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Final Report of the Ecosystem Objectives Committee to the Great Lakes Science Advisory Board, March 1990, Windsor, Ontario

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NOTICE

This report to the Great Lakes Science Advisory Board was carried out as part of the activities of the Ecosystem Objectives Committee. While the Board supported this work, the specific conclusions and/or recommendations do not necessarily represent the views or policies of the International Joint Commission, the Science Advisory Board or its committees.

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CHAIRPERSONS' COMMENTS

This report is the last in a series which began in 1974 with the joint report of the Water Quality Objectives Subcommittee (WQOS) and the Scientific Basis for Water Quality Criteria Committee (SBWQCC). Following this year's activities and the submission of the present report, the Ecosystem Objectives Committee (EOC, formerly the Aquatic Ecosystem Objectives Committee, (A)EOC) is disbanded and the task to ensure that the objectives remain current and protective of the system falls to the Governments of Canada and the United States (the Parties).

It is with a great deal of nostalgia that the chairpersons take this opportunity to express appreciation to the members of the EOC and their predecessors, the WQOS and SBWQCC, and their many colleagues who have given unstintingly of their private as well as institutional time and energy. Without these dedicated efforts, the state of objectives development in the Great Lakes would not be what it is today; in turn, much of the monitoring, identification of Areas of Concern and remedial actions would not have followed. When the process of developing objectives in the Great Lakes was started, one concern was how our proposals compared with those in existence elsewhere -- proposals which were already in place and had the weight of time behind them. The objectives of the Great Lakes Water Quality Agreement served as a model for regulatory and enforceable standards of many jurisdictions in both Canada and the United States; they are also considered by other countries in developing similar objectives.

This report includes material which summarizes the directions and philosophies of the past 15 years. It is intended to provide advice to the Binational Objectives Development Committee (BNOC) that has been established by the two Parties. The Terms of Reference of the BNOC include the making of recommendations on ecosystem as well as chemical objectives which eventually go to the International Joint Commission. It will be their responsibility to develop new directions and to devise additional ways to protect the system as called for in the Agreement (1978, revised 1987). It is with satisfaction that the EOC passes this role on the the BNOC.

William M.J. Strachan, Canadian Co-Chair

Mary G. Henry, United States Co-Chair

Ecosystem Objectives Committee

1.0 RECOMMENDATIONS

1.1 Objectives

1.1.1 Objective for a Healthy Western and Central Lake Erie Ecosystem (Walleye and *Hexagenia* Indicators; see Chapter 4.1)

Lake Erie (central and western basins) should be maintained as a balanced and stable mesotrophic ecosystem with the walleye as top aquatic predator of a coolwater community and the burrowing mayfly as the major benthic macroinvertebrate.

NOTE: In order to determine whether this condition exists, the following criteria should be met:

i. The production of walleye in Lake Erie should exceed an amount capable of sustaining a continuous annual harvest of at least 0.3 kg/ha/a.

NOTE: The quantitative relationship between production and harvest for this species in Lake Erie needs to be determined.

ii. The levels of toxic contaminants in walleye should neither exceed levels that adversely affect the walleye themselves nor levels that are acceptable for human consumption.

iii. Numbers of the burrowing mayfly, *Hexagenia limbata,* in the western basin of Lake Erie should exceed 200/m^2, averaged over three years.

NOTE: From 1930 to 1958, numbers have fluctuated substantially from 30 to 800/m^2 and are likely to continue to do so in a healthy Lake Erie ecosystem. A three-year average is therefore recommended.

1.1.2 Objective for a Contaminant Free Great Lakes Basin Ecosystem (Bald Eagle Indicator; see Chapter 4.2)

The Great Lakes should be restored to the degree that uncontaminated Great Lakes fish and wildlife prey should be available for the successful hatching of bald eagle eggs, and immature and adult bald eagles confirmed to be using the Great Lakes as a primary feeding area.

NOTE: In order to determine whether this condition exists, the following criteria should be met:

i. The average productivity of the restored bald eagle population for each Great Lake should be 1.0 fledged young per occupied territory and more than 50% of the occupied territories should produce fledged young.

ii. Concentration of organochlorine chemicals in bald eagle eggs should be less than the following on a fresh, wet-weight basis: DDE, 1.0 ppm; dieldrin, 0.06 ppm; and PCB, 4.0 ppm.

iii. Agencies of the Parties and jurisdictions, responsible for restoring Great Lakes bald eagle populations, should identify and legally protect habitat suitable for bald eagle occupation, survival and reproduction. The Northern States Bald Eagle Recovery Plan should state specific objectives for bald eagle management near Great Lakes shorelines.

1.1.3 Revision of Article III (see Chapter 2.2.2)

The Parties should consider, in their next revision of the Agreement, the inclusion of the following statement under Article III (General Objectives) :

[These waters should be:]

(f) *maintained and, as necessary, restored to a condition where a balanced and stable community of organisms is present that resembles, as much as is feasible and practicable, the community that existed before the advent of human intervention.*

1.2 Related Recommendations

1.2.1 Potential Use of the Lake Trout and *Pontoporeia hoyi* as an Ecosystem Surrogate for Lakes Huron and Michigan (see Chapter 3)

The Parties should consider the development of ecosystem objectives for Lakes Michigan and Huron using the lake trout and *Pontoporeia hoyi* as indicator species. The Parties should undertake surveys for *P. hoyi* in Lake Huron.

1.2.2 An Ecosystem Indicator for Nearshore Areas (see Chapter 4.3)

The Parties should consider the development of an ecosystem indicator for nearshore areas of the Great Lakes. This might take the form of using the smallmouth bass as an appropriate surrogate species for ecosystem health as well as complementary indicators.

1.2.3 Mixtures (see Chapter 5)

The Parties should consider the development of an ecosystem mixtures objective for waters of the Great Lakes. This should be based on the principle of additivity of effects and use the toxic unit concept.

1.2.4 Assessment of Comprehensive Track Chemicals (see Chapter 6)

The Parties should evaluate the database and other information on the Comprehensive Chemicals with the intention of classifying these substances into the three lists of Annex 1 of the revised (1987) Great Lakes Water Quality Agreement.

1.2.5 Re-evaluation of the Classification of Specific Objectives: Annex 1 (see Chapter 8)

The Parties should examine the present classification of compounds for which there are objectives in the revised (1987) Great Lakes Water Quality Agreement. The examination should consider the division of substances into persistent toxic substances and non-persistent toxic substances, and should specify actions which are appropriate for these two classes.

2.2 Objectives under the (A)EOC/EOC

In 1980, the (A)EOC recommended to the Science Advisory Board (SAB) the adoption of two new objectives (pentachlorophenol and polychlorinated dibenzodioxins), the revision of two existing objectives (lead and microbiology) and the adoption of four objectives previously proposed by the WQOS/SBWQCC (silver, chlorine, temperature and nutrients). In 1981, the (A)EOC's recommendations included the revision of the selenium objective, the confirmation of the mirex objective and the development of a mechanism to define Limited Use Zones. The SAB concurs with these objectives and the International Joint Commission (IJC) has recommended them to the Governments of the United Sates and Canada (the Parties) with caveats for chlorine and temperature.

In 1982, the (A)EOC reconfirmed the silver objective, reviewed a new contaminant (polychlorinated styrenes) and reexamined an old one (asbestos). The (A)EOC also described a number of research activities required to develop objectives. In 1983, the (A)EOC recommended an objective for benzo[a]pyrene and two revised objectives for microbiology -- an indicator species, *Escherichia coli* and a pathogen, *Pseudomonas aeruginosa*. The objective for diazinon was also reviewed and a subsequent revision was presented. In its 1985 report, the (A)EOC presented the first of what was intended to be a series of ecosystem objectives to assist in assessing the health of several parts of the Great Lakes. The lake trout was selected as a measure of Lake Superior ecosystem quality and revised objectives for ammonia, the benzenehexachlorides (replacing the one for lindane) and toxaphene were presented. The 1987 report of the EOC added *Pontoporeia hoyi* as a complementary indicator to the lake trout of a healthy condition for Lake Superior and also recommended a revised zinc objective.

This report includes a new measure of ecosystem quality for mesotrophic parts of the Great Lakes. In addition, a new type of objective which uses the condition of bald eagle populations to determine the level of persistent organochlorine compounds in the system associated with biological effects is also presented.

2.2.1 Specific Objectives for Chemicals

The framework[1] for developing objectives was formulated by the WQOS/SBWQCC and is restated here for clarity. It is understood that the term "water quality" in the former framework is translated to "ecosystem quality" for the purposes of the (A)EOC.

1. In developing the specific water quality objectives, the philosophy of protecting the most sensitive use is employed.

2. The objectives serve as a minimum target wherever water quality objectives currently are not being met.

3. For jurisdictionally designated areas that have outstanding natural resource value and existing water quality exceeds the objectives, the existing water quality should be maintained or enhanced.

4. Specific water quality objectives are to be met at the periphery of mixing zones, assuming that water quality conditions exceedingobjectives will result beyond the mixing zones. The objectives should be implemented in concert with limitations on the extent of mixing zones or zone of influence and localized areas as designated by the regulatory agencies.

5. In recommending objectives to protect raw drinking water supplies, it is assumed that a minimum level of treatment is provided before public consumption.

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[1] International Joint Commission. New and Revised Great Lakes Water Quality Objectives. Volume II. Washington, D.C. and Ottawa, Ontario. October 1977.

6. Adoption of objectives does not preclude the need for further study of the effects of pollutants on the aquatic environment.

7. Since infinite combinations of water quality characteristics may occur, the objectives often are unable to take into account antagonistic, synergistic and additive effects because of lack of data.

8. Since new data may lead to modified recommendations, the objectives are subject to continual review.

9. No adequate scientific data base can exist for establishing scientifically justifiable numerical objectives for "unspecified nonpersistent toxic substances and complex wastes." Therefore, criteria for developing an operationally defined objective for local situations are recommended.

The (A)EOC endorsed this framework with the understanding that the recommended objectives do not consider socio-economic factors. The Committee agreed with previous recommendations (Water Quality Board 1980[2]) that socio-economic impact assessment is the responsibility of the jurisdictions and should be completed to develop regulations or standards. Objectives should be considered goals and used as a basis to develop regulations or standards by individual jurisdictions, rather than standards which must be immediately and comprehensively achieved.

2.2.2 Ecosystem Objectives

The (A)EOC was also charged by the IJC's SAB to develop ecosystem objectives. These particular objectives describe conditions that must be met in order to ensure the health of Great Lakes ecosystems. The health of ecosystems are determined from a combination of factors at different hierarchical levels including chemical conditions (contaminant concentrations, oxygen levels, etc.), the state of indigenous species and the structure or function of the ecosystem as a whole.

