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Trophic Status Evaluation for 154 Lakes in Quebec, Canada: Monitoring and Recommendations

Rosa Galvez-Cloutier* and Michelle Sanchez

Civil Engineering Department, Laval University, Adrien Pouliot Building, Quebec, Canada, G1K 7P4.

Based on chlorophyll *a*, total phosphorus, transparency (Secchi disk), and total nitrogen, 154 lakes located in southern regions of the Quebec province were classified according to their trophic status. Various classification methods were presented and discussed. The evaluation of existing relationships among quality parameters were established, and suggestions for priority actions and restoration initiatives were given. The 'Reseau de surveillance de lacs' of the Ministère de développement durable, environnement et parcs is considered as a very successful program that should be increasingly supported by the government. The program meets sustainable development principles in watershed management. The results showed that although the majority of lakes surveyed were within optimal conditions (oligotrophic status), 22 lakes required closer surveillance and more effective nutrient control measures.

Key words: **trophic status, Quebec lakes, eutrophication, algae blooms, nutrients, cyanobacteria**

Introduction

Eutrophication is a severe problem in America, Europe, and Asia (ILEC 1994). It is expected that global warming will accelerate lake degradation. A trophic status classification provides information on which government and watershed organizations base eutrophication control programs such as watershed restoration plans which often include sediment restoration actions (IJC 2002; Klapper 2003).

Quebec counts a vast number of lakes. These lakes are environmental, social, and economical resources for Quebec and Canada (Baril 2006). According to Environment Canada (1973), 8,275 lakes with surfaces of between 3 and 36,000 km^2 are located within its 14 administrative regions. Lake eutrophication in Quebec is a growing environmental problem (Simoneau 2004; MDDEP 2004) of high social concern that needs solutions in perspective and in action. So far, one recent official report (MDDEP 2004) has presented the water quality evaluation for 26 lakes. Source control has been implemented since the late 1980s for some of these lakes, but with slow positive impacts. The most important negative impacts associated with anthropogenic eutrophication are (Galvez et al. 2002):

- Excessive algal and macrophyte growth (loss of open water);
- Presence of noxious algae (scums; red, blue, or greens blooms; taste and odour; and nonaesthetic);
- Loss of water clarity (small Secchi depths);
- Possible loss of macrophytes (via light limitation by algae and periphyton);
- Low dissolved oxygen (loss of habitat for fish and fish food);
- Excessive organic matter production (smothering eggs and macroinvertebrates);
- Blue-green algae inedible by some zooplankton (reduced food chain efficiency);
- "Toxic" gases formation (e.g., ammonia, hydrogen sulphide) in bottom water (more loss of fish habitat);
- Presence of toxins from noxious species of cyanobacteria;
- Presence of chemical products as a result of lakeshore treatment by homeowners or managers (e.g., copper, diquat, 2,4-dichlorophenoxyacetic acid [2,4-D]);
- Increase in costs of water treatment;
- Loss of sport-fish species (e.g., trout) and associated negative economical impact.

Quebec Government environmental efforts have included the following lake quality monitoring programs: 1) 'le reseau de surveillance volontaire' (voluntary monitoring network) and 2) 'le reseau de surveillance sentinelle' (monitoring sentinel network). The first program was jointly organized with watershed basin associations and municipalities. It operated in 2002 and 2003 on an experimental basis and for a restricted number of lakes. Since 2004, this program was enlarged and now accepts 50 to 60 new lakes per year. The second program has been in operation since 2002 and includes the monitoring of 50 lakes (10 lakes are evaluated each year and are resampled every five years). These programs allow the trophic evaluation and long-term water quality monitoring for the lakes under study. Both programs have generated a water quality data base for 154 lakes (MDDEP 2005). With data of the year 2003, the MDDEP (Ministère de développement durable, environnement et parcs) published a first report called "Info-lacs" (MDDEP 2004) that included the trophic classification for 26 lakes. This classification used chlorophyll *a*, total phosphorus, dissolved organic carbon, and transparency (by Secchi disk) as water quality parameters.

* Corresponding author: rosa.galvez@gci.ulaval.ca

The aim of this study was to evaluate the quality and trophic status of the 154 lakes surveyed by the MDDEP from 2001 to 2004, to obtain a broad water quality portrait, and to present water quality parameter relationships in evidence for Quebec lakes. A second ongoing study aim was to relate watershed activities (of these 154 lakes) to lake water quality status. Specifically, this study included the following objectives:

- To review and discuss the literature on lake quality classification methods;
- To choose classification methods based on the set of parameters available in the MDDEP 2001 to 2004 lake water quality data base (MDDEP 2005);
- To apply these classification methods to establish quality status for 154 lakes in the Quebec province, and to compare classification methods;
- To evaluate existing relationships among quality parameters and establish trends;
- To list lakes with eutrophication problems and suggest priority actions and restoration initiatives.

Lake Trophic Status Classification Methods

Trophic Status Criteria – Preliminary Discussion

Great efforts have been taken to establish quality criteria and thresholds to classify lakes according to their trophic status based on nutrient (P, N) concentrations and on certain physical (e.g., transparency, dissolved oxygen) and biological (e.g., algae pigments) characteristics (OECD 1982). Nutrient ratios (N/P) have been used to explain specific algal populations, or identify a nutrient-limiting factor. From a management point of view, this type of criteria presents limitations because some water

TABLE 1. Available criteria for trophic status classification

Trophic status	*TP (μg/L)*	*Chlorophyll a (μg/L)*		*Transparency* [a] *(m)*		*TN (μg/L)*
		Mean	*Maximum*	*Mean*	*Maximum*	
OECD criteria [b]						
Ultra-oligotrophic	< 4	< 1	< 2.5	> 12	> 6	— [c]
Oligotrophic	< 10	< 2.5	< 8	> 6	> 3	—
Mesotrophic	10–35	2.5–8	8–25	6–3	3–1.5	—
Eutrophic	35–100	8–25	25–75	3–1.5	1.5–0.7	—
Hypereutrophic	> 100	> 25	> 75	< 1.5	< 0.7	—
Canadian criteria [d]						
Ultra-oligotrophic	< 4.0	< 1.0	< 2.5	> 12	> 6	—
Oligotrophic	4–10	< 2.5	< 8	> 6	> 3	—
Mesotrophic	10–20	2.5–8	8–25	6–3	3–1.5	—
Meso-eutrophic	20–35	—	—	—	—	—
Eutrophic	35–100	8–25	25–75	3–1.5	1.5–0.7	—
Hypereutrophic	> 100	> 25	> 75	< 1.5	< 0.7	—
Nürnberg criteria [e]						
Oligotrophic	< 10	< 3.5	—	—	—	< 350
Mesotrophic	10–30	3.5–9	—	—	—	350–650
Eutrophic	31–100	9.1–25	—	—	—	651–1,200
Hypereutrophic	> 100	> 25	—	—	—	> 1,200
Quebec criteria [f]						
Oligotrophic	4–10	1–3	—	12–5	—	—
Mesotrophic	10–30	3–8	—	5–2.5	—	—
Eutrophic	30–100	8–25	—	2.5–1	—	—
Hypereutrophic	—	—	—	—	—	—
Swedish criteria [g]						
Oligotrophic	< 15	< 3	—	> 3.96	—	< 400
Mesotrophic	15–25	3–7	—	2.43–3.96	—	400–600
Eutrophic	25–100	7–40	—	0.91–2.43	—	600–1,500
Hypereutrophic	> 100	> 40	—	< 0.91	—	>1,500

[a] Transparency by Secchi disk depth.
[b] Ryding and Rast (1994).
[c] —, not available.
[d] Environment Canada (2004).
[e] Nürnberg (2001).
[f] MDDEP (2007).
[g] University of Florida (1983).

bodies can be classified under one trophic status based on one parameter, and under a different trophic status based on other parameters. Various sets of criteria reported in the literature for lake studies, and based on nutrient, physical, or biological characteristics, are presented in Table 1 and described below. The literature (Gulati 1983) also describes other potential biological indicators such as benthos, plankton, and species diversity, but because available MDDEP data did not include these parameters, this paper focuses on nutrient, chlorophyll, and transparency parameters.

