EFFECTS OF NON-CATCH RELATED FACTORS IN EXPLAINING VARIATIONS IN ANGLER EFFORT FOR STOCKED LAKES IN BRITISH COLUMBIA'S CENTRAL INTERIOR AND SUBSEQUENT MANAGEMENT OPPORTUNITIES

by

Lee Williston
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Name: Lee Williston

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Examining Committee:

____

Dr. S. Cox
Assistant Professor
School of Resource Management, SFU
Senior Supervisor

____

Mr. E. Parkinson
Senior Scientist, Ecosystems Branch
BC Ministry of Environment
Supervisory Committee

Date Defended/Approved: July 28th, 2008

ABSTRACT

The British Columbia Ministry of Environment (MOE) has set the goal of increasing angling licence sales by 30% (of 2004-2005 levels) by the year 2015. I used a generalized linear model to predict angler effort on stocked lakes in B.C.'s central interior based on non-catch related factors. Lake access, stocking rate, driving distance from Kamloops, presence of a lodge and presence of gear restrictions have the greatest influence on effort. If angler effort generated by B.C.'s lake stocking program is going to be maximized, it is critical for biologists to accurately identify and focus limited available field time on lakes with the greatest potential for improvement. Thus, I provide a method for identifying stocked lakes that are currently performing above or below the regional average, in terms of generating angler days, in B.C.'s central interior.

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INTRODUCTION

1.1. Small Lakes Management in British Columbia

Angling licence sales in British Columbia (B.C.) have decreased by 24% since 1995 (Freshwater Fisheries Society of BC 2006-2007 annual report). As a result, the Ministry of Environment (MOE) (i.e., government agency responsible for management of freshwater fisheries in B.C.) has set the goal of increasing licence sales by 30% (of 2004-2005 levels) by the year 2015 (MOE Freshwater Fisheries Program Plan, 2007). Freshwater fisheries management in B.C. is guided by priorities set forth in the MOE's Freshwater Fisheries Program Plan (2007). The two primary priorities are: i. conservation of wild stocks and their habitats; and ii. maximize opportunities based on the fishery resource (MOE Freshwater Fisheries Program Plan, 2007).

There are more than 600 lakes that support wild stocks of game fish species in B.C.'s central interior (MOE management region 5) (Land and Resource Data Warehouse). While wild stock lakes clearly provide angling opportunities, targeting these lakes to increase angler use, in some cases, may present a risk to these stocks. Depending on the life history and productivity of the stock, uncontrolled angler effort may generate depensatory responses leading to population collapse (Shuter et al. 1998). Results from Cox and Walters (2002b) suggest that depensatory processes are not even required for an unproductive trout population to collapse. Given that conservation of wild stocks and their habitats is listed as a top priority in the MOE's Provincial Freshwater Fisheries Program Plan (2007), management actions with the objective to increase angler effort should be aimed at maximizing use of stocked lakes where there is generally no direct conservation concern.

My research focuses on maximizing recreational opportunities supported by hatchery stocks. In 2006, the Freshwater Fisheries Society of British Columbia (FFSBC) released 2,117,601 fish into a total of 101 lakes throughout B.C.'s central interior (Freshwater Fisheries Society of B.C. 2006-2007 annual report). Unlike wild stocks where the primary objective is conservation, lakes supported by hatchery stocks have a number of management objectives including generating angler days and providing a diversity of angling opportunities. Previous studies indicate an opportunity may exist to increase angler use simply by increasing stocking rates. Cox and Walters (2002a) suggest that generally in recreational fisheries, angling effort is roughly proportional to abundance as measured by indices like stocking rates (Moring 1993, Fraley 1996, Shaner et al. 1996, Cox 2000). Cox (2000) provides empirical evidence illustrating the positive relationship between angling effort and stocking rate. Cox (2000) presented data on the lakes fishery in the interior of B.C. (MOE management regions 3 and 5) and found that effort densities were linearly related to stocking density, although the effort response per fish stocked was lower in region 5.

The positive relationship between stocking rate and angler effort is consistent with findings of several other studies that have illustrated a positive relationship between catch success and angler satisfaction (Forbes 1998, Connelly et al. 2001, Falk et al. 1989, Spencer 1993, Arlinghaus and Mehner 2005, Graefe and Fedler 1986, Matlock et al. 1988, Holland and Ditton 1992). Presumably, satisfied anglers will fish more often and lakes with high abundances of fish (i.e., high stocking rates) generate higher catch rates than lakes where abundance is low. However, there are a number of physical, biological and economic constraints when it comes to stocking fish. Post et al. (1999) and Biro et al. (2003) each provided empirical evidence of density dependent growth in rainbow trout populations therefore, stocking at high densities can result in smaller fish that may not be as desirable to some anglers. Size of rainbow trout at the time of stocking may also affect growth and survival. Godin and Tsumura (1995) found that stocking yearlings resulted in higher returns than stocking fry in Buchanan Lake, which contains a high density of coarsefish competitors and predators. The results in Buchanan Lake are consistent with results from a number of other researchers that have illustrated density-dependant growth and survival in size-structured populations where differences in size among individuals may strongly influence the outcome of competition for food or agonistic interactions among individuals (Elliot 1989a,b, Mittelbach and Osenberg 1993, Tonn et al. 1994, Booth 1995, Forrester 1995, Wagner and Wise 1996, Post et al. 1999). While, in some cases, stocking larger fish results in greater growth and survival of rainbow trout, there are constraints associated with stocking larger fish. Both the economic cost as well as the cost in terms of human and physical resources required is higher when fish are reared to the yearling life stage rather than being released as fry. Rearing to the yearling life stage requires fish to be held in hatchery facilities for an extended period of time, thus requiring more resources (i.e., relative to fry) in terms of food, space in the hatchery and staff time.

Hatcheries in British Columbia that are operated by the FFSBC to provide fish for recreational freshwater fisheries are already at capacity in terms of number of fish produced. Thus, while angler effort has been shown to be linearly related to stocking density in B.C.'s central interior (Cox 2000), physical and financial limits to fish production likely restrict the MOE's ability to increase angler effort through simply increasing stocking rates. Therefore, there is a need to understand how, not only stocking rates, but also other non-catch related factors affect angler effort on small lakes in B.C.'s central interior.

The small lakes fishery in B.C.'s central interior consists of many independent lakes being targeted by a highly mobile angling community. Ideal free distribution (IFD) theory is a simple and robust hypothesis from behavioural ecology that provides the rationale for making predictions about the distribution of foragers (Gillis et al. 1993) and is often used to simulate angler movements in recreational fisheries (Parkinson et al. 2004, Cox et al. 2002, Askey 2007). IFD theory predicts anglers will spread themselves throughout the fishery until anglers on each individual lake experience a similar level of angling quality (Parkinson et al. 2004). Typically, angling quality is based on catch properties with various combinations of catch rates and sizes of fish caught leading to an angling experience of equal quality (Askey 2007). Assumptions of the IFD include zero cost to moving, perfect information about angling quality on all lakes, equivalent costs (e.g., travel time, regulatory complexity) on all lakes and equivalent ancillary benefits (e.g., facilities, aesthetics) on all lakes (Parkinson et al. 2004). However, anglers are very likely to consider more than just catch related factors in choosing a fishing destination. Factors such as facilities, aesthetic values, access and crowding all likely play a role in determining the overall quality of the angling experience. Understanding the role non-catch related factors play in driving angler effort may provide fisheries managers with an opportunity to increase angler use on stocked lakes by manipulating non-catch related factors that are under management control (Hunt and Ditton 1997).

The goal of this paper is to provide a method for identifying over or under performing stocked lakes (i.e., in terms of generating angler effort) thus, providing managers with the ability to direct resources towards lakes with the greatest opportunity for improvement. In spatially-structured fisheries, over or under performance is often driven by measurable factors such as remoteness, accessibility or presence of facilities (Parkinson et al. 2004). This paper quantifies the relationship between several non-catch related variables and angler effort on stocked lakes in B.C.'s central interior.

1.2 Study Area

This study focuses on stocked lakes in B.C. MOE region 5 (Figure 1.1), which is the largest management region in the Fraser Basin, spanning nearly 80,000 square kilometres. There are over 4500 lakes in B.C.'s central interior ranging from 5 to 27,000 hectares in size, which support a host of natural and introduced fish species (Land and Resource Data Warehouse). While anglers target both wild lakes as well as hatchery stocked lakes this study focuses on stocked lakes only. The FFSBC stocks approximately 100 lakes per year throughout B.C.'s central interior. Three species are stocked: rainbow trout (*Oncorhynchus mykiss*), kokanee (*Oncorhynchus nerka*), and eastern brook trout (*Salvelinus fontinalis*) with rainbow trout being most prevalent (Freshwater Fisheries Society of B.C. 2006-2007 annual report).

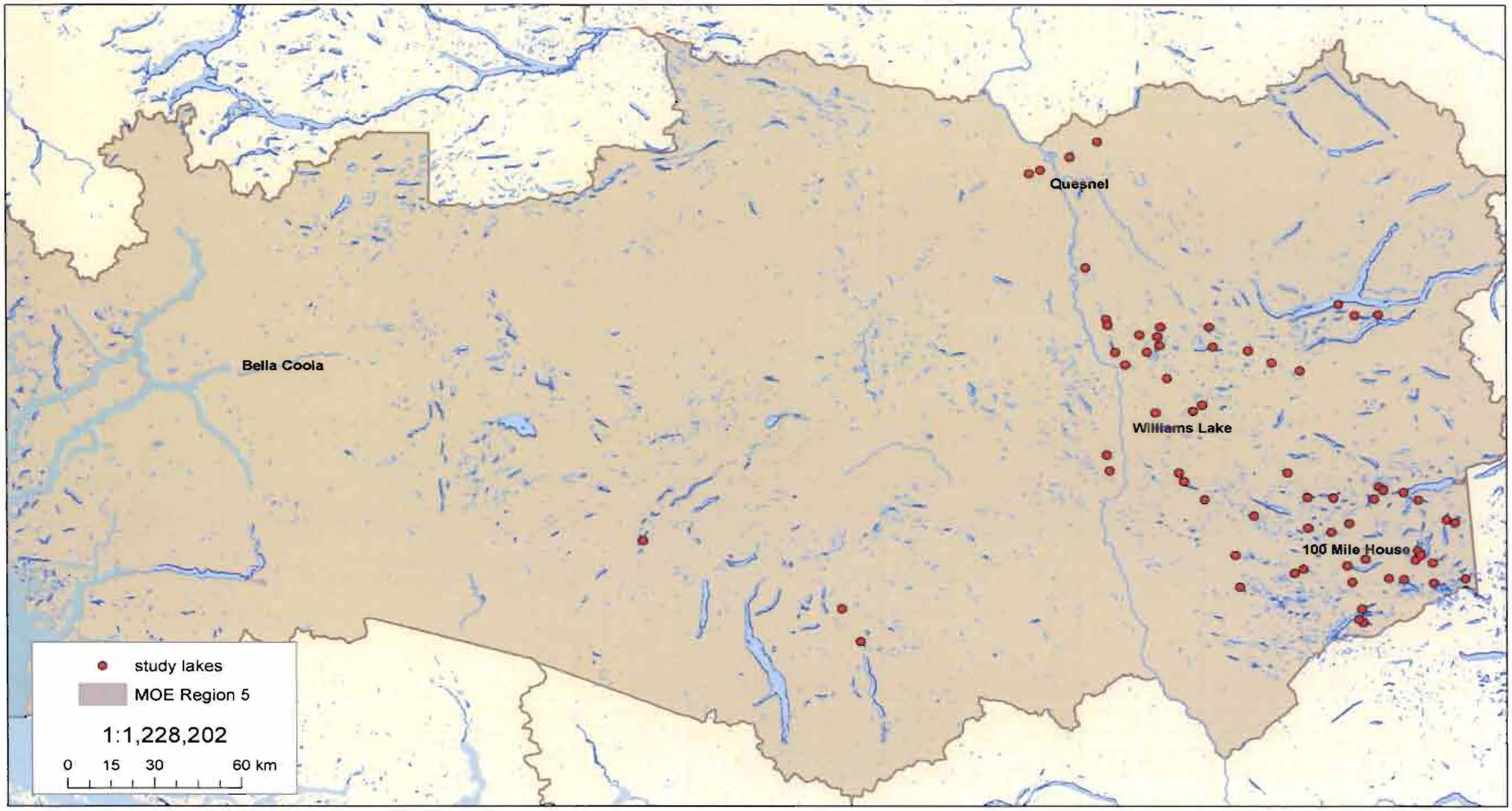

Figure 1.1: Ministry of Environment's management region 5 (shaded area). Study lakes highlighted red (i.e., circles).

