Assessing the vulnerability of wild rainbow trout (*Oncorhynchus mykiss*) stocks to overfishing in the Thompson Nicola Region of British Columbia

by

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Abstract

Overfishing is more commonly associated with commercial fisheries than recreational fisheries, but evidence increasingly suggests recreational fisheries are not immune. In my study, I use a generalized linear model to examine if wild stocks of rainbow trout *Oncorhynchus mykiss* in British Columbia's Southern Interior lakes are vulnerable to over-harvest from recreational anglers. Assuming high angling effort implies high harvest rates, I determined which factors make a lake attractive to anglers. Driving distance, lake productivity, and the presence of facilities such as resorts or campsites have the greatest influence on effort. My results suggest less than 10% of the 326 wild rainbow trout lakes I predicted fishing effort for in the Southern Interior are vulnerable to over-fishing. Lakes that are highly vulnerable to over-harvesting are located close to large population centers in the southern portion of the region, are moderately productive, and offer camping and resort amenities.

Acknowledgements

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Introduction

1.1 Overfishing in Recreational Fisheries

Recreational fisheries are typically viewed as immune to catastrophic collapses such as those that are, unfortunately, increasingly common in commercial and subsistence fisheries (Myers et al. 1997, Jackson et al. 2001, Pauly et al. 2002, Allan et al. 2005). While recreational fisheries are not driven by the same economic and social forces commonly cited as drivers of commercial fisheries, some recreational fisheries are increasingly experiencing too many anglers chasing too few fish (Cox et al. 2003). Many lakes have experienced declines in fish size and catch rates after years of exploitation from sport fishing, but managers are usually hesitant to classify sport fish populations as overfished (Post et al. 2002). Because few recreational fisheries are of strong singular importance, most management agencies do not have the resources to effectively monitor either the fishery or the fish stocks (Pereira and Hansen 2003). As a result, unnoticed incremental steps of over-harvesting could easily be occurring. Post et al. (2002) exposed the myth that recreational fisheries are immune to collapse and highlighted the need for a much more active management and assessment procedure for inland fisheries.

Regulation policy to prevent overharvesting in commercial fisheries typically involves determining the maximum sustainable yield, and then setting the fishing mortality rate. The task is difficult and often controversial for single, large-scale commercial fisheries, but is an overwhelmingly enormous task when dealing with multiple small-scale fisheries (Cox and Walters 2002*b*). Because biologists have rarely been able to monitor the total catch from individual lakes, they have instead tried to manage fishing effort. Typically, effort management for small lakes fisheries involves attempts to limit the effectiveness of anglers using bag limits, size limits, and restrictions on gear type. The effectiveness of fishing regulations in limiting harvest is often unknown, for while regulations may limit the harvest of individual anglers, regulations may not limit total angler harvest (Radomski et al. 2001, Cox and Walters 2002*b*, Post et al. 2003). In addition to the use of regulations, supplementation with hatchery fish has also been a standard response to a perceived or actual decline in fish abundance (Cooke and Cowx 2004). Stock collapses in some recreational fisheries may have been masked by the introduction of hatchery fish.

Managers are increasingly aware that hatchery introductions and fishing regulations are ineffective at maintaining high quality fishing. Catch and release or size limit regulations may be somewhat successful in influencing fish size, but influencing catch rates is very difficult in open-access fisheries. However, managers believe recreational fisheries are unlikely to experience recruitment overfishing because recreational fisheries show strong effort responses (Walters and Martell 2004, Post et al. 2002). Recreational anglers are motivated by the pursuit of quality leisure time (Holland and Ditton 1992), so it is assumed anglers will move on to other fishing opportunities or exit the fishery as fish become scarce (Radomski 2003, Beard et al. 2003). However, there is growing evidence to contradict this assumption, especially in heavily used, easily accessible recreational fisheries (Post et al. 2002, Sullivan 2003).

1.2 Overview of Recreational Fishing and Management in British Columbia

Fish stocks are at greater risk of overfishing now than they were in the past, when many of British Columbia's wild trout were protected from overfishing because they were hard to access by road or were located long distances from population centers. Increased development of lake-front property and expansion of road networks for forestry and mining will result in increased angling pressure on many previously remote lakes. Mottley (1932) noted that "it seems to be a general rule that after a motor road has been built to a new lake depletion begins to operate." Over-harvesting of exceptional trout fisheries was first observed close to travel routes in B.C.'s Interior in the early 1900's and led to the introduction of hatchery supplementation as well as regulation programs to conserve fish stocks (Mottley 1932). The federal Dominion Department of Fisheries started stocking lakes in the Kamloops area in 1909 (Mottley 1932) and a policy of extensive hatchery introductions and regulations was established by the provincial Game Commission when it was founded in 1937 (SFI 1955).

British Columbia has more than 10,000 lakes that offer fishing opportunities and less than 227,000 licenced anglers devoting their angling activity to lake fishing (Levey and Williams 2003). While it may appear that there are few anglers chasing many fish, managers should not assume that angling effort is too low to negatively impact fish stocks. Recreational fishing effort is not evenly dispersed across the province and more than 70% of the provincial recreational fishing effort occurs in the southern third of British Columbia (Levey and Williams 2003). Furthermore, Cox and Walters (2002*b*) argue that the critical angler effort levels that lead to population collapse in rainbow trout *Oncorhynchus mykiss* lakes is much lower than previously recognized. As a result, stocks may be at greater risk than formerly believed. While most fish populations in British Columbia are unlikely to completely collapse, unchecked effort and population collapses on a few provincial lakes may have devastating ripple effects over the entire provincial recreational fishery. Anecdotal reports of over-harvesting already exist for a few provincial lakes, and the collapse of kokanee *Oncorhynchus nerka* and burbot *Lota lota* stocks in Kootenay Lake is attributed to both changes to the lake environment and over-harvesting (Ahrens and Korman 2002, Andrusak 2002).

Provincial fisheries managers are receiving increasing pressure to bolster economic activity related to fishing by developing new angling opportunities. The key for managers is the almost impossible task of determining how to maximize the number of anglers while minimizing the impacts of their collective effort. Determining how to increase angler numbers is also an important question for British Columbia's fisheries agencies because hatchery and research funding are now directly linked to freshwater angling licence sales. While the link between funding and licence sales might be viewed as an incentive to encourage effort, fisheries managers will not want this growth to occur unfettered. Along with the serious negative environmental implications of collapsed fish stocks, there are negative economic implications. Poor fishing quality will likely cause a decline in anglers, and these anglers may not be willing to re-invest in the fishery once it is lost, even if fish stocks rebound and the fishery improves. Balancing conservation with recreational opportunities will require improved assessment of the vulnerability of wild rainbow trout stocks to overfishing.

1.3 Assessment of Recreational Overfishing

The definition of overfishing in recreational fisheries is usually ambiguous or poorly defined (Radomski et al. 2001). Overfishing is typically grouped into two categories: growth overfishing and recruitment overfishing (Hilborn and Walters 1992). Growth overfishing decreases the overall yield of the fishery, for fish are harvested at a smaller average size than the size which would produce the maximum yield-per-recruit. Recruitment overfishing is the more serious case of overfishing in which the adult population is overfished to the point that it has a reduced spawning stock and a correspondingly reduced reproductive capacity, leaving the stock vulnerable to collapse. Collapsed fish stocks may never return or take years to recover, resulting in a permanent or long-term loss in the associated fishery. Recruitment overfishing can have devastating consequences from both an economic standpoint and a biological standpoint, as demonstrated in the collapse of the east coast cod fishery. Few fisheries experiencing growth overfishing would be recognized as collapsed fisheries, as many of the fisheries continue to support high fishing effort and yield. A third classification of overfishing, quality overfishing, is used by some recreational fisheries managers (Radomski et al. 2001). Quality overfishing is non-standardized and varies according to the subjective definition of quality (Pereira and Hansen 2003). Angling quality is typically judged by the number of fish caught and size of the catch or the catch rate (Pereira and Hansen 2003, Parkinson et al. 2004).

Assessments of overfishing in recreational fisheries primarily focus on quality overfishing. Most assessments are done using creel surveys and focus on fish size and catch rates (Baccante 1995). However, the relationship between catch per unit effort (CPUE) and fish abundance on recreational lakes is not well understood. Post et al. (2002) found that angler catch rates are not always reflective of fish abundance until the fish population is near collapse. Beard and Kampa (1999) found catch rates for black crappie *Pomoxis nigromaculatus* and yellow perch *Perca flavescens* did not change during the 24 year time period of their study, and yellow perch catch rates increased slightly. No declines in catch rates occurred despite the fact that stock densities for bluegills *Lepomis macrochirus* and yellow perch declined over the same time period (Beard and Kampa 1999). Peterman and Steer (1981) found the catchability coefficient of recreational chinook *Oncorhynchus tshawytscha* sport fisheries on Vancouver Island increased as fish abundance decreased. They attributed the increase in catchability to the physically restricted environments of the rivers, which are searched effectively by the fishermen.

Fisheries managers are also aware that the distribution of catch amongst anglers from creel surveys is typically skewed, with a few anglers catching most of the fish and most anglers catching few or no fish. Baccante (1995) found that catch is most evenly distributed amongst anglers when total catch is high, and warned of the limited use of CPUE statistics due to the skewed distribution. Shuter et al. (1987) also cautioned managers to interpret CPUE data carefully, for after examining 48 years of creel survey data from Lake Opeongo, Ontario, the authors found population indices from catch per unit effort data could be distorted by temporal changes in angling skills. CPUE data for lakes that attract highly skilled anglers may suggest fish densities are higher than they really are. Additionally, if anglers are targeting smaller sized fish as the abundance of larger fish decreases, there may be no decrease in CPUE at all (Walters and Martell 2004).

Because the relationship between catch rates and abundance is poorly understood, creel surveys have rarely been used to determine fishing mortality rates. One creel study that did look at fishing mortality found the brook trout *Salvelinus fontinalis* population in Meach Lake, Ontario did not show symptoms of overexploitation, such as reduced angler harvest, despite annual fishing mortality rates averaging 50% (Curry et al. 2003). However, the authors acknowledged that overexploitation can be masked and may have been undetectable over a time period of only 7 years.

Angling is size-selective, and as a result, recreational fisheries can have a significant effect on the size distribution of fish in a population (Beard and Kampa 1999). Decreases in the number of anglers due to shifts in the size distribution of fish stocks to a smaller, less desirable fishery is of great concern to managers. Records from an annual sport-fishing contest in Minnesota show declines in large-sized entries and in the mean weight of total entries during a period from 1930 to 1957 (Olson and Cunningham 1989). Muskellunge *Esox masquinongy* and northern pike *Esox lucius* populations showed strong evidence of overexploitation, with a significant decline and loss of trophy-sized entries in the fishing contest. Following the loss of trophy musky and pike, the populations of walleyes *Sander vitreus*, largemouth bass *Micropterus salmoides*, and bluegills experienced a significant decrease in trophy sized fish and mean weight (Olson and Cunningham 1989). Beard and Kampa (1999) looked at changes in bluegill , black crappie , and yellow perch populations in Wisconsin from 1967 to 1991 to see if there was a reduction in the mean size and number of fish in recreational fishing lakes. The authors found there was a major shift in the size structure of bluegill and yellow perch populations towards smaller, less desirable sized fish. Interestingly, the size of the fish retained by anglers during the same time period did not reflect the decrease in size structure (Beard and Kampa 1999). The size of retained black crappies and yellow perch increased and the mean length of bluegills did not change. Anglers are either unable to catch the smaller sized fish or are releasing much of their catch and retaining only the desired larger fish. Therefore, the length of individual fish measured in creel surveys is not necessarily reflective of the size of fish in the population.

There is little acknowledgement of recruitment or growth overfishing in recreational fisheries. Overfishing may occur, but because total harvest is rarely monitored in sport fisheries, these forms of overfishing are hard to document (Radomski et al. 2001). However, a few documented cases of growth and recruitment overfishing do exist. The work of Maceina et al. (1998) indicates that growth overfishing occurred in the sauger *Stizostedion canadense* fishery of the Tennessee River, Alabama. The authors found that a minimum size limit would increase total yield of the fishery. Over-harvesting by recreational anglers in Alberta is cited as the cause of the collapse in a number of walleye fisheries (Sullivan 2003). Anglers did not display effort responses, as expected in recreational fisheries, and abandon the fishery, but continued to exploit the walleye stocks until they reached very low numbers. It is speculated that anglers continue to fish despite very poor catch rates because there are few recreational fishing opportunities in Alberta and no other species to target (Sullivan 2003).

In the absence of quantitative stock assessment programs, growth overfishing may be interpreted as quality overfishing, especially if it takes place over generations. Relatively small levels of recruitment overfishing may also be difficult to detect, but will reduce the fishery for future anglers and may eventually lead to population levels that are highly vulnerable to collapse (Pereira and Hansen 2003). Pauly (1995) introduced the idea of the "shifting baseline syndrome", where each generation of fishery manager accepts, as a baseline, the fishery conditions that exist at the beginning of their career. Recreational fishers may also follow this pattern, believing the stories of bigger fish in the old days to be just another fish tale. If you combine the shifting baseline theory with poor or non-existent stock assessment surveys, it is easy to see that low levels of growth and recruitment overfishing may be very well occurring (Pereira and Hansen 2003).

1.4 Study Objectives

Fishery managers typically use estimates of stock size and basic life history data to assess the vulnerability of stocks to overfishing in commercial fisheries. Acquiring this data is inherently difficult and expensive (Gangl and Pereira 2003). Because recreational fisheries biologists often manage hundreds or thousands of lakes, and because of the high costs involved in monitoring so many systems, detailed stock assessments for individual lakes are rarely available. Due to the data-poor conditions, fisheries managers are often unable to obtain estimates of safe harvest levels and rarely know the total harvest for individual lakes. In British Columbia, information collected from aerial boat counts and creel surveys is intended to allow managers to make decisions for individual lakes, but these data exist for only a few hundred lakes, many of which are stocked. There are thousands of lakes for which managers may potentially have to make decisions based on very little data. There is also an urgent need to assess regional fisheries on a much broader scale than on a lake-by-lake basis. The goal of my project is to assess whether wild stocks of rainbow trout in the Thompson Nicola Region of British Columbia are experiencing effort levels that could lead to population collapse. My objective is to determine the probability that wild trout lakes are overfished. By building a model that will provide insight into the fishery on a regional scale, I identify lakes that are vulnerable to overfishing and in need of monitoring or direct management intervention.

Ideal free distribution (IFD) theory is increasingly used to explain the behaviour of commercial and recreational fishers (Cox et al. 2002, Gillis 2003, Parkinson et al. 2004). In open access fisheries, such as the inland fisheries of British Columbia, anglers are expected to move amongst fishing locations until an equilibrium is met where all anglers experience the same angling quality (Parkinson et al. 2004). Anglers choose their fishing locations for a variety of complex reasons (Holland and Ditton 1992), many of which are difficult to capture. Most angler studies indicate that catch is an important aspect of the fishing experience (Connelly et al. 2001, Holland and Ditton 1992). However, understanding what influences angler's decisions to fish is complicated, for most anglers are also influenced by factors relating to the recreational experience (Holland and Ditton 1992, Fisher 1997). Non-catch aspects of the trip such as the influence of the environment and social interactions can result in varying degrees of angler satisfaction for almost identical angling experiences (Holland and Ditton 1992, Fisher 1997). I propose that anglers will make trade-offs between lake access, habitat quality (which will affect fish stocks), facilities available at the lake, and management regulations or restrictions in making decisions on where to fish. I will examine which factors have the greatest influence for predicting angler effort, for anglers choice in fishing location will subject some fish stocks to considerably more harvesting pressure than fish stocks in other lakes.

Performance measures are often put in place to assess the status of fish stocks. Some of the most common performance measures include catch, biomass, fishing mortality, or recruitment (Francis and Shotton 1997). Managers need to know the probability that the fish stock will fall below a performance measure threshold in order to assess the risk of a fish stock collapsing as a result of overharvesting. Managers can then use the probability to manage the risk of such an event occurring (Francis and Shotton 1997). Due to the absence of catch, biomass, fishing mortality and recruitment data, this approach is not practical for small lakes. However, Cox and Walters (2002*b*) estimated the critical fishing effort levels that lead to population collapse for rainbow trout lakes in British Columbia. I am not aware of any other literature that assesses the vulnerability of inland recreational fisheries to overfishing. I will use Cox and Walters (2002*b*) threshold effort level as a performance measure to assess the vulnerability of trout stocks to overfishing. Quantifying the number of anglers fishing on the surface of a lake, while not a simple task, is inherently easier than quantifying the number of fish below the surface.

1.5 Study Area

This study focuses on lakes within the Thompson Nicola Region (Region 3), which is located in the southern interior of British Columbia (Figure 1.1). The region is known for its "Kamloops" rainbow trout and diversity of angling opportunities, ranging from productive grassland lakes to pristine, forested, walk-in lakes. The southern interior has approximately 3500 lakes, of which over 700 support rainbow trout fisheries. An average of 200 lakes are stocked annually or semi-annually, and another 150 lakes in the region have a history of past fish introductions.

The Thompson Nicola Region is second behind only the Lower Mainland Region for total number of angler days (Levey and Williams 2003). Most of the angling effort is focused on the small lake fishing for which the area is known. The majority of fishing takes place on the large plateau that runs through the middle of the region, from Clearwater, through Kamloops, and down to Merritt. Lakes in the southern portion of the plateau are more productive and have a longer fishing season than lakes in the north. Lakes around Kamloops and to the south receive the highest angling pressure because they are closer to more densely populated areas, such as Kamloops, the Okanagan, and the Lower Mainland. The northern section of the region is sparsely populated and contains a large provincial park, which has limited road access. The western portion of the region contains the four large reservoir lakes Seton, Anderson, Carpenter and Downtown, and is characterized by steep and mountainous terrain, containing more creek and river systems than lake systems. The eastern portion of the region is also characterized by large lakes such as Adams and Shuswap Lakes. Because the western and eastern areas of the region provide fewer small lake fishing opportunities, large lake and river fishing receive a larger share of the effort.

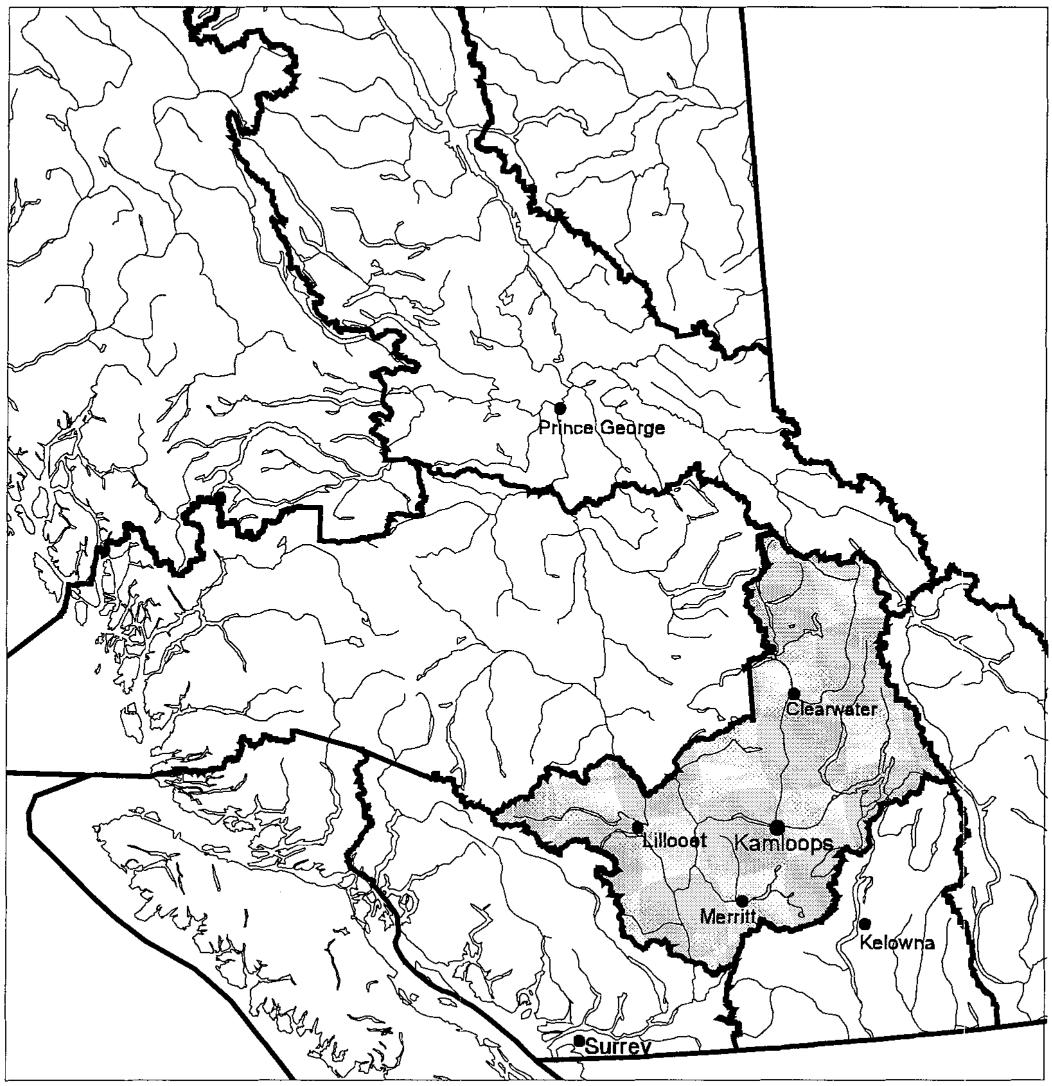

Figure 1.1: British Columbia's major watersheds and management regions (solid borders). The Thompson Nicola Region Study Area is shaded.

Chapter 2

Methods

2.1 Model Development

I used the generalized linear model for my analysis of fishing effort. The generalized linear model (GLM), expands the application of the linear model to accommodate response variables with non-normal conditional distributions (Fox 2002). Generalized linear models consist of three components: 1) response or dependent variates, specified by the random component, 2) a linear predictor, composed of independent explanatory variables or co-variates, and 3) the link function, which transforms the expectation of the response to linear in the predictor (Nelder and Wedderburn 1972, McCullagh and Nelder 1989, Fox 2002, Myers et al. 2002).