This study used the OECD (Organization for Economic Cooperation and Development) (1982) and Nürnberg (1996) criteria, and Carlson's Trophic Status Index (TSI) (1977) methods to classify lakes according to trophic status, and to compare classification results. The justification for this choice include the following arguments: 1) OECD, Nürnberg, Canadian, and Quebec criteria are very similar and use the same parameters, 2) Nürenberg includes nitrogen as an indicator while previous research has shown the use of N or N:P ratios to discuss the presence of dominant algae such as blue algae blooms (e.g., Havens et al. 2003), and 3) the Carlson method is recommended by the United States Environmental Protection Agency (U.S. EPA) and may integrate or relate several parameters.

Criteria from the Organization for Economic Co-operation and Development. In 1982, the OECD established trophic classification criteria according to total phosphorus, chlorophyll *a*, and transparency (Secchi disk depth). This trophic classification was accepted by the international community as standards, and many countries use these criteria to determine the quality of surface water bodies.

Canadian criteria. Because they are internationally accepted, Environment Canada (2004) recommended the values established by the OECD. These ranges are applicable to Canadian waters as standards. For phosphorus, Environment Canada subdivided the OECD category meso-eutrophic (10 to 35 µg/L) into mesotrophic (10 to 20 µg/L) and meso-eutrophic (20 to 35 µg/L) because considerable variability in community composition and biomass exists in Canadian waters over the OECD proposed range (Environment Canada 2004).

The criteria for Quebec lakes took into account the initial OECD (1982) classification in comparison with values presented by Nürnberg (1996), and specific limits were added by adjusting values based on specific Quebec lake studies (e.g., Laurentian lakes studied by Carignan et al. 2003). Overall, these criteria present very close limits.

Other criteria. Nürnberg (1996) reported parameters and values for classification of lakes according to trophic status. Table 1 shows the Nürnberg classification based on values measured during summer periods in the epilimnetic zone of several lakes.

The United States of America has no national nutrient criteria for surface waters, and they present only national criteria for phosphorus and nitrate for protection in estuarine and marine waters. The U.S. EPA divided the country into 14 nutrient ecoregions, and provided national nutrient criteria and technical guidance manuals to regions in order to develop their own guidelines (U.S. EPA 2005). Many states used the Carlson Index which is recommended by the U.S. EPA (2007). Also, a set of criteria developed by Sweden has been adopted by some U.S. states such as Florida. The Swedish criteria consider four parameters to define trophic status, which are presented in Table 1. The MDDEP (2004) study used values close to the Swedish criteria which are stricter in comparison with OECD or the Canadian criteria.

Carlons's Trophic State Index (TSI). In 1977, Carlson developed a Trophic State Index to define the trophic status of a given lake. After establishing the relationship between transparency (Secchi disk) and algal biomass (chlorophyll a), within the scale of transparency variations, Carlson used Secchi disk values to construct the first Trophic State Index (TSI_{SD}) (equation 1). Using regression equations of transparency against total phosphorous and chlorophyll *a*, two other indexes were developed under the same scale (TSI_{CHL}, TSI_{TP}). Thus, three index variables could be correlated using similar regression models and reported as $TSI_{average}$. The TSI scale ranges from 0 (ultra-oligotrophic) to 100 (hypereutrophic).

$$\text{Secchi disk TSI } (TSI_{SD}) = 60 - (14.41 \cdot [Ln(\text{Secchi disk}_{average})]) \quad (1)$$

TSI values can be used as a basis for comparing lake quality at regional scales during lake monitoring programs such as those run by the MDDEP. For the purpose of classification, Carlson proposed that a classification priority must be given to summer chlorophyll *a* concentrations because this variable is apparently free from interference and the best for estimating algal biomass. Total phosphorus may be better at predicting trophic state during the winter and fall seasons. Table 2 shows a summary of Carlson's classifications.

Thus, the best indicator and criteria of trophic status may vary from lake to lake and also seasonally. In order to adopt a regional indicator or criteria, the results of a classification method should be compared with others for similar seasonal conditions, and should be chosen based on its applicability to region-specific lake characteristics.

Methodology

The study used a database (MDDEP 2005) containing measures of up to 12 water quality parameters for 154 lakes monitored during the summers of 2001, 2002, 2003,

TABLE 2. Carlson's classifications based on TSI [a]

TSI	*Classification*	*Description*
< 30	Oligotrophic	Clear water, dissolved oxygen throughout the year in the hypolimnion.
30–40	Oligotrophic	Deep lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
40–50	Mesotrophic	Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.
50–60	Eutrophic	Lower boundary of classical eutrophic; decreased transparency, anoxic hypolimnion during summer, macrophyte problems evident, and warm-water fisheries only.
60–70	Eutrophic	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems.
70–80	Hypereutrophic	Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration.
> 80	Hypereutrophic	Algal scum, summer fish kills, few macrophytes, dominance of rough fish.

[a] Carlson (1977).

or 2004. The measured parameters included: chlorophyll *a*, dissolved organic carbon, ammonia, nitrates, nitrites, total nitrogen, dissolved oxygen, pH, pheophytin, total phosphorus, transparency (Secchi disk), and temperature. The data bank did not include the results for all 12 parameters for each of the 154 lakes, but it generally included those used for the trophic analysis in this study. The lakes and sampling points were geo-referenced and are located in 14 different regions of the southern areas of the Quebec province (Table 3; Fig. 1). The MDDEP collected several samples in each lake under study. Samples were analyzed according to procedures given by the Centre d'expertise en analyse environnementale du Québec (CEAEQ 2006). The data were analyzed with Microsoft Excel.

Methods and Analysis of Quality Parameters

Temperature, pH, and dissolved oxygen. Water temperature has an influence on the concentration of several elements, chemicals, and physical properties, and on biological processes. As water temperature increases, the solubility of dissolved oxygen in water decreases. Also, the increase in biomass accelerates consumption of oxygen.

In natural waters, the pH is between 6.0 and 8.5. Lower values indicate acid water which could be related to the presence of CO_2 and/or organic matter content. pH values higher than 7 may indicate alkaline water and/or high salinity.

TABLE 3. Quebec's regions in which lakes under study are located

Fig. 1 reference	Region
(1)	Bas-Saint-Laurent
(2)	Saguenay – Lac-Saint-Jean
(3)	Capitale-Nationale
(4)	Mauricie
(5)	Estrie
(6)	Montréal
(7)	Outaouais
(8)	Abitibi-Témiscamingue
(9)	Côte-Nord
(10)	Nord-du-Québec
(11)	Gaspésie – Iles-de-la-Madeleine
(12)	Chaudière-Appalaches
(13)	Laval
(14)	Lanaudière
(15)	Laurentides
(16)	Montérégie
(17)	Centre-du-Québec

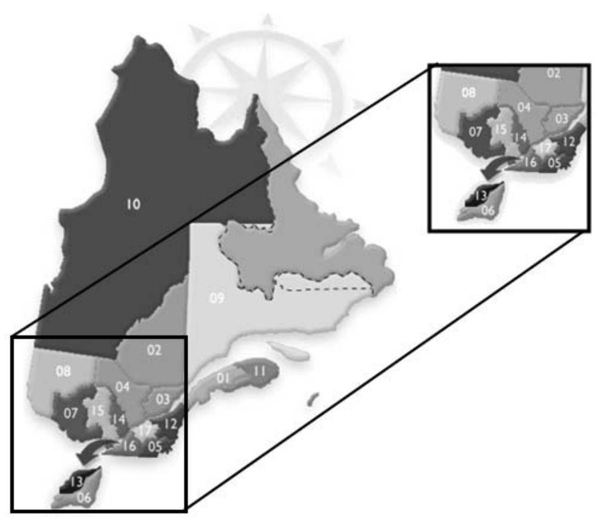

Fig. 1. Location of Administrative Regions in the Quebec province (Gouvernnement du Québec, 2006).

