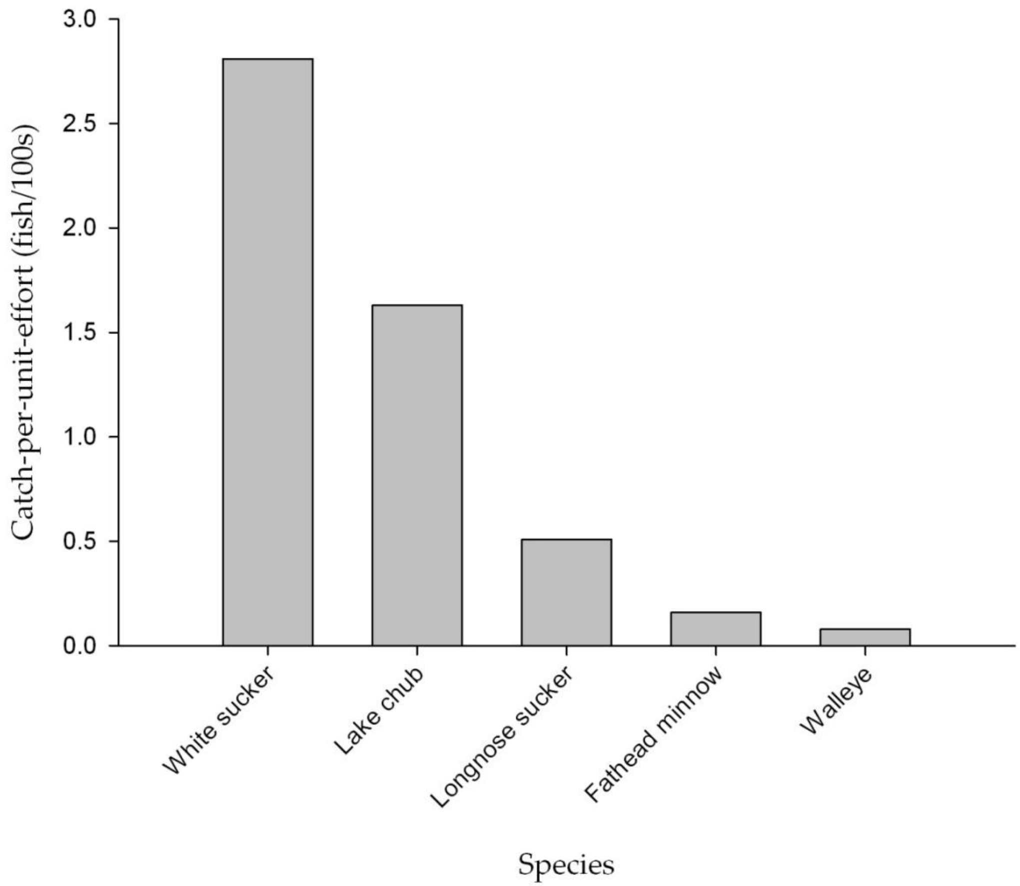

Figure 6. Catch-per-unit-effort of the five most abundant fish species from 50 electrofished sites in the Beaver River watershed, Alberta, 2009-2011.

Table 8. Species composition of fish reported in three historical surveys in the Beaver River watershed, Alberta.

Study	Zones[1]	Capture method	Relative abundance (% of total catch)							Total catch
			NRPK	WALL	YLPR	LKWH	WHSC	LNSC	Other	
Ferrari et al. (1981)	1 and 3	Gill net, trap, seine, electrofishing, drift net	<1	<1	<1	<1	9	11	75[a]	7,785
McLeod et al. (1985)	2	Hoop trap, electrofishing	6	<1			10	83		3,746
McCart and Mayhood (1979)	3	Gill net, seine	23	7	10	3	50		7	30

[1] Zone 1 = Beaver and Amisk rivers upstream of Sand River confluence, Zone 2 = Sand River, Zone 3 = Lower Beaver River downstream of Sand River confluence.

Abbreviations: NRPK = northern pike; WALL = walleye; YLPR = yellow perch; LKWH = lake whitefish; WHSC = white sucker; LNSC = longnose sucker.

[a]Includes 66% identified as Sucker spp.

4.2 Index of Biotic Integrity

Following the responsiveness analysis, five metrics were selected to compose the final IBI. The percentage of benthic invertivores was best predicted by the human disturbance model (${}_{adj}R^2$ = 0.63) and was negatively linked to road density. The percentage of lithophils was positively linked to the water chemistry model (${}_{adj}R^2$ = 0.51) and dissolved oxygen concentration, but negatively linked to human disturbance on bank, road density and TKN. Percentage of carnivores was best predicted by the human disturbance model (${}_{adj}R^2$ = 0.24) and negatively linked to road density. Percentage of invertivorous cyprinids was best predicted by the riparian and instream conditions model (${}_{adj}R^2$ = 0.55) and was linked to wetted width. Finally, the percentage of omnivores was best predicted by the water quality model (${}_{adj}R^2$ = 0.76), and was influenced by both wetted width and road density. Overall, the IBI is best described by the human disturbance model (${}_{adj}R^2$ = 0.70), with strong linkages to road density (Tables 5 and 6).

