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NATIONAL WATER RESEARCH INSTITUTE

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SUMMARY OF PROCEEDINGS LAKE ERIE SCIENCE WORKSHOP MARCH 5, 1998

M.N. Charlton

NWRI Contribution No. 98-127

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NWRI Contribution No. 98-127

Summary of Proceedings
Lake Erie Science Workshop
March 5, 1998
National Water Research Institute
Convened by;

M. N. Charlton, NWRI

M. N. Charlton convened a workshop on Lake Erie science on March 5, 1998. The workshop was intended to bring together for informal information sharing the researchers who have been working one way or another with Charlton and members of the NWRI Lake Remediation Project.

Participants were from DOE, DFO, OME, University of Windsor, University of Waterloo, The Ohio State University, Bowling Green State University, University of Toronto, and Woods Hole Oceanographic Institute

The workshop was held in the context of the controversial assertion publicized by the Ontario Federation of Anglers and Hunters that long standing phosphorus controls should be relaxed in order to promote fish production in Lake Erie **(Globe and Mail March 3, 1998)**. A former OME scientist (R. Griffiths, specialist in stream ecology) claims that phosphorus controls can be relaxed just enough to produce a springtime algal bloom that would stimulate the pelagic food chain and, because of the timing, would not stimulate zebra mussels because they do not feed when the water is still cold in the spring. **See section on this topic below.**

Highlights:

M. Charlton, NWRI: **Lake Erie water quality** has been measured since 1990 as a way of documenting the response to the lake to reduced nutrients and exotic mussels. There has been a reduction of 50% in west basin phosphorus concurrent with achievement of the GLWQA loading targets. As predicted in the early 70s the nutrient reductions had relatively less effect in the central and east basins. Low phosphorus and algae populations were observed as early as 1979 - these have become somewhat lower since then. The oxygen situation in the central basin has improved since 1992. While reduced algae and zebra mussels may be partly responsible the thermoclines tend to be farther off the bottom than usual. We do not understand why this difference in physical features is occurring but it has in the past caused decreased oxygen depletion however briefly. From the lake response data on hand it would seem that an attempt to significantly increase the phosphorus content of the central and east basins would require a full blown return to sewage pollution prevalent in the 1960s.

J. Ciborowski, University of Windsor : **Hexagenia mayfly larvae** which are pollution sensitive bottom dwelling insects and an important food for fish **have returned to the west basin**. They were extirpated in the 1950s likely by transient anoxia caused by excessive algae growth. Since 1991 they have re-colonized most of the west basin. Research is underway to determine why two areas are not yet colonized even though eggs are present. The largest populations are in the south side of the basin and their burrowing activities may explain more turbid water there. Work by L. Corkum shows that the larvae are good monitors of the contaminant status of the sediments

L. Corkum, University of Windsor: Round and Tubenose gobies are **exotic fish species** that were found in Lake St. Clair in 1990. Populations of up to 40 fish per m^2 now occur in southern Lake Michigan through to Lake Erie's west basin and south central basin area. Larger (>7cm) gobies eat zebra mussels. They have negative effects on native mottled sculpin and there is speculation about effects to come on other species. Similar to mussels, their spawning behaviour seems different than in their native habitat. Research continues on their ecology and this will serve to also detect the likely invasion of the feared ruffe (exotic fish) to the lower Great Lakes.

D. Haffner, University of Windsor: Research includes **primary production**, contaminant dynamics on plankton, trophic dilution food web distribution of PAHs and OCs and **modeling of PAH dynamics**.

H. MacIsaac, University of Windsor: **More exotic species have been found!** A Ukranian PDF familiar with Caspian species has identified a new amphipod (crustacean) and a new chironomid (benthic insect larva). Work continues on another exotic amphipod known for some time and monitoring is done for a Daphnia species present in nearby reservoirs in Ohio. Work on the exotic zooplankter Bythotrephes continues to determine differences in Eurasian and Ontario population dynamics.

P. Sale, University of Windsor: Ways to measure the condition of young **perch**, their survival, growth, and feeding continue in an effort to determine the factors which affect chances of **survival** in the first summer and winter.

T. Howell, OME: **Cladophora has re-appeared** in quantities sufficient to foul shorelines in east Lake Erie. Complaints have been received from property owners. The filamentous algae grow attached to the copious rocky shelves in the east basin. Water clarity caused by zebra mussels may allow the alga to exist at greater depths than before. Tissue phosphorus indicates the growth is phosphorus limited; more phosphorus will stimulate more growth. Possibly mussels harvest planktonic phosphorus and excrete soluble phosphorus thereby exacerbating the problem. Local sources of phosphorus may be important. It was hoped this problem would disappear with the achievement of nutrient controls. It is still an issue to be followed closely. Work continues at OME; some experiments by NWRI on productivity of the alga have been done.

R. Hecky, NWRI: **Benthic primary production** was studied on rocky ledges in the east basin during 1997. This is to find out whether benthic production may compensate for primary production lost to mussel populations. Benthic production was surprisingly high - similar to some African lakes. Moreover the presence of mussels seemed to stimulate production by attached algae. A shift in energy flow ie: a new food web is developing and the relationships between the organisms is being examined with isotope techniques. In 1998 cooperative work with T. Howell is intended.

R. Smith, University of Waterloo: **Pelagic Primary Production** was measured at 9-18 stations during cruises of the Limnos commissioned by M. Charlton NWRI. Compared to 1970, production was reduced by 50% as was found in 1993 by S. Millard of DFO. Unfortunately, there are few early primary data to compare and we do not know how typical 1970 was of the era. Primary production measurements by M. Charlton in 1979 in the Central basin were similar to those of 1970. Therefore, there likely has indeed been a reduction in productivity resulting from the 50% reduction in nutrient load called for in the GLWQA. This reduction in productivity was thought necessary to prevent hypolimnetic anoxia in the central basin.

R.M. McKay, Bowling Green University: **Trace metal limitation of phytoplankton** growth has been observed in oceans. NWRI's clean lab work has revealed that metals are 1/10th the concentration thought formerly. The real concentrations are in the range in which limitation could occur. Samples were taken during Charlton's cruises in 1997. Development of methods to indicate metal limitation are under development; field work is likely in 1998.

M. Twiss et al., Woods Hole Oceanographic Institute, INRS-Eau, Université de Québec,Ryerson University: **Trace metal/plankton interactions** were studied 1994-97. Metals are scavenged from the water column by sedimentation of picoplankton and nanoplankton during summer stratification. Scavenging of metals is mitigated by predation by microplankton and this tends to prolong the residence time of metals in the surface water. Iron limitation of phytoplankton was found in 1996 but in 1997 was not found possibly due to different mixing regimes that may have increased transport of iron upwards from bottom water. Cobalt is so low that it approaches oceanic concentrations. It is suggested that nutrient limitation experiments should be conducted using metal clean techniques to avoid masking trace metal limitation. Much of the work was done aboard Limnos using NWRI's clean laboratory.

K. Metzker, The Ohio State University: A **spatially explicit model of lower trophic level dynamics** is under development. The model is designed to take into account the effects of nutrients and Dreissena sp. Mussels by describing both nearshore and offshore in all three basins. More benthic data are needed and Charlton (NWRI) is able to address other shortages by contributing data from research cruises. Limnological, physics, and sedimentation input is needed and M. Charlton, P. Hamblin, and J. Coakley of NWRI are co-investigators in an OHIO Sea Grant project with D. Culver and K. Metzker of OSU.

D. Culver, The Ohio State University: Nutrient loading data needed to assess Lake Erie **lower trophic level dynamics** have not being gathered since 1996. Work continues on west basin chlorophyll, phytoplankton and zooplankton biomass. A clear water phase has been a feature of the west basin in June since 1976. Zooplankton are scarcer offshore; this is different from results from small bays which have mistakenly been taken to represent the whole basin. Work continues on zooplankton grazing, ichthyoplankton (baby fish) and nutrient release by mussels as well as vertical transport of mussel grazing effects.

S. Guildford, University of Waterloo: **Phytoplankton limiting nutrients** were investigated during Limnos cruises in 1997. Silica was very low by June and phosphorus was surprisingly low in the west basin in early September. The highest phosphorus demand was in the offshore area in summer but the demand was not particularly high compared to other lakes. It is felt that Silica and Nitrogen may be contributing to limitation phenomena.

J. Coakley, NWRI: **Zebra Mussel populations** were surveyed using side scan sonar in 1994-95. Side scan records were compared with diver surveys in the west basin. Mussels were prevalent on soft substrates in troughs emanating from rocky reefs. The reefs are thought to export enough shell material to provide substrate for colonization by the microscopic mussel larvae. The mussels seem to be spreading out over the soft bottom areas. Their population, based on previous data on bottom types, is about 10^{13} mussels. Side scan techniques seem offer a way to survey the mussels for comparative purposes.

M. Loewen, University of Toronto: **Do mussels filter the whole water column?** The boundary layer near a mussel infested reef was sampled. Evidence was found that the west basin water column does not always mix completely. Chlorophyll was depleted close to the reef. Mussels can access the water column occasionally but often the bottom 1M is isolated and this produces a food limitation situation on the mussels. The reef was instrumented with a variety of devices to measure currents and turbulence. Seiches were one of the dominant causes of water movement.

P. Hamblin, NWRI: **Modeling of mixing over mussel reefs** is done with the "DYRESM" model system. This system provides a physical basis for other predictions such a thermocline depth which is crucial to the oxygen problem.

R. Smith, V. Hiriart, C. Marwood, B. Greenberg, University of Waterloo:
Ultraviolet radiation and primary production were measured to determine the penetration of UV, to model the exposure of phytoplankton to UV and to measure primary production effects. A new model of UV penetration was developed which depends more heavily on particulates than previous models from small lakes. Previously, Dissolved Organic Carbon was thought to be the only important determinant of penetration. On sunny days photosynthesis by plankton is inhibited in the upper metres of the water column relative to the amount of available radiation. Two different models of algae repair and cumulative effects were compared. It appears that UVA is most responsible for the inhibition. Allowing UVB exposure in addition to UVA had a measurable but small additional effect when depth of penetration was taken into account. This may be important for deeper waters such as the Great Lakes because we expect UVB, not UVA, to increase in the future. Recently, improved water clarity extends light penetration and UVA downward thereby exposing more algae which, in turn, may adapt but UVB is rapidly absorbed in water. Therefore, important UVB effects can be seen in shallow water such as streams that may not, although present, be important in the deep waters of the Great Lakes. At this time UVB cannot be ruled out as a potential threat. The combination of exposure to PAHs and UVB produced more inhibition. These PAH results must be calibrated in the context of water column integration in order to gauge importance. These are early results and more research is needed to confirm the implications. Work is to continue on the Limnos cruises in 1998 (partnership with M. Charlton, R. Bourbonniere. S. Wilhelm, NWRI).

Wm. Taylor, University of Waterloo: **Ecological effects of reduced nutrient loads** are likely to be positive. Although this does not consider the profitability of fisheries the efficiency of production is thought to be higher in benthic dominated systems.

Should Phosphorus Controls be Relaxed in Order to Increase Fish Production?

The question occurs in the context that fishing interests believe reduced nutrient loadings are no longer appropriate now that zebra mussels are changing the amount of plankton available for the pelagic fish food chain.

Nutrient loads have been reduced by 50%. Algal productivity has been reduced by 50% by a combination of nutrient effects and zebra mussel grazing. Productivity of certain fish species is variable or decreasing depending on location in the lake. Apparently, total fish production, which includes all species not just those in demand is not decreasing in proportion to the decreased nutrient load.

The fishing interests have not produced a study for review which would support their notion that relaxing nutrient controls would be a safe, effective, practical, or acceptable way of increasing fish production.

Questions about the safety, practicality and acceptability of nutrient loads sufficient to increase fish production can largely be answered by computer modeling.

Other questions about the notion such as "won't there simply be more zebra mussels and not much more fish" need much more research for a definitive answer. The consensus among most scientists who are studying the lake is that one way or another the mussels would be the main beneficiary of increased nutrient loads while other uses of water near load sources would be compromised.

Roughly half the shoreline is privately owned and/or used for recreation, about 13 million people live around Lake Erie and several million drink the water thus, any action that would increase water pollution should be assessed in a multistakeholder and multiuser context.

Given the high technology used in the sport fishery and the lack of a real limit on the number of fish taken (daily limit per angler not a limit on total catch) it has been suggested that fishing interests should assess their own practices. Some fisheries biologists have suggested that the fisheries can be managed to best utilize species favoured by the species composition developing today.

Fishing in Lake Erie is not going to disappear. Fish populations are changing and adapting to reduced nutrient loads and massive ecological changes wrought by exotic species. In 1997, the highly desirable smallmouth bass was doing well and whitefish are making a comeback. On the other hand, some of the traditional desirable species are fluctuating or doing poorly now. Fishing interests have a valid concern. Unfortunately, more change is coming and science is not likely to provide firm quantitative predictions of effects. Research will provide expertise and consensus with which to make the most informed decisions possible for the management of the few "levers" we have such as pollution levels, fishing , stocking, fish habitat etc.

Many mistakes can stem from the misconception that Lake Erie is a stable system that only needs nutrients poured in to produce more of just the right kind of fish. There has not been stability in the Lake Erie ecosystem since exploitation began and particularly not since important exotic species were introduced over 100 years ago, Some of the recently important fisheries such as smelt are based on exotic species that are actually poorly adapted to cold water temperatures; die offs tend to occur in cold winters and this introduces another form of instability. Walleye were almost extirpated by over fishing in the 1950s; since 1970 walleye have been recovering and this is still causing changes. For example, walleye returned to the east basin in numbers only 10 years ago. These walleye would have an effect like an invading species. Extirpation of important species such as blue pike and sturgeon may still be causing effects. Now several exotic species are present that have come from very different ecosystems in Eurasia. Stability is a notion that is a wish rather than a practical reality in Lake Erie for at least the next few decades.

Relaxation of phosphorus removal is attractive financially. Phosphorus precipitation by the addition of aluminum or iron salts is the simple technique used since the 1970s to achieve the GLWQA effluent goal of 1 mgP/L (after the needed capacity at the secondary treatment level was built). The precipitants cost money and the disposal of the increased amount of sludge costs money.

Sewage phosphorus loads will inevitably increase in the future if the concentration limit in effluent is not adjusted downwards (population growth assumed).

Blooms of toxin producing Blue Green algae were observed by Charlton, NWRI in the west basin in 1994 and have been observed by others since. These algae are highly undesirable. They are a plague in eutrophic European lakes. The re-appearance of these blue greens may be due to competition - the mussels eat the other types. Additional nutrients would probably cause more blue green blooms.

One concern with increasing nutrient levels is that the attached algae Cladophora is again causing complaints in the east basin. These algae will respond with more growth to increased phosphorus.

Another concern with increased nutrient levels is that the recently re-established Hexagenia mayfly population in the west basin depends on a decreased amount of organic production for its existence. Previously, the population was eliminated by the oxygen demand caused by high nutrient loads in the west basin. Hexagenia is an important fish food organism. Increased nutrient loads represent a threat to the re-established population.

Most of the sewage loading increase and decrease was in the west basin. This is why the phosphorus concentration there changed from 40 ug/L to 20 ug/L due to nutrient reduction. The main amount of phosphorus available to re-pollute the lake is in the west basin yet the "productivity problem" is a central and east basin issue. As forecast in the 1970 lead up to the GLWQA the nutrient reductions have had a relatively minor effect on phosphorus in the central and east basins. This is because much of the load to the west basin is retained there. The GLWQA was successful in preventing much damage in the central and eastern basins. Therefore, It would be difficult to increase phosphorus levels in the central and east basins without massive enrichment of the west basin. This would likely be unacceptable.

If there is less phosphorus removal at Detroit (west basin) then there will likely be more co-pollution by other compounds such as PCBs.

Most of the tributaries on the Canadian side exceed the Provincial Water Quality Objectives for phosphorus. This is due to a combination of agricultural and sewage sources. There is damage to river, stream, and wetland ecosystems that is being redressed slowly by better practices. These better practices will tend to decrease the nutrient load to Lake Erie. Mathematically, non-point source pollution of Lake Erie is important but only some of the eroded phosphorus on soils actually grows algae in the lake. The worst case is runoff from rain just after fertilizer has been applied. That phosphorus is highly available to algae. An easy solution to the demand of fishing interests that phosphorus loads should not decrease would seem to be to promise that loads would indeed not decrease further. There would not seem to be any problem with this since the loads are at the GLWQA objectives except that the promise could not be kept without changing either sewage or non-point source objectives.

Computer models of historic Lake Erie nutrient loads suggest that loads today are at least twice the historic background. Rhetoric around the nutrient load issue sometimes gives the impression that sewage controls take nutrients out of the lake. Of course there are still substantial sewage loads. The lake is approaching nutrient levels similar to those of Lake Huron except in the west basin which receives the most sewage and agricultural runoff.

Conclusion:

Fishing interests have valid concerns and there are a few examples of lake fertilization to increase production in much simpler situations. The consensus now amongst the scientists is that, with information now available, relaxation of nutrient loading controls would be inadvisable at this time and possibly dangerous.

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National Water Research Institute

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Materials Presented at the Workshop

Lake Erie Water Quality

M. N. Charlton
National Water Research Institute

- Lake Erie is divided into West, Central, and East Basins. Their depths are roughly 10M (33 ft), 20M (66 ft), and 60M (197ft).

- The two deeper basins stratify into a cold and warm layer in the months of June to September.

- Because the two layers do not mix the oxygen in the lower layer (hypolimnion) is not replaced from the air; thus, the biota can cause an oxygen depletion in the hypolimnion or lower layer. The severity of this is related to lake productivity, temperature, and the thickness of the lower layer. In the past, as late as 1990, the bottom water of the central basin has been anoxic by the end of summer. Since 1993 the hypolimnia have been thicker than usual and the oxygen depletion has not been as rapid each summer. Many areas of the Central Basin bottom water had enough oxygen for fish at the end of the summer of 1997. This means there is now more fish habitat in Lake Erie. We do not know whether this improvement will be permanent.

- Nutrient loading increased with increased agriculture and connection of more and more of the growing population to sewer systems. The worst damage to the lake was in the west end caused by Detroit's sewage and runoff from the Maumee River. Algae laden water flowing from the West basin tends to go down the south shore so Cleveland was badly affected as well.

- Nutrient loading was addressed by the Canada U.S water quality agreement.
- The main cleanup has been where there was the most damage - the West Basin. Most of the nutrient loading is still into the West Basin. This causes a gradient from west to east in nutrient levels.

- Generally, nearshore conditions have been improved throughout the lake.

- Cladophora algae problems (nuisance accumulations) still exist on some areas of east basin shoreline

- The data presented here represent the state of Lake Erie offshore waters in the three summer months. I have done this because these data tend to be the most stable over the years. There are other equally valid ways to look at the information. When the deeper basins stratify in the summer the material falling out of the upper layer is not replaced, thus, algal counts and nutrients tend to be lowest in the summer months and these are the data I an showing here. Therefore, comparisons with target concentrations may be misleading because annual mean concentrations, if they were sampled, would be higher.

- Phosphorus declined about 50% in the West Basin due to nutrient loading controls.

- The regulations on phosphorus concentrations in sewage were effective in lowering the load but as population grows and flow increases the sewage load can increase if more and more stringent treatment is not applied. Many sewage plants can be optimized to take our more phosphorus at little increase in cost.
- Since 1990, effects of Zebra Mussels in the West Basin are seen in increasing observations of water transparency more than 3M. This is measured with a Secchi Disk which is like a dinner plate on a string - we note the depth at which it can no longer be seen. Many observations though are not different from those of the 70s and this means the whole ecosystem effect of the mussels is not so easy to judge yet.

- The transparency of Central Basin has been remarkably good for over 20 years in the summer. Mean transparency of 5-7 M has been common. Chlorophyll concentrations of 1-3 ug/L , only double those of Lake Huron, have been common.

- Low chlorophyll seen lately in the East Basin in summer occurred in 1984 -1985 before Zebra Mussels.

- Nitrate seems to be going up in the East Basin.

- Most rivers and streams flowing into Lake Erie contain more phosphorus than the Provincial guideline.

- Scientists at the National Water Research Institute (Environment Canada) and Fisheries and Oceans Canada have been partnering with colleagues at Waterloo University, Université de Québec, University of Windsor, The State University of Ohio, Woods Hole Oceanographic Institute, and Bowling Green University. Studies include water quality, oxygen, sedimentation, effects of ultraviolet radiation, primary production (algae growth), benthic production (algae growth on the bottom), zooplankton populations, Zebra Mussel filtering, vertical mixing of mussel effects, mussel populations,

- In addition to the finding of more oxygen resulting in more fish habitat in the Central Basin, preliminary results indicate benthic primary production is higher in Zebra Mussel beds in the East Basin. Thus, there may be compensation mechanisms that may make up for the algae lost from the water to the mussels. The greater light penetration in shallow areas most affected by mussels allows more benthic production to greater depths. The Zebra Mussel beds themselves contain a myriad of fish food organisms that were not present before the mussels appeared.

The Lake Erie Problem
1970s

- Canada-U.S. Great Lakes Water Quality Agrement
  - $20 B spent on sewage control
  - Surveillance of Water Quality
  - Sewage loads decreased
  - Concern for Non-Point pollution

The Lake Erie Problem
1980s

- Sewage loads cut in half
  - Targets achieved 1986
  - Low oxygen remained
- Zebra Mussels, Bythotrephes etc

The Lake Erie Problem
1990s

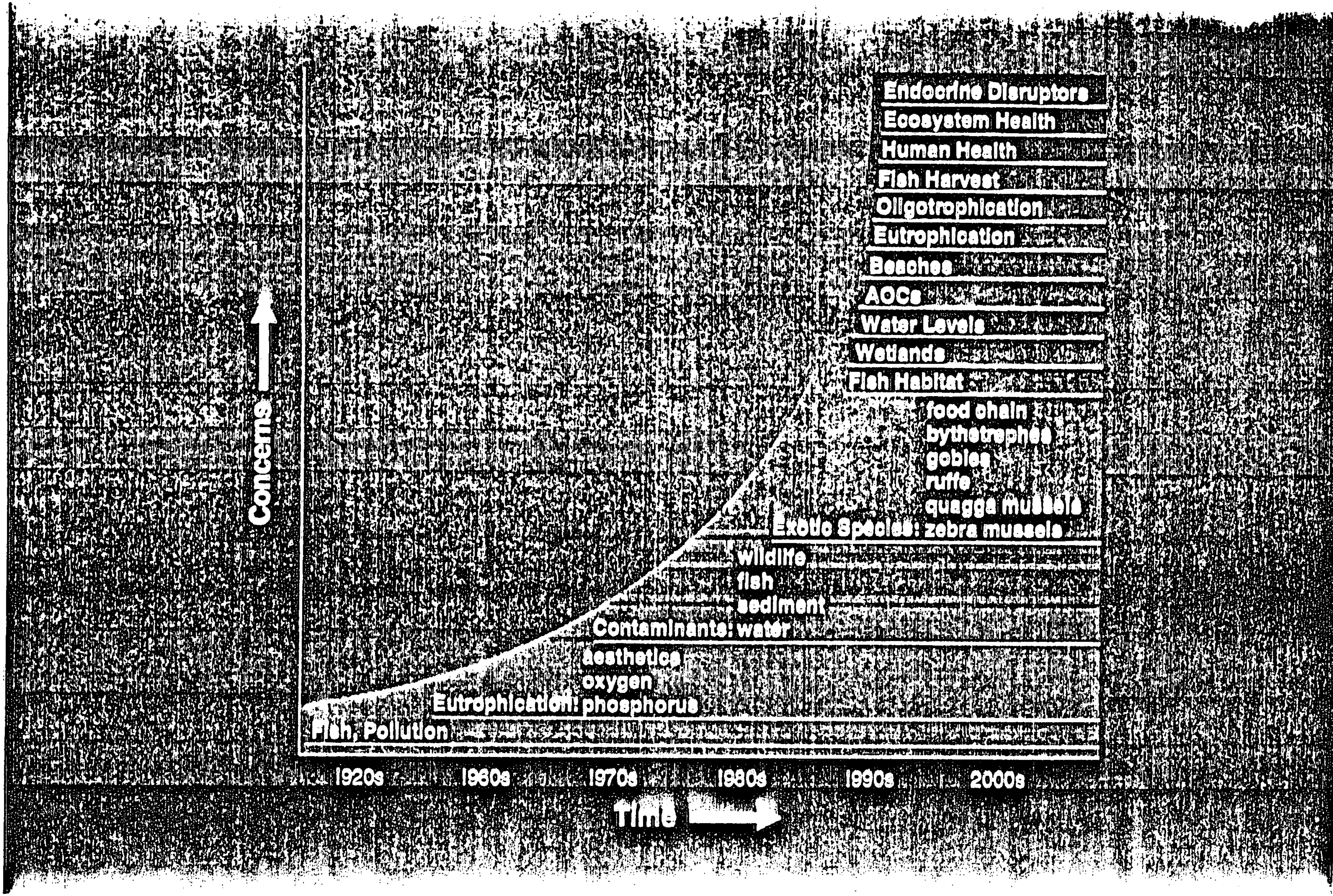
- Fishery in decline
- Cladophora on beaches
- Zebra/Quagga Mussels everywhere
- Taste and Odour problems
- Need more phosphorus???

Zebra Mussels vs GLWQA

- Mussels and achievement of P controls happened about the same time.
- Many effects similar.
- GLWQA effects on lake productivity occurred before mussels.

