A Generic Rule Set for Applying the Alberta Fish Sustainability Index, Second Edition.

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Executive Summary

Province-wide fisheries management strategies must rely on the basic building block of assessments of the status of individual stocks of fish. These strategies and assessments are components of the most basic management task of determining the effect of human disturbance on a fish population, and quantifying the effectiveness of recovery and maintenance actions. For strategies and plans to be consistent at a provincial scale, stock assessments must be consistent and comparable between stocks, areas, and time. To achieve this objective, a standardized process of assessment, called the Alberta Fish Sustainability Index (FSI) has been developed.

The purpose of the FSI is to:

1) Provide landscape-level, provincial overview of fish sustainability
2) Allow for broad temporal comparisons in changes in sustainability
3) Support broad-level comparisons between fish sustainability and management actions (e.g., regulations, land use planning)
4) Provide information to assist in planning priorities for management actions at provincial scales

The FSI assessment process has three major components; organizing stocks into spatial units, assessing the individual stock or stocks within units, and compiling the assessments into a provincial-level strategic information system. The core of this process, however, remains the individual fish stock assessment. This document *A Generic Rule Set for Applying the Alberta Fish Sustainability Index* is an initial set of guidelines intended to assist biologists in conducting consistent stock assessments across the province and across species. These guidelines are expected to change over time, as problems are discovered and solutions found. This FSI rule set is however, expected to be the “operators manual” for maintaining repeatable and scientifically sound fish stock assessments in Alberta.

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1.0 Introduction

A top priority of fisheries managers is to determine the effect of human activities on fish populations and quantify the effectiveness of recovery and maintenance actions. These results are important because they can be used to plot the course of natural resource management by providing direction to provincial strategies such as the *Land Use Framework*, *Water for Life*, or the *Fish Conservation and Management Strategy*. A basic building block for evaluating human impacts is the assessment of individual fish stocks. These assessments must be conducted in a consistent fashion in order to use the results to evaluate human impacts at a provincial scale.

The Alberta Fish Sustainability Index (FSI) is a tool used to bring consistency to individual fish stock assessments across the province. The index provides a standardized approach for evaluating existing data and identifies the types of field data that should be collected in the future to allow for more robust assessments. To provide the ability to report integrated FSI status for multiple focal fish species, lotic results are scaled to an appropriate watershed level (e.g. hierarchical unit code (HUC) watersheds or an individual lake). Lentic results are reported for an individual lake. Populations are evaluated in terms of four groups of metrics:

1. Population integrity
2. Population productivity
3. Threats and the ability to mitigate them
4. Reliability (quantity, quality, and timeliness) of the data used for each metric

Evaluations are made by comparing focal populations to an observed or modeled-theoretical reference population covering the same areal extent but occurring in the most ideal habitat in Alberta, unaffected by anthropogenic influences (e.g., fishing mortality, habitat loss, competition with exotic species). Differences between focal and reference populations are translated to a scale of one to five, and represent four different risk categories (Figure 1) (AESRD 2012). A score of one corresponds to a focal population that is least sustainable and very different from the theoretical population, and a five corresponds to a focal population that is most sustainable and very similar to the theoretical population. This ranking system follows those used elsewhere (Williams et al. 2007, NatureServe 2009). Note that for cases where comparison between the focal and theoretical population are not possible (e.g., extirpated, or no fish were detected), an additional rating of zero has been added to the Alberta FSI. A zero represents a functionally extirpated population (e.g. no fish were detected in recent history, or extirpation is suspected). While a few individuals may still occur in a functionally extirpated population, it is not thought to constitute a viable population. For the majority of FSI metrics, these rankings are easily translated into the risk assessment guidelines identified by AESRD (2012).Where a rank of four and five represent a population at low risk, and where a one is a population at very high risk. A zero represents a functionally extirpated population where extirpation is known or suspected (Figure 1). In addition to allowing the FSI to align with the Species at Risk framework, risk assessment ratings also provide broad categories which may allow biologists to more easily assign FSI ranks in the absence of extensive data.

Figure 1. Proportion of a population metric remaining compared to a theoretical population undisturbed by anthropogenic influences, and the corresponding Alberta Fish Sustainability Index (FSI) ranks. Figure adapted from AESRD (2012).

1.2 FSI Background

The FSI approach to assessing population sustainability by ranking it with respect to a theoretical population, undisturbed by human activities, follows the same general approach used by other large conservation agencies to assess the status of species at risk (Montana State Rank Criteria - Montana Natural Heritage Program 2004, NatureServe Conservation Status Assessments: Methodology for Assigning Ranks - Faber-Langendoen et al. 2009, IUCN Red List Criteria - IUCN 2001, COSEWIC's Assessment Process and Criteria – COSEWIC 2009). The ranking strategies used by these agencies were adapted by U.S. Fish and Wildlife for use in ranking bull trout populations (called core areas, see Fredenberg et al. 2005). In Alberta, members of the Bull Trout Working Group adopted Fredenberg's ranking process and conducted several iterations of it before it was generalised for use with any fish species (the Alberta FSI, see Sullivan and Park 2008). Trout Unlimited's Conservation Success Index (Williams et al. 2007) also played a key role in the process of developing the Alberta FSI (see memo by Sullivan "Status of Alberta Fish initial concepts.doc"). Fisheries biologists in Alberta are finding the FSI ranking process useful in providing relatively accurate status assessments.

1.3 Data Requirements

Each FSI assessment represents a present-day snapshot in time of the current status of a population. Biologists should reassess their population's FSI scores regularly as new data are collected on population integrity and productivity, as the severity of population threats change and as new threats appear, or management actions change. For any particular FSI assessment, the most up-to-date data available should be used in comparisons of the focal fish population against the theoretical population used as a reference. In the absence of current data, historical data may be used as a proxy (particularly for remote populations in which land use and exploitation changes are not viewed as being substantive), but perceived changes to the population since the data were collected must be considered and appropriate adjustments made when rankings are determined. Since reliability of the data is evaluated for each metric considered in the overall FSI, the assessment also aids in prioritization of future data collection. Metrics where the data used may be imprecise or inaccurate, the quantity of data available is limited, or outdated data is used, will be highlighted by low monitoring and vigilance scores.

For example, Terry Clayton, as the Lethbridge/Medicine Hat Area Biologist, might be assessing the hybridization metric of lotic walleye in the Oldman River. He knows hybridization is probable between stocked reservoir populations which came from Saskatchewan and the native Alberta river walleye, but Terry has no genetic data to support this. He suspects some hybrids would be found in most samples he collects of lotic fish from the Oldman and chooses to apply a FSI hybridization rank of two. However, he knows this is really just a guess and he also ranks the monitoring quality, quantity, and timeliness metrics for hybridization all as one, one and zero, respectively (see the description of these metrics at the end of this document). He knows his guess could be imprecise and inaccurate, he has no data to evaluate this metric, and no genetic data has ever been collected looking at hybridization between native river and stocked reservoir walleye in southern Alberta. When Terry is reviewing his FSI assessment for lotic walleye from the Oldman he makes a note of the low monitoring and vigilance scores for the hybridization metric. He puts a sticky note on his monitor to remind himself to set as a condition of any FRL he issues on the Oldman where walleye will be captured that fin clips should be collected and returned to him. He also makes a note to pursue possible funding sources to have the genetic analyses of these samples completed.

1.4 FSI Focal Species

FSI assessments of fish species in the province will be conducted in accordance with provincial objectives and priorities. The following are priority FSI species:

1. Bull trout
2. Lentic and lotic walleye
3. West slope cutthroat trout
4. Lake sturgeon
5. Athabasca rainbow trout
6. Arctic grayling
7. Goldeye and mooneye
8. Lake trout
9. Lentic and lotic northern pike
10. Yellow perch
11. Mountain whitefish
12. Sauger
13. Burbot

1.5 FSI Database

Similar to the way in which data is entered into Fisheries and Wildlife Management Information System (FWMIS), fisheries biologists will use a Microsoft®Access data entry load form to enter FSI assessment information. The Access FSI assessment load form has four sections:

1: HUC or Lake Assessment Information
2: Population Integrity
3: Productive Potential
4: Threats and Threat Mitigation

Beyond the instructions provided here, further instructions are provided to the user on each of the four Access FSI sections. Read these before completing the forms. The first worksheet collects basic information about the FSI assessment, while the remaining data entry sections gather metric scores for the FSI.

2.0 FSI Rule Set

This rule set provides instructions on how to complete each of the worksheets on the Microsoft® Access data entry form to maintain consistency in how populations are assessed. Below is a summary on each group and its underlying categories and metrics (Table 1).

Although fish stocked into put-and-take fisheries do not require FSI assessments, wild and naturalized (self-sustaining) stocked populations do. For example, cutthroat trout populations in the Brazeau River drainage need to be assessed even though they have originated from stocking and are outside the species' native range in Alberta. Walleye stocked in prairie reservoirs also need to be assessed even though they live in artificial habitat. On the other hand, Arctic grayling stocked in ponds in southern Alberta are not self-sustaining and do not require assessment.

Table 1. Summary of Alberta Fish Sustainability Index (FSI) groups, categories and metrics.

Group	Category	Metrics
Population Integrity	Population Density	Historical Adult Density
		Current Adult Density
		Immature Density
	Genetic Integrity	Degree of Hybridization
		Genetic Similarity to Original Stock
		Genetic Distinction
	Ecological Integrity	Changes to Predators
		Changes to Prey
		Change to Competitors
Productive Potential		Geographic Extent
		Natural Limitations to Productivity
		Anthropogenic Limitations to Productivity
Threats and Threat Mitigation		Habitat Protection Need
		Overharvest Protection Need
		Habitat Protection Availability
		Overharvest Protection Availability
		Exotic Species Threat

2.1 FSI Section 1: Assessment Info

When an FSI assessment is commenced, enter the assessment date, assessor name, FWMIS Waterbody ID (s), HUC watershed code, Species, Type (lentic or lotic), Species Presence, and Species Origin as directed in the Access database. Then, define and describe the fish population using the following guide:

2.1.1 Rules for Population Assessment Scale

In 2013, the Fisheries Management Branch in collaboration with ESRD Data Management and Water Management, created a provincially comprehensive and aggregated collection of standard hydrologic units based on USGS standards and procedures. The Hierarchical Unit Code (HUC) watersheds establish a standardized baseline that covers all areas, and where successively smaller hydrologic units are nested within larger hydrologic units, creating a hierarchal watershed boundary dataset. Currently, four levels of nested watersheds have been delineated, 2, 4, 6 and 8-digit HUCs. Where 2-digit HUCs are the largest watersheds and 8-digit watershed are the smallest, finer scale watersheds.

The HUC watershed dataset was delineated based on sound hydrologic principles to ensure that they are not created in favour of a specific department or program objective. As such, they can (and are) being used by a diverse group of government and non-government agencies, and will have a lasting value in water and watershed modelling and management programs, as well as resource inventory assessments. Given that the HUCs were delineated based on hydrologic principles, the scale may never perfectly fit our definition of a species' population, but the closest watershed scale will be chosen and used.

Given their ubiquitous use, HUC watersheds have been chosen as the spatial assessment unit for the FSI when assessing lotic populations. However, the specific scale of HUC watershed used in a FSI assessment will be species specific and reflect life history traits and available genetic information. For the purposes of the FSI when appropriate genetic information is available, we define a population as a group of individuals that exhibit self-assignment rates of ~90% using multilocus genotypes. This means that, at a minimum, 90% of individuals captured within a certain spatial extent (e.g., lake, river, or river system) assign or 'belong' to the same population. However, in the absence of genetic data, telemetry information, or scientific literature can be used to determine at what scale to define a 'population'.