The linear function is of the form (Equation 2.1):

$$Y = b_0 + b_1X_1 + b_2X_2 + ... + b_kX_k \tag{2.1}$$

where Y is the response variate, b_0 is the intercept, $b_1...b_k$ represent the independent contributions of each independent explanatory variable to the prediction of Y, and the X's are explanatory variables.

The generalized linear function is of the form:

$$f(\mu_y) = b_0 + b_1X_1 + b_2X_2 + ... + b_kX_k \tag{2.2}$$

where f is the link function, and μ_y is the expected value of Y.

The explanatory variables may be quantitative or qualitative. Quantitative variates take on numerical values and qualitative variates take on non-numerical values, or factors, from a finite set of values (McCullagh and Nelder 1989). An example of a quantitative variate is driving distance to a lake, while an example of a qualitative variate is fish type, with two classes or levels, stocked or wild. The response variates may be continuous or discrete numerical values, or may take the form of factors (McCullagh and Nelder 1989).

Generalized linear models allow for two extensions beyond the linear model: 1) the response variable may come from an exponential family other than the Gaussian, such as the binomial, Poisson, gamma, or inverse-Gaussian family of distributions (McCullagh and Nelder 1989, Fox 2002), and 2) the link function allows the GLM to include a non-linear model, for there is a separation of the link function distribution from the distribution of the response variable (McCullagh and Nelder 1989, Myers et al. 2002, Fox 2002). I chose to use a GLM over other statistical models for my analysis because it can handle different error distributions and because the response variable is not normally distributed. The response variate data are based on boat counts, which can't be less than zero, so a Poisson error distribution seemed justified. The log link function was used to transform the expectation of the response variable to the linear predictor.

2.2 Fitting the Generalized Linear Model

2.2.1 Model Selection

Observations on angler effort (angler-days/hectare; AD/ha) came from the Small Lakes Assessment and Management (SLAM) database program, which evolved out of the Small Lakes Index Management (SLIM) program. SLIM was conceived in 1989, and was intended to provide regional fisheries biologists with decision making information for individual lakes (Tredger 1990). Annual angler effort is estimated using data from aerial boat counts, which occurred from 1989 to 1992 under the SLIM program and resumed again in 2000 under the SLAM program. Flights are done on 15 to 20 pre-selected weekend days during the fishing season (May to September), capturing "instantaneous boat counts" during mid-day time strata, as outlined in Tredger (1990; 1992). Lakes included in the boat count flights were likely selected because they met one of the following criteria: the lake was located along a logical 3 hour flight path, the lake was known to receive fishing effort, or the lake was of possible management concern. Three hundred and eighty-eight annual boat count records exist for the years 2000 to 2003, representing 216 lakes in Region 3 (B.C. Ministry of Sustainable Resource Management, unpublished data). The annual angler-day values for the study lakes were converted into AD/ha to allow comparison of effort density between lakes. Average effort was used for lakes with more than one year of count data during the four year period. One hundred and eighty-three lakes with effort observations from the 2000 to 2003 fishing season were included in the model selection process, 73 of which are wild rainbow trout lakes (Figure 2.1)(Table 2.1).

Determining which explanatory variables to include was a tradeoff between parsimony and fit. Model selection of the variates was done using a stepwise Akaike information criterion (AIC) procedure. The AIC is an indicator of model fit which takes into account model parsimony by penalizing for the number of parameters; smaller values indicate a better model fit to the data (Fox 2002). An initial model, containing all fish population, lake habitat, and facilities data was run through a backward stepwise search. The following explanatory variables, which are described below, were returned by the stepwise-selected model: driving distance, lake surface area, ecosystem zone, hatchery or wild stock rainbow trout, road or foot access, bag limit regulations, availability of a trailer boat launch, presence of a campsite, and presence of a fishing lodge (Equation 2.3). Driving distance and lake surface area are continuous explanatory variables; the other variables are all qualitative explanatory variables. The values of the generalized linear model parameters (b_0 through to b_k) were obtained by the iterative reweighted least squares (Fisher-scoring) method.

The angler effort GLM is:

$$E = \mu + D + Z + A + T + F + B + L + R + C + R * T \tag{2.3}$$

where E is angler effort (AD/ha), μ is the intercept, D is driving distance (km), Z is the biogeoclimatic ecosystem classification zone the lake is located in, A is lake surface area (hectares), T is the type of fish in the lake ("stocked" or "wild"), F is the type of access to the lake (road or foot access), B is bag limit regulations, L is the presence of a trailer boat launch, C is the presence of a campsite, and R is the presence of a fishing resort or lodge. The angler effort GLM includes observations from 183 individual lakes.

Lake perimeter was removed during the stepwise procedure. Elevation was considered as an explanatory variable, but explained little of the deviance variability, had little influence on the AIC, and was correlated with the ecosystem zone and road kilometers. Elevation is captured in the ecosystem zone, and the higher in elevation a lake is, the further it will be to drive to. The total dissolved solids (TDS) in a lake was a significant variate, but including TDS in the final model would significantly reduce the number of wild

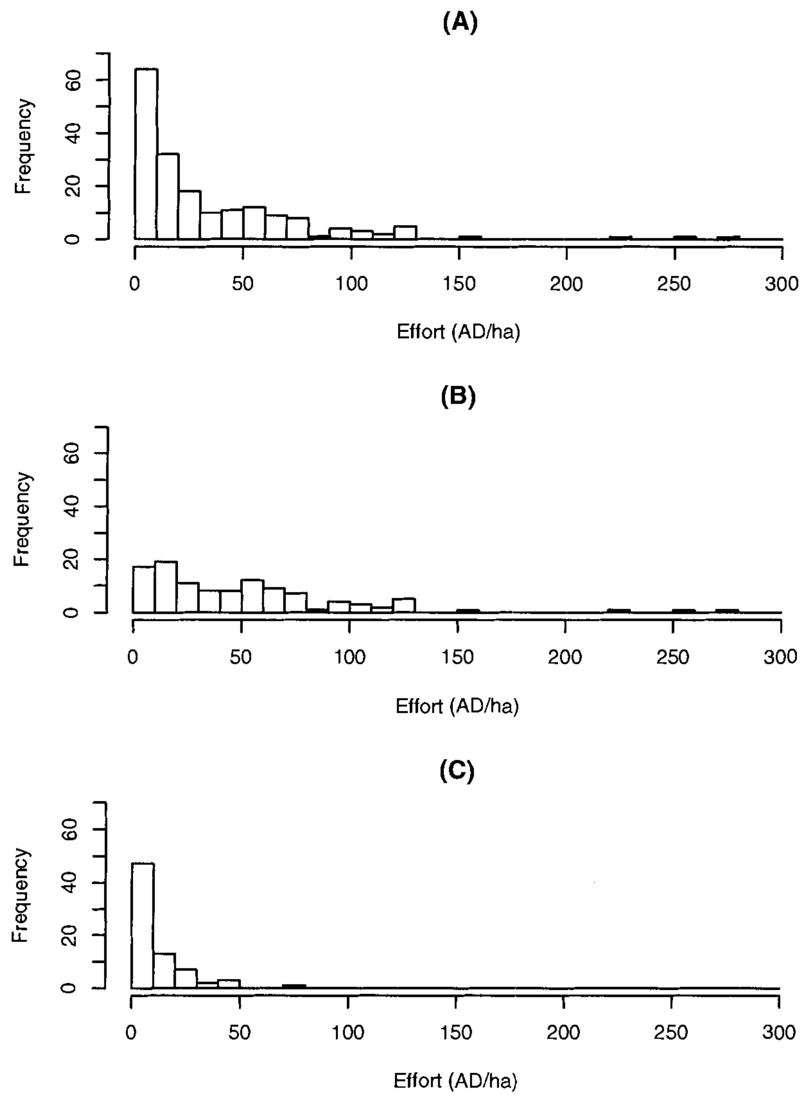

Figure 2.1: Distribution of aerial count effort (AD/ha) from the 183 "wild" and "stocked" rainbow trout lakes used in the model selection process. (A) is the distribution of effort on all 183 lakes, (B) is the distribution of effort on the "stocked" lakes, and (C) is the distribution of effort on the "wild" lakes.

rainbow trout lakes for which effort could be predicted because TDS data is not widely available. I also considered using lake surface pH as a explanatory variable, but pH data is even less available than TDS data for wild trout lakes. Gear restriction and boat restriction regulations were not significant explanatory variables and were removed by the stepwise procedure.

The explanatory variables contain no information about fish in the lakes, even though the model is trying to help explain angler behaviour. The model would likely be improved with fish observations, but because the collection of fish data is time consuming and expensive, fish data exists for only a select number of lakes in the region. Standardized gillnet sets, which can be used to calculate an index of fish abundance, are only available for 31 lakes during the four year period from 2000 to 2003. Catch per unit effort data from creel surveys, which can also be used as a measure of fish abundance, is available for an even smaller subset of lakes during the same time period. Observations of fish populations are also dynamic, and therefore, only relevant over the span of a few years. Information on reproductive potential from inlet streams would likely significantly improve the model, but at this time, no such data exists.

The final step in the model selection was to look for interactions between the explanatory variables. While there was some interaction between lake area and facilities variates (fishing resort, campsite, and boat launch), the addition of interaction terms explained less than 1% of the variation in fishing effort. The minimal improvement in model fit was not worth the added complication. The interaction between fishing resort and fish type ("wild" or "stocked") was included in the model because it explained an additional 1% of the deviance variability in effort.

2.2.2 Explanatory Variables

Driving distance to each lake was determined using GIS analysis for all lakes in Region 3 (BC Ministry of Sustainable Resource Management, unpublished data). The distance was calculated using Surrey, B.C. as the starting point. There are a number of potential problems with using only road kilometer data from Surrey, but it is the best driving access information available. Ideally, I would also have road kilometer distances from Kelowna, to capture anglers that drive from the Okanagan Region (to the south-east), and road kilometers from Kamloops, to represent anglers from the largest population center in the region. However, as local residents make up only a small portion of the total fishing effort and most of the anglers come from the more densely populated Okanagan and Lower Mainland Regions to the south (Levey and Williams 2003), the road kilometer data probably does an adequate job of representing road access for the average angler.

The morphoedaphic index, which is a combined measure of total dissolved solids (TDS) and mean depth of a lake, has been used as an indicator of productivity for years (Ryder et al. 1974). The more productive the lake, the greater the yield of fish. Instead of using TDS and lake depth, I have used the British Columbia biogeoclimatic ecosystem classification (BEC) system to try and capture lake productivity. The BEC system, developed by the B.C. Ministry of Forests to classify terrestrial ecosystems of the province, captures climate, vegetation, and site condition differences in the province's forest and rangeland zones (Meidenger and Pojar 1991). BEC zone information is available for all lakes in Region 3. BEC zones share similar seasonal climates, including temperature and precipitation, and similar soil types, both of which impact TDS. Soil will affect the types of minerals that are available and temperature and precipitation will impact the rate at which minerals are dissolved and transferred. BEC zones are also found at similar elevations and latitude, which when combined with the similar seasonal climate, will coarsely capture regional differences in the timing and length of the recreational fishing season. Lakes that are productive and have longer fishing seasons are expected to receive higher fishing effort. Gangl and Pereira (2003) found the growth index and total length at age 3 for walleye populations in Minnesota's large lakes was positively related to growing season length, while age at maturity was negatively related to the growing season length. Looking at lakes with TDS data, it appears that lakes in the IDF and BGPP zones have significantly higher TDS counts than lakes in the ESSF, MS, and SBS zones (Figure 2.2). As such, I would expect lakes in the IDF and BGPP to be able to support higher angler effort.

Lakes with angler boat count effort data can be found in the BEC zones Bunchgrass - Ponderosa Pine (BGPP), Engelmann Spruce - Subalpine Fir (ESSF), Interior Douglas-fir (IDF), Montane Spruce (MS), and the Sub-Boreal Spruce (SBS). Aerial boat counts do not exist for lake in the Interior Cedar-Hemlock (ICH), Alpine Tundra (AT), and the Sub-Boreal Pine - Spruce (SBPS) zones. Therefore, I am unable to predict effort for lakes in these zones. While BEC zone data does not directly capture lake productivity or fishing season data, I believe it indirectly captures both of these explanatory variables. However, because the BEC zones are an indirect measure, they may also be capturing other variables that influence effort. Some BEC zones may be more popular not because the lake conditions are preferred by fish, but because the lake conditions are preferred by anglers.

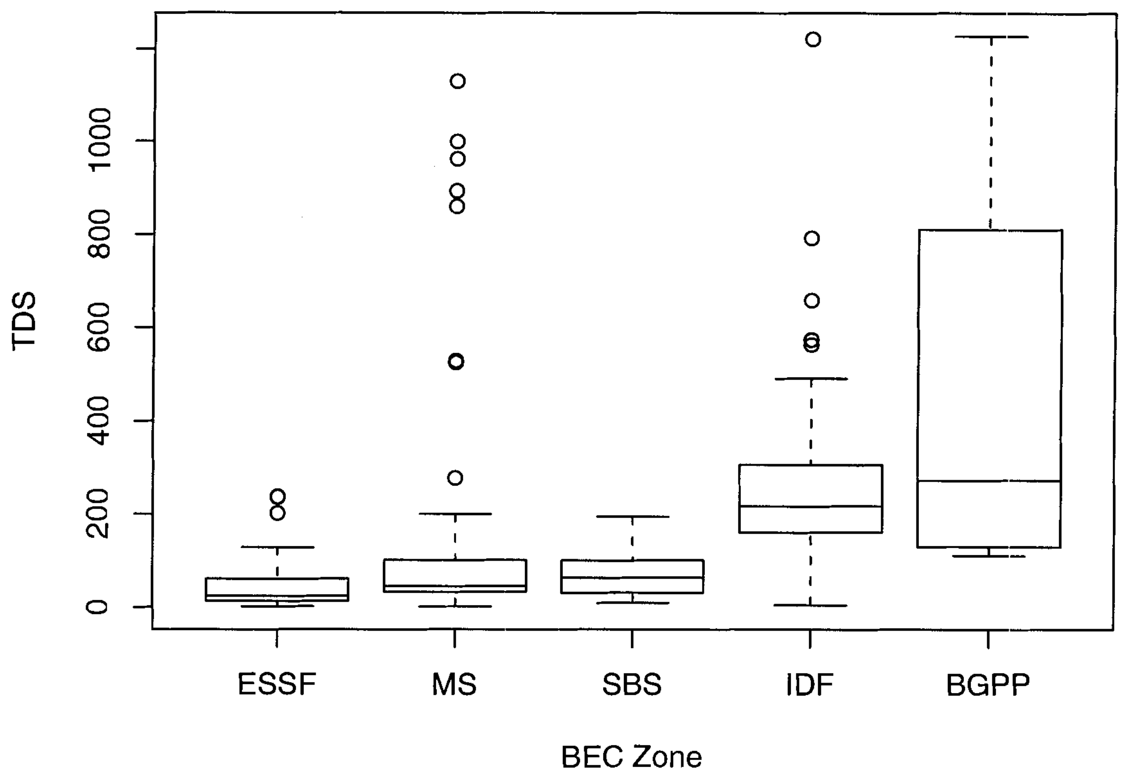

Figure 2.2: Total dissolved solid (TDS) values for lakes in the ESSF, MS, SBS, IDF and BGPP zones in Region 3. For each box, the horizontal line represents the median value and the upper and lower limits of the box represent the 75th and 25th percentiles, respectively. The ends of the vertical lines show the smallest and largest observations that fall within a distance 1.5 times the box size, and the points show TDS levels that are considered to be outliers.

The summer fishing season climate experienced in one zone may be more favourable than climate experienced in other zones. Some BEC zones may be more popular with anglers because they have a better network of logging roads than other zones. Because most backcountry roads are built for timber harvesting in B.C., BEC zones that are heavily forested may offer anglers better access to lakes.

The Bunchgrass and Ponderosa Pine Zones, which I have grouped into one zone (BGPP) for this analysis, occupy the hot valley floors and walls of the southern interior. The zone is the hottest, and because it is in the rainshadow of the Coast and Cascade mountains, receives relatively little precipitation (MOF 1999*b*; 1998*a*). The Engelmann Spruce - Subalpine Fir Zone is found in the uppermost forested elevations of the southern interior of the province. Cold and snowy conditions last in this zone for 5 to 7 months of the year, with snowpacks as heavy as 2 to 3 meters. Summers are short and cool, with mean temperatures of 10°C for only 2 moths of the year (MOF 1998*b*). The Interior Douglas-fir Zone is characterized by rolling hills and valleys covered by dry grassland and open forests. The Coast, Cascade, and Columbia Mountains cast a rainshadow over this dry zone, which has warm and dry summers and cool winters (MOF 1996). The Montane Spruce Zone (MS) lies between the high elevation subalpine forests of the Engelmann Spruce - Subalpine Fir zone and the lower elevation forests of Douglas-fir and lodgepole pine in the Interior Douglas-fir zone. Because of the zone's high elevations and location in the rainshadow of the Coast and Selkirk Mountains, the climate of the MS zone is cool, with short, dry summers and cold winters. The average temperature gets above 10°C for only 2-4 months of the year and most of the annual 300 - 900 mm of precipitation comes in the winter time as snow (MOF 1999*a*). The Sub-boreal Spruce Zone is found in the rolling hills of the interior plateau, with the Kamloops region at the southern tip of its range. Summers are short and warm, and winters are severe and cold. Summer temperatures occasionally reach into the thirties, and most of the zone is under snow from November through to March (MOF 1998*c*).

Lake area (ha) was calculated through GIS mapping (B.C. Ministry of Sustainable Resource Management, unpublished data). Smaller lakes are expected to be more desirable to anglers because the surrounding shoreline will offer more protection from the wind and the smaller area will make it easier to effectively search for fish. I may potentially be adding error to my model predictions by including lake area, for effort data is also measured on an area scale. Because lake areas were measured through mapping and not in the field, some of the lake sizes may be incorrect. Lake area is also not entirely static, for the amount of water in a basin will vary over seasons and years. Some of the lakes are also irrigation impoundments, which will experience even greater fluctuations in surface area over seasons and years. As I will be comparing my effort predictions to those of Cox and Walters (2002*b*), I only included lakes that were less than 200 ha in size.

To determine whether or not a lake is "wild" or "stocked", I compared hatchery stocking records to the list of all Region 3 lakes (B.C. Ministry of Sustainable Resource Management, unpublished data, available at http://srmapps.gov.bc.ca/apps/fidq/). Lakes that had a record of hatchery stocking within the past 20 years (broodstock year was $\geq$1984) were considered "stocked". Three hundred and twenty-six of the over 5000 waterbodies in the Region 3 database are classified as stocked. To be considered a "wild" rainbow trout lake, the lake had to have no record of hatchery stocking for the past 20 years, gillnet data supporting the presence of fish, or evidence to support a fishery occurs on the lake, such as inclusion in the fishing regulations or presence of a fishing lodge. Four hundred and twenty lakes were considered "wild" trout lakes under this criterion. Not all wild rainbow trout lakes will be captured using this selection, but it seems reasonable that I will have captured the lakes that are to be of potential concern for overfishing.

While lakes that have a history of hatchery stocking may not be considered wild from a biological perspective, from a fisheries management perspective, they are the same. The provincial fisheries section has a ban on new hatchery fish introductions into waterbodies until a new stocking policy is in place. As such, all lakes that have not been stocked within the past 20 years are equally at risk of being overfished as "wild" trout lakes.

There are a number of walk-in lakes in the southern interior, especially in the northern half of Region 3. Using B.C. Ministry of Sustainable Resource Management unpublished data and my local knowledge, I compiled a list of lakes that can only be accessed by foot. I recognize that there may be some errors with this data, for new forestry roads will be built, old roads will degrade, and the use of all-terrain vehicles makes almost any lake accessible by motorized vehicle for the persistent angler. However, I do not believe any errors will cause persistent biases.

Bag-limit restrictions for individual lakes were compiled for Region 3 from the Freshwater Fishing Regulations Synopsis. I grouped lakes into 2 separate levels: those with the regional catch quota of 6 rainbow trout/day or more (a small number of lakes have a daily catch quota of 8 rainbow trout), and those having less than the regional quota (catch-and-release or 1 or 2 rainbow trout/day). My analysis will not identify whether the bag-limits are a reflection of the fishing effort, or the fishing effort is a reflection of the bag-limits.

Facilities information was compiled using my local knowledge, guidebooks, and the British Columbia Resort and Outfitters Association membership list. Lakes that have a fishing lodge on them or that are used by fishing resorts were classified as resort lakes. Campground information came from the B.C. Forest Recreation site listing (available at www.for.gov.bc.ca/hfp/rec/sites/map.htm) and the B.C. Parks Campgrounds list (available at wlapwww.gov.bc.ca/bcparks). Lakes with trailer boat-launches were identified using my local knowledge and a backroad mapbook (Mussio and Mussio 1998). Lakes with trailer boat-launches may be more attractive to anglers because of not just the boat launch, but because they are likely to have good quality roads and be accessible to any type of vehicle. Lakes with trailer boat-launches will likely attract different kinds of anglers than lakes without trailer boat-launches.

Table 2.1: Wild rainbow trout lakes included in the GLM. Abbreviations are as follows: WBID, unique identifier for each waterbody in the province; E, annual effort the lake receives, measured as angler-days per hectare; Z, biogeoclimatic ecosystem classification zone the lake is located in; A, lake surface area (hectares); D, driving distance, in kilometers, from Surrey B.C. to the lake; F, whether or not the lake can only be accessed by foot (walk-in access only); R, whether or not the lake is fished by fishing resort clients; C, whether or not a Forest Recreation campsite or B.C. Parks campsite is located on the lake; L, whether or not the lake has a trailer boat-launch; B, bag-limit for the lake, where (6) is for lakes with the regional standard of 6 trout/day or more and (-) is for lakes with a limit of less than 6 trout/day.