Specific objectives contained in the Agreement largely refer to specific chemicals or physical properties, except for one objective requiring the waters to be substantially free from pathogens. These objectives assess ecosystem health at only the lowest hierarchical level and except for the Lake Superior (lake trout and *Pontoporeia hoyi*) objective, are not objectives in the true sense of the word in that they do not specify the desired biological or ecological attributes of the systems.

To address the priority requirement to specify such conditions in the system, the (A)EOC has taken several steps:

1. An additional general objective for inclusion under Article III of the Great Lakes Water Quality Agreement has been recommended to the SAB for transmittal to the IJC and the Parties. It reads:

   [These waters should be:]

   (f) *maintained and, as necessary, restored to a condition where a balanced and stable community of organisms is present that resembles, as much as is feasible and practicable. the community that existed before the advent of human intervention.*

   This objective was presented in the 1985 Annual Report of the (A)EOC and was designed to provide the rationale for specific ecosystem objectives. It is again recommended.

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[2] Alternatives for Managing Chlorine Residuals: A Social and Economic Assessment. Final report of the Chlorine Objectives Task Force to the Great Lakes Water Quality Board, Windsor, Ontario. April 1980.

2.3 Biological Indicators

Many different species have been used to monitor levels of persistent toxic chemicals in the Great Lakes since 1972. Selected organisms have been particularly useful in establishing trends in concentrations -- the lake trout and herring gull, prominent among these. In general, these have demonstrated a decrease in the contaminant levels in the system since the mid-1970s. Such chemical analyses provide vital information on the EXPOSURE half of the assessment equation; there remains still the EFFECTS which the chemicals may exert on the system. These have not been well documented and have not been used to provide official indication of the conditions of the several lakes.

The introduction of the ecosystem objective (for Lake Superior in 1985 and Lake Erie in the present report), for the first time provided monitoring for the condition of a species, which in turn was intended to reflect the desired condition of the lakes. Conceptually, the selected species are responding to a variety of stresses including but not limited to toxic chemicals. An observation that the objective is not being met is analogous to a medical statement that the patient has certain symptoms; there remains the need to diagnose the nature of the illness in both cases.

Population effects of particular species from the Great Lakes have sometimes been used to define a particular stress; the bald eagle is a case in point. This bird, feeding its young largely on fish from the Great Lakes, had virtually disappeared from the area. This was due mainly to accumulation of toxic persistent organochlorine compounds within the organism and, indeed, was mainly the consequence of feeding of the young. The Report thus includes an objective which is intended to generally reflect the system condition for such chemicals. The species is being used to describe a desired state of the system with regards to certain chemicals.

3.0 POTENTIAL USE OF THE LAKE TROUT AS AN ECOSYSTEM INDICATOR FOR LAKES HURON AND MICHIGAN

3.1 Discussion

The lake trout was proposed in 1985 as a feasible surrogate of a coldwater community to determine the relative health of Lake Superior (Ryder and Edwards, 1985). Sufficient lake trout exist in Lake Superior to allow judgments on the relative quality of the environment using the lake trout dichotomous key (Marshall *et al.* 1987). After extensive testing on Lake Superior, the dichotomous key could be appropriately modified and applied to the other upper Great Lakes with reasonable assurance of the results. This approach has been criticized as inappropriate for Lakes Michigan and Huron because:

a. lake trout are not reproducing extensively in either Lake Michigan or Lake Huron; and

b. exotic salmonids, through introduction, have become the predominant terminal predators.

A suggested alternative to the lake trout approach was the inclusion of exotic salmonids as ecosystem indicators. However, this proposition does not utilize the fundamental concepts of the ecosystem surrogate approach, which include the historical presence of the species in the lakes, the extent of its habitat and its significance in the food web.

The lake trout has been a structurally stable component of the relatively unperturbed, oligotrophic systems in the upper Great Lakes over a long period of time. Lake trout, as the top predator in the food web interact with a large variety of indigenous organisms. Historical data (back to the 1800s) exist on the abundance of the lake trout in each of the Great Lakes. In the early days of European settlement, the lake trout occupied almost every major habitat type, at least at certain times of the year. This included the pelagic, demersal and nearshore littoral zones as well as the lower reaches of major tributary streams. Lake trout have been shown to be affected by a variety of stresses including cultural eutrophication, exotic species, deforestation causing increased siltation and toxic chemicals.

Most of the exotic salmonids now prevalent in lakes Huron and Michigan are from the west coast of North America. They are anadromous and, therefore, are representative of an ecosystem quite different from the Great Lakes. Most of the Pacific salmonids have had to make rather dramatic genetic adjustments in order to survive and reproduce successfully in the Great Lakes. Because of their relative short-term presence here, they are not representative of or able to act as surrogates of the indigenous coldwater community of the Great Lakes. Indeed, their levels of stability and persistence are not yet known, especially for chinook, coho salmon and even pink salmon which have persisted for more than three decades. Only in the case of the rainbow trout has some semblance of a steady state been obtained. All of these exotic salmonids have a much shorter lifespan than the native lake trout which accumulates and concentrates heavy body burdens of contaminants over a long lifespan. The presence of large numbers of exotic species, whether through deliberate introduction or merely serendipity, could in itself be regarded as one of the symptoms of ecosystem malaise. Accordingly, the EOC does not believe that exotic salmonids are appropriate either as indicators or integrators of the cold-water community of the Great Lakes system.

Use of the lake trout as an ecosystem surrogate for Lake Michigan may seem inappropriate since there is virtually no lake trout reproduction there. That fact in itself is a prime indication that something is critically wrong with the ecosystem. Abundant and variable stocks of reproducing lake trout without heavy body burdens of contaminants, are usually indicative of an unperturbed environment in general. A similar condition for chinook or coho salmon, however, would be less convincing because they are more restricted in their behavior and habitat requirements. For example, low body burdens of contaminants in Great Lakes Pacific salmon might reflect a restricted, favorable local environment; alternatively, a high body burden might be indicative only of either short-term or local effects. In either case, the results could not be extrapolated confidently to the total system.

What is the prognosis for the future? The EOC recommends the conservative approach, using lake trout as the principal indicator of the state of the oligotrophic system and its contained coldwater communities -- at least for Lake Huron. Much of the material in the dichotomous key for Lake Superior may be applied directly to Lake Huron with minor modifications. Application of *Pontoporeia hoyi* to Lake Huron as a complementary indicator, may not be appropriate, at least until some baseline studies have been completed. However, good quantitative estimates of *P. hoyi* exist for both lakes Superior and Michigan, and Lake Huron may be assumed to have natural levels similar to a mean value for these two lakes.

Current management goals for Lake Michigan may preclude the possibility of achieving a healthy ecosystem based on lake trout alone because of unfavourable environmental conditions and the present fishery management policies which have evolved to deal with these conditions. The best we can hope for on Lake Michigan is a state-of-health based on a mixture of lake trout and exotic salmonids, with the implicit understanding that these types of semi-indigenous, mixed fish assemblages are less predictable, more subject to emergent surprises and may even, on occasion, mask ecosystem insufficiencies because of their narrow and specialized biotopes.

3.2 References

Marshall, T.R., R.A. Ryder, C.J. Edwards and G.R. Spangler, 1987. Using the Lake Trout as an Indicator of Ecosystem Health -- Application of the Dichotomous Key. Great Lakes Fisheries Commission, Ann Arbor, Michigan. Technical Report No. 49, 35 pp.

Ryder, R.A. and C.J. Edwards (eds.). 1985. A Conceptual Approach for the Application of Biological Indicators of Ecosystem Quality in the Great Lakes Basin. Publication of the International Joint Commission and the Great Lakes Fisheries Commission, Windsor, Ontario. 169 pp.

4.0 OBJECTIVES

The objectives recommended in this report were under development when this responsibility was transferred to the Binational Objectives Development Committee of the Parties, under the 1987 Protocol to the Great Lakes Water Quality Agreement. They are, therefore, recommended to the Science Advisory Board (SAB) and to the International Joint Commission (IJC) and the Parties in the manner that prevailed prior to the signing of the 1987 Protocol.

4.1 Objective for a Healthy Western and Central Lake Erie Ecosystem (Walleye and *Hexagenia* Indicators)

4.1.1 Recommendation

Lake Erie (central and western basins) should be maintained as a naturally self-sustaining mesotrophic ecosystem, with the walleye as top aquatic predator of a coolwater community and the burrowing mayfly as the major benthic macroinvertebrate.

NOTE: In order to determine whether this condition exists, the following criteria should be met:

i. The production of walleye in Lake Erie should exceed an amount capable of sustaining a continuous annual harvest of at least 0.3 kg/ha/a.

NOTE: The quantitative relationship between production and harvest for this species in Lake Erie needs to be determined.

ii. The levels of toxic contaminants in walleye should neither exceed levels that adversely affect the walleye themselves nor levels that are acceptable for human consumption.

iii. Numbers of the burrowing mayfly, *Hexagenia limbata,* in the western basin of Lake Erie should exceed 200/m^2, averaged over three years.

NOTE: From 1930 to 1958, numbers have fluctuated substantially from 30 to 800/m^2 and are likely to continue to do so in a healthy Lake Erie ecosystem. A three-year average is therefore recommended.

4.1.2 Purpose of Ecosystem Objectives

Specific objectives for parts of the Great Lakes Basin Ecosystem are intended to provide a means of determining whether the conditions in the named water body are in a healthy state. Indicator species have been selected on the basis of their ecological role in the aquatic community and their ability to respond to stresses within the system. Qualitatively, the specific objectives are not likely change but the quantitative, measurable levels of aspects of the indicator species are subject to change when relevant databases so warrant.

4.1.3 Summary

A high quality mesotrophic environment of moderate depth in Lake Erie supports a coolwater community of organisms dominated by large percids, of which the walleye is the top piscivore. Native species maintain their numbers naturally, and retain a semblance of predictable steady-state over time compared with the rest of the community to allow for harvests proportional to individual species abundance.

A healthy community of bottom fauna should complement a coolwater percid community, with the burrowing mayfly (*Hexagenia limbata*) as the dominant benthic organism. This species thrives in aerobic sediments and hence is a measure of cultural eutrophication and other sediment-water interactions which may stress a mesotrophic system.