For instance, in a genetic analysis of Alberta Arctic grayling, Reilly (2014 *unpublished data*) found that self-assignment rates were relatively high when individuals were grouped by sub-basins (average self-assignment rate = 86%), which is a spatial scale similar to 6-digit HUCs. Conversely, when investigating bull trout population structure using genetic variation at nine microsatellite markers, Warnock (2008) found evidence of at least three populations (according to the FSI definition) in the Castle River 8-digit HUC. In this instance an even smaller HUC (10-digit) would be the appropriate scale of assessment. However, this level of fine-scale watershed delineation does not currently exist in Alberta. Therefore, in this instance we acknowledge and note that our FSI assessment of these lotic populations is likely an average of several individual fish populations.

All HUCs where the focal fish species exist, is suspected to exist, or has been extirpated must be identified and assessed. This can include areas of habitat that are seasonally or temporally unoccupied (IUCN 2008). *In cases of extirpation or range contraction, the pre-disturbance distribution of species, irrespective of present day or historical human impacts, should be assessed.*

To be consistent with the International Union for the Conservation of Nature's definition of extent of occurrence (IUCN 2008), "cases of vagrancy" will be excluded. For example, lake trout in Alberta are occasionally observed in rivers downstream from existing lake populations, but rivers would be excluded from their lentic assessment.

Lotic HUCs may include lakes, if the fish in these lakes are considered part of the larger lotic population. Alternatively, if lentic fish in the lake form a distinct fish population (or it is managed as such by lake-specific angling regulations), the level of assessment is the individual waterbody and the lentic population is defined separately within lotic HUC as the boundaries of the lake and if applicable, any connected streams or lakes frequented by the lentic population.

2.2 FSI Section 2: Population Integrity Group

Population integrity is the first group of metrics in the FSI. Within this group there are three categories of population metrics: population density, genetic integrity, and ecological integrity.

Catch rates or population estimates should be as representative of the entire HUC if possible, rather than based on site-specific sampling. However, this will be difficult given that of the fourteen fish species currently being assessed for the FSI, a standard sampling procedure exists only for lentic walleye (i.e., Fall Walleye Index Netting, see Morgan 2002). This method is also being validated for other species, such as northern pike. Catch rates for lotic fishes (e.g., lake sturgeon, Arctic grayling) are commonly derived from electrofishing or angling data.

Biologists will have to decide whether site-specific catch rates or population estimates are representative of the HUC. For example, depending on what season sampling was done, electrofishing bull trout on a spawning tributary could be biased towards adult fish and higher densities than the HUC as a whole. Electrofishing grayling on the one tributary where they have been caught in the past may not be representative of the entire HUC. In such cases, a biologist may have to adjust their overall ranking of an HUC. Fish density can still be gauged qualitatively using circumstantial evidence of density (e.g., limited historical data, angling CUEs, commercial fishery CUEs, angler reports, and incidental observations) and comparisons to other HUC where quantitative estimates have been used to rank populations more accurately. Whether quantitative or qualitative, it is essential that biologists explain how they arrived at a rank for density in the comments section of the FSI database and if quantitative data are used, explain where these came from, how many sites were sampled, and how these sites were representative or adjust to represent the HUC as a whole.

The only cases when zeros can be entered as FSI metric values for adult (historical and present) density or immature density are when the focal species is a functionally extirpated population (none detected, extirpation suspected) in the HUC being considered. The ecological integrity metrics should still be filled out to assess the role of these factors in the loss or decline of the species. Zeros are also entered for genetic integrity metrics in cases where populations are classified as functionally extirpated.

2.2.1 Population Density Category

Population density is the first category of metrics in the population integrity group of FSI metrics.

i. Current Adult and Immature Density Metrics

Adult and immature density metrics indicate the relative abundance of these two demographic classes of fish compared to a modelled (or in qualitative comparisons, conceptual) undisturbed population. Density comparisons are referenced to what the HUC or lake in question could produce if it had no human impacts and consisted of the most ideal habitat in Alberta. Even if a population is undisturbed by human impacts, if it is at the edge of its range and barely sustainable because of natural habitat limitations, it should be scored as barely sustainable relative to a theoretical population occupying the same area of ideal habitat. When scoring populations fragmented by an extensive human disturbance where there are no barriers to fish movement, consider the once-large, contiguous population and rank each small fragment as the appropriate area-weighted fraction of the larger contiguous population. Rankings and the associated risk assessment guidelines are found in Table 2, and appear on the Access load form.

Table 2. Alberta Fish Sustainability Index and Risk Assessment rankings for adult and immature density in the population density category of the population integrity group.

FSI rank	**Risk Assessment Rank**	**Adult density**	**Immature density**
0	Functionally Extirpated	No adults observed	No immatures observed
1	Very High Risk	Lowest possible without extirpation, adults barely detectable	Lowest possible without extirpation, young barely detectable
2	High Risk	Poor abundance, recruitment overfishing	Poor abundance, recruitment overfishing
3	Moderate Risk	Moderate abundance, growth overfishing below MSY	Moderate abundance, growth overfishing below MSY
4	Low Risk	Very abundant, population at or above MSY with mild growth overfishing	Highest possible, population at MSY, below K, mild growth overfishing
5	Low Risk	Highest possible, population at K	Very abundant, population at K, slight natural recruitment reduction

To show how various populations in Alberta rank with respect to the adult and immature density criteria above, examples have been provided in the species-specific life history parameters and threshold standards (only completed for bull trout, Arctic grayling, northern pike, and lentic walleye at this point, with additional species currently in progress). This should give biologists an idea of how the range of fish populations in Alberta corresponds to FSI density rankings and allow them to rank populations qualitatively with no quantitative data by comparison to these examples.

Quantitative classification of a given population for the FSI population integrity density ranking involves calculating adult and immature catch rates or population estimates separately. Following the AESRD (2012) framework and in collaboration with the Species Leads, fisheries scientists and specialists, species-specific catch rates or population estimates should be determined for each density rank. Note that only cases where no adults or immature fish are caught, fish are believed to be extirpated or no evidence exists of their presence does a density rank correspond to zero. Also, note that in populations with high fish densities where the actual catch rate or population estimate is greater than the modelled theoretically undisturbed value, a FSI density rank of five should still be assigned (this is the maximum rank possible).

It should be noted that whenever possible, fish sex and maturity should be based on data collected from inspection of gonads or other morphological features (e.g., shape of anal fin in goldeye, Nelson and Paetz 1992). To address situations where this was not done during sampling, size-based catch rates or population estimates for fish bigger and smaller than specified lengths should be used.

ii. Historic Adult Density Metric

This metric uses the same criteria as the Current Adult Density metric described in the previous section, but for the undisturbed condition. The purpose of this metric is to capture information about the fish or fishery status at its earliest point of fishing or sampling, or your best estimate of its undisturbed condition. This metric will be used to help describe the original range and abundance of a species, and the changes in abundance relative to the current status. If data is available FSI rankings can follow those in Table 2.

In the absence of fisheries data, local environmental knowledge (LEK), traditional environmental knowledge (TEK) and stories, quotes, photos from anglers and fisheries staff can all be used in assessing this metric. If no early data is available, the biologist should rate this based on their understanding of current density and how current threats and pressure (e.g., harvest / habitat / exotics) most likely has changed that density.

For example, 1) in the Tawatinaw River during the 1940s to 50s, a 1996 LEK historical survey had the following comments:

- Art Delancy: “always good for grayling, nice size, up to 1 lb”
- R.B. Miller: “abundant grayling below Meanook”
- M. Paetz: “grayling fishing by Colinton, but small fish by 1960s”

- John Kormendy: “by Perryvale, 1 lb. grayling easy to catch”
- Peter Marchuk: “fished in the 1950s and 1960s. Around the Rochester area the grayling were really nice “panners”. Average size about 12 - 14 in.”

Based on these stories, the Historical Adult Density in the Tawatinaw River should be ranked as 4.

2) During a 1996 historical LEK survey of Walleye in North Buck Lake the following comments were made:

- Blake Smith fished from 1950 on and never caught any walleye there, but heard of people who did and said it was good.
- Hilaire Ladocoeur started fishing in 1940 and said he’s never once caught a walleye in this lake.
- John Gordey fished in 1960 and said that there used to be a lot of pike and walleye here. “It would be nothing to get 5 - 6 walleye here per day”.
- M. Paetz a previous Superintendent of Fisheries Management said fish here consistently tasted “muddy”. This included the walleye and it is rare for a walleye to taste “muddy”.

Based on these stories and commercial fishing records, the Historical Adult Density would likely be ranked as 3 (certainly present, not abundant for most anglers, perhaps patchy in distribution).

In instances where a fishery was only recently established, e.g. northern pike naturally moving into a previously unoccupied reservoir, the year of establishment will be considered the historical condition of that fish species or fishery. Obviously, appropriate explanations should be added into the comments fields.

2.2.2 Genetic Integrity Category

Genetic integrity is the third category of metrics in the population integrity group of FSI metrics. The three metrics considered are the degree of hybridization, how genetically similar the current stock is to the original stock, and the degree of genetic distinction of the stock. The life history parameters and threshold standards do not provide species-specific assessment techniques for evaluating these metrics. Instead examples are provided here of various populations in Alberta evaluated against the three genetic integrity metrics. Metrics should be evaluated using the best available data. Even if no genetic data exists, historical stocking records and anecdotal evidence should be considered and the reasoning behind each ranking chosen should be recorded in the comments field. Note that for populations stocked in non-native waterbodies, an additional rank of 6 has been added (stocked, naturalized population). Examples would include lentic walleye stocked in the prairie reservoirs, lake trout stocked in Crowsnest Lake, or cutthroat trout stocked in the Red Deer, North Saskatchewan, Athabasca, or Peace drainages.

i. Degree of Hybridization Metric

For the degree of hybridization metric, qualitative, quantitative and the associated risk rankings are as follows (Table 3), and are provided on the Access load form.

Corresponding quantitative rankings from Trout Unlimited's Conservation Status Index (Williams et al. 2007) are provided for reference, but it is unlikely sufficient genetic sampling of entire HUCs exists to determine what proportion of a population is hybridized. Therefore, these rankings may not be used until more genetic data is collected in Alberta.

Table 3. Alberta Fish Sustainability Index rankings for the degree of hybridization metric in the genetic integrity category of the population integrity group.

Qualitative Hybridization Rankings	Trout Unlimited Quantitative Hybridization Rankings	Risk Assessment Rank
0 = functionally extirpated	0 = functionally extirpated	Functionally Extirpated
1 = mostly hybrids	1 = hybrids > 20% of population	Very High Risk
2 = some hybrids in most samples	2 = hybrids 10-20% of population	High Risk
3 = hybrids rare, but presence detected or strongly suspected	3 = hybrids < 10% of population	Moderate Risk
4 = no hybrids known but proximity to non-native fish causes concern	4 = no hybrids known but proximity to non-native fish causes concern	Low Risk
5 = no hybrids in population	5 = no hybrids in population	Low Risk
6= stocked, naturalized population	n/a	n/a

The limit of > 20% hybridization constituting a largely unsustainable population is taken from the U.S. Fish and Wildlife's response to a petition to list westslope cutthroat trout as a threatened species under the Endangered Species Act (USFWS 2003). The U.S. Fish and Wildlife

Service cites literature which indicates that at this level of introgression, the population as a whole could still be considered westslope cutthroat for the purposes of conservation assessment. As a result of including populations with this level of hybridization, USFW concluded that westslope cutthroat were abundant and widely distributed enough that a listing of 'threatened' was not warranted. Some evidence suggests levels of hybridization less than 20% may still impact the sustainability of a population (e.g., Muhlfeld et al. 2009).

