Analysis of Lake and Drainage Area Counts and Measures for Selected Watersheds across Ontario's Shield Region

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by

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Abstract

This report provides a summary and analysis of lake area, drainage area, and lake order data from thirty watersheds in Ontario. The data are compared with previous counts and measures data. The total dataset is compared to the subset of lakes that have been inventoried for their fish assemblage by the Ontario Ministry of Natural Resources.

The results show that this data is similar to that collected previously and that inventory selection is biased toward larger lakes and against headwater systems.

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RESUME

Le rapport fournit un bilan et une analyse de la superficie lacustre, de la superficie drainée et de données concernant l'ordre des lacs à partir de trente bassins versants ontariens. Les données sont comparées à des dénombrements et à des mesures antérieurs. L'ensemble total des données est comparé au sous-ensemble des lacs qui ont été inventoriés pour leur assemblage de poisson par le ministère ontarien des Ressources naturelles.

Les résultats montrent que ces données sont analogues à celles qui ont été collectées antériurement et que la sélection de l'inventaire est faussée à l'avantage des lacs les plus grands et aux dépens des réseaux de sources d'eau.

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Introduction

One aim of the National DFO LRTAP program is to estimate the potential impact of acid precipitation on the whole of the fishery resources of eastern Canada. After developing predictive models of the impact of acid loading watersheds, lakes, and their fish communities using the results of intensive research studies at sites throughout North America, it is required to extrapolate the predictions to a regional level using the results of extensive surveys and basic resource inventory data. Unfortunately, extrapolation efforts have been severely hampered by the lack of descriptive data on the populations of lakes in different regions. Most predictive acidification models require data such as lake area, drainage area, and perhaps lake order.

Existing data for Ontario, although more extensive than those available for other regions, were found to be inadequate for extrapolation purposes. Cox (1978) presented an Ontario Ministry of Natural Resources (OMNR) compilation of counts and measures for Ontario lakes. He provided numbers of lakes by log-order size categories for all 4th order river watersheds in Ontario. Watershed boundaries were not always carefully placed and many values were based on extrapolations from subsamples. The data does give, however, the only complete estimate of the number and total area of lakes for the province. Unfortunately, the Cox dataset did not provide sizes for individual lakes, the drainage area, or the lake order.

This report presents a summary and overview of a new dataset for a

group of 30 4th order river watersheds across the Ontario Shield region. Hough, Stansbury and Michalski Ltd. and J. E. Hanna Associates compiled the data including lake area, drainage (local and total), and lake order, as part of a predictive modelling contract. These new counts and measures are compared with Cox's data.

In addition, the new data were matched with data from the OMNR Lake Inventory database. This database is a cumulative record of basic limnological and fish community data for 8,000+ lakes. Lake selection for the inventory has been biased toward certain fish species, i.e. brook trout and lake trout, and there is a tendency for larger lakes to be preferred. The matched data in the 30 watersheds are compared to the total population in order to examine the biases.

Materials and Methods

Using Cox (1978) as a guide, 30 4th order river watersheds were selected to provide broad coverage of the Ontario Shield (Figure 1). The main criterion, other than location was that the watershed should contain 100 to 300 lakes.

Lake and drainage boundaries were marked on standard 1:50,000 topographic maps. Areas were measured with a digital planimeter. The smallest area measured was 0.01 sq. in. on a map of approximately 0.2 ha at full size. Within a watershed, each lake was assigned a number and the lake area and local drainage, excluding upstream lakes and their drainage, were measured. In addition, the number of the next lake downstream was noted. With that data, the total drainage and lake order can be measured.

Drainage area of a lake does not include its lake area. Areas are

reported in hectares. Headwater lakes have an order of one. All other lakes take an order of one greater than the highest order of lakes draining to it.

Some watersheds were the middle sections of large river systems. So there were some lakes, usually in chains, where the total drainage was incomplete.

Results

The thirty watersheds contained a total of 7,294 lakes of which 7,245 had complete drainage measures. The number of lakes in each watershed ranges from 73 to 436 (Table 1). The lakes and drainages measured covered a wide range of sizes (lake area 0.2 to 17,690.3 ha, total drainage 3.4 to 251,982.9 ha) (Table 2). Drainage area to lake area ratios (DA/LA) range from 0.2 to 100,877.8. There is a wide range of lake orders, but more than half are headwater lakes (Table 3). When grouped by primary watershed, the lake order frequencies are similar across watersheds.

