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Lake Variation and Climate Change Study: ELA Lakes, 1986-1990. I. Study Rationale and Lake Selection Criteria

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ERRATA

Campbell, P. 1993. Lake variation and climate change study: ELA lakes, 1986-1990. I. Study rationale and lake selection criteria. Can. Tech. Rep. Fish. Aquat. Sci. 1897: iv + 7 p.

Figures 1 and 2 should read as follows:

Figure 1. Selection scheme for Lake Variation and Climate Change Study lakes in the Red Lake district and Experimental Lakes Area. The two "mappable" parameters, lake area (Ao) and watershed area (Ad) were used to select two series of lakes. In the Red Lake series, the prime variable is size; with increasing lake size, watershed size has also been increased in order to maintain "constant" τ. The prime variable for the ELA set of lakes is flushing rate. Flushing rates were increased by increasing watershed size while holding lake size "constant". It should be noted that, in the ELA lake series, there is a strong covariance between increasing watershed size and increasing lake order; here, the order of a lake is defined numerically as 1+ (the number of other lakes in its upstream watershed).

Figure 2. Conceptual diagram of the ELA Lake Variation and Climate Change Study design. Theoretical whole-lake water renewal time (τ) is the primary variable. The central hypothesis is that, for very fast flushing systems, nutrient and trophic characteristics will essentially be straightforward reflections of their external inputs, whereas, as water renewal time increases, modifications by in-lake processes will become apparent. Shallow, slow flushing systems should be largely littoral in nature, whereas deeper, stratified lakes will include a significant profundal component (upper panel). Edaphic-induced differences (influence of bog drainage) should be most obvious in fast flushing lakes (lower panel).

In this diagram,

τ = theoretical whole-lake water renewal time based on an average water-year.

As potential indices of the relative influences of littoral vs profundal,

$\bar{z}$ = mean depth, and

A_E/A_O = ratio of littoral (0-5 m) sediment surface area to lake surface area.

As a potential index of the influence of direct inputs from the terrestrial watershed, as opposed to lake-fed systems (lake processed inputs),

S = length of inflowing stream segments uninterrupted by lakes and immediately adjacent to subject lake.

Note that all scales are logarithms.

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LAKE VARIATION AND CLIMATE CHANGE STUDY:

ELA LAKES, 1986-1990.

I. STUDY RATIONALE AND LAKE SELECTION CRITERIA

by

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ABSTRACT

Campbell, P. 1993. Lake variation and climate change study: ELA lakes, 1986-1990. I. Study rationale and lake selection criteria. Can. Tech. Rep. Fish. Aquat. Sci. 1897: iv + 7 p.

This is the introductory report in a series presenting the first five years' data collected on Lake Variation and Climate Change Study lakes located in the Experimental Lakes Area (ELA). This report presents a brief study rationale as well as an outline of criteria used in lake selection. It also includes a summary of research activities on these lakes from 1986 to 1990.

Key words: Lakes; variations; climate change; global warming; Experimental Lakes Area.

RÉSUMÉ

Campbell, P. 1993. Lake variation and climate change study: ELA lakes, 1986-1990. I. Study rationale and lake selection criteria. Can. Tech. Rep. Fish. Aquat. Sci. 1897: iv + 7 p.

Le présent document est le rapport liminaire d'une série de rapports dans lesquels on présente les données obtenues au cours des cinq premières années de l'étude sur la variation des lacs et le changement climatique dans la Région des Lacs Expérimentaux (RLE). On présente brièvement les raisons à l'origine de l'étude ainsi qu'un aperçu des critères dont on a tenu compte lors de la sélection des lacs. On présente également un résumé des travaux de recherche qui ont porté sur ces lacs au cours de la période 1986-1990.

Mots-clés: Lacs; variations; changement climatique; réchauffement du globe; Région des Lacs Expérimentaux.