An advantage of the FSI assessment procedure is that it can be used to prioritize populations for genetic sampling. Some populations can simply be assessed qualitatively and may not need genetic sampling. Historical stocking and observations of morphological features already indicate a high proportion of hybrids (e.g., mainstem Crowsnest River cutthroat trout). Conversely, there may be no evidence of non-native species with which hybridization could occur in the HUC indicating a pure population (e.g., lake sturgeon). It will be the HUCs in between these two conditions that will require more detailed assessments. HUCs that are found to have very low proportion of hybrids may be at a high risk, and efforts to preserve their genetic integrity should be explored (e.g., selective harvest or removal, more intensive genetic sampling to identify genetically pure sub-stocks).

Examples of HUCs from across the province ranked qualitatively for the degree of hybridization are provided below (Table 4).

Table 4. Examples of waterbodies from across the province ranked qualitatively for the degree of hybridization.

Species	Waterbody	Rank	Risk Assessment Rank	Comments
CTTR	Crowsnest River	1	Very High Risk	No genetic data, but supported by historical stocking records and morphological evidence
Athab. RNTR	Lac Beauvert, Jasper National Park	1	Very High Risk	41% of sampled rainbow trout had experienced introgression from hatchery introductions (Taylor et al. 2007)
BLTR	Upper Elbow River and tributaries	1	Very High Risk	Brook trout throughout, high proportion of hybrids identified in Quirk Creek (on average over 20% of charr captured were visually identified as hybrids, genetic analyses conducted on 61 confirmed that they were hybrids (Earle et al. 2007).
Lotic WALL	Pigeon Lake walleye	2	High Risk	Thomas et al. (1999) showed introgression of stocked walleye into a remnant population of native walleye has led to a low frequency of native genotypes. The non-native Winefred Lake genotype was most common at the time of the study.
BLTR	Castle River below Castle Falls	3	Moderate Risk	Limited genetic data from a spawning tributary (Mill Creek) identified one hybrid (Warnock 2008)
Lentic WALL	South Saskatchewan, Oldman, and Bow rivers	3	Moderate Risk	No genetic data, but non-native walleye stocked in reservoirs have dispersed to the rivers through irrigation canals
BLTR	Oldman River above reservoir	4	Low Risk	No confirmed reports of brook trout anywhere in the upper watershed, but they exist in adjacent watersheds (Willow Creek, Crowsnest River)
LKST	South Saskatchewan, Oldman, and Bow rivers	5	Low Risk	No hybrids present, but a background level of risk remains because white sturgeon are sold in pet stores

What is your ranking based on? Quantitative or qualitative information?

The majority of the metrics that make up the FSI will be ranked by biologists qualitatively using their best judgement. However there are five key metrics that can be calculated and ranked quantitatively. These are adult and immature densities, hybridization with exotic or non-native stocks, and geographic extent of the HUC. Values for these metrics can be determined using standardized catch rates, sexual maturity and age-structured population distributions, genetic analyses, and GIS, respectively. Biologists will not have this information available for all the HUCs they manage, and will in many cases rank these metrics qualitatively using circumstantial evidence. Although these educated guesses are still valuable and should be included in the FSI database, their somewhat subjective nature should encourage biologists to prioritize collecting the data necessary for a quantitative assessment. In the meantime, to ensure records are kept of how the five quantitative metrics are ranked, database fields have been added for biologists to quickly identify the methods they used. Methods are listed in the popup box associated with these fields on the Access load form, and multiple methods separated by commas can be entered (e.g., methods 1, 3, 8). Explanations of the data or circumstantial evidence used should be provided in the comments fields.

Metric	Quantitative or qualitative?
Current Adult Density	Either, quantitative preferred
Historical Adult Density	Either, quantitative preferred
Current Immature Density	Either, quantitative preferred
Hybridization	Either, quantitative preferred
Original Stock	Qualitative
Genetic Distinction	Qualitative
Change in Predators	Qualitative
Change in Prey	Qualitative
Change in Competitors	Qualitative
Geographic Extent	Either, quantitative preferred
Productivity	Qualitative
Habitat Protection Need	Qualitative
Habitat Protection Availability	Qualitative
Overharvest Protection Need	Qualitative
Overharvest Protection Availability	Qualitative
Exotics Threat	Qualitative

ii. Genetic Similarity to Original Stock Metric

This metric characterizes how the genetic attributes (i.e., allele frequencies) of a population(s) have been influenced by human activities. Ranks will be based on the findings of genetic data analyses used to detect signatures of genetic bottlenecks, significantly different levels of allele richness or expected heterozygosity, and/or population fragmentation. When genetic data are not available, ranks will be based on the degree of human-induced isolation, evidence of severe declines in population size, or risk of artificial selection pressure (Table 5).

Gene flow between populations acts to homogenize genetic diversity. Conversely, allele frequencies will diverge over time due to genetic drift, mutation, and natural selection if gene flow between populations is reduced or eliminated. Gene flow can be significantly impeded by man-made barriers (e.g., hydroelectric dams, weirs, and culverts) or substantial gaps in species distribution due to overfishing and/or altered environmental conditions (e.g., thermal barriers). Several factors should be considered when evaluating the severity of man-made barriers on the amount and direction of gene flow.

Temporary and one-way barriers, such as culverts during low flow periods, waterfalls or weirs may still allow limited gene flow (i.e., exchange of a few fish per generation) that would slow or prevent population divergence. Barriers also have a ‘zone of influence’; we assume that a barrier has less impact if the population, or group of populations, is further from the barrier than the focal species typically migrates. Lastly, population size should be considered when evaluating the severity of barriers. Over time, reduced gene flow will typically have a greater effect on allele frequencies within small populations.

Genetic bottlenecks increase the risk of population extirpation. A genetic bottleneck occurs when the number of spawning fish in a population is so low that inbreeding reduces genetic diversity or causes the fixation of harmful genes. There are several methods of detecting signatures of bottlenecks using genetic data. When genetic data are not available, the ‘50/500’ rule will be applied. Specifically, populations having fewer than 50 spawning individuals will be considered at risk of inbreeding depression (Jamieson and Allendorf 2012). In some cases, populations may naturally consist of fewer than 50 spawning individuals. Therefore, a population will be considered at risk only if it is experiencing (or potentially experiencing) a genetic bottleneck that is the result of a severe reduction in abundance due to human activities (commercial/ recreational harvest or anthropogenic habitat disturbance).

There is also potential for artificial selection pressure if extreme overharvest or substantial human-induced habitat disturbances have acted to remove certain genotypes through direct mortality. Allele frequencies may be altered if these activities are sustained over multiple generations.

Table 5. Alberta Fish Sustainability Index rankings for the similarity to original stock metric in the genetic integrity category of the population integrity group.

Qualitative Similarity to Original Stock Rankings	Risk Assessment Rank
1 = The population(s) is isolated by a man-made barrier and has experienced a severe reduction in abundance due to human activities (commercial/ recreational harvest or anthropogenic habitat disturbance) that has potentially resulted in a genetic bottleneck.	Very High Risk
2 = The population(s) has experienced a severe reduction in abundance due to human activities (commercial/ recreational harvest or anthropogenic habitat disturbance) that has potentially resulted in a genetic bottleneck or is isolated by a man-made barrier and has low abundance or declining abundance.	High Risk
3 = The population(s) is isolated by a man-made barrier and has moderate to high abundance.	Moderate Risk
4 = The population(s) has likely experienced artificial selection pressure due to a high degree of commercial or recreational harvest or a high degree of anthropogenic habitat disturbance. As a result, allele frequencies may be altered.	Low Risk
5 = The population(s) has not been altered. Little fishing pressure and habitat disturbance.	Low Risk
6= The HUC or lake only contains non-native, naturalized populations.	Low Risk

The following are some examples of populations where these various rankings would apply.

Original stock rank = 1: Lower Kananaskis Lake bull trout

Over a ten-year period, the bull trout population in Lower Kananaskis Lake recovered from a heavily overexploited state and their abundance increased from an estimated 60 adults to 1680 adults after a zero bag limit was implemented (Johnston and Post 2009). Although the authors of this study agree the rapid phenotypic changes in adult life-history characteristics that were observed as fish densities increased were largely the result of phenotypic plasticity in response to changing environmental conditions, they also suggest some of these changes could also have resulted from the size-selective selection pressure the population experienced prior to a zero bag limit being implemented. Whether or not phenotypic changes resulted from artificial selection, the population has likely experienced a bottleneck and is isolated from downstream populations by Pocaterra and Barrier dams.

Original stock rank = 2: Lesser Slave Lake walleye

The Lesser Slave Lake walleye population suffered a severe collapse in the 1960s and 1970s largely due to overharvest. For a number of years, biologists were concerned the population had almost completely disappeared, but in the late 1970s several extremely abundant year-classes were produced and the stock recovered. Allele frequencies have likely been altered from their original state and the population may have experienced a genetic bottleneck. Recent genetic analysis suggests that there is regular movement of individuals between Lesser Slave Lake and the Athabasca River (Burke 2010).

Original stock rank = 2: North Saskatchewan River lake sturgeon

The North Saskatchewan River lake sturgeon population dropped to very low numbers by the 1940s due to overfishing, pollution and ecological changes in the river (Nelson and Paetz 1992). It is thought that sturgeon recolonized the North Saskatchewan River in the late 1950s and early 1960s following sewage treatment plant upgrades and the construction of the Brazeau Dam. However, in 1963, the E.B. Campbell Dam was constructed on the Saskatchewan River at Nipawin, isolating the upstream sturgeon population from the much larger Lake Winnipeg population. It is unknown if this severe reduction in abundance followed by the re-colonization of relatively few fish resulted in a genetic bottleneck. Currently, the population is at low abundance and is isolated from those in the South Saskatchewan River and the downstream Saskatchewan River in Saskatchewan.

Original stock rank = 3: Belly River bull trout

The bull trout population in the Belly River is now isolated from those in the Waterton River due to the Waterton dam. Although the occasional bull trout has been captured in the diversion canal between Waterton Lake and Belly River, it is unknown if they would survive moving through the spillway into the Belly River. In 2008, biologists considered this to be a stable population and estimated abundance at 250 to 500 adults. Therefore, although this population is isolated it has probably not experienced a genetic bottleneck.

Original stock rank = 4: Buck Lake walleye

Buck Lake walleye represent a population that may have experienced significant artificial selection pressure due to harvest. In this lake, it is believed that the majority of the spawning stock now consists of the “hockey stick growth” phenotype, because the majority of larger fish with regular growth rates have been harvested (Spencer 2010). Fish with a “hockey stick growth” pattern show high growth rates when they are young, followed by a much slower growth rate once they approach a harvestable size (Spencer 2010). Fish exhibiting this growth pattern take longer or never reach a harvestable size and therefore spawn for numerous years and produce more offspring than fish with a regular growth (Spencer 2010). If this phenotype has a genetic basis, the higher fitness of the “hockey stick growth” phenotype could result in the loss of genes associated with the regular growth phenotype over many generations.

Original stock rank = 4: Upper Oldman River cutthroat trout

The Upper Oldman and the Livingstone rivers have different angling regulations for cutthroat trout. Harvest is allowed (two fish >300mm) on the Upper Oldman River, whereas it is catch-and-release only on the Livingstone River. Harvest in the Upper Oldman River has resulted in the reduction of the frequency of large fish (>300 mm) relative to that observed in the Livingstone River (Figure 4). Size-selective harvest on the Upper Oldman River could result in the removal of fast or regular growth phenotypes (and possibly associated genes) from the population.