Dissolved oxygen is essential for the survival of all aerobic aquatic organisms. Oxygen comes from the atmosphere and from photosynthetic activity. Its concentration is counterbalanced by biological respiration. Dissolved oxygen increases with decreasing water temperature.

Temperature, pH, and dissolved oxygen were measured in situ using a portable multimeter.

Chlorophyll a. Chlorophyll is a green pigment present in photosynthetic organisms and its concentration is typically proportional to the concentration of algae in water. Chlorophyll exists in five forms: Chlorophyll *a*, *b*, *c*1, *c*2, and *d*. Chlorophyll degradation pigments include pheophytin *a*, *b*, and *c*, and other pigments. Chlorophyll *a* is the pigment present in most algae. Chlorophyll *a* was determined by fluorometry using a wave length of 664 nm following the CEAEQ (2006) protocol MA.800-CHLO. 1.0, edition 2003. Samples were filtered and pigments were separated using solvent extraction. Because it is absorbed at the same wavelength as chlorophyll *a*, pheophytin would be an interference in the results. The CEAEQ method includes a correction step to remove the interference. The detection limit of this method is 0.02 µg/L.

Total nitrogen (TN). Total Nitrogen was determined using the CEAEQ (2006) protocol MA 303-NTot. 1.0. Unfiltered samples were tested to give total nitrogen which includes nitrate, nitrite, ammonia, and organic nitrogen.

Total phosphorus (TP). Most phosphorus in fresh water occurs as organic phosphates, and as cellular constituents in the biota adsorbed to inorganic and dead particulate organic materials. Phosphorus is the least abundant nutrient and the first element to limit biological productivity when this is exhausted.

The CEAEQ (2006) 303-P 5.0 total phosphorus colorimetric method was used to determine total phosphorus. This method, with a detection limit of 2 µg/L, is useful to determine high or low phosphorus concentrations.

Transparency (Secchi depth). Water transparency is the most inexpensive and easy-to-use tool in water quality monitoring. It indicates the amount of light penetration into a lake, which decreases in the presence of suspended material and colour in the water. Suspended material is often associated with phytoplankton biomass and so transparency can be an indication of the amount of algal biomass in the water. Water transparency was measured with a Secchi disk which is a circular metal plate attached to a calibrated rope.

Results and Discussion

Quality Evaluation

Summer values of chlorophyll *a*, TP, and transparency are shown in the histograms in Fig. 2 to 6. Canadian average eutrophic threshold values for each of these parameters are also indicated. The results are presented according to the year in which parameters were measured for specific lakes. As can be seen in years 2001, 2002, and 2003, a small number of lakes were sampled (approximately 20 per year). In year 2004, a larger number of lakes was monitored according to the objectives of each quality monitoring program.

Figures 7 and 8 show the summary of the $TSI_{average}$ results. The $TSI_{average}$ was calculated from individual TSI values for cholorophyll *a*, transparency, and TP when the three parameters where available. All lakes were measured for TP and transparency, thus when chlorophyll *a* was not available, $TSI_{average}$ was calculated using these two parameters.

Figure 9 shows a summary of the trophic classification for the 154 lakes surveyed. Both methods are presented in the same order and sequence of classification status: Oligotrophic > Mesotrophic > Eutrophic > Hypereutrophic. Based on the Carlson TSI, it appears that the majority of lakes under monitoring were in oligotrophic conditions between the years 2001 to 2004.

According to the OECD (1982) and Nürnberg (1996) criteria, 11 lakes presented hypereutrophic or eutrophic conditions. This represents 7% of the total number of lakes studied. According to Carlson's TSI method, 23 lakes (15%) would be in advanced degradation. This is twice the number given by the OECD criteria. Using the precautionary principle, this study considers that the TSI method should be used to identify lakes in potential risk (see Table 4: lakes are presented in order, starting with the lake with the highest TSI down to the one with the lowest TSI). These lakes would require further study indicating the need to implement watershed restoration actions.

Several studies (Bergeron et al. 2002; Galvez-Cloutier et al. 2003, 2006) have shown that Saint-Augustin Lake is in hypereutrophic conditions due to the agriculture-intensive watershed activities of the past. The TSI confirmed this condition. For the last 15 years, the Saint-Augustin Watershed Organization has been performing nutrient source control and has developed a watershed restoration plan with some water quality improvement, but not enough to alliviate eutrophication. In this lake, bottom sediments and groundwater constitute the major sources of phosphorus (Galvez-Cloutier et al. 2003), which needs to be minimized.

Similarly, the Saint-Joseph, Saint-Charles, and Waterloo lakes are known for their eutrophic conditions over the last decade. In particular, Saint-Charles Lake is closely monitored because this lake provides the drinking water source for Quebec City.

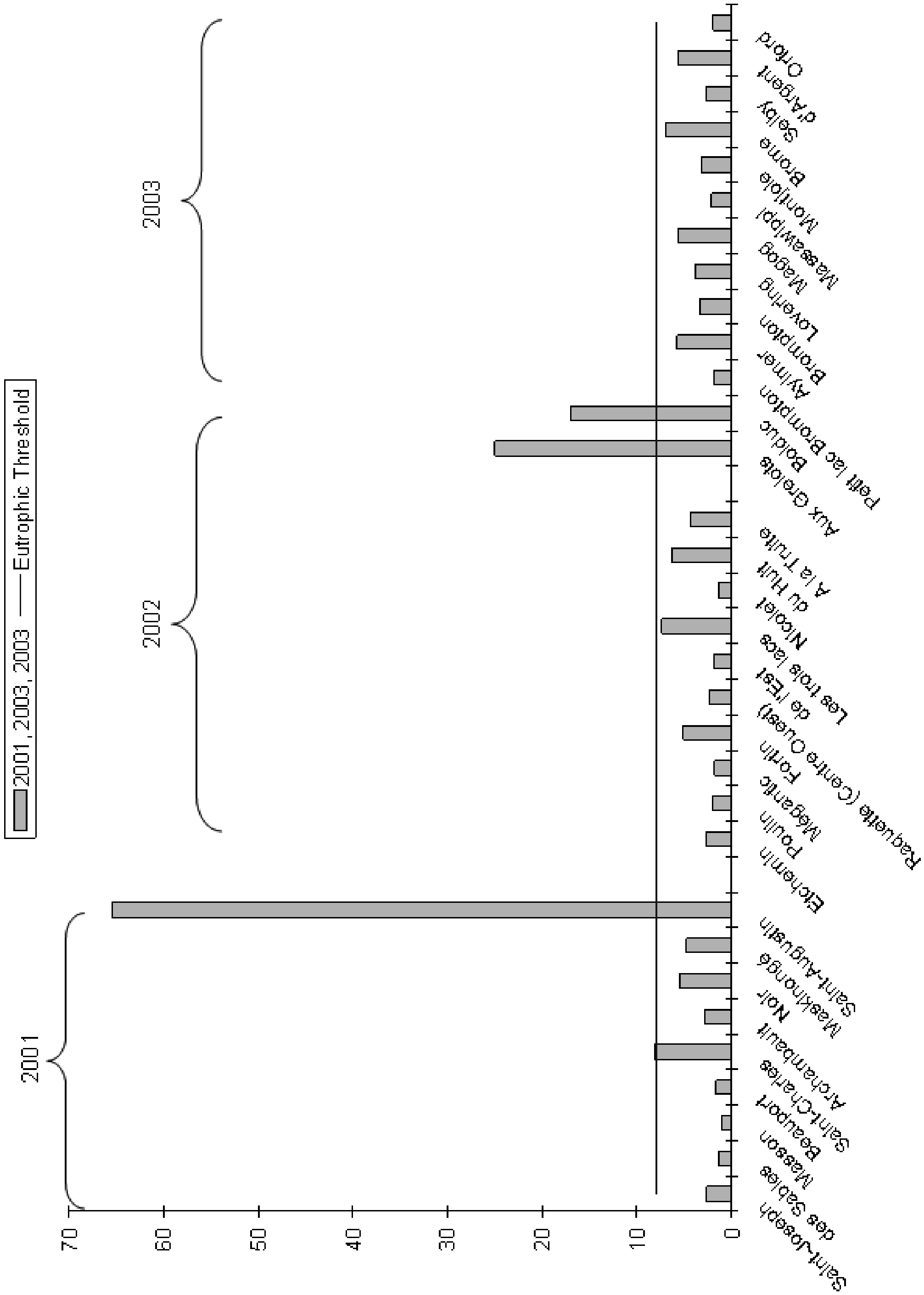

Fig. 2. Chlorophyll *a*, average results for summers 2001 to 2003.