Both species are integrative indicators of the quality of Great Lakes mesotrophic subsystems (Edwards and Ryder, 1990). The Parties should use these species to specify quantitative ecosystem objectives for mesotrophic waters in other lake areas and connecting channels. Criteria are proposed for using the walleye and *Hexagenia* as indicators of the health of the Lake Erie ecosystem. The complexity of the system however may warrant addition of other indicator organisms in Lake Erie and elsewhere in the Great Lakes.

4.1.4 **Rationale**

In the Great Lakes basin, mesotrophic waters are usually found at intermediate depths and include the western and central basins of Lake Erie, the Bay of Quinte in Lake Ontario, Saginaw Bay and parts of Georgian Bay in Lake Huron, lower Green Bay in Lake Michigan and Black Bay in Lake Superior.

Fish in mesotrophic waters are qualitatively different from those in oligotrophic and eutrophic lake systems, and are usually dominated by percid communities (Hartman, 1973; Leach *et al.* 1977). Benthic invertebrates also differ among oligotrophic, mesotrophic and eutrophic systems, particularly in terms of oligochaetes (Howmiller and Scott, 1977). Other benthic organisms such as the burrowing mayfly, *Hexagenia limbata*, may find optimal habitat conditions in mesotrophic systems and will diminish in abundance as the system becomes more oligotrophic, or more eutrophic, deeper, or shallower.

A sequential and orderly response to environmental stress has been documented in each of the mesotrophic systems listed. Populations of of *Hexagenia* are extirpated and a community dominated by oligochaetes and increased numbers of chironomids proliterates. Thus the occurrence and population dynamics of *Hexagenia* is a complementary surrogate organism depicting a healthy mesotrophic system.

One practical approach to the determine an ecosystem's condition is to focus the measurements on indigenous species that have co-existed for a long time. This has been referred to as the "harmonic community" concept. In these aquatic communities, sort, fishes can be grouped by ecological function which tend to maintain themselves in appropriate ratios for efficient energy transfer, even when subjected to moderate stress from fishing. For example, a mesotrophic fish community for Lake Erie may include of a predator functional group including the walleye *(Stizostedion vitreum vitreum)*, the northern pike *(Esox lucius)*, sauger *(Stizostedion canadense)*, blue pike *(Stizostedion vitreum glaucum)* and yellow perch *(Perca flavescens)*. It would also have large benthic feeders such as various species of suckers *(Catostomus* sp., *Moxostoma* sp.) in addition to a host of other species including some abundant prey species.

For Lake Superior, the top predator, the lake trout, has been identified as a key species occupying an integrative node in the community; such a species reflects changes in well-being of the community as a whole and can be used as an indicator of the health of oligotrophic ecosystems (Ryder and Edwards, 1985). Similarly, the Mesotrophic Indicators Work Group (Edwards and Ryder, 1990) recommended that the walleye be used as one species representative of the health of mesotrophic ecosystems. Its position as the top piscivore in mesotrophic "harmonic" communities is an important attribute contributing to its usefulness as such an indicator.

The Ecosystem Objectives Committee, in its report (International Joint Commission 1986) detailing the rationale for the use of the lake trout as an indicator of an oligotrophic lake system, developed a series of criteria for selecting ecosystem indicators. While not all criteria need to be met for a species to be acceptable, a desirable/preferred species would meet most of the criteria. These criteria are found in Table 4.1.

TABLE 4.1 Criteria for Selection of Great Lakes Basin Ecosystem Indicators

The indicator must:

- have a broad distribution in the system
- be easily collected and measured in terms of biomass
- be indigenous and maintain itself through natural reproduction
- interact directly with many components of its ecosystem
- have historical, preferably quantified, information pertaining to its abundance and other critical factors relevant to the state of the organism
- have well documented and quantified niche dimensions expressed in terms of metabolic and behavioral responses
- exhibit a gradual response to a variety of human induced stresses
- serve as a diagnostic tool for specific stresses of many sorts
- respond to stresses in a manner that is both identifiable and quantifiable
- be a suitable species for laboratory investigations
- be generally recognized as important to humans, and
- reflect aspects of ecosystem quality other than those represented by presently accepted parameters.

Walleye *(Stizostedion vitreum vitreum)* as an Ecosystem Indicator

° Distribution

Walleye historically have been widely distributed in the western and central basins of Lake Erie (declining by 1969; Hartman 1988), Saginaw Bay (declining by the mid-1960s; Schneider 1977), northern and southern Green Bay (declining by 1969 and 1956, respectively; Schneider and Leach, 1979) and western Lake Ontario (Scott and Crossman, 1973). Several connecting channels and tributaries historically have also supported walleye populations such as the Detroit, Maumee, Sandusky, Cuyahoga and Grand rivers (Hartman 1988).

° **Biomass Estimates**

Commercial catch records historically have been available for the years leading to and following the decline of walleye in mesotrophic areas throughout the Great Lakes. Due to its desirability as a sport fish, creel census data are also available in certain locations and make accurate biomass estimates of walleye plausible. Since major declines in walleye abundance in the '50s and '60s, extra effort has been expended to survey strength-of-year classes recruited into [which have become part of] the fishery.

° **Indigenous and Naturally Reproducing**

Walleye are indigenous to the Great Lakes. Since their decline and the closure of the commercial fishery in Lake Erie, 1970, the Great Lakes Fishery Commission has overseen an interagency effort to pool historic and current data to use in establishingannual quotas for each jurisdiction on the lake. The recovery of walleye populations has been dramatic, with estimated fishing stocks 43 cm (17 inches) or larger at 21.8 million fish (Hartmann 1988). A recent effort to increase controls on nutrient loading into the Bay of Quinte has also stimulated reproduction in walleye populations in that area (Hartmann 1988).

° **Ecosystem Interaction**

The walleye has been identified as a key-predator that is essential to the well-being of the remainder of the community (Ryder and Kerr, 1978). If the walleye maintains its ecological role as the top predator within the percid fish community, it will also retain its ecological ratio to other members of the harmonic community and represent the level of health of mesotrophic waters.

° **Historical Evidence**

The historical decline of the walleye has been documented and evaluated by many investigators. For example, Schneider and Leach (1979) documented changes in Saginaw Bay, several authors in Lake Erie (Regier *et al.* 1969; Parsons 1970; Hartmann 1988), Hurley and Christie (1977) in Lake Ontario and Spangler *et al.* (1977), in Lake Huron.

° **Stress Response**

Although the historical decline of walleye populations in many of the mesotrophic waters of the Great Lakes (especially Lake Erie) has often been attributed to overfishing, other stress responses were evident in resident populations. Degraded water quality due to nutrients has been linked to walleye decline in the Bay of Quinte. The inferred cause-effect relationship between nutrients and population decline has been strengthened with observed increases in species abundance concomitant with improved pollution controls.

Sedimentation and eutrophication have also been implicated in spawning and nursery habitat degradation and toxics have influenced fishing regulations. The specific stress responses associated with these variables have been more difficult to quantify. As these conditions improve, more information will be garnered relating specificity of response to the causal stress.

° **Importance to Humans**

The sport and commercial value of the walleye fishery in Lake Erie alone has been estimated at several million dollars annually. The importance of this fishery is growing throughout the basin.

Hexagenia spp. as an Ecosystem Indicator

Ideally, complementary species should be used to add confidence to any assessment made on the basis of a single species. For this purpose, a complementary organism representative of mesotrophic ecosystems community integration at a different trophic level from that occupied by the walleye is needed. Following a review of several candidate species, the work group found that the mayfly (*Hexagenia* spp.), a member of the diverse benthic community of mesotrophic systems in the Great Lakes, was the indicator organism that best complemented the walleye with little overlap in the system properties represented. The mayfly is an important food item for both subadult and adult walleyes. It is strongly indicative of healthy surficial sediments with adequate levels of dissolved oxygen in the overlying water columns. Mayfly abundance is easily quantified and many data exist about past levels of abundance. It occupies an integrative node in the ecosystem in that it tends to reflect the effects of interactions at the sediment-water interface. As this particular ecotone is not addressed directly when using the walleye as an indicator, mayfly provides additional information regarding the state of the mesotrophic system that does not duplicate that provided by walleye. As such, mayfly is a complementary indicator to the walleye.

- **Distribution**

Prior to 1950, *Hexagenia limbata* was widely distributed in the Great Lakes, particularly in the shallower, more mesotrophic systems, notably western and central Lake Erie (Table 1, in Reynoldson *et al.*, 1989), Saginaw Bay (Surber 1955; Schuytema and Powers, 1966; Schneider *et al.* 1969), Green Bay (Surber and Cooley, 1952; Howmiller and Beeton, 1971), Lake St. Clair (Gobas *et al.* 1989) and the Bay of Quinte. It was also an important and abundant species in parts of the St. Marys (Schloesser and Hiltunen, 1984), St. Clair and Detroit rivers.

- **Biomass Estimates**

Numerous studies have quantified the distribution of *H. limbata*, which can be easily collected using a variety of sampling devices (Reynoldson *et al.* 1989) and the taxonomy is straightforward. Quantitative estimates of abundance can be made using either numbers or biomass (Rasmussen 1988).

- **Ecosystem Interaction**

Although a benthic species, the response of *H. limbata* to ecosystem change is well documented (Britt 1955a, 1955b; Burns 1985). Furthermore, it has been hypothesized that changes in the percid community in western Lake Erie may be attributed to the disappearance of *H. limbata* (Hayward and Margraf, 1987).

- **Historical Evidence**

The historic changes in *H. limbata* distribution and abundance have recently been documented (Reynoldson *et al.* 1989). The data for western Lake Erie are most complete, from 1930 to the present, but historical data can also be found from Green Bay (Surber and Cooley, 1952; Howmiller and Beeton, 1971) and Saginaw Bay (Surber 1955; Schuytema and Powers, 1966; Schneider *et al.* 1969).

- **Laboratory Organism**

Successful culture of *Hexagenia* spp. under laboratory conditions (Henry *et al.* 1987) will offer additional opportunities to delineate specificity of lethal and sublethal responses to anoxia, contaminants and substate type (Ciborowski, pers. comm.; Henry and Landrum, 1988).

- **Niche Dimensions**

Additional work is required in the exact definition of the habitat requirements for *H. limbata*. However, Hunt (1953) and Eriksen (1968) have described some of *H. limbata*'s substrate and oxygen and temperature requirements. Recent work focuses on the use of this species as a bioassay organism. This work will undoubtedly provide considerable information on this species sensitivity to toxicants.