Original stock rank = 5: Undisturbed fisheries having received little to no angling pressure

Outside of the national parks, few, if any, examples of native, un-fished and undisturbed sport fish populations exist in Alberta (Michael Sullivan, pers. comm.). If such populations still do exist, it is probably because they are small, difficult to access, and no one knows about them yet (including Alberta Fish and Wildlife). Possible bull trout examples might exist in Willmore Wilderness Park, remote Arctic grayling populations in small streams flowing from the Birch Mountains outside of Wood Buffalo National Park, or populations of walleye, lake trout, or northern pike in lakes too small to land floatplanes on in northern Alberta. If such populations do exist, Fisheries Management Branch would like to know about them so we can move towards protecting them and establishing them as long-term reference populations.

Original stock rank = 6: Lac La Biche walleye

Recent genetic analysis has shown that the original walleye stock in this lake has been almost completely replaced by non-native stock from other lakes. Out of a sample of 300 fish, only three were suspected to be of native origin (Burke 2010).

iii. Genetic Distinction Metric

This metric describes the number and distribution of naturally-occurring genetically distinct or unique populations within a HUC. Currently, there is no universally-accepted definition of ‘population’; the pattern of genetic differentiation of wild species, particularly those continuously distributed across a landscape, is often more like a cline than discrete units. For this evaluation, we define a population as a group of individuals that exhibit self-assignment rates of ~90% using multilocus genotypes. This means that, at a minimum, 90% of individuals captured within a certain spatial extent (e.g., lake, river, or river system) assign or ‘belong’ to the same population (Figure 2). The remaining 10% represent putative migrants or admixed individuals. This definition should be revisited regularly to incorporate advances in genetic theory and associated technologies. The spatial extent of populations can also be evaluated by a suite of other analyses if self-assignment rates have not been calculated. Multiple analytical approaches, such as individual or group clustering techniques, spatial autocorrelation, and ordination, should be used to validate observed patterns of genetic differentiation.

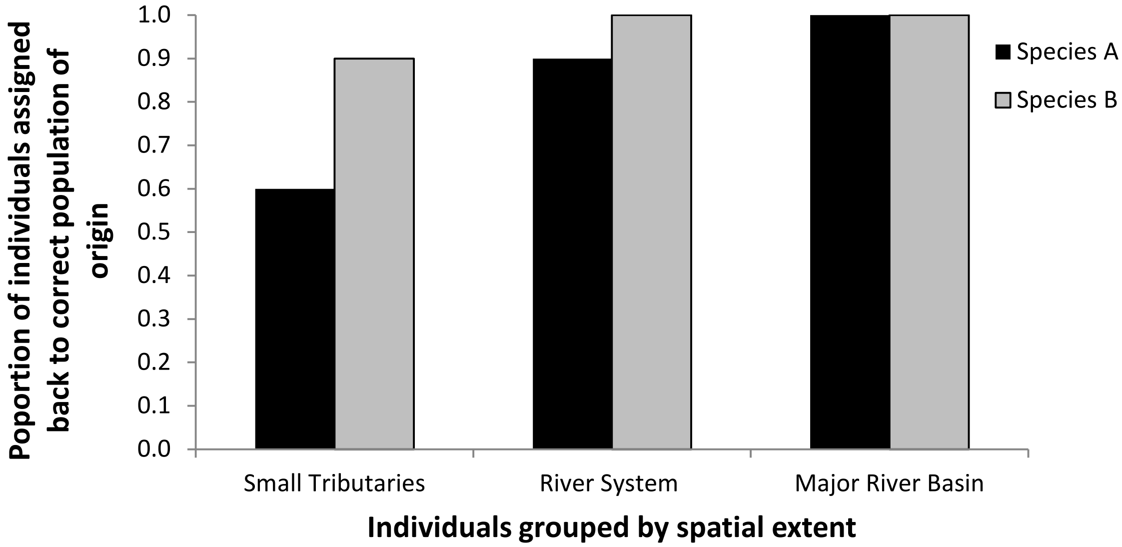

Figure 2. Hypothetical self-assignment rates of two lotic fish species. In this example, 'River Systems' hold distinct populations of Species A and 'Small Tributaries' hold distinct populations of Species B.

When local genetic data are not available, biologists should base their evaluation on: 1) the findings of population genetic studies from other regions; 2) the species propensity to home or stray, and 3) the presence/absence of natural barriers to gene flow, such as waterfalls. Man-made barriers can also result in population divergence, but the required timeframe could be substantial depending on species (i.e., decades to centuries) (Table 6). Additionally, divergence will be minimized if even a few fish are able to move downstream across the barrier and reproduce. For this evaluation, we will assume that man-made barriers constructed in the past 150 years have not yet resulted in significant divergence, unless genetic data show otherwise.

Conserving locally-adapted populations is essential for the preservation of native genetic lineages and continued species evolution. The cost of losing certain populations may be higher in terms of overall species diversity because they contain uncommon or unique genes. Typically, population genetic studies analyse genetic variation at putatively *neutral* areas of the genome, such as microsatellites or SNPs, which are not good indicators of the degree of local adaption (i.e., number and nature of non-neutral, or *coding*, genes). Therefore, we will use persistence in atypical or isolated habitats and uncommon life history and morphological characteristics as indicators of potential uncommon or unique genes.

Table 6. Alberta Fish Sustainability Index rankings for the genetic distinction metric in the genetic integrity category of the population integrity group.

Qualitative Genetic Distinction Rankings	Risk Assessment Rank
1 = The only population in the HUC or lake is isolated due to natural barriers or has unique habitat/ life history.	Very High Risk
2 = Several populations in the HUC or lake are isolated due to natural barriers or have unique habitats/life histories.	High Risk
3 = One population out of many in the HUC or lake is isolated due to natural barriers or has unique habitat/life history.	Moderate Risk
4 = The HUC or lake contains multiple populations, or one population, that are somewhat isolated from each other or from those in neighbouring HUCs/ lakes due to reproductive behaviour, distance, or partial/temporary barriers.	Low Risk
5 = The HUC or lake contains a population that continues into adjoining HUCs/ lakes and there are no known movement barriers.	Low Risk
6= The HUC or lake only contains non-native, naturalized populations.	Low Risk

The following are some examples of populations where these various rankings would apply.

Genetic distinction rank = 1: Rock Lake lake trout (no genetic data)

Rock Lake, just outside Willmore Wilderness Park and Jasper National Park, has a native population of lake trout, isolated from any other population. The lake was stocked in 1983, 1986 and 1987, but a creel survey in 1989 suggested these stockings were unsuccessful (Berndt 1990). Even though the stocked fish were not marked prior to release so they could be the identified in the 1989 creel survey, the 2+, 3+, and 6+ age classes were not strongly represented in angler catch. Instead, natural reproduction appeared to have produced the strongest age class observed (4+, Berndt 1990). This lake was ranked a 1 for genetic distinction because of its isolation and the lack of evidence of multiple, distinct spawning stocks.

Genetic distinction rank = 1: Buck Lake walleye (genetic data available)

Walleye in Buck Lake represent a unique foothills population near the western limit of the species distribution, which is somewhat isolated from the North Saskatchewan River by a long distance along Modeste Creek and Buck Lake Creek. Burke (2010) analysed genetic variation of walleye from Buck Lake and 11 other lakes in Alberta at 15 microsatellite loci. The overall self-assignment rate was ~94%, and all Buck Lake walleye were successfully assigned. There was no evidence of further population structure within Buck Lake. Taking into account the self-assignment rate and the possibility that the location of this population within the foothills region may indicate uncommon genes, Buck Lake was ranked a 1 for genetic distinction.

Genetic distinction rank = 3 & 4: Oldman River and Castle River bull trout (genetic data available)

Bull trout population structure in the Castle and Oldman River drainages was investigated using genetic variation at nine microsatellite markers (Warnock 2008). Self-assignment rates were compared when individuals were grouped based on their stream-of-origin (i.e., capture location; Figure 3a) or according to the results of individual clustering analysis (Figure 3b). Grouping individuals by clustering analysis resulted in significantly higher self-assignment rates (Figure 4). From this analysis, we conclude that there are at least three distinct populations in the Castle River 8-digit HUC (Cb_p, Wca_p, and Mi_p) and the HUC is ranked a 4 for genetic distinction. In contrast, we conclude that there are at least four distinct populations in the Oldman River 8-digit HUC (Ra_p, Hi_p, Uli_p, and Lli_p). The Uli_p population is isolated due to a waterfall and may contain uncommon genes because bull trout in this area exhibit a resident life history and are sympatric with pure strain cutthroat trout. Therefore, the Oldman River HUC is ranked a 3 for genetic distinction.

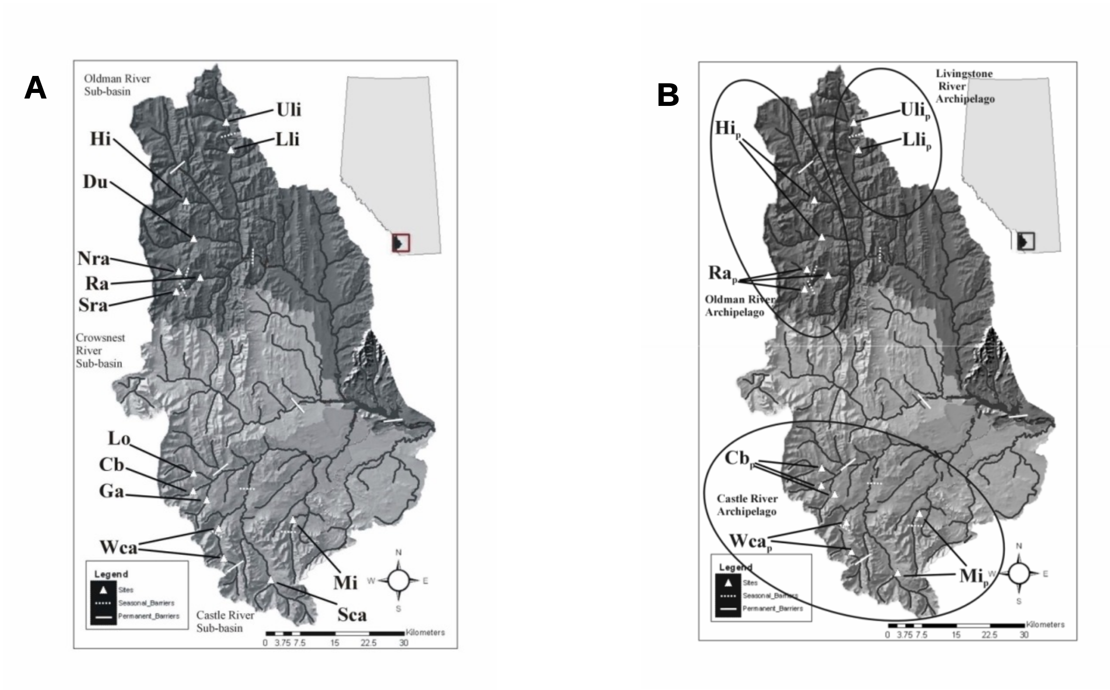

Figure 3. Maps showing Oldman River and Castle River HUC boundaries in red and locations of bull trout populations defined based on: A) streams-of-origin; and B) individual clustering analysis (adapted from Warnock 2008).

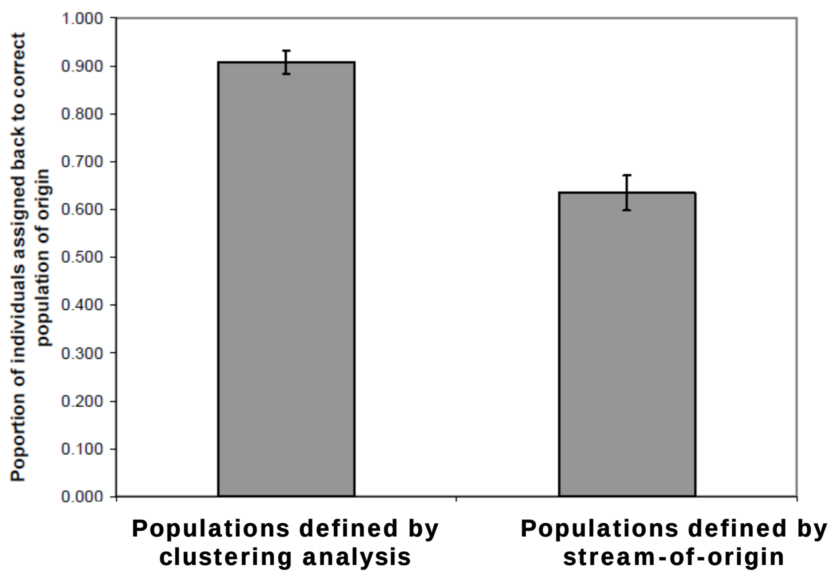

Figure 4. Total proportions of individuals successfully self-assigned to their population.