Based on the IBI results, three broad zones of human disturbance, where biotic and abiotic characteristics differ, were identifiable within the Beaver River watershed (Table 9; Figures 7 and 8; Appendix 5). The first zone comprises the Amisk and Beaver rivers, upstream of the Sand River confluence. This zone presents the lowest IBI values, with an average of 9.4 (range: 4-13) and is characterized by low water levels, high nutrient values and high densities of tolerant and omnivore fish species (white suckers and fathead minnows) (Table 9; Figures 7 and 8). The Sand River comprises the second zone and has the highest IBI values, with an average of 25.2 (range: 21-29). While remaining relatively high, IBI values in the second zone generally decreased upstream into the CLAWR. This area is characterized by low levels of human disturbance, low nutrient levels and the lowest density of omnivores within the watershed. The lower section of the Beaver River, downstream of the Sand River confluence, is the third zone and has an average IBI value of 22.7 (range: 17-29). This zone has the highest percentage of exposed soil, total suspended solids and urban density within the watershed, but it also has the highest percentage of invertivorous cyprinids (lake chub, longnose dace and spottail shiner) (Table 9; Figures 7 and 8).

Table 9. Mean (±SD) values of selected metrics, environmental variables, and IBI values for three zones of the Beaver River watershed, Alberta, 2009-2011.

Data	Beaver and Amisk rivers upstream of Sand River confluence	Sand River	Beaver River downstream of Sand River confluence
Metrics			
Benthic invertivores (n)	0.1 (0.2)	11.9 (±10.8)	9.8 (±5)
Invertivorous cyprinids (%)	2.8 (±4.1)	21.1 (±18.3)	40.9 (±14.3)
Lithophils (%)	79.4 (±31.3)	97.1 (±5.6)	98.5 (±1.9)
Omnivores (%)	87.7 (±23.3)	29.7 (±19.7)	45.7 (±12.4)
Carnivores (%)	0.8 (±1.5)	2.7 (±3.4)	3.1 (±3.1)
Variables			
Exposed soil (%)	3.4 (±4.4)	7.8 (±3.9)	10.5 (±5)
Human disturbance on bank (0-10)	2.4 (±1.3)	0.1 (±0.1)	0.9 (±1.5)
Dissolved oxygen (mg/L)	8.8 (±1.3)	8.6 (±0.7)	8.2 (±0.6)
Total phosphorus (mg/L)	0.21 (±0.1)	0.07 (±0.02)	0.07 (±0.03)
Ammonia (mg/L)	0.09 (±0.1)	0.05 (±0.01)	0.11 (±0.1)
Total Kjeldahl nitrogen (mg/L)	3.0 (±5.2)	1.0 (±0.1)	0.9 (±0.2)
Total suspended solids (mg/L)	5.9 (±6.2)	39.3 (±24.0)	44.5 (±25.9)
Urban in basin (%)	0.04 (±0.1)	0 (±0)	0.3 (±0.3)
Road density in basin (m/ha)	6.0 (±0.3)	0.3 (±0.1)	4.5 (±0.6)
WQI	80.0 (±13.3)	95.3 (±6.9)	95.3 (±3.8)
IBI	9.4 (±2.5)	25.2 (±2.9)	22.7 (±4.5)