° Stress Response

The disappearance of *H. limbata* from regions in the Great Lakes where it was formerly abundant is clearly one important stress response. However, recent estimates of abundance from palaeolimnological data, suggest a series of responses to changes in Great Lakes water quality (Reynoldson, pers. comm.). Data from western Lake Erie indicate a slow and gradual increase in abundance followed by a period of instability before the demise of the species in 1953-54. Other stress responses of this species can be determined at the individual level and include growth rate, respiration rate and gill ventilation rate (Malueg *et al.* 1984; Nebeker *et al.* 1984). These responses are readily quantifiable and can be measured in the field or laboratory.

° Importance to Humans

This species was once so abundant that they were cleared from city streets using snow ploughs during peak emergence. Hunt (1953) has described their economic importance for commercial fish bait and as a food source for economically important fisheries.

Objective Development

Historically, the commercial walleye catch in Lake Erie was relatively constant until 1935. From 1915 to 1935, the annual harvest ranged from 338,000 kg (1919) to 1,367,000 kg (1931), with a mean of 802,000 kg (Baldwin *et al.* 1979). Sporadic records from 1885 to 1908 from the United States suggest similar harvests in earlier years. After 1935, the annual harvest increased steadily, reaching a peak of 7,000,000 kg in 1956. This was followed by a precipitous decline to 45,000 kg in 1970 (Baldwin *et al.* 1979). This decline may be due to overfishing, loss of spawning habitat through siltation, summer anoxia in the central basin hypolimnion, loss of the burrowing mayfly (*Hexagenia* spp.) in the western basin, predation on walleye fry by the proliferating populations of rainbow smelt or any combination of these events. Regardless of the exact cause of their decline, the relatively constant and continuous harvests up until 1935 suggest that walleye in the central and western basins of Lake Erie are capable of sufficient production to allow a sustained annual harvest of at least 800,000 kg/a or 0.3 kg/ha/a. This level of production of walleye would, therefore, be one indicator of a healthy mesotrophic ecosystem in Lake Erie. The quantitative relationships between production and harvest for this species in this lake and elsewhere need to be determined. Once determined, this level of production can be used with even greater confidence as one criteria of the health of the ecosystem.

The recorded abundance of *Hexagenia* spp. in the western basin of Lake Erie from 1930 to 1958 averaged 262/m^2, but has varied considerably from year to year. Low levels of 33, 44 and 49 individuals/m^2 were recorded in 1937, 1953 and 1958, respectively (Shelford and Boesel, 1942; Britt 1955b; Beeton 1962). Much higher levels of 394, 350, 235 and 828/m^2 were recorded in 1930, 1941-44, 1951-52 and 1954, respectively (Wright and Tidd, 1933; Chandler 1963; Wood 1963; Britt 1955a). Although variable, *Hexagenia* spp. abundance was always above 30/m^2. Early studies indicate *Hexagenia* spp. were more abundant than all other organisms combined. Studies conducted from 1961 to 1975, however, consistently report *Hexagenia* spp. abundances of zero to 1/m^2 (Carr and Hiltunen, 1965; Brinkhurst *et al.* 1968; Veal and Osmond, 1968; Pliodzinskas 1978) and substantial increases in oligochaetes. This coincides with frequent anoxia in the bottom waters. An abundance of *Hexagenia* spp. of at least 200/m^2, averaged over three years, would, therefore, be expected in a healthy mesotrophic ecosystem in the western basin of Lake Erie.

Mesotrophic ecosystems may have greater numbers of species and more complex interactions than oligotrophic systems. A complete mesotrophic ecosystem objective could therefore be more complex than an oligotrophic ecosystem objective and should probably contain multiple endpoints for measuring system condition. The data on species other than the walleye and *Hexagenia* spp. have not been examined sufficiently to recommend them as indicators at this time; the possibility of doing so, however, should be investigated. It is recommended that the criteria be used to establish the health of the Lake Erie ecosystem; however, appropriate surveys should be conducted and literature and other information sources examined to define levels of these species in other mesotrophic parts of the Great Lakes.

4.1.5 References

Baldwin, N.S., R.W. Saalfield, M.A. Ross and H.J. Buettner, 1979. Commercial fish production in the Great Lakes, 1966-1977. Great Lakes Fish. Comm., Ann Arbor, Michigan, Tech. Rep. No. 3. 187 pp.

Beeton, A.M., 1962. Environmental Changes in Lake Erie. Trans. A. Fish. Soc. 90:153-159.

Brinkhurst, R.O., A.L. Hamilton and H.B. Herrington, 1988. Components of the bottom fauna of the Great Lakes. University of Toronto. Great Lakes Inst., Toronto, Ontario. pp. 33

Britt, N.W., 1955a. Hexagenia (*Ephemeroptera*) population recovery in western Lake Erie following the 1953 catastrophe. Ecology 36(3):520-522.

Britt, N.W., 1955b. Stratification in western Lake Erie in summer of 1953: Effects on the *Hexagenia (Ephemeroptera)* population. Ecology. 36(2):239-144.

Burns, N.M., 1985. Erie: The Lake That Survived. Rowan and Allanhead, Totowa, New Jersey.

Carr, J.F. and J.K. Hiltunen, 1965. Changes in the bottom fauna of western Lake Erie from 1930 to 1961. Limnol. & Oceanog. 10:551-569.

Chandler, D.C., 1963. Burrowing mayfly nymphs in western Lake Erie prior to 1947 (abstract). Great Lakes Res. Div., University of Michigan, Ann Arbor, Michigan. pp. 267-268.

Edwards, C.J. and R.A. Ryder, 1990. Report of the Mesotrophic Indicators Work Group: Biological surrogates of mesotrophic ecosystem health in the Laurentian Great Lakes. International Joint Commission, Windsor, Ontario. 169 pp.

Eriksen, C.H., 1968. Ecological significance of respiration and substrate for burrowing *Ephemeroptera*. Canad.. J. Zool. 46(1):93-103.

Gobas, F.A.P.C., D.C. Bedard, J.J.H. Ciborowski and G.D. Haffner, 1989. Factors regulating the bioaccumulation of chlorinated hydrocarbons by *Hexagenia (effemeroptera:* EPHEMERIDAE) nymphs in Lake St. Clair. J. Great Lakes Res. 15:581-588.

Hartman, W.L., 1988. Historical changes in the major fish resources of the Great Lakes. <u>In</u>: Toxic Contaminants and Ecosystem Health: A Great Lakes Focus. M.S. Evans (ed.). John Wiley and Sons, Inc. pp. 103-131.

Hartman, W.L., 1973. Effects of exploitation, environmental changes and new species on the fish habitats and resources of Lake Erie. Great Lakes Fisheries Commission, Ann Arbor, Michigan. Tech. Rep. 22, 43 pp.

Hayward, R.S. and F.J. Margraf, 1987. Eutrophication effects on prey size and food available to yellow perch in Lake Erie. Trans. Am. Fish. Soc. 116:210-233.

Henry, M.G., B.M. Davis, P.L. Hudson and B.A. Manny, 1987. Effect of upper connecting channels sediment on the burrowing mayfly, *Hexagenia limbata*. Presented at IAGLR 30th Conference, Ann Arbor, Michigan. May 1987.

Henry, M.G. and P.F. Landrum, 1988. A comparison of the utility of *Pontoporeia* and *Hexagenia* in bioassessments of contaminated sediments. Presented at IAGLR 31st Conference, Hamilton, Ontario. May 1988.

Howmiller, R.P. and A.M. Beeton, 1971. Biological evaluation of environmental quality, Green Bay, Lake Michigan. WPCFJ. 43:123-133.

Howmiller, R.P. and M.A. Scott 1977. An environmental index based on relative abundance of oligochaete species. WPCFJ. 49:809-815.

Hunt, B.P., 1953. The life history and economic importance of the burrowing mayfly, *Hexagenia limbata*, in southern Michigan lakes. Inst. Fish. Res. Bull. Michigan Department of Conservation. 4:1-151.

Hurley, D.A. and W.J. Christie, 1977. Depreciation of the warmwater fish community in the Bay of Quinte, Lake Ontario. J. Fish. Res. Bd. Can. 34:1848-1860.

International Joint Commission, 1986. 1985 Annual Report of the Aquatic Ecosystem Objectives Committee. Windsor, Ontario. 119 pp.

Leach, J.H., M.G. Johnson, J.R.M. Kelso, J. Hartmann, W. Numan and B. Entz, 1977. Responses of percid fishes and their habitats to eutrophication. J. Fish. Res. Bd. Can. 34:1964-1971.

Malueg, K.W., G.S. Schuytema, D.F. Krawozyk, J.H. Gakstatter, 1984. Laboratory sediment toxicity tests, sediment chemistry and distribution of benthic macroinvertebrates in sediments from the Keweenaw Waterway, Michigan. Environ. Toxicol. Chem. 3:233-242.

Nebeker, A.V., M.A. Cairns, J.H. Gakstatter, K.W. Malueg, G.S. Schuytema and D.F. Krawczyk, 1984. Biological methods for determining toxicity of contaminated freshwater sediments to invertebrates. Environ. Toxicol. and Chem. 3:617-630.

Parsons, J.W., 1970. Walleye fishery of Lake Erie in 1943-62 with emphasis on contributions of the 1942-61 year-classes. J. Fish. Res. Bd. Can. 27:1475-1489.

Pliodzinskas, A.J., 1978. Aquatic oligochaetes in the open water sediments of western and central Lake Erie. CLEAR Technical Report No. 98, Columbus, Ohio. 160 pp.

Rassmussen, J.B., 1988. Habitat requirements of burrowing mayflies (*Ephemeridae: Hexagenia*) in lakes, with special reference to the effects of eutrophication. J. N.A. Benthol. Soc. 7(1):51-64.

Regier, H.A., U.C. Applegate and R.A. Ryder, 1969. The ecology and management of the walleye in western Lake Erie. Great Lakes Fish. Comm., Ann Arbor, Michigan. Tech. Rept. No. 15:101 pp.

Reynoldson, T.B., D.B. Schloesser and B.A. Manny, 1989. Development of a benthic invertebrate objective for mesotrophic Great Lakes water. J. Great Lakes Res. 15(4):669-686.

Ryder, R.A. and C.J. Edwards (eds.). 1985. A Conceptual Approach for the Application of Biological Indicators of Ecosystem Quality in the Great Lakes Basin. Publication of the International Joint Commission and the Great Lakes Fisheries Commission, Windsor, 169 pp.

Ryder, R.A. and S.R. Kerr, 1978. The adult walleye in the percid community - a niche definition based on feeding behaviour and fond specificity. In: Selected cool-water fishes of North America. R.L. Kendall (ed.). Am. Fish. Soc. Spec. Publ. No. 11, pp 39-51.