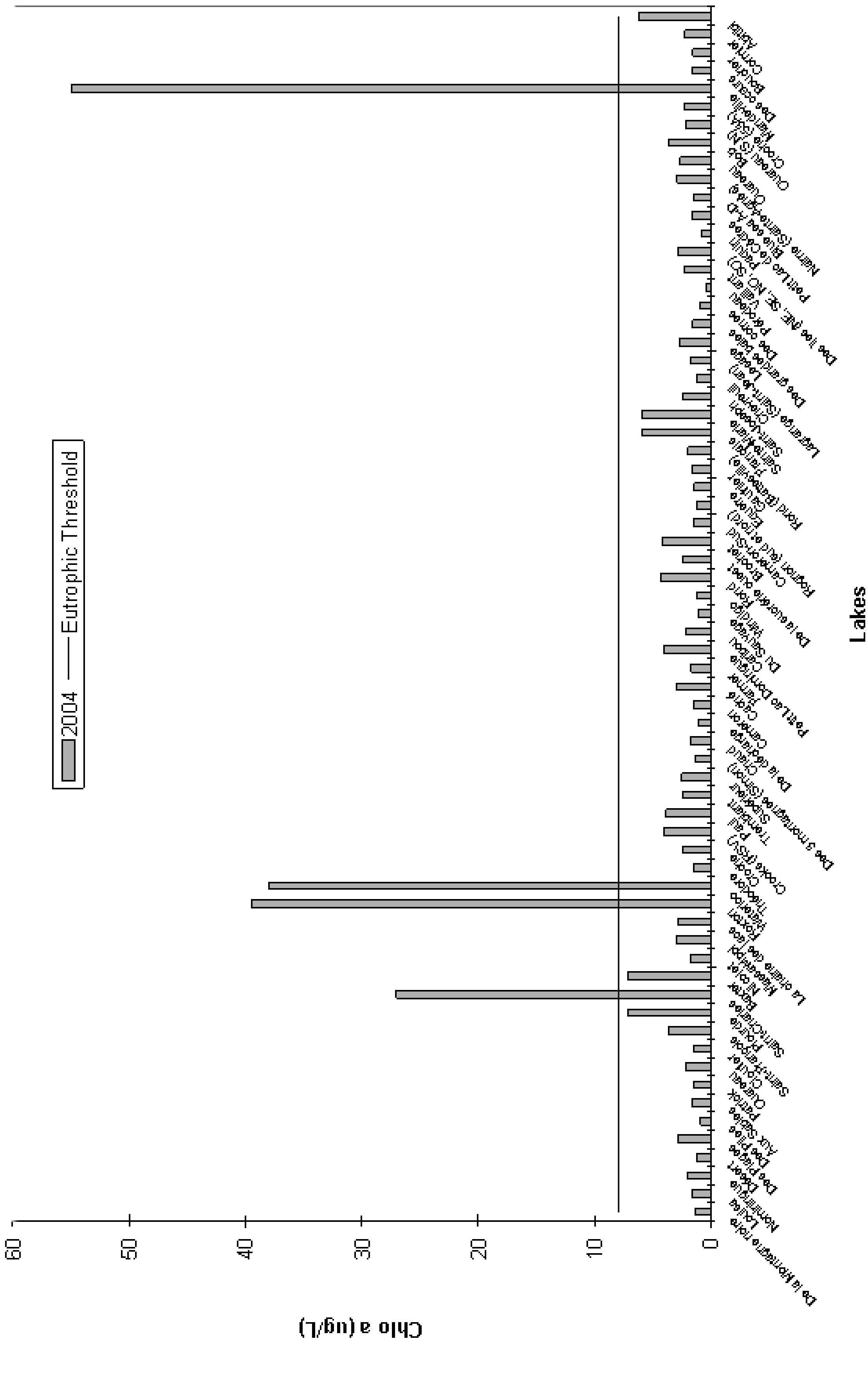

Fig. 3. Chlorophyll *a*, average results for summer 2004.

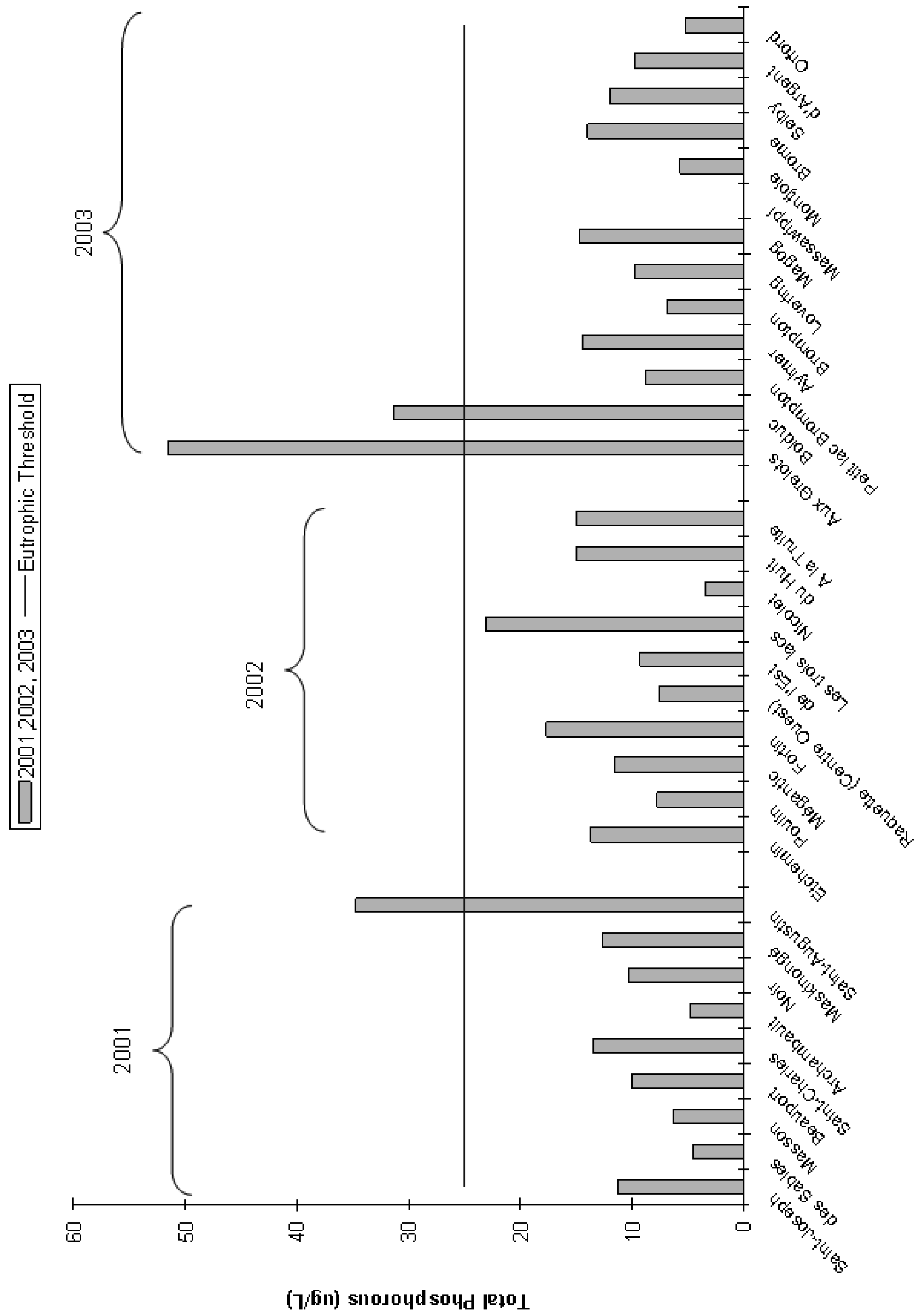

Fig. 4. Total phosphorous, average results for summers 2001 to 2003.