STUDY RATIONALE

By the early 1980's, it had become apparent to a number of Freshwater Institute researchers that temporal and spatial variation naturally inherent in lakes had to be better elucidated, particularly in order to attain acceptable levels of confidence for environmental impact assessments as well as for accurate interpretations of our own whole-lake experiments. Concomitantly, it was also recognized that if major alterations to climate were to occur, for example as modelled by Manabe and Wetherald (1986), the potential would be great for very important changes to Canada's freshwater systems and their fisheries. In 1985, therefore, the Fish Habitat Research Division, Central and Arctic Region, initiated a research program to systematically examine within-lake and among-lake variability in order to facilitate accurate predictions and timely detection of limnological changes due to alterations in climate or other anthropogenically-induced perturbations. The ultimate goal is construction of models which will serve as a framework for development of accurate and comprehensive environmental impact assessment and prediction procedures which may be "universally" applied to lakes of the temperate Precambrian Shield. Concurrently, the study design will facilitate more rigorous assessments of the transferability of results from ELA whole-lake chemical addition experiments to i) larger and ii) shallower and/or faster flushing lakes, respectively. Key limnological parameters which are important determinants of productivity of fishes and their food organisms are being investigated. It is the plan that study lakes will be sampled repeatedly and consistently for a minimum of 10 years.

LAKE SELECTION CRITERIA

Two sets of remote lakes situated on the Precambrian Shield of northwestern Ontario were selected in order to examine responses to changes in i) temperature and ii) rates of water supply. The first set of six lakes (Fee et al. 1989) extends over a size range from <100 ha to >30,000 ha (Fig. 1) and is located in the Red Lake district north of Kenora, Ontario; flushing rates of all six lakes are similar. Lakes Nipigon and Superior were added to the lake-size series in 1990; collectively, this group of lakes is commonly referred to as the Northern Ontario Lake Size Series (NOLSS) lakes. The second set of lakes, the subject of this report series, was selected in order to attain a wide range of flushing rates. The lakes are located in close proximity to one another in the Experimental Lakes Area (ELA) southeast of Kenora (Brunskill and Schindler 1971). They all share a common geology and are subject to the same weather, etc. The lakes are approximately the same size; lake surface areas (Ao's) range from 16 to 27 ha. Watershed areas (Ad's), however, range from 80 to 12,000 ha (Fig. 1), resulting in an 800-fold difference in theoretical whole-lake water renewal rates (τ's) between the slowest and fastest flushing systems.

In April and May of 1986, approximately 30 ELA lakes were reconnoitred. In addition to the primary variable, τ, two other variables also believed to be potentially important in both maximizing and explaining among-lake differences in nutrient and trophic status were taken into consideration in the final selection. These secondary variables were morphometry (depth) and an edaphic factor (influence of bog drainage). By early June, eight lakes had been selected in order to establish i) a deep, thermally stratified series as well as ii) a series of shallow, will-mixed lakes, each series covering a broad range of flushing rates. The deep ($Z_{max} \approx 20$ m), stratified series was comprised of Lakes 377, 442 and 373 (Fig. 1); on average, water renewal times are approximately 6 months, 3 years, and 15 years, respectively. The second series of shallow ($Z_{max} \approx 5$ m), well-mixed lakes consisted of Lakes 938, 165, 164, 640, and 149. Average water renewal times range from about 1 week to 2.5 years. (Note that Lake 164 is approximately 7 meters deep; although not fully stratified, it does develop a metalimnion for most of the open-water season). The edaphic variable was factored into the study design by including the Lake 164/65 brown-water system in the shallow lake series.

Figure 2 is a relative-importance diagram that illustrates the eight-lake study as originally conceptualized. The primary forcing function, τ, is central. The basic premise was that nutrient and trophic characteristics of fast flushing systems should in the main, simply and directly reflect those of their external inputs, whereas significant modification by internal processes should become apparent in slow flushing lakes. The nature of shallow, slow flushing lakes should be to a large

extent "littoral"; deep, slow flushing lakes should be characteristically more "profundal" (top panel, Fig. 2). Edaphic differences (the influence of bog drainage in comparison to clear, lake-fed systems) should be most apparent in fast flushing, shallow systems (bottom panel, Fig. 2).

RESEARCH ACTIVITIES, 1986-1990

The eight lakes selected for the ELA Lake Variation and Climate Change Study were all included in the first survey of the ELA carried out in 1967 by Cleugh and Hauser (1971). A number of synoptic chemical and biological surveys were done on these eight lakes and their inlets and outlets in 1986. Lake 640 was found to be polluted with road salt, and perhaps herbicides and other chemicals, as well. As a result, it was subsequently dropped from the shallow, well-mixed series; a tractable substitute for Lake 640 was never found.