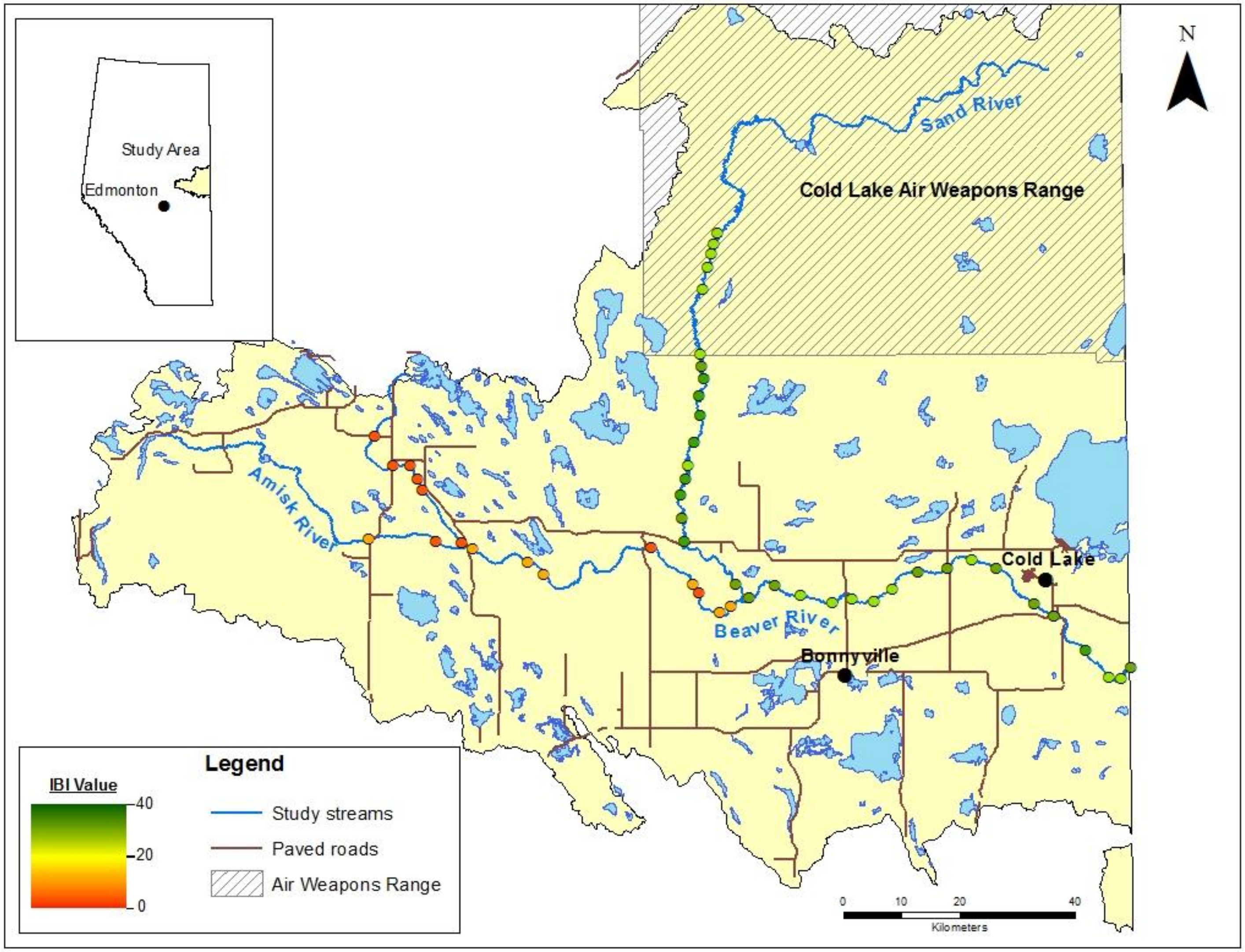

Figure 7. Distribution of IBI scores for study sites in the Beaver River watershed, 2009-2011.