Given that drainage area/lake area ratio spans a wide range, the data were sorted using a binary sequence of classes (2, 4, 8, etc.) and cross-tabulated by lake order (Table 4) and log-order lake size class (Table 5). While there is a tendency for the ratio to increase with increasing lake order, it tends to decrease with increasing lake size.

Analysis of variance on lake area, total drainage, and their ratio (all $\log_e$-transformed) indicates that there are significant regional and lake order differences (Table 6). The lake order differences are more pronounced. Higher order lakes tend to be larger and, not surprisingly, drainage areas get larger (Table 7).

The counts and measures from this study are similar to those of

Cox (1978) (Table 1). There is good agreement for percent water in the watershed (Table 8). The Cox lake number totals are generally higher than those from this study, even when the Cox numbers are scaled to equal water or watershed areas (Table 8). The mean ratio of total water area (this study over Cox) is 0.994 ± 0.144 (min. = 0.561, max. = 1.352). The ratio of watershed area is 1.079 ± 0.120 (min. = 0.712, max. = 1.326).

Out of the total sample, 498 (6.9 percent) had been inventoried by OMNR up to 1981. Headwater lakes are under-represented in the Inventory sample (Table 9). Inventoried lakes tend to be larger (Table 10), particularly in higher order lakes. This result is consistent with the bias in OMNR inventory lake selection for those supporting important game fish species.

Discussion

Count and measure data bases such as are given here are needed in all regions if impact assessments and resource management schemes are to consider the whole resource. Basic data on numbers, areas of lakes, drainage areas, and networks are necessary to extrapolate from surveys, inventories, and intensive study sites.

There is a wide array of lake types, even when only a few simple morphometric features are considered. If chemical and biological factors are included, an even greater diversity would be evident.

The comparison with Cox's counts and measures suggest that overall, the Cox estimate of lake population size and structure is reasonable, so that where data requirements only extend to numbers and total lake area, Cox's figures would be useful. In extrapolation, which require lake and

drainage area, this present data base could be used.

The comparison of the total dataset with the inventoried subset, provides some insight into the biases underlying many surveys and inventories. This is not to imply that fishery resource managers should only conduct stratified random inventories. These managers must direct their resources to the fish species or assemblages which sustain exploitation or other stress. Many small lakes contain only minor unfishable species.