<u>Genetic distinction rank = 4: Clearwater River bull trout (no genetic data)</u>

Genetic data have not been collected for bull trout in the Clearwater River. Therefore, the genetic distinction assessment will rely on the findings of population genetic studies from other regions and professional opinion based on the current knowledge of the system. In general, the spatial extents of bull trout populations tend to encompass 4th order or adjacent 4th order streams when there are no natural barriers to movement (Warnock 2008; Taylor 2010; Taylor 2012). The Clearwater River 8-digit HUC contains several 4th order or adjacent 4th order streams (Figure 5) in which bull trout have been captured, and so it is assumed that there is more than one bull trout population in the HUC. Additionally, there have been no reports of uncommon life history and morphological characteristics and no known movement barriers. Therefore, the HUC is ranked a 4 for genetic distinction.

Figure 5. Stream network within the Clearwater River HUC showing 4th order streams (orange lines) and locations of captured bull trout (open circles).

Genetic distinction rank = 4 & 5: Athabasca River basin Arctic grayling (genetic data)

Arctic grayling population structure in the Athabasca River basin was investigated using genetic variation at nine microsatellite markers (Reilly 2014). Self-assignment rates were compared when individuals were grouped based on their capture location (Figure 5b) and by two configurations of river basin (Figure 6c-d). Grouping individuals by river basin (Mcleod and Athabasca rivers pooled) resulted in the highest self-assignment rate of 90% (Figure 7). However, this rate was not significantly different from the rate when the Mcleod and Athabasca rivers were treated separately (self-assignment rate = 86%, t-test, P=0.79). From this analysis, we conclude that populations tend to span multiple 8-digit HUCs (Figure 6a) and tend to be encompassed by 6-digit HUCs. Additionally, there have been no observed differences in life history or morphological characteristics. Therefore, all 8-digit HUCs that contain sampled Arctic grayling are ranked a 5 for genetic distinction, with the exception of the Freeman River HUC. The Freeman River HUC contains one population (self-assignment rate of 91%) and is ranked a 4 for genetic distinction.

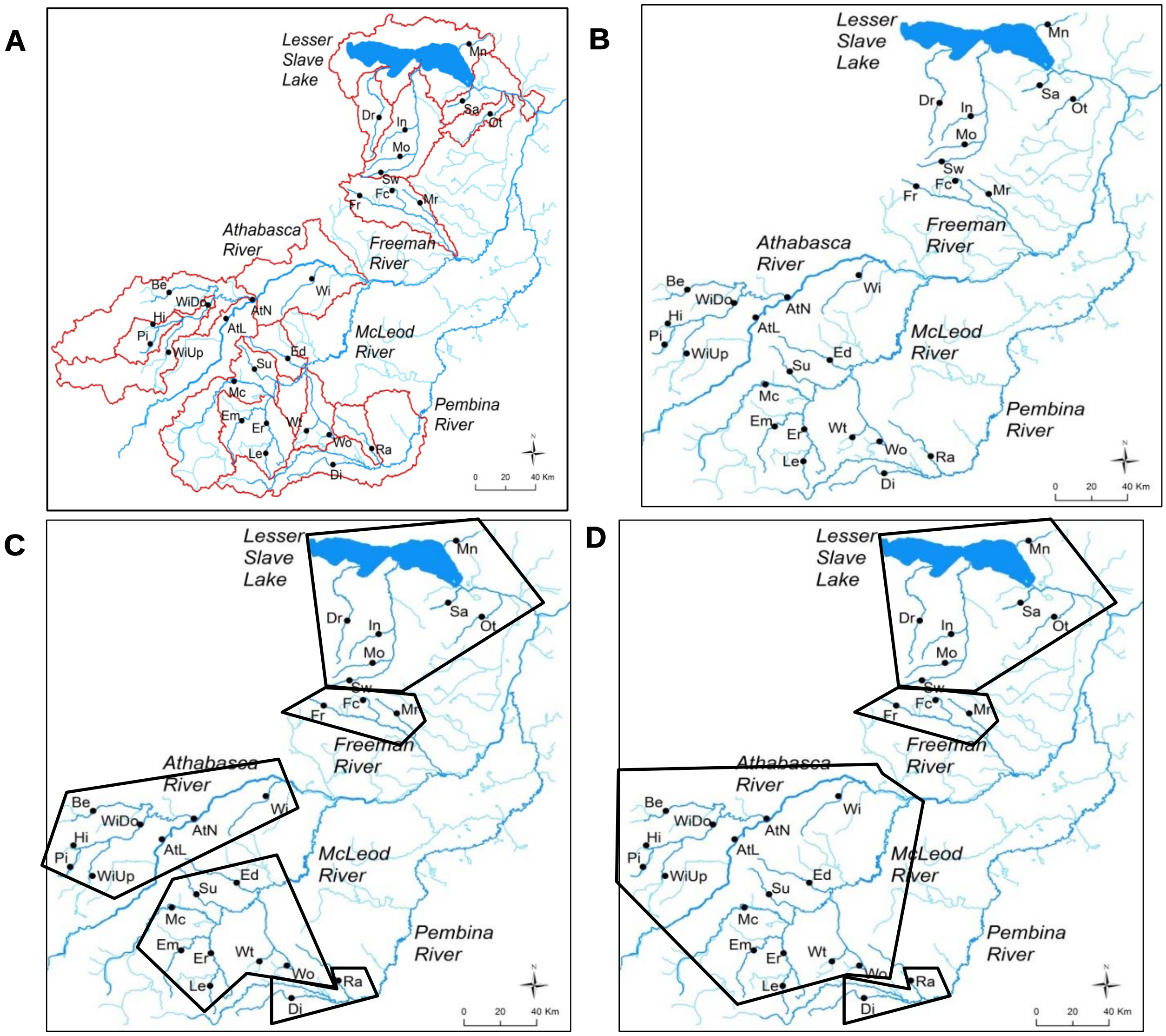

Figure 6. Maps showing Athabasca River basin HUCs (A) and locations of Arctic grayling populations defined based on: B) capture location; C) river basin; and D) river basin with Mcleod and Athabasca rivers pooled (adapted from Reilly 2014).

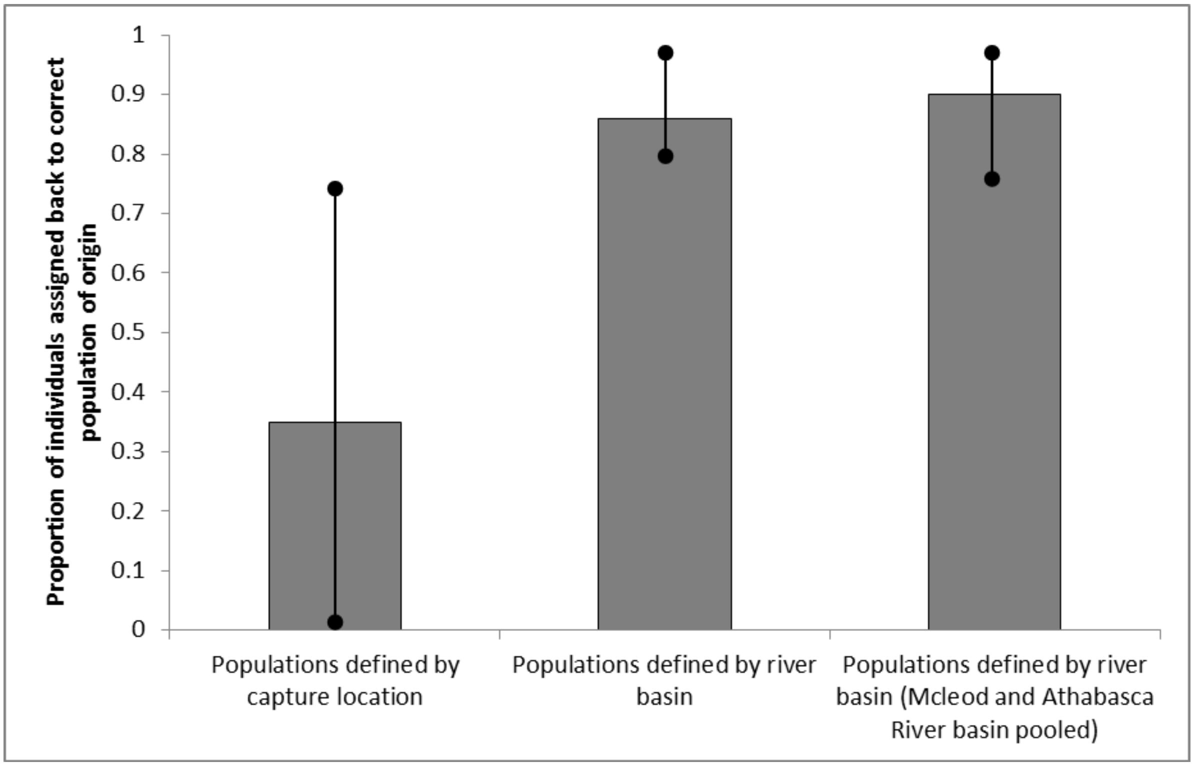

Figure 7. Total proportions of individuals successfully self-assigned to their population.

2.2.3 Ecological Integrity Category

Ecological integrity metrics address how changes in *other* fish in the focal fish species' community are impacting the focal fish. A sample of, or at least knowledge of, the entire fish community of which the focal fish species is a part of is required, but ranking of these metrics is qualitative. They have been included in the FSI largely because biologists are often concerned about these types of changes in the ecosystem. Unfortunately, although biologists suspect such ecosystem level changes have occurred, we do not have many substantiated Alberta examples of these ecosystem-level shifts.

I. Changes to Predators, Prey and Competitors Metrics

These three metrics individually address whether the focal fish's predators, prey, and competitors are the same as they would be in a sustainable, undisturbed population. Differences over the focal species' entire life cycle and in both species composition and abundance are considered. Native, non-native, and exotic invasive fish should be considered as predators, prey, and competitors. Ultimately, you're trying to answer the question, has the community changed enough that recovery will be problem or prevented in the future? For instance, how will the ecological integrity of the fish community change with the presence of Prussian carp in the Bow River? In this situation, the effects of an exotic fish species would not only be considered in changes to focal fish's predators, prey and competitors metrics, but also in the exotic species threat metric in the threat mitigation group.

Even non-fish predators and competitors should be considered in some cases (e.g., double-crested cormorants). Keep in mind that predators at an early life stage may become prey at a later life stage. For example, forage fish may prey on young walleye fry shortly after they hatch, but as the young walleye grow larger the forage fish switch from being predators to prey. Many Alberta lakes have seen recruitment failures resulting from overfishing decreasing the number of walleye preying on forage fish, which in turn has led to a large number of walleye fry being consumed by forage fish (e.g., Lac La Biche yellow perch, Pigeon Lake emerald shiners, Ethel and Wolf lake spottail shiners; see Sullivan 2003). In these situations, a predator change threatens the sustainability of the walleye population (forage fish eating fry) so the FSI "Change in Predators" metric might be ranked as a one, while the FSI "Change in Prey" metric might still be ranked as five (no depletion of prey, there are actually more prey because of fewer walleye predators).