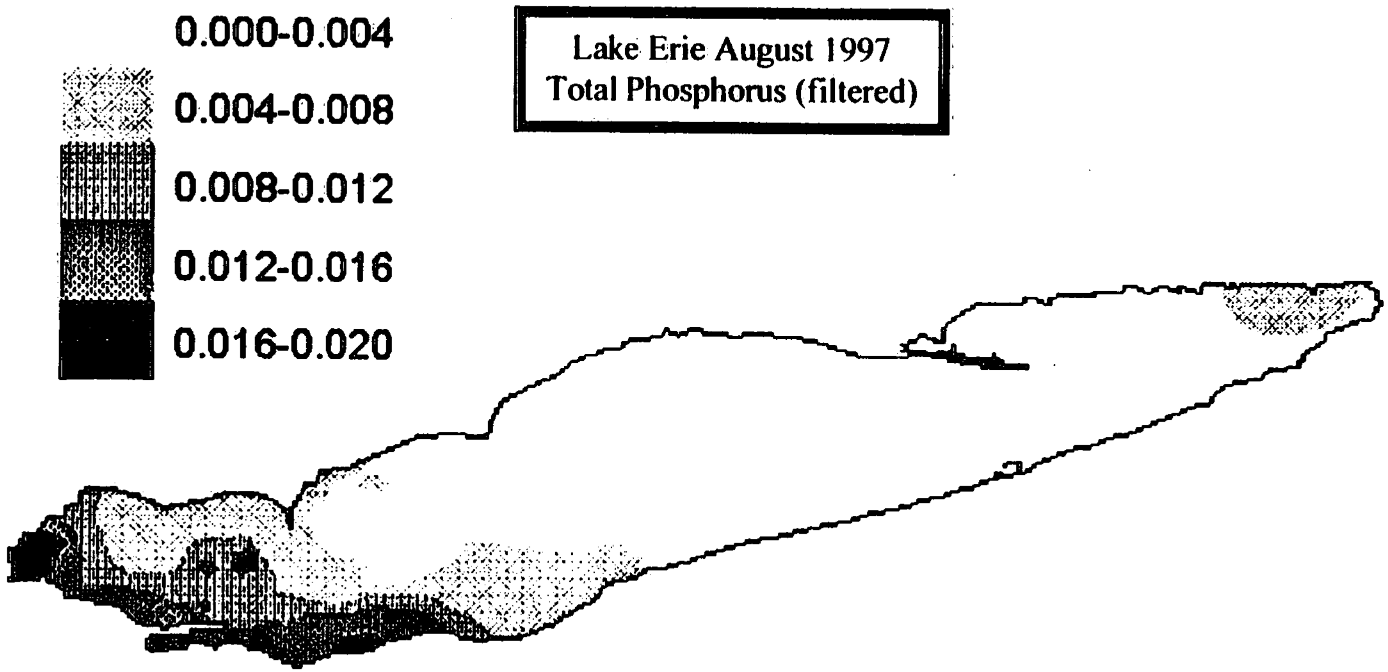
Effects of Zebra Mussels

- Depth Dependent
  - Eg:Long Point Bay
- Soluble Nutrients Released
  - Stimulate attached algae?
- Food Chain
  - enhance sedimentation, new Benthos pops, new contamination vector, less plankton, different fish



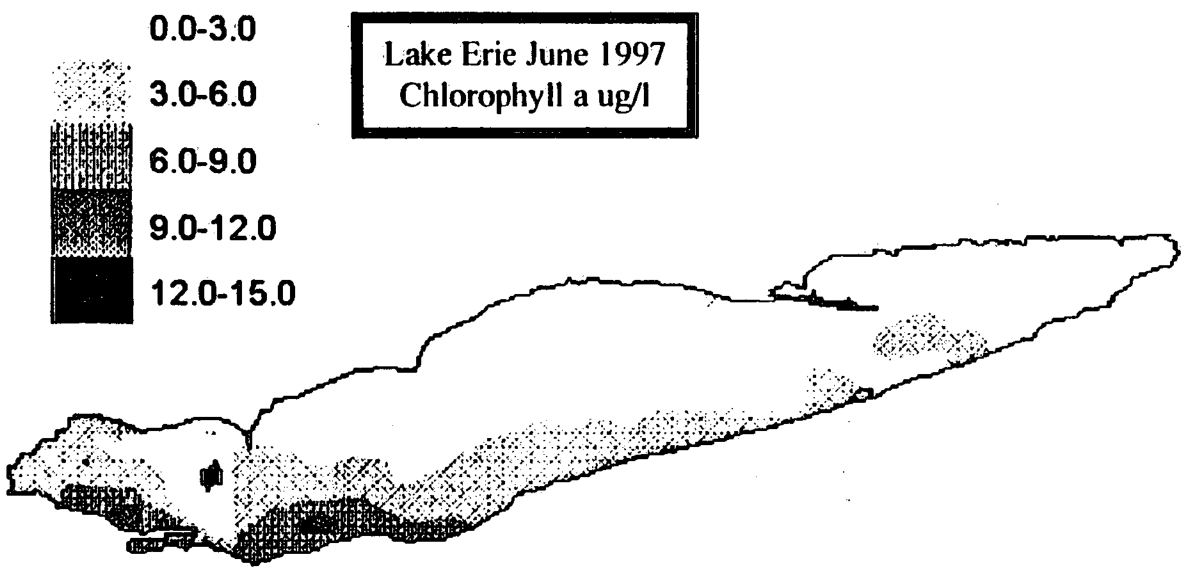
Endocrine Disruptors
Ecosystem Health
Human Health
Fish Harvest
Oligotrophication
Eutrophication
Beaches
AOCs
Water Levels
Wetlands
Fish Habitat
food chain
bythotrephes
gobies
ruffe
quagga mussels
Exotic Species: zebra mussels
wildlife
fish
sediment
Contaminants: water
aesthetics
oxygen
Eutrophication: phosphorus
Fish, Pollution
Concerns
1920s
1960s
1970s
1980s
1990s
2000s
Time

Phosphorus Distribution



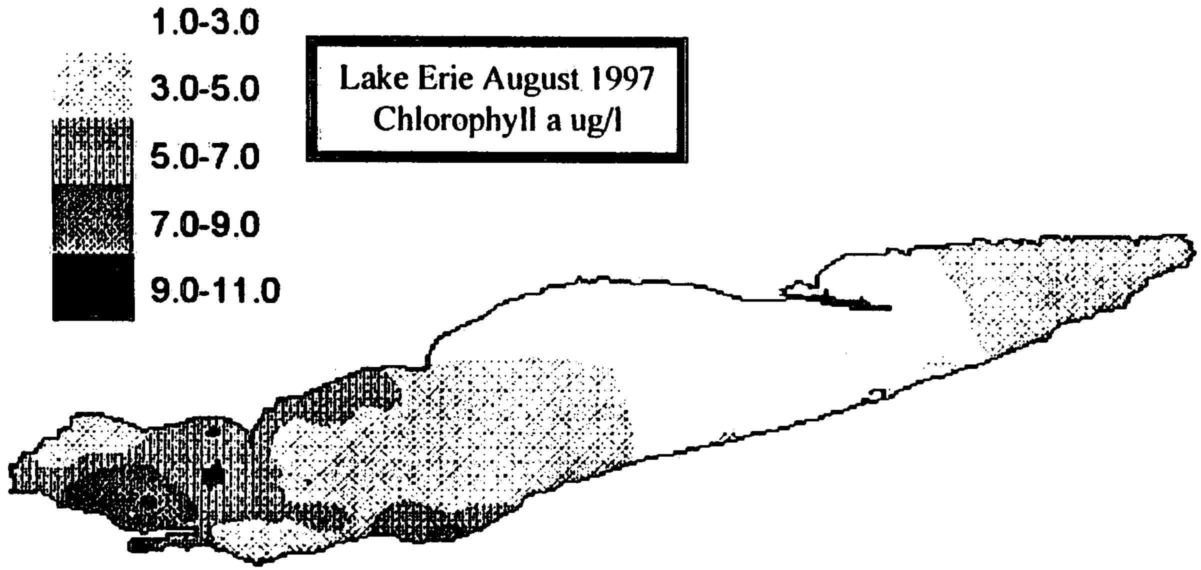
- Typical distribution of soluble phosphorus

Chlorophyll Distribution



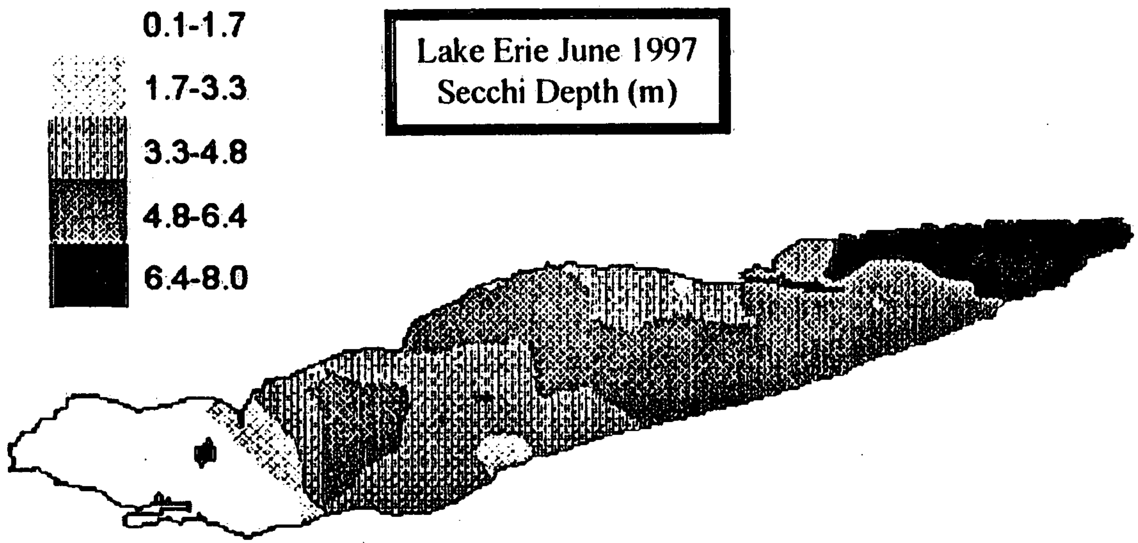
- A west to east gradient in algae begins.to develop early in the season following the outflow from the west basin

Chlorophyll Distribution



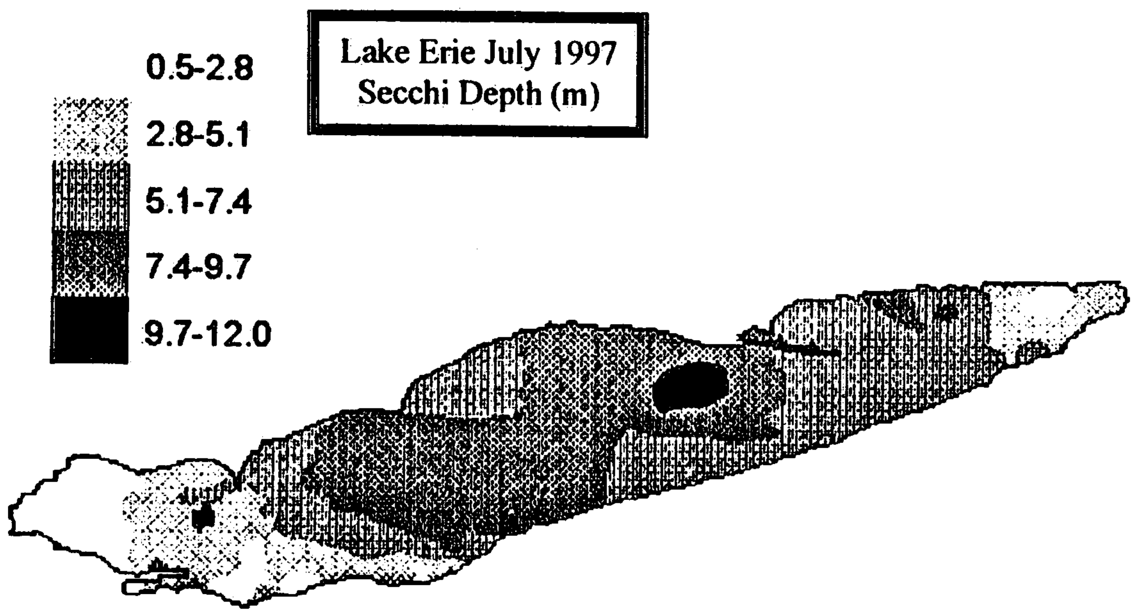
- There is a west to east gradient of algae in the lake consistent with the nutrient gradient

Transparency Distribution



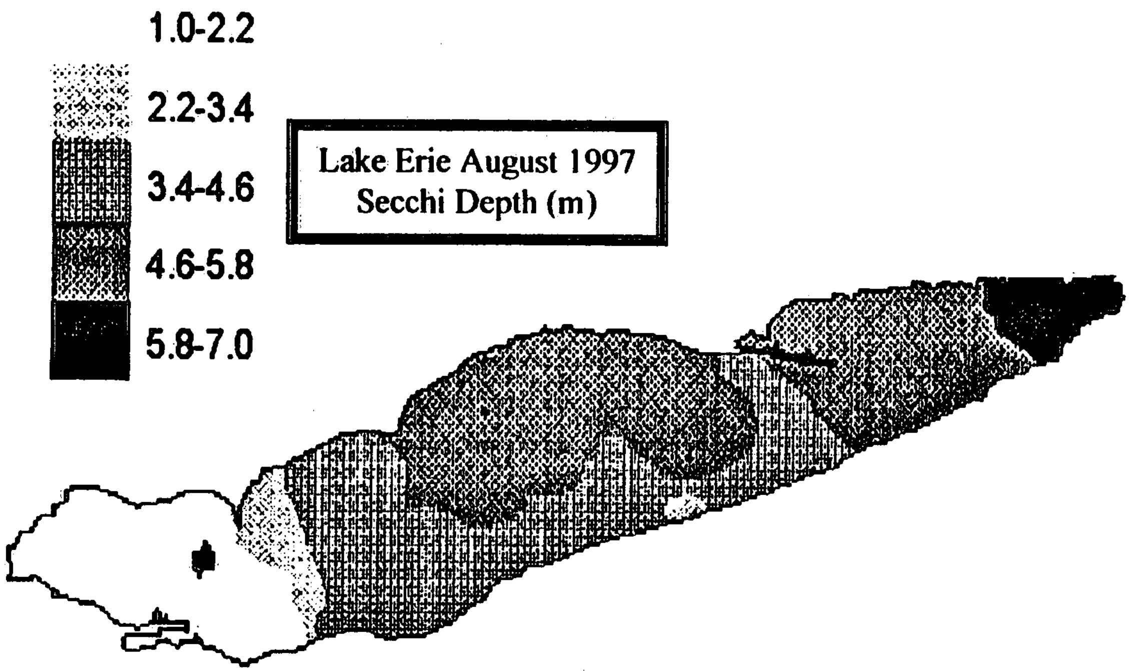
- Transparency varies from month to month and the pattern changes.

Transparency Distribution



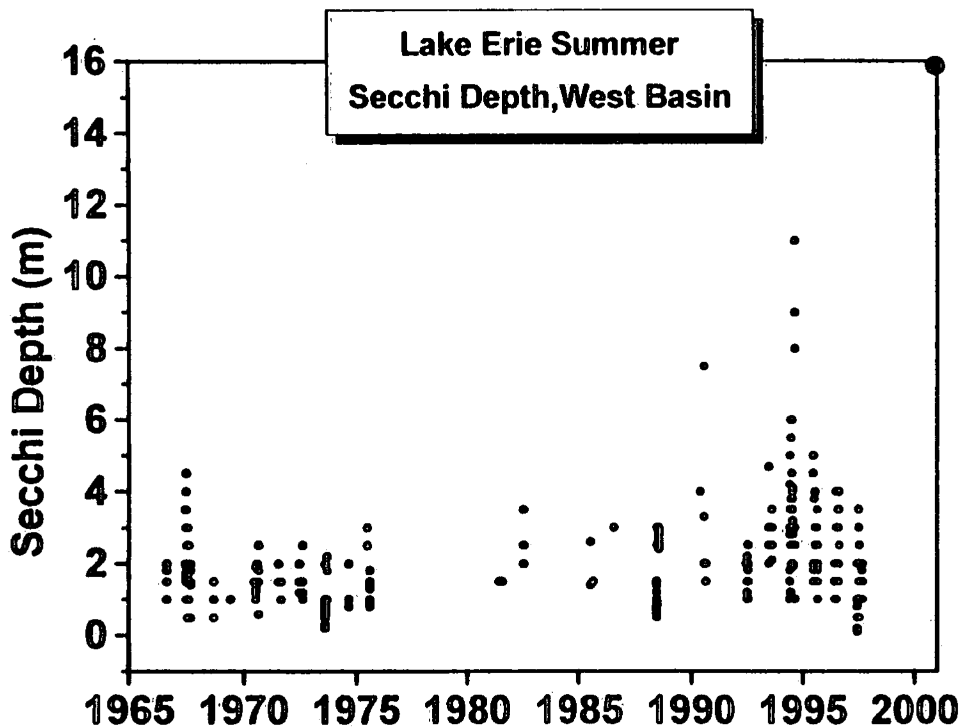
- Transparency varies from month to month. In this case some more turbid water was found in the east basin.

Transparency Distribution



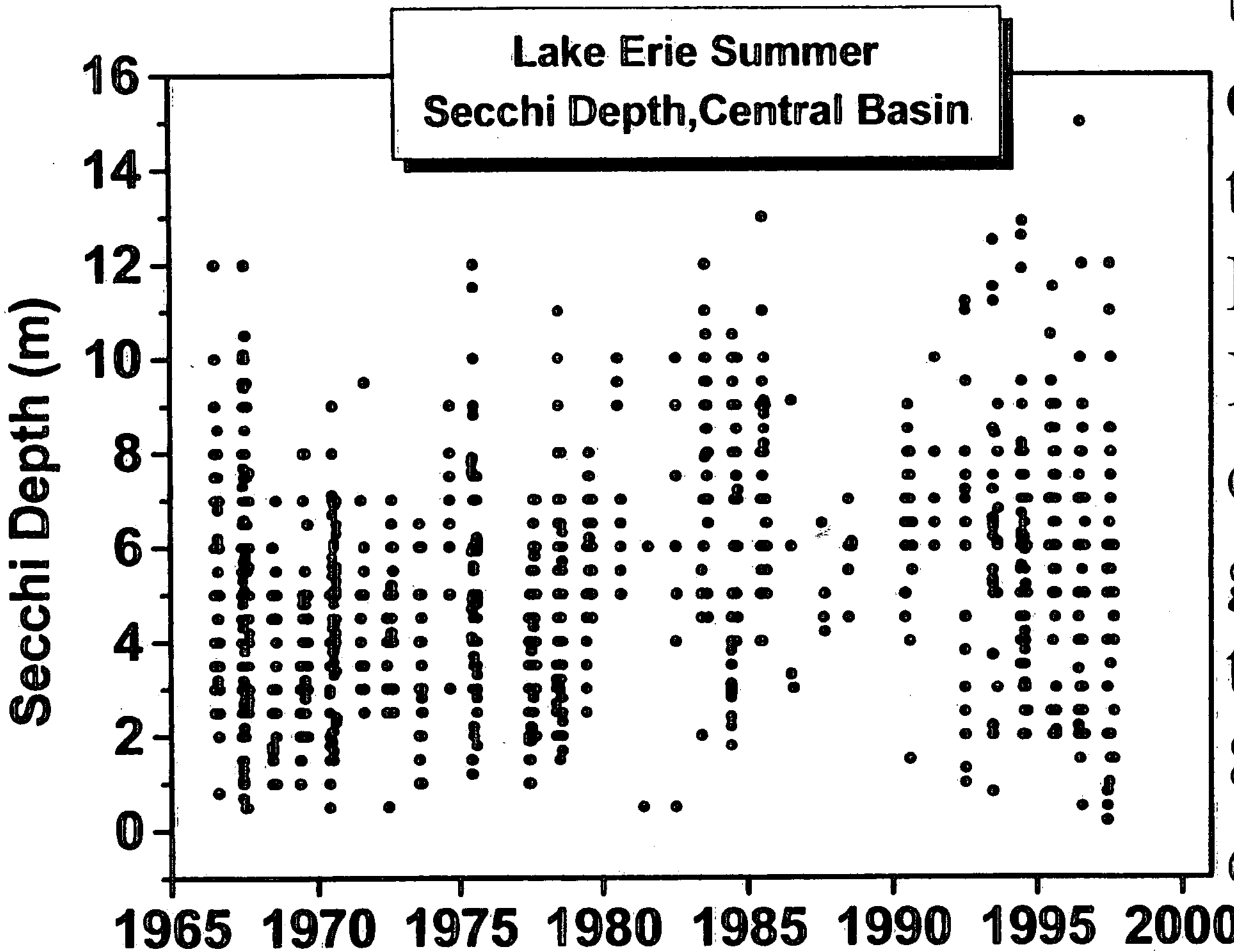
- There is a west to east gradient in water transparency. Offshore water is very clear except in the West Basin

Transparency West Basin



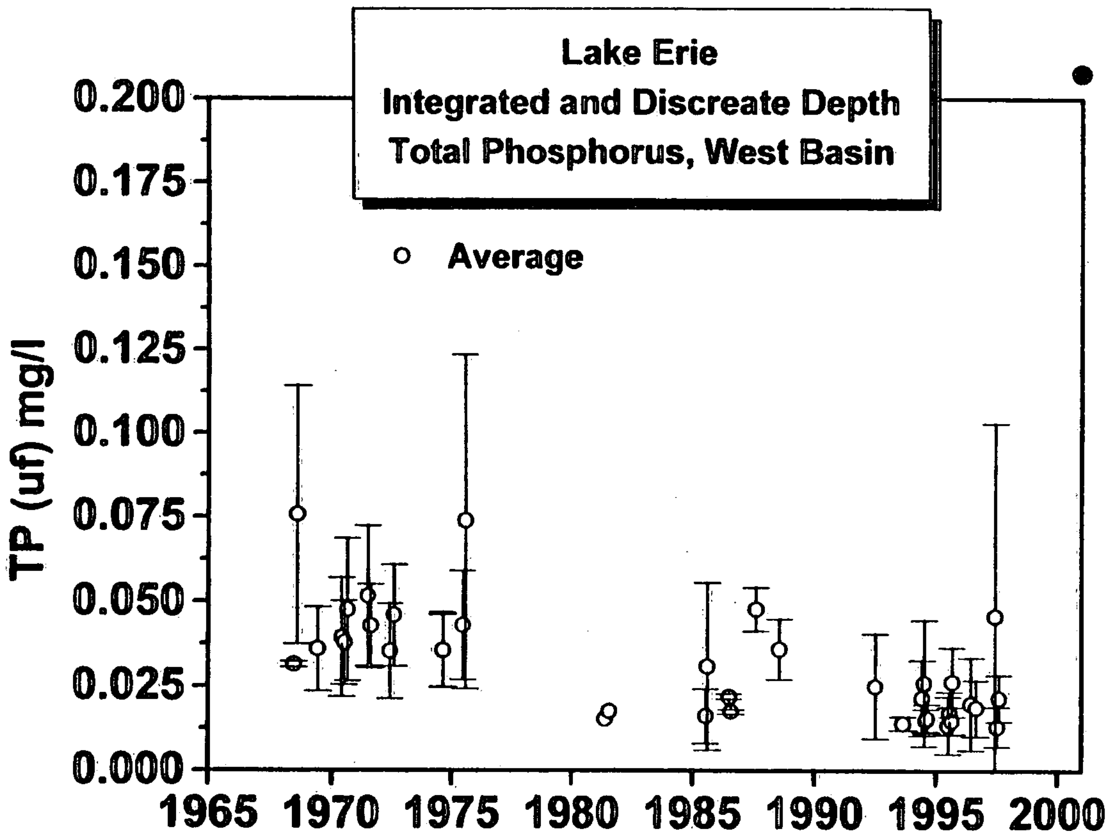
Since 1990 transparency has increased in some areas. About half of the observations are similar to those of the 1970s

Transparency Trend Central Basin



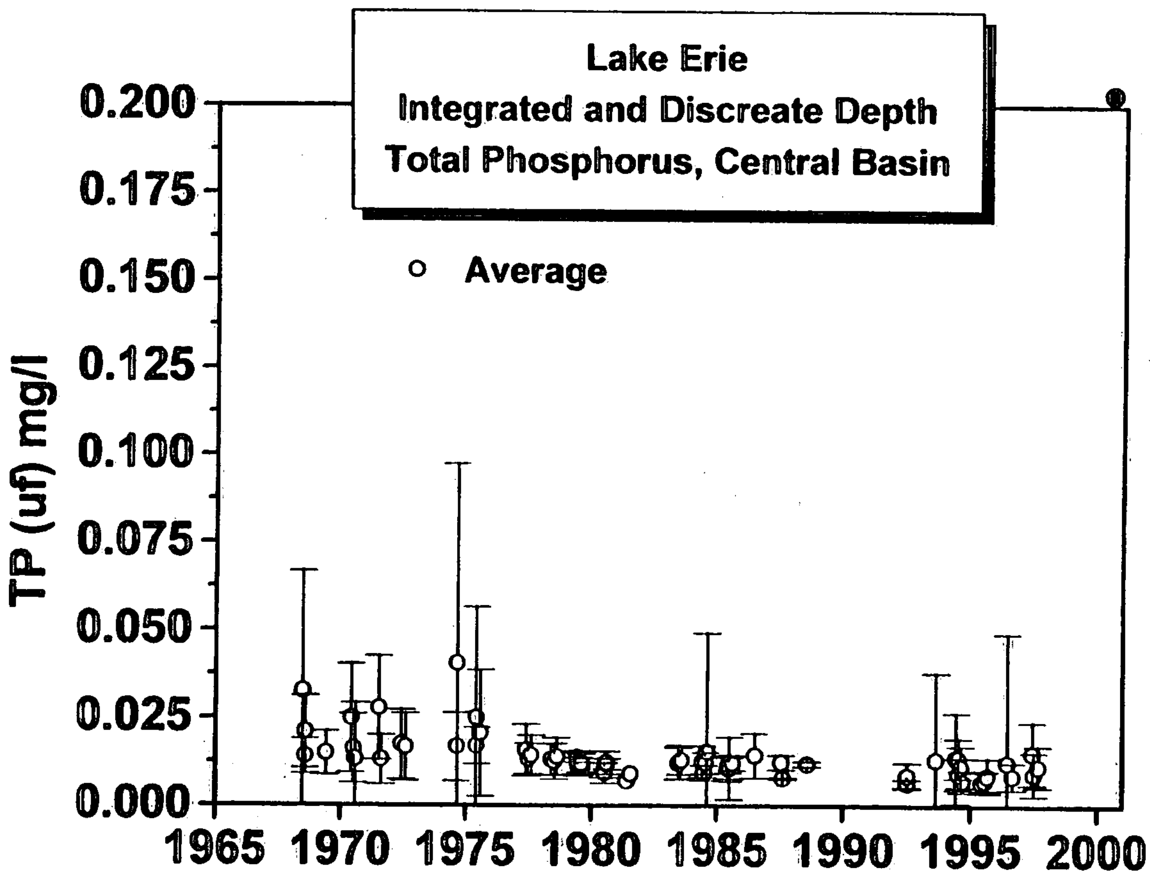
- Summer transparency is quite variable in the Central Basin. Individual observations of good transparency of 8-10 M occurred decades ago.