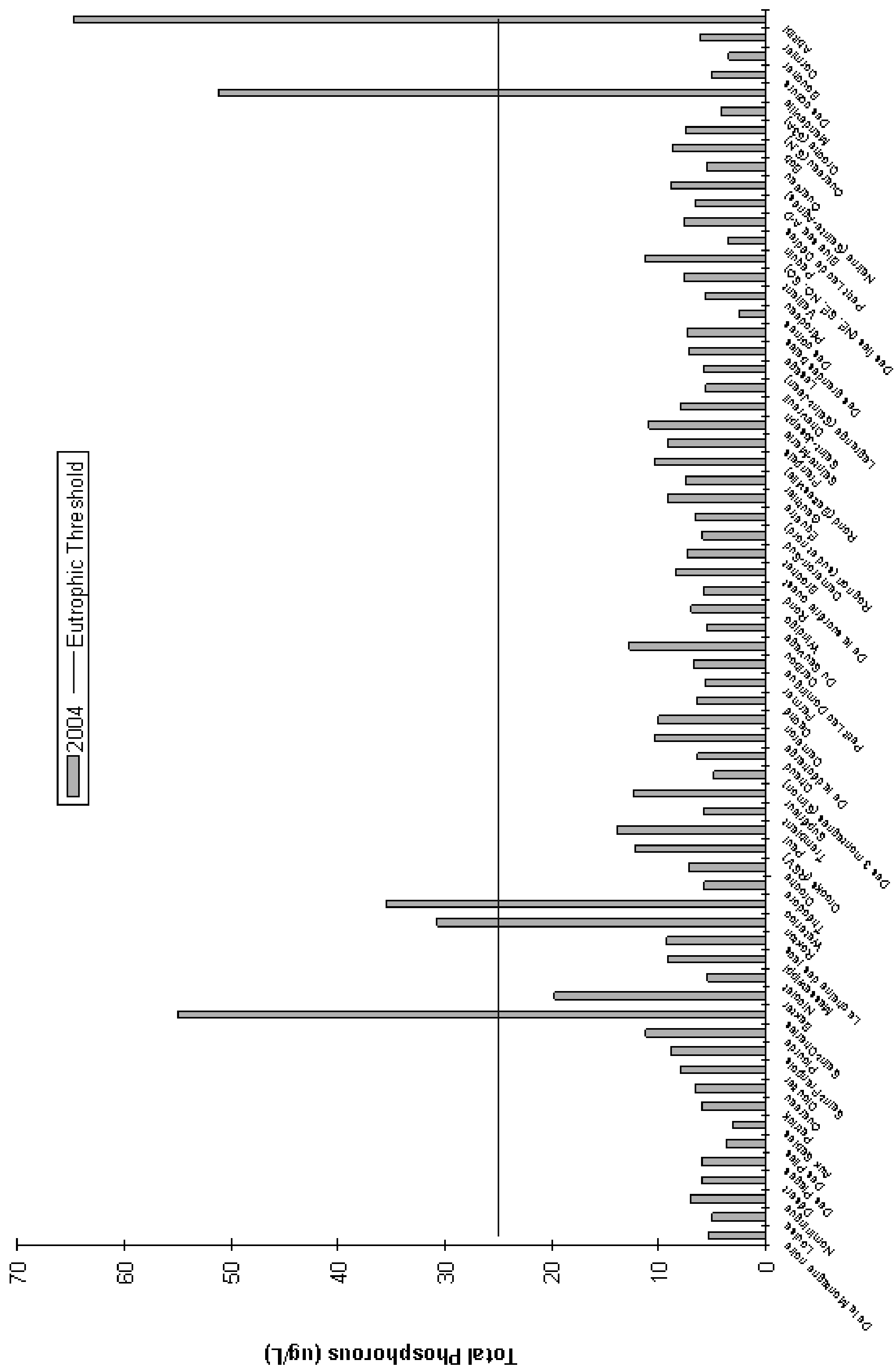

Fig. 5. Total phosphorous, average results for summer 2004.