Qualitative rankings of the ecological integrity metrics are provided below (Table 7) and in the Access load form. Beyond the example provided above, no further examples are given, as few cases of these types of interactions have been clearly demonstrated in Alberta. To aid in metric rankings it may also useful to visualize fish species presence in a waterbody using in ArcGIS or IMF.

Table 7. Alberta Fish Sustainability Index rankings for changes to the focal fish's predators, prey, and competitors metrics in the ecological integrity category of the population integrity group.

Predator Ranks: Have predators changed from undisturbed state, threatening sustainability of the stock?
1 = focal species has voracious new predator in high numbers or its native predator has been completely lost 2 = focal species has new predator that is becoming more common or its native predator is becoming rare 3 = focal species has mostly the same predators, but in different abundances 4 = focal species has same predators, moderately different abundances 5 = no changes (focal species has same native predators in similar numbers)

Prey Ranks: Have prey changed from undisturbed state, threatening sustainability of stock?
1 = focal species has lost its native prey
2 = focal species has different prey (some still native)
3 = focal species has mostly same prey, but different abundances
4 = focal species has same prey, moderately different abundances
5 = no changes (focal species has same prey, similar abundances)

Competitors Ranks: Have competitors changed from undisturbed state, threatening sustainability of stock?
1 = new species completely outcompetes focal species
2 = focal species has different competitors (some still native)
3 = focal species has mostly same competitors, different abundances
4 = focal species has same competitors, moderately different abundances
5 = no changes (same competitors, similar abundances)

2.3 FSI Section 3: Productive Potential Group

The productive potential group of metrics addresses how the size and productivity of a population's habitat protects or endangers it with respect to human disturbances. Larger populations in more productive habitats will be more resilient to anthropogenic influences than those in smaller, less productive habitats (e.g. Hilderbrand and Kershner 2000, Rieman et al. 2007). Within the productive potential group of metrics there are three metrics to consider: geographic extent, and natural and anthropogenic habitat limitations to productivity.

i. Geographic Extent Metric

While an HUC represents all connected sections of river and stream where a contiguous fish population could potentially occur, the geographic extent of this population within an HUC represents only where the fish is known or suspected to be commonly found. In most cases biologists will assume the geographic extent of a population will be the same as that of its HUC, but in some cases there will be evidence indicating it is less. Unlike the HUC, the geographic extent of a population should not include its pre-disturbance distribution, since the purpose of this metric is to identify to what extent the focal species has a restricted distribution and therefore a greater risk of extirpation. For example, if historical human impacts have restricted the distribution of bull trout in a particular HUC to just the headwaters, the geographic extent of this population would be a fraction of the extent of the entire HUC.

The geographic extent of lotic fish species is most often assessed in terms of linear extent, e.g. U.S. Fish and Wildlife Service (Fredenberg et al. 2005) and Trout Unlimited (Williams et al. 2007). However, given large differences between species-specific life history and habitat requirements of focal fish species, defining geographic extent breakpoints for the five FSI ranks for lotic HUCs was difficult. For example, Trout Unlimited's Conservation Success Index (Williams et al. 2007) uses different categories (< 10 km, 10-20 km, 20-30 km, 30-50 km, > 50 km), but these categories are not as broadly applicable to the FSI because they are too small in size. Therefore, although linear extent is reported in the FSI, rankings are primarily made using qualitative categories combined with knowledge of species-specific life history and habitat requirements (Table 8)

Table 8. Alberta Fish Sustainability Index rankings for the geographic extent metric of lotic populations within Hierarchical Unit Code (HUC) watersheds in the productive potential group.

FSI Rank	Lotic Watershed Description	Risk Assessment Rank
1	Habitat specialist or currently restricted to habitat within a very small proportion of the watershed (<20%)	Very High
2	Habitat specialist or only occupies 20-50% of the watershed	High
3	Occupies 50-70% of the watershed	Moderate
4	Habitat generalist or occupies a large proportion of all lotic habitats within the watershed (70-90%)	Low
5	Habitat generalist, completely ubiquitous throughout the watershed	Low

Geographic extent breakpoints defining the five FSI ranks for lentic waterbodies were developed by Sullivan (2009) using the relation between lake size and angler effort. Using data from creel surveys at 111 walleye fisheries in Alberta, Sullivan (2009) observed a decline in angler effort (i.e., hours per ha) with increasing lake size. Natural breakpoints in this decline were used to define five lake size sustainability classes (i.e., <750 ha, 750-1500 ha, 1500-4500 ha, 1500-10000 ha, >10000 ha). To ensure these sustainability classes made sense, Sullivan (2009) simulated FWIN catch rates in each of the size classes using FishSim, a computer model designed by John Post, Andrew Paul, and others at the University of Calgary (Post et al. 2003). Populations were simulated for 50 years assuming catch-and-release angling with 10% loss due to hooking mortality and illegal harvest. For each of the five lake size classes (i.e., the five proposed sustainability classes) the average angling effort (h/ha) that was applied during the simulations was the average effort in that size class from the 111 creel surveys. At the smallest lake size class (< 750 ha), within 20 years the FWIN catch rates declined to levels of the lowest population density suitability class (see walleye life history parameters and threshold standard and Sullivan 2009). The next smallest lake size class (750-1500 ha) showed a more gradual decline in FWIN catch rate, but still after 20 years the average catch rate declined to levels in the second lowest population density suitability class (see walleye life history parameters and threshold standard and Sullivan 2009). So simulations at these two lake size classes showed that at average angling pressure a catch-and-release fishery was still not sustainable. Simulation results for the remaining three lake size class (1500-4500, 4500-10000, and >10000 ha) also showed strong correspondence between FWIN catch rates after 20 years and the population density suitability class proposed in the walleye life history parameters and threshold standard. It is assumed the lake size breakpoints developed by Sullivan (2009) can be applied to all lentic species in Alberta.

The ranking criteria for the geographic extent of populations are fairly broad, which should allow biologists to categorize their HUCs and lakes relatively easily. To determine the linear extent of lotic populations, estimate the total length of occupied stream. Estimates are done using GIS either using a tool such as Utility Network Analyst. Biologists should contact their RIUs for GIS assistance if they are unable to do these measurements themselves. Note that when determining the geographic extent of lotic HUCs that include lakes, simply determine the linear extent of the occupied habitat measuring a straight line through the lakes from inlet to outlet. To determine the aerial extent of lentic HUCs, the surface areas of these habitats should be determined. Ranks for lotic and lentic populations are provided in the Access load form (Table 9). Where populations lie on the boundary between categories, choose the lower rank.

Table 9. Alberta Fish Sustainability Index rankings for the geographic extent metric of lentic populations within Hierarchical Unit Code (HUC) watersheds in the productive potential group.

FSI rank	**Lentic Area (ha)** (Sullivan 2009)	**Risk Assessment Rank**
1	<750	Very High
2	750-1,500	High
3	1,500-4,500	Moderate
4	4,500-10,000	Low
5	>10,000	Low

ii. Natural and Anthropogenic Habitat Limitations to Productivity Metrics

The second and third metrics in the productive potential group of metrics assess the productivity of all fish habitat within the HUC, including occupied and unoccupied habitat. These metrics assesses whether the overall productivity of the habitat is as high as it can be in Alberta or whether it is limited by natural or anthropogenic factors. Ranking is subjective, but biologists are asked to integrate available information and use their best judgment. Broad categories of habitat limitations to consider are water quantity (river flows and lake levels), water quality (temperature and growing degree days, dissolved oxygen, sediment), and the amount or quality of critical habitat (e.g., spawning, rearing, feeding, cover). The natural limitations metric was created to capture limiting factors in the absence of human influence. Although this may be difficult to assess, it should represent your best estimate of fish habitat in the absence of any anthropogenic disturbance. For the anthropogenic metric, the effects of angling and commercial harvest should not be considered, and only the effects of human habitat disturbance. To provide some direction to a biologist when ranking their HUCs, the table below outlines whether temperature and dissolved oxygen are natural and anthropogenic factors that can be limiting habitat productivity for the fourteen FSI priority fish species (Table 10). A map of average annual growing degree days above 5°C for Alberta is also provided (Figure 8).

Table 10. Limitations of high and low temperature (Hi and Low temp) and low dissolved oxygen (Low DO) to the habitat productivity of fourteen priority Alberta Fish Sustainability Index fish species.

	Natural productivity limitations			**Anthropogenic productivity limitations**		
Species	**Hi temp**	**Low temp**	**Low DO**	**Hi temp**	**Low temp**	**Low DO**
BLTR	X		X	X		X
Le-WALL		X				X
CTTR	X		X	X		X
LKST		X	X	X		X
Ath-RNTR	X		X	X		X
ARGR	X		X	X		X
Lo-WALL	X	X	X		X	X
GOLD/ MOON		X				X
NRPK		X	X	X		X
LKTR	X		X			X
MNWH	X		X	X		X
LKWH	X		X	X		X
YLPR		X				X
SAUG		X	X			X
BURB	X		X	X		X

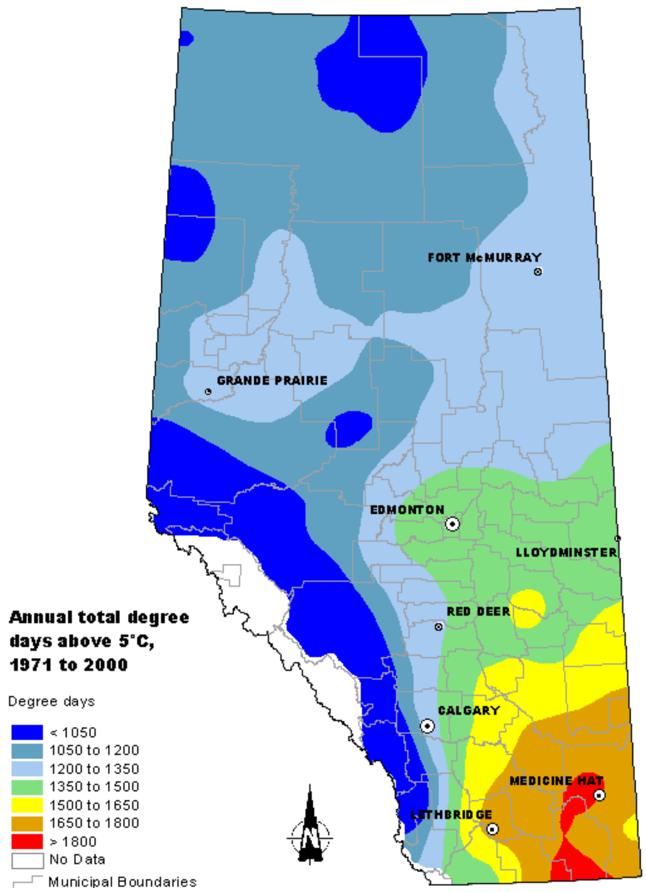

Figure 8. Annual total growing degree days above 5°C, 1971 to 2000, for the province of Alberta. Data from Environment Canada, Alberta Environment, and the U.S. National Climate Data Centre.

To further assist biologists rank the habitat limitations to productivity of their HUCs and lakes, the following table provides some examples of naturally high and anthropogenically low productivity habitats for the fourteen priority FSI fish species (Table 11).

Table 11. Examples of naturally high and anthropogenically low productivity habitats for the numerous priority Alberta Fish Sustainability Index fish species.