CHAPTER 2

METHODS

2.1. Data

Angler effort data was obtained from the "Small Lakes Inventory Management" (SLIM) database. Each year aerial boat counts are conducted over a large number of lakes on weekends throughout the summer angling season. Boat counts are then converted to an estimate of total angler effort for the season based on methods derived by Tredger (1992). I collected data for all stocked lakes that had at least one year of boat count data since the year 2000. In total, 66 lakes had effort data available between the years 2000 and 2006. For lakes where more than one year of boat count data exists, I calculated the average estimated effort for use as the dependent variable. Observed effort densities from aerial boat counts can be observed in Table 3.3.

For each of the 66 lakes where effort data exists, I collected data for the following eleven potential explanatory (predictor) variables: biogeoclimatic zone; stocking rate (fish/ha of lake surface area); trailer access; presence or absence of a lodge or resort; distance from Kamloops (measured in total road kilometres); presence or absence of a boating restriction; presence or absence of a gear restriction; presence or absence of a bag limit (i.e., different from the regional standard of 5/day); presence or absence of sterile fish; presence or absence of a maintained campsite; and lake surface area (Table 2.1).

2.2. Explanatory Variables

I defined lakes as having no access if you cannot reasonably pull a trailer to the lake. A lake with no trailer access is expected to support fewer angler days than a lake with good trailer access. Webb (2006) found that lakes with a trailer boat launch receive approximately 13% more effort than lakes without a trailer boat launch in MOE management region 3. I did not have data for the presence or absence of trailer boat launches, however, it is reasonable to assume that lakes without trailer access are unlikely to have trailer boat launches. Access data was compiled based on a mix of my local knowledge of the area as well as from the British Columbia Lake and Stream Summary System (MOE provincial fisheries database). Much of the access data found in the Lake and Stream Summary System is relatively old, however the quality of access for the majority of lakes could be validated by fisheries biologists from MOE management region 5, thus limiting potential bias of inaccurately rating lake access.

Cox (2000) presented data on the B.C. lakes fishery illustrating a positive linear relationship between angler effort densities and stocking density in MOE management regions 3 and 5. Therefore, I would also expect to see a positive relationship between stocking rates and angler effort. For each lake, I calculated the average number of fish stocked per year between 2000 and 2006. I then standardized stocking rates, setting the stocking rate for each lake as the average number of fish stocked per hectare each year.

While lakes in B.C.'s central interior receive a substantial amount of angler effort from resident anglers (i.e., anglers who live in the central interior), in 2000 anglers from outside of B.C.'s central interior comprised 80% of the angler population (Levey & Williams, 2003). The majority of British Columbia's population base is located south of Williams Lake (location of MOE region 5 office) and thus the largest pool of potential anglers comes from the south. Kamloops is the nearest large population center south of Williams Lake and therefore, I would expect to see an inverse relationship between driving distance from Kamloops and angler effort. Each lake's distance from Kamloops was calculated using the MOE mapping program "iMap".

B.C.'s central interior is famous for having highly productive lakes that provide exceptional angling opportunities. Typically productivity is measured in terms of total dissolved solids (TDS). However, TDS data does not exist for several of the lakes in the analysis. Therefore, I used the British Columbia Biogeoclimatic Ecosystem Classification (BEC) to try to capture lake productivity. BEC zone data exists for all stocked lakes in B.C.'s central interior and was obtained from B.C.'s Lake and Stream Summary System. Lakes with angler boat count data could be found in the BEC zones: Sub-Boreal Pine-Spruce (SBPSZ), Sub-Boreal Spruce (SBSZ), Interior Douglas Fir (IDFZ), and Interior Cedar-Hemlock (ICHZ). Lakes that transcend BEC boundaries were classified according to the zone in which the majority of the lake lies. While I am using BEC zone as an index of TDS, it should be noted that BEC zone captures a wide range of factors that may be correlated. BEC zones share similar climates, including temperature and precipitation, and similar soil types, both of which impact TDS (Webb 2006). 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 (Webb 2006). Based on lakes with TDS data, it appears that lakes in the IDFZ have substantially higher TDS levels than lakes in any other zone (Figure 2.1). Therefore, I would expect lakes in the IDFZ to support more angler days. The median TDS levels for lakes in the SBPSZ and SBSZ zones are very similar (Figure 2.1) and therefore, I would expect to see lakes in these zones support a similar number of angler days. Lakes in the ICHZ appear to have substantially lower TDS levels than lakes in any other zone and thus, I would expect lakes in the ICHZ to support fewer angler days.

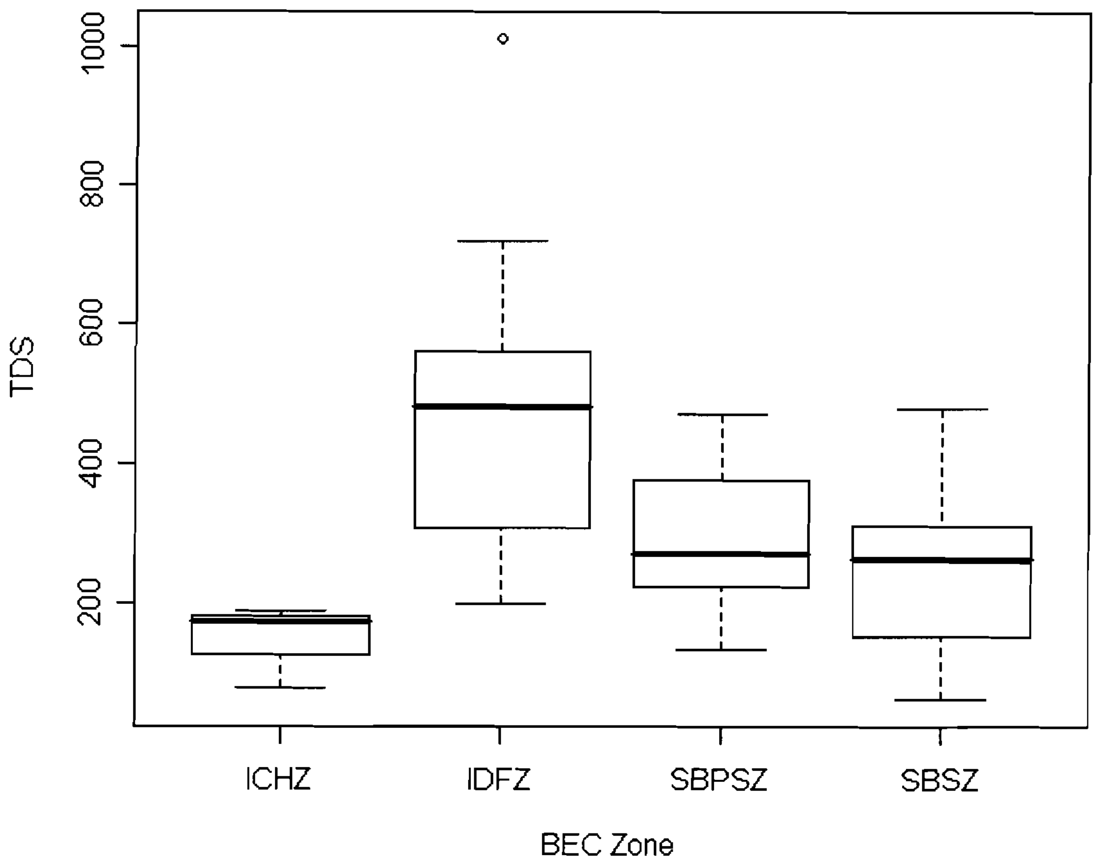

Figure 2.1: Total dissolved solids (TDS) values for lakes in the ICHZ, IDFZ, SBPSZ and SBSZ biogeoclimatic zones in B.C.'s central interior. For each box, the horizontal line represents the median value and the upper and lower limits of the box represent the 75th and 25th percentiles, respectively. The ends of the vertical lines show the smallest and largest observations that fall within a distance of 1.5 times the box size, and the points show TDS levels that are considered to be outliers.

I would expect lakes with lodges or resorts on them to support more angler effort. 80% of angler days spent in B.C.'s central interior comes from visiting anglers (i.e., anglers who live outside of MOE management region 5) (Levey and Williams 2003). Anglers coming from outside B.C.'s central interior require additional facilities such as accommodation. Information regarding the presence of a lodge or resort was compiled using my local knowledge, guidebooks (Mussio and Mussio 2002), and the British Columbia Resort and Outfitters Association membership list. Lakes that have at least one fishing lodge on them were classified as having a lodge.

Stocking sterile fish (i.e., 3N fish that are reproductively unviable) has become increasingly popular in recent years. In 2006, 74 lakes were stocked with sterile fish in B.C.'s central interior (B.C. Lake and Stream Summary System). The males still undergo physical changes associated with maturation; however, they are reproductively unviable. Female fish that have gone through the sterilization process do not undergo any of the changes associated with maturity. Therefore, in theory, rather than expend energy developing reproductive gametes and dropping out of the fishery, female fish can continue directing energy towards growth, thus, reaching larger sizes. I would expect that the presence of larger fish would attract more anglers to lakes that are stocked with sterile fish. A lake was classified as having been stocked with sterile fish if sterile's had been stocked at least once prior to the year 2004. Thus, the stocked sterile fish would all be greater than 3 years old and fully recruited to the fishery.

In general, when asked in a survey situation anglers react negatively towards increasingly restrictive regulations (Arlinghaus and Mehner 2005, Connelly et al. 2001), which would lead one to expect lakes with boating restrictions, bag limits, and/or gear restrictions to support fewer angler days. However, Webb (2006) showed that lakes with reduced bag-limits supported an average of 7% more angler days than lakes without reduced bag-limits (i.e., reduced from the regional standard). My analysis will illustrate any significant association between presence of boating restrictions, bag limits, gear restrictions and angler effort for stocked lakes in B.C.'s central interior. However, the analysis will not be able to identify whether the restrictive regulations were implemented because of the fishing effort or if the fishing effort is a result of the restrictive regulations. Lakes were classified as having a boating restriction if the lake was listed under the Region 5 "Boating Restriction" column in B.C.'s Freshwater Fishing Regulation Synopsis (2007-2008 edition). Presence of a boating restriction includes engine power restrictions and electric motors only restrictions. Lakes were classified as having a bag-limit restriction if the daily bag-limit was less than the regional standard of five per day. Lakes were classified as having a gear restriction if the lake was listed under the "Gear Restriction" column in B.C.'s Freshwater Fishing Regulation Synopsis (2007-2008 edition).