Acknowledgments

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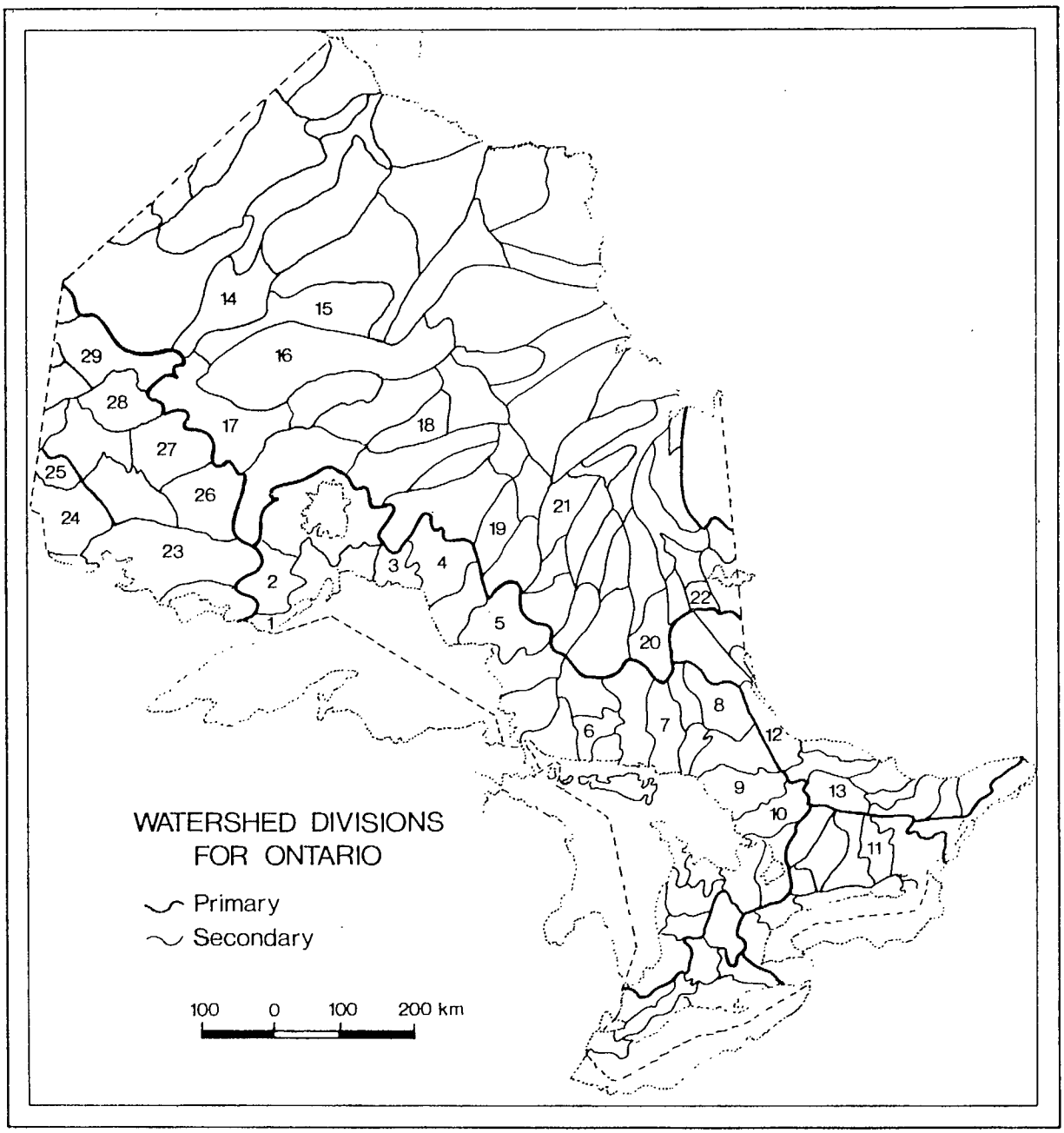

Fig. 1 Map of Ontario showing the location of the selected 4th order river watersheds.

TABLE: 1 Comparison of results from this study with that of Cox (1978)

Watershed Name		This Survey				Cox's Counts and Measures			
		N	Water	Watershed	%	N	Water	Watershed	%
1. 2AA03	Arrow River	210	11465.7	99042.3	11.5	301	9830.4	93282.0	10.5
2. 2AB06	Dog Lake	229	10775.0	123677.4	8.7	255	19205.9	111290.9	17.2
3. 2BA06	Little Pic River	413	7966.5	113305.7	7.0	551	7917.8	118170.7	6.7
4. 2BB02	Black River	271	4998.7	129558.8	3.8	389	5186.5	118777.8	4.3
5. 2BD10	Goldie River	255	5445.6	52011.6	10.4	307	5193.4	47753.9	10.8
6. 2CC08	Wakomata L.	136	4418.2	22540.8	19.6	185	4819.9	19830.0	24.3
7. 2CF07	Vermilion R.	361	6793.7	107870.9	6.2	583	8800.8	126264.6	6.9
8. 2DC07	Marten R.	172	5673.3	56690.8	10.0	196	5586.8	50991.5	10.9
9. 2EA19	Upper Seguin R.	205	4018.3	43084.1	9.3	100	3732.9	39660.0	9.4
2EA22	Upper Magnetawan R.	139	8480.7	47024.3	18.0	110	8690.0	39660.0	21.9
10. 2EB10	Lake of Bays	145	3398.8	72998.4	4.6	185	3400.6	72845.0	4.6
11. 2HL05	Skootamatta R.	436	11791.0	105682.1	11.1	580	11750.3	115742.6	10.1
12. 2JE15	Matabitchuan R.	139	4616.4	67171.5	6.8	181	4698.9	64751.1	7.2
13. 2KD03	Little Mississippi R.	159	9193.2	84028.6	10.9	97	11149.3	74463.7	14.9
14. 4CB09	Upper Windigo R.	237	5690.2	72154.9	7.8	181	5363.8	65560.5	8.1
15. 4DA27	North Pipestone R.	178	6280.9	74886.0	8.3	96	6606.6	63537.0	10.3
16. 4FA25	Kawinogans R.	225	10817.6	107256.1	10.0	137	12403.4	92675.0	13.3
17. 4GA15	Miniss R.	433	27505.6	169242.0	16.2	251	26762.4	142452.4	18.7