Phosphorus Trend West Basin



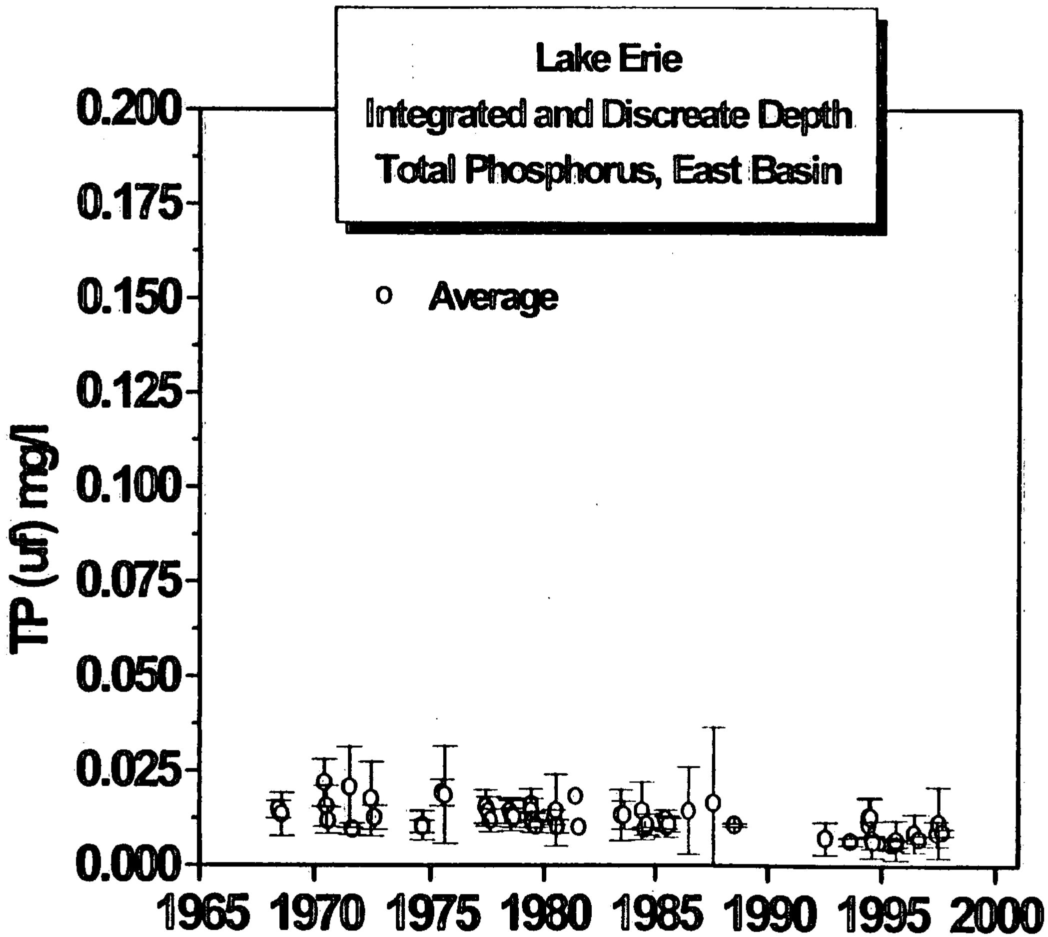
- The biggest decline of total P in the lake has been in the West Basin from about 40 ug/L to about 20 ug/L in the summer

Phosphorus Trend Central Basin



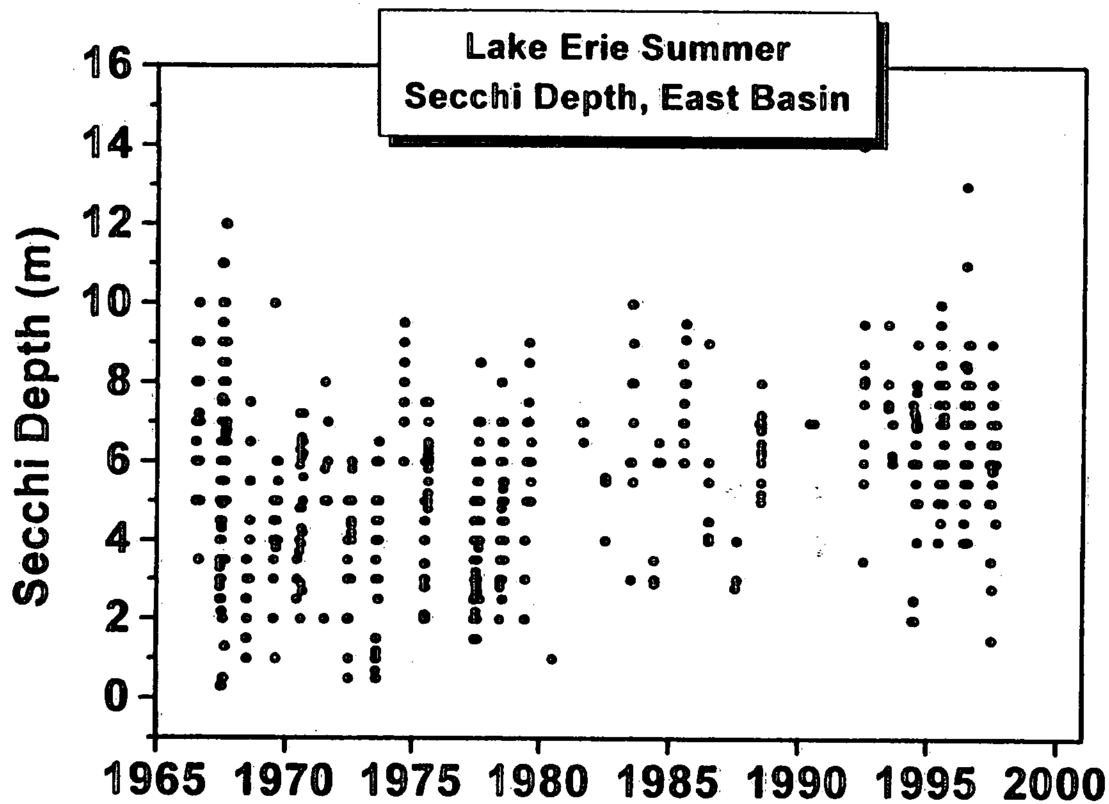
Summer total P has declined from about 13 ug/L to about 10 ug/L. Summer values are the lowest in the year.

Total Phosphorus Trend East Basin



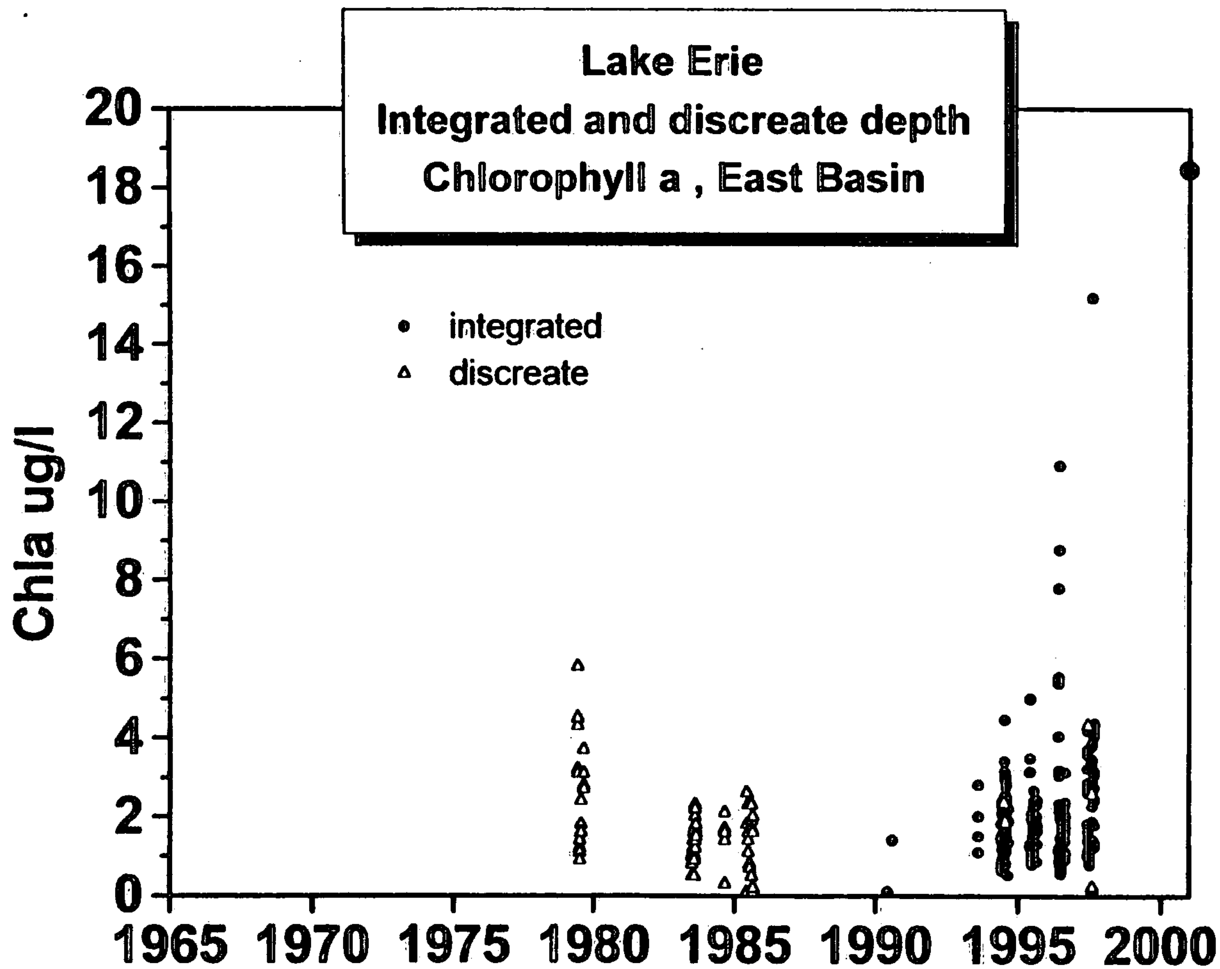
- Total P has decreased in the East Basin.
- The survey averages seem to be increasing in the last two years up to about 10 ug/L..

Transparency Trend East Basin



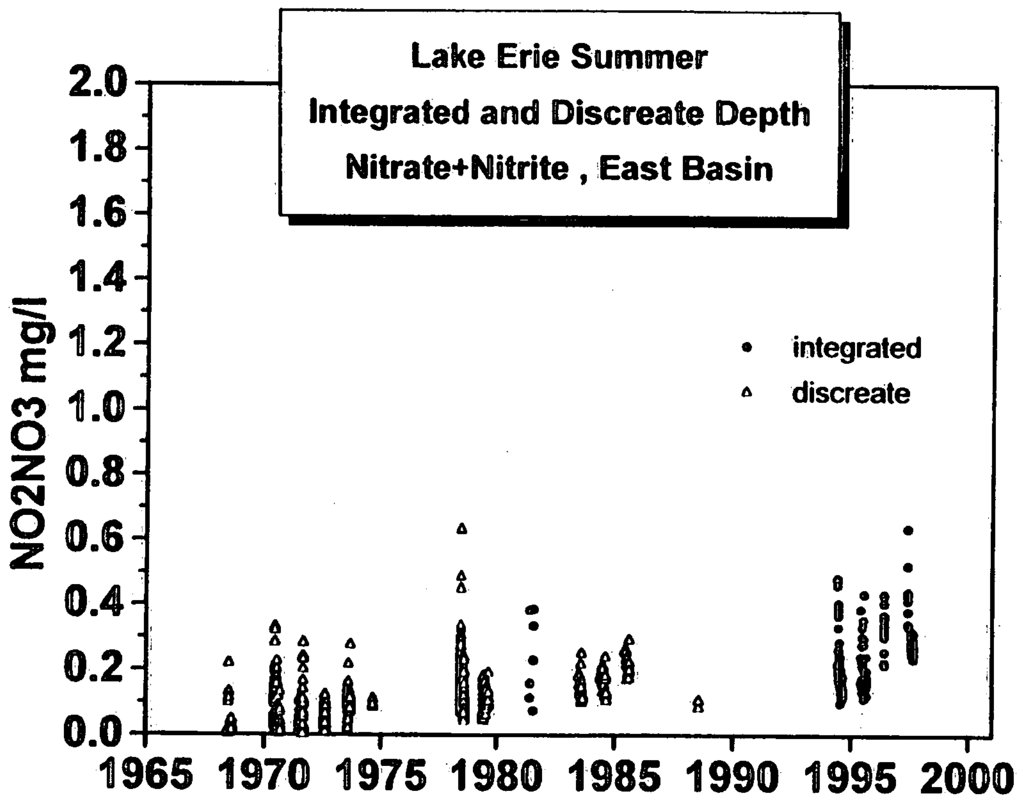
- Offshore transparency in the summer has increased slightly - many observations are as before.

Chlorophyll Trend East Basin



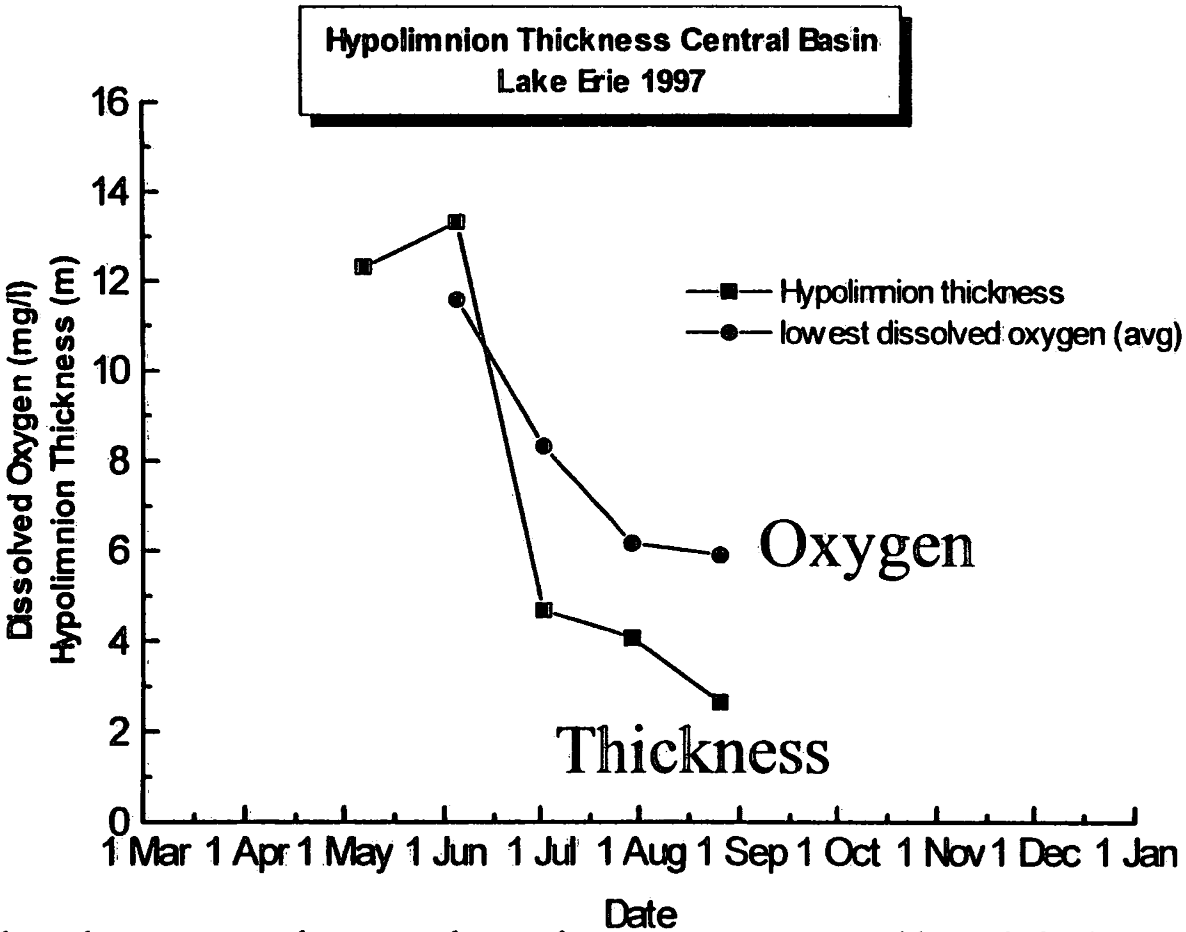
Low chlorophyll has been seen before in the East Basin.

Nitrate Trend East Basin



- Nitrate, another nutrient seems to be increasing in the East Basin.

Central Basin Oxygen



The bottom layer has been unusually thick this slows down the oxygen depletion rate.

- For the last 4 years oxygen has been high enough to support fish in the bottom waters of the Central Basin. As late as 1990 this water had no oxygen.

Littoral Benthic Photosynthesis and Respiration Studies in Lake Erie in 1997

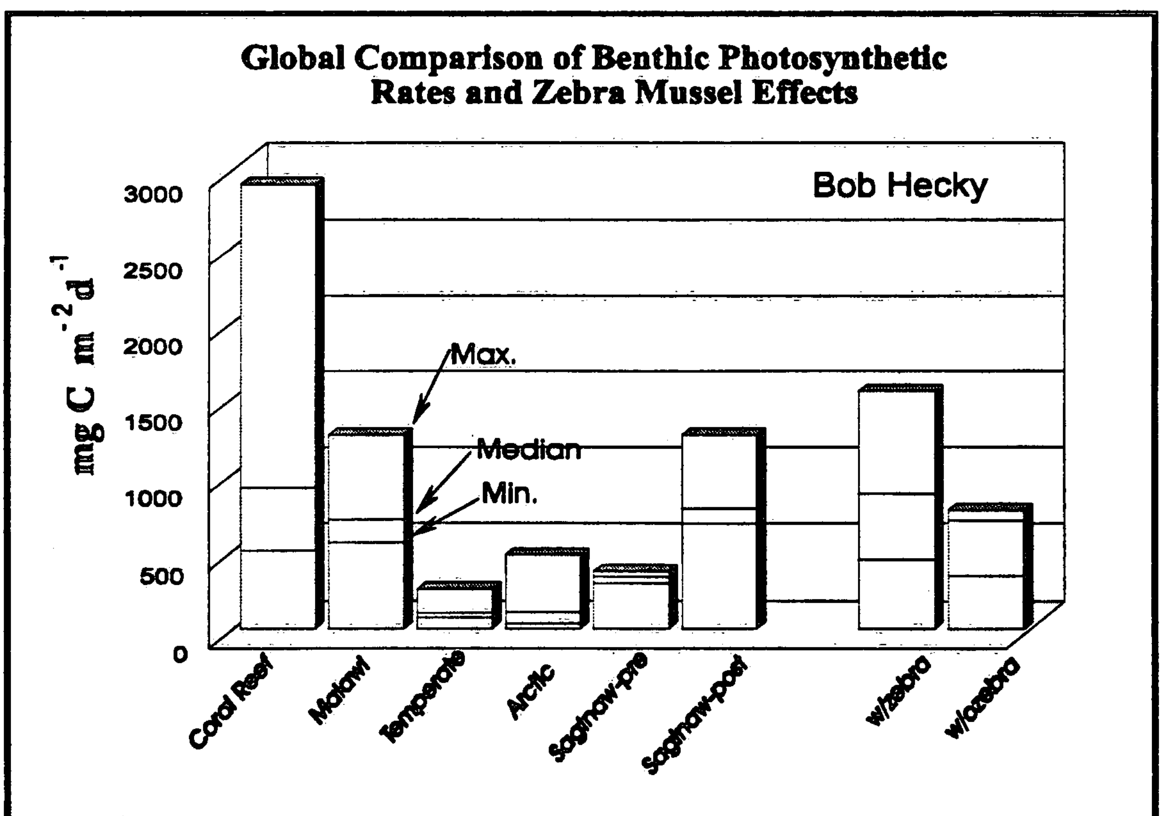
by R.E. Hecky, Environment Canada, National Water Research Institute, Burlington, Ontario

Introduction: The zebra mussel invasion has increased light penetration in Lake Erie because of the animals high abundance and high filtration rate. The mussel feeds on fine particulate matter from the water column, and its activities have been invoked to account for reduced phytoplankton abundance in Lake Erie. Littoral algae and macrophytes should benefit from the increased light penetration through an expansion to greater depths of the littoral area which can sustain photosynthesis. This effect has been documented in Saginaw Bay through photosynthetic measurements using radiocarbon at constant depths before and after mussel invasion. A second affect that zebra mussels can have is to cause a reallocation of recycled phosphorus from pelagic phytoplankton to the littoral benthos through the mussels excretions and often inefficient feeding (production of pseudofeces). In 1997 a programme of measurement of benthic algal photosynthesis was initiated at Long Point Bay in eastern Lake Erie with the intent to develop a model of benthic algal photosynthesis and its response to physical and biogeochemical changes imposed by the successful zebra mussel invasion. Primary objectives were: to determine the extent to which enhanced benthic photosynthesis can offset losses of pelagic photosynthesis in Lake Erie, to evaluate the possibility that zebra mussels where enhancing littoral benthic photosynthesis through both improved light penetration and increased nutrient flux, and to determine the extent that the littoral consumers were dependent on benthic littoral photosynthesis. The first year was devoted to methods development and looking at issues of replication and habitat variability. But some insights to the larger questions were gained which should be followed up through future research.

Methods: All measurements were made August 16-28 1997 with diving support from Technical Operations of the National Water Research Institute. Photosynthetic driven changes in both DIC (dissolved inorganic carbon) and O_2 where followed over incubation periods from six to 12 hours in light and dark *in situ* plexiglass chambers using gas chromatographic techniques for DIC and Winkler titrations for oxygen concentrations. Both methods gave comparable results with a mean productivity quotient of 1.2 for all incubations. The oxygen chambers gave better sensitivity at lower rates. Incubations were made on rock substrata from 2 to 3 m depth with and without variable numbers of zebra mussels in the chambers and at 6-8 meters depth on sand with and without the macroalga *Chara* in the chambers at natural densities. Incubations at a site were run over 24 to 48 hours, with water renewal (resetting of the chambers on the same incubated area) in experiments lasting over 24 hours. Surface light was measured and light extinction was measured with appropriate LiCor sensors.

Results: The attached figure gives results for rock incubations only and compares Lake Erie results with other published data for gross benthic photosynthesis at 2-5 meter depths. Lake Erie median benthic photosynthetic rates compare well with median values reported from Saginaw Bay (radiocarbon method) in Lake Huron after mussel invasion, and they are well above most temperate softwater and cold water lakes measured with comparable methods. Median values in Lake Erie (in August) compare well with median values for tropical Lake Malawi which has similar ambient DIC concentrations and was measured with comparable methods. In fact the median Lake Erie values (in August) are comparable to the most productive benthic habitats know which are coral reefs. The most unexpected result was that even in chambers with complete coverage of the rock surface by mussels that the enclosed areas were giving net photosynthesis over 24 hours and that chambers with mussels present had much higher gross photosynthetic rates especially over 48 hour incubations than chambers without mussels present.

Discussion: It is too early to reach substantive conclusions about the effect of zebra mussels on littoral benthic photosynthesis in Lake Erie, but the results to date support the hypothesis that the results may have been quite positive. Still to be determined are the spatial and seasonal variation of these rates and a light response relationship which could be used to model the lake wide effect. Also in the future, the dependence of consumers on benthic algal photosynthesis and the species of benthic algal which are benefitting from the putative enhanced P flux, e.g. diatoms or Cladophora, need to be determined. Examination of stable isotope data (unpublished Mark Servos, NWRI) demonstrated that there likely is a littoral food web dependent on benthic algal photosynthesis which is isotopically heavier than phytoplankton productivity. This isotopic signature can be used to elucidate the littoral species which should be benefitting from the increased energy flow through the benthic algae. An additional beneficial aspect of this enhanced energy flow through benthic algae and consumers is that the top consumers will likely have lower contaminant burdens compared to pelagic food webs if patterns observed in other great lake systems hold true in Lake Erie (e.g. Lake Malawi). Future research will use stable isotopes to define the littoral food web in Long Point Bay and western Lake Erie, develop a light dependent model for benthic photosynthesis, and examine the interaction between zebra mussels and the nuisance alga Cladophora which shares the rocky substrate (including zebra mussel shells) with the mussels.



Recent and Planned Research Activities for western Lake Erie
Aquatic Ecology Research Group
University of Windsor
March 1998

Jan Ciborowski

Benthic changes in western Lake Erie with especial reference to *Hexagenia* mayflies

Hexagenia mayflies were eradicated from western Lake Erie in the 1950s. Adult *Hexagenia* were observed at isolated locations in 1991 following 20 years of reduced phosphorus inputs and the invasion of zebra mussels. Semi-annual benthic surveys have documented expansion of the range of *Hexagenia* larvae from west to east, and two- to four-fold annual increases in density, to >2,000 larvae m^{-2} at some sites in 1997. Since 1994, adult *Hexagenia* have been observed throughout western Lake Erie but in only isolated shoreline locations in central or eastern basins. Continued absence of larvae north of Pelee Island and south of Middle and East Sister islands suggests that benthic conditions may be limiting recovery in some regions. Size frequency distributions of larvae in May (before emergence) of each year change as a function of time since colonization. Sites apparently colonized within one year harboured almost exclusively large larvae. Sites colonized for 2 or more years exhibited distinct size bimodality or only smaller larvae. Possible explanations are that 1) density-dependence is strong; 2) eggs may become buried to anoxic depths in sediments and subsequently re-exposed by either a) wave-action; or b) bioturbation activity of larger larvae. Any of these mechanisms may slow development, limit growth, and ultimately impose a two-year life cycle.

Our surveys in 1997 clearly documented the limits of *Hexagenia* distribution. Boundaries seem to be clearly demarcated both by qualitative attributes of the sediment and by benthic community composition. Sites that were devoid of *Hexagenia* supported the highest densities of *Chironomus* in the basin. Jocelyn Gerlofsma found *Hexagenia* eggs in cores from sites lacking larvae, which also suggests that absence is due to environmental rather than limits to colonization. In 1998 we hope to deploy continuous oxygen-temperature recorders in 5 or 6 locations to document the spatial extent and pattern of hypoxia as related to prevaling weather conditions and sediment traps to estimate epibenthic oviposition rates.

Postdoctoral Fellow Margo Chase is compiling historical records of epibenthic oxygen conditions that can be related to weather conditions. We hope to reconstruct the *Hexagenia* colonization and population growth pattern as regulated by hypoxia and temperature, and ultimately predict spatially explicit population density and growth. A new student will begin to investigate direct interactions among profundal groups (*Hexagenia*/*Chironomus*, *Hexagenia*/tubificids).

With Trefor Reynoldson's help, in 1997 we conducted a multisampler comparison to give improved conversion factors that will better let us reconstruct community composition and density estimates from older studies that used a diversity of sampling techniques.

We will also continue our monitoring of composition and contaminant burdens of the midsummer emergence of adult aquatic insects on Middle and East Sister islands.

Lynda D. Corkum

Ecology, behaviour, and reproductive habits of the exotic round goby, *Neogobius melanostomus*, and its interactions with other biota: predictions for Lake Erie.