Species	Naturally high productivity habitat	Anthropogenically low productivity habitat
Bull trout	*Adfluvial populations*: Jacques Lake (JNP) and Marie Lake (Willmore). Despite their northern latitude and montane surroundings they still support high densities (~20 fish/ha) and high angling CUEs (12 to 2 fish/h) (Sullivan et al. 2005 and Sullivan 2007). *Fluvial populations*: Castle and Oldman river basins in southwestern Alberta (pre-human disturbance). Likely was some of Alberta's most productive bull trout habitat given its southern latitude. Recent electrofishing CUEs as high as 1.8 fish/100 seconds (Blackburn 2008, 2009).	*Adfluvial population*: Crowsnest Lake. The main inflowing tributary, Crowsnest Creek, has been channelized and rerouted to alleviate flooding the railway. This may have removed critical spawning habitat. Extirpation was also due to overharvest and stocking lake trout and book trout. *Fluvial population*: Crowsnest River. Wastewater inputs, channelization, heavily disturbed landscape (Frank Slide, coal mining, forestry, urban development). Extirpation was partly due to over harvest, but the habitat may no longer support bull trout (spawning habitat may be gone).
Lentic walleye	Lakeland district: Wolf and Seibert lakes. These lakes, southeast of the Primrose Lake Air Weapons Range, have undeveloped shorelines and drainage basins entirely owned by the federal or provincial governments. Access is limited.	Lake Isle west of Edmonton experiences frequent summer and winter fish kills. It is believed that this is primarily due to high levels of anthropogenic nutrient input (i.e. phosphorus) from the surrounding landscape which results in increased algal growth.
Cutthroat trout	Castle and Oldman river basins in southwestern Alberta. Pre-human disturbance was likely Alberta's most productive habitat given its southern latitude. Recent electrofishing has found 265.5 fish/km and 112.2 sexually mature fish/km (Blackburn 2008).	Creeks draining the Livingstone/Porcupine Hills in southwestern Alberta. Many use to support strong populations, but no longer due to heavy grazing and OHV impacts (even non-native rainbow are gone). Examples include Callum Creek, Beaver Creek, Todd Creek, and Trout Creek.
Lake sturgeon	North and South Saskatchewan Rivers	Downstream of Edmonton and Calgary before sewage treatment (low dissolved oxygen). Low flow periods on the South Saskatchewan River during droughts.
Athabasca rainbow trout	Tri-Creeks area west of Jasper National Park: Wampus Creek, tributary of the McLeod River. Supports some of the highest densities of this species.	Carrot Creek once supported a strong population of Athabasca rainbow trout (Mayhood 1992). Now thought to be extirpated, due to agricultural impacts and winter kill (Michael Sullivan, pers. comm.).
Arctic grayling	Little Smoky River, a tributary of the Smoky and Peace rivers. The most productive southern Arctic grayling population in Alberta (Stanislawski 1997). Large sizes (up to 450 mm) and high densities (angling CUE up to 10 fish/hr, Sullivan unpublished data).	Tawatinaw River, a tributary of the Athabasca River south of the town of Athabasca. A 1996 historical survey of fisheries indicated it once supported an abundant population of grayling. Recent surveys suggest population now extirpated or close to it (electrofishing by David Park and Michael Sullivan, pers. comm.).

Table 11 continued.

Lotic walleye	North and South Saskatchewan Rivers and major tributaries	Battle River once supported a strong population of walleye (David Christiansen, pers. comm.), but due to agricultural impacts and winter kill the species in now rarely observed in this system. In a recent study by the ACA walleye were only captured at upstream sites south of Pigeon Lake and downstream sites east of Highway 36. Walleye were most abundance at downstream sites around CFB Wainright (65 of 79 were caught east of highway 36: 82%), while none were observed north of Red Deer where agricultural intensity is greatest (Stevens and Council 2008).
Goldeye and mooneye	North and South Saskatchewan Rivers and major tributaries	See above for lotic walleye. Except for one fish west of highway 36, goldeye and mooneye were only observed around CFB Wainright (Stevens and Council 2008), although they were once distributed much further upstream (Nelson and Paetz 1992).
Lake trout	Cold Lake	Lesser Slave Lake: Lake trout were present in Lesser Slave Lake, but were extirpated in the 1920s, probably due to overharvest by the commercial fishery (Nelson and Paetz 1992). Dissolved oxygen levels are now too low in the lake to reintroduce the species (Mitchell and Prepas 1990).
Mountain Whitefish	In 1996, in the Sheep River by Black Diamond the population was estimated at 1629 fish/km (Buchwald and Willis 2004)	Bearberry Creek near Sundre has been drastically altered due to the effects of the surrounding agricultural landscape and extensive channelization within the town of Sundre (V.Buchwald pers. comm.).

Ranks for natural and anthropogenic habitat limitations to productivity are provided in the Access load form (Table 12).

Table 12. Alberta Fish Sustainability Index rankings for natural and anthropogenic habitat limitations to the productivity of Hierarchical Unit Code (HUC) watersheds metric in the productive potential group.

FSI Ranks for Natural Limitations to Habitat Productivity	**Risk Assessment Rank**
1 = Severely limited, barely sustainable. Recruitment failures or winter or summer fish kills are naturally recurring.	Very High Risk
2 = High level of natural habitat limitation, natural recruitment failures or fish kills likely.	High Risk
3 = Moderate level of natural habitat limitation, natural recruitment failures or fish kills rare.	Moderate Risk
4 = Low level of natural habitat limitation, no natural recruitment failures or fish kills.	Low Risk
5 = Among the most productive habitats for this species in Alberta, or was prior to human habitat disturbance. Supports or could support (without human habitat disturbance) one of the strongest populations in Alberta.	Low Risk

FSI Ranks for Anthropogenic Limitations to Habitat Productivity	**Risk Assessment Rank**
1 = Due to human disturbance, the habitat no longer supports the fish species or its population is barely sustainable with recurring recruitment failures or winter or summer fish kills.	Very High Risk
2 = High level of human habitat disturbance, recruitment failures or fish kills likely.	High Risk
3 = Moderate level of human habitat disturbance, no recruitment failures or fish kills yet.	Moderate Risk
4 = Low level of human habitat disturbance, recruitment failures or fish kills unlikely.	Low Risk
5 = No anthropogenic habitat limitations, fish habitat is undisturbed by humans. Not necessarily the most productive habitat in Alberta, but productivity is not limited by humans.	Low Risk

Although unlikely, it is possible an HUC could be ranked as a 1 for natural habitat limitations but 5 for anthropogenic habitat limitations, or vice versa, ranked as a 5 for natural and 1 for anthropogenic limitations. For example, walleye in the McLeod River are at the far western limits of the species native range and naturally the habitat productivity is very low, but anthropogenically there has been very little disturbance to this low productivity. Conversely, Buffalo Lake north of Stettler and the main northern pike spawning area Spotted Lake were once naturally productive habitats, but this is believed to no longer be the case due to a series of water management projects. Specifically, control structures, channel dredging, and drawing large quantities of water for agricultural purposes.

2.4 FSI Section 4: Threats and Threat Mitigation Group

Habitat loss resulting from human activities, overharvest by recreational and commercial fisheries, and impacts of exotic species (introduced fish, invertebrates, algae, diseases and parasites that could or do threaten the focal species) are all considered in the threats and threat mitigation group of FSI metrics. Note that the exotic threat faced by the focal species should still be ranked even if that species is itself introduced (e.g., walleye in prairie reservoirs threatened by perch) (Table 13).

Ranks in each category are meant to denote both the severity of these human-caused threats and the effectiveness of our management actions in mitigating the threats. Ranks are mostly qualitative, but should be based on available land use data, land use practices and policies, knowledge of angler pressure, sportfishing regulations and FWMIS records.

For instance, when ranking Habitat Protection Need and Habitat Protection Available, biologists could consult land ownership classes, protected areas, and Codes of Practice layers in GIS to visualize the current level of habitat disruption and protection available in a HUC or surrounding a lake. Further, since proximity to major and minor urban centers is often a surrogate for angling pressure, when ranking Overharvest Protection Need biologists could create buffers around urban centers in GIS to determine overharvest risk to a fishery. As a last example, if non-native trout were considered an exotic threat to a focal fish species, FWMIS records could be pulled and mapped in GIS to determine the distribution and severity of the Exotic Species Threat metric.

Table 13. Alberta Fish Sustainability Index rankings for the need and availability of habitat and overharvest protection and the threat of exotic species metrics in the threat mitigation group.

FSI Ranks for Habitat Protection Need	Risk Assessment Rank
1 = Protection badly needed, severe and imminent threats.	Very High Risk
2 = Significant need for protection. Severe threats, but not imminent.	High Risk
3 = Normal threats, neither severe nor imminent.	Moderate Risk
4 = Minimal threats, additional protection could be afforded, but not a priority.	Low Risk
5 = No threats, no additional protection needed.	Low Risk

FSI Ranks for Habitat Protection Availability	Risk Assessment Rank
1 = Little effective protection (e.g., industry operates under 'Green Zone' exemption or land privately owned with little restriction on land use or riparian setbacks)	Very High Risk
2 = Some protection, land management plan in place (e.g., FLUZ), industry complies with Water Act Code of Practice for Watercourse Crossings	High Risk
3 = DFO and AENV involved in site-specific review and approval of any point-source activities impacting fish habitat (i.e., Class 'A' habitat designation), but there is no landscape control	Moderate Risk
4 = Government or NGO has landscape control, limited agriculture, industry, or development	Low Risk
5 = Government has landscape control, foot access only, no agriculture, industry, or development of any kind	Low Risk

Table 13 continued.

FSI Ranks for Overharvest Protection Need (a measure of effective fishing effort)	Risk Assessment Rank
1 = Accessible by 2WD, within 2 hour drive from Calgary or Edmonton (e.g., Pigeon Lake, Lac Saint Anne, Bow River, Lake Newell, Crowsnest River)	Very High Risk
2 = Accessible by 2WD, within an hour of Lethbridge, Grand Prairie, Red Deer, Fort McMurray, or Medicine Hat (e.g., Sturgeon Lake, South Saskatchewan River)	High Risk
3 = Further from cities but still accessible by 2WD (North and South Wabasca lakes, Lesser Slave Lake, Calling Lake, Upper Oldman watershed: Castle, Oldman, Livingstone rivers)	Moderate Risk
4 = OHV access only (Upper Blackstone River north of Nordegg)	Low Risk
5 = No road access (Willmore Wilderness Park) or restricted access areas (CFB Wainwright, Primrose Air Weapons Range)	Low Risk

FSI Ranks for Overharvest Protection Available	Risk Assessment Rank
1 = General provincial regulations	Very High Risk
2 = Waterbody-specific bag/size limits in place	High Risk
3 = Harvest controlled by Special Harvest License tags	Moderate Risk
4 = Catch and release regulations in place	Low Risk
5 = Angling is fully controlled, closed to the public	Low Risk

FSI Ranks for Exotics Threat	Risk Assessment Rank
1 = severe threat (e.g., in system now)	Very High Risk
2 = high threat (e.g., in closely connected system)	High Risk
3 = moderate threat (e.g., in distantly connected system)	Moderate Risk
4 = low threat (e.g., in area, but not in connected system)	Low Risk
5 = no significant threats (e.g., possible but none currently in area or species present but not considered a threat)	Low Risk

2.5 FSI Sections 2-4: Data Reliability Group

i. Monitoring Quality, Quantity and Timeliness Metrics

In each of the three sections of the load form described above there is also an area where metrics relating to monitoring and vigilance (date of most recent field work) are evaluated. This addresses how likely the assessment is erroneous due to incorrect, inaccurate, or lacking data. The three monitoring metrics considered are monitoring quality, monitoring quantity, and monitoring timeliness. The majority of FSI ranks are all qualitative, subjective, and relatively straightforward to assign. Note that in cases where the focal fish species was never surveyed in an HUC, a zero score is permitted for the timeliness metric. These ranks are provided in the Access load form (Table 15).