Schloesser, D.W., and J.K. Hiltunen, 1984. Life cycle of a mayfly, *Hexagenia limbata*, in the St. Marys River between Lakes Superior and Huron. J. Great Lakes Res. 10(4):435-439.

Schneider, J.C., 1977. History of the walleye fisheries of Saginaw Bay, Lake Huron, MI. Dept. Nat. Res. Fish. Res. Rept. No. 1850. Ann Arbor, MI.

Schneider, J.C. and J.H. Leach, 1979. Walleye stocks in the Great Lakes, 1800-1975: Fluctuations and possible causes. Great Lakes Fish. Comm., Ann Arbor, Michigan. Tech. Rept. No. 31, 51 pp.

Schneider, J.C., F.F. Hooper and A.M. Beeton, 1969. The distribution and abundance of benthic fauna in Saginaw Bay, Lake Huron. Proceedings of 12th Conference on Great Lakes Research. pp. 80-90.

Schuytema, G.S. and R.E. Powers, 1966. The distribution of benthic fauna in Lake Huron. University of Michigan. G.L. Res. Div. Publ. 15:155-163.

Scott, W.B. and E.J. Crossman, 1973. Freshwater fishes of Canada. Bull. Fish. Res. Bd. Can. 184, 966 pp.

Shelford, V.E. and M.W. Boesel, 1942. Bottom animal communities of the island area of western Lake Erie in the summer of 1937. Ohio J. Sci. 42:179-190.

Spangler, G.R., N.R. Payne and K. Winterton, 1977. Percids in the Canadian waters of Lake Huron. J. Fish. Res. Bd. Can. 34:1839-1848.

Surber, E.W., 1955. Results of a biological survey of Saginaw Bay, June 24th. Mich. Water Resource Comm. Report.

Surber, E.W. and H.L. Cooley, 1952. Bottom fauna studies of Green Bay, Wisconsin, in relation to pollution. U.S. Public Health Service, Comm. Water Poll., Washington, D.C.

Veal, D.M., and D.S. Osmond, 1968. Bottom fauna of the western basin and nearshore Canadian waters of Lake Erie. Proceedings of 11th Conference of Great Lakes Research. pp. 151-160.

Wood, K.G. 1963. The bottom fauna of western Lake Erie, 1951-1942. Proceedings of 6th Conference of Great Lakes Research. pp. 258-265.

Wright, S. and W.M Tidd, 1933. Summary of limnological investigations in western Lake Erie in 1929 and 1930. Trans. Am. Fish. Soc. 63:271-185.

4.2 Objective for a Contaminant-Free Great Lakes Basin Ecosystem (Bald Eagle Indicator)

4.2.1 Recommendation

The Great Lakes should be restored to the degree that uncontaminated Great Lakes fish and wildlife prey should be available for the successful hatching of bald eagle eggs, and immature and adult bald eagles confirmed to be using the Great Lakes as a primary feeding area.

NOTE: In order to determine whether this condition exists, the following criteria should be met.

i. The average productivity of the restored bald eagle population for each lake should be 1.0 fledged young per occupied territory and more than 50% of the occupied territories should produce fledged young.

ii. When unhatched eggs are collected, levels of organochlorine chemicals in bald eagle eggs should be less than the following concentrations on a fresh, wet-weight basis: DDE, 1.0 ppm; dieldrin, 0.06 ppm and PCB, 4.0 ppm.

iii. Agencies of the Parties and jurisdictions, responsible for restoring Great Lakes bald eagle populations, should identify and legally protect habitat suitable for bald eagle occupation, survival and reproduction. The Northern States Bald Eagle Recovery Plan should state specific objectives for bald eagle management near Great Lakes shorelines.

4.2.2 Purpose of Ecosystem Objectives

Specific objectives for parts of the Great Lakes Basin Ecosystem are intended to provide a means of determining whether the conditions in Lake Erie are in a healthy state. Indicator species have been selected on the basis of their ecological role in the aquatic community and their ability to respond to stresses within the system. Qualitatively, the specific objectives are not likely to change but the quantitative, measurable levels of aspects of the indicator species are subject to change when relevant databases so warrant.

4.2.3 Summary

The bald eagle is an indigenous terminal predator formerly distributed throughout the Great Lakes Basin Ecosystem. Release of organochlorine compounds caused the widespread disappearance of this species through adult mortality and reproduction impairment. The species appears to be one of the most highly exposed and sensitive species in the Great Lakes Basin Ecosystem. Restoration of the bald eagle population should be an ecosystem objective and the welfare of the bald eagle should be used to define a healthy ecosystem in which levels of persistent toxic substances are greatly reduced, if not absent.

4.2.4 Rationale

On November 18, 1987, representatives of the Governments of the United States and of Canada signed a Protocol that amending the 1978 Great Lakes Water Quality Agreement. The Protocol stated that the Parties reaffirmed their determination to restore water quality in the Great Lakes system and acknowledged that impaired water quality was causing injury to health and property. The Parties concluded that one of the means to achieve improved water quality was by adopting common objectives. The International Joint Commission (IJC) has stated that the threat posed to human health and the aquatic ecosystem by persistent toxic substances has emerged as the major issue confronting the Great Lakes today. The Protocol contains provisions for the virtual elimination of the discharge of persistent toxic substances and outlines lakewide management plans for controlling those "critical pollutants" that have caused impairment of beneficial uses. The Protocol defines several beneficial uses that have been impaired and notes, among other losses: degradated of fish and wildlife populations; bird or animal deformities or reproductive problems; and loss of fish and wildlife habitat. The IJC Ecosystem Objectives Committee was, under its terms of reference, required to develop ecosystem objectives that describe: (a) the effects of pollution on various uses and (b) the desired state for the various lakes, based on the most sensitive use. An ecosystem objective must be developed concerning persistent toxic substances that describes the level of restoration required and defines the meaning of virtual elimination in relation to the most sensitive species affected.

Over the past 30 years, various species in the Great Lakes Basin Ecosystem that have been affected by exposure to persistent toxic substances (IJC 1986). Bioconcentration of these substances in fish has exposed fish-eating birds and mammals to high levels of contaminants. Severe reproductive impairment has been documented for herring gulls, Forster's terns and black-crowned night herons. These species are not, however, the most sensitive nor the most highly exposed; other fish-eating predators such as the otter, mink, double-crested cormorant, osprey and bald eagle exhibited population declines and even widespread extirpation. Databases on population status of these species and on the interrelationship with exposure to persistent organic chemicals are of variable quality. Otter and mink tend to be secretive and difficult to census, except through trapping. Double-crested cormorants have been studied extensively and show great promise as useful indicator organisms, particularly in their response to exposures to high levels of organochlorine pollutants. Though studies on the reproductive success of the osprey have been used as an index of ecosystem health on the New England coast, little work has been completed on this species in the Great Lakes basin. In contrast, extensive long-term studies have been undertaken on the population status and reproductive success of bald eagles within the Great Lakes basin. The following is a consideration of bald eagle characteristics in relation to the criteria (noted in Table 4.1) for selection as ecosystem indicators. The material is based on reviews by Brownell and Oldham (1985), Colborn (1989), Stalmaster (1987) and on Appendix B of the IJC Water Quality Board (IJC 1987).

Application of the Criteria to the Bald Eagle

º Distribution in the Great Lakes System

The bald eagle was distributed throughout the Great Lakes basin up until the 1950s. With the introduction of DDT and other persistent toxic substances, the subsequent contamination of Great Lakes fish, the Great Lakes population of bald eagles suffered a drastic decline. A major nesting area, centered in the Great Lakes states of Minnesota, Wisconsin and Michigan (Sprunt *et al*. 1973; Marshall and Nickerson, 1976; Madsen *et al*. 1985), has pollutant levels that are relatively low compared to the Great Lakes. New York and Ohio formerly contained many nesting bald eagles and efforts are being made to re-establish the species (Sprunt 1969; Nye 1983). The extensive population in southern Ontario was extirpated by about the late 1960s (McKeating 1985) and only a relict population of five pairs survived near Lake Erie. In more recent years, few bald eagles have nested on the shores and islands of the Great Lakes themselves, and those that have reproduced poorly (Sprunt *et al*. 1973; Sindelar 1985 cited in Kozie 1986). In Lake Superior and Lake Erie, where pollutant levels have declined sufficiently, eagles have successfully re-established and reproductive success has improved though it is still anomalously low (Postupalsky 1978; Kozie 1986). The range of the bald eagle in the Great Lakes system prior to the introduction of organochlorine compounds was broad and the re-establishment of bald eagle populations in their former territories provides a useful indicator of improved conditions reflecting declines in organochlorine residue levels and efforts to improve its habitat.

- **Ease of Collection and Measurement**

A pair of bald eagles establishes a territory and builds a nest that may be annually reoccupied over a long period. Thus when the distribution of nest locations has been determined it is relatively easy to collect information on site occupancy and on reproductive success using fixed wing aircraft or a helicopter. Where eggs fail to hatch or chicks die in the nest, these can sometimes be collected at the time that large nestlings are banded, though earlier collection is preferable. Chicks that die should, ideally, be collected immediately for them to be useful, particularly for contaminant analysis. However, dead chicks are only rarely found in nests at the time of normal banding operations and they usually have either rotted or been consumed. Many eggs that fail to hatch are also lost before the time of banding. Where no nestlings are present after a sufficient incubation period, these sites should be visited to collect failed eggs for residue analysis. In territories with histories of failure, eggs could be collected during incubation since this would have little effect on overall productivity and could yield valuable data on contaminant burdens. Banding operations are already being undertaken by biologists throughout much of the Great Lakes basin where bald eagles persist.

The bald eagle is officially recognized as an "endangered" (likely to become extinct) species in much of the United States and the Province of Ontario and a "threatened" (likely to become endangered) species in Minnesota, Wisconsin and Michigan. Thus, it is not feasible to collect eggs and birds for routine monitoring of residue levels. Occasionally, addled eggs and dead birds are recovered for residue analysis (Belisle *et al.* 1972; Kaiser *et al.* 1980; Reichel *et al.* 1984; Wiemeyer *et al.* 1972; 1984) and from these, the evidence of the causal role of organochlorine chemicals in reproductive failure and population declines has been compiled (Wiemeyer *et al.* 1984; Nisbet 1987).