(cont'd)

	Watershed Name (cont'd)		This Survey				Cox's Counts and Measures			
			N	Water	Watershed	%	N	Water	Watershed	%
18.	4GE15	Upper Ogoki R.	214	12927.5	111070.4	11.6	266	13618.3	98745.4	13.7
19.	4JC01	Nagagami R.	288	4708.1	116074.9	4.0	212	3785.5	112505.0	3.3
20.	4LA05	Minisinakwa R.	155	4362.2	47359.0	9.2	201	4381.6	44111.6	9.9
21.	4LK06	Pivabiska R.	154	4833.2	119712.8	4.0	215	5006.8	115337.9	4.3
22.	4MB04	Watabeag R.	148	4282.9	60169.3	7.1	274	4463.7	58235.5	7.6
23.	5PB07	Redgut Bay	73	19188.2	100381.8	19.1	406	23106.0	107932.0	21.4
24.	5P007	Adams-Black Rs.	329	25413.9	133789.2	18.9	472	21726.8	187778.2	11.5
25.	5PE01	Winnipeg R.	416	41296.4	219534.0	18.8	469	30553.6	165520.0	18.4
26.	5QA05	Osaguan R.	180	20138.3	101984.4	19.7	274	19690.8	82962.3	23.7
27.	5QB08	Whitemud-Wenasaga Rs.	380	28796.8	255803.1	11.2	499	28749.8	224605.4	12.8
28.	5QC02	Lower Chukuni R.	376	53548.4	309595.4	17.2	582	53091.8	255645.4	20.7
29.	5RC06	Oowling R.	288	15341.2	114674.4	13.3	350	13988.6	102387.6	13.6

TABLE: 2 Summary of lake area, drainage area, and drainage/lake area ratio data for 30 quaternary watersheds.

Watershed	N	Lake Area (ha)				Drainage Area (ha)				DA/LA Ratio			
		$\bar{x}$	s.d.	min.	max.	$\bar{x}$	s.d.	min.	max.	$\bar{x}$	s.d.	min.	max.
2AA03	210	54.6	318.8	0.2	3316.9	1609.5	7187.4	5.5	83333.9	387.0	2890.6	2.6	41262.7
2AB06	229	47.1	438.0	0.3	6613.5	1283.0	5275.2	7.4	72023.4	216.6	829.6	3.2	7939.0
2BA06	413	19.3	125.5	0.3	2394.4	1479.5	7047.7	3.4	104589.8	221.1	1430.2	2.9	25454.1
2BB02	271	18.5	36.7	0.5	242.9	1340.7	7259.5	7.3	104767.2	99.3	395.9	2.6	5431.7
2BD10	255	21.4	105.7	0.3	1448.6	1762.2	5913.0	9.8	51501.0	739.3	4858.5	3.0	62519.4
2CC08	136	32.5	216.9	0.2	2470.5	510.7	1847.3	5.5	20070.4	179.1	647.8	2.7	5366.1
2CF07	361	18.8	80.7	0.5	1079.0	2583.9	10189.0	8.6	107900.3	192.1	1129.6	2.4	17968.3
2DC07	172	33.0	131.2	0.2	1313.7	1602.4	6457.9	3.5	56690.9	505.3	2388.1	3.4	27231.8
2EA19	205	19.6	54.0	0.2	454.8	1022.3	3852.0	6.0	42905.1	292.0	2486.6	1.0	35529.7
2EA22	237	24.0	78.6	0.2	924.4	1321.4	5522.4	3.2	63742.6	229.1	1504.2	0.2	22621.9
2EB10	139	61.0	598.1	0.2	7058.1	627.4	2885.9	5.3	33184.1	238.5	1205.0	3.2	13847.8
2HL05	145	23.4	112.3	0.2	1263.9	480.0	1792.7	11.3	19529.6	1111.7	5636.6	3.3	64999.0
2JE15	436	27.0	122.7	0.2	2107.4	1352.8	7274.0	9.2	104790.3	146.5	539.0	3.2	6855.8
2KD03	139	33.2	172.0	0.2	1956.9	1082.6	5811.5	16.1	61303.9	129.8	328.6	2.8	3050.4
4CB09	159	57.8	455.7	1.6	5725.8	1769.7	7442.9	9.7	75064.0	228.9	1308.9	2.4	10977.7
4DA27	178	35.3	112.2	0.2	916.1	1882.0	8933.3	4.8	74145.7	89.8	250.4	1.5	2258.1
4FA25	225	48.1	159.3	1.6	1382.3	1824.4	8815.7	11.3	101928.8	70.9	247.7	2.3	2941.3