The year 1987 marked commencement of our regular sampling program with the intent that, from that time on, station locations, sampling procedures, and analytical procedures, having been carefully selected, should remain invariate for the duration of the program. The study is a multidisciplinary one. Specific areas of investigation, including frequencies of observation during the period 1987-1990, are summarized in Table 1. Uninterpreted results from these studies will be presented in the current report series. These reports will include essentially all physical, chemical, and biological data collected from 1986 through 1990.

ACKNOWLEDGMENTS

This study was formulated only after much discussion and debate, formal and informal, over the winter of 1983-84. Sessions were usually led and moderated by R.E. Hecky; core participants included R.W. Newbury, K. Patalas, E.J. Fee, J.W.M. Rudd, R.A. Bodaly, and D.M. Rosenberg. I am grateful that they were interested, participated, and shared their important thoughts and insights. Susan Kasian's involvement at this stage was particularly helpful and appreciated. D. Laroque typed this manuscript. Graphics were by A. Blouw and assistants. Reviewers included M.A. Turner, K. Patalas, and R.E. Hecky.

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Table 1. Research subjects, frequency of sampling, and periods of record. ELA Lake Variation and Climate Change Study lakes. 1987-1990.

Research subject	Usual sampling frequency	Years sampled	Lakes sampled	Notes
Physical				
Bathymetry	-	-	All	-
Watershed mapping	-	-	All	-
Physiography	-	-	All	-
Local weather	Bi-weekly, open water season	All	All	-
Lake stage	Bi-weekly, open water season	All	All	-
Discharge	Continuous	-	-	Limited to L.938 outflow (1989-1990), L.164 outflow (1987-1990), and L.373 outflow (1990)
Light, Secchi disk	Bi-weekly, open water season	All	All	-
Light, photometer	Bi-weekly, open water season	All	All	-
Temperature	Bi-weekly, open water season	All	All	Including inflows and outflows
Chemistry				
Chlorophyll	Bi-weekly, open water season	All	All	-
Major nutrients	Bi-weekly, open water season	All	All	Including inflows and outflows
Major ions	Bi-weekly, open water season	All	All	Including inflows and outflows
pH, alkalinity	Bi-weekly, open water season	All	All	Including inflows and outflows
Algae				
Nutrient status	Bi-weekly, open water season	1989, 1990	All	4-week intervals in 1989
Phytoplankton populations	Bi-weekly, open water season	1990	All	Samples collected in earlier years, but not processed
Primary production	Bi-weekly, open water season	All	All	-
Zooplankton				
Populations	Bi-weekly, open water season	1988-1990	All	Sampled in 1987, but limited data workup because of change in sampling method
Zoobenthos				
Populations	Bi-weekly, open water season	All	All	
Fish				
Populations	Spring and Fall	1990	373, 377, 442	Lake 373 fish populations have been monitored since 1986. Synoptic surveys have been done on all lakes

Figure 1. Selection scheme for Lake Variation and Climate Change Study lakes in the Red Lake district and Experimental Lakes Area. The two "mappable" parameters, lake area (Ao) and watershed area (Ad) were used to select two series of lakes. In the Red Lake series, the prime variable is size; with increasing lake size, watershed size has also been increased in order to maintain "constant". The prime variable for the ELA set of lakes is flushing rate. Flushing rates were increased by increasing watershed size while holding lake size "constant". It should be noted that, in the ELA lake series, there is a strong covariance between increasing watershed size and increasing lake order; here, the order of a lake is defined numerically as 1+ (the number of other lakes in its upstream watershed).