Table 2.1: Stocked lakes that have aerial boat count data available since the year 2000 and their associated explanatory variable values. Abbreviations are as follows: WBID, unique identifier for each waterbody; A, whether or not a lake has trailer access; S, average annual stocking rate since the year 2000 (fish/ha); Z, biogeoclimatic ecosystem classification zone the lake is located in; R, the distance a lake is located away from Kamloops (measured in road kilometres); L, whether or not a lodge is present; B, whether or not any boating restrictions are present; T, whether or not sterile fish have been stocked at least once prior to the year 2004; G; whether or not any gear restrictions are present; SA, lake surface area.

Lake	WBID	A	S	Z	R	L	B	T	G	SA
Sheridan	00790BRID	Yes	209	SBPSZ	159	Yes	No	Yes	No	1659
Horse	01006DOGC	Yes	122	IDFZ	176	Yes	No	No	No	1162
Bridge	00903BRID	Yes	86	SBPSZ	173	Yes	No	No	No	1371
Watch	00896GRNL	Yes	181	SBPSZ	215	Yes	Yes	No	No	249
Deka	00154BRID	Yes	129	SBSZ	171	Yes	No	No	No	1154
Howard	01675MAHD	Yes	138	ICHZ	191	No	Yes	No	No	167
Fawn	00737BRID	Yes	466	SBSZ	151	Yes	Yes	No	No	32
Ten Mile	00001QUES	Yes	417	SBSZ	430	No	No	No	No	243
Mcleese	00295TWAC	Yes	188	IDFZ	332	Yes	No	Yes	No	218
Timothy	01451SAJR	Yes	45	SBPSZ	232	Yes	No	No	No	444
Lorin	01824MAHD	Yes	54	SBSZ	218	No	No	No	No	277
Sulphurous	00252BRID	Yes	135	SBPSZ	171	Yes	No	No	No	381
Big	02219QUES	Yes	59	SBSZ	318	No	No	No	No	578
Dugan	00051SAJR	Yes	886	IDFZ	285	No	No	Yes	No	95
Tyee	02197QUES	Yes	117	SBSZ	335	Yes	No	No	No	309
Chimney	01071MFRA	Yes	228	IDFZ	278	No	No	Yes	No	431
Valentine	00521BRID	Yes	153	IDFZ	217	No	Yes	Yes	Yes	56
Helena	01769SAJR	Yes	132	IDFZ	249	No	No	Yes	No	238
Greeny	01476SAJR	Yes	266	SBPSZ	233	No	Yes	No	No	75
Forest	00849TWAC	Yes	206	IDFZ	329	No	Yes	Yes	Yes	97
Irish	00783BRID	Yes	470	IDFZ	177	No	Yes	No	No	28
Gustafsen	00439DOGC	Yes	70	IDFZ	323	No	No	Yes	No	142
Horn	00051HOMA	Yes	117	IDFZ	525	No	No	No	No	171
Jackson	02099QUES	Yes	303	SBSZ	358	No	Yes	No	Yes	37
Dewar	00003SAJR	Yes	759	IDFZ	290	No	No	No	No	43
Hen Ingram	01929QUES	Yes	50	ICHZ	364	No	No	No	No	368
Ruth	01610MAHD	Yes	187	SBSZ	229	No	No	Yes	No	284
Till	00476MFRA	Yes	148	IDFZ	336	No	No	No	No	79
Bouchie	01192COTR	Yes	155	SBSZ	425	No	No	No	No	129
Jim	01449GRNL	Yes	137	SBPSZ	186	No	No	No	No	110
Edmund	00426BRID	Yes	110	ISFZ	204	No	No	Yes	No	91
Simon	02116SAJR	Yes	187	IDFZ	211	No	No	Yes	Yes	78
Hathaway	00191BRID	Yes	66	SBSZ	174	Yes	No	No	No	152
Felker	00934MFRA	Yes	183	IDFZ	280	No	No	Yes	No	227
Rail	01024SAJR	Yes	130	SBPSZ	243	No	No	No	No	230
Milburn	01224COTR	Yes	553	SBSZ	430	No	No	No	No	34
French	02052MAHD	Yes	133	SBSZ	184	No	Yes	No	Yes	57

Table 2.1 – continued from previous page

Lake	WBID	A	S	Z	R	L	B	T	G	SA
Donnely	01806MAHD	No	53	SBSZ	192	No	Yes	Yes	Yes	113
108 Mile	02012SAJR	Yes	126	IDFZ	215	No	Yes	Yes	No	119
Dorsey	02030QUES	Yes	325	SBSZ	332	No	No	No	No	15
Little Green	00596HORS	Yes	121	SBSZ	196	No	No	No	No	17
Blue	00597TWAC	Yes	308	IDFZ	327	No	Yes	Yes	No	34
Big Onion	01152TASR	Yes	130	SBPSZ	475	No	No	Yes	No	57
Bellos	01031COTR	Yes	144	SBSZ	438	No	No	No	No	23
Kestrel	00238TWAC	Yes	45	SBSZ	352	No	No	Yes	Yes	76
Howes	02233QUES	Yes	101	SBSZ	341	No	No	No	No	65
Cuisson	01630NARC	Yes	91	SBSZ	344	No	No	Yes	No	164
Elk	01978QUES	Yes	172	SBSZ	358	No	Yes	Yes	No	32
Rimrock	01682NARC	Yes	582	SBSZ	347	No	No	Yes	Yes	58
Lower	00064BRID	Yes	242	SBPSZ	222	No	No	No	No	19
Earle	00298BRID	No	111	IDFZ	183	No	No	Yes	No	57
Faulkner	00802BRID	Yes	68	SBSZ	192	No	No	Yes	No	22
Snag	01862MFRA	Yes	199	IDFZ	268	No	Yes	No	Yes	91
Greenlee	01604MAHD	Yes	122	IDFZ	246	No	Yes	No	No	29
Nolan	01333GRNL	No	61	IDFZ	182	No	No	No	No	82
Mcintyre	00839MFRA	Yes	260	IDFZ	326	No	No	Yes	No	18
Abbott	02402QUES	No	242	SBSZ	322	No	Yes	No	Yes	24
Gardner	01317MFRA	Yes	118	IDFZ	277	No	No	No	No	17
Schoolhouse	01527MAHD	No	43	SBSZ	241	No	No	Yes	No	86
Blue	00919NARC	Yes	56	SBSZ	374	No	No	Yes	No	14
Klinne	01811QUES	Yes	83	ICHZ	366	No	No	No	Yes	26
Oslie	00021HORS	No	117	ICHZ	376	No	No	No	Yes	20
Baillon	02280QUES	No	98	SBSZ	328	No	No	Yes	Yes	21
Dor	01535MAHD	No	348	SBSZ	237	No	No	No	No	29
Reservoir	00059SAJR	Yes	964	IDFZ	299	No	No	No	No	4
Big	00851TASR	Yes	37	IDFZ	459	No	No	Yes	No	90

2.3. Model Development

I used a generalized linear model (GLM) to explore the relative importance of a number of non-catch related variables in attracting anglers to different lakes in B.C.'s central interior. A GLM is similar to multiple regression in that it's a common method used to specify the relationship between a dependent variable (Y) and a set of predictor variables (X's), so that

$$Y = b_0 + b_1X_1 + b_2X_2 + ... + b_kX_k \qquad (2.1)$$

where b_0 is the regression coefficient for the intercept and the b_i values are the regression coefficients (for variables 1 through k) computed from the data.

While GLMs are similar to multiple regression the use of a GLM has two major advantages: First, the distribution of the dependent variable can be non-Gaussian and does not have to be continuous; second, the dependent variable values are predicted from a linear combination of predictor variables, which are "connected' to the dependent variable via a link function. Thus, GLMs can be used to predict responses both for dependent variables with discrete distributions and for dependent variables, which are nonlinearly related to the predictors (Nelder and Wedderburn 1972, McCullagh and Nelder 1989, Fox 2002).

In this study I analyze the effects of eleven continuous (e.g., kilometres from Kamloops) and discrete (e.g., biogeoclimatic zone) predictor variables on angler effort which is measured in angler days per hectare. The dependent variable (i.e., angler effort) is estimated angler days derived from boat counts from aerial surveys. I assumed a poisson error distribution and a log “link function” since angler effort is always greater than or equal to zero.

2.4. Model Selection Procedures

2.4.1. Standard Explanatory Variable Selection

Selection of explanatory variables into the model was done using the Akaike Information Criterion (AIC). The AIC is an operational way of trading off the complexity of an estimated model against how well the model fits the data (Akaike 1974, Mazerolle 2006). The AIC not only rewards goodness of fit, but also includes a penalty that is an increasing function of the number of estimated parameters (Akaike 1974). This penalty discourages overfitting as the preferred model is the one with the lowest AIC value (Akaike 1974). Upon running the initial GLM, using all eleven potential explanatory variables and effort data for all 66 lakes, the AIC procedure removed the campsite and bag limit variables which suggest these variables do not improve model fit enough to justify the added complexity of including them in the model.

2.4.2. Bootstrapped Explanatory Variable Selection

To address uncertainty in model selection and effort predictions I bootstrapped the GLM and AIC procedure. Bootstrapping the AIC illustrates a more accurate range of possible AIC values and effort predictions than is shown through the standard explanatory variable selection procedure alone. The bootstrapping procedure is a method that involves repeatedly sampling with replacement from the original sample (Effron and Tibshirani 1993). Using this methodology I created 100 representative data sets based on the original 66 lakes. For each data set, I then ran the GLM and AIC procedure, each time recording which explanatory variables were selected. In this situation, the AIC statistic is a random variable and therefore, explanatory variables will be included and excluded at random as well. Thus, bootstrapping assesses the probability of including different explanatory variables based on different realized data sets.

2.5. Prediction

Using the AIC selected model for the base data GLM I predicted angler effort for all stocked lakes in B.C.'s central interior for which angler effort data exists from aerial boat counts since the year 2000. Comparing model predictions generated from the base data GLM to observed effort levels from aerial boat counts provides a static assessment of the relative performance of stocked lakes (i.e., performance as measured in terms of angler days per hectare). It is a static evaluation because predicted effort levels are based on the current conditions surrounding the fishery, such as: size of available angler pool, current economic conditions, and current management practices (e.g., number of lakes stocked, regulations, etc.). Predicted angler effort values represent the average number of angler days per hectare a stocked lake in B.C.'s central interior supports, given the lakes characteristics (i.e., explanatory variable values). I use this static evaluation of the current performance of stocked lakes in B.C.'s central interior to identify stocked lakes that are currently either "under performing" or "over performing" given their characteristics (i.e., explanatory variable values). Angler effort predictions that are greater than observed angler effort values for a given lake indicate the lake is currently “under performing”. Whereas, angler effort predictions that are less than the observed angler effort values for a given lake indicate the lake is currently “over performing”.

I also generated angler effort predictions based on each of the 100 bootstrapped data sets to obtain a range of possible angler effort predictions for each lake. Lakes were identified as “under performing” if observed angler effort was less than predicted effort minus two bootstrapped standard deviations. Lakes were identified as “over performing” if observed angler effort was greater than predicted angler effort plus two bootstrapped standard deviations. Lakes where observed angler effort was within the range of predicted effort plus or minus two bootstrapped standard deviations were identified as performing at an “average” level. I used bootstrapped standard deviations as a basis for detecting “under performing” and “over performing” lakes because the bootstrapping procedure provides the most accurate range of possible AIC selected models and subsequent effort predictions.