Lake	WBID	E	Z	A	D	F	R	C	L	B
Adler	00217DEAD	3	MS	34	394	Yes	No	No	No	6
Arrowhead	02092MAHD	20	SBS	16	444	Yes	No	No	No	6
Beckwith	00252BONP	9	SBS	5	394	Yes	Yes	No	No	6
Belcache	00169BONP	8	ESSF	14	446	Yes	Yes	No	No	6
Blowdown	02091MAHD	3	SBS	16	444	No	No	No	No	-
Braman	00948LNTH	11	ESSF	25	394	Yes	Yes	No	No	6
Bushwater	00148BONP	0	ESSF	7	429	Yes	Yes	No	No	6
Buss's Puddle	00149BONP	0	ESSF	3	429	Yes	Yes	No	No	6
Cameron	01500NICL	19	MS	30	354	No	No	No	No	6
Chataway	00254LNIC	78	MS	22	277	No	Yes	Yes	Yes	6
Chester	00146BONP	21	ESSF	5	429	Yes	Yes	No	No	6
Christina	00942LNTH	0	ESSF	2	394	Yes	Yes	No	No	6
Cone	00322LNTH	9	SBS	35	439	No	Yes	No	No	6
Corsica	01615MAHD	0	SBS	67	498	No	No	No	No	6

Table 2.1 – continued from previous page

Lake	WBID	E	Z	A	D	F	R	C	L	B
Couture	01215LNTH	3	ESSF	15	394	Yes	Yes	No	No	6
Crater	00291LNTH	40	SBS	11	439	No	Yes	No	No	6
Deer	00331LNTH	18	SBS	33	439	No	No	Yes	No	6
Deube	01825MAHD	6	SBS	19	471	Yes	No	No	No	6
Double	01746MAHD	26	SBS	31	471	No	No	Yes	No	6
Dumbell	00089DEAD	7	MS	40	394	Yes	Yes	No	No	6
Earl	01918MAHD	0	SBS	4	471	Yes	No	No	No	6
Estelle	00163DEAD	14	MS	15	394	Yes	Yes	No	No	-
Friendly	02062MAHD	1	ESSF	54	439	Yes	No	No	No	6
Gourd	02089MAHD	0	SBS	6	444	Yes	No	No	No	6
Grizzly	00223LNTH	10	ESSF	22	441	No	Yes	Yes	No	-
Hardcastle	00280LNTH	44	SBS	18	439	No	Yes	No	No	6
Herby	01897MAHD	4	SBS	6	471	Yes	No	No	No	6
Hidden	02015NICL	0	ESSF	9	279	No	No	No	No	6
Hoopatatkwa	01133LNTH	6	MS	81	394	Yes	Yes	No	No	6
Hoover	00250DEAD	25	MS	20	394	Yes	No	No	No	6
Italia	01573MAHD	0	SBS	131	475	No	No	Yes	No	6
Keith	00190BONP	0	ESSF	4	394	Yes	Yes	No	No	6
Knouff	01360LNTH	12	MS	30	364	No	No	No	No	6
Little O.K.	00912THOM	12	MS	9	306	No	No	No	No	6
L. Patrick	00914LNTH	0	ESSF	5	408	Yes	Yes	No	No	6
Lloyd	00179DEAD	21	MS	13	394	Yes	Yes	No	No	-
Lorenzo	02102MAHD	8	ESSF	20	444	No	No	No	No	-
Lost Horse	00270LNTH	11	SBS	36	439	No	Yes	Yes	No	6
Lower Secret	00901BONP	0	MS	28	454	Yes	Yes	No	No	6
Malarky	00268BONP	41	SBS	4	394	Yes	Yes	No	No	6
Malcolm	00176BONP	8	ESSF	14	394	Yes	Yes	No	No	6
Mamit	00584GUIC	11	IDF	171	271	No	No	No	Yes	6
McGillvray	01522LNTH	10	ESSF	85	386	No	No	Yes	Yes	6
Minnie	01306NICL	5	IDF	135	284	No	No	No	No	6
Mollimarn	00174DEAD	0	MS	45	394	Yes	Yes	No	No	6
Monticola	02077MAHD	5	SBS	64	444	No	No	No	No	6
Moosepasture	01179LNTH	0	MS	6	394	Yes	Yes	No	No	6
North Island	00105DEAD	14	MS	11	394	Yes	Yes	No	No	6
Palmer	00989LNTH	0	SBS	3	394	Yes	Yes	No	No	6
Paradise	01900NICL	9	MS	117	300	No	No	No	No	6
Patricia	01779MAHD	2	SBS	23	471	Yes	No	No	No	6
Patrick	00904LNTH	0	ESSF	16	429	Yes	Yes	No	No	6
Pimainus No.3	00956THOM	24	MS	53	306	No	Yes	Yes	Yes	6
Pimainus No.4	00954THOM	0	MS	3	306	No	No	No	No	6

Table 2.1 – continued from previous page

Lake	WBID	E	Z	A	D	F	R	C	L	B
Pioneer	00414LNTH	20	SBS	33	444	No	No	No	No	-
Renee	00108DEAD	0	MS	8	394	Yes	Yes	No	No	6
Rioux	01848MAHD	20	SBS	27	471	No	No	No	No	6
Rock Island	00300LNTH	28	SBS	62	439	No	Yes	Yes	No	6
Roscoe	00168LNIC	10	MS	35	282	No	Yes	Yes	No	6
Rose	00275LNTH	31	SBS	7	439	Yes	Yes	No	No	6
Siam	00152DEAD	0	MS	8	394	Yes	Yes	No	No	6
Sicily	01705MAHD	8	SBS	21	471	No	No	Yes	No	6
Stoney	00979LNTH	8	SBS	6	394	Yes	Yes	No	No	6
Surrey	00174LNIC	50	MS	50	274	No	Yes	No	No	6
Tahoola	02063MAHD	3	ESSF	36	439	Yes	No	No	No	-
Triangle	00936LNTH	3	ESSF	49	394	Yes	Yes	No	No	6
Tuwut	00246DEAD	0	MS	29	394	Yes	No	No	No	6
Two Mile	01871MAHD	0	SBS	5	471	Yes	No	No	No	6
Unnamed	00204GUIC	11	MS	157	299	No	No	Yes	No	6
Upper Secret	00910BONP	3	MS	39	454	Yes	Yes	No	No	6
White	00080LNTH	26	SBS	5	471	No	No	Yes	No	6
Willowgrouse	00239DEAD	1	MS	85	394	Yes	No	No	No	6
Windy	01904MAHD	5	SBS	30	471	Yes	No	Yes	No	6

2.2.3 Prediction

The final component of my analysis involved making fishing effort predictions for wild lakes in the region for which we have no effort observations. There are over 5000 waterbodies in the Region 3 provincial dataset, but many of these do not support rainbow trout populations, or are unable to support fish. To compile a list of all lakes in Region 3 that have known populations of rainbow trout, or are expected to have rainbow trout populations, I pooled lakes that were in the stocking database, secondary road access database, fishing regulations database, gillnet database, and creel lakes database. For this analysis, effort was only predicted for small lakes, as defined earlier. The final list contains 704 lakes, of which 396 are "wild" fish lakes. Of the 396 "wild" lakes, 326 are small lakes that I predict effort for. The list is incomplete, but I believe it captures most of the lakes in the region that may be of management concern. Lakes located in the Interior cedar-hemlock, Sub-boreal Pine Spruce, Alpine Tundra, and Bunchgrass Ponderosa Pine BEC zones were not included in the final model, for the BEC zones were not included as levels in the GLM. The expected value of the response variable was predicted for each of the 326 individual "wild" lakes using the base data GLM.

To test how the initial base data model would stand up to other datasets, I used the bootstrap method (Efron and Tibshirani 1991) to create 100 pseudoreplicate datasets by resampling from the original lakes I had angler effort data for. The GLM was then re-specified using the stepwise AIC procedure for each resampled dataset, and the expected value of the response variable for the 326 individual "wild" trout lakes was predicted using each bootstrap GLM.

2.3 Assessment of Overfishing

Cox and Walters (2002*b*) identified "optimal fishing effort policies" and the "critical fishing effort levels that lead to population collapse" for rainbow trout populations in British Columbia's southern interior. While high effort is usually associated with high fish densities, anglers may also be attracted to lakes by factors such as location and amenities. I also assume that high effort implies high catch rates. By combining an age-structured model with an exploitation model based on fishing effort densities, Cox and Walters (2002*b*) estimated that stocks which exhibit low recruitment compensation have an optimal fishing effort ($\pm$ SD) of 9.4 $\pm$ 2.4 AD/ha and a critical fishing effort of 23.4 $\pm$ 5.1 AD/ha. The optimal fishing effort for high recruitment compensation stocks was estimated at 18.8 $\pm$ 3.7 AD/ha (Cox and Walters 2002*b*). I used the effort estimates identified by Cox and Walters (2002*b*) to set up management guidelines to identify stocks that are vulnerable to being overfished. I erred on the side of caution and applied the low compensation scenario to all lakes. 28.3 AD/ha (23.4 AD/ha + 1 standard deviation) is the critical value at which lakes are considered highly vulnerable to overfishing and 18.1 AD/ha (23.4 AD/ha - 1 standard deviation) is the critical value at which lakes are considered moderately vulnerable to overfishing.

2.3.1 Parametric Method

To assess the vulnerability of a lake to overfishing for the base data GLM, I used a parametric method that assumes the predicted effort is normally distributed. Lakes were assessed as highly vulnerable to overfishing if there was more than a 30% probability that the predicted effort was greater than 28.3 AD/ha. If there was less than a 30% probability that the predicted effort was greater than 28.3 AD/ha, but more than a 30% probability that the predicted effort was greater than 18.1 AD/ha, lakes were assessed at being moderately vulnerable to being overfished. All other lakes were assumed unlikely to be overfished.

In order to calculate the probability that a lake is overfished using the base data GLM, I first calculated the upper bound (b), or maximum amount of effort for each lake. The upper bound is assumed to be 4 standard deviations greater than the mean:

$$b = m + (4\sigma) \tag{2.4}$$

where m is the predicted effort and σ is the predicted standard error for each lake.

The probability density function for effort on a given lake is assumed normally distributed.

$$P(z) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp(-\frac{(z-m)^2}{2\sigma^2}). \tag{2.5}$$

The area under the normal curve is estimated by mid-point approximation using one hundred intervals. The intervals range from a lower bound that is four standard deviations less than the mean to the upper bound (b).

The probability that a lake is overfished (PL) is calculated by integrating the probability function from the pre-determined critical value(s) c to the upper bound (b), determined by Equation 2.4:

$$PL = \sum_{c}^{b} P(z)\Delta z \tag{2.6}$$

where c is 28.3 and 18.1 AD/ha, as defined above.

2.3.2 Bootstrap Method

To assess the vulnerability of a lake to overfishing using the bootstrap data GLM's, I looked at the proportion of point effort predictions (expected values given the model) for each lake that exceeded the critical value(s). Lakes were assigned a risk factor of high if more than 30% of the effort predictions were greater than 28.3 AD/ha. If less than 30% of the effort predictions for each lake were greater than 28.3 AD/ha, but more than 30% of the effort predictions were greater than 18.1 AD/ha, lakes were assessed as moderately vulnerable to overfishing. All other lakes were assumed unlikely to be overfished.

Chapter 3

Results

3.1 Parametric Method

3.1.1 Explanatory Variables Selection and Parameter Estimates

To ensure there were no systematic errors in the base data model, I created partial-residual plots (Figure 3.1) in order to assess the relationship between the response variable and the individual explanatory variates. Non-linearity for the continuous explanatory variable (driving distance and lake area) would suggest a systematic error from the functional form specified by the model (Fox 2002). Differences in the boxplot sizes for the qualitative explanatory variables (BEC zones, bag limit, stocking type, availability of a boat launch, availability of camping facilities, presence of a resort, and foot access) would suggest a systematic error due to one of these explanatory variables. The results of the partial-residual plots (Figure 3.1) suggest I have not introduced a systematic error to the model.

Driving distance and BEC zone were the two most influential explanatory variables in the base data GLM. Driving distance accounted for more than half of the total explained deviance variability and BEC zone accounted for nearly one quarter of the total explained deviance variability in the GLM. The parameter estimates for the base data GLM are explained in further detail below and are listed in order of the role the explanatory variables played in explaining the deviance variability.

Driving distance is the most significant explanatory variable in the GLM, accounting for 26% of the deviance variability (Table 3.1). A decrease of 0.0034 AD/ha occurs for each

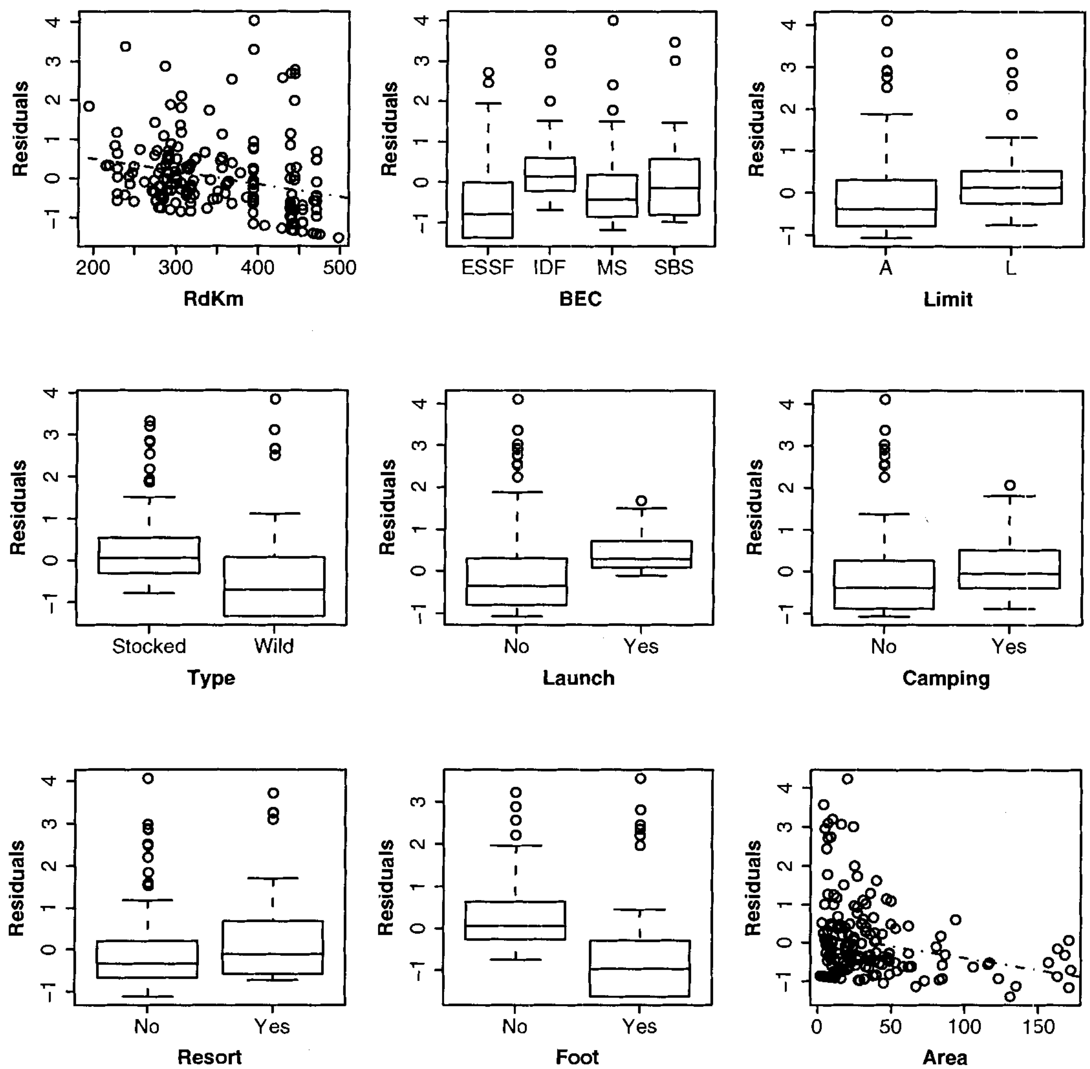

Figure 3.1: Partial-residual plots for the base data GLM. The partial residuals are created by adding the fitted linear component of the explanatory variable to the least squares residuals. The dashed line, included on the graphs for the continuous explanatory variables (RdKm, the driving distance to a lake, and Area, lake surface area), is the least squares line.

additional road kilometer. The maximum road kilometer difference between lakes within the region is approximately 375 kilometers, so if all other explanatory variables are held fixed, fishing effort on the most northern lake in the region is 1.275 AD/ha lower than fishing effort on the most southern lake.

The Biogeoclimatic Ecosystem Classification zone a lake is located in accounted for 12% of the deviance variability (Table 3.1). Of the 4 BEC zones included as levels in the GLM, lakes in the ESSF zone receive the least amount of effort. With all other explanatory variables held fixed, a shift from the ESSF to MS zone is associated with a 4% increase in effort (parameter estimate shifts from 4.2629 to 4.4512). A shift from the ESSF zone to the SBS zone is associated with a 10% increase in effort (parameter estimate is 4.6932). Lakes found in the IDF zone receive the greatest amount of fishing effort. A shift in from the ESSF zone to the IDF zone is associated with approximately a 16% increase in effort (paramater estimate is 4.9286).

The presence of a trailer boat-launch accounted for 9% of the variability in the GLM (Table 3.1). Lakes with a trailer boat-launch receive approximately 13% more angler effort than lakes without a boat-launch.

The effect of a lake having wild fish accounted for 6.8% of the deviance variability in the GLM (Table 3.1). The type of fish found in a lake had a significant effect on angler effort. Unstocked, wild lakes, receive approximately 19% less effort than stocked lakes.

Foot access accounted for 6% of the deviance variability in the GLM (Table 3.1). Lakes that can only be accessed by foot receive approximately 21% less effort than lakes that are accessible by vehicle.

The bag limit variable explained 4.1% of the deviance variability in the GLM (Table 3.1). The effect of a bag-limit of less than the regional 6 fish/day limit is an increase in effort of approximately 7% over lakes with a bag-limit of 6 or more fish/day.

The camping facilities variable explained 2.3% of the deviance variability in the GLM (Table 3.1). The effect of the presence of camping facilities on a lake is an increase in effort of 4% over lakes without camping facilities.

The presence of a fishing camp or resort caused an increase in effort of approximately 6% over lakes without resort facilities and accounted for 1% of the deviance variability in the GLM (Table 3.1). Fish type (wild or stocked) and presence of a resort was included as an interaction term. Wild stock lakes with a fishing resort receiving almost 11% more effort

Table 3.1: Analysis of deviance table for the base data GLM. Data from 183 lakes in Region 3 were used to fit the model. Parameter estimates (regression coefficients) are shown for the continuous explanatory variables (Road Km and Area) and discrete explanatory variables with 2 levels.

Source	d.f.	Parameter Estimate	Parameter s.e.	p-value	Residual Deviance	% Explained
NULL					7866.6	
Road Km	1	-0.0034	0.0003	<0.0000	5844.4	25.7
BEC Zone	3			<0.0000	5117.4	12.4
Area	1	-0.0035	0.0004	<0.0000	5113.7	0.1
Limit(Less)	1	0.3264	0.0276	<0.0000	4902.9	4.1
Type(Wild)	1	-0.8073	0.0714	<0.0000	4570.1	6.8
Launch(Yes)	1	0.5638	0.0350	<0.0000	4167.5	8.8
Camping(Yes)	1	0.1719	0.0278	<0.0000	4070.6	2.3
Resort(Yes)	1	0.2746	0.0427	<0.0000	4033.6	0.9
Foot(Yes)	1	-0.9077	0.0608	<0.0000	3788.2	6.1
Type*Resort	1	0.4568	0.0880	<0.0000	3760.7	0.7
Intercept		4.2629	0.1615	<0.0000		
Model					3760.7	52.2

than lakes that didn't have resort facilities and wild rainbow trout stocks. The interaction term accounting for an additional 1% of the deviance variability (Table 3.1).

Larger lakes appear to be less attractive to anglers than small lakes. For example, a 200 ha lake would have an associated decrease in effort of 0.6 AD/ha over a 20 ha lake if all other explanatory variables were held fixed. While lake surface area explained less than 1% of the deviance variability in the model (Table 3.1), the omission of the lake surface area variable from the model would have resulted in a decrease of almost 2% in the explained deviance variability for the entire model.

3.1.2 Effort Predictions

Compared to the observed effort from the SLAM aerial boat counts, the base data GLM tends to overestimate effort for lakes that receive low angling pressure, and underestimate effort for lakes that receive higher angling pressure (Figure 3.2). The lakes that the base data GLM underestimates effort for are almost all resort lakes, or are located along a major forestry road in the Nehalliston Plateau, in the northern section of the region. The lakes for which the base data GLM overestimated effort, compared to the aerial boat count observed effort, were also mostly resort lakes, or were located in the southern section of the region with shorter driving distances.