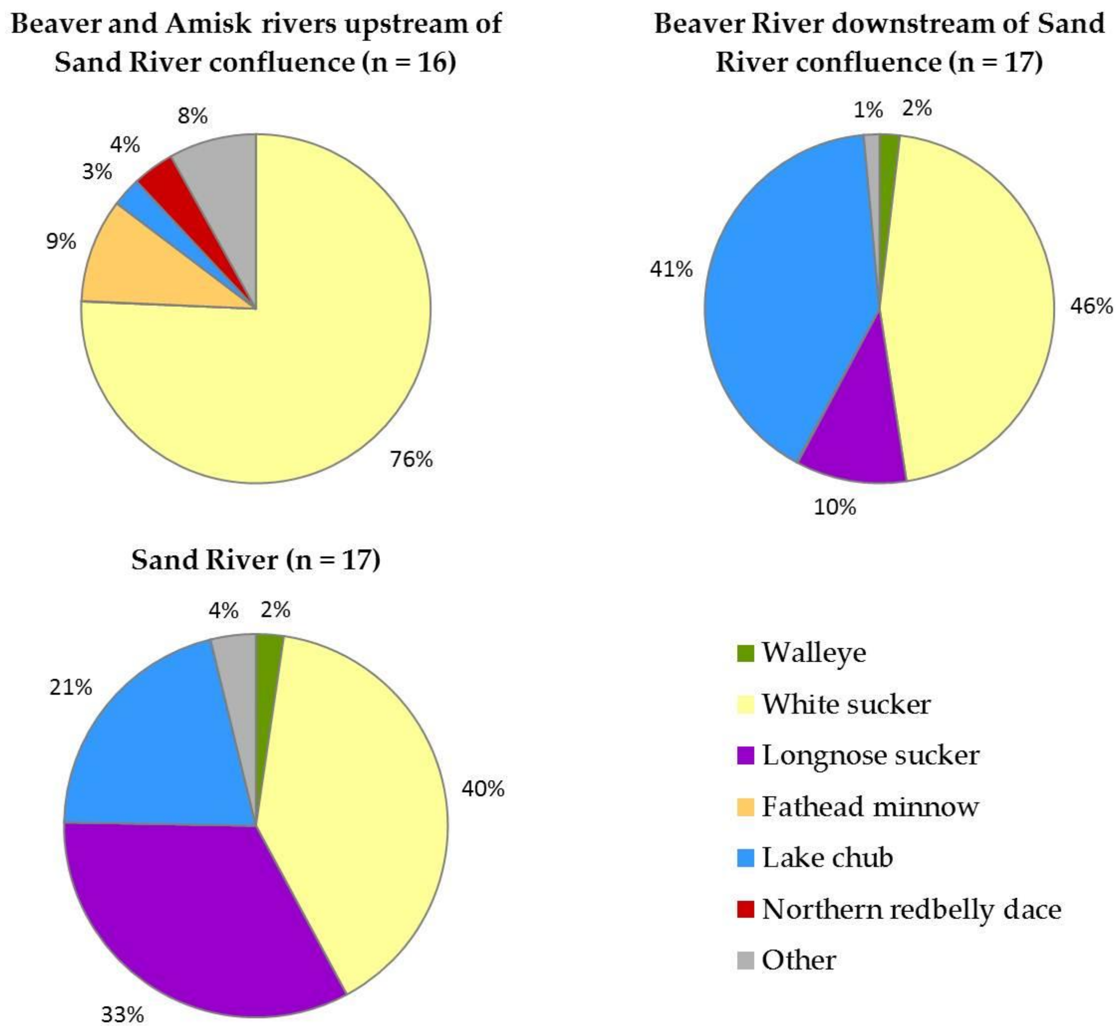

Figure 8. Relative abundance of the six most abundant fish species in three zones of the Beaver River watershed, Alberta, 2009-2011. n is the number of sites sampled in each zone.

5.0 DISCUSSION

We developed a fish-based index of biological integrity for assessing and monitoring ecological condition in the Beaver River watershed. Our study identified five metrics (percentage of invertivorous cyprinids, percentage of benthic invertivores, percentage of omnivores, percentage of lithophils and percentage of carnivores) that were key for characterizing conditions in the watershed and were consistently related to human disturbance. The Beaver River watershed fish community is relatively depauperate, containing only 17 species, and is dominated by white sucker. These factors result in an IBI based on only five metrics. Studies that used more metrics in their IBI were in regions with higher species richness (Hughes et al. 1998; Bramblett et al. 2005; Pinto et al. 2006) and often covered larger spatial scales (Emery et al. 2003; Whittier et al. 2007) than our study. The five metrics selected for the Beaver River IBI are mainly related to trophic guild, but also comprise elements of habitat and reproductive guilds, resulting in an IBI that adequately describes the composition and structure of the fish community. Three of the five metrics (percentage of omnivores, percentage of benthic invertivores, and percentage of lithophils) identified in our study were similar to those identified by Stevens et al. (2010) in a multi-metric study conducted on the Battle River, Alberta.

In our study some metrics were rejected because they were non-responsive to human disturbance. Such non-responsiveness may be an artifact of low abundances of fish species comprised in that metric (e.g. the percentage of intolerant species and the low abundance of longnose dace). Rankin and Yoder (1999a) suggest removing dominant species from the IBI data analysis to avoid overwhelming the metrics and diminishing the contribution of other species, especially when the high abundance appears unrelated to environmental quality. Although white suckers substantially dominated the catch in our study, we retained this species in our analysis as we believe the prevalence of this tolerant omnivore is more likely reflective of the Beaver River watershed ecosystem health. Percentage of omnivores is a negative scoring metric that has been used in various studies over the past 20 years as a measure of ecosystem health (Karr et al. 1987; Hughes et al. 1998; Pont et al. 2006; Whittier et al. 2007).

The IBI created for the Beaver River watershed and three of the metrics used to build it (percentage of invertivorous cyprinids, percentage of benthic invertivores and percentage of carnivores) were mainly explained by the human disturbance model. The IBI and four of the metrics selected (percentage of benthic invertivores, percentage of lithophils, percentage of omnivores, and percentage carnivores) exhibited a strong relationship to road density. Road density and urban development are known to have long-term negative impacts on stream communities, particularly on species with minimal tolerance to human disturbance (Wheeler et al. 2005). Percentage of benthic invertivores, percentage of lithophils, and percentage of carnivores decreased with higher road density. The importance of road density may be attributed to its role as a surrogate for many human disturbances (Stevens et al. 2010). Road density may affect fish assemblages through a variety of mechanisms, such as pollution, hydrologic alteration, stream channelization, fragmentation from improperly maintained culverts, and elimination of nursery habitat (Allan 2004; Wheeler et al. 2005; Stevens et al. 2010).