(cont'd)

Table 2 (continued)

Watershed	N	Lake Area (ha)				Drainage Area (ha)				DA/LA Ratio			
		$\bar{x}$	s.d.	min.	max.	$\bar{x}$	s.d.	min.	max.	$\bar{x}$	s.d.	min.	max.
4GA15	433	63.5	406.9	0.2	6319.0	1863.4	9322.3	7.3	110239.5	325.6	4866.0	2.7	100877.8
4GE15	214	60.4	474.0	0.2	6620.8	1315.8	7134.8	8.2	81476.9	91.6	187.3	3.1	1458.6
4JC01	288	19.8	59.5	0.5	651.5	960.3	6111.5	3.9	91637.4	130.9	470.8	2.1	4830.7
4LA05	155	28.1	154.9	0.2	1912.6	972.6	3832.3	6.9	39951.7	183.9	531.7	3.3	3676.4
4LK06	154	31.4	129.1	0.2	1231.1	2434.2	11443.7	12.6	114300.0	226.9	746.0	2.2	6996.9
4MB04	148	28.9	178.4	0.2	2166.6	1185.4	5566.2	12.6	57346.2	67.4	176.6	2.0	1749.6
5PB07	73	262.9	1167.4	0.2	8614.5	2319.3	10722.8	25.5	88704.2	55.4	130.9	2.9	859.9
5PD07	329	77.3	611.0	0.7	10912.9	2200.3	10939.5	9.2	124693.6	100.5	588.4	2.6	7653.2
5PE01	416	99.3	481.6	0.5	7964.5	3776.6	20314.7	8.9	21643.9	50.0	196.0	0.4	3302.5
5QA05	180	111.9	540.1	0.2	5313.5	2337.2	2504.8	9.8	98091.9	216.0	954.3	2.8	11386.4
5QB08	380	75.8	257.4	0.2	2644.7	4305.0	21934.1	14.2	222479.7	77.2	260.9	2.1	4032.3
5QC02	376	142.4	1098.5	0.2	17690.3	3175.5	20470.5	10.3	251982.9	135.4	1157.3	1.1	21660.3
5RC06	288	53.3	191.4	0.8	2926.5	2946.1	10201.7	12.9	114215.6	178.7	900.2	2.2	8251.2

TABLE: 3 Frequency distribution of lake order by drainage region.

Lake Order	Region			Total
	2	4	5	
1	1755	1118	1133	4006
2	649	353	387	1389
3	341	176	178	695
4	195	88	105	388
5	109	53	63	225
6	72	33	41	146
7	49	25	26	100
8	39	15	19	73
9	25	10	15	50
10	19	6	12	37
>	78	13	45	136
TOTAL	3331	1890	2024	7245

TABLE: 4 Frequency distribution of lake order by DA/LA ratio categories.

Ratio	Order										
	1	2	3	4	5	6	7	8	9	10	>
2	2	0	0	0	0	0	0	0	0	0	0
4	7	0	1	0	0	0	0	0	0	0	0
8	239	28	5	3	0	0	0	0	0	0	0
16	959	147	39	15	6	5	1	1	2	0	1
32	1183	299	95	43	21	8	5	5	3	0	1
64	758	274	99	62	27	11	12	13	5	1	9
128	447	249	151	60	31	25	10	8	4	3	12
256	195	184	110	78	33	22	18	9	7	7	18
512	121	105	81	45	45	23	16	7	5	6	17
1024	55	53	66	40	28	23	11	7	8	6	17
	40	50	48	42	34	29	27	23	16	14	61