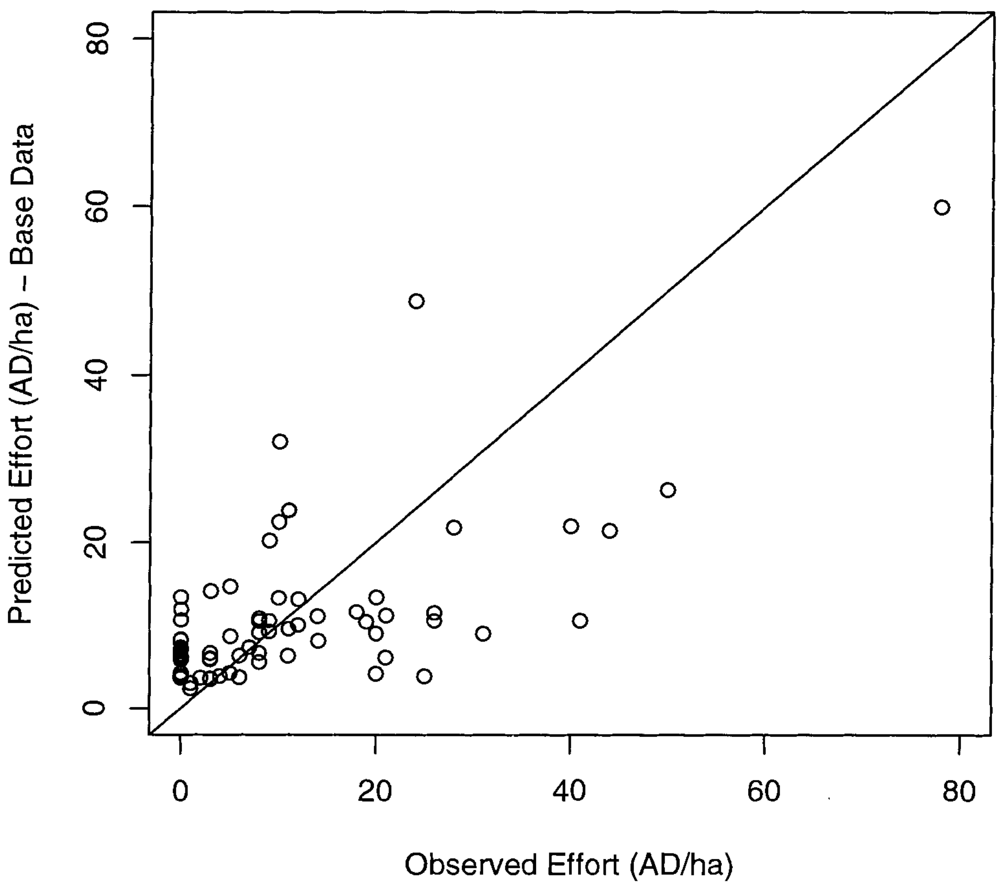

Figure 3.2: Predicted effort (AD/ha) from the base data GLM versus observed effort from aerial boat counts for "wild" rainbow trout lakes.

Effort predictions from the base data GLM for "wild" rainbow trout lakes ranged from 1 to 60 AD/ha. Ninety four percent of the 326 "wild" rainbow trout lakes for which effort was predicted using the base data model had less than 20 AD/ha of fishing pressure, and only 3 lakes (less than 1%) of the lakes had predicted angler effort greater than 30 AD/ha (Figure 3.6). Predicted efforts for the 326 individual "wild" rainbow trout lakes can be viewed in the Appendix B.1.

3.1.3 Vulnerability to Overfishing

Of the 326 lakes I predicted effort for with the base data GLM, 3 lakes were ranked as highly vulnerable to overfishing and 21 lakes were ranked as moderately vulnerable to overfishing using the parametric method (Figure 3.4)(Table 3.3). Figure 3.3 illustrates the probability density functions for fishing effort on 2 lakes that were assessed as highly vulnerable to overfishing (Pimainus No.3 and Roscoe), 2 lakes that were assessed as moderately vulnerable to overfishing (Hardcastle and Rock Island) and 2 lakes that were considered unlikely to be overfished (Arthur and Lorenzo). The predicted effort from the base data GLM is 51% greater than the observed effort for Pimainus No.3 Lake and 68% greater than the observed effort for Roscoe Lake. The observed SLAM effort for both lakes is not even within the 95% confidence interval of the predicted effort. While both Pimainus No.3 and Roscoe lakes are ranked as highly vulnerable to overfishing, both lakes would not have been considered vulnerable to overfishing from the SLAM data. The observed effort on Chataway Lake is 23% greater than the predicted effort from the base data GLM (Table 3.3). Chataway Lake is ranked as highly vulnerable to overfishing using the parametric method and would be considered highly vulnerable to overfishing from the SLAM effort observations. The observed effort from the SLAM aerial counts for Hardcastle and Rock Island Lakes is high enough that both lakes would have been flagged as highly vulnerable to overfishing. The parametric method ranks both lakes as moderately vulnerable to overfishing. There is no observed effort from boat count flights for Arthur or Lorenzo Lakes. Arthur Lake is on the high side of not being vulnerable to overfishing, for while the predicted effort falls within one confidence interval of being moderately vulnerable to overfishing, there is not more than a 30% probability that the predicted effort for Arthur Lake is greater than 18.1 AD/ha. Lorenzo Lake is representative of the majority of wild rainbow trout lakes that were not predicted to be vulnerable to overfishing by the parametric method.

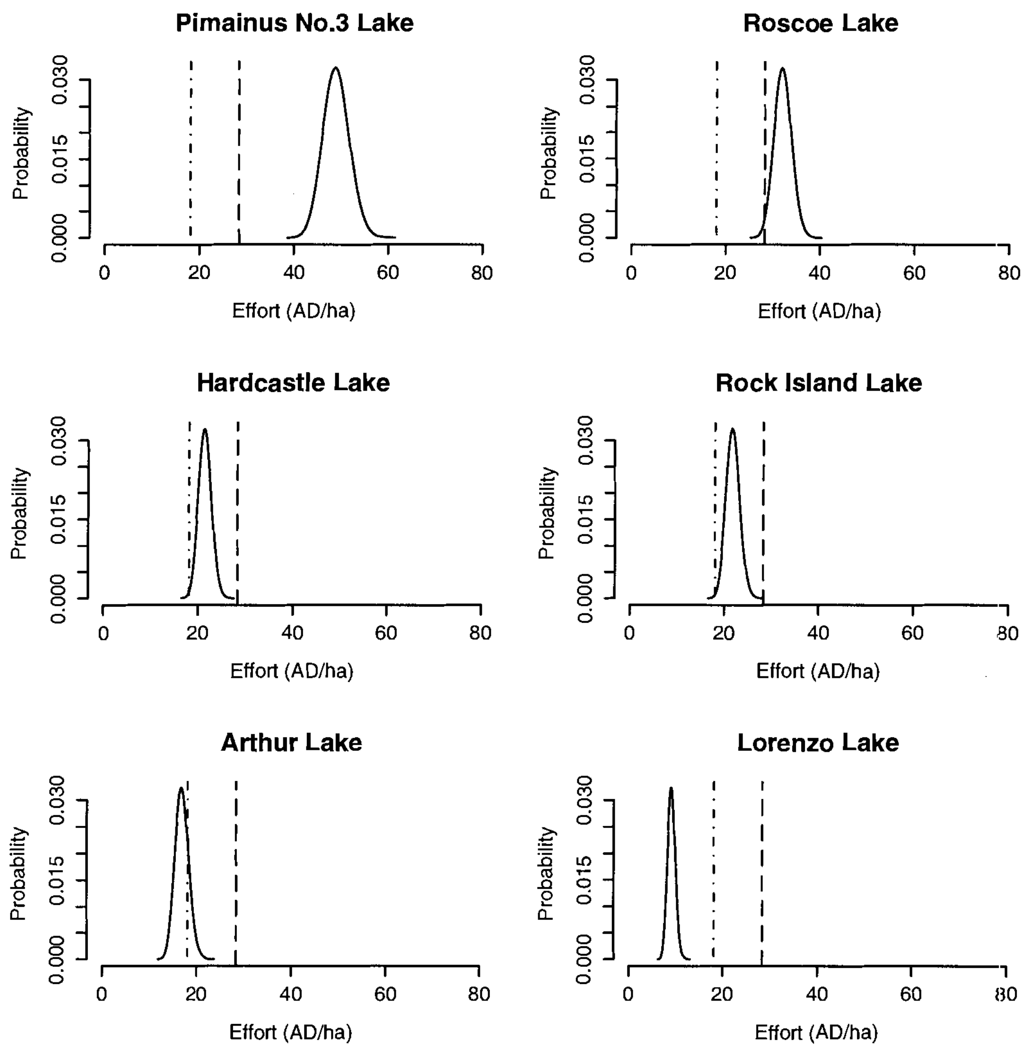

Figure 3.3: Probability density functions of fishing effort (AD/ha) for wild trout lakes in the Thompson Nicola Region, as predicted by the parametric method. The vertical dash line at 28.3 AD/ha represents the critical cut-off point for overfishing. Lakes that have more than a 30% predicted probability of the fishing effort exceeding the critical threshold (more than 30% of the probability density function area occurs to the right of the critical threshold line) are considered highly vulnerable to overfishing. Where there is more than a 30% probability that fishing effort on a lake is > 18.1 AD/ha (vertical dot-dash line) but ≤ 28.3 AD/ha, lakes are categorized as moderately vulnerable to overfishing. Lakes that have more than a 70% predicted probability of attracting ≤ 18.1 AD/ha of fishing effort are considered unlikely to be overfished.

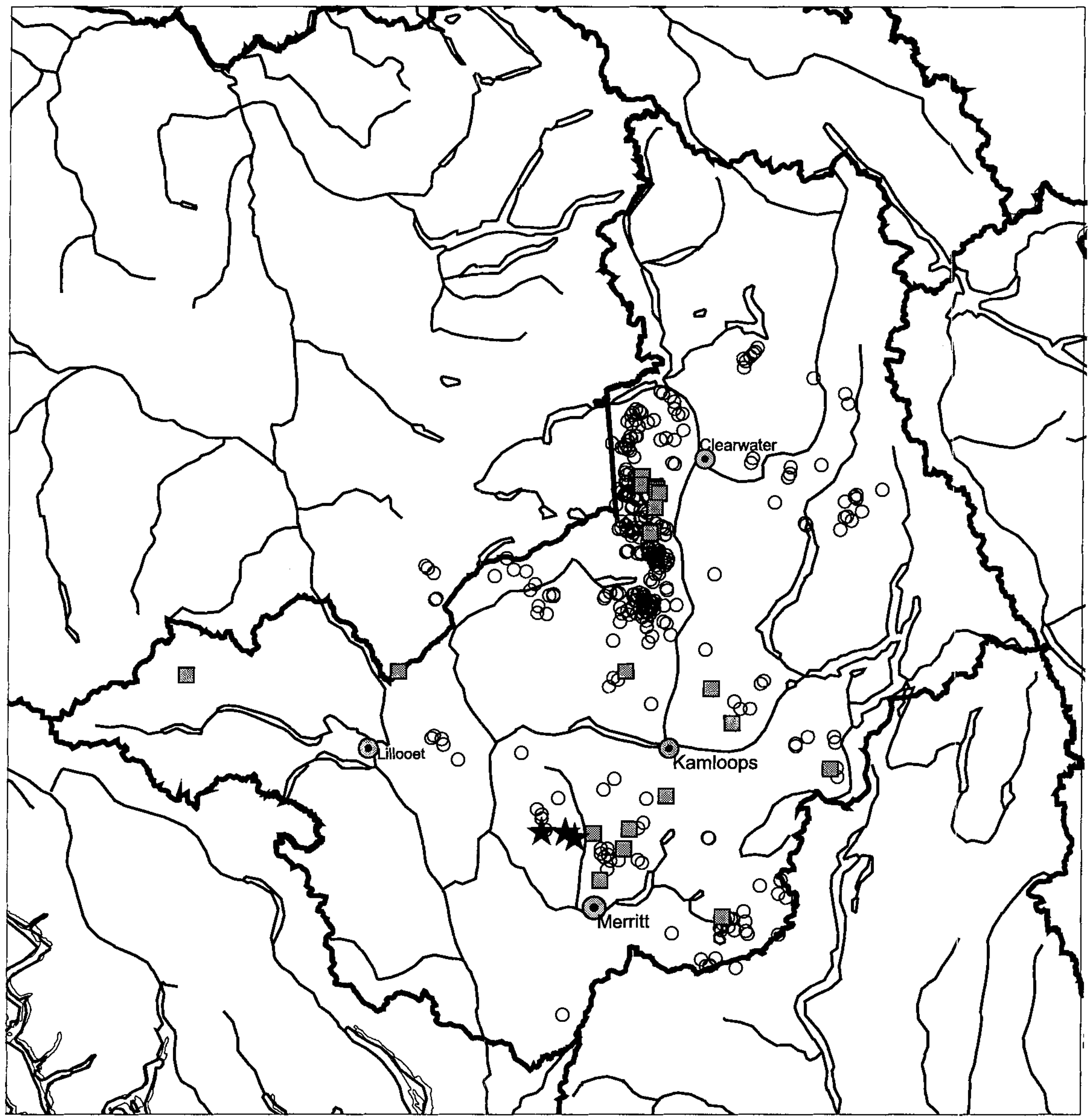

Figure 3.4: Lakes that are vulnerable to overfishing, as predicted by the parametric method. Lakes that are highly vulnerable to being overfished are represented by the ★ and lakes that are moderately vulnerable to being overfished are represented by the gray □. Lakes that are unlikely to be overfished are represented by the ∘. Cities and towns in the region are shown by the gray ⊙.

Table 3.2: Summary table for the bootstrap GLM explanatory variables. The Frequency of Occurrence is the number of times the stepwise AIC procedure selected the variable for each of the 100 bootstrap GLM's. The Parameter Estimates, p-value, and % Explained for the base data GLM explanatory variables are included for comparison.

		Bootstrap GLM		Base Data GLM		
Variable	d.f.	Frequency (%) of Occurrence	Average p-value	Parameter Estimate	p-value	% Explained
Road Km	1	96	0.0003	-0.0034	0.0000	25.7
BEC Zone	3	100				12.4
- *(IDF)*		100	0.0102	0.6657	0.0000	
- *(MS)*		100	0.0963	0.1883	0.0230	
- *(SBS)*		100	0.0599	0.4303	0.0000	
Area	1	93	0.0051	-0.0035	0.0000	0.1
Limit(Less)	1	98	0.0014	0.3264	0.0000	4.1
Type(Wild)	1	100	0.0000	-0.8073	0.0000	6.8
Launch(Yes)	1	100	0.0000	0.5638	0.0000	8.8
Camping(Yes)	1	81	0.0033	0.1719	0.0000	2.3
Resort(Yes)	1	100	0.0547	0.2746	0.0000	0.9
Foot(Yes)	1	100	0.0000	-0.9077	0.0000	6.1
Type*Resort	1	89	0.0094	0.4568	0.0000	0.7
Intercept			0.0000	4.2629	0.0000	

3.2 Bootstrap Method

3.2.1 Explanatory Variable Selection

The stepwise AIC procedure for the bootstrap GLM did not select camping facilities as an explanatory variable for 19% of the models, the interaction term for 11% of the models, surface area as an explanatory variable for 7% of the models, driving distance or the interaction term as an explanatory variable for 4% of the models, and bag limit as an explanatory variable for 2% of the models. BEC zone, stock type, trailer boat-launch, fishing resort, and foot access were selected as explanatory variables for all of the 100 bootstrap GLM models (Table 3.2).

3.2.2 Effort Predictions

Effort predictions from the bootstrap GLM are not statistically different from the mean effort predictions from the base data model. Figure 3.5 illustrates the mean effort predictions from the bootstrap GLMs for each of the wild lakes in relationship to the base data GLM effort predictions. The relationship is very close to a 1:1, with a slope of 1.028, p-value <0.001, and adjusted r^2 of 0.997.

Mean predicted efforts from the bootstrap data GLM for the "wild" trout lakes ranged from 1 AD/ha to 61 AD/ha. Three hundred and six (just under 94%) of the 326 "wild" lakes for which effort was predicted for using the bootstrap data GLM had effort prediction of less than 20 AD/ha, which is almost the same result as the base data GLM predictions (Figure 3.6). The same 3 lakes (Chataway, Pimainus No.3 and Roscoe Lakes) had predicted fishing effort of 30 or more AD/ha using both the base data GLM and bootstrap GLM. Mean effort predictions from the bootstrap data GLM can be viewed for each of the "wild" rainbow trout lakes in Appendix B.1.

The median effort is less than the mean effort for 310 (95%) of the 326 "wild" rainbow trout lakes that effort was predicted for using the bootstrap GLMs (see Appendix B.1). The frequency of the observed fishing effort is skewed, with most of the lakes receiving less than 30 AD/ha of fishing pressure and a small number of lakes receiving more than 100 AD/ha of effort. The skewed data likely resulted in a couple of bootstrap data sets that are not representative of the base data. As a result, I expected the median effort to be less than the mean effort for most of the bootstrap GLM predictions.

3.2.3 Vulnerability to Overfishing

Of the 326 lakes I predicted fishing effort for using the bootstrap data, 5 lakes were ranked as highly vulnerable to overfishing. Three of the 5 lakes were also ranked as highly vulnerable to overfishing by the parametric method and the other 2 lakes were ranked as moderately vulnerable by the parametric method. The remaining 19 lakes that were classified as moderately vulnerable to overfishing using the parametric method were also classified as moderately vulnerable using the bootstrap method. However, the bootstrap method classified an additional 8 lakes as moderately vulnerable to overfishing (Figure 3.8)(Table 3.3). Figure 3.7 illustrates the histograms of predicted fishing effort for the same lakes shown in Figure 3.3 for the parametric method. The predicted effort for Pimainus No.3 and Roscoe Lakes, both of which were assessed as highly vulnerable to overfishing by the bootstrap method, is 52% and 69%, respectively, greater than the observed effort from the boat count flights. While both the bootstrap and parametric methods identified Pimainus No.3 and Roscoe Lakes as highly vulnerable to overfishing, neither lakes would have been considered highly vulnerable to overfishing from the SLAM effort observations.

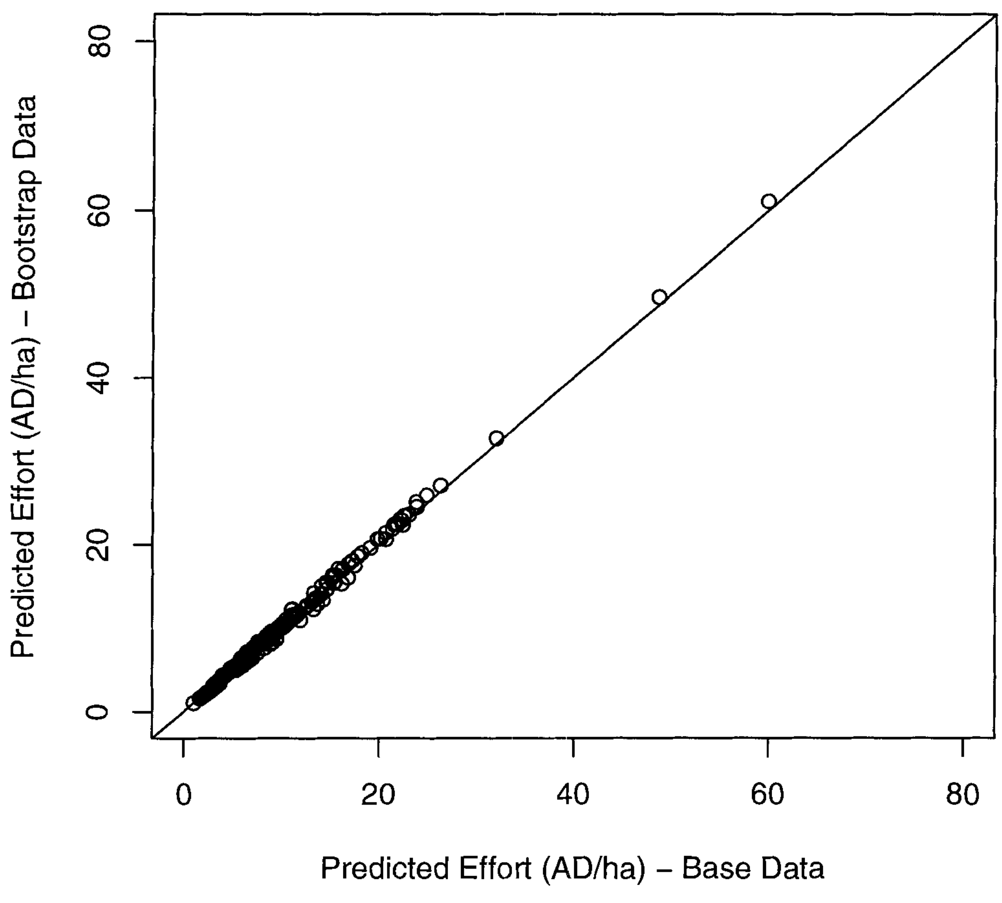

Figure 3.5: Mean effort predictions from the bootstrap GLMs versus the base data GLM predictions.

Table 3.3: Wild rainbow trout lakes vulnerable to being overfished, as predicted by the bootstrap method and parametric method. WBID is the unique waterbody identifier for the lake and the observed effort (Obs. Effort) is from the aerial boat count flights. Effort is defined in terms of angler-days per hectare (AD/ha). The vulnerability (Vuln.) of a lake to being overfished is listed as high, moderate (mod) and low. The predicted mean effort, standard error (SE), and predicted median effort (Med. Effort) from the bootstrap GLMs are listed under the Bootstrap Method columns. If more than 30 of the effort predictions were greater than 18.1 AD/ha, the lake was classified as moderately vulnerable to overfishing using the Bootstrap Method. If more than 30 of the 100 effort predictions were greater than 28.3 AD/ha, the lake was classified as highly vulnerable to overfishing. The predicted effort (Pred. Effort) and standard error (SE) from the base data GLM are listed under the Parametric Method columns. If there is more than a 30% probability that the predicted effort from the base data GLM is greater than 18.1 AD/ha, the lakes are defined as moderately vulnerable to overfishing. If there is more than a 30% probability that the predicted effort is greater than 28.3 AD/ha, the lakes are defined as highly vulnerable to overfishing.