2.5.1. Cross Validation

Leave-one-out cross validation analysis was conducted as a check to assess predictive error from the GLM. Leave-one-out cross validation involves using a single observation from the original sample as the validation data for testing the model, and the remaining observations as the training data (i.e., data used to fit the model). This is repeated until each observation in the sample is used once as the validation data. One of the benefits of using leave-one-out cross validation is that the procedure does not waste data. When training, all but one of the data points are used, so the resulting regression coefficients and effort predictions should be very similar to predictions made when all data points are used to fit the model (i.e., base data GLM predictions). However if the presence of a particular data point is a dominant factor in determining its own predicted effort level, then effort predictions based on the training data set and effort predictions based on the full data set will differ substantially (Effron and Tibshirani 1993).

To evaluate how a lakes presence in the model fitting process affected its own classification as "under performing" or "over performing" I compared observed angler effort levels to angler effort predictions generated by the cross validation procedure and classified each lake as either "under performing" or "over performing". As was the case for identifying "under performing" and "over performing" lakes using angler effort predictions from the base data GLM; lakes were identified as "under performing" if observed angler effort was less than predicted effort (i.e., from cross validation analysis) minus two bootstrapped standard deviations and identified as "over performing" if observed angler effort was greater than predicted angler effort plus two bootstrapped standard deviations. I then compared lakes categorized as "under performing" and "over performing" by the base data GLM and cross validation GLM to assess the model's ability to correctly categorize lakes as"under performing" or "over performing".

Chapter 3

RESULTS

3.1. Explanatory Variable Selection and Parameter Estimates

I created residual plots (Figure 3.1) to assess the relationship between the response variable and the individual explanatory variables. Residual plots assess the level of homogeneity in the variance of the residuals with respect to model predictions. Figure 3.1 suggests there is a lack of systematic pattern in the residuals, indicating that I have not introduced a systematic error to the model.

The campsite and bag limit variables were removed from the model when the initial GLM was conducted. Table 3.1 shows estimated coefficient values for each explanatory variable selected for by the AIC procedure. The presence of a boating restriction and stocking rate were the two most influential explanatory variables explaining 30.9% and 18.4% of the deviance variability respectively (Table 3.1).

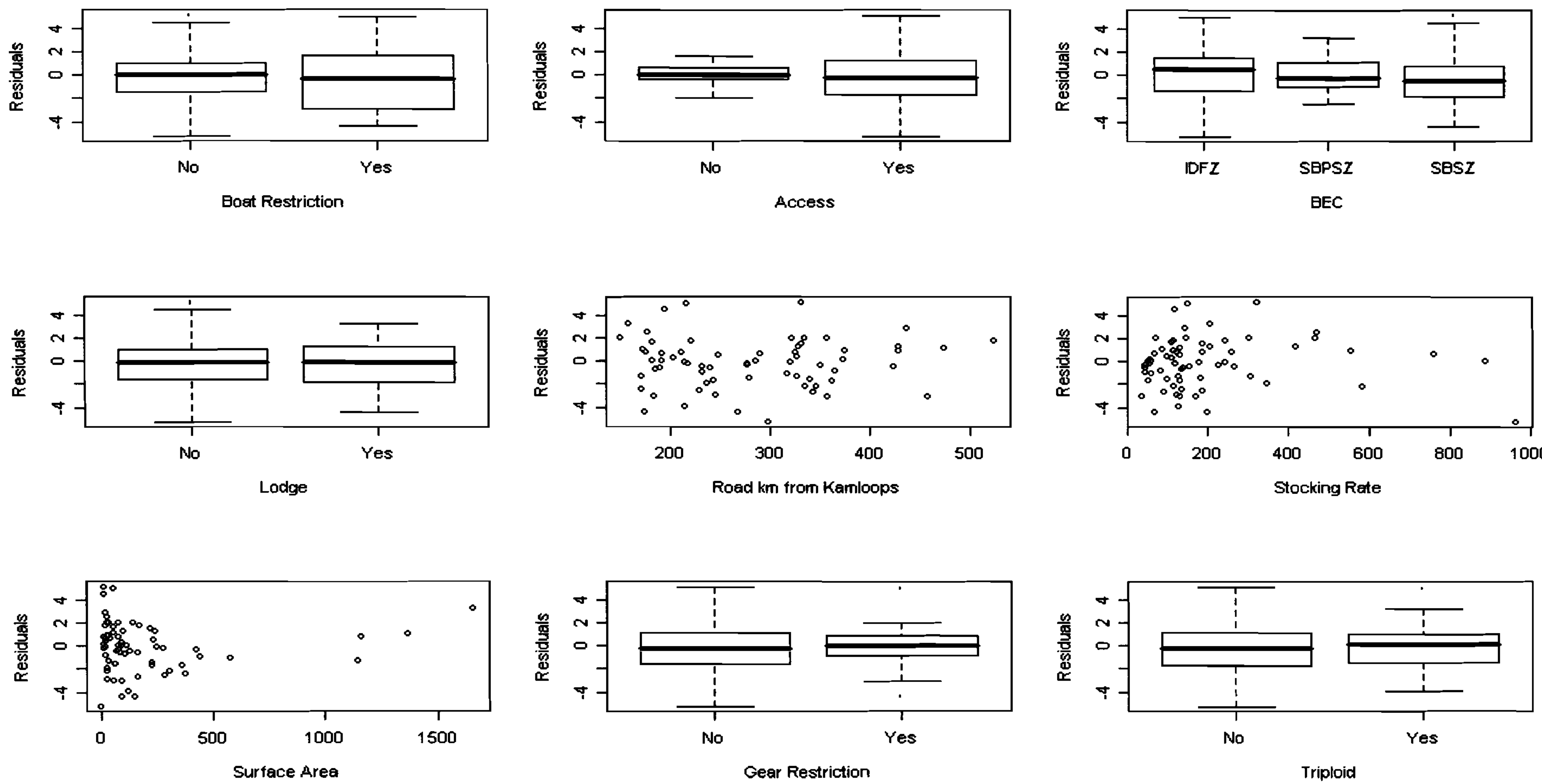

Figure 3.1: Residual plots for the base data GLM. Residual boxplots were created for categorical explanatory variables and scatterplots of residuals were created for continuous explanatory variables.

There was no statistically significant (significance level: $p<0.05$) relationship between presence of sterile fish and angler effort or between biogeoclimatic zone and angler effort. However, the presence of a boating restriction, stocking rate (fish/ha), access, presence of a lodge, lake surface area, distance a lake is located from Kamloops (road kilometres) and presence of a gear restriction were all significantly related to angler effort. The presence of a boating restriction, stocking rate, access and presence of a lodge were all positively related with angler effort. Lake surface area, distance a lake is located from Kamloops and presence of a gear restriction were all negatively related with angler effort (Table 3.1).

Table 3.1: Analysis of deviance table for the base data GLM. Data from 66 stocked lakes in B.C.'s central interior were used to fit the model.

Source	d.f.	Parameter Estimate	Parameter s.e.	p-value	% Deviance Explained
Boat Restrict	1	0.7911	0.0853	<0.05	30.9
Stocking Rate	1	0.0016	0.0002	<0.05	18.4
Surface Area	1	-0.0010	0.0002	<0.05	15.3
Access (Yes)	1	1.2637	0.1844	<0.05	11.4
Lodge (Yes)	1	0.5333	0.1031	<0.05	10.5
Road km	1	-0.0023	0.0005	<0.05	8.8
BEC	3				7.7
- (IDFZ)		-0.1435	0.1752	0.4126	
- (SBPSZ)		-0.1628	0.1825	0.3724	
- (SBSZ)		0.2146	0.1717	0.2113	
Gear Restrict (Yes)	1	-0.2326	0.1067	0.0292	1.8
Sterile (Yes)	1	-0.1408	0.0807	0.0809	1.0
Intercept		1.6301	0.2684	<0.05	
Model					69.0

3.1.2. Bootstrapped Explanatory Variable Selection

Access, stocking rate, distance a lake is located from Kamloops and biogeoclimatic zone a lake is located in were all selected by the bootstrapped AIC procedure for at least 91 of the 100 bootstrapped data sets. The bag limit and presence of a lodge variables were selected for 75 and 71 of the bootstrapped data sets respectively. The presence of a boating restriction, presence of sterile fish, campsite and gear restriction variables were all selected for between 67 and 69 bootstrapped data sets and the lake surface area variable was selected for 56 of the bootstrapped data sets (Table 3.2).

Table 3.2: Summary table for the bootstrap GLM explanatory variable selection. The d.f. column represents the degrees of freedom for each explanatory variable. The frequency of occurrence is the number of times the stepwise AIC procedure selected the variable for each of the 100 bootstrap GLMs.

Variable	d.f.	Frequency of Occurrence
Access	1	100
Stocking Rate	1	99
Road km	1	97
BEC Zone	3	91
- IDFZ		91
- SBPSZ		91
- SBSZ		91
Bag limit	1	75
Lodge	1	71
Gear Restriction	1	69
Sterile	1	68
Campsite	1	68
Boating Restriction	1	67
Lake Surface Area	1	56

3.2. Effort Predictions

Angler effort predictions from the base data GLM range from 2 to 120 angler days per hectare and are reasonably close to observed effort levels from aerial boat counts for the majority of lakes (Figure 3.2). However, there is a tendency for model predictions to overestimate effort for relatively low use lakes (i.e., <20 AD/ha) as well as large lakes (i.e., surface area >300 ha) and to underestimate effort for high use lakes (i.e., >20 AD/ha) (Figure 3.2).

Effort predictions from the bootstrap GLM are not significantly different (significance level: $p<0.05$) from mean effort predictions from the base data model ($p=0.982$). Mean predicted effort from the bootstrap data ranged from 3 to 62 angler days per hectare (Table 3.3). The median effort predictions are similar to mean effort predictions from the bootstrap data GLM. However, predicted median effort levels are lower on average (not statistically significant) than the mean effort predictions. The average median effort level is 13.77 angler days per hectare, where as the average mean effort level is 15.15 angler days per hectare.