- **Indigenous to the Great Lakes Basin**

The bald eagle was formerly present throughout the Great Lakes basin and thus is an indigenous species. It is able to maintain itself through natural reproduction in inland areas where pollutant levels are relatively low. Efforts are underway in New York State (Nye 1983), in Ohio and in the Province of Ontario (McCullough and Robinson, 1986) to re-establish breeding populations of bald eagles. If these reintroductions are successful and coastal populations are re-established, the bald eagle could be used as a sensitive indicator of ecosystem quality throughout the Great Lakes system. Their continuing absence and/or chronic reproductive impairment in coastal areas partly indicate unacceptable degradation of water quality and contamination of prey species with persistent toxic substances. Habitat alterations have also occurred on a widespread basis and there is a need to conserve and restore suitable bald eagle habitat.

- **Interaction with Many Ecosystem Components**

The following three major factors affect bald eagle populations and their reproductive success: availability of food; availability of suitable nesting habitat; and human influences including shooting, pesticides and habitat destruction (Snow 1973; Peterson 1986). Thus, bald eagles are useful indicators of multiple stresses on an ecosystem.

- **Historical Information on Abundance**

Prior to 1960 there was no systematic survey of the North American population of bald eagles. Broley (1952) published systematic data on the productivity and population of the Florida bald eagle during the critical years 1941-1951 when the insecticide DDT was introduced. In 1960, the National Audubon Society initiated a Continental Bald Eagle Project. In the Great Lakes states, the Ohio nesting population declined from approximately 20 pairs in 1959 to five in 1979 (Case 1980). At least 40 pairs of bald eagles nested in New York State, however, by 1979 there was only a single active nest (Nye 1979). Work undertaken through the Continental Bald Eagle Project resulted in a review of the productivity and population status in six subpopulations, three of which were in the Great Lakes region (Sprunt *et al.* 1973). In northern Wisconsin away from the Great Lakes, the productivity was 1.00 young per active nest and in the inland portion of the Michigan lower peninsula, 0.52 young per active nest were produced. However, along the shores of the Great Lakes, only 0.14 young per active nest were produced. In addition, historical data are also available on the decline in the proportion of juvenile bald eagles that pass through counting stations on migration compared with the number of adults (Sprunt 1969).

Recent surveys have shown a general improvement in productivity in inland bald eagle subpopulations in Michigan, Wisconsin and Minnesota (Postupalsky 1978; Madsen *et al.* 1985). Bald eagles have successfully re-established themselves on Lake Superior shorelines and sporadically produce fledged young (Kozie 1986; Postupalsky 1978). Preliminary evidence suggests that eagles that eat gulls in addition to fish are prone to poisoning (Kozie 1986; Ludwig 1987) and excess rates of mate replacement. These findings are consistent with the higher accumulated levels of contaminants in the gulls than in the fish that they and the bald eagle eat.

Stalmaster (1987) devotes several pages to summarizing on the effects of human disturbance in his book, entitled The Bald Eagle. Human disturbance at the nest site, particularly early in a nesting season, can have a detrimental effect (Grier 1969; Dunstan *et al.* 1975) and human activity at wintering sites has a significant influence on feeding behavior (Stalmaster and Newman, 1978).

In addition, there is extensive literature on the graded response of the bald eagle to the presence of organochlorine compounds, particularly DDT, on productivity and population status (Sprunt *et al.* 1973; Wiemeyer *et al.* 1972; 1984; Nisbet 1987). Declines of bald eagle populations in the Great Lakes states are associated with a decline of at least 12% in eggshell thickness (Wiemeyer *et al.* 1972; 1984). Grier (1982) working in northwestern Ontario reported on the graded improvement of bald eagle productivity with declining levels of DDT following the ban on use of the product. It is possible that the presence of other organochlorine compounds in the Great Lakes system, such as PCBs and dioxin, may contribute to the continued absence of the bald eagle from large sections of the Great Lakes coastline. Extensive data implicate dieldrin in the poisoning deaths of bald eagles (reviewed in Wiemeyer *et al.* 1984).

- **Diagnostic Tool for Specific Stresses of Many Kinds**

The bald eagle is valued as an indicator of aquatic ecosystem health is that it is one of the first species to exhibit signs and symptoms of the presence of organochlorine compounds because it is highly exposed and sensitive to the pollutants. Broley (1952) published a unique series of data on bald eagle nesting failures on the Florida subpopulation he was studyied before, during and after the widespread introduction of DDT. In 1947, one year after the widespread introduction of this compound, nesting failure began to be characterized by failure of eggs to hatch, failure of adults to nest and failure to return to claim the nest. Similarly, Grier (1982) published data on the subpopulation in the Lake of the Woods area showing improvement in bald eagle productivity as DDE levels declined following the ban on its use.

Based on research on golden eagles (*Aquila chrysaetos*) nesting in Scotland, levels of 0.86 ppm of dieldrin in eggs reduced productivity to 31% through increased embryonic mortality (Lockie *et al.* 1969). At 0.34 ppm of dieldrin, reproduction improved to 69%. The research was complicated by the presence of low concentrations of DDE that were co-correlated with the dieldrin and by a decline in DDE concentrations. The golden eagle seems to be more sensitive to the effects of dieldrin than other species (reviewed in Wiemeyer *et al.* 1984).

Declining populations of the congeneric species, the white-tailed sea eagle (*Haliaeetus albicilla*) in the Baltic (Jensen *et al.* 1970; Helander *et al.* 1982), were associated with high levels of PCB and DDE. There is some suggestion that high levels of mercury have caused repeated reproductive failure in a pair of nesting bald eagles at Deer Lake, Michigan (Ludwig, pers. comm. 1988).

As is noted in the section on Graded Response, bald eagles are susceptible to a variety of human stresses such as shooting, trapping, electrocution and shoreline development. Autopsies (Reichel *et al.* 1984) on dead eagles have resulted in a profile of these stresses, even though the data are subject to many biases and the relative importance of each stress is still uncertain. The stress of excess cottage development, for example, can be inferred from observations of birds nesting in suboptimal habitat (Juenemann 1973; Gerrard *et al.* 1975).

In Ontario, the only Canadian province that adjoins the Great Lakes, the database is mostly anecdotal except for systematic studies in northwestern Ontario undertaken since the mid-1960s by Grier (1982) and other occasional surveys (Postupalsky 1971). The historic distribution was reconstructed from data from the Ontario Nest Record Scheme (McKeating 1985), which showed that the subpopulation in southern Ontario, bounded by Manitoulin Island, the Ottawa River and the shorelines of Lakes Huron, Erie and Ontario, had poor reproduction in the 1960s. By the late 1970s, only about five pairs remained on the north shore of Lake Erie and suffered poor reproductive success. Broley (1952; 1958) noted the passing of the extensive bald eagle subpopulation in the Kingston and Rideau Lakes area. Quilliam (1973) summarized the known reports of the territories of the former population in the 30-mile radius around Kingston, Ontario.

Recent reintroductions of juvenile bald eagles to Long Point, Lake Erie and declines of organochlorine concentrations in Lake Erie fish indicate that the prognosis for this species is improving. Recent data show that the productivity has steadily improved since 1980 (Prevett, Ontario Ministry of Natural Resources, pers. comm., 1989).

° Niche Dimensions, Metabolism and Behavioral Responses

Niche dimension for the bald eagles includes territory size which, in part, determines ecosystem productivity, basal metabolic rate and suitability of habitat for bald eagle reproduction (Snow 1973; Peterson 1986). The primary nesting requirement appears to be suitable trees close to a large body of water. Since bald eagles are primarily fish-eaters by choice, water productivity is an important factor for nest site locations. In northern Ontario, the greatest nesting concentration is associated with waters having relatively high fish productivity and long shorelines (Ontario Ministry of Natural Resources 1979). In northwestern Ontario, Grier and Hamilton (1978) stated that lakes with less than 5 km of shoreline were not usually important nesting areas unless they were within 1 km of larger water bodies. Stalmaster (1987) has reviewed the research on the food requirements of bald eagles under various environmental conditions.

- **Graded Response to a Variety of Human-Induced Stresses**

In Wisconsin and Minnesota, Juenemann (1973) found that eagle nests are frequently located more than 1 km from shore. Gerrard *et al.* (1975) interpreted this removal from preferred shoreline sites to be the result of increased human presence and cottage development on the studied lakes, forcing the eagles to choose less favorable sites further from open water.

Shooting remains a major cause of bald eagle death (62% of all deaths between 1960 and 1965, decreasing to 20% in 1980) (Belisle *et al.* 1972; Kaiser *et al.* 1980; Reichel *et al.* 1984). Shooting deaths at nest sites in southern Ontario occurred in 1962, 1963, 1966, 1968; there were three recorded between 1969 and 1973 and one in 1974 (Weekes 1974; 1975). In addition, a number of cases of bald eagles dying of anticholinesterase poisoning have been found in recent years (Wiemeyer, in press). Data are also being compiled from autopsies that are now undertaken by the National Wildlife Health Research Center at Madison, Wisconsin.

Other mortality factors include: impact injuries such as collisions with high voltage wires (c. 10%); electrocution (c. 10%); accidental trapping; ingestion of poisoned bait; and secondary ingestion of lead shot.

- **Identifiable and Quantifiable Response to Stress**

The following two observations are routinely measured by researchers working on bald eagle populations: occupied nests and fledged young. From these two measurements alone, it can be inferred the subpopulation is under stress. However, in a saturated nesting population with a moderate "pool" of nonbreeding adults, a decline in the overall population could be missed for several years until the pool of adults was "consumed." Extensive research over the past 30 years has resulted in reliable interpretations of the causes of the observed anomalies in subpopulations in several parts of the continent.

Wiemeyer *et al.* (1984) and Nisbet (1987) have undertaken statistical analyses of the bald eagle residue data relative to eggshell thinning and productivity. From 1947 to 1981, bald eagles suffered from reproductive failure caused primarily by DDE and pesticide-induced mortality attributed most frequently to dieldrin, although possibly also due to DDT, endrin and compounds of the chlordane family. The dose-response function for the effect of DDE on productivity is very steep, with most of the effect occurring between 2.5 ppm and 5 ppm on a wet-weight basis in the eggs.

Levels of organochlorine compounds associated with avian mortality have been determined using passerines. Residue levels in the brain of more than 4 ppm of dieldrin (Stickel *et al.* 1969), more than 9 ppm of heptachlor epoxide (Stickel *et al.* 1979) or, for technical chlordane, levels of more than 3.4 ppm heptachlor epoxide together with more than 1.1 ppm of oxychlordane were causally associated with mortality. The toxicities of individual DDT metabolites were lower for the parent compound and thus the following formula was used to determine levels in the brain associated with mortality: $DDE/15 + DDD/5 + DDT$; 20 ppm by this formula accounted for the mortality (Stickel *et al.* 1970). Brain levels of PCB over 310 ppm were also causally associated with death (Stickel *et al.* 1984). Such contaminant levels causing adult mortality are of great concern. However, such mortality is not considered an appropriate endpoint on which to base "safe" limits in biota. Determination of levels associated with more subtle effects are urgently needed.