In the Beaver River watershed, road density was highly correlated to percentage of cropland and cattle density. As less than 1% of land cover in the watershed is urban development, roads in the study area likely service the agricultural or petroleum sectors. Agricultural activity (cropland and cattle grazing) accounted for the majority of disturbance observed in the watershed. Clearing of riparian areas, a consequence of farming and cattle grazing, intensifies nutrient run-off and soil erosion with negative impacts on both water and habitat quality (Carpenter et al. 1998; Findlay et al. 2001). Sedimentation, erosion and destruction of natural riparian habitat can affect invertivores and carnivores by decreasing the abundance of the invertebrate food base for these species (Hughes et al. 1998). Percentage of omnivores, a negative scoring metric, increased with road density as expected. Omnivores likely increase with disturbances because they are opportunistic foragers that can adapt to perturbation and alteration of river food webs (Karr 1981). In contrast, abundances of more specialized groups, like invertivores and lithophils, decrease when resources and habitat become less available (Karr et al. 1986).

The water quality model was the best for explaining the two remaining metrics, percentage of lithophils and percentage of omnivores. The decrease in percentage of lithophils could be a result of eutrophication and higher sediment deposition linked to agriculture. Sedimentation can lead to a decrease in the abundance of lithophils by reducing the availability of gravel and cobble substrates necessary for spawning habitat

(Rabeni and Smale 1995; Bramblett et al. 2005). In contrast, omnivores easily adapt to habitat changes and would benefit from a change in water quality (Karr 1981).

The differences in biotic and abiotic characteristics between the three zones of the watershed (Table 9) can be explained by differences in water flow, and land use and substrate composition. High nutrient concentrations and abundance of tolerant fish species (fathead minnow, white sucker) in the Amisk and upper sections of the Beaver River are likely related to the low flows and high nutrient concentrations we observed in this zone. Over the past 20 years, nutrients concentrations, particularly the dissolved fraction, have increased in the upper Beaver River as a consequence of human disturbance (Alberta Environment 2006b). No walleye and only a few northern pike (< 600 mm) were caught above the Sand River confluence, suggesting that this zone does not currently support long-lived sport species. During our historical survey, long-time area anglers reported pike and walleye in great abundance upstream of the Sand River confluence until the 1980s; since then lower flows, beaver dams and oil and agricultural activity in the watershed are thought to have degraded the fishery (van Huystee and Furukawa 2009). Gauging stations located in this zone (Amisk River and Beaver River at Goodridge) had average flows over 5 and 10 m^3/sec, respectively in the 1970s, but average flow has decreased to under 2 m^3/sec in the past 30 years. Similar reductions in flow have occurred throughout the watershed, but in the Amisk and Beaver rivers, where flows were already lower, the fish community appears to have been more heavily impacted. According to a study completed by Komex International Ltd. (2003) for the Lakeland Industry Community Association, the lower flows in the Beaver River watershed after 1976 are likely consequences of the Pacific Decadal Oscillation. Thus, a natural phenomenon, the Pacific Decadal Oscillation, likely exacerbates the effects of human disturbance.

As expected, overall IBI values were highest in the Sand River zone, where the level of human disturbance is the lowest in the watershed. However, overall fish abundance was the lowest in the watershed. Fish abundance and percentage of carnivores decrease progressively upstream from the confluence with the Beaver River, particularly within the CLAWR, which resulted in progressively lower IBI values. The paucity of fish and associated low IBI values likely result from the relatively homogeneous habitat present on the Sand River. The historical survey suggests that angling was likely never important on the Sand River because of either low fish abundance or the lack of road access (van Huystee and Furukawa 2009). Studies done on the Sand River in the 1980s, extending 22 km upstream of the Wolf River confluence (therefore likely into the CLAWR), show that suckers were the dominant species in the river (Ferrari et al. 1981; McLeod et al. 1985), which is similar to our observations and suggests that the fish assemblage in this zone may not have changed much over the past 30 years.

The effect of the relatively high flows entering the Beaver River from the Sand River is noticeable in the middle section of the Beaver River. Although bank disturbance and agriculture are prevalent, IBI values in this zone are higher than the watershed average. This zone also contains the highest densities of fish, particularly of sensitive invertivores and lithophillic species. The relatively high IBI values are likely the result of the combination of appropriate substrate in the Beaver River and high flows from the Sand River. There could be a positive longitudinal effect masking the negative effects of human disturbance; that is as the river gets bigger more fish species are present in spite of the high level disturbance present in the surrounding landscape (Vannote et al. 1980; Mebane et al. 2003). Nonetheless, IBI values are lower downstream than upstream of the city of Cold Lake. This decrease in IBI values is likely the result of nutrient accumulation from the watershed, and high levels of human disturbance and exposed soil in that area.