			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Chataway	00254LNIC	78	61.07	16.22	58.98	high	59.95	3.66	high
Pimainus 3	00956THOM	24	49.70	11.86	49.16	high	48.75	2.82	high
Roscoe	00168LNIC	10	32.74	7.54	32.32	high	32.05	1.86	high
Surrey	00174LNIC	50	27.07	6.73	26.39	high	26.33	1.62	mod
Morgan	00826GUIC		25.88	8.08	24.30	high	24.91	1.88	mod
Mamit	00584GUIC	11	25.08	7.87	23.61	mod	23.82	1.89	mod
Lost Horse	00270LNTH	11	24.50	6.00	23.99	mod	23.85	1.55	mod
Dot	00777LNTH		23.59	5.72	23.43	mod	23.07	1.48	mod
Bute	00782STHM		23.42	7.17	22.30	mod	22.57	1.70	mod
Unnamed	00956NICL		23.02	7.04	22.09	mod	22.19	1.67	mod
Thuya	00762LNTH		22.90	5.55	22.88	mod	22.36	1.43	mod
Rock Island	00300LNTH	28	22.56	5.94	21.98	mod	21.79	1.45	mod
Latremouille	00410LNTH		22.42	6.24	21.30	mod	21.55	1.47	mod
Crater	00291LNTH	40	22.42	5.37	22.35	mod	21.91	1.41	mod
Grizzly	00223LNTH	10	22.38	8.06	22.30	mod	22.46	1.91	mod
Hardcastle	00280LNTH	44	21.90	5.25	22.01	mod	21.38	1.37	mod
Bolean	00468STHM		21.40	5.27	20.85	mod	20.68	1.33	mod
Cone	00322LNTH	9	20.72	5.04	20.92	mod	20.16	1.31	mod
Spruce	00110SETN		20.63	7.49	20.15	mod	20.70	1.74	mod
Pear	01094BBAR		20.62	6.45	19.52	mod	19.83	1.53	mod
Tranquille	00055THOM		19.58	4.23	19.61	mod	19.12	1.23	mod
L. Pinantan	01713LNTH		18.95	5.95	18.24	mod	18.21	1.41	mod
L. Heffley	01539LNTH		18.59	5.89	17.81	mod	17.84	1.39	mod
Ukulele	00156STHM		18.06	6.08	17.22	mod	17.26	1.39	low
River	02178GRNL		17.64	5.96	16.97	mod	16.85	1.36	low
Helmer	00434LNIC		17.45	4.50	17.01	mod	17.48	1.27	mod
Long Island	00449LNTH		17.13	6.40	15.66	mod	15.84	1.31	low
Miller	00145STHM		17.04	5.47	16.42	mod	16.32	1.29	low
China	00136STHM		16.86	5.38	16.23	mod	16.15	1.27	low
Rock	01036NICL		16.33	4.61	16.05	mod	15.27	1.12	low
Arthur	00451STHM		15.98	5.84	15.68	mod	16.81	1.46	low
Unnamed	01354LNIC		15.26	7.38	13.92	mod	16.18	1.81	low

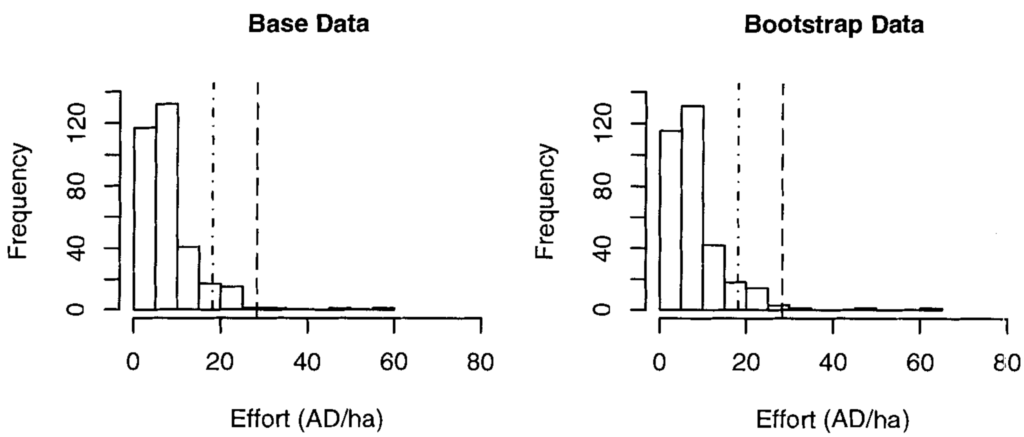

Figure 3.6: Histograms of predicted fishing effort (AD/ha) for wild trout lakes in the Thompson Nicola Region from the base data and bootstrap data. Predicted bootstrap data is the mean predicted effort. The vertical dash line at 28.3 AD/ha represents the critical cut-off point for overfishing. The vertical dash-dot line at 18.1 AD/ha represents the cut-off point below which lakes are considered unlikely to be overfished.

The larger standard error in the bootstrap GLM mean effort predictions, compared to the standard error for the base data GLM effort predictions, allows for a wider range of possibilities in fishing pressure estimates and overfishing vulnerabilities. However, given the relatively similar effort and vulnerability predictions between the bootstrap and parametric methods, I have some confidence that my conclusions are relatively robust.

The 3 lakes that are classified as highly vulnerable to overfishing by both the parametric method and bootstrap GLM are all located close together in the southern portion of the region between the cities of Kamloops and Merritt. All 3 lakes are approximately a three hour drive from the Lower Mainland, are in the MS BEC zone, are accessible by vehicle (are not walk-in lakes), have camping facilities and are fished by resort clients. All of the lakes that are classified as moderately vulnerable to overfishing have either a short driving distance, are located in the IDF BEC zone, are accessible by vehicle, or are fished by a resort (see Appendix A.1). The strong influence of driving distance on fishing effort is illustrated in Figures 3.4 and 3.8. While the majority of wild rainbow trout lakes I predict effort for are located north of Kamloops, a relatively small proportion of the lakes are vulnerable to overfishing. There are considerably fewer wild rainbow trout lakes in the southern portion of the region, but almost half of the lakes classified as moderately vulnerable to overfishing are located around or south of Kamloops. Lakes in the southern

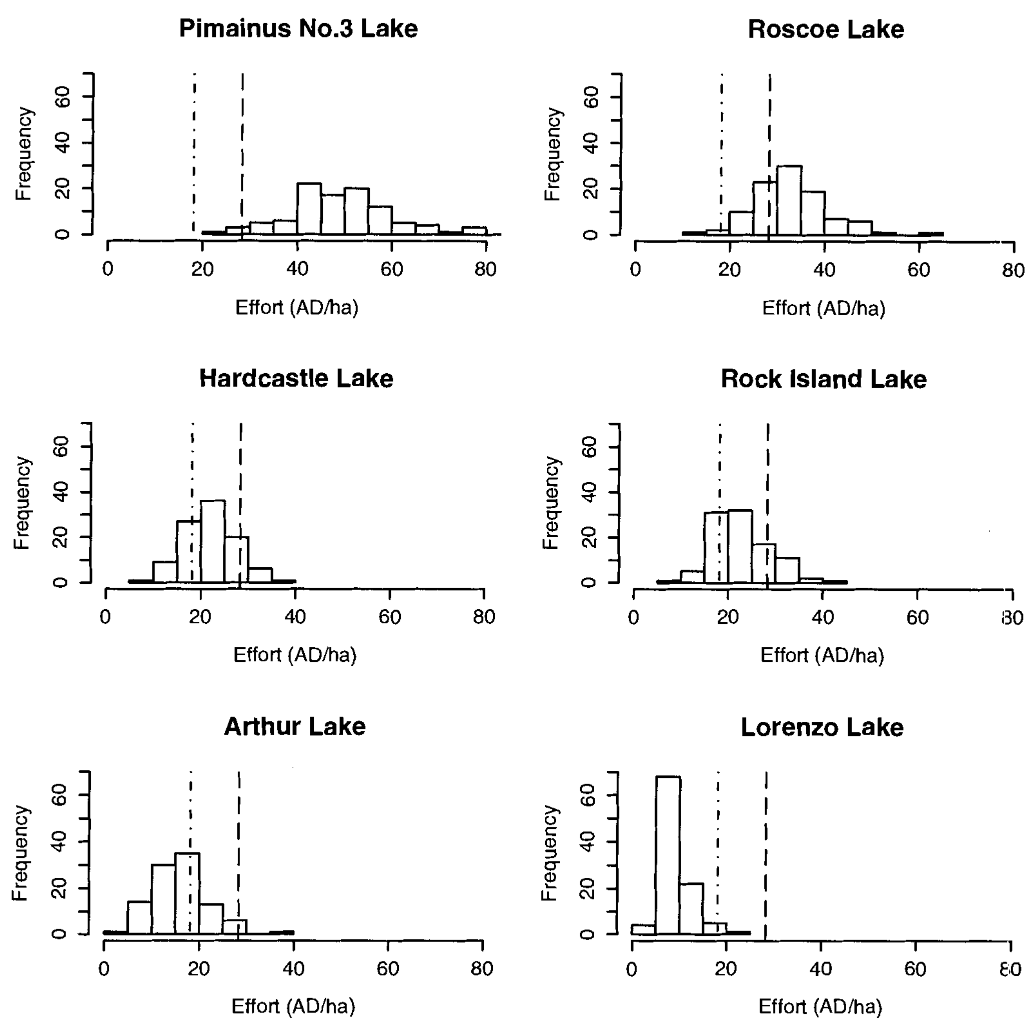

Figure 3.7: Histograms of fishing effort (AD/ha) for individual wild trout lakes in the Thompson Nicola Region, as predicted by the bootstrap method. The vertical dash line at 28.3 AD/ha represents the critical cut-off point for overfishing. Lakes where more than 30% of the predicted fishing effort values exceed the critical threshold (more than 30% of the effort frequency occurs to the right of the critical threshold line) are considered highly vulnerable to overfishing. Where more than 30% of the predicted fishing effort values for a lake are > 18.1 AD/ha (vertical dot-dash line) but ≤ 28.3 AD/ha, lakes are categorized as being moderately vulnerable to being overfished. Where more than 70% of the predicted fishing effort values are ≤ 18.1 AD/ha, lakes are considered unlikely to be overfished.

portion of the region have a shorter driving distance for the majority of anglers that travel from the Lower Mainland and Okanagan regions to the south.

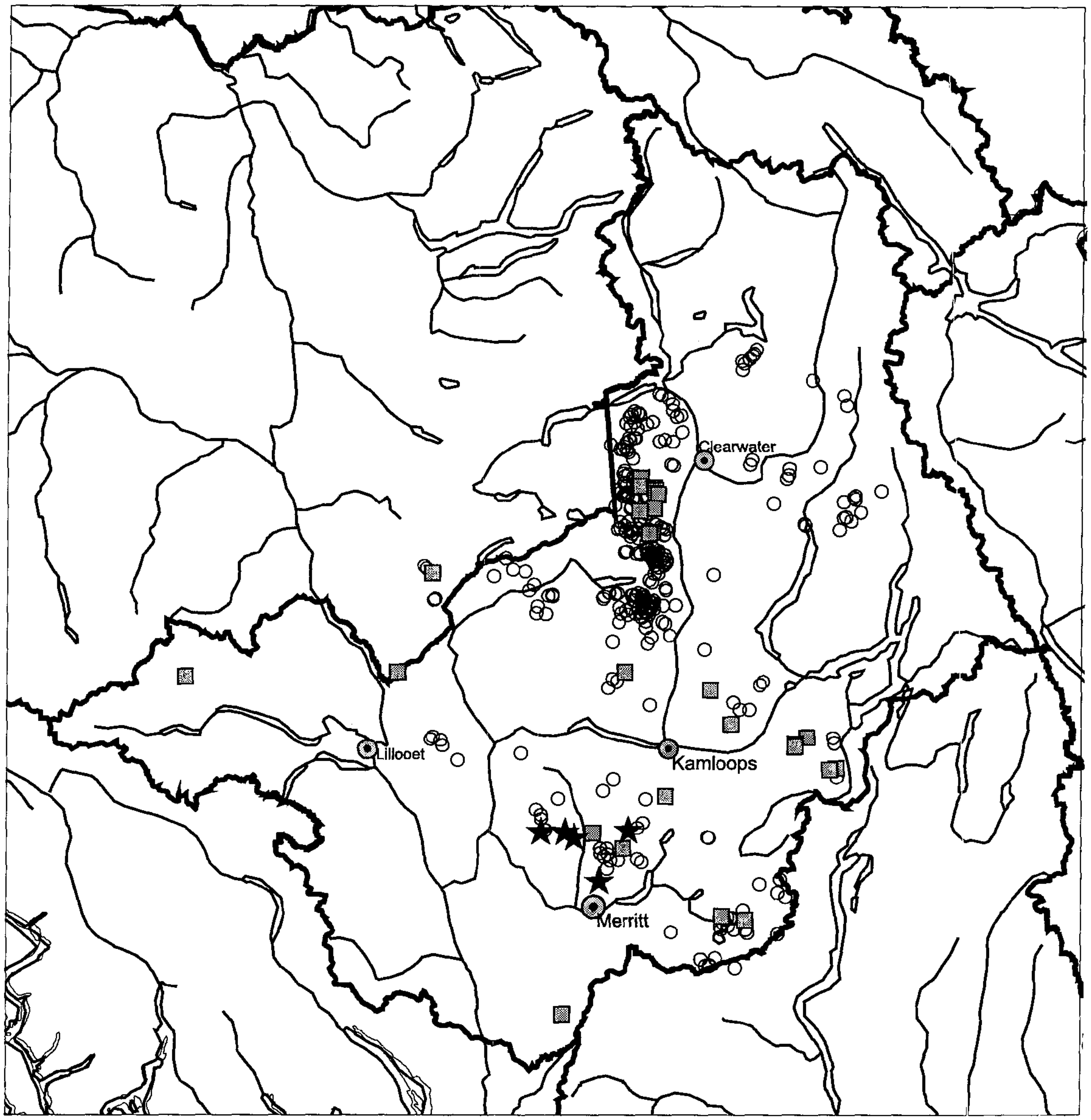

Figure 3.8: Lakes that are vulnerable to overfishing, as predicted by the bootstrap method. Lakes that are highly vulnerable to being overfished are represented by the ★ and lakes that are moderately vulnerable to being overfished are represented by the gray □. Lakes that are unlikely to be overfished are represented by the ∘. Cities and towns in the region are shown by the gray ⊙.

Chapter 4

Discussion

The objective of this project was to assess the vulnerability of wild rainbow trout lakes to overfishing in the Thompson Nicola Region of British Columbia. My results suggest that few lakes are exposed to effort levels high enough for fish stocks to be vulnerable to collapse under current conditions. Lakes that are vulnerable to overfishing are characterized by having short driving distances, are accessible by vehicle, are productive (located in the IDF BEC zone), or are fished by a resort. More than 90% of the wild trout lakes I assessed were not vulnerable to overfishing. These lakes tended to be more difficult to access (longer driving distance or no road access), were less productive (located in the ESSF BEC zone), or did not offer camping or resort facilities.

While the study results give reason to be optimistic, I would caution fisheries biologists and managers from interpreting the results as an indication that current management practices are protecting wild rainbow trout stocks. Many wild trout lakes in the region are protected because of their remoteness, undeveloped access, and distance from large populations centers. Lakes that are easily accessible and close to large population centers may be at greatest risk to overfishing if managers and anglers continue to accommodate decreasing angling quality. Managers may be willing to accept poor angling quality on a number of lakes, but in the absence of clear understanding as to when poor fishing quality may switch to collapsing fish stocks, this acceptance will become increasingly risky. The point at which fish abundance is driven low enough to discourage additional angling effort may also be the point that is low enough to reach recruitment overfishing (Walters and Martell 2004). Lakes located between Merritt and Kamloops, which are located closest to large population centers and to major highways, will be at greatest risk of overfishing.

An inverse relationship between travel time and recreational demand is well documented in economic literature (McConnell and Strand 1981, Earnhart 2004). However, other than passing references to heavy fishing pressure on lakes close to major population centers (Lester et al. 2003), few studies have attempted to quantify the relationship between access and recreational fishing effort. The relationship between road access and angling effort has long been acknowledged for lakes in the Thompson Nicola Region, so it is not surprising that driving distance was the most influential explanatory variable in the base data model. Anecdotal tales from the area's early pioneers recount the disappearance of trout from waters within a few kilometers of Kamloops and as early as the 1930's, lakes that were easily accessible, such as Paul, Pinantan and Knouff, were recognized as being subject to a heavy fishing pressure (Mottley 1932).

While road access is the most influential explanatory variable in the GLM, the ability of access to explain angler effort would likely be improved if the condition of the road, and not just road distance alone, was included in the model. Lakes located close to major highways are probably more attractive to the recreational angler than lakes that require travel over rough dirt roads. A few of the lakes for which I predicted lower effort than the observed aerial effort were located right beside a major forestry road in the northern portion of the region. While I did not have the data to effectively test whether four-wheel drive vehicle access negatively impacts angler effort, the results of the trailer boat-launch variable, as discussed below, suggests that it likely would.

Foot access captures another element of accessability. Lakes that cannot be accessed by road likely attract a smaller segment of the angling population because they require more physical work to reach, require a longer time commitment because of the additional hiking time, and are harder to abandon in favour of another lake if the fishing is poor. Walk-in lakes are also typically less well known, and therefore, attract the effort of small numbers of local anglers who have an intimate knowledge of the area. Visiting anglers, which make up more than 75% of the anglers fishing in the Thompson Nicola Region (Levey and Williams 2003), are much less likely to know how to access walk-in lakes than local anglers.

My results suggest that anglers prefer to fish more productive lakes, which may support bigger fish or more fish. While productive lakes are able to support a more productive fishery than less productive lakes, productive lakes usually have a greater amount of capital investment in the form of resorts, campsites, and boat launches. Thus, the economic and social hardship associated with overfishing productive lakes is greater than that associated with less productive lakes should a collapse occur.

Angler preferences for smaller lakes may be a result of smaller lakes being easier to fish from small boats and float tubes. The total lake can be swept much more effectively, increasing the chance of anglers targeting vulnerable fish. Smaller lakes are also more protected from wind by shoreline vegetation and surrounding hillsides, making it easier to manoeuver and cast. In addition, because of the windscreen offered by the shoreline vegetation and landscape, and because of the shorter distances to travel in small lakes, less capital investment is required in the form of large boats and motors for safety, or to effectively search the lake for fish. Smaller lakes may also be more attractive to anglers because they generally produce more fish per hectare. Smaller lakes typically have a lower mean depth and higher morphoedaphic index than larger lakes (Ryder et al. 1974). The more productive the lake, the greater the yield of fish.

Lakes with facilities on them, such as boat launches, fishing resorts, or campsites, are probably attractive to anglers for a number of reasons. The Thompson Nicola is the number one fishing destination region in the province (Levey and Williams 2003) and visiting anglers require additional facilities, such as accommodation. Therefore, visiting anglers are more likely to fish lakes where resort and camping facilities are available. Anglers who have committed time and money to a planned fishing vacation are also less likely than local anglers to abandon their activity if the fishing is slow. The presence of trailer boat launch facilities may attract more anglers to a lake because boat size is not a limiting factor. Anglers with both big boats and small boats can easily launch their vessel. However, I caution there is also the confounding possibility that lakes with trailer boat launches are attractive to anglers not because of the launch, but because of the good road access. It is very unlikely that trailer boat launches would be built on lakes with rough road access.

The results from my study indicate effort is higher on rainbow trout lakes with daily bag limits of less than 6 fish (primarily 2-fish limit lakes), and lower on lakes with daily bag limits of 6 fish. This is contrary to the recreational angler response results of Beard et al. (2003) in which angler effort was significantly higher on lakes with bag limits of 5 walleyes/day than lakes with bag limits of 2 or 3 walleyes/day. The effectiveness of bag-limits in controlling angler effort and harvest is being increasingly questioned. Research also suggests bag-limits may be having the opposite effect intended by managers, for bag-limits may be indirectly affecting the perceived "attractiveness" of a lake fishery (Beard et al. 2003). The regulation may be influencing an anglers choice to fish at a given site. For example, decreasing the bag-limit to 2 fish from 6 fish may cause an increase in effort and overall increase in harvest if anglers perceive the decrease in limit to mean the lake provides bigger fish. It is unclear as to whether anglers are attracted to lakes with lower bag-limits, or, and more likely, if managers in the Thompson Nicola Region are correctly identifying lakes with high effort and are putting more restrictive bag-limits in place on such lakes. It is also unclear as to whether or not the bag-limit restrictions are limiting harvest levels enough to ensure the fisheries are sustainable.

4.1 The Bootstrap Method versus the Parametric Approach to Addressing Model Uncertainty

While the results using the parametric method and bootstrap method are very similar, I believe the bootstrap method has some advantages and offered additional insights. One of the biggest advantages of the bootstrap method is that it doesn't assume one model is superior over another. In addition, I was able to assess how the base data GLM, which was used in the parametric method, would behave with other data sets (Hilborn and Mangel 1997). Instead of assuming that the base data model, or any one particular model provided the "best" estimate of angler effort, I included estimates from all 100 of the bootstrapped models to assess the vulnerability of lakes to being overfished.

Another advantage of bootstrapping is that I could address model uncertainty, for I was able to evaluate bias in the model estimates and in the model variable selection (Efron and Tibshirani 1991, Power and Moser 1999). While BEC zone, stock type, boat launch, fishing resort and foot access were selected as explanatory variables for every bootstrap data set, driving distance, area, bag-limit, camping and the interaction term were not. Explanatory variables may not have been selected because of skewed data, or because the variable is dependent on the combination of lakes included in the base data set. However, while there may be some concern that a few of the variables do not do a good job of explaining angler effort, this concern should be small. All of the explanatory variables were selected more than 80% of the time, and all but the camping and interaction variables were selected more than 90% of the time.

The base data distribution is highly skewed, with the majority of the lakes receiving angling pressure of less than 30 AD/ha. During the bootstrapping process, when individual lakes are selected with replacement, there is a greater probability that lakes with low fishing effort will be selected. As a result, the median predicted effort from the bootstrap GLMs is lower than the mean predicted effort. Because high effort lakes are not included in the bootstrap data sets as frequently as low effort lakes, the confidence intervals are much greater for high effort lakes than low effort lakes.

4.2 Potential Model Improvements

There are a couple of potential problems with using the observed SLAM aerial boat count effort data. Managers are cautioned from being too rigid in their interpretation of SLAM effort data due to some known problems with the results (Tredger 1992). Large coefficient of variation values in the SLAM effort estimates indicate a high degree of variability, and errors are greatest on lakes with low effort counts (Tredger 1992). This is somewhat problematic for my analysis given that most wild rainbow trout lakes experience considerably lower effort than hatchery stocked lakes. In addition, while it is not clear how lakes are selected for the aerial boat counts, it is unlikely that lakes are chosen at random, potentially adding bias to the GLM predictions. Lakes that receive high angling effort tend to be assessed with greater frequency, for managers receive more public input on popular fishing lakes. For the above reasons, the SLAM effort variables I included in my analysis may represent lakes with higher than average fishing effort for the region. Therefore, I would expect my effort predictions to be biased high on low effort lakes and biased low on high effort lakes compared to the SLAM observations.