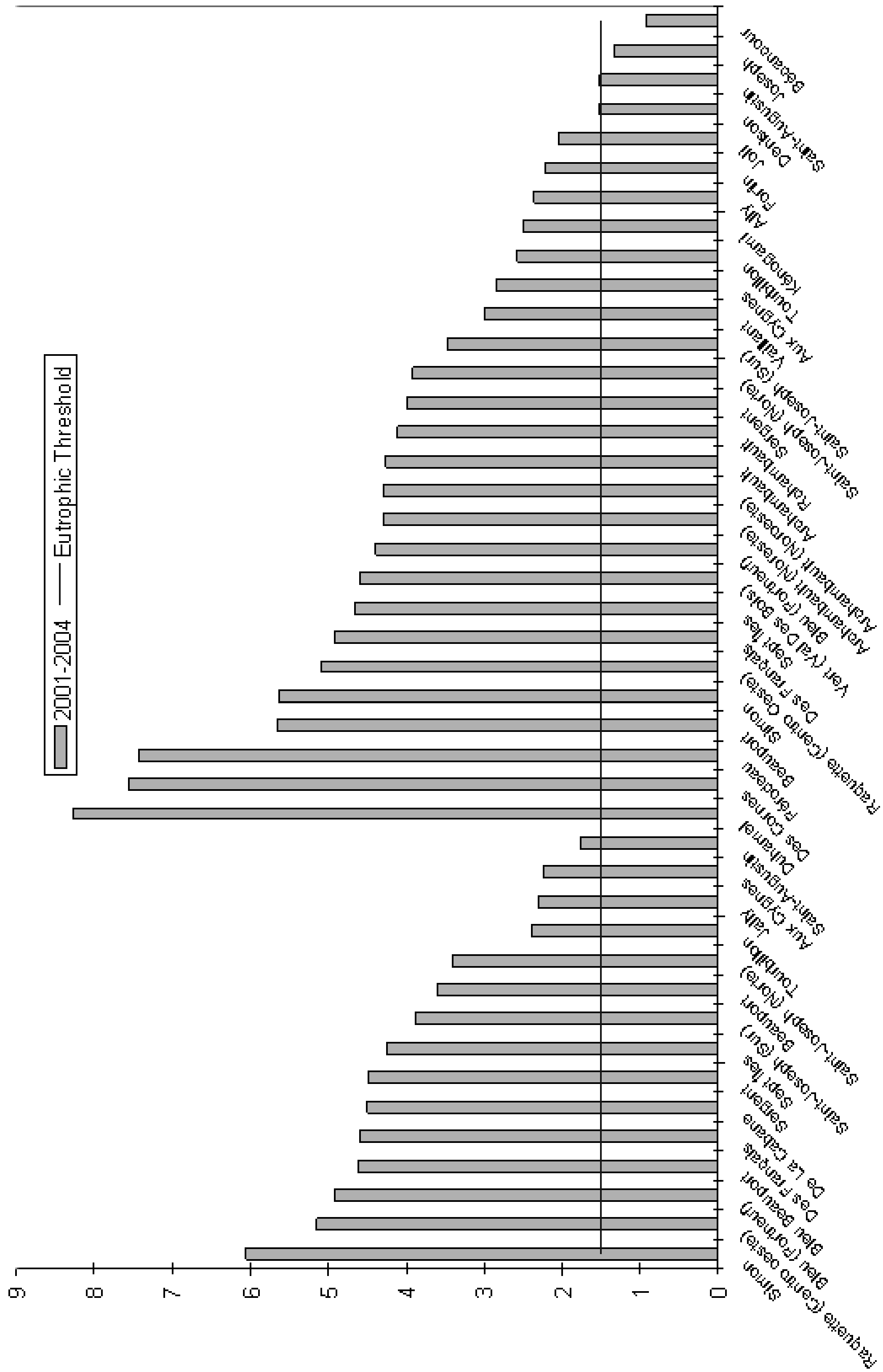

Fig. 6. Transparency, average results for summers 2001 to 2004.

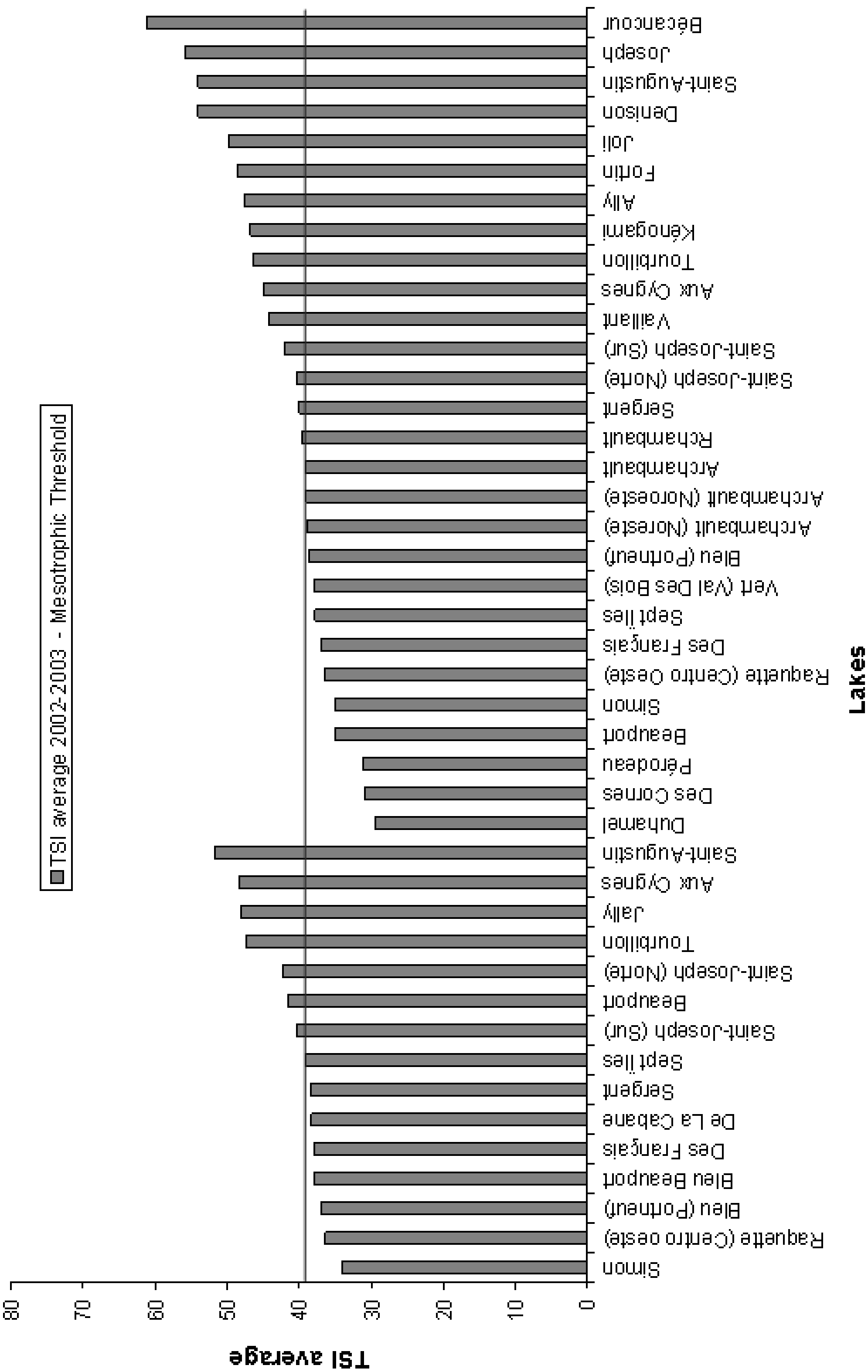

Fig. 7. TSI average values 2002 to 2003.

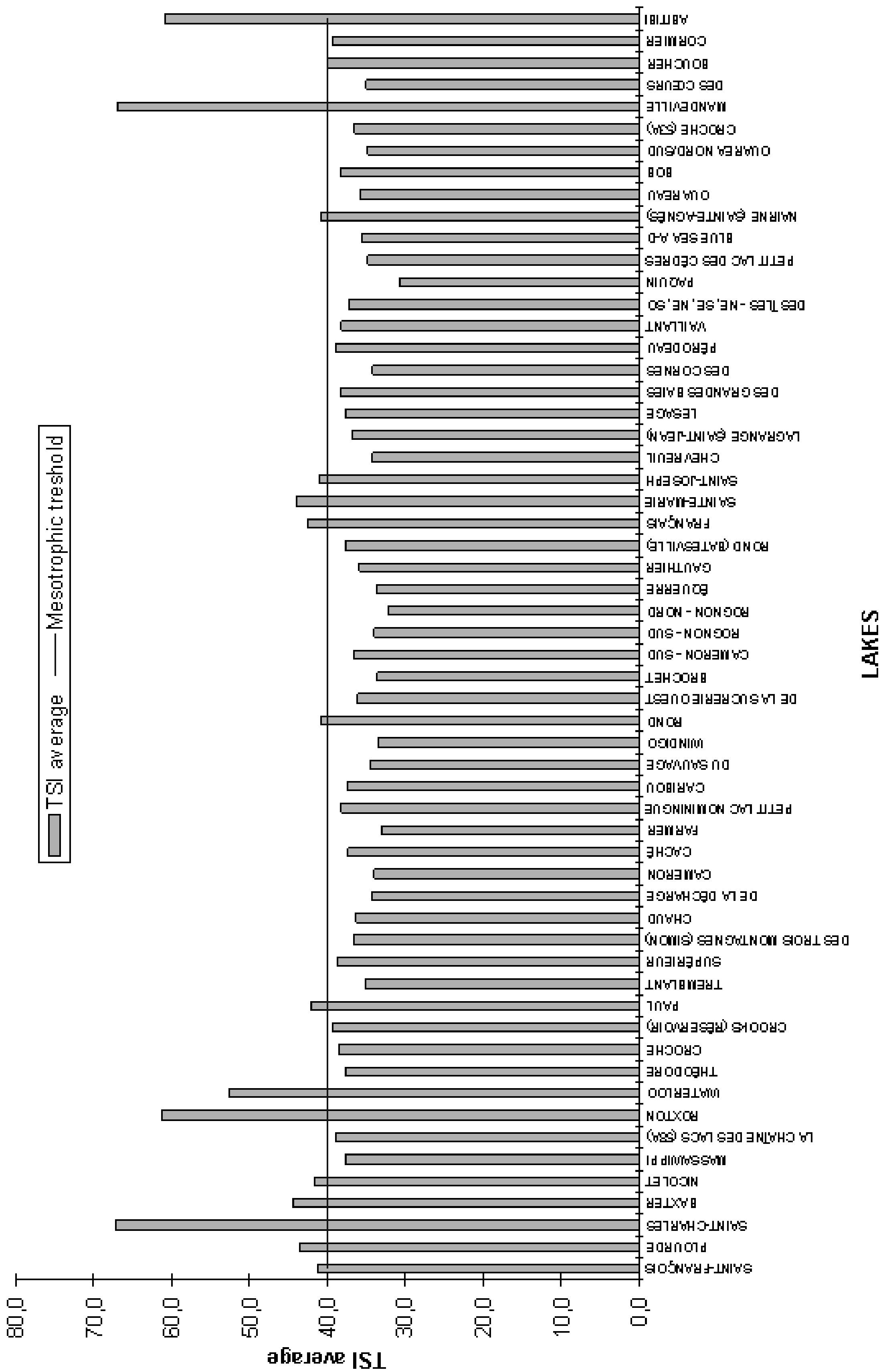

Fig. 8. TSI average values 2004.