- **Suitability for Laboratory Investigations**

  In the early 1960s a series of laboratory investigations was undertaken at Petersburg, Alaska to find out whether the presence of DDT in feral bald eagles could be responsible for recorded mortality (Stickel *et al.* 1966). Similarly, Pattee *et al.* (1981) used captive bald eagles in a lead poisoning study. It may be difficult to conduct laboratory investigations on bald eagles because they are an officially endangered species and thus permission to use them may not be granted. Bald eagles are not easy to maintain in captivity because some do not adapt well to captive conditions. Adequate samples of captive birds would be difficult to obtain to provide statistically valid results in some studies. Bald eagles are not organisms used conventionally in laboratory investigations but experiments completed thus far show that they can be used.

- **Importance to Humans**

  Early in the investigations of the demise of the bald eagle (U.S. Department of the Interior 1962) there was fear that the bald eagle, the national emblem of the United States, was becoming increasingly scarce and that its reproductive success was low. The bald eagle is a potent symbol for the people of the United States and is many official insignias. The possibility of using the bald eagle as the ultimate indicator of ecosystem quality, as well as a symbol of national unity, has been suggested by the American anthropologist, Margaret Mead (1970).

- **Non-Duplication of Existing Indicators of Ecosystem Quality**

  Inasmuch as the bald eagle is an indicator of the collective level of persistent toxic substances in the Great Lakes, it does not duplicate any existing indicator. In addition, the bald eagle also is an indicator of terrestrial and aquatic aspects of the ecosystem.

Development of An Ecosystem Objective for the Bald Eagle

Recovery plans have been prepared for the bald eagle populations throughout the contiguous United States; the Great Lakes basin is included in the recovery plan for the northern states. There have been steadily increasing numbers of nesting bald eagles and continued, generally high productivity in the region addressed by the Northern States Bald Eagle Recovery Plan. A limited recovery of the population that formerly nested on the shorelines of the Great Lakes has also occurred. Much of the Great Lakes Basin Ecosystem remains too toxic for successful re-establishment of or reproduction at bald eagle territories.

Though available population models for bald eagles (Grier 1982) remain unvalidated, this species has low recruitment rates, high adult survival rates and slow population turnover. Young (1968) produced a mathematical model describing the severe effects that increasing adult mortality would have upon bald eagle populations as a result of insecticide exposure. Sprunt *et al.* (1973) found that a stable bald eagle population produces 0.7 young per occupied nest and 50% of the occupied nests were successful. This model suggests populations with successful nests producing 1.4 or more fledglings are unstressed and healthy and conversely, a population producing less than 0.7 fledglings per occupied nest is exhibiting some stress. It suggests that the condition of the Great Lakes should be restored to the degree that productivity of the "recovered" bald eagle population is 1.0 fledged young per occupied nest and more than 50% of the occupied territories are producing fledged young.

Nisbet (1987) has shown, on the basis of statistical analysis of the relationship between organochlorine residues in bald eagle eggs and reproductive success, that an incipient decline in productivity is associated with about 2.5 ppm DDE in the eggs. Wiemeyer *et al.* (1984) indicated that a production of one young per occupied breeding area is associated with 1.3 ppm DDE in bald eagle eggs, 0.7 young with 3.5 ppm and 0.25 young with 15 ppm. A DDE concentration of 1 ppm in bald eagle eggs should therefore be low enough to eliminate association with biologically significant reductions in productivity.

Similarly, research (Lockie *et al.* 1969) on Scottish golden eagles (*Aquila chrysaetos*) indicated incipient embryonic mortality at levels of dieldrin at 0.34 ppm. As this persistent compound bioaccumulates the "safety factor" of 0.2 indicates an objective level of 0.06 ppm to protect the species. The data on golden eagles should, however, be used with great caution since no other species are known to be as sensitive to dieldrin effects on reproduction as golden eagles.

While DDE seems to be the compound that has caused the most serious effects on bald eagle production (Wiemeyer *et al.* 1984; Nisbet 1987), PCBs are implicated in embryonic mortality, reduced production and developmental abnormalities in many avian species. PCB levels in bald eagle eggs are co-correlated with levels of DDE, and thus it is difficult to separate the effects of PCB from those of DDE on avian reproduction. Based on an analysis of productivity data and egg residue data, Wiemeyer *et al.* (1984) indicated that there is no statistically significant decrease in production with levels up to 20 ppm of PCB in bald eagle eggs. The data, however, indicated that to attain the objective of one young per active nest, the level of PCB would have to be below 4 ppm. This is consistent with other data from Great Lakes studies of bald eagle production *versus* organochlorine residue analysis in which a threshold value for a reduction in production from one young per active nest corresponded to 4 ppm PCB. It is also consistent with findings in other Great Lakes studies on avian reproduction. Platonow and Reinhart (1973) showed reduced hatchability of chicken eggs at levels above 5 ppm. Kubiak *et al.* (1989) found evidence of edema in egg embryos from a reference colony that was part of the 1983 Forster's tern study in Wisconsin. The PCB level in the reference colony was 4.5 ppm. Bald eagles are among the species that have exhibited the crossed bill phenomenon consistent with the presence of PCBs and related compounds with dioxin-like activity. The presence of these teratogenic compounds in the Great Lakes ecosystem is a matter of great concern. It is therefore recommended that a PCB objective for eggs of bald eagles in the Great Lakes basin should be 4 ppm. New data on the toxicity of specific PCB congeners in prey of Great Lakes bald eagles may require modification of this objective.

4.2.5 References

Belisle, .A., W.L. Reichel, L.N. Locke, T.G. Lamont, B.M. Mulhern, R.M. Prouty, R.B. DeWolf and E. Cromartie, 1972. Residues of organochlorine pesticides, polychlorinated biphenyls, and mercury and autopsy data for bald eagles, 1969 and 1970. Pesticide Monitoring Journal. 6:133-138.

Broley, M.J., 1952. Eagle Man. Pellegrini and Cudahy, New York.

Broley, C.L., 1958. Plight of the American bald eagle. Audubon Magazine. 60:162-171.

Brownell, V.R. and M.J. Oldham, 1985. Status report on the bald eagle in Canada. *Haliaeetus leucocephalus*. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Ontario.

Case, D.S., 1980. *Haliaeetus leucocephalus* (bald eagle) conservation in Ohio. Paper presented at the 1980 Great Lakes Regional Conference of the American Association of Zoological Parks and Aquaria, Cincinnati, OH.

Colborn, T., 1989. Draft report on Cause-Effect Linkages. Bald eagles in the Great Lakes basin. Prepared under contract for the International Joint Commission, Great Lakes Regional Office, Windsor, Ontario, Canada.

Dunstan, T.C., J.E. Mathisen and J.F. Harper, 1975. The biology of bald eagles in Minnesota. Loon. 47(l):5-10.

Gerrard, J.M., P.N. Gerrard, W.J. Maher and D.W.A. Whitfield, 1975. Factors influencing nest site selection of bald eagles in northern Saskatchewan and Manitoba. Blue Jay. 33:169-176.

Grier, J.W., 1969. Bald eagle behavior and productivity responses to climbing to nests. J. Wildl. Manage. 33(4):961-966.

Grier, J.W., 1982. Ban of DDT and subsequent recovery of reproduction in bald eagles. Science. 218:1232-1235.

Grier, J.W. and G.D. Hamilton, 1978. Annual census of bald eagles in the West Patricia Planning Area. West Patricia Land Use Plan. Wildl. Tech. Rep. No. 7. 54 pp.

Helander, B., M. Olsson and L. Reutergardh, 1982. Residue levels of organochlorine and mercury compounds in unhatched eggs and the relationships to breeding success in white-tailed sea eagles (*Haliaeetus albicilla*) in Sweden. Holarctic Ecology. 5:349-366.

International Joint Commission, 1986. Literature review of the effects of persistent toxic substances on Great Lakes biota. Report of the Health of Aquatic Communities Task Force. J. Fitchko (ed.) to the Great Lakes Science Advisory Board, Windsor, Ontario. 256 pp.

International Joint Commission, 1989. Appendix B of the 1987 Water Quality Board Report. Great Lakes Water Quality Board, Windsor, Ontario. 3 volumes.

Jensen, S., A.G. Johnels, M. Olsson and T. Westermark, 1970. The avifauna of Sweden as indicators of environmental contamination with mercury and chlorinated hydrocarbons. In: Proc. XV. Int. Ornithol. Congr. The Hague, 1970. K.H. Voous (ed.). Brill. Leiden, 1972. 745 pp.

Juenemann, B.G., 1973. Habitat evaluation of selected bald eagle nest sites on the Chippewa National Forest. M.S. Thesis, Univ. of Minnesota, Minneapolis, Minnesota.

Kaiser, T.E., W.L. Reichel, L.N. Locke, E. Cromartie, A.J. Krynitsky, T.G. Lamont, B.M. Mulhern, R.M. Prouty, C.J. Stafford and D.M. Swineford, 1980. Organochlorine pesticide, PCB residues and necropsy data for bald eagles from 29 states, 1975-1977. Pest. Monit. J. 13(4):145-149.

Kozie, K.D., 1986. Breeding and feeding ecology of bald eagles in the Apostle Island National Lakeshore. M.Sc. Thesis. Department of Natural Resources. University of Wisconsin, Stevens Point.

Kubiak, T.J., H.J. Harris, L.M. Smith, T.R. Schwartz, D.L. Stalling, J.A. Trick, L. Sileo, D.E. Docherty and T.C. Erdman, 1989. Microcontaminants and reproduction impairement of the Forster's tern on Green Bay, Lake Michigan - 1983. Archives of Environmental Contamination and Toxicology. 18:706-727.

Lockie, J.D., D.A. Ratcliffe and R. Balharry, 1969. Breeding success and organochlorine residues in golden eagles in West Scotland. J. Appl. Ecol. 6:381-389.

Ludwig, J.P., 1987. Immature bald eagle death following heavy consumption of adult ring-billed gulls. Unpublished note. Ecological Research Services Inc., Bay City, Michigan.

Madsen, C.R., T.J. Sheldrake, J.T. Leach and J. Engel, (eds.), 1985. Bald eagle production in the Great Lakes States, 1975-1985. U.S. Fish and Wildlife Service, 1985. Twin Cities, Minnesota. 25 pp.