Another shortcoming of my assessment is that there is no explanatory variable to account for the effect of average fish size or population density of fish in the lakes. While the BEC zone is used as a surrogate for lake productivity, and therefore, fish abundance, it is not a direct measure of the fish population. Lake productivity plays an important role in producing desirable fish and attracting fishing effort, but another important part of fish habitat requirements is missing from the model. Ultimately, the amount of spawning and rearing habitat present in lakes affects the density of fish in a lake. Stream habitat is essential for rainbow trout reproduction (Scott and Crossman 1973). Because stream habitat data is poor or non-existent for most Southern Interior lakes, stream productivity was not accounted for in the effort model. The omission of stream habitat data may have caused the incorrect assessment of the vulnerability of some lakes to overfishing. Knowledge of local stream habitat by fisheries managers may be able to address some of this concern. Where there is uncertainty or lack of knowledge, lakes should be further assessed.

I did not distinguish between mixed-species lakes and monoculture rainbow trout lakes in the analysis, primarily because I lacked the adequate data. However, literature demonstrates that mixed-species lakes, which are common in the Bonaparte Plateau area north of Kamloops, would be at greater risk of overharvesting. Lakes with game-fish and non game-fish stocks, such as northern pikeminnow *Ptychocheilus oregonensis*, may especially be vulnerable to overfishing. Because the sport fishery is only targeting the rainbow trout, the trout stock may be reduced to a population size at which they cannot compete with the non-sport fish (Walters and Kitchell 2001, Sadovy 2001, Cox and Kitchell 2004). Predator-prey interactions may result in the two species reaching a new equilibrium, one at which the fishery is no longer attractive to anglers.

My analysis is only effective in identifying lakes vulnerable to overfishing when the stock remains resilient under sustained harvest pressure. In the absence of stock assessment data, I am not certain that some of the lakes included in the base data GLM haven't already been overfished. While I have assumed that some lakes receive low effort because of the attractiveness of the lake, the low effort may a result of poor fishing on an already over-harvested stock. If this is the case, the level of fishing effort that can be explained by the explanatory variables may be inaccurate. As a result, stocks that have already collapsed may be incorrectly assessed as having a low vulnerability to overfishing.

4.3 Management Implications

The use of personal intuition and experiences, along with anecdotal reports from the fishing public and resort owners, may have allowed fisheries biologist to adequately manage wild fish stocks in the past, but such an approach will become an increasingly risky management strategy (Shuter et al. 1998, Cox and Walters 2002*b*). Provincial fisheries biologists are coming under increasing economic and social pressure to understand effort dynamics and the potential impacts of fisheries on wild rainbow trout stocks. With thousands of individual waters to manage across the province, provincial fisheries programs will always be pressed for resources and money as they try to rise to this task. The results of my assessment procedure could be used to help rank or prioritize survey work for both fishing effort and stock assessments. For example, high-risk lakes may be candidates for a more detailed assessment of angling effort and fish community age-structure. Gillnet surveys could also be used to monitor maturity, growth, and the coefficient of variation of the annual gillnet catch per unit effort, three key biological performance indicators that Gangl and Pereira (2003) found were sensitive to exploitation in Minnesota walleye lakes.

Fisheries biologists who manage stocked and wild trout populations in lakes should be especially wary of the influence stocked lakes may have on their perceptions of sustainable fishing effort. The collapse of many inland fish populations may have already been masked by the introduction of stocked fish (Post et al. 2002, Cooke and Cowx 2004). In addition, the ability of stocked lakes to support artificially high effort levels may diminish the ability of fisheries managers to recognize the lower, but much more critical effort levels at which wild lakes become vulnerable to overexploitation (Cox and Walters 2002*b*). Because stocked lakes have the same number of juvenile fish released into them each year, maintaining a consistent population, recruitment overfishing will never be a problem. Changing attitudes towards biodiversity and the importance of protecting genetic diversity within fish stocks will increasingly require fisheries managers to find ways to effectively limit harvest, because stocking wild lakes with hatchery fish is unlikely to be an acceptable response to declines in fish abundance in the future.

While it is important to identify lakes that are vulnerable to overfishing, identification is just the first step in protecting wild fish stocks. Managers will also need a better understanding of how to actively manage fishing effort in order to effectively limit total harvest when required (Lester et al. 2003). One of the hardest things to do in fisheries management is to reduce fishing pressure (Hilborn and Walters 1992). My analysis suggests the most effective tool managers have to limit effort on vulnerable wild trout lakes is to restrict access. Lakes that are more difficult to access, take longer to drive to, or are only accessible by foot experience less effort. Restricting access is easier to do before a road is built than after, so fisheries managers should continue to engage in access discussions with local governments and the forestry and mining sectors, for forestry and mining are the main activities that lead to easier road access. Effort limitation in areas where wild trout lakes may be vulnerable to overfishing could be achieved by limiting road construction, decommissioning old forestry roads, or erecting seasonal road closures. Compliance with road de-activation will be an issue, but with limited enforcement, compliance with any regulation will be an issue.

Fisheries managers should be cautious in assuming that more restrictive regulations will protect wild trout stocks. While most recreational anglers believe bag limits are important in conserving fish populations, most fisheries managers acknowledge that creel limits are relatively ineffective in controlling total harvest for individual lakes (Radomski et al. 2001, Walters and Martell 2004). Creel limits restrict the harvest of individual anglers, but do not restrict the overall harvest rate (Post et al. 2003, Radomski et al. 2001). While some managers feel that creel limits are effective at distributing harvest among a larger pool of anglers or at reducing total harvest during periods of high catch rates, Radomski et al. (2001) found no data to support these hypotheses. In addition, because anglers respond in complex ways to regulation changes, the effectiveness of regulation changes is often hard to predict (Beard et al. 2003). Changing harvest regulations on lakes may not always bring about the angler response that managers are looking for.

The dynamic interaction between anglers, fishing quality, and regulations often results in regulations being completely ineffective at sustaining native fish stocks near high concentrations of potential anglers (Post et al. 2003). While the introduction of restrictive fishing regulations may temporarily reduce fishing effort, resulting improvements in fishing quality (catch per unit effort) will likely attract effort back to the fishery (Post et al. 2003). There have been increasing calls for a "limited entry" system similar to those in place in wildlife management to allow for quality fishing on some lakes (Cox and Walters 2002*a*, Post et al. 2002). Work by van Poorten and Post (2005) suggests that providing high quality fisheries on even "limited entry" systems will be very difficult, for catch rates in their experimental lightly exploited populations decreases quickly, becoming indiscernible from fully exploited populations. Clearly, more experimental work needs to be done in the area of recreational fishing regulations if they are to be an effective tool for conserving fish stocks.

Very little was known about the overfishing potential of wild rainbow trout lakes before this study and nothing was known about the angling effort on hundreds of lakes throughout the region. My results show that fishing effort is highest on wild trout lakes with low driving distances, productive lakes (those within the IDF BEC zone), and lakes with fishing resorts. The results from my study also indicate that anglers prefer stocked lakes over wild trout lakes. The current objective of the provincial government is to increase angling licence sales and fishing revenue. Results from the National Sport Fish Survey (Levey and Williams 2003) show that a lack of leisure time prevents many anglers from fishing as much as they would like to and that anglers are more motivated to go fishing for relaxation than to catch fish. Most anglers are not willing to drive long distances to reach their fishing destination, so I would not recommend marketing remote fishing locations unless an effective set of regulations could be developed. By encouraging anglers to fish hatchery lakes to the south of the region and by working to effectively manage stocked lake fisheries in order to maintain their attractiveness to anglers, fishing effort on most wild stock lakes will be sustainable.

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Appendix A

Explanatory Variables

Table A.1: Explanatory variables for wild rainbow trout lakes that are highly and moderately vulnerable to overfishing, as predicted by the bootstrap method. Abbreviations are as follows: WBID, unique identifier for each waterbody in the province; E, annual effort the lake receives, measured as angler-days per hectare; Z, biogeoclimatic ecosystem classification zone the lake is located in; A, lake surface area (hectares); D, driving distance, in kilometers, from Surrey B.C. to the lake; F, whether or not the lake can only be accessed by foot (walk-in access only); R, whether or not the lake is fished by fishing resort clients; C, whether or not a Forest Recreation campsite or BC Parks campsite is located on the lake; L, whether or not the lake has a trailer boat-launch; B, bag-limit for the lake, where A is for lakes with the regional standard of 6 trout/day or more and L is for lakes with a limit of less than 6 trout/day.

Lake	WBID	Z	A	D	F	R	C	L	B
Chataway	00254LNIC	MS	22	277	No	Yes	Yes	Yes	A
Morgan	00826GUIC	IDF	3	264	No	No	No	No	A
Pimainus 3	00956THOM	MS	53	306	No	Yes	Yes	Yes	A
Roscoe	00168LNIC	MS	35	282	No	Yes	Yes	No	A
Surrey	00174LNIC	MS	50	274	No	Yes	No	No	A
Arthur	00451STHM	ESSF	76	375	No	Yes	Yes	No	A
Bolean	00468STHM	MS	71	374	No	Yes	Yes	No	A
Bute	00782STHM	IDF	4	292	No	No	No	No	A
China	00136STHM	IDF	18	376	No	No	No	No	A
Cone	00322LNTH	SBS	35	439	No	Yes	No	No	A
Crater	00291LNTH	SBS	11	439	No	Yes	No	No	A
Dot	00777LNTH	SBS	6	429	No	Yes	No	No	A
Grizzly	00223LNTH	ESSF	22	441	No	Yes	Yes	No	L
Hardcastle	00280LNTH	SBS	18	439	No	Yes	No	No	A
Helmer	00434LNIC	MS	17	264	No	No	Yes	No	A
L. Heffley	01539LNTH	IDF	9	356	No	No	No	No	A

Table A.1 – continued from previous page

Lake	WBID	Z	A	D	F	R	C	L	B
L. Pinantan	01713LNTH	IDF	9	350	No	No	No	No	A
Latremouille	00410LNTH	SBS	75	429	No	Yes	Yes	No	A
Long Island	00449LNTH	SBS	149	444	No	Yes	Yes	No	A
Lost Horse	00270LNTH	SBS	36	439	No	Yes	Yes	No	A
Mamit	00584GUIC	IDF	171	271	No	No	No	Yes	A
Miller	00145STHM	IDF	16	375	No	No	No	No	A
Pear	01094BBAR	IDF	3	331	No	No	No	No	A
River	02178GRNL	IDF	4	378	No	No	No	No	A
Rock	01036NICL	MS	65	300	No	No	No	No	L
Rock Island	00300LNTH	SBS	62	439	No	Yes	Yes	No	A
Spruce	00110SETN	ESSF	40	396	No	Yes	No	No	L
Thuya	00762LNTH	SBS	15	429	No	Yes	No	No	A
Tranquille	00055THOM	MS	53	365	No	Yes	No	No	A
Ukulele	00156STHM	IDF	2	373	No	No	No	No	A
Unnamed	00956NICL	IDF	4	297	No	No	No	No	A
Unnamed	01354LNIC	ESSF	10	189	No	No	No	No	A

Table A.2: Explanatory variables for wild rainbow trout lakes that are not vulnerable to overfishing. Abbreviations are as follows: WBID, unique identifier for each waterbody in the province; E, annual effort the lake receives, measured as angler-days per hectare; Z, biogeoclimatic ecosystem classification zone the lake is located in; A, lake surface area (hectares); D, driving distance, in kilometers, from Surrey B.C. to the lake; F, whether or not the lake can only be accessed by foot (has no road access); R, whether or not the lake is fished by fishing resort clients; C, whether or not a Forest Recreation campsite or BC Parks campsite is located on the lake; L, whether or not the lake has a trailer boat-launch; B, bag-limit for the lake, where A is for lakes with the regional standard of 6 trout/day or more and L is for lakes with a limit of less than 6 trout/day.

Lake	WBID	Z	A	D	F	R	C	L	B
Adler	00217DEAD	MS	34	394	Yes	No	No	No	A
Alberta	00811BBAR	IDF	111	392	No	No	No	No	A
And Another	01992NICL	MS	4	300	Yes	No	No	No	A
Another	01995NICL	MS	8	300	Yes	No	No	No	A
Arrowhead	02092MAHD	SBS	16	444	Yes	No	No	No	A
Bear	00654LNTH	SBS	4	429	Yes	Yes	No	No	A
Beaverdam	00614LNTH	SBS	14	446	No	No	No	No	A
Beckwith	00252BONP	SBS	5	394	Yes	Yes	No	No	A
Bedard	00596THOM	MS	20	286	Yes	No	No	No	A
Belcache	00169BONP	ESSF	14	446	Yes	Yes	No	No	A
Bitchy	00729LNTH	SBS	1	412	Yes	Yes	No	No	A
Blowdown	02091MAHD	SBS	16	444	No	No	No	No	L

Table A.2 – continued from previous page

Lake	WBID	Z	A	D	F	R	C	L	B
Bob	01330LNTH	ESSF	1	363	Yes	No	No	No	A
Boundary Line	01881MAHD	SBS	13	471	No	No	Yes	No	A
Braman	00948LNTH	ESSF	25	394	Yes	Yes	No	No	A
Brown Hat	01189LNTH	ESSF	4	394	Yes	No	No	No	A
Buck	00705LNTH	SBS	4	429	Yes	Yes	No	No	A
Bushwater	00148BONP	ESSF	7	429	Yes	Yes	No	No	A
Bus's Puddle	00149BONP	ESSF	3	429	Yes	Yes	No	No	A
Cameron	01500NICL	MS	30	354	No	No	No	No	A
Campeau	00655BONP	IDF	10	417	Yes	No	No	No	A
Cannine	01226LNTH	MS	7	394	Yes	No	No	No	A
Chester	00146BONP	ESSF	5	429	Yes	Yes	No	No	A
Christina	00942LNTH	ESSF	2	394	Yes	Yes	No	No	A
Circle	00153LNTH	SBS	2	448	Yes	No	No	No	A
Clapperton	00244THOM	IDF	2	335	Yes	No	No	No	A
Cobb	00027BONP	SBS	18	446	Yes	No	No	No	A
Colborne	00028LNTH	ESSF	4	475	Yes	No	No	No	A
Corsica	01615MAHD	SBS	67	498	No	No	No	No	A
Couture	01215LNTH	ESSF	15	394	Yes	Yes	No	No	A
Cutoff	01977MAHD	ESSF	3	441	No	No	No	No	A
Dam	00117LNTH	SBS	4	471	Yes	No	No	No	A
Danish	00676GUIC	MS	3	266	Yes	No	No	No	A
Dartt	00520LNIC	MS	5	262	Yes	No	No	No	A
Deer	00331LNTH	SBS	33	439	No	No	Yes	No	A
Deube	01825MAHD	SBS	19	471	Yes	No	No	No	A
Dewey	00092DEAD	MS	6	394	Yes	Yes	No	No	A
Donna Belle	00415NICL	MS	4	311	Yes	No	No	No	A
Double	01746MAHD	SBS	31	471	No	No	Yes	No	A
Doug	00522NICL	ESSF	4	381	Yes	No	No	No	A
Dumbell	00089DEAD	MS	40	394	Yes	Yes	No	No	A
Earl	01918MAHD	SBS	4	471	Yes	No	No	No	A
Efdee	00016LNTH	SBS	31	468	Yes	No	No	No	A
Elk	01040BONP	IDF	42	385	Yes	No	No	No	A
Ellen	01451NICL	MS	26	300	No	No	No	No	A
Emar	00510LNTH	SBS	25	429	Yes	Yes	No	No	A
End	00987LNTH	SBS	1	394	Yes	No	No	No	A
Estelle	00163DEAD	MS	15	394	Yes	Yes	No	No	L
Eve	00675GUIC	MS	6	266	Yes	No	No	No	A
Fern	01650MAHD	SBS	1	475	Yes	No	No	No	A
Finney	01335BONP	IDF	13	305	Yes	No	No	No	A
Four Pond	01999MAHD	ESSF	3	441	No	No	No	No	A

Table A.2 – continued from previous page

Lake	WBID	Z	A	D	F	R	C	L	B
Fowler	01374UNTH	ESSF	34	510	Yes	No	Yes	No	A
Frank	00158LNTH	SBS	5	448	Yes	No	No	No	A
Frankie	01139LNTH	MS	7	394	Yes	Yes	No	No	A
Friendly	02062MAHD	ESSF	54	439	Yes	No	No	No	A
Frogpond	00090DEAD	MS	1	394	No	No	No	No	A
Gablehouse	01833CLWR	ESSF	10	456	Yes	No	No	No	A
Goodwin	01362MAHD	ESSF	18	479	Yes	No	No	No	A
Gords	00050BONP	SBS	4	446	Yes	No	No	No	A
Gourd	02089MAHD	SBS	6	444	Yes	No	No	No	A
Grant	01154LNTH	MS	11	394	Yes	Yes	No	No	A
Grizzly	01850CLWR	ESSF	18	470	No	No	No	No	A
Hagen	01114LNTH	MS	10	394	No	No	No	No	A
Harvey	00715BONP	MS	4	394	Yes	No	No	No	A
Heger	01955MAHD	ESSF	4	441	No	No	No	No	A
Heller	00168DEAD	MS	89	454	Yes	Yes	No	No	A
Herby	01897MAHD	SBS	6	471	Yes	No	No	No	A
Hidden	00187BONP	ESSF	4	394	Yes	No	No	No	A
Hidden	02015NICL	ESSF	9	279	No	No	No	No	A
Hidden	02075MAHD	SBS	2	451	Yes	No	No	No	A
Homecabin	00251DEAD	MS	22	391	Yes	No	No	No	A
Hoopatatkwa	01133LNTH	MS	81	394	Yes	Yes	No	No	A
Hoover	00250DEAD	MS	20	394	Yes	No	No	No	A
Howlong	00104DEAD	MS	4	394	Yes	Yes	No	No	A
Italia	01573MAHD	SBS	131	475	No	No	Yes	No	A
Jackpine	00703LNTH	ESSF	13	429	Yes	Yes	No	No	A
Janning	01010LNTH	MS	6	394	Yes	No	No	No	A
John	01411MAHD	ESSF	7	479	Yes	No	No	No	A
Johns	01994NICL	MS	7	300	Yes	No	No	No	A
Johnston	01587MAHD	SBS	15	498	No	No	No	No	A
Johnston	00005LNTH	ESSF	5	468	No	No	Yes	No	A
Kanz	00701LNTH	SBS	7	446	Yes	Yes	No	No	A
Keith	00190BONP	ESSF	4	394	Yes	Yes	No	No	A
Kitty Ann	01731MAHD	SBS	8	471	No	No	Yes	No	A
Knouff	01360LNTH	MS	30	364	No	No	No	No	A
L. Calling	00929THOM	MS	5	302	Yes	No	No	No	A
L. O.K.	00912THOM	MS	9	306	No	No	No	No	A
L. Patrick	00914LNTH	ESSF	5	408	Yes	Yes	No	No	A
L. Pennask	01194NICL	MS	7	297	Yes	No	No	No	A
Lindy	00939LNTH	ESSF	9	402	Yes	Yes	No	No	A
Lloyd	00179DEAD	MS	13	394	Yes	Yes	No	No	L

Table A.2 – continued from previous page

Lake	WBID	Z	A	D	F	R	C	L	B
Long	00557NICL	ESSF	5	370	No	No	No	No	A
Lorenzo	02102MAHD	ESSF	20	444	No	No	No	No	L
Lost	01240LNTH	MS	3	394	Yes	No	No	No	A
Lower Biscuit	00329LNTH	SBS	2	439	Yes	No	No	No	A
Lower McCorvie	01647UNTH	SBS	17	464	No	No	No	No	A
Lower Secret	00901BONP	MS	28	454	Yes	Yes	No	No	A
Mab	00519LNIC	MS	31	262	No	No	No	No	A
Magnesia	00847BONP	IDF	27	374	Yes	No	No	No	A
Malarky	00268BONP	SBS	4	394	Yes	Yes	No	No	A
Malcolm	00176BONP	ESSF	14	394	Yes	Yes	No	No	A
Marsden	00412BONP	IDF	13	399	No	No	No	No	A
Marten	00744LNTH	SBS	3	429	Yes	Yes	No	No	A
Martha	00093DEAD	MS	5	394	Yes	Yes	No	No	A
McCorvie	01659UNTH	SBS	8	464	Yes	No	Yes	No	A
McGillvary	01522LNTH	ESSF	85	386	No	No	Yes	Yes	A
McKenzie	01786CLWR	SBS	33	468	No	No	No	No	A
Meighan	01306LNTH	ESSF	4	363	Yes	No	No	No	A
Mellin	00813NICL	MS	51	300	Yes	No	No	No	L
Michelle	00195LNIC	MS	6	274	Yes	No	No	No	A
Mink	00754LNTH	SBS	1	429	Yes	Yes	No	No	A
Minnie	01306NICL	IDF	135	284	No	No	No	No	A
Mollimarn	00174DEAD	MS	45	394	Yes	Yes	No	No	A
Monteith	00418ADMS	ESSF	63	468	Yes	No	No	No	A
Monticola	02077MAHD	SBS	64	444	No	No	No	No	A
Moose	01303LNTH	MS	1	363	No	No	No	No	A
Moose	00681LNTH	SBS	9	429	Yes	Yes	No	No	A
Moosehead	01989MAHD	ESSF	3	441	Yes	No	No	No	A
Moosehorn	00889BONP	IDF	20	385	Yes	No	No	No	A
Moosepasture	01179LNTH	MS	6	394	Yes	Yes	No	No	A
Morrisey	00010STHM	ESSF	20	386	No	No	Yes	No	A
Mulholland	01002LNTH	MS	9	399	Yes	No	No	No	A
Neil	00089LNTH	SBS	5	471	Yes	No	No	No	A
NoName	01220LNTH	MS	6	394	Yes	No	No	No	A
Norma	01120LNTH	MS	14	394	Yes	Yes	No	No	A
North Dunbar	00809LNTH	SBS	6	412	Yes	No	No	No	A
North Island	00105DEAD	MS	11	394	Yes	Yes	No	No	A
N. Kernaghan	00149STHM	ESSF	4	439	No	No	No	No	A
North Koens	00047DEAD	MS	5	454	Yes	No	No	No	A
Otter	01702UNTH	ESSF	7	487	Yes	No	No	No	A
Palmer	00989LNTH	SBS	3	394	Yes	Yes	No	No	A