Non-indigenous species (NIS) modify energy flow, habitat, and community composition, and lead to the demise or reduction in growth and survival of native species. *Neogobius melanostomus* (round goby) and *Proterorhinus marmoratus* (tubenose goby), two NIS that likely arrived in ballast water discharged from ships originating in the Black and Caspian seas, were found in the St. Clair River in 1990. The larger, more aggressive round goby now occurs in all of the Great Lakes. The most concentrated populations (up to 40 fish per m^2) of round gobies occur in the Huron/Erie corridor, western and south-central Lake Erie and southern Lake Michigan. Reasons for the proliferation of round goby populations include the ability of larger (TL > 7 cm) gobies to eat zebra mussels and the fact that individual gobies spawn repeatedly throughout spring and summer. Male round gobies guard nests of eggs that are laid by several females. My students (Dubs, MacInnis, Ray, Wickett) and I are the first in Canada to document habitat preference (rubble), age structure (age 0, 1, 2), survivorship/growth (rapid growth & early maturity) and spawning season (May to August) of round gobies in the Detroit River and their negative effects on the native mottled sculpin. We expect round gobies to have significant effects on the benthic community and on other benthivorous fishes.

Results from our videography of shipwrecks (artificial reefs) in western Lake Erie in 1997 show that round gobies spawn at greater depths (> 10 m) than previously demonstrated (1-2 m). Our initial models will test implications of round gobies spawning in deep waters. Is predation risk to round goby nests similar in near and off-shore habitats? Do parental males structure the composition of round goby populations? Do abiotic factors (habitat structure, water temperature, disturbance) alter reproductive success between on and off-shore habitats? Field studies will test differences in species composition with habitat complexity among several shipwrecks. Windermere traps will be used to capture live fish for manipulation (male removal) experiments. Predation risk will be estimated using videography. Artificial nests will be used to examine spawning success in different habitats.We anticipate that the recruitment of round gobies will increase substantially in Lake Erie owing to the presence of artificial (shipwrecks) and natural reefs. Our techniques and surveys are also amenable to the detection of invasion by ruffe (*Gymnocephalus cernuus*) to the lower Great Lakes.

Spatial distribution, contaminant burdens and population biology of the burrowing mayfly, *Hexagenia*, in Lake Erie

Monitoring Contaminants: *Hexagenia* populations, eradicated in the 1950s by anoxia, are recovering in the western basin of Lake Erie. I use adult *Hexagenia* mayflies to monitor exposure of organisms to organochlorines and metals in aquatic habitats. An empirically derived contour map of *Hexagenia* body burdens of PCBs in the western Lake Erie indicates a contaminant gradient from west to east with decreasing concentrations towards both northern and southern shorelines of the lake. Highest PCB concentrations reflected local sources of contaminated sediments. *Hexagenia* are efficient monitors of organochlorines.

Michelle Dobrin and I have determined if fluctuating asymmetry in insect wings and appendages of *Hexagenia rigida* adult males would serve as an economical biomonitor of contaminant stress in aquatic habitats. A high degree of asymmetry should reflect environmental stress. Adults were collected at six sites, representing a gradient of contamination in the Detroit River and western Lake Erie as well as a reference site (Balsam Lake). There were no significant differences among 30 variables examined, indicating that lack of symmetry was unrelated to contaminant stress. Asymmetry was lowest for variables related to fitness (area of forewing and forcep length).

Present Studies: In the summer of 1997, my student (Doug Laing) and I estimated density of adult emerging *Hexagenia* populations spatially and temporally in the western basin of Lake Erie. These data along with estimates of nymphal benthic density will be combined to predict spatial distributions of *Hexagenia* in the basin, Margo Chase (post-doc 1997/98) is collaborating with Jan Ciborowski and I to derive a physiological/ecological based model of *Hexagenia* development, survival, fecundity and population growth using our existing field and laboratory data.

RECENT PUBLICATIONS:

Corkum, L.D., A.J. MacInnis, & R.G. Wickett. 1997. Reproductive habits in round gobies. *Great Lakes Research Review* 3 (in press).

Corkum, L.D., J.J.H. Ciborowski, & R. Lazar. 1997. Analysis of contaminants in adults of the burrowing mayfly in Lake Erie after population recovery. *J. Great Lakes Res* 383-390.

Ray, W.J. & L.D. Corkum. 1997. Predation of zebra mussels by round gobies, *Neogobius melanostomus*. *Environmental Biology of Fishes* 50:267-273.

, L.D., J.J.H. Ciborowski & R. Poulin. 1997. Effects of emergence date & maternal size on egg development and sizes of eggs and first-instar nymphs of a semelparous aquatic insect. *Oecologia* 111:69-75.

Dubs, D. and L.D. Corkum. 1996. Behavioural interactions between the round goby (*Neogobius melanostomus*) and the mottled sculpin (*Cottus bairdi*). *J. Great Lakes Res.* 22:838-844.

Kovats, Z.E., J.J.H. Ciborowski, and L.D. Corkum. 1996. Inland dispersal by adult aquatic insects. *Freshwater Biology* 36:265-276.

Doug Haffner

Primary production and contaminant dynamics in western Lake Erie.

Last year Lake Erie work included;

1. Primary productivity in situ, estimates of carbon turnover rate in phytoplankton. Nutrient analysis N, P, alkalinity; plus temperature, DO, conductivity. redox, pH, water column measures, light penetration.

2. Contaminant dynamics in plankton, quantifying trophic dilution phenomena.

3. Distributions of PAHs in plankton and invertebrates.

4. Continued food web distributions of OCs.

All work was done near Middle Sister Island.

This year I will try to continue the above studies with emphasis on PAH trophodynamics and toxicity. Will initiate developing a model to predict PAH dynamics in aquatic ecosystems in collaboration with Heather Morrison DFO.

Hugh MacIsaac

Ecology and biogeography of invading species

I plan on intensifying our efforts to identify new exotic species in the Lake Huron -- Lake Erie corridor. We collected through this area in Sept-Oct 97 and believe (almost with certainty) that we have 2 new species: *Corophium mucronatum* (eastern European amphipod tolerant of brackish waters) and *Pentapedilium exactum* (an eastern European chironomid). The former could be potentially of great importance. My Ukrainian postdoc identified both. As well, we intend to continue our work on *Echinogammarus* looking at potential interactions between it and *Gammarus fasciatus* in west Erie. The former is now very common at study sites in Ohio and Middle Sister Island. It and *Gammarus* have relatively inverse abundances in relation to depth (*Echinogammarus* at greater depths). We intend to continue work on determinants of *D. bugensis* in Lake Erie - its distribution continues to move west (we found a few specimens in the lower Detroit River this past summer). Also, we have been monitoring western Erie for 1 year waiting for the appearance of *Daphnia lumholtzi*. It is now found in reservoirs in eastern and western Ohio and should be able to get into west Erie soon (because of its relative turbidity, the species should do best in this basin in any of the Great Lakes).

I am continuing uni- and multivariate analysis of *Bythotrephes* distributions in Eurasia and Ontario.

Peter Sale

Dynamics and regulation of fish populations in western Lake Erie

The Sale Lab at the University of Windsor will continue research on fish in western Lake Erie during 1998. Our research interests are in young fish (age-0 and 1) survival and growth at the individual and population levels. Research at the population level will focus on developing a better description of growth rates, size-dependent mortality, and feeding in yellow perch (Pierce flavescens) to determine if the faster or slower growing fish in a year class have greater chance to survive until the end of their first summer and survive the winter. Research at the individual level has examined alternate techniques to describe fish health or condition. We've used non-traditional techniques that characterize body dimensions using body proportion ratios (e.g., head length:body length ratio) in yellow perch, and we have also characterized blood cell production (erythropoiesis) as a new surrogate to describe growth in rock bass (Ambloplites rupestris), bluegill sunfish (Lepomis macrochirus), and pumpkinseed sunfish (Lepomis gibbosus). Both approaches were tested relative to measures of fish condition through estimates of daily growth rates using fish otoliths.

Research during 1998 will refine our understanding of the use of erythropoiesis as a surrogate for growth in rock bass and investigate the use of truss analysis (cross-dimensions) as an alternate technique for condition assessment in yellow perch. Population-level investigations with this species will also continue. Fish collections will be made bi-weekly at multiple locations on the north shore of western Lake Erie during 1998.

Occurrence of Cladophora along the north shore of eastern Lake Erie.

T. Howell, Environmental Monitoring and Reporting Branch, Ontario Ministry of Environment. 125 Resources Rd., Etobicoke, Ontario M9P 3V6

The cycle of growth, detachment and shoreline-fouling by the benthic alga Cladophora has been a feature of the lower Great Lakes for decades. Reductions in phosphorus loadings in the 1970's have alleviated the Cladophora problem, however, Cladophora continues to be abundant in certain areas. In July 1995, 16 sites on the north shore of eastern Lake Erie were surveyed to determine the amounts of Cladophora present over areas of rocky bottom.. Beyond providing recent monitoring data, a purpose of the study was to explore conditions and develop hypotheses that might account for the seemingly paradoxical condition of nutrient-related shoreline fouling at a time when open-lake P levels in the eastern basins were near Great Lakes Water Quality Agreement objectives for P.

The sites were extensively covered by lawns of Cladophora. The surface coverage averaged from 60 to 100% over the 0.5 m to 1.5 m depth among sites. Median thickness ranged from ~5 cm to ~20 cm. Median thickness was ~10 cm or greater at seven sites. The shoreline adjacent to the sites was fouled by decaying mats of washed up Cladophora at several sites. At other sites little adverse impact was apparent at the time of the survey. The concentrations of phosphorus and nitrogen in Cladophora tissue suggested that growth was highly phosphorus limited at most sites.

The observations collected over the 1995 survey suggested that: i) the ambient nutrient regime in the nearshore zone was sufficient to sustain growth of Cladophora , ii) the greater than average abundance of Cladophora at some of sites was likely due to a local source of nutrient enrichment, iii) there was adequate Cladophora at some locations to cause shoreline fouling, and, iv) Cladophora growth is likely to be responsive to changes in P loading, both increases and decreases.

A numbers of questions were also suggested by the survey. To what extent is the ambient nutrient regime in the immediate nearshore affected by shoreline inputs of nutrients; does this account for the abundance of Cladophora? Dreissenid mussels and Cladophora coexist intimately in the littoral zone. Do nutrients derived from the wastes of dreissenid mussels contribute to the nutrition of Cladophora? As an attached alga, the amount of stable substrate in a favorable light regime is a key factor determining the overall abundance of Cladophora. In eastern Lake Erie there is considerable rocky bottom between 5-20 m depth. Have recent increases in water clarity altered habitat availability for Cladophora?

Identifying Factors that Constrain Phytoplankton Growth and Standing Crop in the Great Lakes: Trace Metals Revisited

R. Michael L. McKay, Bowling Green State University, Bowling Green, OH

Low availability of Fe has been identified as the proximate factor limiting productivity in the equatorial Pacific and possibly other "high nutrient-low chlorophyll" oceanic regions. Limitation by other trace metals has been postulated and is currently under investigation. In striking contrast, the major role played by phosphorus in regulating primary production in lakes is a cornerstone in the foundation of limnology. As a result, the potential for trace metal limitation in the Great Lakes has received only sporadic attention. In particular, for much of the past decade, very little attention has been afforded to the topic of bioactive trace metals in the Great Lakes. Several recent findings, however, have given cause for a reexamination of trace metals as a factor constraining productivity and phytoplankton standing crop in the lakes. I will outline these findings and present rationale in support of future studies of trace metal limitation in limnetic ecosystems.

SUMMARY OF RESEARCH ACTIVITIES ON LAKE ERIE (1994-97) FOCUSING ON TRACE METAL/PLANKTON INTERACTIONS:
FOR DISTRIBUTION AT *LAKE ERIE SCIENCE DAY* (CCIW, MARCH 5 1998)

Michael R. Twiss
Department of Marine Chemistry and Geochemistry
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Collaborators: J.-C. Auclair, INRS-Eau, Université du Québec; P.G.C. Campbell, INRS-Eau, Université du Québec; M.N. Charlton, NWRI; M. Saito, WHOI.

OVERVIEW

It has become increasingly evident that planktonic organisms are fundamental components of the biogeochemical cycle of many trace elements in surface waters. In some cases, the growth of plankton may be limited by trace metals from either a nutritive or toxic standpoint. Changes to our current understanding of trace metal interactions with plankton in the Laurentian Great Lakes of North America have been stimulated by two major factors: i) advances in trace metal sampling and analysis and ii) the discovery of the ecological significance of the microbial food web. First, the application of clean sampling and processing techniques has demonstrated that very low total dissolved concentrations of trace metals prevail in surface waters of the Great Lakes during summer stratified conditions (Nriagu et al. 1993, 1996)). These low concentrations of trace metals are attributed to the sorption of these elements from solution by particles (*scavenging*) and the subsequent sedimentary loss of these particles. Secondly, our comprehension of the microbial food web has challenged our comprehension of the fate of particles and the trace elements that they scavenge in surface waters.

Recent evidence suggesting Zn (Nriagu et al. 1996) and Fe (Twiss, Auclair and Charlton) limitation of phytoplankton growth suggests that the "chemical ecology of trace metals" in surface waters may be a key factor in determining the primary productivity of Lake Erie. In light of the stimulatory effects of low levels of Fe additions, I would strongly suggest that experimentalists looking at other forms of growth stimulation (light, macronutrients) employ trace metal clean techniques in order to avoid confounding effects in the event of trace metal contamination of a water sample!

The following series of abstracts describes work done on Lake Erie over the previous four field seasons. The studies address scavenging, microbial food web effects on trace metal geochemistry, physiological responses to Fe and phosphate additions, and analytical measurements of essential trace elements in solution - the first step in characterizing the chemical speciation of trace metals in Lake Erie surface waters and beginning the task of deciphering the chemical ecology of this environment.

One caveat to emphasize here is that the focus of these studies is the surface waters of Lake Erie during stratification. During this time, the causal agents affecting such things as trace metal limitation are expected to be exacerbated due to reduced metal inputs from rainfall, and the reduced contact with bottom waters and the sediment as seen during isothermal conditions.

TOPICS

A. Scavenging
B. Fate of trace metal in the microbial food web
C. Linking ecological and geological fates
D. Evidence for trace metal limitation of phytoplankton productivity
E. What next?

A. Scavenging

Scavenging of ^{137}Cs, ^{109}Cd, ^{65}Zn, and ^{153}Gd by Plankton of the Microbial Food Web in Pelagic Lake Erie Surface Waters (Twiss and Campbell, submitted)

Inorganic dissolved ^{137}Cs, ^{109}Cd, ^{65}Zn and ^{153}Gd were added, at concentrations well below their respective solubility limits, to screened water (<210 μm) sampled from the pelagic epilimnion of Lake Erie during the summers of 1994 and 1995. The hypotheses tested were that scavenging occurs in all of the ecologically significant size fractions that comprise the microbial food web (picoplankton, 0.2-2 μm; nanoplankton, 2-20 μm; microplankton, 20-210 μm), and that scavenging by plankton is directly related to the respective particle-reactivity of the elements (Gd > Zn > Cd >> Cs). Size-selective filtration at intervals over periods of 22-30 h established that picoplankton and nanoplankton were the dominant scavenging phases in this environment. Scavenging of ^{153}Gd, ^{65}Zn and ^{109}Cd by plankton was more similar than predicted on the basis of their anticipated particle-reactivity and ^{137}Cs was weakly scavenged. Except for the picoplankton, ^{65}Zn was the element most readily scavenged by the plankton size fractions. Anomalously high accumulation of ^{109}Cd in the picoplankton may reflect the sorption of this element by calcite associated with autotrophic picoplankton or a metabolic requirement for Cd. These experiments quantify the partitioning of trace metals within the plankton of the microbial food web (0.2-210 μm), a dynamic community of particles that dominates the seston in the pelagic surface waters of Lake Erie during thermal stratification, and suggest that plankton dynamics should be considered in predictions of the geochemical fate of trace metals in this environment. Earlier studies of ^{109}Cd, ^{65}Zn scavenging in Lake Michigan (Parker et al. 1982) treated particles <28 μm as "mainly nonliving detrital material and mineral particles", especially during summer months. We know that particles <28 μm can have significant geochemical influences over trace metal fates.

B. Fate of Trace Metal in the Microbial Food Web

Regeneration, Recycling, and Trophic Transfer of Trace Metals by Microbial Food Web Organisms in the Pelagic Surface Waters of Lake Erie (Twiss, Campbell and Auclair, 1996)

Rapid regeneration of ^{109}Cd and ^{65}Zn from their picoplankton prey into the dissolved phase by microzooplankton was observed in water sampled from the pelagic surface waters of Lake Erie (summer 1994 and 1995). Trace metals were added to grazing (lake water <210 μm) and control (lake water <0.2 μm) treatments in the form of radiolabeled-Synechococcus. Picoplankton (0.2-3 μm) were grazed heavily by consumers in the nanoplankton (3-20 μm) and microplankton (20-210 μm) size classes, collectively referred to as microzooplankton, as confirmed by dilution assays used to measure grazing activity independently. The majority of consumed trace metals were regenerated into the dissolved phase (<0.2 μm) but some trophic transfer of ^{109}Cd and ^{65}Zn from radiolabeled-prey into the nanoplankton and microplankton did occur: ^{65}Zn

was 2.9 and 2.5 times more efficiently transferred than ^{109}Cd into the microplankton and nanoplankton, respectively. Recycling of regenerated ^{109}Cd back into plankton biomass was greater than that for ^{65}Zn. Grazing by microzooplankton influenced the molecular size distribution of regenerated trace metal in the dissolved phase (77 ± 6% ^{109}Cd <5 kD; 8 ± 24% ^{65}Zn <5 kD). These results, and those obtained in the laboratory (Twiss and Campbell 1995), show that microzooplankton grazing will tend to prolong the residence times of such metals as Cd and Zn in the pelagic surface waters of large lakes.

C. Linking Ecological and Geological Fates

TRACE METAL CYCLING IN THE SURFACE WATERS OF LAKE ERIE: LINKING ECOLOGICAL AND GEOCHEMICAL FATES (Twiss and Campbell, submitted)

The highly productive plankton that comprise the microbial food web are ideally suited to trace metal scavenging, the removal of particle-reactive trace metals from the aqueous phase. Scavenging is considered to be the key factor controlling the concentrations of trace metals in the surface waters of large lakes during thermal stratification. Observed characteristics of the various plankton size fractions in the microbial food web (ability to scavenge trace metals from the dissolved phase; potential to regenerate these metals back into the dissolved phase; population dynamics) were incorporated into a dynamic model of trace metal cycling, as affected by microbial food web activity. The model yields estimates of epilimnetic trace metal residence times under the assumption of steady state conditions: Cs = 514 d, Cd = 19 d, Zn = 24 d, Gd = 50 d. These trace metal residence times were significantly greater than the residence time predicted when microzooplankton grazing activity was eliminated from the model simulations (Cs, +46%; Cd, +62%; Zn, +58%; Gd, +84%). The increase of residence time by microzooplankton grazing is attributed to the trace metal regeneration that results from incomplete assimilation by the grazer of metal previously scavenged by the prey item. The results illustrate the important influence of the microbial food web activity on the geochemical fates of trace metals in the pelagic surface waters of large lakes during thermal stratification.

D. Evidence for Trace Metal Limitation of Phytoplankton Productivity

LIMITATION BY IRON OF PHYTOPLANKTON IN PELAGIC LAKE ERIE
(Twiss, Auclair, and Charlton; unpublished)

During July 1996 and 1997, enrichment experiments were conducted to determine the response of the Lake Erie phytoplankton community to Fe (1996) and Fe-P (1997) additions using trace metal clean sampling techniques in a Class 100 mobile laboratory aboard the CCGS Limnos. Lakewater samples were pre-filtered (<20µm) to remove large grazers, enriched, and incubated in 2-L polycarbonate bottles in a shipboard incubator.

In 1996, biomass accrual (as measured by changes in chl-a) increased by 300% and 30% in the picoplankton and nanoplankton size-fractions respectively, relative to controls. Increases in the picoplankton 14C-assimilation ratios mirrored this increase over the first 24 hours, suggesting a release from Fe physiological limitation. The addition of Zn (0.05 nM and 0.5 nM) had no observable effect in the picoplankton or nanoplankton. This is the first report of Fe limitation in a Great Lakes phytoplankton community. In contrast, Fe enrichment in July 1997, marginally increased or did not result in significantly increased growth relative to P enrichment alone.

We hypothesize that the inter-year difference is related to the more pronounced increase in meta/hypolimnetic entrainment which occurred in Lake Erie in early July 1997 relative to 1996. The frequency and magnitude of wind induced hydrodynamic mixing and increase in epilimnetic thickness appear to be critical in alleviating Fe limitation in Lake Erie.

Note: testing for Fe limitation in the Great Lakes is not novel (Lin and Schelske 1981, Lake Huron; Storch and Dunham 1986, Lake Erie) but the use of trace metal clean techniques in our efforts allows for an unambiguous interpretation of the results, something that is absent in the earlier studies.

TOTAL COBALT AND COPPER CONCENTRATIONS IN LAKE ERIE SURFACE WATERS
(Saito and Twiss, to be presented at IAGLR 98)

Water was sampled at a depth of 5 m using trace metal clean techniques from the eastern, central and western basins of Lake Erie between July 29 and August 30th, 1997. Samples were filtered through 0.2-µm pore sized filters and preserved frozen. Total dissolved cobalt was measured after UV irradiation using cathodic stripping voltammetry/rapid scan techniques adapted from sea water analyses (detection limit 3 pM). Total dissolved Co at Station 23 in the eastern basin, was 151 ± 4 pM (mean ± SD, n = 2). Copper was analyzed in a 0.016 M nitric acid matrix by direct injection into a graphite furnace atomic absorption spectrophotometer. Average total dissolved Cu concentration across the pelagic basins was 9.8 ± 0.8 nM (range 8.6 - 10.8 nM), in agreement with measurements of pelagic Lake Erie surface waters during thermal stratification made by other workers (Nriagu et al. 1996, 13 ± 1 nM; Coale and Flegal 1989, 11 ± 2 nM). These first measurements of Co in Lake Erie using sensitive and clean techniques show that Co levels approach levels found in the open ocean ($10\text{-}10^2$ pM), suggesting potential interactions between phytoplankton and trace metal species.

*Note that cyanobacteria (marine) are not considered to have Zn requirements, rather Co is the analogue for Zn in cyanobacterial proteins (Sunda and Huntsman 1995). Cd can substitute for Co, thereby providing a possible explanation for the anomalous scavenging behaviour of Cd in Lake Erie (see **A** above), especially in light of the low measured total dissolved Co concentrations.*

E. WHAT NEXT?

Continue searching for the conditions of trace metal limitation (Fe, Zn, Co) in pelagic plankton (algae and cyanobacteria). Experiments involve sampling and manipulating water with clean techniques, trace metal additions at realistic concentrations and size-fractionated ^{14}C uptake measurements.

Determine if strong metal-binding ligands are present in pelagic surface waters of Lake Erie, as observed in marine systems. Temporal and spatial changes in Cu-ligand concentration have been correlated with changes in cyanobacterial (*Synechococcus*) abundance (Moffett 1995). Analytical methodology requires competitive ligand exchange-cathodic stripping voltammetry and the search/characterization of an artificial ligand to open a *detection window* for the analysis of natural ligands in Lake Erie water samples. Initial efforts will look for Cu-binding ligands.

ACKNOWLEDGEMENTS

This research was funded in part by GLURF award no. 93-011 to P.G.C. Campbell, an NSERC grant to J.-C. Auclair, and NSERC post-graduate and post-doctorate fellowships to MRT. The assistance of Murray Charlton and David Lean in facilitating cruise work is greatly appreciated.

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Twiss, M.R. and Campbell, P.G.C. Modeling the fate of trace metals in the surface waters of Lake Erie: Linking ecological and geochemical fates. (submitted to *Journal of Great Lakes Research*).

Twiss, M.R., Auclair, J.-C., and Charlton, M.N. Limitation by iron of phytoplankton in pelagic Lake Erie. (unpublished results).