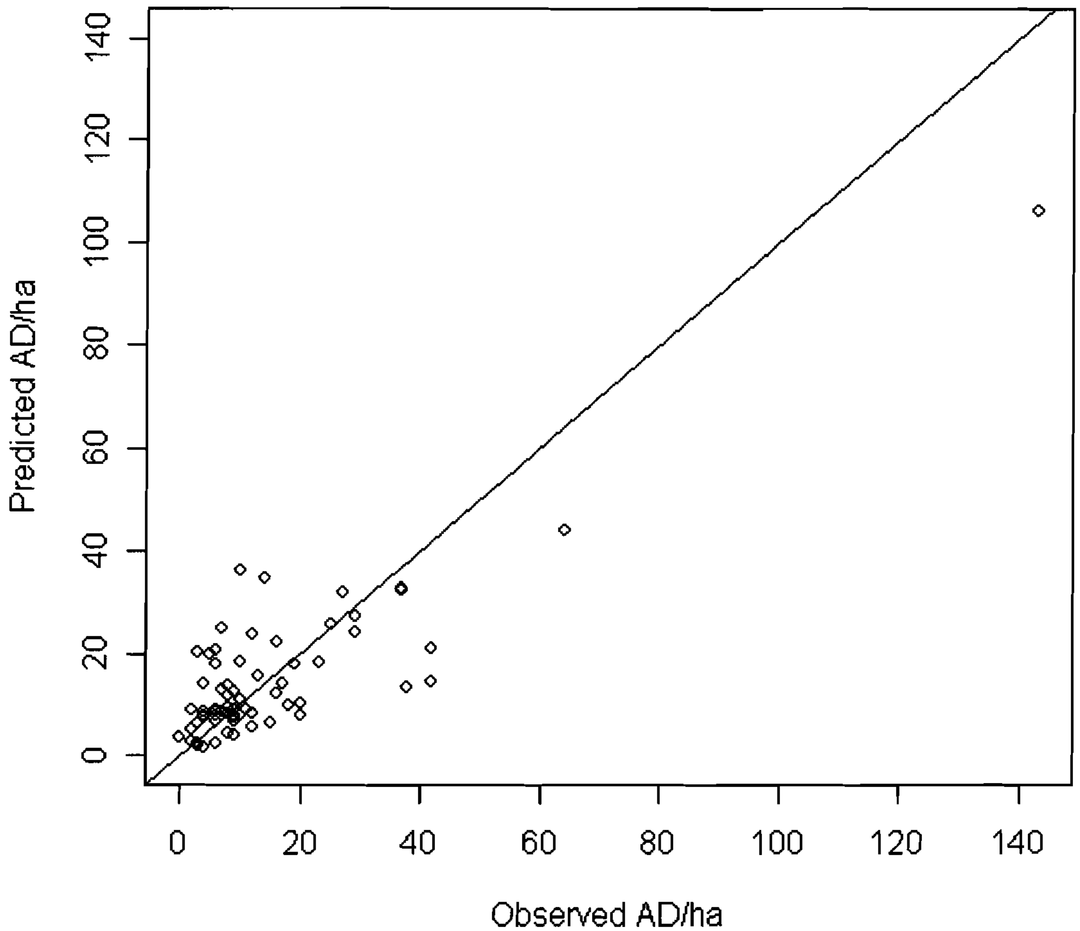

Figure 3.2: Predicted effort from the base data GLM versus observed effort from aerial boat counts for stocked lakes in B.C.'s central interior.

Table 3.3: Summary of observed effort and predicted effort for stocked lakes in B.C's central interior (i.e., only lakes with available aerial boat count data). WBID is the unique waterbody identifier for the lake and observed effort (Obs.Effort) is from aerial boat count flights. Effort is measured in angler days per hectare. The predicted effort (Pred.Effort) and standard error (SE) from the base data GLM are listed under the Standard Method columns. The predicted mean effort, standard error (SE) and predicted median effort from the bootstrap GLMs are listed under the Bootstrap Methods columns.

			Standard Method		Bootstrap Method		
Lake	WBID	Obs. Effort	Pred. Effort	SE	Mean Effort	SE	Median Effort
Sheridan	00790BRID	13	4.43	1.10	23.65	16.25	21.24
Horse	01006DOGC	9	6.97	1.22	17.75	9.00	15.50
Bridge	00903BRID	8	5.31	1.00	15.74	9.56	12.90
Watch	00896GRNL	37	37.25	3.82	15.09	6.49	13.99
Deka	00154BRID	6	10.06	1.67	28.14	15.80	26.41
Howard	01675MAHD	29	31.91	2.92	21.61	9.88	19.39
Fawn	00737BRID	143	120.24	9.56	62.17	36.32	59.87
Ten Mile	00001QUES	17	12.39	1.19	14.33	3.50	13.97
Mcleese	00295TWAC	18	12.24	1.58	11.17	4.87	10.51
Timothy	01451SAJR	8	10.90	1.15	10.63	4.38	10.02
Lorin	01824MAHD	10	10.82	0.94	15.97	5.30	15.61
Sulphurous	00252BRID	7	15.45	1.65	16.18	6.88	15.71
Big	02219QUES	4	6.43	0.69	10.87	2.94	10.63
Dugan	00051SAJR	27	26.95	2.90	53.87	42.15	39.51
Tyee	02197QUES	8	15.71	1.57	13.47	5.79	12.07
Chimney	01071MFRA	6	6.76	0.57	12.64	3.78	12.10
Valentine	00521BRID	42	17.49	1.80	13.22	4.79	12.61
Helena	01769SAJR	9	7.50	0.61	11.63	3.44	10.93
Greeny	01476SAJR	25	27.54	2.97	14.63	5.26	14.11
Forest	00849TWAC	19	14.16	1.44	9.68	3.94	8.58
Irish	00783BRID	64	46.27	3.74	30.09	12.55	27.01
Gustafsen	00439DOGC	12	6.30	0.53	7.86	2.79	7.14
Horn	00051HOMA	9	4.71	0.70	4.20	2.71	3.29
Jackson	02099QUES	37	26.08	2.59	14.61	5.26	13.10
Dewar	00003SAJR	29	25.88	2.24	36.16	22.08	30.03
Hen Ingram	01929QUES	3	7.03	0.64	8.92	2.37	8.51
Ruth	01610MAHD	4	11.46	1.13	20.75	5.91	20.82
Till	00476MFRA	15	8.37	0.78	8.27	2.73	7.82
Bouchie	01192COTR	8	9.19	0.83	8.64	2.18	8.41
Jim	01449GRNL	9	11.08	1.28	13.38	4.55	13.22
Edmund	00426BRID	10	9.28	0.88	13.26	4.00	12.99
Simon	02116SAJR	11	8.44	1.13	14.54	5.61	13.22
Hathaway	00191BRID	6	24.42	2.46	23.54	12.03	20.46
Felker	00934MFRA	4	7.67	0.58	11.42	3.33	10.79
Rail	01024SAJR	4	8.53	0.87	10.62	3.75	10.25

Table 3.3 – continued from previous page

			Standard Method		Bootstrap Method		
Lake	WBID	Obs. Effort	Pred. Effort	SE	Mean Effort	SE	Median Effort
Milburn	01224COTR	23	19.00	1.77	19.12	6.06	18.15
French	02052MAHD	14	28.93	2.92	21.05	10.57	19.62
Donnely	01806MAHD	6	5.92	1.12	4.80	2.24	4.40
108 Mile	01012SAJR	5	19.60	1.86	13.55	5.48	12.57
Dorsey	02030QUES	42	16.75	1.13	17.28	3.92	16.89
Little Green	00596HORS	38	16.42	1.51	20.08	7.63	18.66
Blue	00597TWAC	16	22.16	2.19	12.65	5.07	11.37
Big Onion	01152TASR	8	5.26	0.76	5.07	3.16	4.51
Bellos	01031COTR	20	9.74	0.94	8.07	2.19	7.94
Kestrel	00238TWAC	6	6.81	0.77	9.59	4.65	8.72
Howes	02233QUES	6	10.88	0.82	10.66	2.45	10.38
Cuisson	01630NARC	2	8.50	0.74	10.84	2.69	10.56
Elk	01978QUES	7	18.24	2.15	11.87	4.58	11.04
Rimrock	01682NARC	12	21.30	1.96	30.08	11.92	28.71
Lower	00064BRID	20	13.24	1.49	14.33	4.82	13.84
Earle	00298BRID	6	2.86	0.57	3.92	1.56	3.73
Faulkner	00802BRID	16	13.35	1.47	19.04	6.36	17.62
Snag	01862MFRA	3	18.35	1.93	11.33	4.04	10.51
Greenlee	01604MAHD	10	22.49	2.12	11.31	4.32	10.53
Nolan	01333GRNL	3	2.93	0.60	3.42	1.34	3.26
Mcintyre	00839MFRA	12	9.62	0.75	11.17	3.34	10.48
Abbott	02402QUES	7	7.38	1.40	4.07	1.82	3.63
Gardner	01317MFRA	9	9.70	0.93	9.72	3.02	9.32
Schoolhouse	01527MAHD	2	3.05	0.58	3.91	1.19	3.84
Blue	00919NARC	9	8.71	0.82	9.05	2.48	8.81
Klinne	01811QUES	6	8.41	0.47	9.39	4.41	8.37
Oslie	00021HORS	4	2.45	0.96	2.65	1.48	2.41
Baillon	02280QUES	3	2.35	0.45	3.15	1.66	2.80
Dor	01535MAHD	2	6.05	1.12	7.21	2.96	6.36
Reservoir	00059SAJR	10	36.70	3.87	58.18	51.10	43.14
Big	00851TASR	0	4.60	0.54	4.69	2.62	4.10

3.3. Cross Validation

Figure 3.3 illustrates the close relationship between each lake's predicted effort from the base data GLM (i.e., data from all stocked lakes is used to fit the model) and effort predictions from the cross validation analysis (i.e., data for the lake being predicted for is not included in the model fitting process). Effort predictions from the cross validation analysis are not significantly different from effort predictions generated from the base data GLM. However, effort predictions for Fawn Lake do appear to change substantially when Fawn Lake is not included in the model fitting process (Table 3.4).

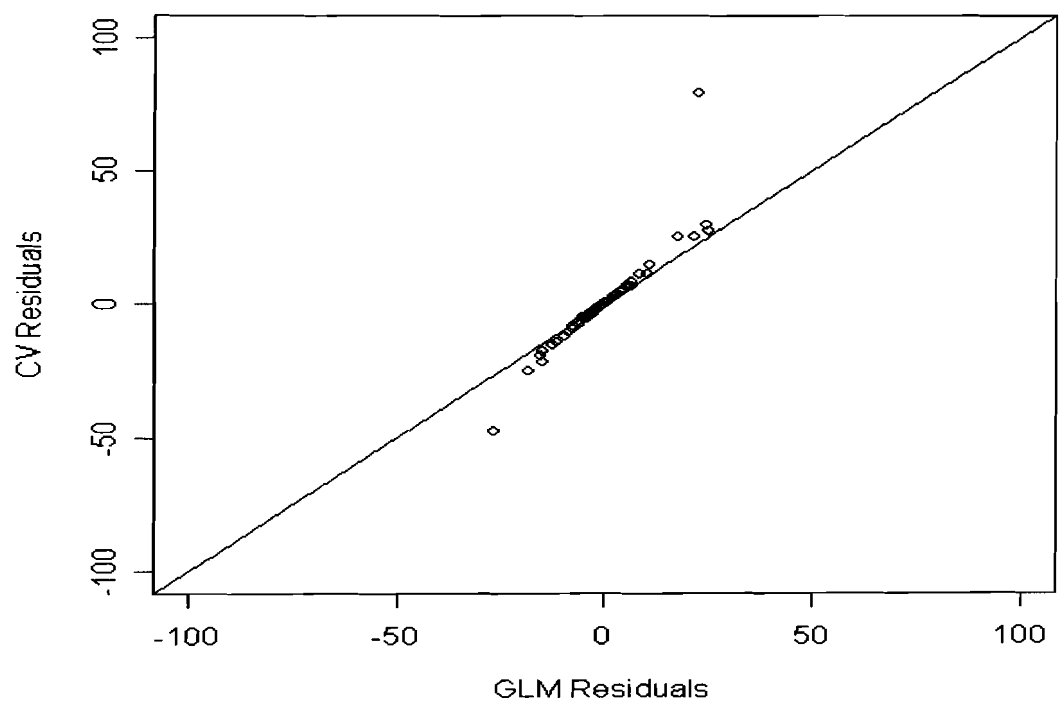

Figure 3.3: Comparison of residuals from the base data GLM and cross validation analysis. Data points close to the 1:1 line represent a high degree of agreement between the base data GLM effort predictions and effort predictions from the cross validation analysis.