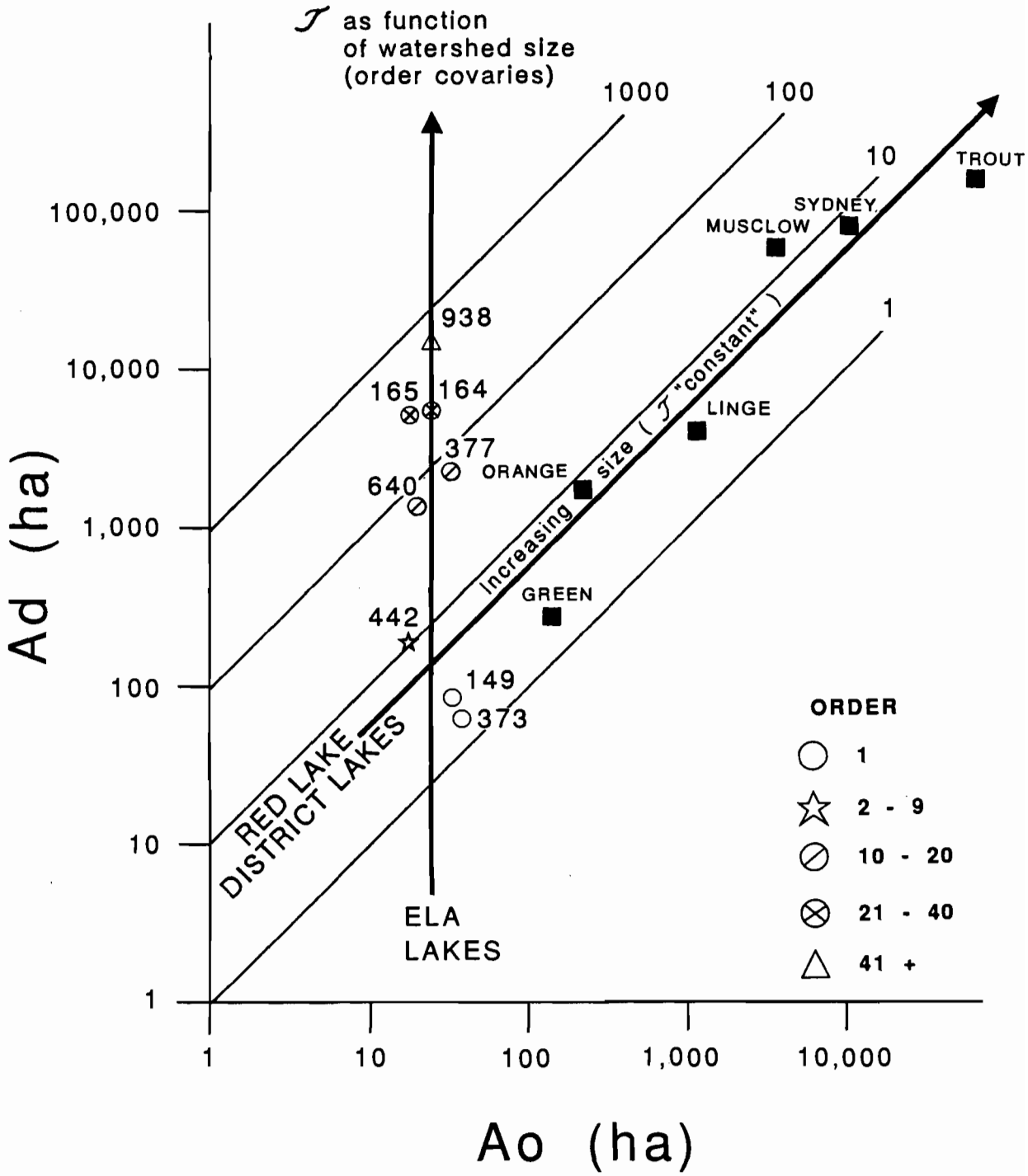
𝒯 as function
of watershed size
(order covaries)
1000
100
10
1
TROUT
SYDNEY
MUSCLOW
LINGE
ORANGE
GREEN
938
165
164
377
640
442
149
373
Increasing size (𝒯 "constant")
RED LAKE
DISTRICT LAKES
ELA
LAKES
ORDER
1
2 - 9
10 - 20
21 - 40
41 +
100,000
10,000
1,000
100
10
1
Ad (ha)
1
10
100
1,000
10,000
Ao (ha)

Figure 2. Conceptual diagram of the ELA Lake Variation and Climate Change Study design. Theoretical whole-lake water renewal time ( ) is the primary variable. The central hypothesis is that, for very fast flushing systems, nutrient and trophic characteristics will essentially be straightforward reflections of their external inputs, whereas, as water renewal time increases, modifications by in-lake processes will become apparent. Shallow, slow flushing systems should be largely littoral in nature, whereas deeper, stratified lakes will include a significant profundal component (upper panel). Edaphic-induced differences (influence of bog drainage) should be most obvious in fast flushing lakes (lower panel).

In this diagram,

= theoretical whole-lake water renewal time based on an average water-year.

As potential indices of the relative influences of littoral vs profundal,

$\bar{z}$ = mean depth, and

A_E/A_O = ratio of littoral (0-5 m) sediment surface area to lake surface area.