Lake Erie Spatially Explicit Model of Lower Trophic Level Dynamics:

Design, Status, and Needs

Kathy Metzker
Ohio State University

A. DESIGN

I. Epilimnion Model Construction

Submodels

phosphorus
phosphorus sedimentation/dissolution
nitrogen
photosynthesis
phytoplankton community
herbivorous zooplankton community
predatory zooplankton community
adult zebra mussel population
zebra mussel filtration and spawning
veligers
planktivorous fish and planktivory
piscivorous fish and piscivory
phytoplankton nutrient uptake
grazing behavior
predation on veligers and adult mussels
settling rates
zooplankton reproduction
respiration
photosynthesis
detritus

II. Hypolimnion Model Construction

Submodels

- detritus
- adult zebra mussel population
- zebra mussel filtration
- zebra mussel spawning
- veliger settling
- benthic community
- Veliger/benthic community predation
- phosphorus sedimentation/dissolution
- Dissolved Oxygen
- Respiration

III. Intercell Linkage Models Construction

Submodels

- Horizontal Water Movement
- Vertical Water Movement
- Seiches
- Spring and Fall Overturns
- Diffusion
- Nutrient Point Source Locations and Concentrations
- Nutrient Nonpoint Source Locations and Concentrations
- Cell Volumes and Perimeters
- Intermodel Communication Function

B. MODEL STATUS

1. Epilimnion model under construction
   a. structural design partially completed
   b. interaction equations partially determined
   c. initial parameters partially determined
   d. Site characteristics partially incorporated

2. Hypolimnion model in conceptual design phase
   a. structural design in process
   b. interaction equations under investigation
   c. initial parameters under investigation

3. Intercell Linkage Model in conceptual design phase

C. MODEL NEEDS

A. Epilimnion Model

1. Additional Phytoplankton Distribution and Abundance
2. Additional Zooplankton Distribution and Abundance
3. Ichthyoplankton Identification
4. Zebra Mussel Spawning Behavior and Patterns
5. Additional Nutrient Loading Data
    a. Point Source
    b. Nonpoint Source
    c. Atmospheric Deposition
6. Additional Data on Physical and Water Quality Characteristics
    a. Phosphorus Compounds
    b. Nitrogen Compounds
    c. Temperature
    d. Secchi Depth
    e. Surface Light Intensity
7. Zebra Mussel Filtration and Filtration Zone of Influence (from DYRESM)

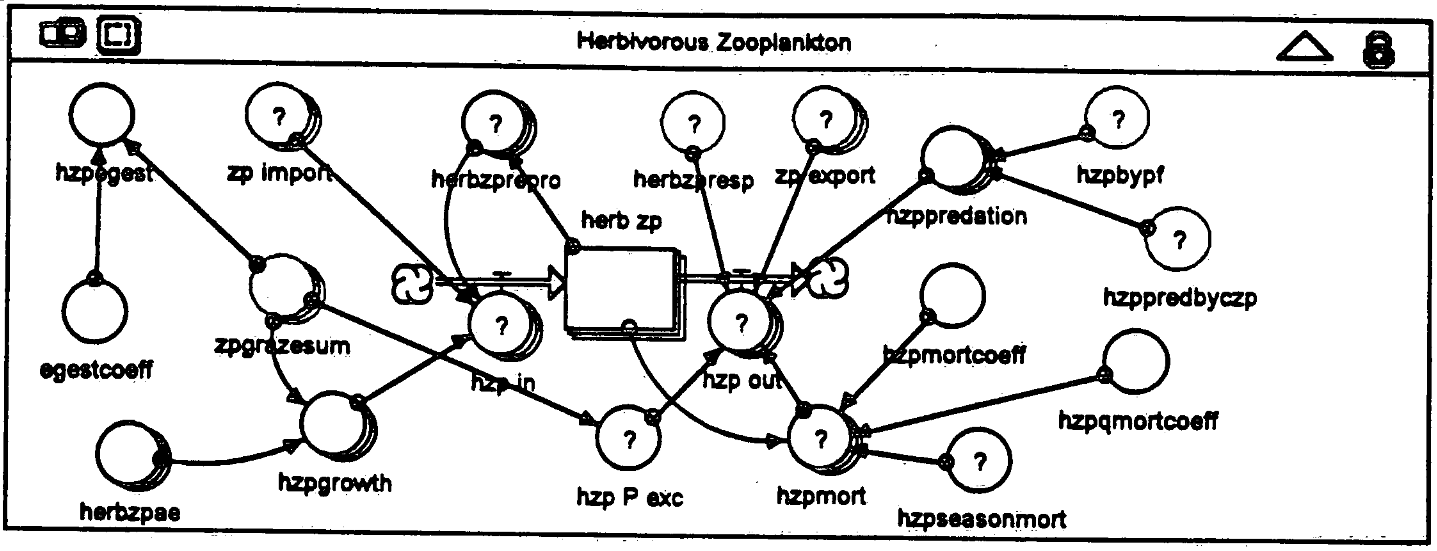
B. Hypolimnion Model

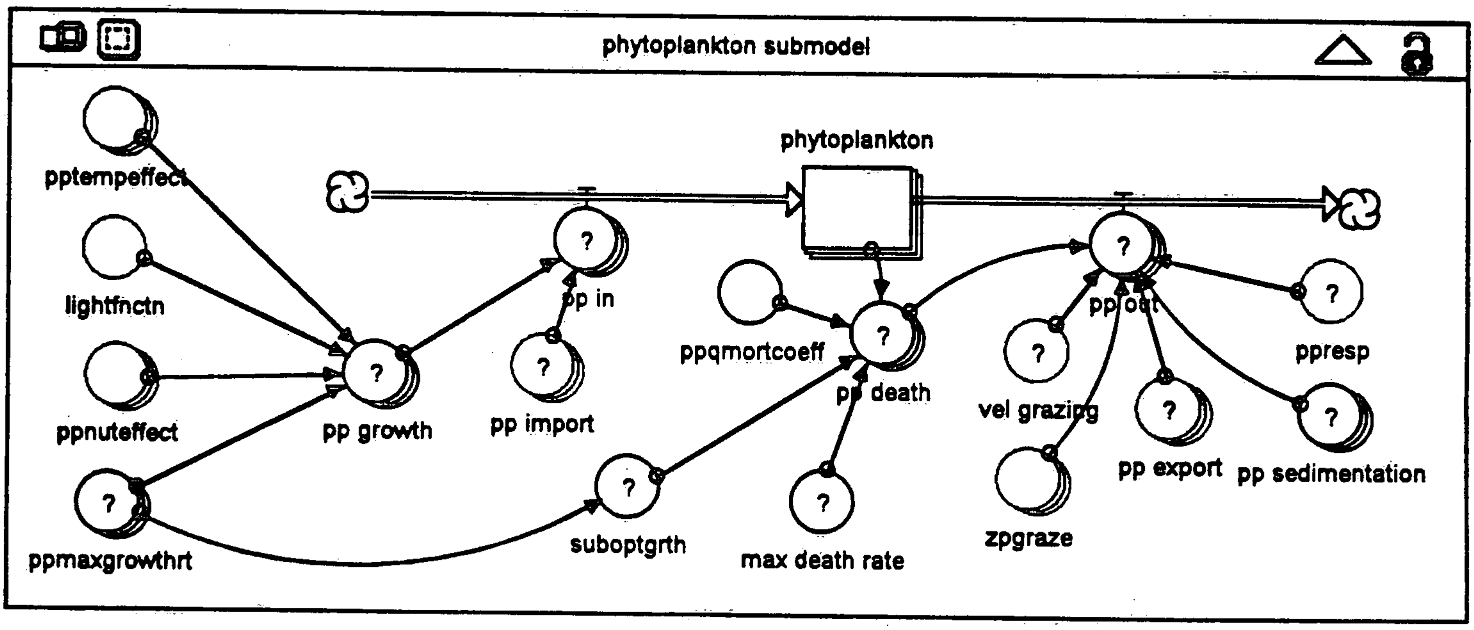
1. Zebra Mussel Distribution
2. Lake Sediment Characteristics
3. Veliger Settling Distribution and Mortality
4. Lakewide Hypolimnion Water Quality
    a. Phosphorus Compounds
    b. Nitrogen Compounds
    c. Temperature
    d. Dissolved Oxygen
5. Benthic Community Structure
6. Adult Zebra Mussel Predation Vulnerability
7. Detritus Data
8. Zebra Mussel Filtration Dynamics (DYRESM)

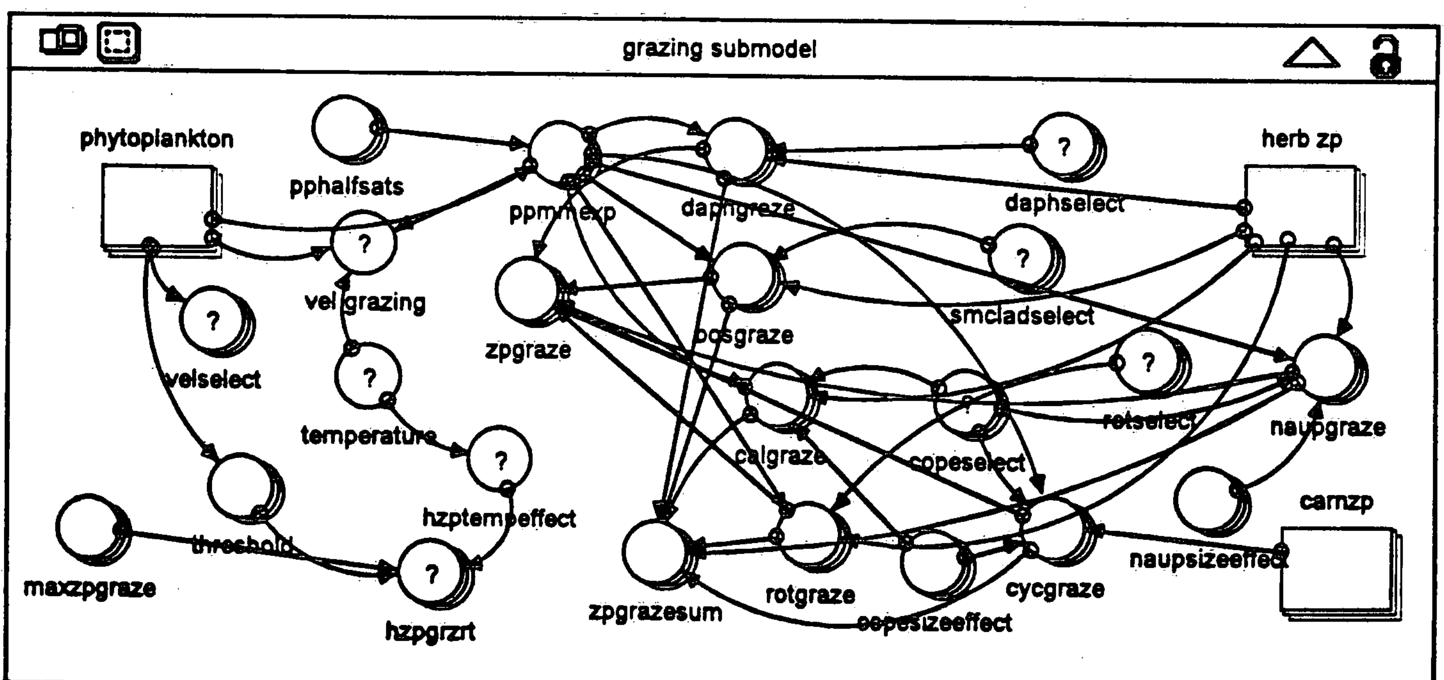
C. Intercell Linkage

Lake Hydrodynamics

- Seiche behavior
- Current Patterns
- Upwelling dynamics


Herbivorous Zooplankton
hzpegest
zp import
herbzprepro
herbzpresp
zp export
hzpbypf
herb zp
hzppredation
hzppredbyczp
egestcoeff
zpgrazesum
hzp in
hzp out
hzpmortcoeff
hzpqmortcoeff
herbzpae
hzpgrowth
hzp P exc
hzpmort
hzpseasonmort


phytoplankton submodel
phytoplankton
pptempeffect
lightfnctn
ppnuteffect
ppmaxgrowthrt
pp growth
pp in
pp import
ppqmortcoeff
pp death
suboptgrth
max death rate
pp out
vel grazing
zpgraze
pp export
ppresp
pp sedimentation


grazing submodel
phytoplankton
pphalfsats
ppmmexp
daphgraze
daphselect
herb zp
vel grazing
velselect
zpgraze
bosgraze
smcladselect
temperature
calgraze
copeselect
rotselect
naupgraze
threshold
hzptempeffect
maxzpgraze
hzpgrzrt
zpgrazesum
rotgraze
copesizeeffect
cycgraze
naupsizeeffect
carnzp

Murray Charlton
From: Mark Loewen
Sent: February 24, 1998 1:59 PM
To: Murray Charlton
Cc: Paul.Hamblin@CCIW.ca
Subject: Re: ERie Science Day

Murray; Here is an abstract of what I will talk about March 5th. It is an abstract of a talk I gave last year at the ASLO meeting.
Mark

HYDRODYNAMICS AND MIXING OVER A BED OF ZEBRA MUSSELS IN LAKE ERIE

Loewen, M.R., Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, Ontario, Canada M5S 3G8
Ackerman, J.D., UNBC, Prince George, British Columbia, Canada V2N 4Z9
Hamblin, P.F., National Water Research Institute, Burlington, Ontario, Canada L7R 4A6

We conducted a field experiment centered on an isolated bed of zebra mussels in the western basin of Lake Erie in order to investigate the biophysical factors
effecting benthic-pelagic coupling. The experiment included: (1) An intensive
series of attended measurements (seston sampling and boat-mounted ADCP) during a four day period in July of 1994; and (2) deployment of an array of unattended instruments, which included four ultrasonic current meters with built-in water temperature sensors, a water level recorder and three transmissometers on the reef for approximately 6 weeks. A detailed analysis of
the current meter data was carried out in order to investigate the relative importance of the different forcing functions which effect the flow over the reef. Cross-spectral analysis of water levels and the current meter data indicates that surface gravitational seiches are one of the dominant forcing functions for the near-bottom currents the other being the hydraulic flow from
west to east. The surface currents are driven by a superposition of various forcing functions including seiches, wind waves and surface wind drift. The effect of bed roughness, stratification, seiching and surface waves on the hydrodynamics and mixing over the reef was investigated. The implications of these physical observations on the benthic-pelagic coupling of zebra mussels is
addressed in a second presentation (Ackerman et al, this session).

****

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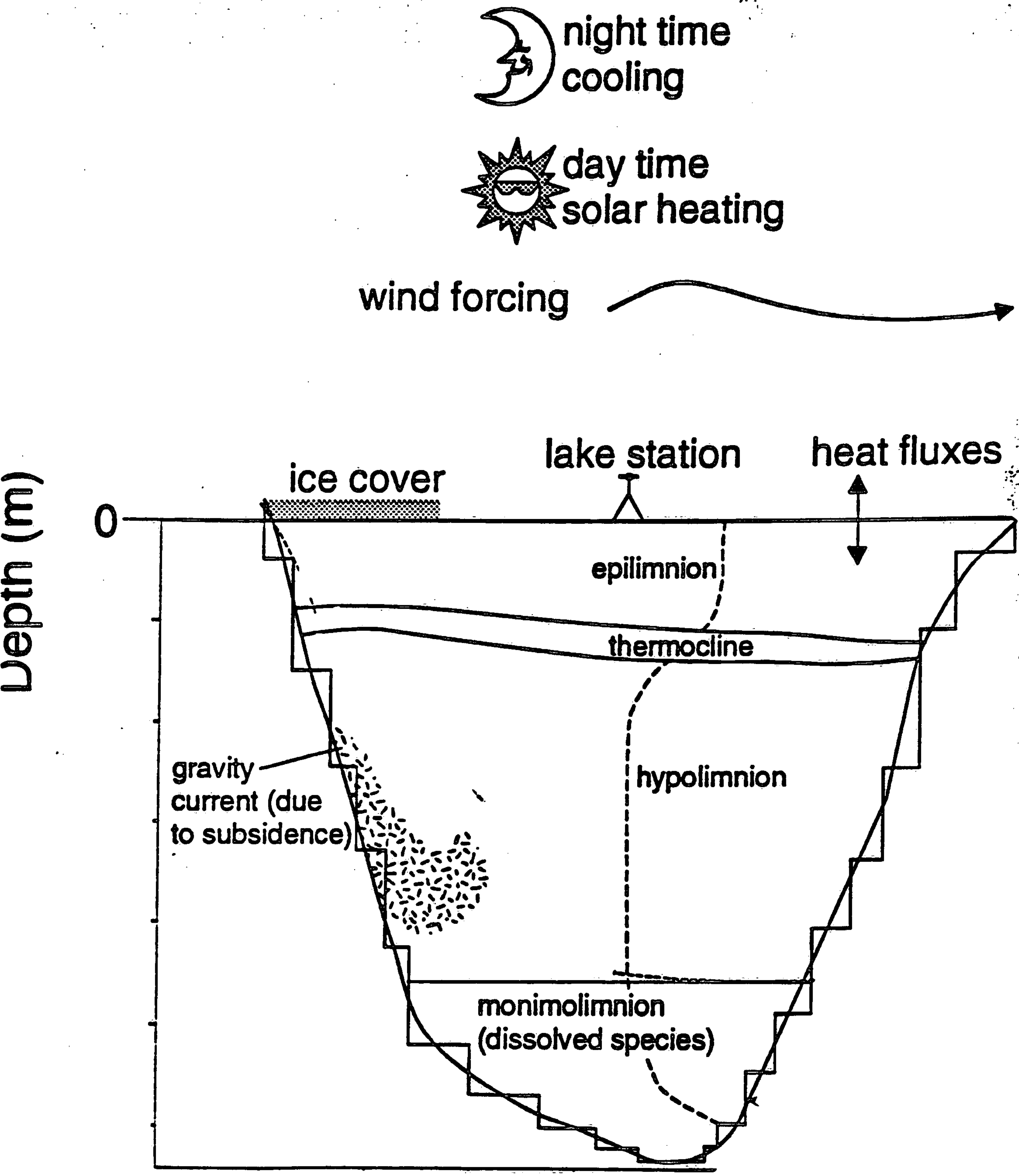
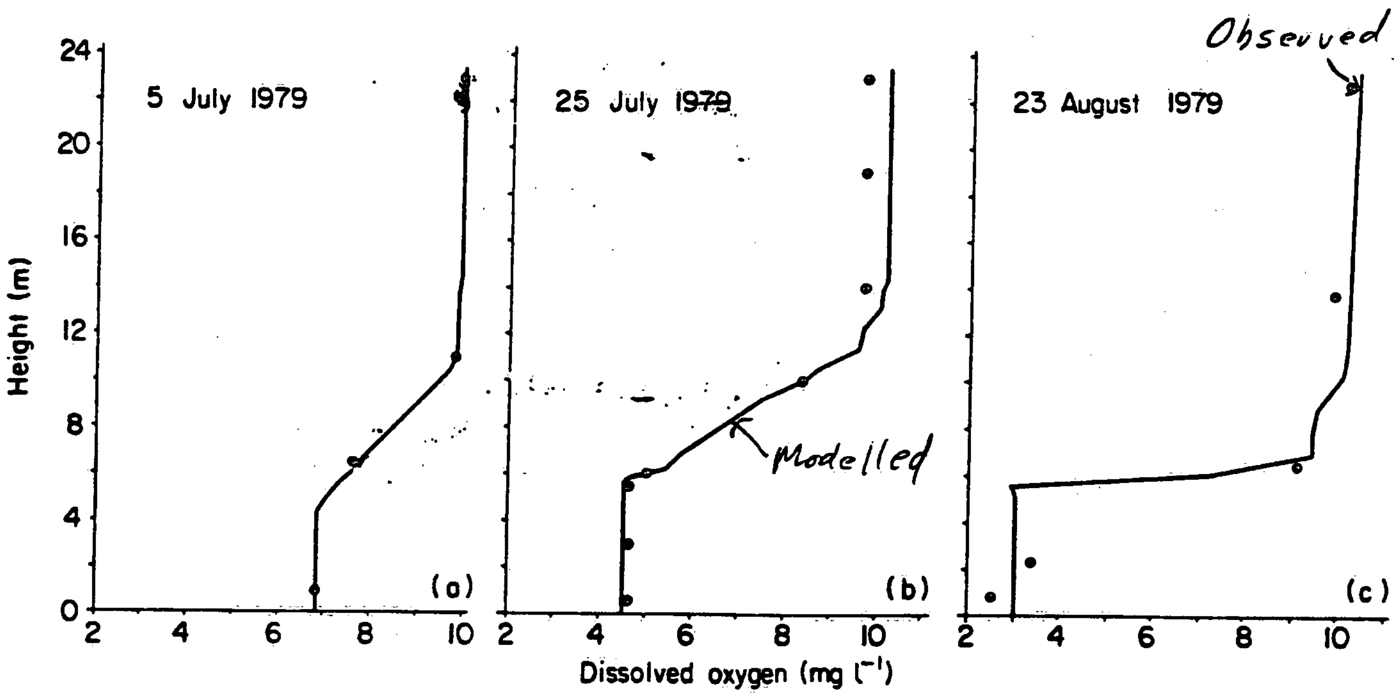
Paul Hamblin NWRI

DYRESM Modelling in Lake Erie", Here are the notes for each:
1) What is DYRESM? Schematic showing nature of model and most important processes included.
2)Thermal Modelling of Central Basin, Ivey & Patterson, 1984 L&O
3)Dissolved Oxygen "——" , Patterson et al., 1985 Freshwater Bio.
4) Specific Production Curve assumed
5)1995 NWRI & UofT Study of Lake Erie: an example of surface wind measurements
6)Model Modifications made by McCrimmon, 1988 Schematic of Particulate Phosphorus model
7) McCrimmon's Schematic of Dissolved Oxygen
8)same as 7 but phosphorus model equation
9)DO model equations
10) Links to other models: Lake Erie Ecosystem Model & schematic

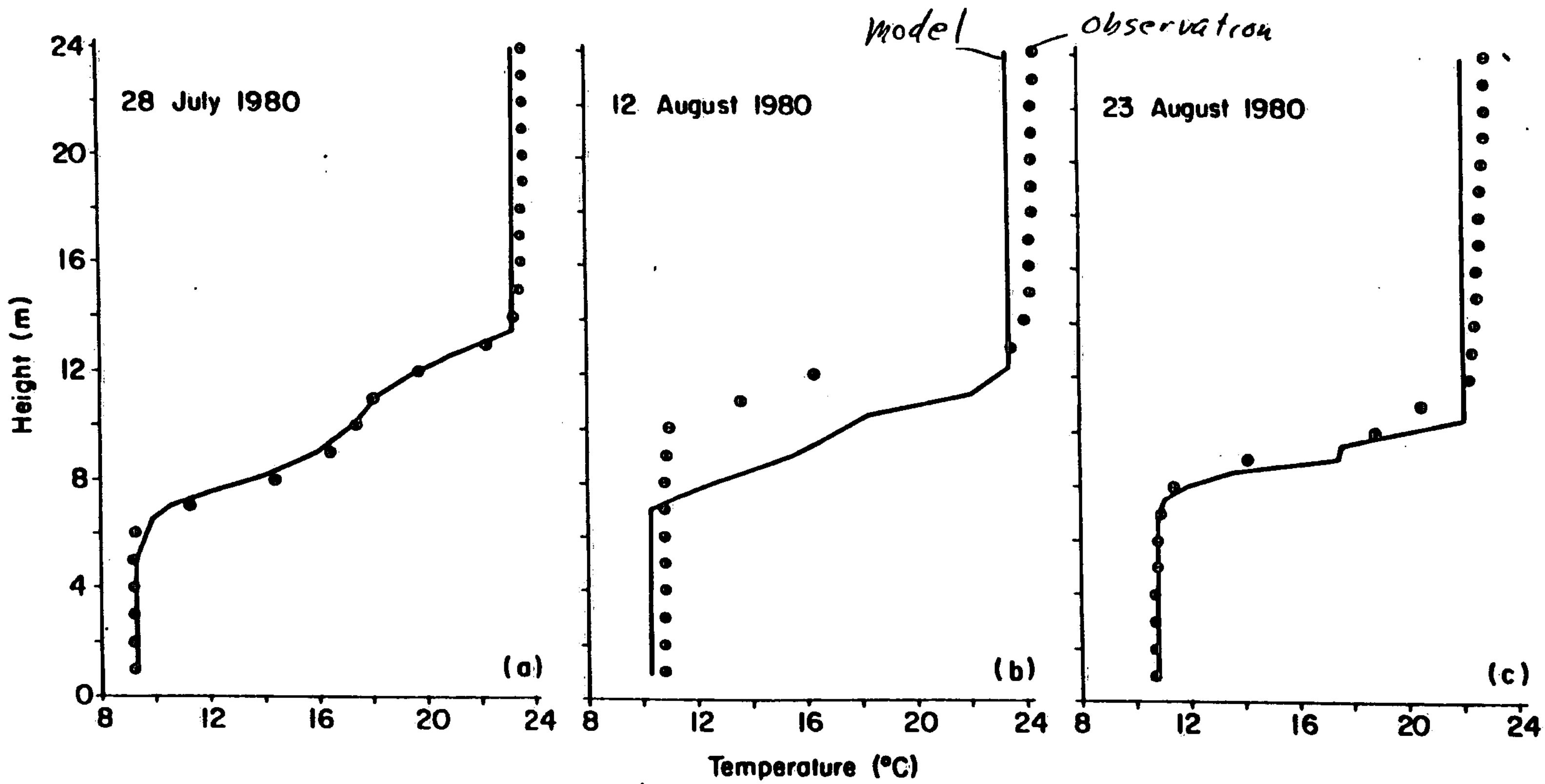

night time cooling
day time solar heating
wind forcing
lake station
heat fluxes
ice cover
Depth (m)
0
epilimnion
thermocline
hypolimnion
gravity current (due to subsidence)
monimolimnion (dissolved species)

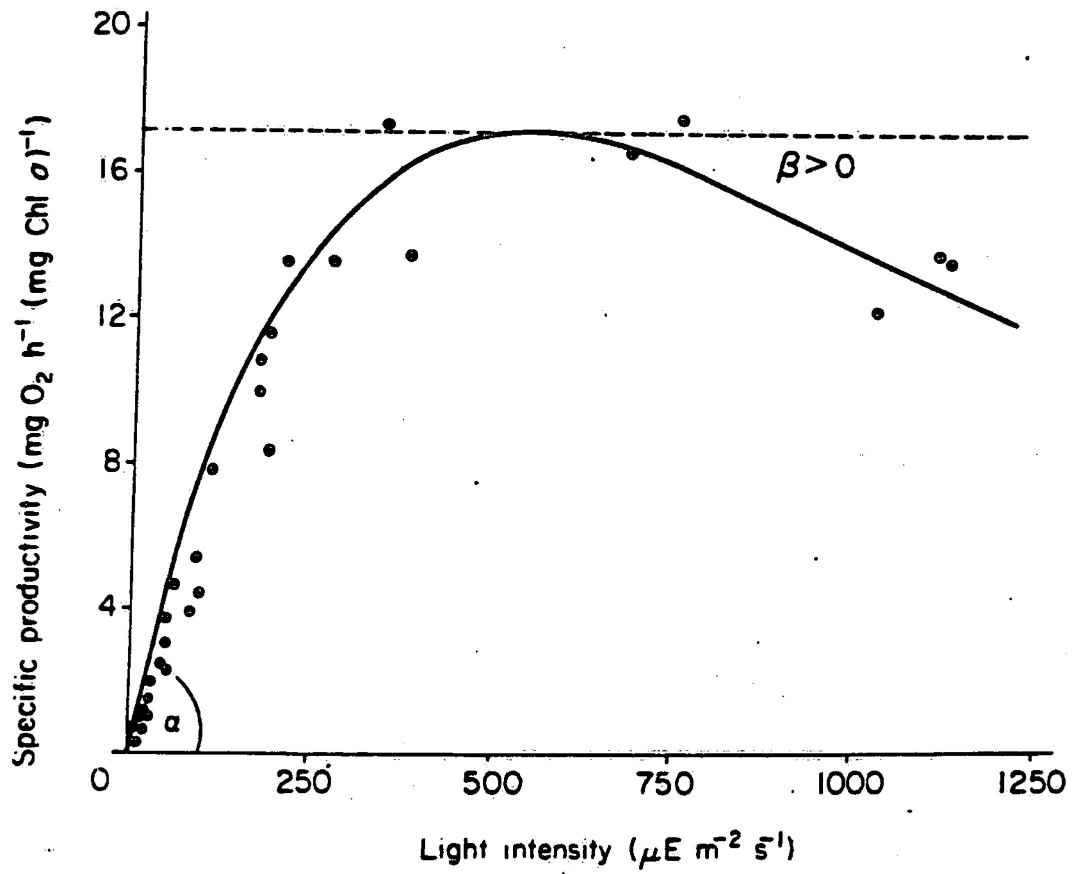
J. C. Patterson, B. R. Allanson and G. N. Ivey 1985