3.4. Evaluation of Performance

Model predictions from the base data GLM classify five lakes as currently "under performing" (i.e., observed effort is less than the predicted effort minus two bootstrapped standard deviations) and eight lakes as currently "over performing" (i.e., observed effort is greater than the predicted effort plus two bootstrapped standard deviations) given their characteristics (i.e., explanatory variable values) (Table 3.4).

Model predictions from the cross validation analysis classify eight lakes as currently "under performing" and nine lakes as "over performing" given their characteristics. Based on the cross validation analysis Hathaway Lake, French Lake and Howes Lake each changed classifications from being "average performing" (i.e., observed effort is within the predicted effort plus or minus two bootstrapped standard deviations) stocked lakes to "under performing" stocked lakes. Conversely, Fawn Lake changed classifications from being an "average performing" stocked lake to an "over performing" stocked lake based on predictions from the cross validation analysis (Table 3.4).

Table 3.4: Summary of standard method and leave-one-out cross validation angler effort predictions for stocked lakes in B.C.'s central interior and evaluation of performance. WBID is the unique waterbody identifier for the lake and observed effort (Obs.Effort) is from aerial boat count flights. Effort is measured in angler days per hectare. The performance of a lake is classified as either under performing (under), performing at an average level (average), or over performing (over). The predicted angler effort plus or minus 2 bootstrapped standard errors are listed for both the standard and leave-one-out cross validation predictions. If observed angler effort is less than predicted effort minus 2 bootstrapped standard errors the lake is categorized as "under performing". If observed angler effort is between predicted effort plus or minus 2 bootstrapped standard errors the lake is categorized as "average". If observed angler effort is greater than predicted effort plus 2 bootstrapped standard errors the lake is categorized as "over performing".

			Standard Method			Cross Validation		
Lake	WBID	Obs. Effort	Pred.Eff -2SE	Pred.Eff +2SE	Performance	Pred.Eff -2SE	Pred.Eff +2SE	Performance
Sheridan	00790BRID	13	0.00	36.94	Average	0.00	34.42	Average
Horse	01006DOGC	9	0.00	24.97	Average	0.00	24.43	Average
Bridge	00903BRID	8	0.00	24.43	Average	0.00	23.81	Average
Watch	00896GRNL	37	24.27	50.23	Average	24.43	50.39	Average
Deka	00154BRID	6	0.00	41.66	Average	0.00	43.24	Average
Howard	01675MAHD	29	12.16	51.67	Average	13.23	52.75	Average
Fawn	00737BRID	143	47.61	192.87	Average	0.00	136.63	Over
Ten Mile	00001QUES	17	5.39	19.40	Average	4.81	18.81	Average
Mcleese	00295TWAC	18	2.50	21.98	Average	1.10	20.58	Average
Timothy	01451SAJR	8	2.14	19.66	Average	2.55	20.07	Average
Lorin	01824MAHD	10	0.22	21.42	Average	0.29	21.49	Average
Sulphurous	00252BRID	7	1.68	29.21	Average	3.55	31.09	Average
Big	02219QUES	4	0.55	12.32	Average	0.75	12.51	Average
Dugan	00051SAJR	27	0.00	111.24	Average	0.00	111.21	Average
Tyee	02197QUES	8	4.13	27.30	Average	5.61	28.77	Average
Chimney	01071MFRA	6	0.00	14.33	Average	0.00	14.36	Average
Valentine	00521BRID	42	7.91	27.06	Over	2.85	22.01	Over
Helena	01769SAJR	9	0.62	14.38	Average	0.54	14.30	Average
Greeny	01476SAJR	25	17.01	38.07	Average	18.22	39.28	Average
Forest	00849TWAC	19	6.29	22.03	Average	5.47	21.21	Average

Table 3.4 – continued from previous page

			Standard Method			Cross Validation		
Lake	WBID	Obs. Effort	Pred.Eff -2SE	Pred.Eff +2SE	Performance	Pred.Eff -2SE	Pred.Eff +2SE	Performance
Irish	00783BRID	64	21.16	71.38	Average	13.90	64.12	Average
Gustafsen	00439DOGC	12	0.71	11.89	Over	0.44	11.62	Over
Horn	00051HOMA	9	0.00	10.13	Average	0.00	9.66	Average
Jackson	02099QUES	37	15.57	36.59	Over	11.96	32.98	Over
Dewar	00003SAJR	29	0.00	70.04	Average	0.00	69.30	Average
Hen Ingram	01929QUES	3	2.28	11.78	Average	2.53	12.03	Average
Ruth	01610MAHD	4	0.00	23.28	Average	0.59	24.23	Average
Till	00476MFRA	15	2.92	13.82	Over	2.71	13.61	Over
Bouchie	01192COTR	8	4.82	13.55	Average	4.91	13.65	Average
Jim	01449GRNL	9	1.99	20.18	Average	2.34	20.54	Average
Edmund	00426BRID	10	1.27	17.29	Average	1.20	17.22	Average
Simon	02116SAJR	11	0.00	19.66	Average	0.00	19.21	Average
Hathaway	00191BRID	6	0.37	48.48	Average	7.03	55.15	Under
Felker	00934MFRA	4	1.01	14.32	Average	1.17	14.49	Average
Rail	01024SAJR	4	1.03	16.04	Average	1.47	16.49	Average
Milburn	01224COTR	23	6.89	31.12	Average	6.10	30.34	Average
French	02052MAHD	14	7.79	50.08	Average	14.49	56.79	Under
Donnely	01806MAHD	6	1.43	10.41	Average	1.40	10.38	Average
108 Mile	02012SAJR	5	8.65	30.55	Under	11.96	33.86	Under
Dorsey	02030QUES	42	8.91	24.59	Over	6.89	22.57	Over
Little Green	00596HORS	38	1.16	31.68	Over	0.00	28.54	Over
Blue	00597TWAC	16	12.02	32.30	Average	13.77	34.05	Average
Big Onion	01152TASR	8	0.00	11.58	Average	0.00	11.25	Average
Bellos	01031COTR	20	5.36	14.11	Over	4.36	13.12	Over
Kestrel	00238TWAC	6	0.00	16.11	Average	0.00	16.19	Average

Table 3.4 – continued from previous page

			Standard Method			Cross Validation		
Lake	WBID	Obs. Effort	Pred.Eff -2SE	Pred.Eff +2SE	Performance	Pred.Eff -2SE	Pred.Eff +2SE	Performance
Howes	02233QUES	6	5.98	15.78	Average	6.30	16.10	Under
Cuisson	01630NARC	2	3.12	13.87	Under	3.58	14.32	Under
Elk	01978QUES	7	9.07	27.40	Under	12.24	30.58	Under
Rimrock	01682NARC	12	0.00	45.14	Average	0.18	47.86	Average
Lower	00064BRID	20	3.59	22.89	Average	2.28	21.58	Average
Earle	00298BRID	6	0.00	5.99	Over	0.00	5.60	Over
Faulkner	00802BRID	16	0.62	26.08	Average	0.11	25.57	Average
Snag	01862MFRA	3	10.27	26.42	Under	14.45	30.61	Under
Greenlee	01604MAHD	10	13.85	31.12	Under	17.14	34.42	Under
Nolan	01333GRNL	3	0.26	5.60	Average	0.25	5.59	Average
Mcintyre	00839MFRA	12	2.95	16.30	Average	2.80	16.14	Average
Abbott	02402QUES	7	3.74	11.02	Average	3.88	11.16	Average
Gardner	01317MFRA	9	3.65	15.75	Average	3.72	15.82	Average
Schoolhouse	01527MAHD	2	0.68	5.43	Average	0.82	5.56	Average
Blue	00919NARC	9	3.74	13.68	Average	3.71	13.65	Average
Klinne	01811QUES	6	0.00	17.22	Average	0.00	17.52	Average
Oslie	00021HORS	4	0.00	5.42	Average	0.00	5.26	Average
Baillon	02280QUES	3	0.00	5.67	Average	0.00	5.61	Average
Dor	01535MAHD	2	0.13	11.98	Average	1.22	13.06	Average
Reservoir	00059SAJR	10	0.00	138.90	Average	0.00	159.81	Average
Big	00851TASR	0	0.00	9.84	Average	0.00	10.17	Average

Chapter 4

DISCUSSION

The goal of this project was to identify "under performing" and "over performing" stocked lakes in B.C.'s central interior. Aerial boat counts alone allow one to monitor trends in effort for an individual lake. However, effort estimates based on boat count data must be put into perspective, in terms of a lakes characteristics (e.g., access, facilities, etc.,) to evaluate performance relative to other lakes in the region. Parkinson et al. (2004) suggests that lakes with varying levels of non-catch related factors should vary in effort densities. Therefore, identifying "under performing and "over performing" lakes requires one to quantify the relative importance of a variety of non-catch related factors in attracting anglers to different stocked lakes in B.C.'s central interior. Study results indicate the following seven factors are of particular importance (listed in order of most influential to least influential in terms of variability explained): presence of a boating restriction; stocking rate; lake surface area; access; presence of a lodge; distance a lake is located away from Kamloops; and presence of a gear restriction.

Results of the bootstrapping procedure illustrate varying degrees of certainty regarding the influence of each variable (Effron and Tibshirani 1993). The consistent selection of lake access, stocking rate, and distance from Kamloops variables suggests their importance is not particularly sensitive to the data set used by the bootstrapping procedure; therefore, selection of these variables appears to be driven by data from the majority of lakes in the region rather than a select few. Results of the bootstrapping procedure provides limited evidence that the presence of a lodge, gear restriction, or boating restriction, as well as lake surface area are important variables affecting angler effort. The low to moderate frequency of selection by the bootstrapped AIC procedure suggests that selection of these variables depends on a relatively small proportion of lakes in the dataset, which may not be representative of overall angler behaviour throughout the region.

Stocking rate is one of the key management inputs that biologists may control directly and therefore, research that improves the effectiveness of stocking regimes is certainly beneficial. My results support existing research that suggests a positive relationship exists between angler effort and stocking rate (Moring 1993, Fraley 1996, Shaner et al. 1996, Cox and Walters 2002a). A significant positive relationship exists between stocking rate and angler effort in B.C.'s central interior indicating the potential for increasing angler days simply by increasing rainbow trout stocking densities. However, density dependent growth of rainbow trout has been empirically demonstrated from whole-lake experiments (Post et al. 1999, Biro et al. 2003), which means that increases in stocking rates would eventually lead to smaller fish and slower recruitment to catchable size. Slower growth to recruitment size also means that more fish will die from natural mortality prior to recruitment. Biro et al. (2003) suggests the strength of density dependent effects on growth of rainbow trout is a function of lake productivity.

Therefore, more productive lakes likely have a greater capacity to support increased stocking rates.

Results of my research, as well as from Webb (2006) and Cox (2000), suggest that lakes located in the central interior must provide a substantially higher level of angling quality to attract anglers from distant population centres such as Vancouver, B.C. Webb (2006) found that distance from Surrey, B.C. (i.e., a central point in the Vancouver area) had a significant effect in explaining differences in angler effort on small lakes in the B.C. southern interior (MOE Region 3). Cox (2000) used a mechanistic modelling approach to suggest that rainbow trout lakes in the southernmost areas of the interior attract approximately 2.5 times more anglers-per-unit fish density than do more distant lakes located in the Cariboo-Chilcotin (Region 5). The majority of B.C.'s population is located between Kamloops and Vancouver, including Kelowna. This area also represents the largest pool of potential anglers and likely explains the positive relationship found between distance from Kamloops and angler effort.