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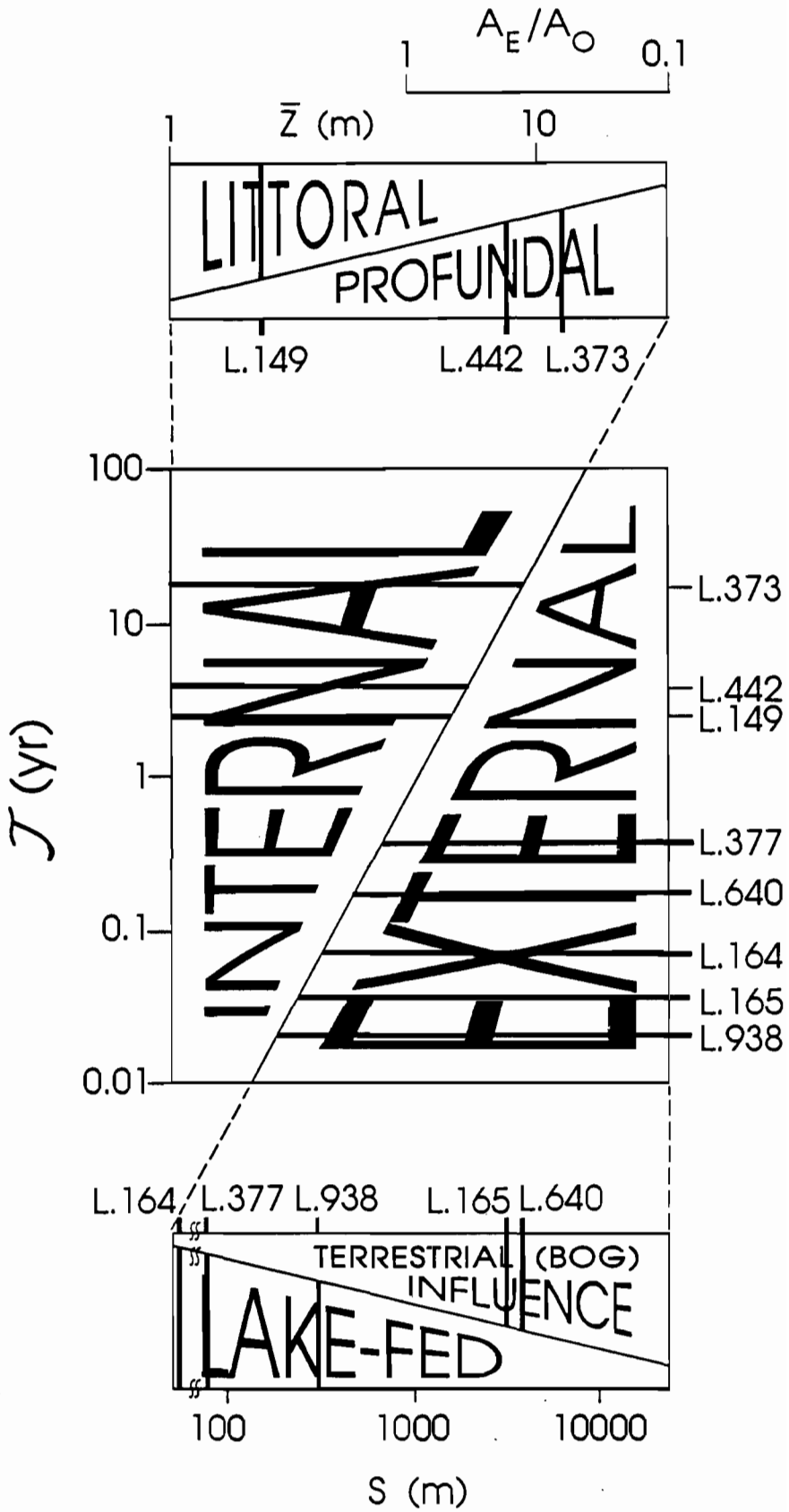
S = length of inflowing stream segments uninterrupted by lakes and immediately adjacent to subject lake.

Note that all scales are logarithms.


A_E/A_O
1
0.1
$\bar{Z}$ (m)
1
10
LITTORAL
PROFUNDAL
L.149
L.442
L.373
100
10
1
0.1
0.01
$\mathcal{T}$ (yr)
INTERNAL
EXTERNAL
L.373
L.442
L.149
L.377
L.640
L.164
L.165
L.938
L.164
L.377
L.938
L.165
L.640
TERRESTRIAL (BOG)
INFLUENCE
LAKE-FED
100
1000
10000
S (m)