Although we did not include the abundance of fish lice in our analysis, the presence of this parasite in the Beaver River watershed is undoubtedly a concern for aquatic ecosystem health. The life cycle of fish lice is temperature-dependent. The distribution of lice we observed over the course of our study, where water temperature ranged from 16 to 25°C, is most likely an artifact of this seasonality. We followed Mebane et al. (2003) in arguing that parasite occurrence is independent of water quality and did not include DELTS in our analyses. However, the prevalence of fish lice might suggest that fish in the Beaver River watershed are exposed to stresses that make them more susceptible to infection (Lafferty and Kuris 1999). More research on the occurrence of fish lice in Alberta would help us understand the effects of this parasite on fish communities.

The development and application of an IBI for a northern river is challenging, as the biota of these systems are thought to be dominated by habitat, trophic, and reproductive generalists adapted to unstable flow regimes with harsh, fluctuating environmental conditions making them more tolerant than in other regions (Bramblett et al. 2005; Stevens et al. 2010). For the Beaver River watershed study, this challenge is exacerbated by the lack of adequate reference sampling sites and quantitative historical data predating the 1980s, which limits our interpretations. Thus, similar to Bramblett et al. (2005), the measures of ecosystem health we report are associated with a particular spatial and temporal scale, as we do not have adequate data to stipulate on conditions that existed prior to the onset of human disturbance. The IBI we developed assesses biotic integrity relative to conditions as they exist currently (Bramblett et al. 2005). For example, a site that obtained the maximal score of 40 should be interpreted as having excellent ecosystem health compared to other sites in the watershed in 2009-2011 only, but not necessarily compared to the same site at the beginning of the 20th century or a similar site in another watershed. Long-time anglers in the watershed reported that sport fish species abundance has declined since 1980, suggesting that a site we consider to be currently good, may have been regarded as poor quality habitat 30 years ago. The IBI is a relative tool, but it can be adapted to account for more spatial and temporal variation as data become available.

Our results corroborate those from the State of the Beaver River Watershed Report (Alberta Environment 2006b) in identifying agriculture as playing an important role in the decline of aquatic ecosystem health in the Beaver River watershed. Agricultural practices affect streams and rivers by increasing nonpoint source inputs of pollutants, impacting riparian and stream habitat, and altering flows (Allan 2004). Road density in the northeastern portion of Alberta is also correlated to petroleum well site density (Cumming and Cartledge, 2004). It is likely that some of the variation in the fish community linked to road density in our study, may also be related to the negative effects of petroleum extraction.

The fish-based IBI we developed is a useful tool for biological monitoring of the Beaver River watershed. It could be used in the future to assess the effects of industrial development and remediation strategies throughout the watershed. Similarities in terms of fish species, metrics selected, and sources of human disturbance, between our results and those of a recent study performed on the Battle River suggest that our findings may be valuable in developing an IBI for other Alberta watersheds.

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7.0 APPENDICES

Appendix 1. Environmental variables measured for the Beaver River IBI.

GIS-related parameters
Easting
Northing
Basin size (ha)
Perennial cropland upstream (%; 1x5km scale)
Perennial cropland upstream (%; 2x10km scale)
Perennial cropland in basin (%)
Annual cropland upstream (%; 1x5km scale)
Annual cropland upstream (%; 2x10km scale)
Annual cropland in basin (%)
Livestock upstream (cattle/ha; 5km x basin-scale)
Livestock upstream (cattle/ha; 10km x basin-scale)
Livestock in basin (cattle/ha)
Road density in basin (m/ha)
Urban cover in basin (%)
Human density in basin (pop/ha)
Human density 5km radii (pop/ha)
Human density 10km radii (pop/ha)

Water quality parameters
Alkalinity (total $CaCO_3$) (mg/L)
Ammonia-n (mg/L)
Bicarbonate (mg/L)
Calcium (ca) (mg/L)
Carbonate (mg/L)
CCME water quality index
Chloride (mg/L)
Chlorophyll-a (ug/L)
Dissolved oxygen (% saturation)
Dissolved oxygen (mg/L)
Fluoride (mg/L)
Hardness ($CaCO_3$) (mg/L)
Hydroxide (mg/L)
Ion balance (%)
Iron (fe) (mg/L)
Magnesium (mg) (mg/L)
Manganese (mn) (mg/L)
Nitrate (n) (mg/L)
pH
Phosphorus, total (mg/L)
Phosphorus, total dissolved (mg/L)
Potassium (k) (mg/L)
Silica (mg/L)
Sodium (Na) (mg/L)
Sulphate (SO_4) (mg/L)
TDS (calc) (mg/L)
Temp (^{O}C)
TKN (total Kjeldahl nitrogen) (mg/L)

Habitat assessment variables
Stream wetted width (m)
Stream bank full width (m)
Stream wetted depth (m)
Velocity (m^3/s)
Stream substrate (%)
Aquatic vegetation cover (%)
Over hanging vegetation cover (%)
Undercutting distance (cm)
Large woody debris (%)
Riparian width (m)
Bank Slope (^{o})
Bank Erosion (scale; 1-10)
Bank vegetative cover (%)
Human disturbance on bank (scale; 1-10)

Appendix 2. Habitat field data sheets.