Table A.2 – continued from previous page

Lake	WBID	Z	A	D	F	R	C	L	B
Paradise	01900NICL	MS	117	300	No	No	No	No	A
Parky	01208LNTH	MS	7	394	No	No	No	No	A
Patricia	01779MAHD	SBS	23	471	Yes	No	No	No	A
Patrick	00904LNTH	ESSF	16	429	Yes	Yes	No	No	A
Peanut	01973MAHD	ESSF	5	441	Yes	No	No	No	A
Pefferle	01314NICL	MS	27	297	No	No	No	No	A
Pems	01221LNTH	MS	6	394	Yes	No	No	No	A
Phyllis	01659MAHD	SBS	12	498	Yes	No	No	No	A
Pimainus 4	00954THOM	MS	3	306	No	No	No	No	A
Pinerock	01152LNTH	MS	7	394	Yes	Yes	No	No	A
Pioneer	00414LNTH	SBS	33	444	No	No	No	No	L
Pollard	00880BBAR	IDF	10	378	Yes	No	No	No	A
Pothole	01138LNTH	MS	3	394	Yes	No	No	No	A
Rainbow	01013NICL	MS	6	297	Yes	No	No	No	L
Ralls	00179THOM	IDF	3	365	Yes	No	No	No	A
Randy	02099MAHD	ESSF	6	444	No	No	No	No	A
Randy	00790LNTH	SBS	3	429	Yes	Yes	No	No	A
Rat	01380NICL	MS	28	300	No	No	No	No	A
Reflector	01860CLWR	ESSF	44	456	No	No	Yes	No	A
Renee	00108DEAD	MS	8	394	Yes	Yes	No	No	A
Reservoir	01902NICL	MS	56	300	No	No	Yes	No	A
Revelle	00736GUIC	MS	8	264	Yes	No	No	No	A
Rioux	01848MAHD	SBS	27	471	No	No	No	No	A
Rose	00275LNTH	SBS	7	439	Yes	Yes	No	No	A
Rouse	01340NICL	MS	30	294	Yes	No	No	No	A
Running Bear	01722UNTH	SBS	6	464	Yes	No	No	No	A
Saul	00091THOM	MS	34	365	No	No	Yes	No	A
Saxon	00804GUIC	MS	14	264	Yes	No	No	No	A
Scott	00113BONP	ESSF	11	429	Yes	No	No	No	A
Scott	01099LNTH	MS	13	394	No	No	Yes	No	A
Sedge	00492LNTH	SBS	7	429	Yes	No	No	No	A
Shambrook	00257GUIC	MS	13	290	No	No	No	No	A
Shannon	01501UNTH	ESSF	10	510	Yes	No	No	No	A
Sheep	00546LNIC	MS	16	266	No	No	No	No	A
Shillings	00985LNTH	SBS	14	394	Yes	No	No	No	A
Siam	00152DEAD	MS	8	394	Yes	Yes	No	No	A
Sicily	01705MAHD	SBS	21	471	No	No	Yes	No	A
Silvernail	00605STHM	MS	2	365	Yes	No	No	No	A
Skinny	00813LNTH	SBS	6	412	Yes	Yes	No	No	A
Skyline	01692UNTH	SBS	3	464	No	No	Yes	No	A

Table A.2 – continued from previous page

Lake	WBID	Z	A	D	F	R	C	L	B
Smith	00993LNTH	MS	22	399	Yes	No	No	No	A
Sophia	00696GUIC	MS	12	266	Yes	No	No	No	A
South Koens	00072DEAD	MS	6	454	Yes	No	No	No	A
Spectacle	02046MAHD	SBS	2	439	Yes	No	No	No	A
Spectacle	02050MAHD	SBS	4	439	Yes	No	No	No	A
Stadia	00277DEAD	MS	15	391	No	No	No	No	A
Stevens 1	01250MURT	ESSF	163	567	Yes	No	No	No	A
Stevens 2	01277MURT	ESSF	34	567	Yes	No	No	No	A
Stevens 3	01294MURT	ESSF	22	567	Yes	No	No	No	A
Stevens 4	01331MURT	ESSF	81	496	Yes	No	No	No	A
Stevens 5	01423MURT	ESSF	43	496	Yes	No	No	No	A
Stevens 6	01454MURT	ESSF	52	496	Yes	No	No	No	A
Stevens 7	01496MURT	ESSF	138	496	No	No	No	No	A
Stoney	00979LNTH	SBS	6	394	Yes	Yes	No	No	A
Strachan	00129THOM	MS	15	365	Yes	No	No	No	A
Surprise	01857CLWR	ESSF	26	470	Yes	No	No	No	A
Swap	00187DEAD	MS	4	394	Yes	No	No	No	A
Sydney	00919THOM	MS	8	302	No	No	No	No	A
Tahoola	02063MAHD	ESSF	36	439	Yes	No	No	No	L
Tibbetts	00181BONP	ESSF	5	446	No	No	No	No	A
Tin Cup	01826GRNL	IDF	83	399	Yes	No	No	No	A
Tobe	00012BONP	SBS	76	446	No	No	No	No	A
Today	01201LNTH	ESSF	5	394	Yes	No	No	No	A
Tolman	00689GUIC	MS	3	266	No	No	No	No	A
Tom Peter	00710GUIC	MS	5	262	No	No	No	No	A
Tortoise	00646LNTH	SBS	38	446	Yes	No	No	No	A
Treadgold	00358NICL	MS	6	382	Yes	No	No	No	A
Triangle	00936LNTH	ESSF	49	394	Yes	Yes	No	No	A
Trurans	00867BONP	IDF	53	374	Yes	No	No	No	A
Tuwut	00246DEAD	MS	29	394	Yes	No	No	No	A
Twin	01134LNTH	MS	8	394	Yes	Yes	Yes	No	A
Twin East	01831MAHD	SBS	7	471	No	No	No	No	A
Twin West	01823MAHD	SBS	11	471	No	No	No	No	A
Two Mile	01871MAHD	SBS	5	471	Yes	No	No	No	A
Unnamed	00017BONP	SBS	2	446	Yes	No	No	No	A
Unnamed	00079GUIC	MS	12	294	Yes	No	No	No	A
Unnamed	00085BONP	ESSF	3	446	Yes	No	No	No	A
Unnamed	00107LNIC	MS	3	274	Yes	No	No	No	A
Unnamed	00157GUIC	MS	8	289	Yes	No	No	No	A
Unnamed	00211DEAD	IDF	8	385	Yes	No	No	No	A

Table A.2 – continued from previous page

Lake	WBID	Z	A	D	F	R	C	L	B
Unnamed	00213DEAD	MS	3	454	Yes	No	No	No	A
Unnamed	00222BONP	SBS	2	394	Yes	No	No	No	A
Unnamed	00323DEAD	ESSF	8	394	Yes	No	No	No	A
Unnamed	00349BONP	MS	3	394	Yes	No	No	No	A
Unnamed	00369LNIC	MS	9	301	Yes	No	No	No	A
Unnamed	00376LNIC	MS	4	301	Yes	No	No	No	A
Unnamed	00384DEAD	MS	11	391	Yes	No	No	No	A
Unnamed	00393BONP	MS	2	394	Yes	No	No	No	A
Unnamed	00394LNTH	SBS	3	453	Yes	No	No	No	A
Unnamed	00416ADMS	ESSF	7	482	Yes	No	No	No	A
Unnamed	00435LNTH	ESSF	11	450	Yes	No	No	No	A
Unnamed	00447ADMS	ESSF	6	468	Yes	No	No	No	A
Unnamed	00457ADMS	ESSF	8	468	Yes	No	No	No	A
Unnamed	00478ADMS	ESSF	3	468	Yes	No	No	No	A
Unnamed	00520BONP	MS	1	394	Yes	No	No	No	A
Unnamed	00536BONP	MS	2	394	No	No	No	No	A
Unnamed	00559THOM	IDF	5	310	Yes	No	No	No	A
Unnamed	00579LNTH	SBS	3	429	Yes	No	No	No	A
Unnamed	00581ADMS	ESSF	4	480	Yes	No	No	No	A
Unnamed	00599DEAD	MS	4	384	Yes	No	No	No	A
Unnamed	00600LNTH	SBS	2	444	Yes	No	No	No	A
Unnamed	00601ADMS	ESSF	4	480	Yes	No	No	No	A
Unnamed	00607ADMS	ESSF	3	459	Yes	No	No	No	A
Unnamed	00612LNTH	SBS	3	446	Yes	No	No	No	A
Unnamed	00619ADMS	ESSF	2	459	No	No	No	No	A
Unnamed	00640ADMS	ESSF	2	459	No	No	No	No	A
Unnamed	00656ADMS	ESSF	4	480	Yes	No	No	No	A
Unnamed	00662BONP	MS	2	394	Yes	No	No	No	A
Unnamed	00683ADMS	ESSF	19	480	Yes	No	No	No	A
Unnamed	00695LNTH	SBS	3	446	Yes	No	No	No	A
Unnamed	00722LNTH	SBS	6	446	Yes	No	No	No	A
Unnamed	00746LNTH	SBS	4	446	Yes	No	No	No	A
Unnamed	00790BONP	IDF	4	416	Yes	No	No	No	A
Unnamed	00888BONP	IDF	3	385	Yes	No	No	No	A
Unnamed	00917BONP	IDF	4	385	Yes	No	No	No	A
Unnamed	00925LNTH	ESSF	2	408	Yes	No	No	No	A
Unnamed	00961LNTH	SBS	2	402	Yes	No	No	No	A
Unnamed	00974NICL	IDF	3	297	Yes	No	No	No	A
Unnamed	00978LNTH	ESSF	2	394	Yes	No	No	No	A
Unnamed	00981LNTH	SBS	2	399	Yes	No	No	No	A

Table A.2 – continued from previous page

Lake	WBID	Z	A	D	F	R	C	L	B
Unnamed	00985NICL	IDF	5	297	Yes	No	No	No	A
Unnamed	00986LNTH	SBS	2	399	Yes	No	No	No	A
Unnamed	01014NICL	MS	2	294	Yes	No	No	No	A
Unnamed	01038NICL	IDF	5	297	Yes	No	No	No	A
Unnamed	01052LNTH	IDF	5	401	No	No	No	No	A
Unnamed	01112NICL	MS	6	297	Yes	No	No	No	A
Unnamed	01176LNTH	ESSF	10	394	Yes	No	No	No	A
Unnamed	01189UNTH	ESSF	5	521	No	No	No	No	A
Unnamed	01207LNTH	MS	3	381	Yes	No	No	No	A
Unnamed	01241NICL	MS	7	297	Yes	No	No	No	A
Unnamed	01268LNTH	ESSF	2	363	Yes	No	No	No	A
Unnamed	01278LNTH	MS	3	363	Yes	No	No	No	A
Unnamed	01340BONP	IDF	2	305	Yes	No	No	No	A
Unnamed	01348BONP	IDF	3	302	Yes	No	No	No	A
Unnamed	01359BONP	IDF	3	296	Yes	No	No	No	A
Unnamed	01590LNTH	MS	2	360	Yes	No	No	No	A
Unnamed	01658LNTH	MS	2	356	Yes	No	No	No	A
Unnamed	01661LNTH	IDF	1	356	Yes	No	No	No	A
Unnamed	01698CLWR	ESSF	7	479	No	No	No	No	A
Unnamed	01716UNTH	SBS	4	464	Yes	No	No	No	A
Unnamed	01717CLWR	ESSF	6	479	No	No	No	No	A
Unnamed	01750MAHD	ESSF	2	474	No	No	No	No	A
Unnamed	02081MAHD	SBS	3	451	Yes	No	No	No	A
Unnamed	02095MAHD	SBS	3	453	No	No	No	No	A
Unnamed	02170GRNL	IDF	26	401	Yes	No	No	No	A
Unnamed	02238GRNL	IDF	7	417	No	No	No	No	A
Unnamed	00163BONP	ESSF	5	446	No	Yes	No	No	A
Unnamed	00166BONP	ESSF	16	447	No	Yes	No	No	A
Unnamed	00204GUIC	MS	157	299	No	No	Yes	No	A
Upper Biscuit	00336LNTH	SBS	1	439	Yes	No	No	No	A
Upper Loon	00998BONP	IDF	149	385	Yes	No	No	No	A
Upper Secret	00910BONP	MS	39	454	Yes	Yes	No	No	A
U. No Man's	00063BONP	SBS	11	446	Yes	No	No	No	A
Venos	00023DEAD	MS	8	454	Yes	No	No	No	A
Wallensteen	00138STHM	ESSF	9	439	No	No	Yes	No	A
White	00080LNTH	SBS	5	471	No	No	Yes	No	A
Whitewood	01272LNTH	MS	15	363	No	No	Yes	No	A
Wilderness	01184LNTH	MS	11	394	Yes	Yes	No	No	A
Will	00466DEAD	ESSF	4	363	No	No	No	No	A
Willowgrouse	00239DEAD	MS	85	394	Yes	No	No	No	A

Table A.2 – continued from previous page

Lake	WBID	Z	A	D	F	R	C	L	B
Windfall	00406LNTH	SBS	2	444	Yes	No	Yes	No	A
Windy	01904MAHD	SBS	30	471	Yes	No	Yes	No	A

Appendix B

Effort Predictions

Table B.1: Effort predictions for all wild rainbow trout lakes. WBID is the unique waterbody identifier for the lake and the observed effort (Obs. Effort) is from the aerial boat count flights. Effort is defined in terms of angler-days per hectare (AD/ha). The vulnerability (Vuln.) of a lake to being overfished is listed as high, moderate (mod) and low. The predicted mean effort, standard error (SE), and predicted median effort (Med. Effort) from the bootstrap GLMs are listed under the Bootstrap Method columns. If more than 30 of the effort predictions were greater than 18.1 AD/ha, the lake was classified as moderately vulnerable to overfishing using the Bootstrap Method. If more than 30 of the 100 effort predictions were greater than 28.3 AD/ha, the lake was classified as highly vulnerable to overfishing. The predicted effort (Pred. Effort) and standard error (SE) from the base data GLM are listed under the Parametric Method columns. If there is more than a 30% probability that the predicted effort from the base data GLM is greater than 18.1 AD/ha, the lakes are defined as moderately vulnerable to overfishing. If there is more than a 30% probability that the predicted effort is greater than 28.3 AD/ha, the lakes are defined as highly vulnerable to overfishing.

			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Adler	00217DEAD	3	3.68	1.13	3.55	low	3.60	0.30	low
Alberta	00811BBAR		11.55	3.02	11.37	low	11.07	0.86	low
And Another	01992NICL		5.61	1.86	5.38	low	5.50	0.47	low
Another	01995NICL		5.54	1.82	5.29	low	5.42	0.46	low
Arrowhead	02092MAHD	20	4.20	1.31	4.13	low	4.12	0.34	low
Arthur	00451STHM		15.98	5.84	15.68	mod	16.81	1.46	low
Bear	00654LNTH		9.72	2.78	9.48	low	9.38	0.65	low
Beaverdam	00614LNTH		10.13	2.36	9.85	low	10.19	0.69	low
Beckwith	00252BONP	9	10.99	3.51	10.64	low	10.53	0.76	low
Bedard	00596THOM		5.58	1.88	5.35	low	5.46	0.46	low
Belcache	00169BONP	8	5.17	1.58	5.00	low	5.56	0.43	low

Table B.1 – continued from previous page

			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Bitchy	00729LNTH		10.43	3.14	10.11	low	10.04	0.71	low
Blowdown	02091MAHD	3	14.99	4.16	14.56	low	14.13	1.02	low
Bob	01330LNTH		3.41	1.27	3.21	low	3.72	0.36	low
Bolean	00468STHM		21.40	5.27	20.85	mod	20.68	1.33	mod
Boundary Line	01881MAHD		11.16	2.82	10.84	low	11.16	0.80	low
Braman	00948LNTH	11	5.94	1.82	5.75	low	6.39	0.50	low
Brown Hat	01189LNTH		3.03	1.10	2.85	low	3.31	0.32	low
Buck	00705LNTH		9.72	2.78	9.48	low	9.38	0.65	low
Bushwater	00148BONP	0	5.60	1.70	5.46	low	6.04	0.46	low
Bus's Puddle	00149BONP	0	5.67	1.72	5.56	low	6.12	0.47	low
Bute	00782STHM		23.42	7.17	22.30	mod	22.57	1.70	mod
Cameron	01500NICL	19	10.33	2.48	9.97	low	10.35	0.74	low
Campeau	00655BONP		6.27	2.42	5.85	low	5.84	0.54	low
Cannine	01226LNTH		4.04	1.31	3.90	low	3.95	0.34	low
Chataway	00254LNIC	78	61.07	16.22	58.98	high	59.95	3.66	high
Chester	00146BONP	21	5.64	1.71	5.51	low	6.08	0.47	low
China	00136STHM		16.86	5.38	16.23	mod	16.15	1.27	low
Christina	00942LNTH	0	6.41	1.96	6.26	low	6.92	0.54	low
Circle	00153LNTH		4.34	1.37	4.25	low	4.26	0.35	low
Clapperton	00244THOM		8.44	3.11	7.99	low	7.93	0.70	low
Cobb	00027BONP		4.14	1.29	4.06	low	4.06	0.34	low
Colborne	00028LNTH		2.32	0.88	2.09	low	2.51	0.24	low
Cone	00322LNTH	9	20.72	5.04	20.92	mod	20.16	1.31	mod
Corsica	01615MAHD	0	7.12	1.60	6.95	low	7.10	0.49	low
Couture	01215LNTH	3	6.14	1.87	5.92	low	6.61	0.52	low
Crater	00291LNTH	40	22.42	5.37	22.35	mod	21.91	1.41	mod
Cutoff	01977MAHD		6.42	2.43	6.02	low	7.02	0.64	low
Dam	00117LNTH		3.99	1.22	3.81	low	3.91	0.32	low
Danish	00676GUIC		6.36	2.25	6.09	low	6.20	0.54	low
Dartt	00520LNIC		6.41	2.29	6.14	low	6.24	0.54	low
Deer	00331LNTH	18	11.57	2.74	11.31	low	11.60	0.81	low
Deube	01825MAHD	6	3.79	1.14	3.65	low	3.72	0.31	low
Dewey	00092DEAD		8.43	1.89	8.63	low	8.23	0.55	low
Donna Belle	00415NICL		5.40	1.76	5.13	low	5.30	0.45	low
Dot	00777LNTH		23.59	5.72	23.43	mod	23.07	1.48	mod
Double	01746MAHD	26	10.49	2.56	10.21	low	10.48	0.74	low
Doug	00522NICL		3.17	1.15	3.01	low	3.46	0.33	low
Dumbell	00089DEAD	7	7.52	1.63	7.53	low	7.31	0.49	low

Table B.1 – continued from previous page

			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Earl	01918MAHD	0	3.99	1.22	3.81	low	3.91	0.32	low
Efdee	00016LNTH		3.67	1.10	3.52	low	3.60	0.30	low
Elk	01040BONP		6.19	2.15	5.87	low	5.82	0.51	low
Ellen	01451NICL		12.56	2.99	12.18	low	12.61	0.88	low
Emar	00510LNTH		9.07	2.64	8.85	low	8.71	0.61	low
End	00987LNTH		5.28	1.86	5.04	low	5.14	0.44	low
Estelle	00163DEAD	14	12.16	3.51	11.84	low	11.06	0.78	low
Eve	00675GUIC		6.29	2.22	6.05	low	6.13	0.53	low
Fern	01650MAHD		3.97	1.22	3.76	low	3.90	0.32	low
Finney	01335BONP		8.99	3.31	8.33	low	8.45	0.74	low
Four Pond	01999MAHD		6.42	2.43	6.02	low	7.02	0.64	low
Fowler	01374UNTH		2.27	1.00	2.06	low	2.39	0.25	low
Frank	00158LNTH		4.30	1.35	4.22	low	4.22	0.35	low
Frankie	01139LNTH		8.41	1.88	8.58	low	8.20	0.55	low
Friendly	02062MAHD	1	2.20	0.77	2.10	low	2.39	0.22	low
Frogpond	00090DEAD		10.07	2.99	9.26	low	10.00	0.79	low
Gablehouse	01833CLWR		2.41	0.89	2.21	low	2.63	0.25	low
Goodwin	01362MAHD		2.18	0.82	1.99	low	2.36	0.22	low
Gords	00050BONP		4.34	1.37	4.27	low	4.26	0.35	low
Gourd	02089MAHD	0	4.34	1.37	4.25	low	4.26	0.35	low
Grant	01154LNTH		8.29	1.84	8.42	low	8.09	0.54	low
Grizzly	00223LNTH	10	22.38	8.06	22.30	mod	22.46	1.91	mod
Grizzly	01850CLWR		5.55	2.14	5.25	low	6.04	0.55	low
Hagen	01114LNTH		9.75	2.79	9.06	low	9.69	0.75	low
Hardcastle	00280LNTH	44	21.90	5.25	22.01	mod	21.38	1.37	mod
Harvey	00715BONP		4.09	1.33	3.94	low	4.00	0.35	low
Heger	01955MAHD		6.39	2.42	6.00	low	6.99	0.64	low
Heller	00168DEAD		5.27	1.35	5.11	low	5.03	0.39	low
Helmer	00434LNIC		17.45	4.50	17.01	mod	17.48	1.27	mod
Herby	01897MAHD	4	3.96	1.21	3.79	low	3.89	0.32	low
Hidden	02015NICL	0	10.93	4.28	10.08	low	11.94	1.17	low
Hidden	00187BONP		3.03	1.10	2.85	low	3.31	0.32	low
Hidden	02075MAHD		4.30	1.35	4.20	low	4.22	0.35	low
Homecabin	00251DEAD		3.87	1.21	3.75	low	3.79	0.32	low
Hoopatatkwa	01133LNTH	6	6.59	1.56	6.45	low	6.34	0.44	low
Hoover	00250DEAD	25	3.86	1.22	3.74	low	3.78	0.32	low
Howlong	00104DEAD		8.49	1.91	8.72	low	8.29	0.55	low
Italia	01573MAHD	0	7.49	2.11	7.09	low	7.30	0.56	low