TABLE 4. Lakes needing eutrophication control measures

Order[a]	*Lake*
1.	Saint-Augustin
2.	Waterloo
3.	Saint-Charles
4.	Aux Grelots
5.	Brome Roxton
6.	Bolduc
7.	Abitibi
8.	Baxter
9.	Rond
10.	Bécancour
11.	Saint-Joseph
12.	Les trois Lacs
13.	Denison
14.	Aux Canards
15.	Brochet
16.	Rose
17.	Joli
18.	Fortin
19.	Ally
20.	Maskinongé
21.	Plourde
22.	Nairne
23.	Saint-Francois
Other lakes with TN/TP<29	
	Petit Lac Brompton
	Shelby Argent
	Orford
	Magog

[a] Lakes listed from that with highest down to that with lowest TSI.

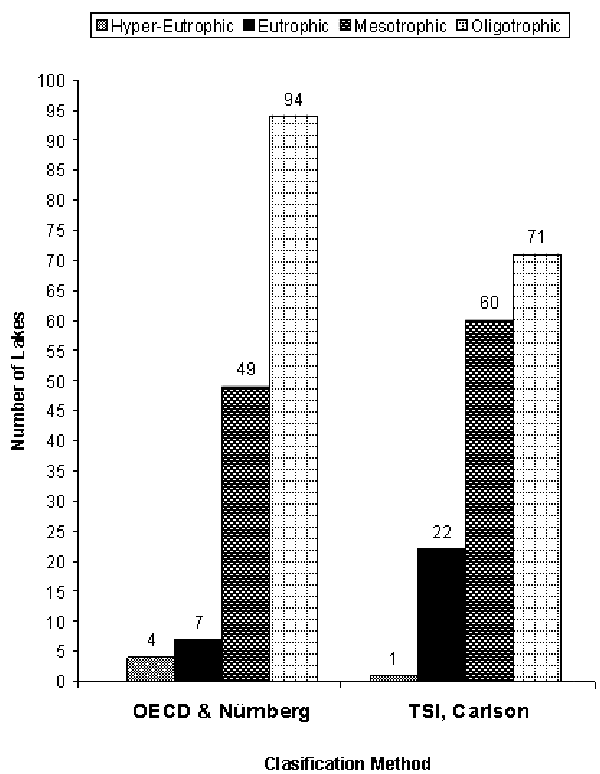

Fig. 9. Trophic status classification results – summary.

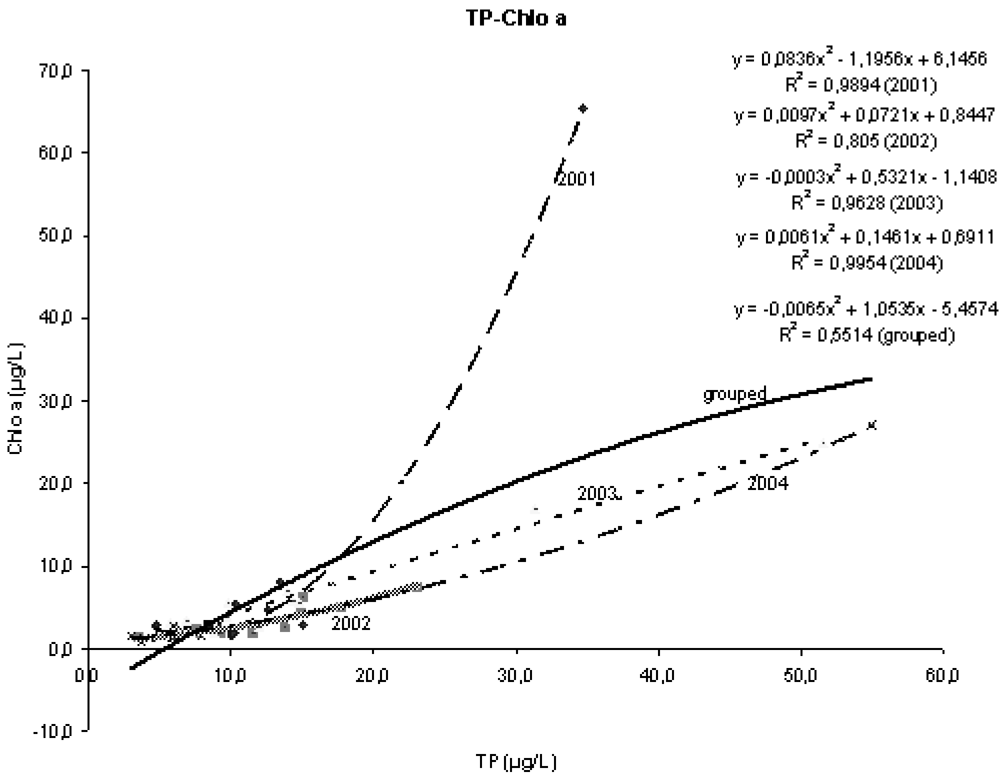

Fig. 10. Relation between total phosphorus and chlorophyll a.

Lakes in Table 4 belong to different regions. Human activities in the different watersheds are diversified. Agriculture but also intensive urban development can be found in some of these watersheds. A study following this one will aim to establish the link of watershed activities and land utilisation with lake water quality.

Quality Parameter Relationships

As can be seen in Figure 10, systematically, chlorophyll *a* values increased with an increase in TP. This situation was observed for the four surveys and presented high correlation ratios (0.80 to 0.99). The highest chlorophyll *a* content for the summer of 2001 was due to the algae bloom in Saint-Augustin Lake. Other studies at Saint-Augustin Lake (Galvez-Cloutier et al. 2003) have reported up to 80 µg/L of chlorophyll *a* in this lake. The direct relation between TP and chlorophyll *a* can also be inferred from the fact that, whether based on TP or chlorophyll *a*, the same number of lakes and the same lakes fall under the eutrophic category (8 lakes).

The major advantage of using chlorophyll *a* is that it reflects the amount of plant material in the water, thus it is the best measure of an actual eutrophication problem. A high chlorophyll *a* level is an excellent standard that triggers nutrient management programs. The disadvantage of using chlorophyll *a* is that it only measures the consequences of nutrient enrichment. It is possible to have fairly high nutrient levels without high algal growth. Also, the level of chlorophyll *a* in water may vary as a result of turbidity and other factors unrelated to nutrient levels.

Because of the nutrient transport phenomenon, chlorophyll *a* problems may manifest at some distance from upstream loading, making the appropriate assignment of responsibility difficult. Chlorophyll *a* can be difficult to sample because it is not evenly dispersed and usual sampling methods would not measure the amount of macrophytic or periphytic plant life.