Table 14. Alberta Fish Sustainability Index rankings for the quality and quantity of monitoring data and the timeliness of these data metrics in the data reliability group.

FSI Ranks for Monitoring Quality (Is the data precise and accurate?)
1 = Imprecise and inaccurate 2 = Precise but inaccurate data 3 = Accurate but imprecise 4 = Likely OK 5 = Precise and accurate
FSI Ranks for Monitoring Quantity (Is sufficient data available to evaluate this metric?)
1 = No data 2 = Insufficient data 3 = Moderately sufficient data 4 = Nearly sufficient data 5 = Sufficient data
FSI Ranks for Monitoring Timeliness (How likely is it the population being assessed is functionally different from when the last field data were collected?)
0 = The focal fish species has never been surveyed in this HUC (overall score) 1 = Extremely different 2 = Very different 3 = Moderately different 4 = Slightly different 5 = Not different

By assessing each individual metric with these ranks, it allows for biologists to easily see which areas of their FSI are weakest and provides them with direction in terms of where to focus future data collection. Low reliability rankings should be flagged for future work.

3.0 Summary

The Alberta Fish Sustainability Index (FSI) is a standardized process that brings consistency to individual stock assessments province-wide. This level of evaluation allows for a landscape-level assessment and broad temporal comparisons of fish sustainability and status. Further, it assists in planning fisheries management priorities and actions.

Diligently following the above outlined generic rule set and revising it when necessary, will allow for provincially reliable and scientifically defensible fish stock assessments.

4.0 References

AESRD. 2012. Alberta's Biodiversity Management System. Internal Draft prepared by H. Norris. 65 p.

ASRD. 2002. Status of the lake sturgeon (*Acipenser fulvescens*) in Alberta. Alberta Sustainable Resource Development, Fish and Wildlife Division, and Alberta Conservation Association, Wildlife Status Report No. 46, Edmonton, AB. 30 p.

Berndt, D. 1990. Rock Lake weekend creel survey July 8 – August 27, 1989. Department of Forestry, Land, and Wildlife, Fish and Wildlife Division, Edson, Alberta.

Blackburn, J. 2008. Population abundance and stock assessment of westslope cutthroat trout in the Upper Oldman River watershed. Data report, D-2008-009, produced by the Alberta Conservation Association, Lethbridge, Alberta, Canada. 38 p + App.

Buchwald, V.G., and J.M Willis. 2004. Sport fish population studies in the Highwood River watershed, 1995-96. Alberta Sustainable Resource Development, Fish and Wildlife Division, Red Deer, Alberta. 100p.

Burke, L.A. 2010. Genetic population structure of Walleye (*Stizostedion vitreum*) in northern Alberta and application to species management. M.Sc. Thesis, University of Alberta, Edmonton, Alberta. 99p.

COSEWIC. 2009. COSEWIC's Assessment Process and Criteria (Updated May 2009). COSEWIC committee . Canadian Wildlife Service Environment Canada Ottawa, Ontario. see http://www.cosepac.gc.ca/eng/sct0/assessment_process_e.cfm

Earle, J.E., A.J. Paul, and J.D. Stelfox. 2007. Quirk Creek Population Estimates and One-pass Electrofishing Removal of Brook Trout, 2005 and 2006. Fish and Wildlife Division, Alberta Sustainable Resource Development. Cochrane, Alberta. 61 p.

Fitch, L.A. 1997. Bull trout in southwestern Alberta: notes on historical and current distribution. Pages 147-160. *In:* W.C. Mackay, M.K. Brewin, and M. Monita, editors. Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), *c/o* Trout Unlimited Canada, Calgary, Alberta.

Fredenberg, W., J. Chan, and J., Young. 2005 Bull Trout Core Area Conservation Status Assessment. U.S. Fish and Wildlife Service, Portland, Oregon.

Hildebrand, R.H., and J.L. Kershner. 2000. Conserving inland cutthroat trout in small streams: how much stream is enough? North American Journal of Fisheries Management 20:513:520.

IUCN. 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK.

IUCN. 2008.Strategic Planning for Species Conservation: A Handbook. Version 1. The Species Conservation Planning Task Force, Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK.

Jamieson, I.G. and F.W. Allendorf. 2012. How does the 50/500 rule apply to MVPs? Trends in Ecology and Evolution 27: 578-584.

Johnston, F.D. and J.R. Post 2009. Density-dependent life-history compensation of an iteroparous salmonid. Ecological Applications, 19: 449–467.Lethbridge, Alberta, Canada. 29 p. + App.

Mayhood, D. W. 1992. A preliminary assessment of the native fish stocks of Jasper National Park. Part 3 of a fish management plan for Jasper National Park. Report prepared for the Canadian Parks Service, Jasper National Park, Jasper, Alberta, by Freshwater Research Limited, Calgary, Alberta. 296 p. + maps.

Mitchell, P., and Prepas, E.E. 1990. Atlas of Alberta lakes. University of Alberta Press, Edmonton, Alberta.

Montana Natural Heritage Program. 2004. Montana State Rank Criteria. Montana Natural Heritage Program, Helena, MT. see http://mtnhp.org/animal/2004_SOC_Criteria.pdf

Morgan, G.E. 2002. Manual of instructions – Fall Walleye Index Netting (FWIN). Ontario Ministry of Natural Resources, Percid Community Synthesis Diagnostics and Sampling Standards Working Group. 35 p.

Muhlfeld, Clint C., Steven T. Kalinowski, Thomas E. McMahon, Mark L. Taper, Sally Painter, Robb F. Leary, and Fred W. Allendorf. 2009. Hybridization rapidly reduces reproductive success of a native trout in the wild. Biology Letters. Published online: 03/18/09 (doi:10.1098/rsbl.2009.0033).

NatureServe. Faber-Langendoen, D., L. Master, J. Nichols, K. Snow, A. Tomaino, R. Bittman, G. Hammerson, B. Heidel, L. Ramsay, and B. Young. 2009. NatureServe Conservation Status Assessments: Methodology for Assigning Ranks. NatureServe, Arlington, VA. see http://www.natureserve.org/publications/ConsStatusAssess_RankMethodology.pdf

Nelson, J., and M. Paetz. 1992. The Fishes of Alberta. 2nd edition. University of Alberta Press, Edmonton, Alberta.

Post, J. R., C. Mushens, A. Paul, and M. Sullivan. 2003. Assessment of alternative harvest recreational fisheries: model development and application to bull trout. North American Journal of Fisheries Management 23:22-34.

Reilly J.R., C.A. Paszkowski, D.W. Coltman. 2014. Population genetics of Arctic grayling distributed across large, unobstructed river systems. Transaction of the American Fisheries Society 143: 802-816.

Rieman, B.E., D. Isaak, S. Adams, D. Horan, D. Nagel, C. Luce and D. Myers. 2007. Anticipated Climate Warming Effects on Bull Trout Habitats and Populations Across the Interior Columbia River Basin. Transaction of the American Fisheries Society 136: 1552-1565.

Robinson, M. D. 2007. The ecological consequences of hybridization between native westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) and introduced rainbow trout (*O. mykiss*) in South Western Alberta. M.Sc. Thesis. University of Lethbridge, Lethbridge, AB.

Schindler, D.W., A.-M. Anderson, J. Brzustowski, W. F. Donahue, G. Goss, J. Nelson, V. St. Louis, M. Sullivan, and S. Swanson. 2004. Lake Wabamun: A Review of Scientific Studies and Environmental Impacts. Prepared for Alberta Environment, Edmonton, Alberta.

Spencer, S. C. 2010. The Increasing Prevalence of Smaller Fish in Highly Exploited Fisheries: Concerns, Diagnosis and Management Solutions. Ph.D. Thesis. Department of Biological Sciences, University of Alberta, Edmonton, Alberta. 91 p.

Stanislawski, S. 1997. Fall and winter movements of Arctic grayling (*Thymallus arcticus*) in the Little Smoky River, Alberta. M.Sc. Thesis. Department of Biological Sciences, University of Alberta, Edmonton, Alberta. 91 p.

Stevens, C., and T. Council. 2008. A fish-based index of biological integrity for assessing river condition in central Alberta. Technical Report, T-2008-001, produced by the Alberta Conservation Association, Sherwood Park and Lethbridge, Alberta, Canada. 29p. + App.

Sullivan, M. G. 2003. Management of Low-Productivity Fisheries: Collapse and Recovery of Alberta's Walleye (*Sander vitreus*) Fisheries. Ph.D. Thesis. Department of Biological Sciences, University of Alberta, Edmonton, Alberta. 173 pp.

Sullivan M. G. and M.F. Coombs. 2010a. Fisheries Management Branch Life History Parameters and Thresholds Standard: Walleye Population Reference Parameters. Draft report for Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, AB.

Sullivan M. G. and M.F. Coombs. 2010b. Fisheries Management Branch Life History Parameters and Thresholds Standard: Bull Trout Population Reference Parameters. Draft report for Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, AB.

Sullivan, M.G. 2009. Fisheries Management Branch, Life History Parameters and Thresholds Standard: Lake size as an indicator of walleye population sustainability. Unpublished report for Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, AB.

Sullivan M. G. and D. Park. 2008. Chapter 1 - Proposed Framework for Fish Population Status Assessment. Unpublished report for Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, AB.

Sullivan, M. G. 2007. Bull trout sampled from Jacques Lake, Alberta, December 2006 and January 2007. Memorandum to Ward Hughson, Aquatic Specialist, Jasper National Park, Parks Canada (on file in Edmonton, dated 8 January 2007).

Sullivan, M. G., C. F. Johnson, and W. Hughson. 2005. Quantifying thresholds of ecological integrity: population abundance and structure of bull trout *Salvelinus confluentus* in Jacques Lake, Alberta. Alberta Fish and Wildlife Division.

Taylor, E.B., P. Tamkee, G. Sterling, W. Hughson. 2007. Microsatellite DNA analysis of rainbow trout (*Oncorhynchus mykiss*) from western Alberta, Canada: native status and evolutionary distinctiveness of ‘‘Athabasca’’ rainbow trout. Conservation Genetics. 8:1–15.

Taylor, E.B. 2010. Microsatellite DNA analysis of populations of bull trout (*Salvelinus confluentus*) in the Upper Red Deer River Drainage, Alberta. Unpublished report from University of British Columbia Department of Zoology to Alberta Conservation Association, Rocky Mountain House, Alberta.

Taylor, E.B. 2012. Microsatellite DNA analysis of populations of bull trout (*Salvelinus confluentus*) in the North Saskatchewan River system, Alberta. Unpublished report from University of British Columbia Department of Zoology to Alberta Conservation Association, AB.

Thomas, J.E., C. Prozniak, R. Sandham, H. Kirk, L. Chew, and V. Buchwald. 1999. Genetic variation in populations of walleye (*Stizostedion vitrieum*) from Central Alberta. Prepared for the Fisheries and Wildlife Management Division, Natural Resources Service, Alberta Environment and the Alberta Conservation Association, University of Lethbridge, Lethbridge, AB. 38 p.

USFWS. 2003. Endangered and Threatened Wildlife and Plants: Reconsidered Finding for an Amended Petition To List the Westslope Cutthroat Trout as Threatened Throughout Its Range. Federal Register. 68:46989-47009.

Warnock, W.G. 2008. Molecular tools reveal hierarchical structure and patterns of migration and gene flow in bull trout (*Salvelinus confluentus*) populations of south western Alberta. M.Sc. Thesis. University of Lethbridge, Lethbridge, AB.

Williams, J.E., A.L. Haak, N.G. Gillespie, and W.T. Colyer 2007. The Conservation Success Index: Synthesizing and Communicating Salmonid Condition and Management Needs. Fisheries. 32: 477-493.