Table B.1 – continued from previous page

			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Jackpine	00703LNTH		5.49	1.66	5.30	low	5.91	0.45	low
Janning	01010LNTH		4.06	1.32	3.91	low	3.97	0.34	low
John	01411MAHD		2.27	0.86	2.04	low	2.45	0.23	low
Johns	01994NICL		5.56	1.83	5.31	low	5.44	0.46	low
Johnston	01587MAHD		8.50	2.12	8.45	low	8.51	0.59	low
Johnston	00005LNTH		7.02	2.83	6.63	low	7.55	0.73	low
Kanz	00701LNTH		9.06	2.48	8.97	low	8.76	0.60	low
Keith	00190BONP	0	6.37	1.94	6.21	low	6.87	0.53	low
Kitty Ann	01731MAHD		11.35	2.91	11.03	low	11.36	0.82	low
Knouff	01360LNTH	12	10.00	2.45	9.66	low	10.01	0.73	low
L. Calling	00929THOM		5.56	1.83	5.31	low	5.44	0.46	low
L. Heffley	01539LNTH		18.59	5.89	17.81	mod	17.84	1.39	mod
L. O.K.	00912THOM	12	13.06	3.24	12.63	low	13.11	0.94	low
L. Patrick	00914LNTH	0	6.05	1.83	5.91	low	6.53	0.50	low
L. Pennask	01194NICL		5.62	1.86	5.38	low	5.50	0.47	low
L. Pinantan	01713LNTH		18.95	5.95	18.24	mod	18.21	1.41	mod
Latremouille	00410LNTH		22.42	6.24	21.30	mod	21.55	1.47	mod
Lindy	00939LNTH		6.09	1.85	5.87	low	6.57	0.51	low
Lloyd	00179DEAD	21	12.24	3.54	11.87	low	11.14	0.79	low
Long	00557NICL		8.05	2.89	7.47	low	8.87	0.80	low
Long Island	00449LNTH		17.13	6.40	15.66	mod	15.84	1.31	low
Lorenzo	02102MAHD	8	8.81	3.37	8.49	low	9.07	0.82	low
Lost	01240LNTH		4.10	1.34	3.96	low	4.01	0.35	low
Lost Horse	00270LNTH	11	24.50	6.00	23.99	mod	23.85	1.55	mod
Lower Biscuit	00329LNTH		4.48	1.43	4.41	low	4.40	0.37	low
L. McCorvie	01647UNTH		9.44	2.20	9.31	low	9.49	0.64	low
Lower Secret	00901BONP	0	6.44	1.61	6.42	low	6.22	0.46	low
Mab	00519LNIC		14.10	3.60	13.59	low	14.11	1.00	low
Magnesia	00847BONP		6.77	2.39	6.42	low	6.36	0.56	low
Malarky	00268BONP	41	11.02	3.52	10.67	low	10.56	0.76	low
Malcolm	00176BONP	8	6.16	1.88	5.94	low	6.64	0.52	low
Mamit	00584GUIC	11	25.08	7.87	23.61	mod	23.82	1.89	mod
Marsden	00412BONP		15.97	5.50	15.40	low	15.20	1.25	low
Marten	00744LNTH		9.75	2.79	9.50	low	9.41	0.65	low
Martha	00093DEAD		8.46	1.90	8.68	low	8.26	0.55	low
McCorvie	01659UNTH		4.83	1.64	4.57	low	4.70	0.42	low
McGillvary	01522LNTH	10	12.21	4.54	11.60	low	13.28	1.26	low
McKenzie	01786CLWR		8.82	1.98	8.67	low	8.85	0.59	low

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			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Meighan	01306LNTH		3.37	1.25	3.17	low	3.68	0.36	low
Mellin	00813NICL		7.11	2.75	6.59	low	6.47	0.56	low
Michelle	00195LNIC		6.11	2.12	5.87	low	5.97	0.51	low
Miller	00145STHM		17.04	5.47	16.42	mod	16.32	1.29	low
Mink	00754LNTH		9.81	2.81	9.53	low	9.47	0.66	low
Minnie	01306NICL	5	15.45	4.52	14.52	low	14.70	1.12	low
Mollimarn	00174DEAD	0	7.40	1.61	7.37	low	7.19	0.48	low
Monteith	00418ADMS		1.94	0.69	1.85	low	2.10	0.20	low
Monticola	02077MAHD	5	8.63	1.93	8.45	low	8.62	0.58	low
Moose	01303LNTH		11.12	3.03	10.56	low	11.11	0.84	low
Moose	00681LNTH		9.56	2.74	9.40	low	9.21	0.64	low
Moosehead	01989MAHD		2.60	0.95	2.37	low	2.83	0.27	low
Moosehorn	00889BONP		6.70	2.42	6.39	low	6.28	0.56	low
Moosepasture	01179LNTH	0	8.43	1.89	8.63	low	8.23	0.55	low
Morgan	00826GUIC		25.88	8.08	24.30	high	24.91	1.88	mod
Morrisey	00010STHM		8.64	3.09	8.29	low	9.47	0.88	low
Mulholland	01002LNTH		3.95	1.28	3.79	low	3.86	0.33	low
Neil	00089LNTH		3.97	1.22	3.80	low	3.90	0.32	low
NoName	01220LNTH		4.06	1.32	3.91	low	3.97	0.34	low
Norma	01120LNTH		8.21	1.81	8.32	low	8.01	0.53	low
North Dunbar	00809LNTH		4.86	1.63	4.76	low	4.75	0.40	low
North Island	00105DEAD	14	8.29	1.84	8.42	low	8.09	0.54	low
N. Kernaghan	00149STHM		6.43	2.43	6.03	low	7.04	0.64	low
North Koens	00047DEAD		3.37	1.23	3.10	low	3.25	0.30	low
Otter	01702UNTH		2.21	0.85	1.99	low	2.39	0.23	low
Palmer	00989LNTH	0	11.06	3.53	10.70	low	10.60	0.77	low
Paradise	01900NICL	9	9.32	2.41	9.04	low	9.19	0.67	low
Parky	01208LNTH		9.85	2.85	9.13	low	9.79	0.76	low
Patricia	01779MAHD	2	3.73	1.12	3.63	low	3.66	0.30	low
Patrick	00904LNTH	0	5.43	1.64	5.23	low	5.85	0.45	low
Peanut	01973MAHD		2.58	0.94	2.35	low	2.81	0.27	low
Pear	01094BBAR		20.62	6.45	19.52	mod	19.83	1.53	mod
Pefferle	01314NICL		12.65	3.01	12.30	low	12.70	0.89	low
Pems	01221LNTH		4.06	1.32	3.91	low	3.97	0.34	low
Phyllis	01659MAHD		3.54	1.07	3.35	low	3.47	0.29	low
Pimainus 3	00956THOM	24	49.70	11.86	49.16	high	48.75	2.82	high
Pimainus 4	00954THOM	0	13.34	3.38	12.85	low	13.39	0.97	low
Pinerock	01152LNTH		8.41	1.88	8.58	low	8.20	0.55	low

Table B.1 – continued from previous page

			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Pioneer	00414LNTH	20	14.14	3.81	13.75	low	13.32	0.95	low
Pollard	00880BBAR		7.11	2.61	6.75	low	6.66	0.59	low
Pothole	01138LNTH		4.10	1.34	3.96	low	4.01	0.35	low
Rainbow	01013NICL		8.38	3.28	7.78	low	7.65	0.68	low
Ralls	00179THOM		7.61	2.82	7.10	low	7.13	0.64	low
Randy	00790LNTH		9.75	2.79	9.50	low	9.41	0.65	low
Randy	02099MAHD		6.29	2.38	5.86	low	6.87	0.62	low
Rat	01380NICL		12.47	2.96	12.09	low	12.53	0.88	low
Reflector	01860CLWR		6.36	2.40	6.12	low	6.87	0.64	low
Renee	00108DEAD	0	8.38	1.87	8.54	low	8.17	0.54	low
Reservoir	01902NICL		13.51	3.20	13.28	low	13.49	0.94	low
Revelle	00736GUIC		6.30	2.23	6.07	low	6.13	0.53	low
Rioux	01848MAHD	20	8.91	2.03	8.85	low	8.95	0.60	low
River	02178GRNL		17.64	5.96	16.97	mod	16.85	1.36	low
Rock	01036NICL		16.33	4.61	16.05	mod	15.27	1.12	low
Rock Island	00300LNTH	28	22.56	5.94	21.98	mod	21.79	1.45	mod
Roscoe	00168LNIC	10	32.74	7.54	32.32	high	32.05	1.86	high
Rose	00275LNTH	31	9.29	2.59	9.18	low	8.97	0.62	low
Rouse	01340NICL		5.25	1.74	5.11	low	5.13	0.43	low
Running Bear	01722UNTH		4.06	1.25	3.93	low	3.98	0.33	low
Saul	00091THOM		11.76	3.13	11.43	low	11.68	0.86	low
Saxon	00804GUIC		6.17	2.19	5.92	low	6.01	0.52	low
Scott	01099LNTH		2.63	0.94	2.42	low	2.87	0.27	low
Scott	00113BONP		11.57	3.58	11.10	low	11.39	0.90	low
Sedge	00492LNTH		4.56	1.48	4.50	low	4.47	0.37	low
Shambrook	00257GUIC		13.60	3.38	13.17	low	13.66	0.97	low
Shannon	01501UNTH		2.03	0.82	1.83	low	2.19	0.21	low
Sheep	00546LNIC		14.63	3.76	14.17	low	14.67	1.05	low
Shillings	00985LNTH		5.05	1.78	4.76	low	4.92	0.42	low
Siam	00152DEAD	0	8.38	1.87	8.54	low	8.17	0.54	low
Sicily	01705MAHD	8	10.85	2.70	10.53	low	10.85	0.77	low
Silvernail	00605STHM		4.53	1.44	4.30	low	4.44	0.38	low
Skinny	00813LNTH		10.26	3.09	9.91	low	9.87	0.70	low
Skyline	01692UNTH		11.82	3.03	11.51	low	11.83	0.86	low
Smith	00993LNTH		3.77	1.19	3.63	low	3.69	0.32	low
Sophia	00696GUIC		6.17	2.18	5.92	low	6.01	0.52	low
South Koens	00072DEAD		3.36	1.23	3.08	low	3.24	0.30	low
Spectacle	02050MAHD		4.45	1.42	4.38	low	4.37	0.36	low

Table B.1 – continued from previous page

			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Spectacle	02046MAHD		4.48	1.43	4.41	low	4.40	0.37	low
Spruce	00110SETN		20.63	7.49	20.15	mod	20.70	1.74	mod
Stadia	00277DEAD		9.66	2.69	8.99	low	9.62	0.74	low
Stevens 1	01250MURT		1.03	0.48	0.95	low	1.06	0.12	low
Stevens 2	01277MURT		1.57	0.70	1.41	low	1.66	0.17	low
Stevens 3	01294MURT		1.64	0.74	1.45	low	1.73	0.18	low
Stevens 4	01331MURT		1.67	0.62	1.57	low	1.79	0.17	low
Stevens 5	01423MURT		1.89	0.71	1.79	low	2.04	0.19	low
Stevens 6	01454MURT		1.84	0.69	1.74	low	1.98	0.19	low
Stevens 7	01496MURT		3.43	1.34	3.13	low	3.64	0.36	low
Stoney	00979LNTH	8	10.95	3.50	10.59	low	10.49	0.76	low
Strachan	00129THOM		4.32	1.35	4.13	low	4.24	0.36	low
Surprise	01857CLWR		2.18	0.80	2.01	low	2.37	0.22	low
Surrey	00174LNIC	50	27.07	6.73	26.39	high	26.33	1.62	mod
Swap	00187DEAD		4.09	1.33	3.94	low	4.00	0.35	low
Sydney	00919THOM		13.28	3.31	12.83	low	13.34	0.96	low
Tahoola	02063MAHD	3	3.44	1.30	3.20	low	3.52	0.33	low
Thuya	00762LNTH		22.90	5.55	22.88	mod	22.36	1.43	mod
Tibbetts	00181BONP		6.27	2.38	5.87	low	6.85	0.62	low
Tin Cup	01826GRNL		5.12	1.72	4.76	low	4.81	0.43	low
Tobe	00012BONP		8.24	1.88	8.11	low	8.21	0.56	low
Today	01201LNTH		3.02	1.09	2.84	low	3.30	0.31	low
Tolman	00689GUIC		15.31	4.04	14.87	low	15.35	1.12	low
Tom Peter	00710GUIC		15.42	4.08	14.95	low	15.45	1.13	low
Tortoise	00646LNTH		3.87	1.20	3.67	low	3.79	0.31	low
Tranquille	00055THOM		19.58	4.23	19.61	mod	19.12	1.23	mod
Treadgold	00358NICL		4.22	1.35	4.06	low	4.13	0.35	low
Triangle	00936LNTH	3	5.50	1.74	5.37	low	5.88	0.47	low
Trurans	00867BONP		6.17	2.10	5.76	low	5.81	0.50	low
Tuwut	00246DEAD	0	3.74	1.16	3.58	low	3.66	0.31	low
Twin	01134LNTH		10.08	2.80	9.77	low	9.71	0.68	low
Twin East	01831MAHD		9.55	2.31	9.40	low	9.59	0.66	low
Twin West	01823MAHD		9.42	2.25	9.26	low	9.46	0.65	low
Two Mile	01871MAHD	0	3.97	1.22	3.80	low	3.90	0.32	low
Ukulele	00156STHM		18.06	6.08	17.22	mod	17.26	1.39	low
Unnamed	00956NICL		23.02	7.04	22.09	mod	22.19	1.67	mod
Unnamed	01354LNIC		15.26	7.38	13.92	mod	16.18	1.81	low
Unnamed	01052LNTH		16.35	5.83	15.64	low	15.53	1.30	low

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			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Unnamed	00085BONP		2.56	0.94	2.34	low	2.78	0.26	low
Unnamed	00607ADMS		2.45	0.91	2.23	low	2.66	0.25	low
Unnamed	00619ADMS		6.08	2.38	5.72	low	6.62	0.61	low
Unnamed	00640ADMS		6.08	2.38	5.72	low	6.62	0.61	low
Unnamed	00656ADMS		2.28	0.88	2.05	low	2.47	0.24	low
Unnamed	00683ADMS		2.17	0.81	1.98	low	2.35	0.22	low
Unnamed	00925LNTH		2.91	1.05	2.72	low	3.18	0.30	low
Unnamed	00978LNTH		3.05	1.11	2.87	low	3.34	0.32	low
Unnamed	01176LNTH		2.97	1.06	2.80	low	3.24	0.31	low
Unnamed	01189UNTH		4.98	2.20	4.68	low	5.31	0.52	low
Unnamed	01268LNTH		3.39	1.26	3.20	low	3.71	0.36	low
Unnamed	00323DEAD		2.99	1.07	2.82	low	3.27	0.31	low
Unnamed	01698CLWR		5.61	2.25	5.33	low	6.08	0.57	low
Unnamed	01717CLWR		5.63	2.26	5.34	low	6.10	0.57	low
Unnamed	01750MAHD		5.80	2.33	5.48	low	6.30	0.59	low
Unnamed	00163BONP		13.35	4.78	12.84	low	14.23	1.19	low
Unnamed	00166BONP		12.82	4.54	12.29	low	13.65	1.14	low
Unnamed	00211DEAD		7.00	2.60	6.62	low	6.55	0.59	low
Unnamed	00559THOM		9.10	3.37	8.51	low	8.54	0.75	low
Unnamed	00790BONP		6.43	2.52	5.96	low	5.98	0.56	low
Unnamed	00888BONP		7.13	2.68	6.73	low	6.67	0.60	low
Unnamed	00416ADMS		2.24	0.86	2.02	low	2.43	0.23	low
Unnamed	00917BONP		7.10	2.67	6.71	low	6.64	0.60	low
Unnamed	00974NICL		9.59	3.61	8.93	low	8.99	0.79	low
Unnamed	00985NICL		9.52	3.57	8.87	low	8.93	0.79	low
Unnamed	01038NICL		9.52	3.57	8.87	low	8.93	0.79	low
Unnamed	01340BONP		9.36	3.50	8.79	low	8.78	0.77	low
Unnamed	01348BONP		9.42	3.53	8.82	low	8.84	0.78	low
Unnamed	01359BONP		9.62	3.62	8.95	low	9.02	0.80	low
Unnamed	01661LNTH		7.90	2.92	7.38	low	7.41	0.66	low
Unnamed	00435LNTH		2.45	0.89	2.23	low	2.67	0.25	low
Unnamed	02170GRNL		6.22	2.26	5.86	low	5.83	0.52	low
Unnamed	02238GRNL		15.45	5.72	14.66	low	14.61	1.25	low
Unnamed	00079GUIC		5.58	1.85	5.34	low	5.46	0.46	low
Unnamed	00107LNIC		6.18	2.15	5.92	low	6.03	0.52	low
Unnamed	00157GUIC		5.76	1.93	5.53	low	5.63	0.48	low
Unnamed	00213DEAD		3.39	1.25	3.12	low	3.27	0.30	low
Unnamed	00349BONP		4.10	1.34	3.96	low	4.01	0.35	low

Table B.1 – continued from previous page

			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Unnamed	00369LNIC		5.50	1.81	5.27	low	5.39	0.46	low
Unnamed	00376LNIC		5.60	1.85	5.36	low	5.48	0.47	low
Unnamed	00384DEAD		4.02	1.29	3.88	low	3.94	0.34	low
Unnamed	00447ADMS		2.36	0.88	2.13	low	2.56	0.24	low
Unnamed	00393BONP		4.12	1.35	3.98	low	4.02	0.35	low
Unnamed	00520BONP		4.13	1.36	3.99	low	4.04	0.35	low
Unnamed	00536BONP		10.03	2.97	9.25	low	9.97	0.78	low
Unnamed	00599DEAD		4.22	1.36	4.08	low	4.13	0.36	low
Unnamed	00662BONP		4.12	1.35	3.98	low	4.02	0.35	low
Unnamed	01014NICL		5.77	1.93	5.57	low	5.65	0.48	low
Unnamed	01112NICL		5.63	1.87	5.40	low	5.52	0.47	low
Unnamed	01207LNTH		4.28	1.38	4.12	low	4.19	0.36	low
Unnamed	01241NICL		5.62	1.86	5.38	low	5.50	0.47	low
Unnamed	01278LNTH		4.54	1.44	4.31	low	4.45	0.38	low
Unnamed	00457ADMS		2.34	0.87	2.13	low	2.54	0.24	low
Unnamed	01590LNTH		4.60	1.47	4.37	low	4.52	0.38	low
Unnamed	01658LNTH		4.67	1.48	4.44	low	4.58	0.39	low
Unnamed	00204GUIC	11	9.85	2.93	9.73	low	9.53	0.75	low
Unnamed	00222BONP		5.26	1.85	5.02	low	5.12	0.44	low
Unnamed	00394LNTH		4.26	1.33	4.15	low	4.18	0.35	low
Unnamed	00579LNTH		4.63	1.50	4.56	low	4.53	0.38	low
Unnamed	00600LNTH		4.41	1.39	4.33	low	4.32	0.36	low
Unnamed	00612LNTH		4.36	1.37	4.28	low	4.28	0.36	low
Unnamed	00695LNTH		4.36	1.37	4.28	low	4.28	0.36	low
Unnamed	00722LNTH		4.31	1.36	4.23	low	4.23	0.35	low
Unnamed	00478ADMS		2.38	0.90	2.15	low	2.58	0.25	low
Unnamed	00746LNTH		4.34	1.37	4.27	low	4.26	0.35	low
Unnamed	00961LNTH		5.11	1.76	4.91	low	4.99	0.43	low
Unnamed	00981LNTH		5.17	1.80	4.96	low	5.04	0.43	low
Unnamed	00986LNTH		5.17	1.80	4.96	low	5.04	0.43	low
Unnamed	01716UNTH		4.08	1.26	3.95	low	4.01	0.33	low
Unnamed	02081MAHD		4.28	1.34	4.19	low	4.21	0.35	low
Unnamed	02095MAHD		10.28	2.48	9.93	low	10.34	0.71	low
Unnamed	00017BONP		4.37	1.38	4.29	low	4.29	0.36	low
Unnamed	00581ADMS		2.28	0.88	2.05	low	2.47	0.24	low
Unnamed	00601ADMS		2.28	0.88	2.05	low	2.47	0.24	low
Upper Biscuit	00336LNTH		4.50	1.44	4.43	low	4.41	0.37	low
Upper Loon	00998BONP		4.33	1.52	4.08	low	4.01	0.38	low

Table B.1 – continued from previous page

			Bootstrap Method				Parametric Method		
Lake	WBID	Obs. Effort	Mean Effort	SE	Med. Effort	Vuln.	Pred. Effort	SE	Vuln.
Upper Secret	00910BONP	3	6.21	1.53	6.11	low	5.99	0.44	low
U. No Man's	00063BONP		4.24	1.33	4.15	low	4.16	0.34	low
Venos	00023DEAD		3.33	1.21	3.06	low	3.21	0.30	low
Wallensteen	00138STHM		7.57	2.89	7.17	low	8.22	0.78	low
White	00080LNTH	26	11.47	2.97	11.16	low	11.48	0.83	low
Whitewood	01272LNTH		12.66	3.54	12.24	low	12.57	0.95	low
Wilderness	01184LNTH		8.29	1.84	8.42	low	8.09	0.54	low
Will	00466DEAD		8.27	2.97	7.67	low	9.12	0.83	low
Willowgrouse	00239DEAD	1	3.09	0.94	2.93	low	3.01	0.26	low
Windfall	00406LNTH		5.27	1.81	4.98	low	5.14	0.46	low
Windy	01904MAHD	5	4.37	1.46	4.11	low	4.25	0.37	low