Freshwater Biology

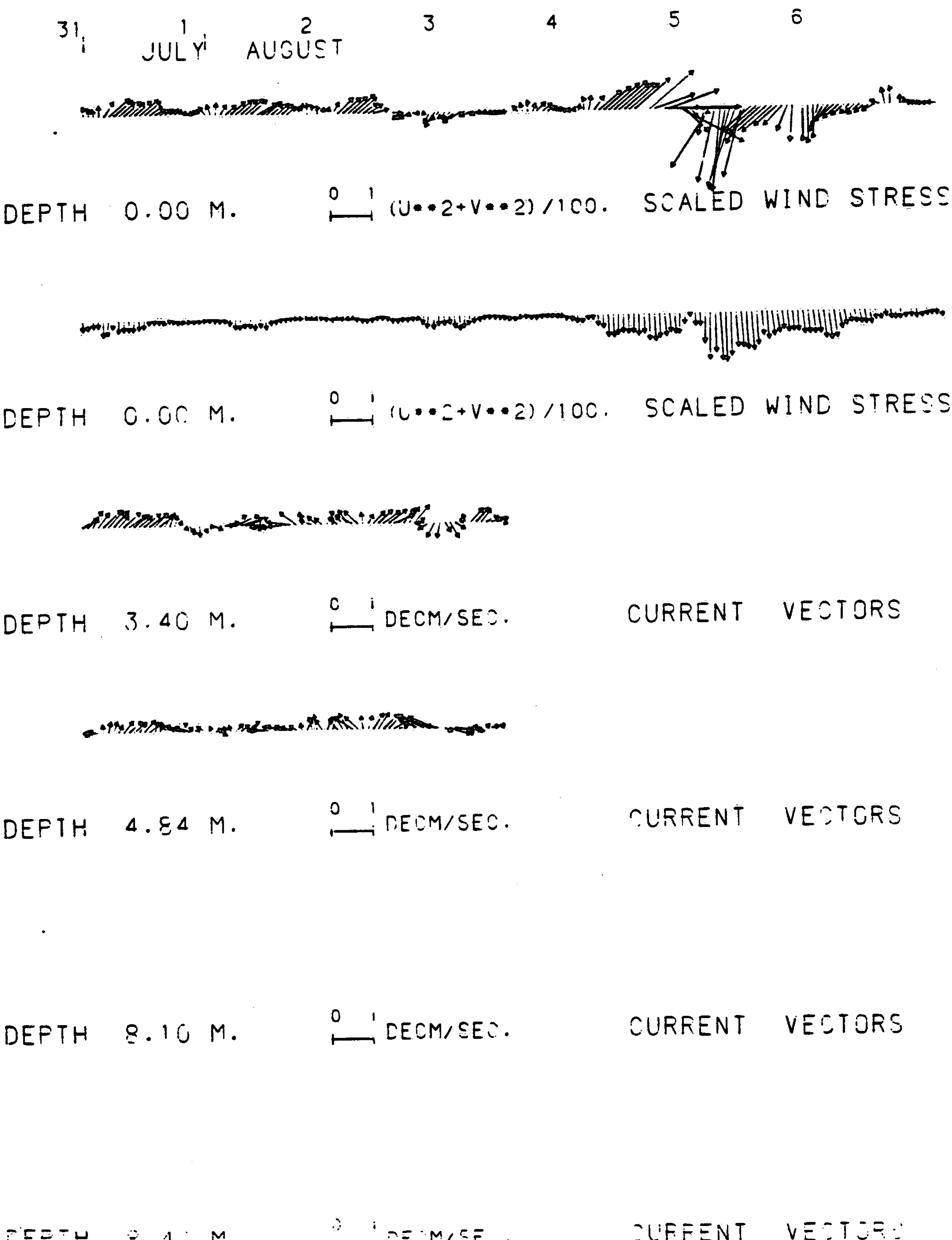


Ivey & Patterson (1984, L&O)



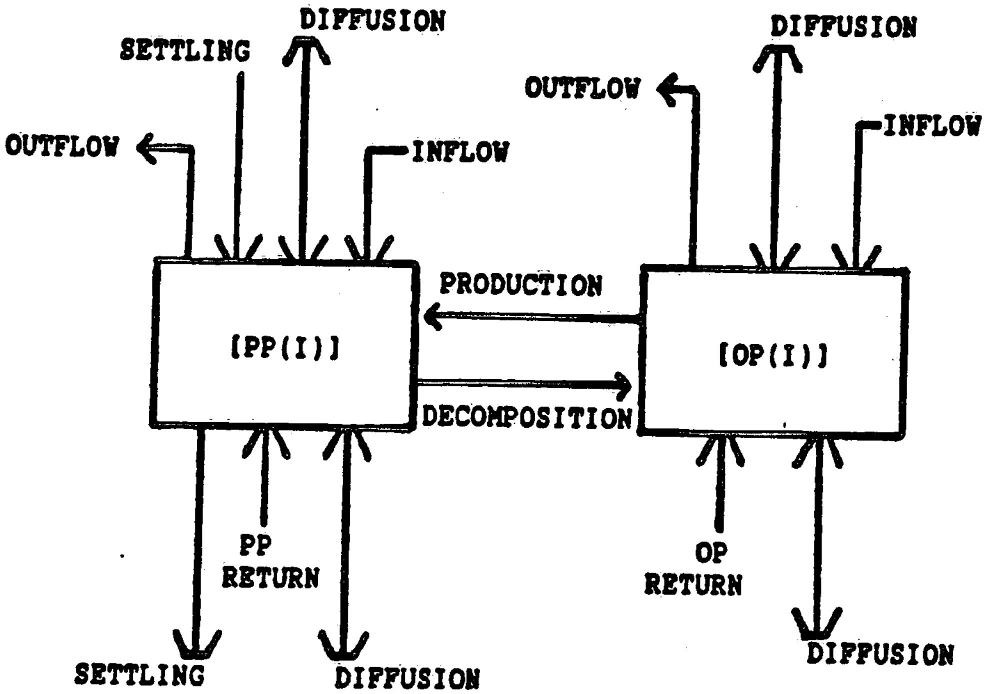


20
16
12
8
4
0
250
500
750
1000
1250
Specific productivity (mg O_2 h^{-1} (mg Chl a)$^{-1}$)
Light intensity (μE m^{-2} s^{-1})
β>0
α

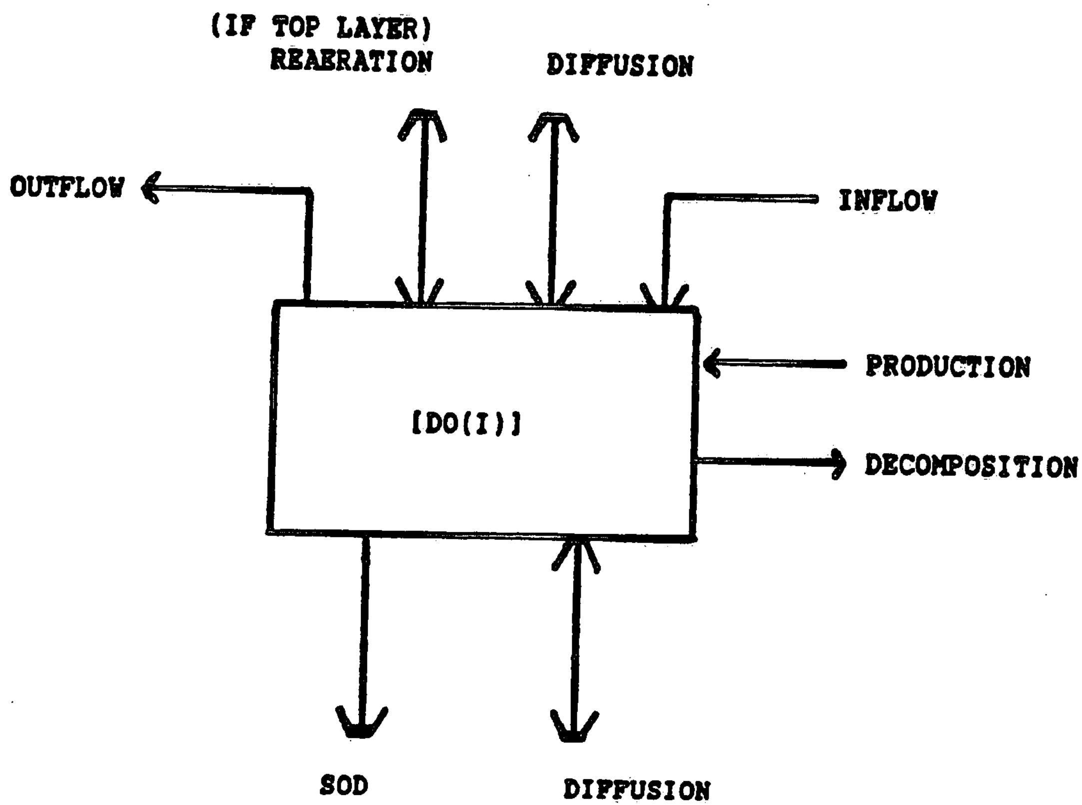


31
1
JULY
2
AUGUST
3
4
5
6
DEPTH 0.00 M.
0 1 (U**2+V**2)/100.
SCALED WIND STRESS
DEPTH 0.00 M.
0 1 (U**2+V**2)/100.
SCALED WIND STRESS
DEPTH 3.40 M.
0 1 DECM/SEC.
CURRENT VECTORS
DEPTH 4.84 M.
0 1 DECM/SEC.
CURRENT VECTORS
DEPTH 8.10 M.
0 1 DECM/SEC.
CURRENT VECTORS
DEPTH
M.
DECM/SE
CURRENT

M^c Crimmon, 1988



SCHEMATIC REPRESENTATION OF PHOSPHORUS MASS BALANCE



SCHEMATIC REPRESENTATION OF DO MASS BALANCE

TABLE 3-1 MATHEMATICAL FORMULATION OF PHOSPHORUS MODEL

$$[PP]:\quad V(I)\,\frac{d[PP(I)]}{dt} = G_{max}1.066^{T(\bar{z}(I))}\,\frac{L_{av}\exp[-k_e\bar{z}(I)]}{L_s}$$

$$*\exp\left[1-\frac{L_{av}\exp[-k_e\bar{z}(I)]}{L_s}\right]\frac{[OP(I)]}{K_{mp}+[OP(I)]}[PP(I)]V(I)$$

$$-K_2 \cdot T(I) \cdot [PP(I)]\,\frac{[DO(I)]}{[DO(I)]+K_d}\,V(I)$$

$$+ g \cdot \langle [PP(I+1)]-[PP(I)] \rangle \cdot A(I)$$

$$+ PP_{ret} \cdot \langle A(I) - A(I-1) \rangle$$

$$[OP]:\quad V(I)\,\frac{d[OP(I)]}{dt} = -G_{max}1.066^{T(\bar{z}(I))}\,\frac{L_{av}\exp[-k_e\bar{z}(I)]}{L_s}$$

$$*\exp\left[1-\frac{L_{av}\exp[-k_e\bar{z}(I)]}{L_s}\right]\frac{[OP(I)]}{K_{mp}+[OP(I)]}[PP(I)]V(I)$$

$$+K_2 \cdot T(I) \cdot [PP(I)]\,\frac{[DO(I)]}{[DO(I)]+K_d}\,V(I)$$

$$+ OP_{ret} \cdot \langle A(I) - A(I-1) \rangle$$

TABLE 3-2 MATHEMATICAL FORMULATION OF DISSOLVED OXYGEN

$$[DO]:\quad V(I)\,\frac{d[DO(I)]}{dt} = F\,G_{max}\,1.066^{\bar{T}(z(I))}\,\frac{L_{av}\exp[-k_e\bar{z}(I)]}{L_s}$$

$$*\ \exp\left[1-\frac{L_{av}\exp[-k_e\bar{z}(I)]}{L_s}\right]\frac{[OP(I)]}{K_{mp}+[OP(I)]}\,[PP(I)]V(I)$$

$$-\ F\,.\,K_2\,.\,T(I)\,.\,[PP(I)]\,\frac{[DO(I)]}{[DO(I)]+K_d}\,V(I)$$

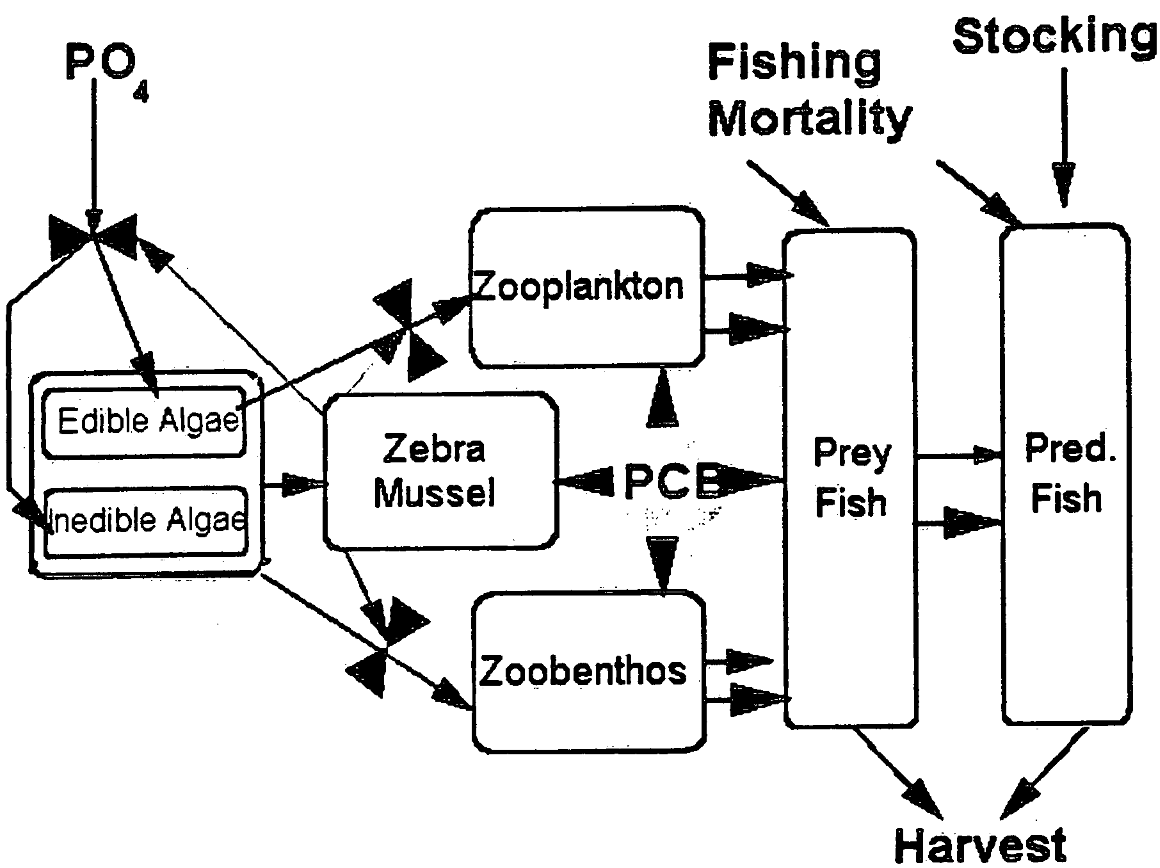
$$-\ u_{max}(T_o)\,.\,K_{S2}^{(T(I)-25)}\,\frac{[DO(I)]}{[DO(I)]+K_{S1}}\,.\,\{A(I)-A(I-1)\}$$

for I=NS (surface layer) include the following

$$+\ K_{aw}\,.\,A(NS)\,.\,\langle\, DOsat - [DO(NS)]\,\rangle\,.\,(1-FICE)$$

Lake Erie Ecological Model

Joseph F. Koonce and Ana B. Locci



ULTRAVIOLET RADIATION AND PRIMARY PRODUCTION IN LAKE ERIE, 1997

Ralph Smith, Veronique Hiriart, Chris Marwood and Bruce Greenberg

University of Waterloo

Ultraviolet radiation and primary production in Lake Erie, 1997

Ralph Smith, Veronique Hiriart, Chris Marwood and Bruce Greenberg. Biology Department, University of Waterloo

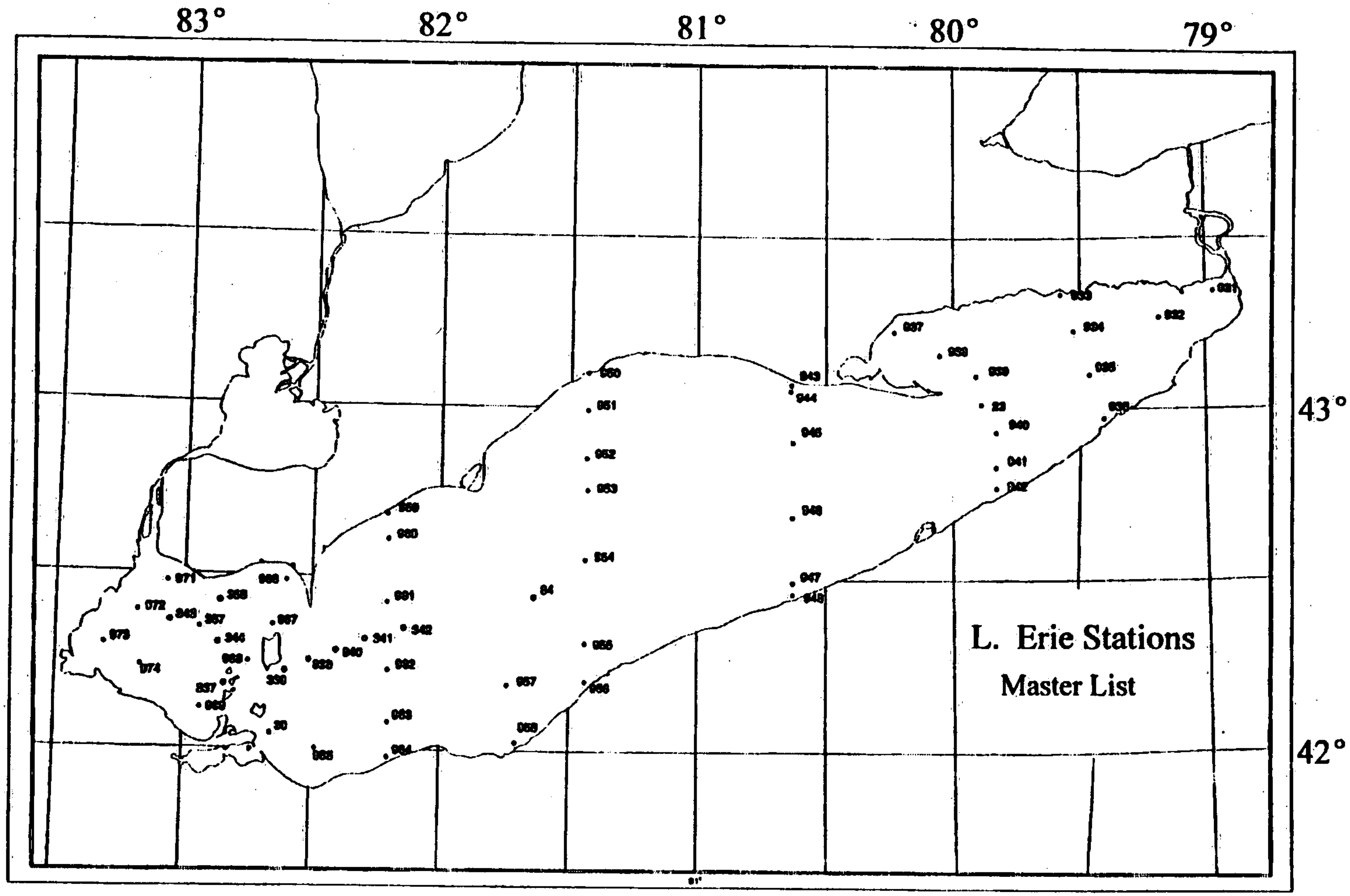
Phytoplankton photosynthesis was measured by radiocarbon and fluorescence methods on five lake-wide cruises from May through August, and experiments were performed to determine the effects of solar ultraviolet radiation (UVR). Integrated primary production rates calculated from the radiocarbon results were compared to similar measurements in 1993 and 1994, and suggested little systematic change relative to the large temporal and spatial variation within years. As part of the UVR studies, a new model to predict the penetration of UVB (290-320 nm) and UVA (320-400 nm) was developed. Unlike models recently published for smaller lakes, the L. Erie model assigns an important role to particulate matter and a secondary role to dissolved organic matter. The UVR experiments confirmed the sensitivity of L. Erie phytoplankton to both UVB and UVA, with more than 50% inhibition observed in simulated near-surface exposures on sunny days. Biological weighting functions and kinetic models are being tested and developed with the experimental data so that the impact of UVR on integrated primary production in the lake can be assessed. Work proposed for 1998 includes experiments designed to give better resolution of biological weighting functions in the UVR and the first measurements of how phosphorus cycling and PAH toxicity may be affected by UVR in the Great Lakes.

OBJECTIVES

1. **Develop empirical model(s) to predict ultraviolet radiation penetration and exposure in Lake Erie and other large lakes.**

2. **Test and develop models to predict the impact of ultraviolet radiation exposure on short-term primary production rates.**

3. **Determine spatio-temporal variability of primary production in Lake Erie.**



83°
82°
81°
80°
79°
43°
42°
L. Erie Stations
Master List

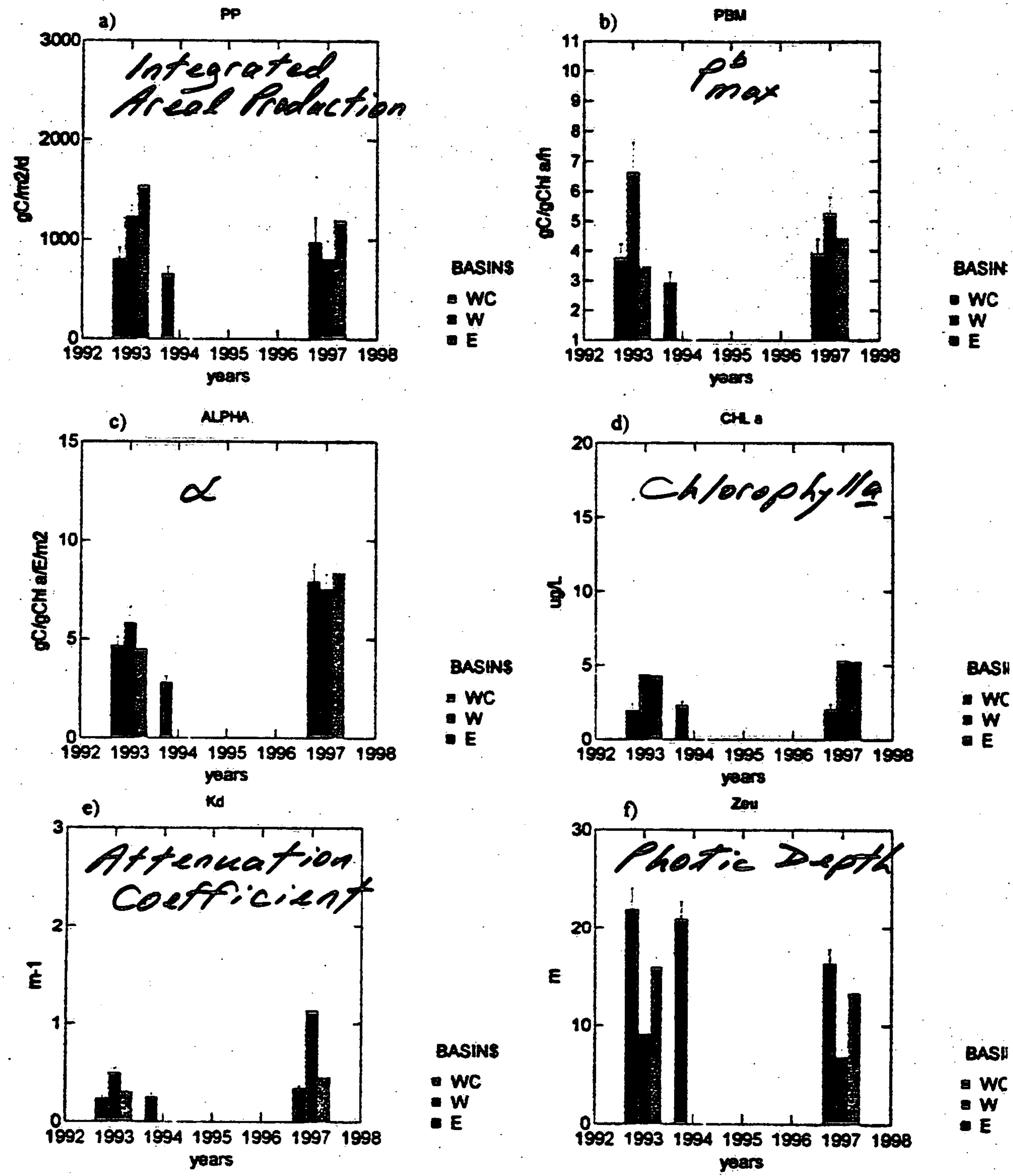
APPROACH TO OBJECTIVES

1. Primary production

The P-I modelling approach as exemplified by Fee or Platt was used. Short-term photosynthesis-irradiance responses were measured using ^{14}C in a small volume light gradient incubator and used to fit the P-I model. The fitted P-I model was then combined with measured irradiance and biomass (=chlorophyll) profiles to calculate depth and time-integrated production rates.

Five cruises of 5 days each from early May to late August were done, with 9 to 18 stations for primary production lake-wide per cruise. Considering the method used, the results should be considered closer to gross than to net primary production.

Primary production and related variable
Average (May ⇒ August) $\bar{c}$ std. dev.