Rainbow trout lakes with trailer access had higher levels of angler effort than lakes without such access. Trailer access could attract additional anglers who fish from larger boats, while lack of trailer access could restrict a lake primarily to anglers with pontoon or belly boats. While many angler vehicles are equipped with boat racks, and therefore could still launch an aluminium boat without having trailer access, loading and unloading the boat becomes more physically demanding, which is especially relevant given that the average age of the angler population has continuously increased over the last decade (Levey and Williams 2003).

My research supports findings of both Forbes (1998) and Connelly et al. (2001) who have previously identified amenities such as accommodations and basic facilities as being important factors in selecting a fishing destination. There are several possible factors that would explain why lakes with lodges exhibit higher angler use than lakes without lodges. Because 80% of the angler population originates from outside of B.C.'s central interior (Levey and Williams 2003), many visitors presumably require some level of overnight accommodation. The presence of facilities likely also appeals to families because activities other than angling (e.g., horseshoes, paddle boats, etc.) are also important to a quality angling experience. Lodge businesses also advertise both within and outside of the central interior, which would increase awareness of a particular lake, its location, and amenities. On the other hand, lakes without lodges become known mainly through their fishery alone. Even fishing performance may be better on lakes with lodges because lodge owners quickly report any decrease in catch rates or fish size to management biologists. Therefore, lakes with lodges have several factors that lead to greater attention than lakes without lodges.

Anglers often resist traditional recreational fishery regulations such as gear restrictions and bag limits (Arlinghaus and Mehner 2005). My results indicate that gear restrictions are associated with lower angler effort. However, the base data AIC procedure did not select the bag limit variable as being influential in explaining differences in angler effort. These results support a pathology indicated by Webb (2006) and Post et al. (2003) which suggests that while the introduction of restrictive fishing regulations may temporarily reduce fishing effort, resulting improvements in fishing quality (i.e., catch success) will likely attract effort back to the fishery. Unfortunately, long-term studies have yet to demonstrate empirically that such pathology exists.

The presence of sterile fish and biogeoclimatic zone were both identified as important variables by the base data AIC procedure; however, neither variable exhibited a statistically significant relationship to angler effort. Lack of positive relationship between sterile fish and angler effort suggests that further evaluation as to whether or not stocking sterile fish is likely to meet management objectives of increasing angler effort. BEC zone was included in the analysis as an indirect measure of lake productivity (i.e., total dissolved solids). Lakes in the IDFZ are generally the most productive and therefore, would most likely provide the greatest yield of fish. Lack of a significant relationship between BEC zone and angler effort has several potential explanations. First, although lakes in the IDFZ are generally the most productive, lakes in each zone are reasonably productive with median TDS values of at least 180 ppm. Therefore, actual fish biomass in these lakes may not differ enough to affect angler effort. Webb (2006) also notes that because BEC zones are an indirect measure of lake productivity, they may also be capturing other variables that influence effort such as lake elevation and typical weather conditions.

Understanding the effects of non-catch related variables allows biologists to generate effort predictions for a lake without acquiring detailed stock or catch information that are often costly to obtain and thus, generally lacking for most management agencies. Results of my research allow biologists to quickly put effort estimates generated from aerial boat counts into perspective as lake by lake effort estimates alone do not allow one to accurately evaluate management performance. Predicted effort estimates are generated based on the current performance of the entire fishery (i.e., many spatially segregated independent lakes). Thus, comparing observed and predicted effort estimates allows a biologist to evaluate a lakes performance (i.e., in terms of angler days generated) relative to the current performance of other lakes in the region. Lakes that are not performing up to the current regional average will have predicted effort estimates that are higher than observed. Conversely, lakes that are performing above the current regional average will have predicted effort estimates that are lower than observed. This model provides a tool for identifying and focusing valuable field time towards assessing lakes where improvement is probably needed. While lakes that are performing below the regional average should be given priority in order to get them back on track, I would also recommend giving priority status (i.e., for biological assessment) to lakes that are performing above the regional average. Determining why certain lakes are performing better than others in the region could provide valuable insight into management actions that are having positive impacts on angler effort and may be applicable to other stocked lakes. Effort predictions from the base data GLM identifies five lakes that are currently performing well below the regional average (i.e., predicted effort is less than two bootstrapped standard deviations) and eight lakes that are currently performing well above the regional average.

4.1. Potential Model Improvements

Webb (2006) identified at least two potential problems with using aerial boat count data. First, Webb (2006) notes that managers should be cautioned from being too rigid in their interpretation of SLIM effort data because many effort estimates are highly uncertain and errors tend to be greatest on lakes with low effort counts (Tredger 1992). Second, Webb (2006) also points out that it is unlikely that lakes are selected for aerial boat counts at random, which potentially adds bias to the GLM predictions. Lakes that receive high angling effort tend to be assessed with greater frequency because managers receive more public pressure on popular fishing lakes (Webb 2006). Thus, SLIM effort variables I included in my analysis may represent lakes with higher than average fishing effort for the region, potentially causing future predictions for lakes with no observed effort data to be biased high.

I included effort data for all lakes that had at least one year of aerial boat count data since the year 2000. Given the high degree of variability inherent with effort predictions based on aerial boat counts it would be beneficial to use only lakes where multiple years of aerial boat count estimates exist and then use the average effort estimate. Such an approach will likely increase accuracy from variable effort estimates as using information from multiple years of aerial boat counts will increase the probability of obtaining effort estimates closer to the true value. Fortunately, the MOE's B.C.'s small lakes committee has committed to conducting different flight lines in consecutive three year blocks. Thus, I would recommend conducting this analysis concurrently with the flight lines. Therefore, the analysis would be conducted and the results updated at the end of every third year providing biologists with a method to detect potential changes in angler behaviour.

Lakes in B.C.'s central interior are stocked with a variety of rainbow trout strains (Freshwater Fisheries Program Plan, 2007). I did not differentiate between which strain was stocked although it is believed by many that anglers may express a preference for certain strains. Different strains may possess differential characteristics that may be desirable to anglers such as differences in catchability and fighting performance. I am currently unaware of any studies that analyze potential differences in angler preference for different rainbow trout strains. While this was originally an explanatory variable that I wanted to include, the majority of lakes in B.C.'s central interior have been stocked with a mix of strains and therefore, any potential effects could not be reliably differentiated. However, I would recommend that further work be directed towards examining potential differences in performance (i.e., angler effort) of lakes stocked with different strains of rainbow trout.

4.2. Management Implications

The Ministry of Environment has set the goal of increasing licence sales by 30% (of 2004-2005 levels) by the year 2015 (MOE's Freshwater Fisheries Program Plan 2007). Two priority actions identified in the MOE's Freshwater Fisheries Program Plan (2007) to achieve this goal are to evaluate client preferences as a key input to management approaches and to deliver stocking programs that optimize angling opportunities. My research provides insight for both of these priority actions.

Valuating attributes for site selection, when it comes to recreational use, is often done using stated preference techniques (Holland and Ditton 1992, Hunt and Ditton 1997, Connelly et al. 2001). Stated preference techniques ask respondents what factors are most important to them in forming decisions (e.g., selecting a fishing destination). However, in using stated preference techniques, individuals do not actually make any behavioural changes, they only state that they would behave in a particular fashion. Thus, stated preference techniques are commonly criticized because of the hypothetical nature of the questions and the fact that actual behaviour is not observed (Cummings et al. 1986, Mitchell and Carson 1989). Relationships reported in this paper between various non-catch related factors and angler effort are based on observed fishing effort and thus represent revealed preferences of current anglers. However, it should be noted, that while revealed preference techniques do not suffer from the hypothetical nature of stated preference techniques, by focussing only on revealed preferences, results reported in this paper represent preferences of active anglers only. Because inactive anglers are represented in the observed effort, no information regarding inactive angler preferences can be gathered. Therefore, despite limitations with stated preference techniques, future work in this area may be beneficial in providing a more complete picture regarding preferences of all potential anglers (i.e., active and inactive).

Based on aerial boat count data I have identified seven explanatory variables that currently exhibit a significant relationship to angler density on stocked lakes in B.C.'s central interior. The relationships established through this analysis can be used as a first step towards identifying areas of potential concern and prioritizing where further experimental work is most needed. For example, my research indicates that sterile fish, while not statistically significant (i.e., alpha value = 0.05), currently exhibits an inverse relationship with angler effort. Even though no significant relationship was observed between presence of sterile fish and angler effort the fact that no evidence was observed to suggest stocking sterile fish results in an increase in angler effort may be particularly concerning to managers given an increased investment is required (i.e., both in terms of monetary cost and personnel time) to produce sterile rainbow trout. Therefore, understanding the causal mechanism (e.g., decreased survival, decreased catchability, increased mortality of fish stocked in subsequent years due to increased predation from large sterile adults, etc.) for the observed relationship (or lack there of) between angler effort and presence of sterile fish may be a priority factor to be examined through more rigorous experimental study. McAllister et al. (1992) showed that block designs with three to six spatial replicates and relatively short durations generated high statistical power in developing a large-scale fishing experiment designed to test the hypothesis that size-selective harvesting of large fish is causing a significant reduction in economic value of commercial pink salmon harvests along the coast of BC. Designing a similar experiment on a regional spatial scale to test the hypothesis that the presence of sterile fish does not have any affect on angler effort may provide managers with a deeper insight into the causal factors at play between angler effort and presence of sterile fish and under what circumstances may the use of sterile fish be most likely to meet management objectives (i.e., maximize effort, provide diversity of angling opportunities, etc.).

Understanding the role non-catch related factors play will be critical if effort is to be maximized on stocked lakes in B.C.'s central interior as 69% of total variation in effort, since the year 2000, can be explained by non-catch related factors examined in this analysis. Previous studies have indicated that angling quality decreases quickly when effort increases (Post et al. 2003, Askey et al. 2006). Given the limitations to quality of angling at high effort levels (Cox and Walters 2002), the MOE may have to shift to an angler-oriented approach to keep anglers satisfied. The objective of an angler-oriented approach, as indicated by Hunt and Ditton (1997), is to increase the probability of a person having a good experience when they go fishing, thus increasing the chances of retaining anglers in the fishery. This type of approach has been described previously as the multiple-satisfactions approach to wildlife management (Hendee 1974). By not only focussing on status of fish stocks and catch rates, but also looking at other elements that contribute to quality angling experiences and angler satisfaction managers may be able to provide people with a positive experience even if catch success happens to be low.