DATE:	**TIME:**	**CREW:**
SITE:	Easting =	Northing =

Channel width(m) = *Wetted(m)=* *Bankfull(m)=*

	LDB	**RDB**
Bank angle(& distance to partner)=		
Bankfull height =		
Undercut distance=		
Bank erosion rank(0-10)=		
Riparian width =		

Riparian Plot (20m long x 10m laterally):

Dec. Tree (DBH>0.3m) (%)=		
Con. Tree (DBH>0.3m) (%)=		
Small Dec. Tree (%)=		
Small Con. Tree(%)=		
Woody Shrubs(%)=		
Grass/Sedge(%)=		
Exposed Soil(%)=		
Other? =		

In-Stream Littoral Plot (20m long x10m laterally):

Bedrock(%)=		
Boulder (>256 mm) (%)=		
Aquatic veg (algae/macro)(%)=		
Overhanging veg(%)=		
Undercutting(%)=		
Woody debris(%)=		
Other(?)=		

Human Disturbance on Bank?
(If yes, describe and rank severity 1-10):
LDB = RDB=

Human Disturbance <10m of bank?
(If yes, describe and rank severity 1-10):
LDB = RDB=

Photographs (record temporary image file #) LDB =
RDB =

Comments:

Appendix 2. Continued

DATE:	**TIME:**	**CREW:**
SITE:	*Wetted Width:*	*Transect Length:*

X-Sectional Depth Profile and Dominant Substrate Characterization

Transect #=

	1	2	3	4	5	6	7
Depth =							
%Dominant Substrates							

Transect #=

	1	2	3	4	5	6	7
Depth =							
%Dominant Substrates							

Transect #=

	1	2	3	4	5	6	7
Depth =							
%Dominant Substrates							

Transect #=

	1	2	3	4	5	6	7
Depth =							
%Dominant Substrates							

Transect #=

	1	2	3	4	5	6	7
Depth =							
%Dominant Substrates							

Transect #=

	1	2	3	4	5	6	7
Depth =							
%Dominant Substrates							

Transect #=

	1	2	3	4	5	6	7
Depth =							
%Dominant Substrates							

Substrate - bedrock, boulder(>256mm), cobble(64-256mm), gravel (2-64mm), sand, clay/silt

Appendix 2. Continued.

DATE:	TIME:	CREW:
SITE:	*Wetted Width:*	*Transect Length:*

Longitudinal Thalweg Depth & Dominant Substrate Characterization (Every 100-150m)

	1	2	3	4	5	6	7
Distance =							
Depth =							
%Dominant Substrates=							

	8	9	10	11	12	13	14
Distance =							
Depth =							
%Dominant Substrates=							

	15	16	17	18	19	20	21
Distance =							
Depth =							
%Dominant Substrates=							

	22	23	24	25	26	27	28
Distance =							
Depth =							
%Dominant Substrates=							

Longitudinal Tally of LWD (>0.15m diameter, >3m length) =

Longitudinal Tally of Off-channel Habitat (e.g., sloughs, oxbows with surface water connections) =

Appendix 3. Metadata for the creation of land-use variables using GIS.

Name: Watershed boundaries
Source: Government of Canada, Natural Resources Canada, Earth Sciences Sector, Centre for Topographic Information (Canadian digital elevation data).
Date: 2000
Scale: 1:50,000
Details: We used ArcHydro and the digital elevation model (Canadian digital elevation data) to delineate watersheds for each surveyed reach. The upstream start point of the reach was used as the drainage point for watershed delineation.

Name: Cattle density in basin
Source: Alberta Agriculture Food and Rural Development
Contact: David Spiess (Phone: 780-427-3739)
Date: 2006
Scale: Based on PFRA watershed boundaries (1:50,000)
Details: We assumed cattle were evenly distributed across the landscape. Example calculation: Cattle layer area = 40,000 ha, Watershed layer area = 10,000 ha, 10,000/40,000 = 25%. Number of cows in cattle layer = 25,000. The number of cows in the watershed would be 25% of 25,000 = 6250. Cattle density = 6250 cows/10,000 ha = 0.625 cows/ha.