Contingency X^2 = 2570.1 on 100 df, significant at P = 0.001

TABLE: 5 Cross-tabulation by lake size and DA/LA ratio categories

DA/LA Ratio Category	Lake Size Category					
	1	10	100	1000	10000 ha	
2	0	0	0	2	0	0
4	0	1	5	2	0	0
8	1	52	175	43	4	0
16	4	438	645	83	5	1
32	24	865	659	104	11	0
64	62	791	344	61	13	0
128	93	637	231	35	4	0
256	99	399	152	26	5	0
512	110	270	73	18	0	0
1024	98	166	43	7	0	0
	175	166	42	1	0	0

TABLE: 6 Analyses of variance to examine the importance of region and lake order from values of area, total drainage, and the ratio of drainage to lake area.

Source of Variation	d.f.	ln Area		ln Drainage		ln Ratio	
		MS	F	MS	F	MS	F
Region	2	681.9	313.9	115.9	133.3	239.0	149.7
Order	5	429.2	197.6	2,689.4	3,092.1	973.6	609.9
Region X Order	10	12.6	5.8	3.5	4.1	4.9	3.0
Residuals	7,227	2.2	-	0.9	-	1.6	-
TOTAL	7,244	2.7	-	2.8	-	2.4	-

TABLE: 7 Frequencies and means for ln area, ln drainage and ln ratio by Region and order.

Category		N	ln Area	ln Drainage	ln Ratio
Region	2	3331	1.56	5.21	3.64
	4	1890	1.98	5.24	3.26
	5	2024	2.56	5.54	2.97
Order	1	4006	1.57	4.31	2.74
	2	1389	2.03	5.52	3.49
	3	695	2.26	6.31	4.06
	4	388	2.60	6.92	4.32
	5	225	2.69	7.38	4.68
	>	542	3.39	8.81	5.43

TABLE: 8 Results of statistical comparison of data from this study and that of Cox (1978).

	X	Y	Intercept			Slope			R
	This Study	Cox	Coeff	Std Dry	T-test	Coeff	Std Dry	T-test	
a)	% Water	% Water	-0.470	1.197	0.40	1.068	0.098	10.94	0.900
b)	N	N	33.48	51.930	0.65	1.076	0.196	5.50	0.519
c)	N	N water	0.346	51.490	0.007	1.214	0.194	6.26	0.583
d)	N	N wshed	39.22	52.294	0.75	1.122	0.197	5.69	0.536

N water = Cox N scaled by the ratio of water areas

N wshed = Cox N scaled by the ratio of watershed areas.

TABLE: 9 Frequency of OMNR - inventoried lakes by order and region in the 30 watersheds and comparison with the total sample.

Lake Order	Region 2	4	5	Total	% Inventory	% This Study
1	111	18	14	143	28.7	55.3
2	54	10	14	78	15.7	19.2
3	41	9	12	62	12.4	9.6
4	33	4	15	52	10.4	5.4
5	23	6	7	36	7.2	3.1
6	15	5	11	31	6.2	2.0
7	7	5	5	17	3.4	1.4
8	13	2	7	22	4.4	1.0
9	8	3	3	14	2.8	0.7
10	4	2	2	8	1.6	0.5
>	19	4	12	35	7.0	1.9
Total	328	68	102	498	-	-

TABLE: 10 Comparison of mean ln lake area by order and region for the total sample and inventoried lakes.

Region	Order						Total
	1	2	3	4	5	>	
This Study							
2	1.23	1.56	1.84	2.15	2.19	2.65	1.56
4	1.64	2.16	2.33	2.64	2.55	3.72	1.98
5	2.05	2.70	2.97	3.42	3.69	4.48	2.56
(a) Total	1.57	2.03	2.26	2.60	2.69	3.39	1.95
Inventoried							
2	2.52	3.27	3.70	4.42	3.94	5.02	3.58
4	2.40	3.56	4.30	4.18	4.36	5.77	4.14
5	4.15	4.39	5.66	5.48	5.84	6.47	5.58
(b) Total	2.66	3.51	4.17	4.71	4.38	5.60	4.07
Ratio = exp (b)-(a).	2.97	4.39	6.75	8.25	5.42	9.12	8.33