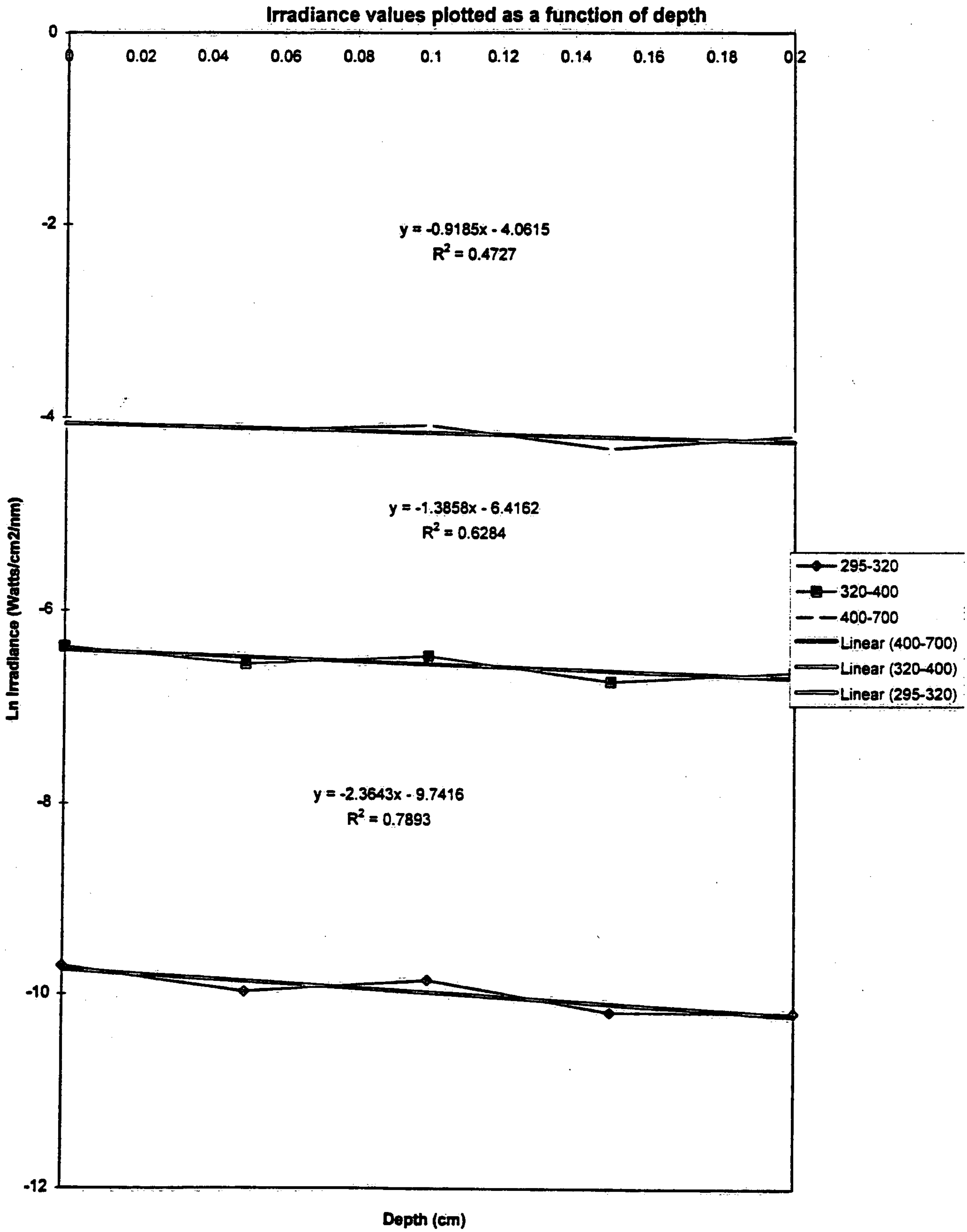


APPROACH TO OBJECTIVES

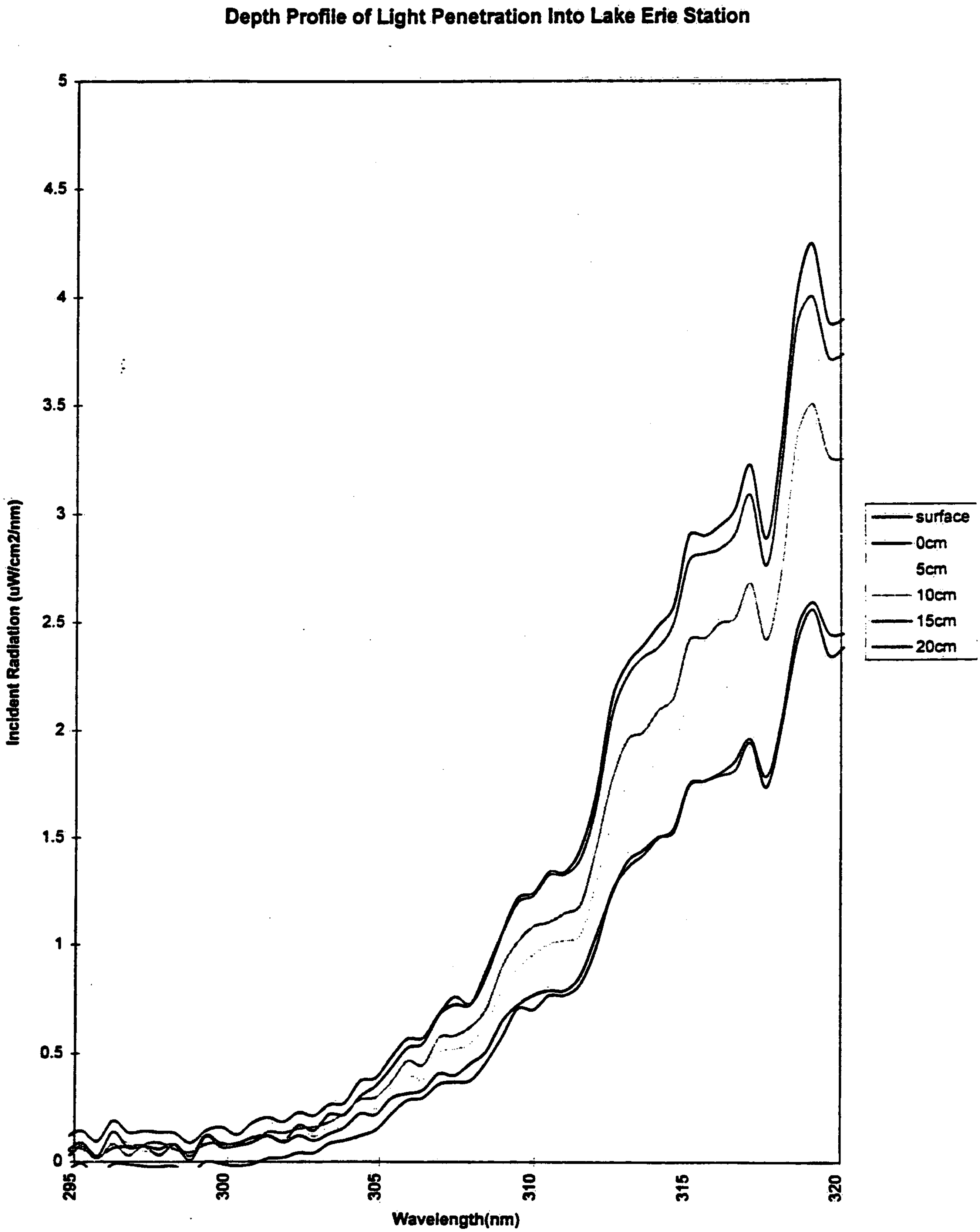
2. Ultraviolet radiation penetration and exposure

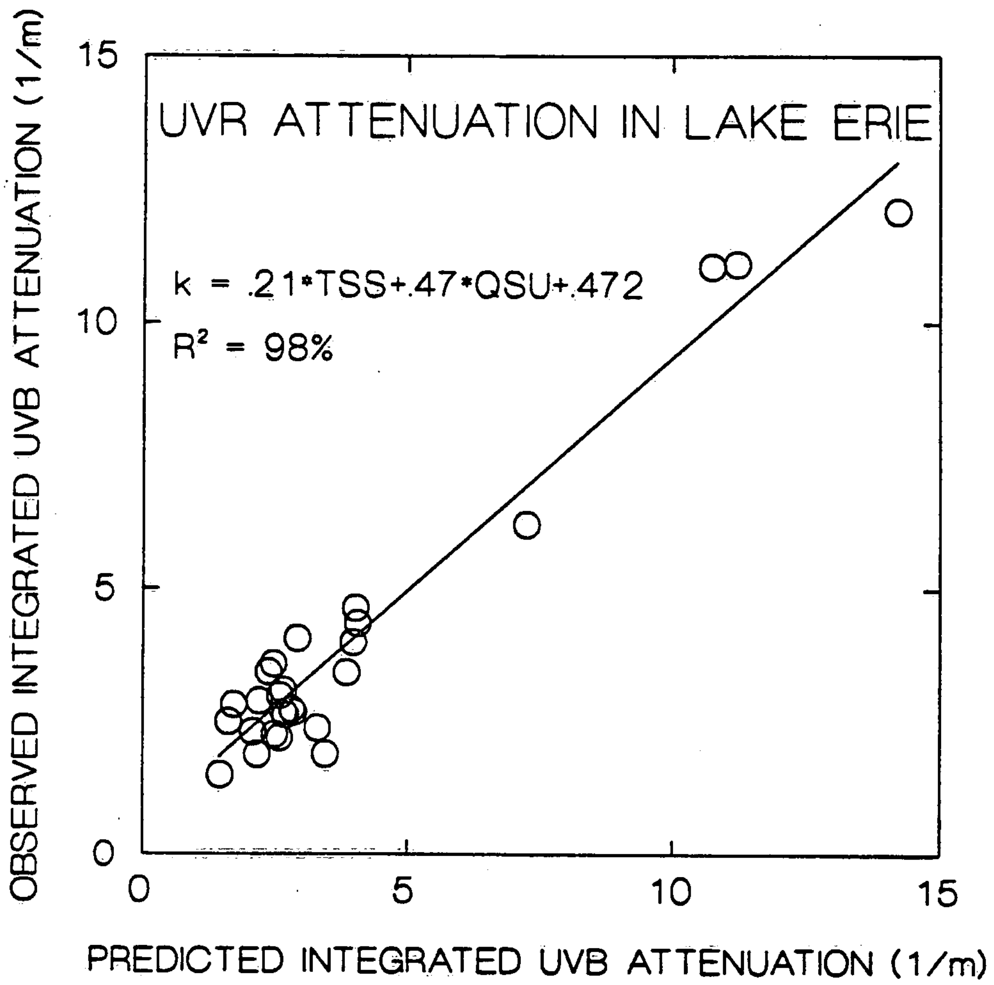
Lacking a profiling spectroradiometer, a deck-top arrangement was made so that spectral radiation could be measured in captive water samples using the submersible collector of our Oriel Instaspec diode array spectroradiometer. Spectral attenuation coefficients were then modelled as a function of water column characteristics pertinent to ultraviolet radiation, notably dissolved organic matter, suspended particles, and chlorophyll. With an acceptable model for spectral attenuation, incident radiation (for which climatic values are increasingly available) can be translated into exposures for any desired depths or locations for which relevant water quality variables are available.

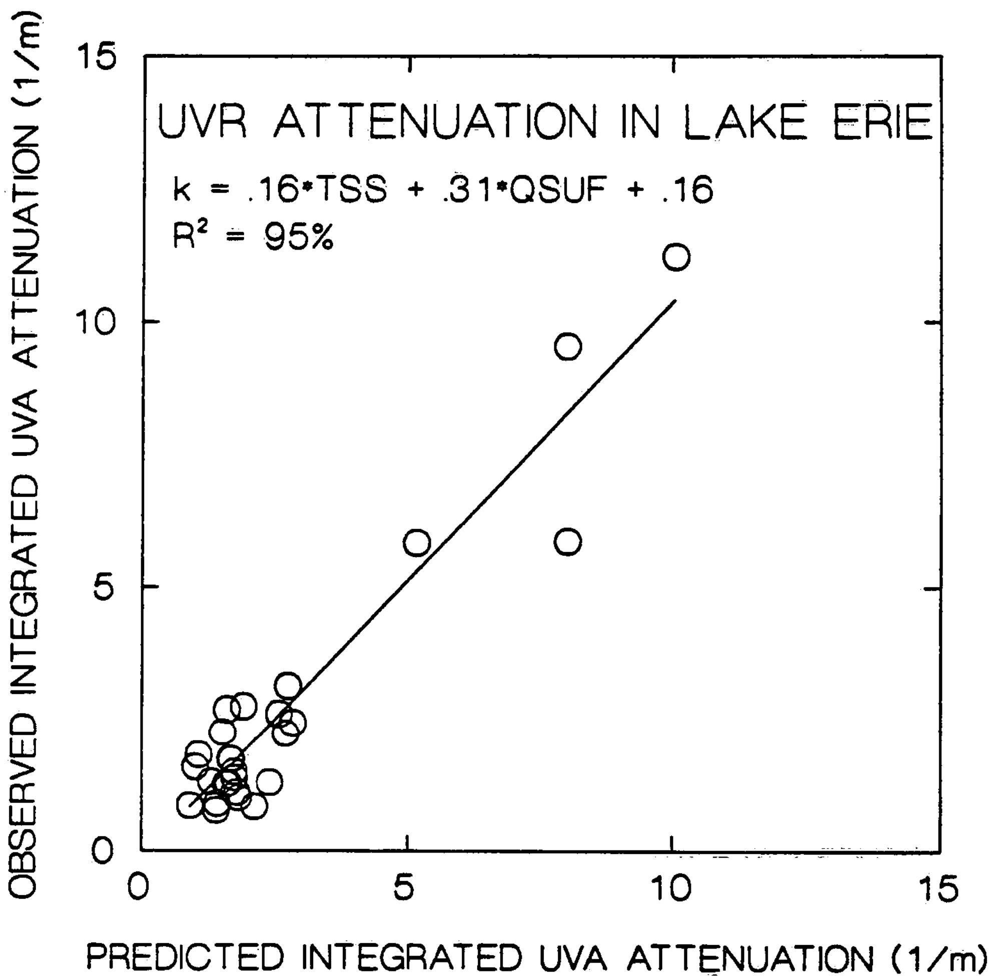
Work could only be done near mid-day under clear skies and with fairly flat water. A total of 29 spectral attenuation measurements was made in the course of the 5 cruises in 1997, at locations scattered unsystematically about the lake.



Irradiance values plotted as a function of depth
0
-2
-4
-6
-8
-10
-12
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
y = -0.9185x - 4.0615
R² = 0.4727
y = -1.3858x - 6.4162
R² = 0.6284
y = -2.3643x - 9.7416
R² = 0.7893
295-320
320-400
400-700
Linear (400-700)
Linear (320-400)
Linear (295-320)
Ln Irradiance (Watts/cm2/nm)
Depth (cm)


Depth Profile of Light Penetration Into Lake Erie Station
Incident Radiation (uW/cm2/nm)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
295
300
305
310
315
320
Wavelength(nm)
surface
0cm
5cm
10cm
15cm
20cm


UVR ATTENUATION IN LAKE ERIE
k = .21*TSS+.47*QSU+.472
R² = 98%
OBSERVED INTEGRATED UVB ATTENUATION (1/m)
PREDICTED INTEGRATED UVB ATTENUATION (1/m)
0
5
10
15
0
5
10
15



UVR ATTENUATION IN LAKE ERIE
k = .16*TSS + .31*QSUF + .16
R² = 95%
OBSERVED INTEGRATED UVA ATTENUATION (1/m)
PREDICTED INTEGRATED UVA ATTENUATION (1/m)
0
5
10
15

APPROACH TO OBJECTIVES

3. Impact of ultraviolet radiation on primary production

We follow the modelling approach exemplified by J. Cullen and co-workers, which requires

a) elucidation of a biological weighting function to translate spectral exposure into biological effectiveness
b) adoption of a model for biological response (= a kinetic model)
c) combination of the BWF-kinetic model with spectral irradiance as a function of time and depth to predict photoinhibition

Weaknesses of the approach:

Data-intensive, statistically-demanding, short-term

Strengths of the approach:

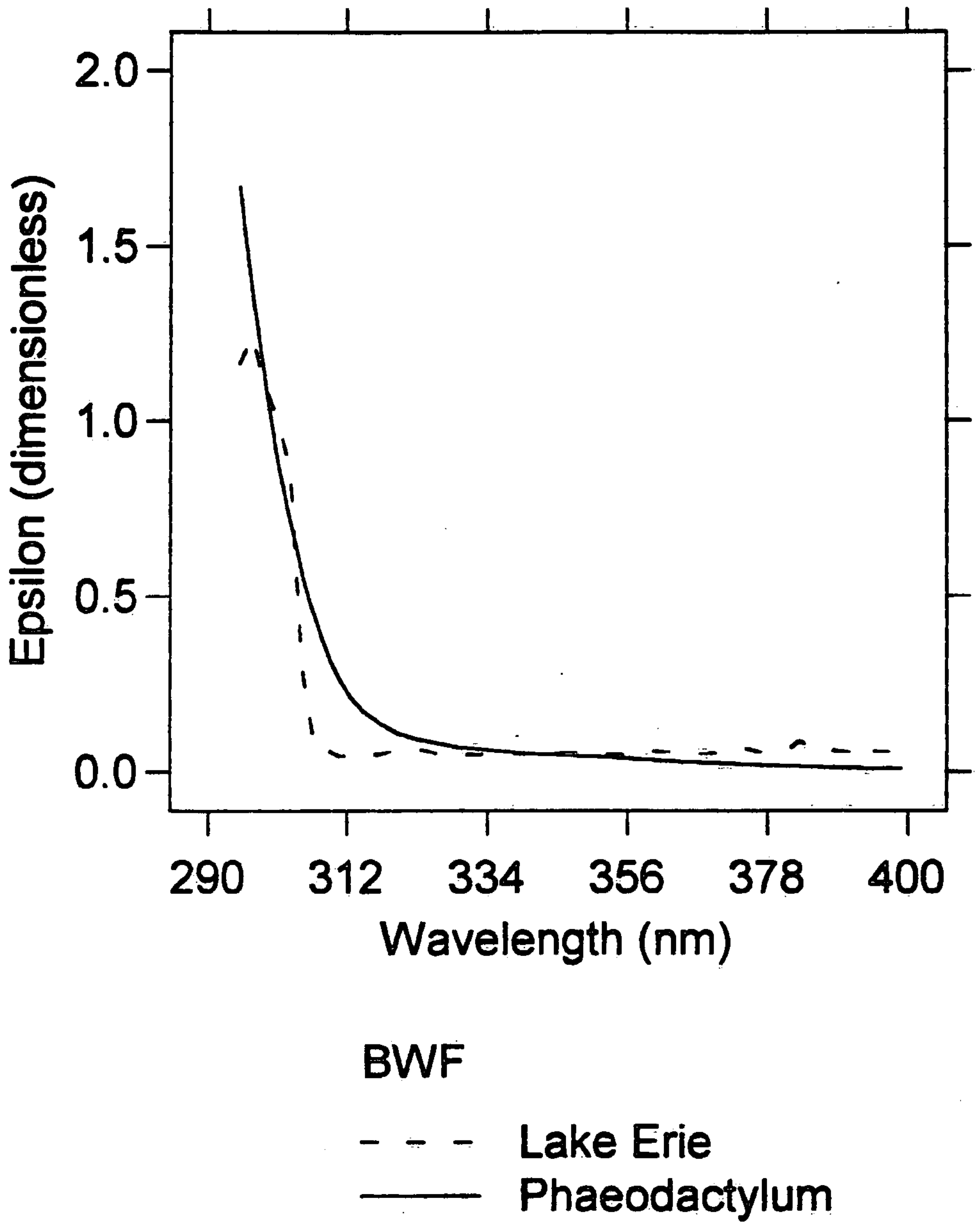
Assumptions are made explicit, sensitivity analysis can be done, and a realistic assessment of inhibition in a mixing water column can be made

MEASUREMENTS

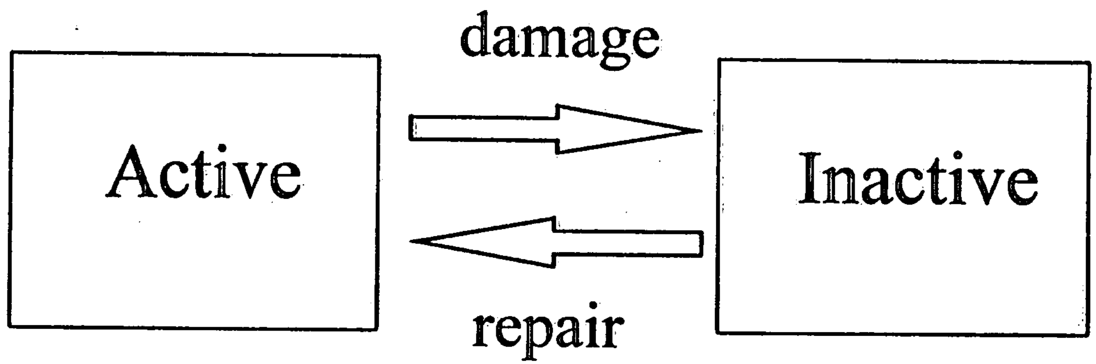
Deck-top incubations with ^{14}C to monitor time-course of photosynthesis and photoinhibition under treatments of varying spectral quality and total irradiance. Parallel experiments to measure extent and rate of recovery of photoinhibited plankton.

Approximately 15 experiments in total, at stations throughout Lake Erie as opportunity offered.

BWF for Phaeodactylum and Lake Erie Phytoplankton



Kinetic modelling



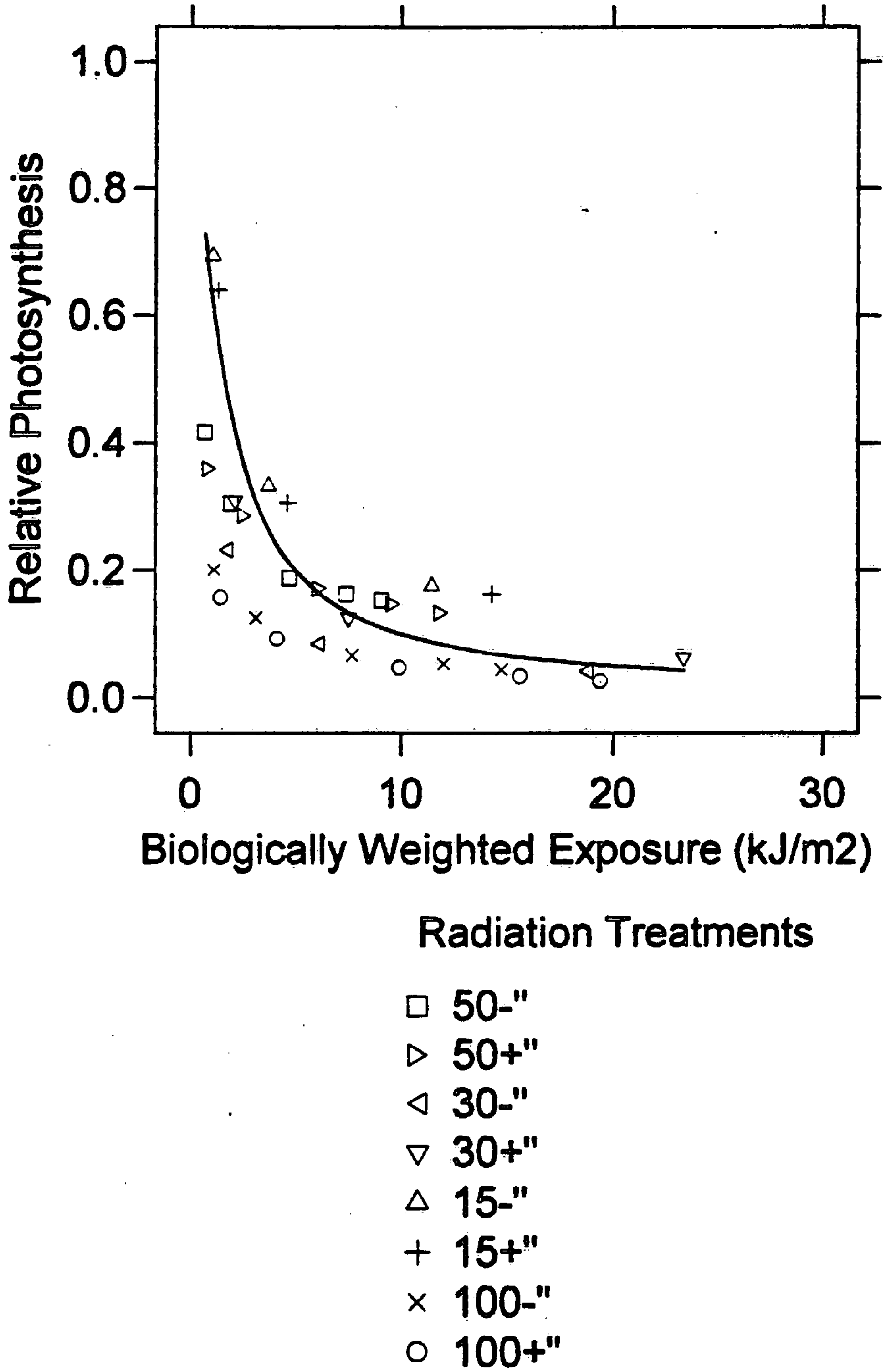
a) Rapid repair and equilibrium: irradiance model

$$P/P_{opt} = 1/(1+E')$$

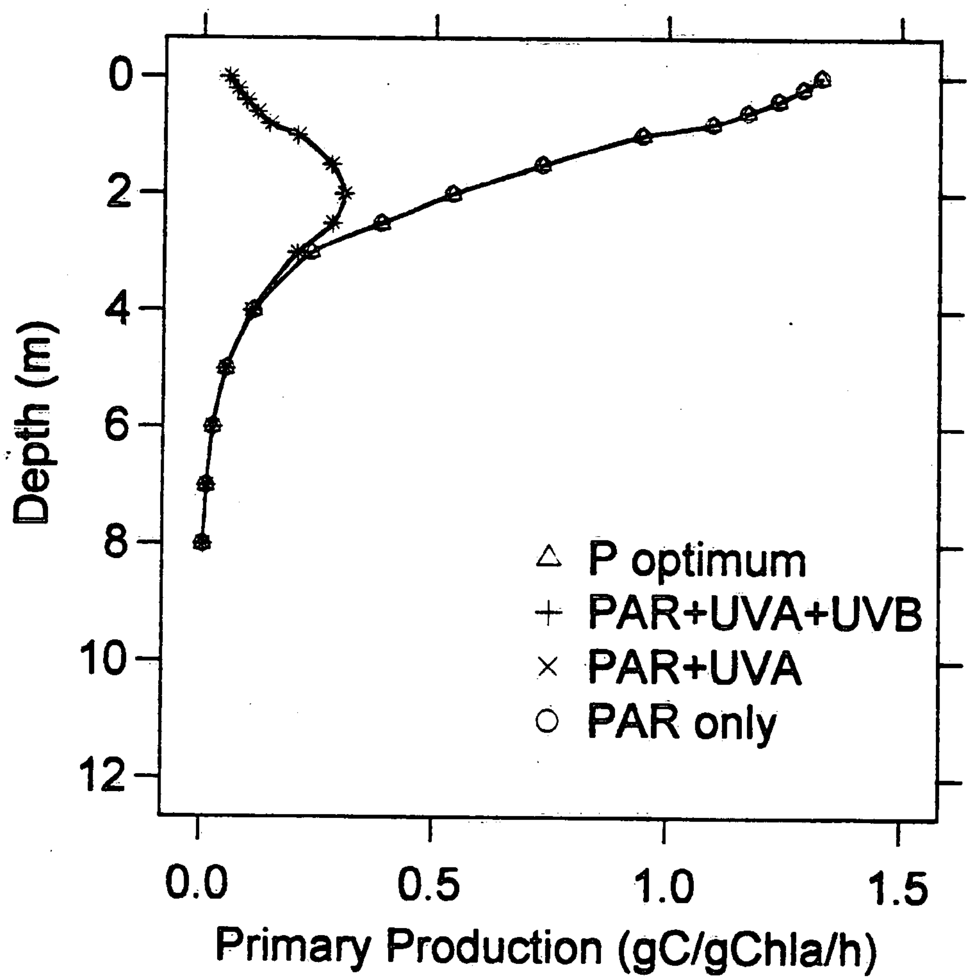
b) Very slow repair: cumulative exposure model

$$P/P_{opt} = [1-\exp(-H')]/H'$$

Lake Erie Exposure Model: June 3, 1997, Stn 946



Primary Production Profiles: June 3, 1997, Stn 946



ULTRAVIOLET AND VISIBLE RADIATION DAMAGE TO PRIMARY PRODUCTION: STA. 946 (CENTRAL B.), JUNE 3, 1997

WAVEBANDS	PERCENT LOSS OF DAILY PRODUCTION
PAR only	0
PAR + UVA	64.9
PAR+ UVA + UVB	65.1

Estimates based on cumulative exposure model with a BWF for the subject phytoplankton, and assuming NO VERTICAL MOTION during the photoperiod. Results could differ substantially when effects of mixing are modelled.