Development of an angler-oriented approach requires an understanding of current angler preferences. Results of my research indicate that anglers currently prefer lakes with high stocking rates, trailer access, lodges or resorts on them and no gear restrictions (listed in order from most influential to least influential). The MOE Fisheries Branch in conjunction with the Freshwater Fisheries Society of BC have direct control over stocking rates and gear restrictions. As such, setting stocking rates and gear restrictions is already part of fisheries management activities in B.C.'s central interior. However, access and the presence of lodges or resorts are not under direct management control. Therefore, the development of collaborative relationships with agencies that do control these variables may have positive results in terms of increasing angler days in B.C.'s central interior. Potential partners could include the Cariboo Regional District, the Ministry of Forests (MOF) and the Ministry of Tourism, Sports and Arts (MOTSA). With the precarious state of the forest industry (e.g., uncertain affects of the pine beetle epidemic), which the economy of B.C.'s central interior presently relies heavily upon, both the Cariboo Regional District and MOTSA have a vested interest in promoting other sectors of the economy such as tourism. Approximately 80% of angler effort in B.C.'s central interior comes from outside the region (Levey and Williams 2003), which implies that substantial revenue may not enter the region in the absence of angling opportunities. Ensuring members of the Regional District are aware of the magnitude of the economic benefits generated by the fisheries resource and then providing evidence (i.e., such as results presented in this paper) of the benefits of lodges or resorts in attracting anglers to lakes in the region may persuade them to consider various incentives to stimulate development (or maintenance) of lodges or resorts. Potential incentives may include things such as zoning pieces of lakeshore property for development restricted to enterprises providing recreational services or providing tax breaks to lodge or resort owners. The role of fisheries managers would be to identify lakes where the presence of lodges or resorts would have the greatest benefits without putting wild stocks at risk. Developing a partnership with the MOF may provide benefits in terms of increasing angler days and protecting wild stocks. Part of the MOF mandate is to manage the network of forest service roads, bridges and rights of way in consideration of their recreation use and values. Access had the strongest effect on effort of any variable examined in this analysis. Therefore, an opportunity may exist to increase effort through identifying stocked lakes, for the MOF, where poor access may be limiting angler use. Given the significant relationship between lake access and angler effort it may be beneficial for fisheries managers to work with MOF to ensure any roads created for logging, that provide access to wild stock lakes (particularly for wild stock lakes close to Kamloops where the angler response is greatest, thus posing the greatest risk to stocks), are de-activated when the road is no longer required.

One should note that while the MOE currently has the goal of increasing angler effort by 30% (of 2004-2005 levels) by 2015, one of the program goals stated in the Freshwater Fisheries Program Plan (2007) is to protect wild stocks and their habitats. Therefore, any work that aids in the strategic development of stocked lake fisheries is beneficial in working towards achieving the MOE's goals.

BIBLIOGRAPHY

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control. **19(6)**: 716-723.

Arlinghaus, R., and T. Mehner. 2005. Determinants of management preferences of recreational anglers in Germany: Habitat management versus fish stocking. Limnologica. **35**: 2-17.

Askey, P.J., S.A. Richards, J.R. Post, and E.A. Parkinson. 2006. Linking Angling Catch Rates and Fish Learning Under Catch-and-Release Regulations. North American Journal of Fisheries Management. **26**: 1020-1029.

Askey, P. 2007. Towards optimal management of spatially-structured, recreational fisheries: linking ecology and angler dynamics in British Columbia rainbow trout (*Oncorhynchus mykiss*) lakes. Department of Biological Sciences. Calgary, Alberta.

Biro, P.A., J. Post, and E.A. Parkinson. 2003. Density-dependent mortality is mediated by foraging activity for prey fish in whole-lake experiments. Journal of Animal Ecology. **72**

Booth, D.J. 1995. Juvenile groups in a coral-reef damselfish: density-dependent effects on individual fitness and population demography. Ecology. **76**: 91-106.

Carpenter, S.R., A. Munoz-Del-Rio, S. Newman, P.W. Rasmussen, and B.M. Johnson. 1994. Interactions of anglers and walleyes in Escanaba Lake, Wisconsin. Ecological Applications. **4**: 822-832.

Connelly, N.A., Knuth, B.A., and T.L. Brown. 2001. An Angler Typology Based on Angler Fishing Preferences. Transactions of the American Fisheries Society. **130**: 130-137.

Cox, S.P. 2000. Angling quality, effort response, and exploitation in recreational fisheries: field and modelling studies on British Columbia rainbow trout lakes. Doctoral dissertation, University of British Columbia, Vancouver.

Cox, S.P., D.T. Beard, and C. Walters. 2002. Harvest control in open-access sport fisheries: hot rod or asleep at the reel? Bulletin of Marine Science. **70**: 749-761

Cox, S.P., and C.J. Walters. 2002a. Maintaining quality in recreational fisheries: how success breeds failure in management of open-access sport fisheries. Pages 107-119 in T.J. Pitcher and C.E. Hollingsworth, editors. Recreational fisheries: Ecological, Economic, and Social Evaluation. Fish and Aquatic Resources, Blackwell Publishing, Oxford, UK.

Cox, S.P., and C.J. Walters. 2002b. Modeling Exploitation in Recreational Fisheries and Implications for Effort Management on British Columbia Rainbow Trout Lakes. North American Journal of Fisheries Management. **22**: 21-34.

Cox, S.P., C.J. Walters, and J.R. Post. 2003. A model-based evaluation of active management of recreational fishing effort. North American Journal of Fisheries Management. **23**: 1294-1302.

Cummings, R., D. Brookshire, and W. Schulze. 1986. Valuing environmental goods: An assessment of the contingent valuation method. Totowa, NJ: Rowman & Allandeld.

Effron, B., and R.J. Tibshirani. 1993. An Introduction to the Bootstrap. Chapman and Hall/CRC.

Falk, J.M., A.R. Graefe, and R.B. Ditton. 1989. Patterns of participation and motivation among salt water tournament anglers. Fisheries. **10(4)**: 10-17.

Forbes, J.T., D.A. Gill, H.L. Schramm, Jr., and G.S. Bray. 1998. Factors important to fishing site selection for freshwater anglers in Mississippi. Page 125 in Book of abstracts, seventh international symposium on society and resource management. University of Missouri – Columbia, Columbia.

Fox, J. 2002. An R and S-plus companion to applied regression. Sage Publications Inc., Thousand Oaks, CA.

Fraley, J. 1996. Cooperation and controversy in wilderness fisheries management. Fisheries. **21(5)**: 16-21.

Freshwater Fisheries Program Plan. 2007. Province of British Columbia Ministry of Environment.

Freshwater Fisheries Society of B.C. 2006-2007 annual report.

Gillis, D.M., R.M. Peterman, T.V. Albert. 1993. Movement dynamics in a fishery: Application of the Ideal Free Distribution to spatial allocation of effort. Canadian Journal of Fisheries and Aquatic Science. **50**: 323-333.

Godin, T.R., and K. Tsumura. 1995. Rainbow trout broodstocks for coarsefish lakes. Habitat Conservation Trust Fund Final Report. Fisheries Project Report No. RD39.

Graefe, A.R., and Fedler, A.J. 1986. Situational and subjective determinants of satisfaction in marine recreational fishing. Leisure Sciences. **8**: 275-295.

Hendee, J.C. 1974. A multiple satisfactions approach to game management. Wildlife Society Bulletin. **2(3)**: 104-113.

Holland, S.M., and R.B. Ditton. 1992. Fishing trip satisfaction: A typology of anglers. North American Journal of Fisheries Management. **12**: 28-33.

Hunt, K.M, and R.B. Ditton. 1997. The social context of site selection for freshwater fishing. North American Journal of Fisheries Management. **17**: 331-338.

Levey, J., and R. Williams. 2003. 2000 survey of sport fishing in British Columbia. Fish and Wildlife Recreation and Allocation Branch, Ministry of Water, Land and Air Protection; Ottawa, Ontario.

Matlock, G.C., G.E. Saul, and C.E. Bryan. 1988. Importance of fish consumption to sport fishermen. Fisheries. **13(1)**: 25-26.

Mazerolle, M. 2006. Improving data analysis in herpetology: using Akaike's Information Criterion (AIC) to assess the strength of biological hypotheses. Amphibia – Reptilia. **27(2)**: 169-180.

McAllister, M., R.M. Peterman, and D.M. Gillis. 1992. Statistical evaluation of large-scale fishing experiment designed to test for a genetic effect of size-selective fishing on British Columbia Pink Salmon (*Oncorhynchus gorbuscha*). Canadian Journal of Fisheries and Aquatic Science. **49**: 1294-1304.

McCullagh, P., and J.Nelder. 1989. Generalized linear models. 2nd edition. Chapman and Hall Ltd., London; New York.

Mitchell, R., and R. Carson. 1989. Using surveys to value public goods: The contingent valuation method. Washington DC: Resources for the Future.

Mittelbach, G.G., and C.W. Osenberg. 1993. Stage-structured ineractions in bluegill: consequences of adult resource variation. Ecology. **74**: 2381-2394.

Moring, J.R. 1993. Effect of angling effort on catch rate of wild salmonids in streams stocked with catchable trout. North American Journal of Fisheries Management. **13**: 234-237.

Mussio, R., and W. Mussio. 2002. Backroad mapbook. V4. Cariboo, 2nd edition. Mussio Ventures Ltd, New Westminister, B.C.

Nelder, J., and R. Wedderburn. 1972. Generalized Linear Models. Journal of the Royal Statistical Society, Series A. **135**: 370-384.

Parkinson, E.A., J.R. Post, and S.P. Cox. 2004. Linking the dynamics of harvest effort to recruitment dynamics in a multistock, spatially structured fishery. Canadian Journal of Fisheries and Aquatic Science. **61**: 1658-1670.

Post, J.R., E.A. Parkinson, and N.T. Johnston. 1999. Density-dependent processes in structured fish populations: Interaction strengths in whole-lake experiments. Ecological Monographs. **69**: 155-175.

Post, J.R., C. Mushens, A. Paul, and M. Sullivan. 2003. Assessment of alternative harvest regulations for sustaining recreational fisheries: Model development and application to Bull Trout. North American Journal of Fisheries Management. **23**: 22-34.

Province of British Columbia Lake and Stream Summary System.

Province of British Columbia Land and Resource Data Warehouse.

Ryder, R., S. Kerr, K. Loftus, and H. Reiger. 1974. The morphoedaphic index, a fish yield estimator-review and evaluation. Journal of the Fisheries Research Board of Canada. **31**: 663-688.

Shaner, B.L., Maceina, M.J., McHugh, J.J. and Cook, S.F. 1996. Assessment of catfish stocking in public fishing lakes in Alabama. North American Journal of Fisheries Management. **16**: 880-887.

Shuter, B.J., M.C. Jones, R.M. Korver, and N.P. Lester. 1998. A general, life history based model for regional management of fish stocks: the inland lake trout (*Salvelinus namaycush*) fisheries of Ontario. Canadian Journal of Fisheries and Aquatic Science. **55**: 2161-2177.

Spencer, P.D. 1993. Factors influencing satisfaction of anglers on Lake Miltona, Minnesota. North American Journal of Fisheries Management. **13**: 201-209.

Tonn, W.M., I.J. Holopainen, and C.A. Paszkowski. 1994. Density-dependent effects and the regulation of crucian carp in single-species ponds. Ecology. **75**: 824-834.

Tredger, C.D., 1992. Estimation of angler effort using index boat counts. Fisheries technical circular no. 94, Fisheries Branch, Ministry of Environment, Lands and Parks.

Wagner, J.D., and D.H. Wise. 1996. Cannibalism regulates densities of young wolf spiders: evidence from field and laboratory experiments. Ecology. **77**: 639-652.

Walters, C.J., and J.R. Post. 1993. Density-dependent growth and competitive asymmetries in size-structured fish populations: a theoretical model and recommendations for field experiments. Transactions of the American Fisheries Society. **122**: 34-45.

Webb, S.L. 2006. Assessing the vulnerability of wild rainbow trout (*Oncorhynchus mykiss*) stocks to overfishing in the Thompson Nicola Region of British Columbia. Simon Fraser University.