Name: Human density in basin
Source: Office of Statistics and Information, Alberta Employment and Immigration
Contact: Richard Williams (Phone: 780-427-9271)
Date: 2006
Scale: Census Sub-division
Details: We assumed humans were evenly distributed across the landscape. Example calculation: Human census layer area = 40,000 ha, Watershed layer area = 10,000 ha, 10,000/40,000 = 25%. Number of humans in census layer = 25,000. The number of humans in the watershed would be 25% of 25,000 = 6250. Human density = 6250 humans/10,000 ha = 0.625 humans/ha

Appendix 3. Continued.

Name: Percent cropland in basin
Source: Agriculture and Agri-Food Canada
Date: 2008
Scale: 1:250,000

Name: Road density in basin
Source: Alberta Sustainable Resource Development, Resource and Information Branch, Spatial Data Warehouse Ltd.
Date: October 26, 2007
Scale: no scale provided

Name: Percent urban cover in basin
Source: Alberta Sustainable Resource Development, Resource and Information Branch, Spatial Data Warehouse Ltd.
Date: September 30, 2007
Scale: no scale provided

Appendix 4. Correlation matrix of candidate metrics for the Beaver River IBI. The bottom portion of the diagonal is the correlation coefficient (Spearman's ρ) and the top portion is the probability associated with the test. Correlation coefficients greater than 0.8 and their associated probability are shaded.

	% tolerant	% long-lived	% invertivorous cyprinids	% top carnivores	% intolerant	% benthic invertivores	% omnivores	% tolerant reproductive	% fathead minnows	% of individuals with DELTS	% lithophils	Relative abundance (catch/100s)	Richness
% tolerant	1	0.7538	<0.0001	0.2031	0.0735	<0.0001	<0.0001	0.0035	0.0113	0.0597	0.2783	0.3668	0.0501
% long-lived	-0.05	1	0.0271	<0.0001	0.6782	0.1006	0.4344	0.3505	0.2094	0.0126	0.6273	0.4316	0.0055
% invertivorous cyprinids	-0.57	0.31	1	<0.0001	0.0113	0.0730	<0.0001	0.0855	0.0531	0.5148	0.0330	<0.0001	<0.0001
% top carnivores	-0.18	0.62	0.39	1	0.9861	0.3778	0.0989	0.2303	0.2151	0.0411	0.1910	0.0568	<0.0001
% intolerant	-0.26	-0.06	0.36	2.5E-03	1	0.4500	0.0442	0.7140	0.2829	0.9140	0.3782	0.0250	0.0132
% benthic invertivores	-0.59	0.23	0.26	0.13	0.11	1	<0.0001	0.0002	0.0049	0.6276	0.0002	0.0784	0.2574
% omnivores	0.96	-0.11	-0.59	-0.24	-0.29	-0.64	1	0.0002	0.0006	0.1068	0.0887	0.6869	0.0267
% tolerant reproductive	0.40	-0.13	-0.25	-0.17	-0.05	-0.51	0.50	1	<0.0001	0.7767	<0.0001	0.9984	0.6445
% fathead minnows	0.36	-0.18	-0.28	-0.18	-0.15	-0.39	0.47	0.84	1	0.1413	<0.0001	0.8720	0.8380
% of individuals with DELTS	0.27	0.35	0.09	0.29	0.02	-0.07	0.23	0.04	0.21	1	0.72	0.0017	0.2502
% lithophils	-0.16	-0.07	0.30	-0.19	0.13	0.50	-0.24	-0.62	-0.54	0.05	1	0.4586	0.0869
Relative abundance (catch/100s)	0.13	0.11	0.51	0.27	0.32	-0.25	0.06	3.0E-04	0.02	0.43	0.11	1	0.0078
Richness	-0.28	0.39	0.54	0.65	0.35	0.16	-0.31	0.07	0.03	0.17	-0.24	0.37	1

Appendix 5. Mean (±SD) values of rejected metrics collected in three zones of the Beaver River watershed, Alberta, 2009-2011.

Metrics	Upstream of Sand confluence	Sand River	Lower Beaver River
Tolerant reproductive guild (%)	9.7 (±14.6)	0.3 (±0.9)	0.2 (±0.4)
Tolerant (%)	84.5 (±25.4)	39.1 (±12.9)	45.8 (±12.4)
Fathead minnows (%)	8.1 (±13.0)	0.1 (±0.3)	0.1 (±0.2)
Intolerant (%)	0 (±0)	0.1 (±0.2)	0.1 (±0.3)
Long-lived (%)	2.4 (±7.4)	2.8 (±3.5)	2.2 (±1.3)
Relative abundance (catch/100s)	4.9 (±3.6)	2.5 (±1.7)	7.7 (±1.8)
Richness (# of species)	3.3 (±1.7)	4.2 (±1.5)	5.1 (±1.2)
DELTS (%)	4.4 (±5.6)	2.5 (±1.7)	4.2 (±3.4)

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Conserving Alberta's Wild Side