The major advantage of using TP is that this parameter ties the standard directly to the underlying cause of eutrophication (e.g., excess nutrients). When TP standards are exceeded, no cause and effect relationships have to be established before going directly to management strategies (although relative shares and waste load allocations must still be developed). Using TP also provides a way to address nutrient transport from upstream. The disadvantage of TP is that it is possible to have high levels of nutrients in certain bodies of water without having excess algal growth. While this may ultimately cause problems downstream, this will not cause any immediate problems, justifying to some that it may not be necessary to take any action.

Figure 11 shows the indirect relationship between transparency and chlorophyll *a* for a large range of values on both parameters. The curve was fitted using available data which included 73 lakes. This high number of lakes may be considered as representative of the lakes located

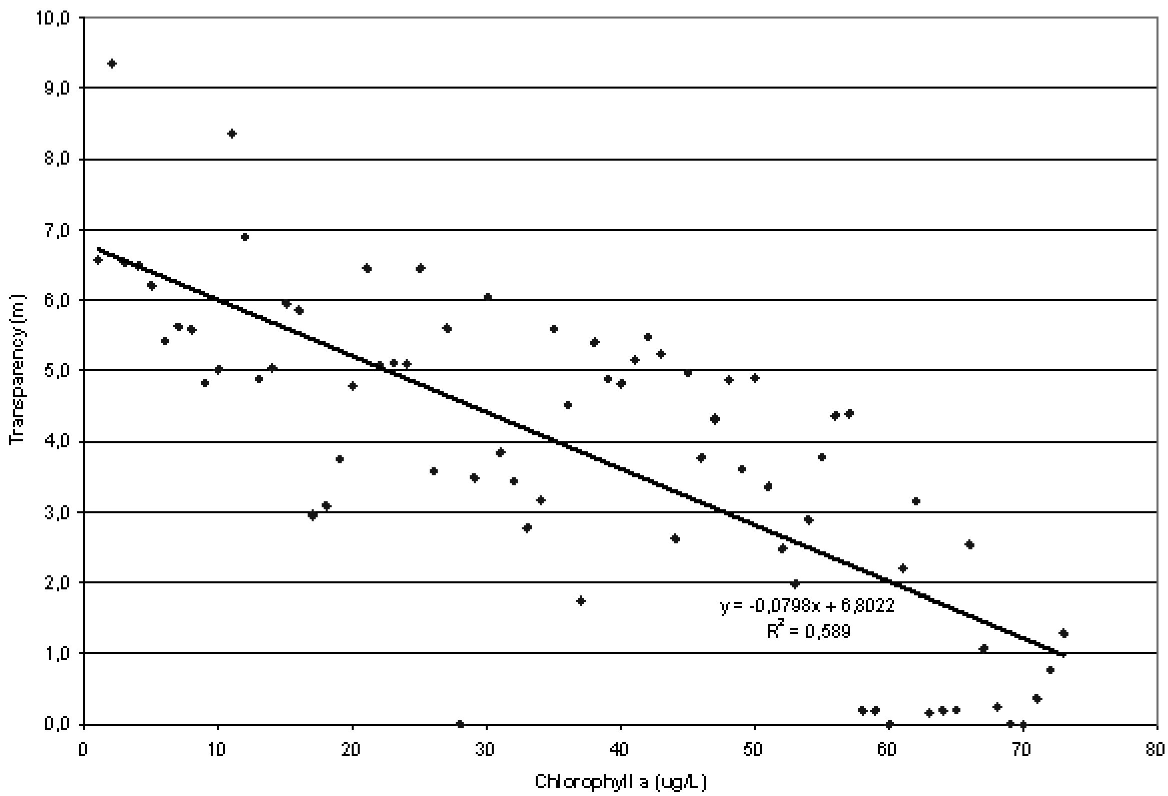

Fig. 11. Relation between chlorophyll a and transparency.

in southern Quebec. The higher chlorophyll *a* values corresponded to lower transparencies. Transparency (by Secchi disk) is the easiest and most cost effective parameter that can be obtained. Volunteer citizens can easily be trained to measure this parameter. Because transparency is related to chlorophyll *a*, and chlorophyll *a* has been shown to be related to TP for lakes in the southern regions of Quebec, transparency should be used extensively and widely during future monitoring studies. Because of the interdependency of these three quality parameters, the TSI appears to be an adequate integrating eutrophication indicator.

Total Nitrogen to Total Phosphorus (TN/TP) Ratio

Healthy algae contain approximately 16 atoms of nitrogen for every atom of phosphorus (in molecular weights: 224/30 = 7.46) which is known as the Redfield Ratio (Wetzel 1983). Meybeck et al. (1989) and Chapman (1996) suggested that, in fresh waters where the TN/TP mass ratio is greater than 7, phosphorus will be the limiting nutrient, whereas for TN/TP ratios below 7, nitrogen will be the limiting nutrient for algal growth (in practice, TN/TP less than 10 would indicate a nitrogen deficiency, and TN/TP greater than 20 would indicate a phosphorus deficiency). Often TN/TP ratios are low in eutrophic lakes and high in mesotrophic and oligotrophic lakes. All the lakes in this study showed TN/TP ratios between 7 and 107, with 27 being the average value. These values indicate that in Quebec lakes, the limiting nutrient is phosphorus. The high direct correlation between TP and chlorophyll *a* presented provides support for this conclusion.

The presence of cyanobacteria is a major risk to human and ecosystem health, and is frequently associated with eutrophic conditions. It is important to mention that, in recent summers, several lakes in Quebec (some included in this study) had reported the presence of algal blooms with the presence of cyanobacteria. Since many bloom-forming cyanobacteria can fix atmospheric N_2, it has been reasoned, based on resource ratio theory, that cyanobacteria should dominate at low TN/TP ratios, with cyanobacteria being rare when the TN/TP ratio is greater than 29 (by mass), and more often dominanting when the ratio is less than 29 (Smith 1983; UNEP 2006). In our study, all lakes classified as eutrophic presented TN/TP < 29. Table 4 also shows other lakes presenting TN/TP lower than 29. Downing et al. (2001) showed that individual concentrations of TP and TN can also be correlated with the presence of cyanobacteria. They predicted that the risk of cyanobacteria dominance is about 40% when TP is between 30 and 70 µg/L, and rises asymptotically to around 80% near 100 µg/L of TP.

Conclusions

While reviewing the criteria described earlier (Lake Trophic Status Classification Methods), and determining quality status, it was found that several countries/states chose numerical (quantitative) criteria, and others developed narrative standards, especially with respect to limits that may permit or allow certain usages of water. Having both qualitative and narrative standards offered flexibility for better control strategies. In addition, some standards included recommendations on sampling frequency, sampling strategies, and basic data treatment to be performed. These recommendations would assist in the interpretation and quality trends evaluation that should be considered in restoration plans.

Given the large number of lakes in Quebec, the survey of lakes under the basis of voluntary work following a formal request by watershed stakeholders appeared to be a very positive government initiative. The 'Reseau de surveillance de lacs' of the MDDEP should be considered as a very successful program and it should be increasingly supported by the government. It satisfies several of the sustainable development principles in watershed management. In particular, it enhances local community participation in the decision processes and stimulates general public participation and environmental education, it is a better approach to organize databases and their exploitation, and it provides conditions for integration of scientific data and interpretation.

Overall, the results showed that although the majority of lakes surveyed were within optimal conditions (oligotrophic status), 22 lakes showed the necessity to increase nutrient control measures.

Recommendations for future surveys include the following: 1) increase the number of lakes surveyed, 2) standardize sampling periods and location in the water column (same summer period and at certain depth i.e. hypolimnion) to allow for consistent comparisons, 3) increase the frequency and number of locations of the measure of transparency, 4) given that parameters vary over the season, and that a criteria is given in a general basis, determine compliance based on seasonable averages, one or x number of times that exceed the criteria or another more rigorous sampling strategy, and lastly 5) measure biological parameters, particularly in lakes where status can not be clearly defined.

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