PLANS FOR 1998

1. Additional experiments to better elucidate the shape of the BWF for Lake Erie phytoplankton and pursue refinement of the kinetic model.

2. Experiments to determine the effects of ultraviolet radiation on phosphorus cycling and partitioning between algae and bacteria.

3. Experiments to determine the effects of ultraviolet radiation on PAH toxicity towards plankton communities.

4. More efforts towards synoptic primary production estimates???

Murray Charlton
To: Bill Taylor
Subject: RE:

Many thanks Bill - I'll use these comments from you in the summary of the meeting.
Murray

From: Bill Taylor[SMTP:wdtaylor@sciborg.uwaterloo.ca]
Sent: February 28, 1998 11:32 AM
To: murray.charlton@cciw.ca
Cc: sguildfo@sciborg.uwaterloo.ca

Hi Murray,

Here is a response to your request for ideas on what has and will go on in Lake Erie, and whether there is a safe way to enhance fish production. It is in the form of series of comments in, I hope, a logical order.

TP and chlorophyll have declined in lake Erie, probably due to some combination of loading reductions, zebra mussel invasion, and strong piscivore populations/reduced planktivory. While reduced loading is likely important, the other factors may also reduce TP and chlorophyll yield relative to TP.

Indices of nutrient limitation in phytoplankton collected by Guildford and group in 1997, Lean & Bentzen in 1994 and earlier indicate that phytoplankton are not strongly P-limited, especially in the western basin, as would be expected if the system were responding solely to reduced loading. These indices suggest that grazing (or, less likely, light) is an important control. Photosynthesis appears to be high, as one expect if nutrient limitation is weak.

Zebra mussel grazing is an additional loss process, and quantitatively significant. There are strong Daphnia populations at times. Culver and co-workers have noted the correspondence between clear water periods and zooplankton, and our 1994 work lends support.

Western Erie is susceptible to Microcystis blooms and heavy Cladophora growth, despite the low TP. This is consistent with weak nutrient limitation as a result of high grazing losses. Increased nutrient loading would exacerbate both of these serious problems.

Most limnologists believe that high TP and chlorophyll, and high planktivore populations, favour the flow of energy mainly through the planktonic food web. This situation results in low ecological efficiency, relatively low production of fish, and a predominance in small pelagic species in that production. This situation is generally considered to be a degraded state, but one that was prevalent in the lower Great Lakes until recently.

Conversely, the natural state of the Lakes was likely low chlorophyll and TP, a high ecological efficiency, and a large standing stock of piscivorous fish rather than planktivores. Energy flow through the benthos would have been relatively important. This was, I thought, where we wanted to go, and we may be arriving.

Most aspects of the new or future state of the lake (if we keep moving in the present direction) are positive: clearer water; good fishing for piscivores and benthivores; fewer piscivorous birds (especially gulls and cormorants); and, I think, low contaminant bioaccumulation accompanying the high ecological efficiency.

The possible downsides: low abundance of forage species; smaller maximum size of piscivores (food limitation); susceptibility of the phytoplankton to fluctuate between clear water and heavy blooms of noxious forms; excess periphyton growth; abundant macrophytes. We will not see the more negative effects if loading is minimized, especially in summer, and if harvest of piscivores alleviates food limitation.

If one wanted to preserve forage species and maintain strong nutrient limitation, one might achieve that by keeping strong fishing pressure on the top predators. Maybe someone has data on the factors contributing to mortality in perch?

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(519) 746-0614 (fax)

Nutrient Status Research in Lake Erie in 1997

S.J. Guildford[1], W.D. Taylor[1] and R.E. Hecky[2]
[1]University of Waterloo, Department of Biology, Waterloo, Ontario
[2]National Water Research Institute, Environment Canada, Burlington ON

Introduction: In response to concerns about declining nutrient availability and declining productivity in the eastern basin of Lake Erie as a result of P loading reductions and zebra mussel invasion, the University of Waterloo and the National Water Research Institute collaborated on a series of cruises in 1997 to evaluate the current nutrient conditions and the nutrient status of the pelagic plankton community in all three basins of Lake Erie. Cruises were approximately monthly beginning in early May and extending into early October and were concurrent with Murray Charlton's water quality surveys (data presented elsewhere) and studies of ultraviolet effects on photosynthesis conducted by other researchers from the University of Waterloo. A suite of nutrient fractions, dissolved SiO_2, total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), particulate C, N, and P and total P were determined from samples on which microbial nutrient status measurements, chlorophyll specific alkaline phosphatase activity (APA) , ammonium uptake and phosphorus uptake, radioactive ^{33}P turnover, and size fractionation of the suspended P were done. These data will be compared with previous measurements of some of these parameters on Lake Erie and in the case of others not measured before they will be compared to values from other systems and laboratory chemostat cultures (Guildford et al 1994) to evaluate the current degree of macronutrient deficiency in Lake Erie in 1997.

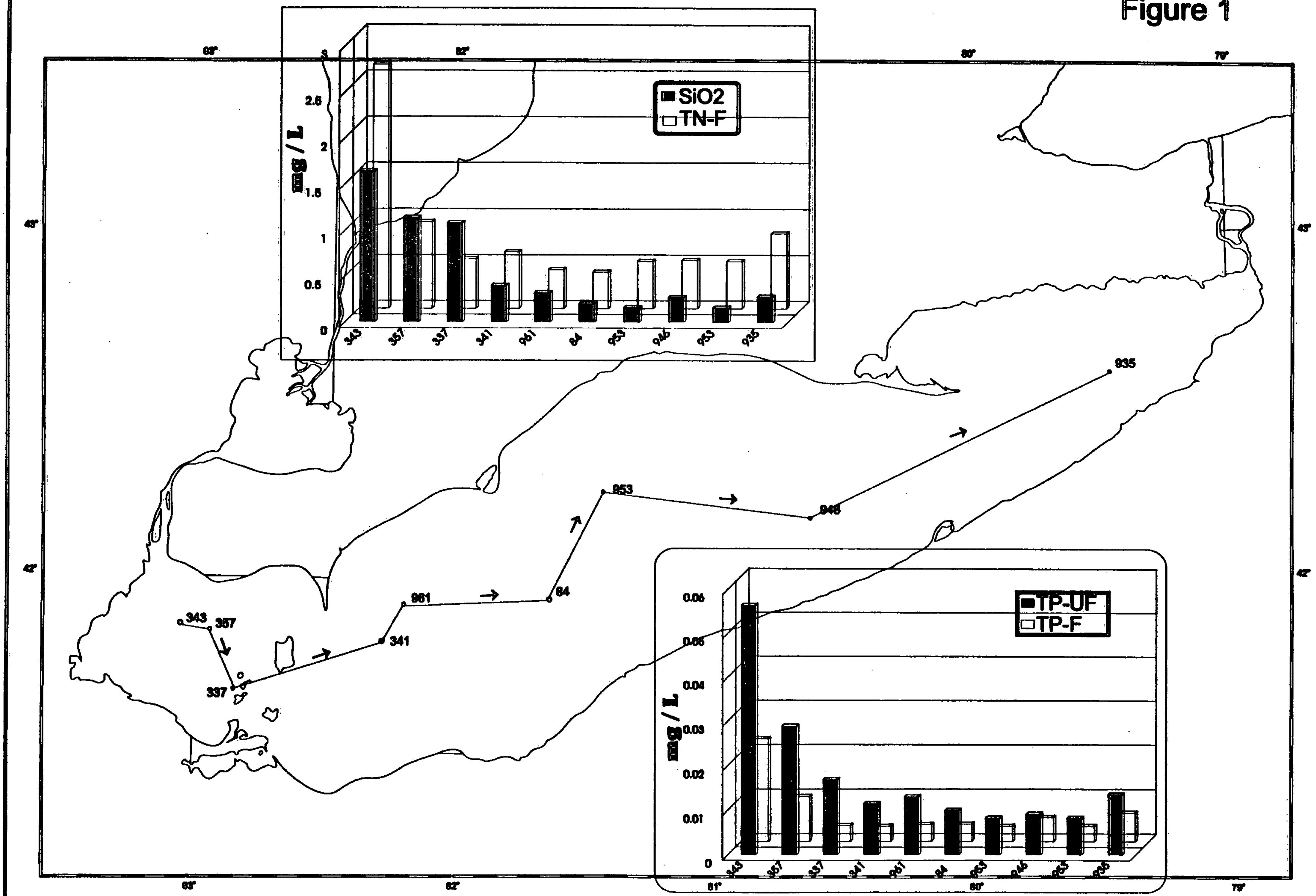
Methods: Methods and approach to interpretations are described in Guildford et al. (1994).

Guildford, S.J., L.L. Hendzel, H.J. Kling, E.J. Fee, G.G.C. Robinson, R.E. Hecky and S.E.M. Kasian. 1994. Effects of lake size on phytoplankton nutrient status. Can. J. Fish. Aquat. Sci. 51: 2769-2783.

Critical values indicative nutrient deficiency in following figures: APA>0.002 μM P/ μg chl a/h; P uptake>0.075 μM/μg chl a; N uptake>0.15 μM/μg chl a

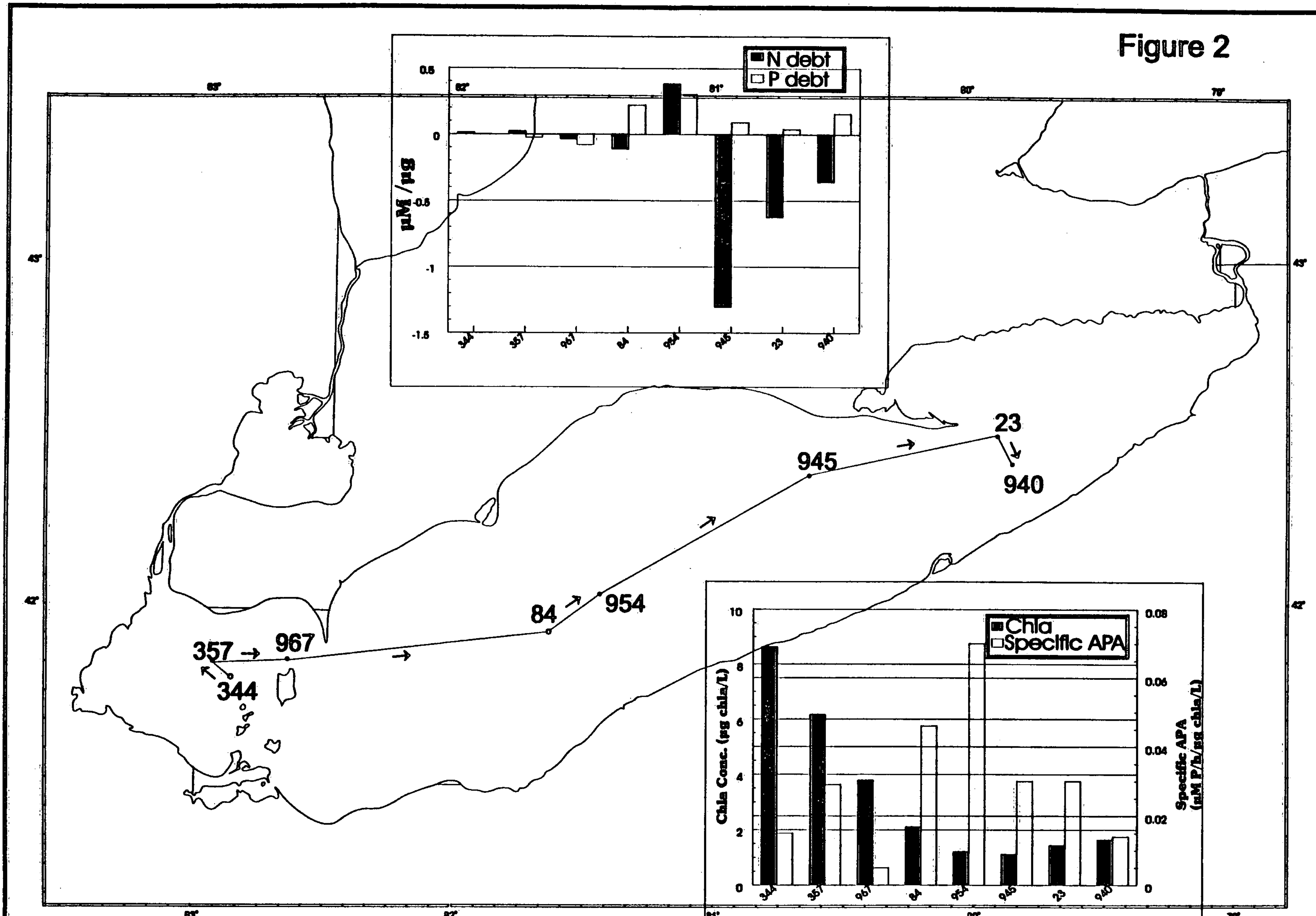
Results and Discussion: Particulate C, N and P data are not yet available, nor have ^{33}P turnover times been calculated. Only a few highlights of the data are presented here along with some first impressions. TP concentrations went below 5 μg/L in the east and central basin in midsummer and became as low as 10 μg/L in the west (Fig. 1). P deficiency indicators showed that by the end of June all the Lake Erie basins were showing signs of P deficiency (Fig. 2) which would influence their mean growth rates with little differentiation among the basins suggesting that the higher concentrations of TP in the west may be influenced by a non-bioavailable fraction. N deficiency was indicated by high rates of ammonium uptake in the dark at some stations on every cruise, but these uptake rates were highest in spring and fall (e.g. Figure 3). SiO_2 concentrations dropped as low as 30 μg/l in the central basin by the end of June (Fig.4) and were below 200 μg/l, a concentration considered limiting for many freshwater diatoms for most of the summer (Fig. 1) in the east and central basin and got as low as 500 μg/L in the western basin by the end of August (Fig. 5). Although P deficiency was indicated by APA and P uptake, it was not as severe as measured in many other aquatic systems including Lakes Nipigon and Superior on which these measurements have been made. Also noteworthy was the evidence for co-limitation at times by the nutrients N and Si (at least for the diatoms and some chrysophytes). This co-limitation in itself constitutes evidence that P is sufficiently available to drive down the concentrations of other essential nutrients to levels which may limit the growth of some algal species. Tentative conclusions are that P likely affects growth rates and biomass of algae in mid-summer over most of the lake, but at that time there is also likely limitation of some diatom species by SiO_2 availability and some other algae by N. If P concentrations were allowed to rise by allowing relaxation of loading targets, the P would likely flow to enhance the growth of blue-greens in the summer which can outcompete other species for N. Diatom growth might not have any great benefit from increased P because SiO_2 might become severely limited. The zebra mussel might also shunt the added P to littoral algae including nuisance algae such as Cladophora. These are the bad old days to which the lake could readily return.

Figure 1



Stephanie Guildford

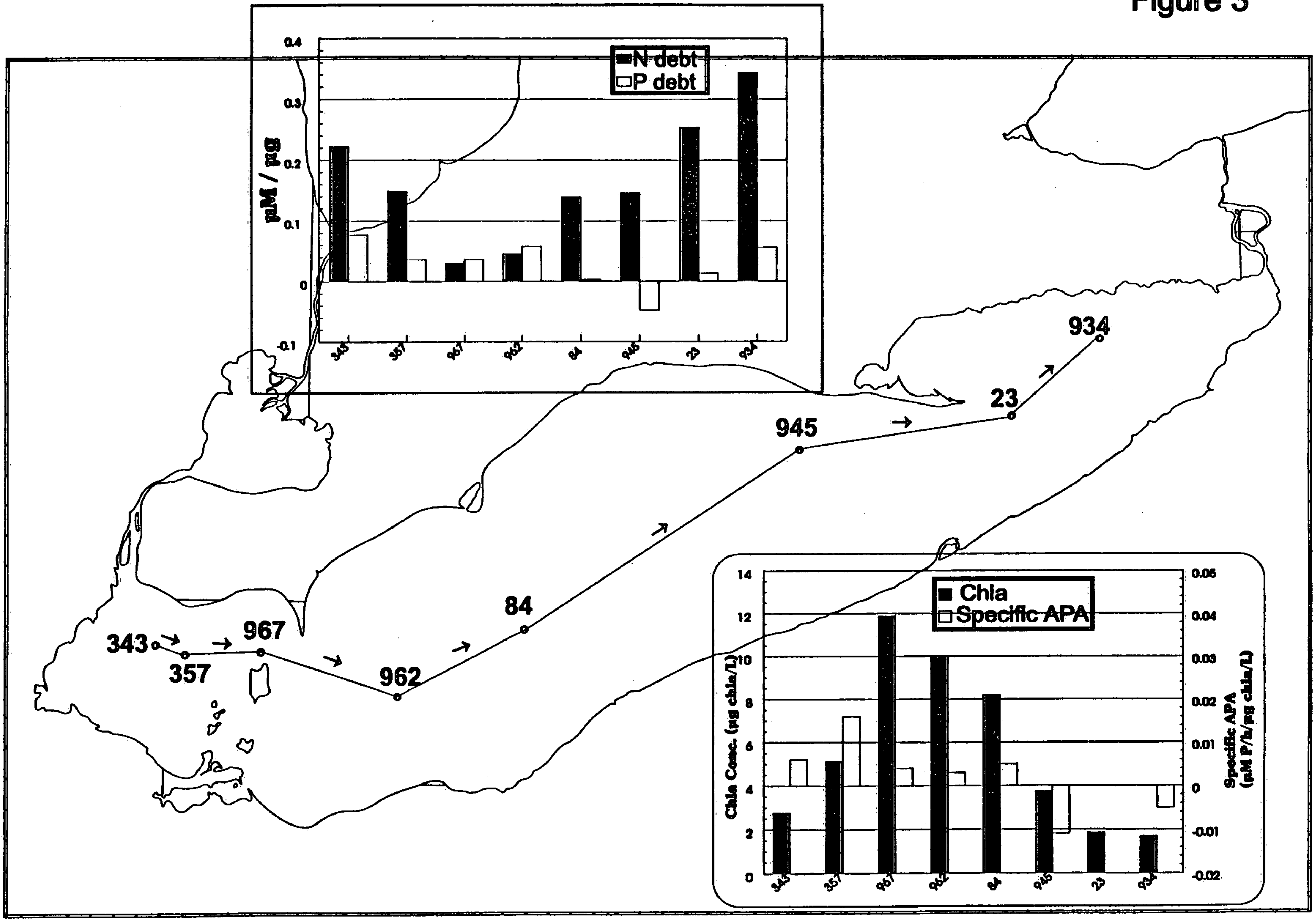
Lake Erie, Cruise 04,
Jun 02-05, 1997



Stephanie Guildford

Lake Erie, Cruise 06,
Jun 30-Jul 03, 1997

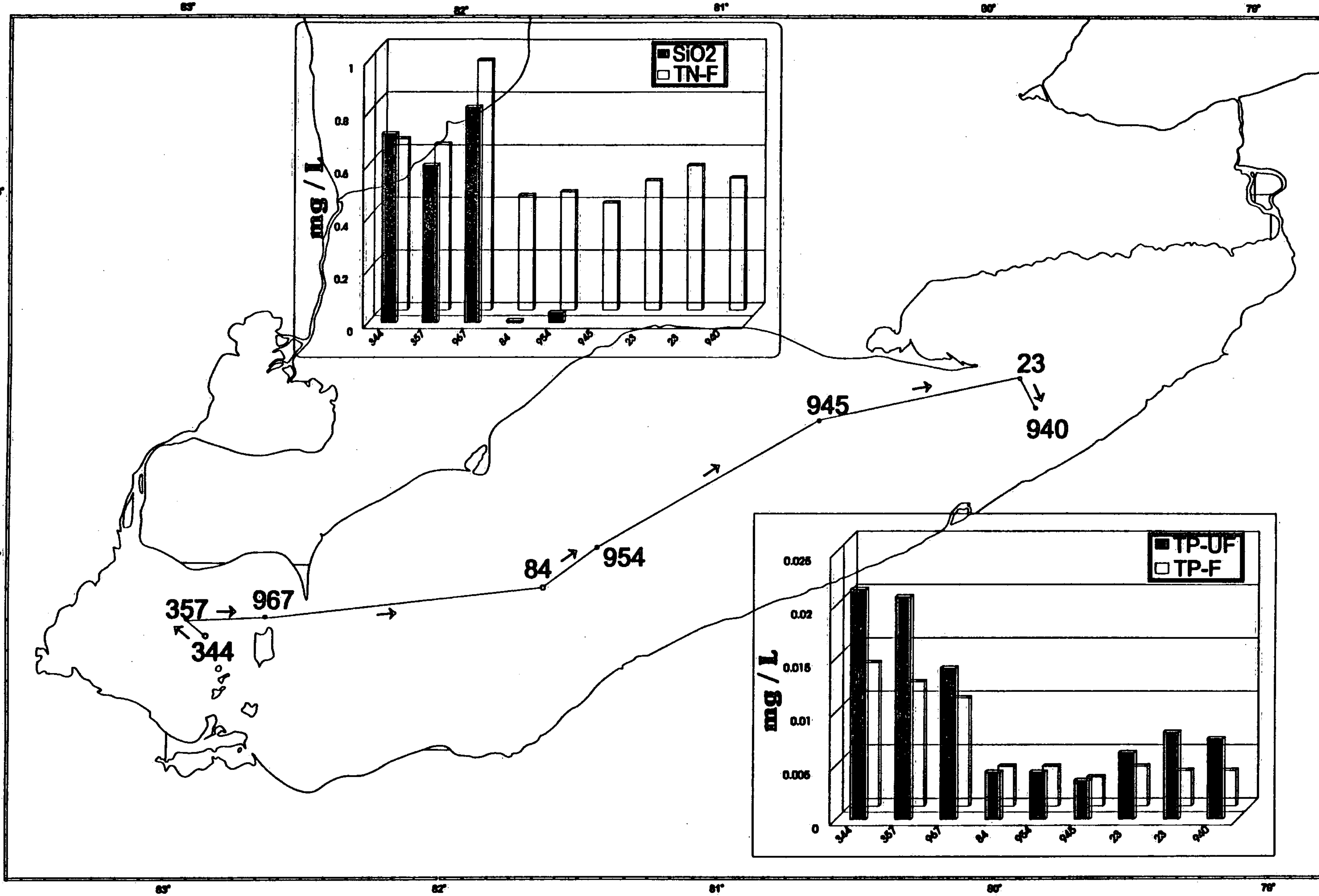
Figure 3



Stephanie Guildford

Lake Erie, Cruise 14,
October 06-08, 1997

Figure 4



Stephanie Guildford

Lake Erie, Cruise 06,
Jun 30-Jul 03, 1997

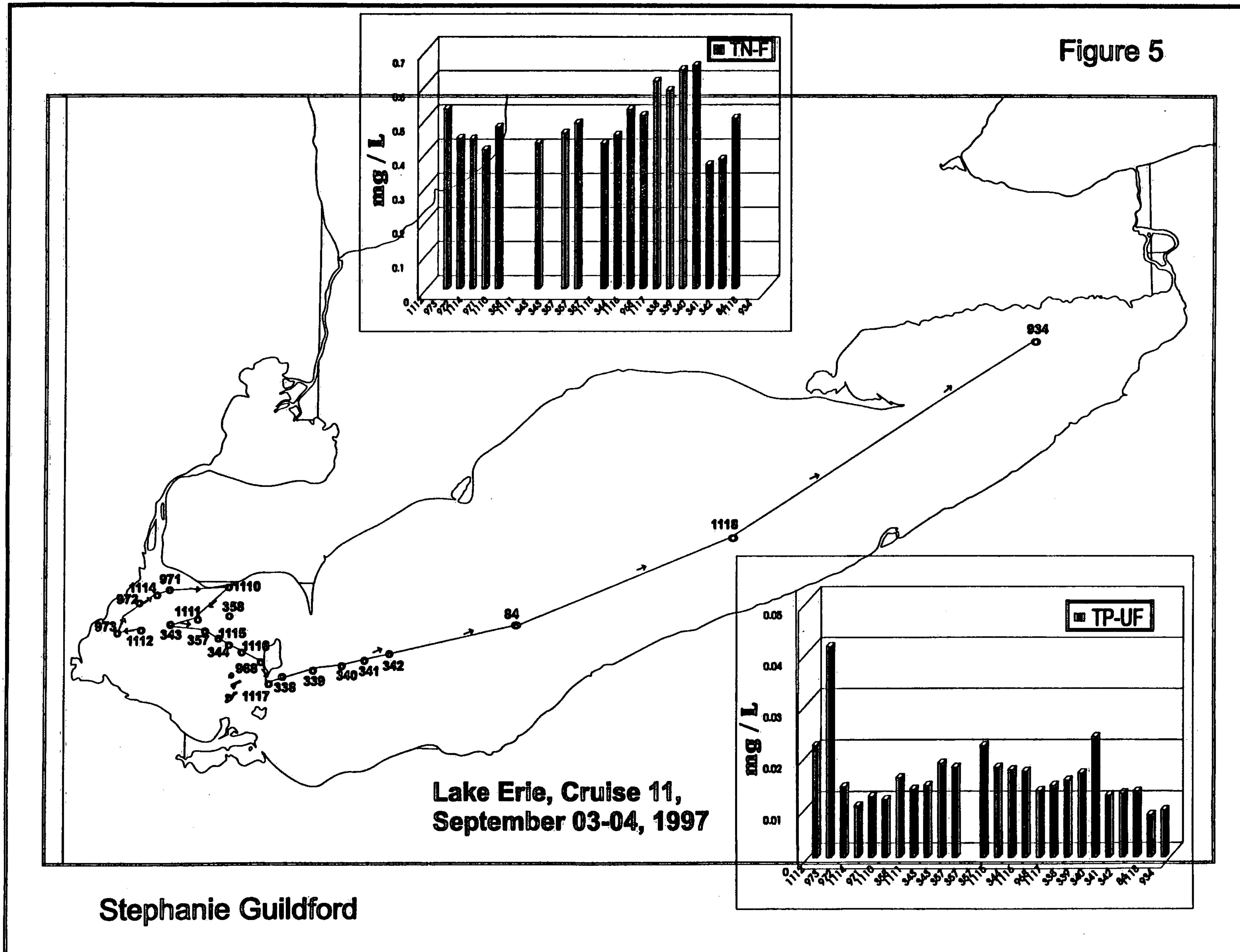


Figure 5
TN-F
mg / L
TP-UF
mg / L
0.05
0.04
0.03
0.02
0.01
934
1118
84
342
341
340
339
338
1117
968
1116
344
357
1115
343
358
1111
1110
971
1114
972
973
1112
Lake Erie, Cruise 11,
September 03-04, 1997
Stephanie Guildford

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Environment Canada Environnement Canada

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