Marshall, D.B. and P.R. Nickerson, 1976. The bald eagle: 1776-1976. Nat. Parks and Conserv. Mag. (July). pp. 14-19.

McCullough, G. and J.T. Robinson, 1986. Summary report: Long Point National Wildlife Area Bald Eagle Project. Canadian Wildlife Service, Ontario Region.

McKeating, G., 1985. Charles Broley: Eagles then and now in southern Ontario. In: The bald eagle in Canada. Gerrard, J.M. and T.M. Ingram (eds.). White Horse Plains Publishers, Headingly, Manitoba and the Eagle Foundation, Box 155, Apple River, Illinois. 272 pp.

Mead, M., 1970. We need a religious system with science at its very core. Look. April 21, 1970.

Nisbet, I.C.T., 1987. Organochlorines, reproductive impairment, and declines in bald eagle populations: mechanisms and dose-response relationships. In: Raptors in the Modern World. Proceedings of the third World Conference on Birds of Prey. Eilat. Israel. March 22-27, 1987.

Nye, P., 1979. Endangered species II: Present and historic activity of bald eagles in New York. Final Report: Project #E-1-3. New York State Department of Environmental Conservation.

Nye, P., 1983. A biological and economic review of the hacking process for the restoration of bald eagles. In: Biology and management of bald eagles and ospreys. Bird, D.M. (ed.). Raptor Research Foundation, 1983.

Ontario Ministry of Natural Resources, 1979. Bald eagle, great blue heron and osprey. West Patricia Land Use Plan. 9 pp.

Pattee, O.H., S.N. Wiemeyer, B.H. Mulhern, L. Sileo and J.W. Carpenter, 1981. Experimental lead-shot poisoning in bald eagles. Journal of Wildlife Management. 45:806-810.

Peterson, A., 1986. Habitat suitability index models: Bald eagle (breeding season). U.S. Fish and Wildlife Service, Department of the Interior. Biological Report 82 (10.126).

Platonow, N.S. and B.S. Reinhart, 1973. The effects of polychlorinated biphenyls (Aroclor 1254) on chicken egg production, infertility and hatchability. Canadian Journal of Comparative Medine. 37:341-346.

Postupalsky, S., 1971. Toxic chemicals and declining bald eagles and cormorants in Ontario. Can. Wildl. Serv., Pesticides Section. Report No. 20. 45 pp.

Postupalsky, S., 1978. The bald eagles return. Natural History. 87(7):62-63.

Quilliam, H.R., 1973. History of the birds of Kingston, Ontario. Second edition.

Reichel, W.L., S.K. Schmeling, E. Cromartie, T.E. Kaiser, A.J. Krynitsky, T.G. Lamont, B.M. Mulhern, R.M. Prouty, C.J. Stafford and D.M. Swineford, 1984. Pesticide, PCB and lead residues and necropsy data for bald eagles from 32 states -- 1978-81. Env. Monit. Assess. 4:395-403.

Sindelar, C.R., 1985. Wisconsin bald eagle breeding survey -- 1985. General Report. Wisconsin Department of Natural Resources. Bureau of Endangered Species. 14 pp.

Snow, C., 1973. Habitat management series for endangered species. Southern bald eagle (*Haliaeetus leucocephalus leucocephalus*) and northern bald eagle (*Haliaeetus leucocephalus alascanus*). U.S. Department of Interior, Bureau of Land Management. Tech. Note. No. 5, 58 pp.

Sprunt, A. IV, 1969. Population trends of the bald eagle in North America. In: Peregrine falcon populations. J.J. Hickey (ed.). University of Wisconsin Press. pp. 347-351.

Sprunt, A. IV, W.B. Robertson Jr., S. Postupalsky, R.J. Hensel, C.E. Knoder and F.J. Ligas, 1973. Comparative productivity of six bald eagle populations. Transactions 38th North American Natural Resources Conference, Washington, D.C. pp. 96-106.

Stalmaster, M.V., 1987. The Bald Eagle. Universe Books, New York. 227 pp.

Stalmaster, M.V. and J.R. Newman, 1978. Behavioral responses in wintering bald eagles to human activity. J. Wildl. Manage. 42(3):506-513.

Stickel, W.H., L.F. Stickel, R.A. Dryland and D.L. Hughes, 1984. Aroclor 1254 residues in birds: Lethal levels and loss rates. Arch. Environ. Contam. Toxicol. 13:7-13.

Stickel, L.F., W.H. Stickel, R.D. McArthur and D.L. Hughes, 1979. Chlordane in birds: A study of lethal residues and loss rates. In: Toxicology and occupational medicine. W.B. Deichman (ed.). Elsevier/North Holland, New York. pp. 387-396.

Stickel, W.H., L.F. Stickel and J.W. Spann, 1969. Tissue residues of dieldrin in relation to mortality in birds and animals. In: Chemical fallout: Current research on persistent pesticides. M.W. Miller and G.G. Berg (eds.). Charles C. Thomas, Springfield, Illinois. pp. 174-204.

Stickel, W.H., L.F. Stickel and F.B. Coon, 1970. DDE and DDD residues correlated with mortality of experimental birds. In: Pesticides Symposia. W.B. Deichmann (ed.). Seventh Inter. Am. Conf. Toxicol. Occupational Med., Hale and Associates, Inc., Miami, Florida. pp. 287-294.

Stickel, L.F., N.J. Chura, P.A. Stewart, C.M. Menzie, R.M. Prouty and W.L. Reichel, 1966. Bald eagle pesticide relations. Trans. no. Am. Wildl. Natural Resources Conf. 41:190-200.

U.S. Department of Interior, 1962. Effects of DDT on bald eagles. Pesticide - Wildlife Studies. A review of Fish and Wildlife Service investigations during 1961-62. Circular 167:78-80.

U.S. Department of Interior, 1963. Effects of DDT on bald eagles. Pesticide-Wildlife Studies, 1963. Circular 199:79-80; 86-87.

Weekes, F.M., 1974. A survey of bald eagle nesting attempts in southern Ontario, 1969-1973. Can. Field-Nat. 88(4):415-419.

Weekes, F.M., 1975. Bald eagle nesting attempts in southern Ontario in 1974. Can. Field-Nat. 89(4):438-444.

Wiemeyer, S.N., in press. Effects of environmental contaminants on raptors in the midwest. Nat. Wildl. Fed. Sci. Tech. Series.

Wiemeyer, S.N., T.G. Lamont, C.M. Bunck, C.R. Sindelar, F.J. Gramlich, J.D. Fraser and M.A. Byrd, 1984. Organochlorine pesticides, polychlorobiphenyl and mercury residues in bald eagle eggs, 1969-79, and their relationships to shell thinning and reproduction. Arch. Environ. Contam. Toxicol. 13:529-549.

Wiemeyer, S.N., B.M. Mulhern, F.J. Ligas, R.J. Hensel, J.E. Mathisen, F.C. Robards and S. Postupalsky, 1972. Residues of organochlorine pesticides, polychlorinated biphenyls and mercury in bald eagle eggs and changes in shell thickness, 1969 and 1970. Pest. Monit. J. (6)1:50-55.

Young, H., 1968. A consideration of insecticide effects of hypothetical avian populations. Ecology. 49:991-994.

4.3 Nearshore Waters of the Great Lakes

Shallow nearshore waters and embayments of the lakes and connecting channels and deltic regions of tributaries are often relatively eutrophic. Many Areas of Concern in the Great Lakes contain such waters in degraded states; numerous pristine areas also contain such subsystems. These are also the waters most likely to be stressed by human activities.

In such waters the smallmouth bass, a centrarchid, is a dominant predator. A rationale for its use as an integrative indicator should be examined along lines similar to the Board's efforts with the oligotrophic and mesotrophic indicators. This species could then be used to specify ecosystem objectives for numerous inshore eutrophic environments in the lakes and rivers.

It is recommended that:

- The Parties develop an ecosystem objective for shallow nearshore waters of the lakes and connecting channels.

5.0 MIXTURES

5.1 Recommendation

It is recommended to the Binational Objectives Development Committee that it consider a mixtures objective for toxic contaminants in the Great Lakes based on the principle of additivity and the toxic unit concept.

5.2 Background

In its 1981 report, the Aquatic Ecosystem Objectives Committee ((A)EOC) considered a "toxic unit" approach to protecting the Great Lakes Basin Ecosystem from the collective effects of metals. AEOC recommended that monitoring data on metals be treated in this manner to identify areas where metal concentrations might be a problem, even though levels of individual elements have not exceeded their objective. The relationship presented was:

$$\Sigma \ \frac{Mi}{Oi} \leq 1$$

where M and O are the field concentrations and objective levels, respectively, of the different metals and these ratios should add up to less than one. The assumption then was that the effects of these chemicals were additive; this was generally unproven at the time but it was felt to be a compromise between the possibility of synergistic (more than) or antagonistic (less than) additive effects.

More recently, the EOC considered the development of an objective for mixtures using the toxic unit relationship and, in particular, whether it should be limited to metals or be expanded to include organics and other substances. This work was not completed at the time of this final report and some data and comments are therefore recommended to the Binational Objectives Development Committee for their consideration, and we hope, objective development.

5.3 Discussion

An examination of the limited data on the sublethal or chronic toxicity of contaminant mixtures (Table 5.1) indicates that the assumption of additivity as presented in the recommendation is justified. Sublethal tests with a fairly wide range of aquatic organism and chemical types have demonstrated a potential for additive joint action for the diverse mixtures that might be expected to occur in the field. Further, the EOC has found that it is difficult or impossible to predict accurately the collective toxic effects from QSAR data, acute data or the results of single-chemical toxicity tests. The data in the table also indicate that there does not appear to be a rational basis for deriving separate mixtures objectives for organics and inorganics using different assumptions and formulas for each. It should be noted that a mixture objective cannot be obtained without knowledge of individual objective concentrations for all significant mixture components which will already have been assessed. An expanded objective (to include substances other than metals) could be expressed as:

$$\Sigma \ \frac{Ci}{Oi} \leq 1$$

where Ci is the concentration of all individual contaminants.

An alternative to this calculation of mixtures objectives is to derive them through chronic toxicity tests with specific mixtures of concern at specific sites. To insure their applicability to field conditions, these tests should be conducted in site water or a substitute water with similar chemical characteristics (e.g., pH, hardness, other contaminants present at a concentration less than one-tenth of their objective values); with a sensitive resident alga, invertebrate and fish species; and the contaminants of concern should be tested at approximately the same concentration ratio as found or anticipated in the site water. All factors have been found to significantly influence the toxicity and/or the nature of the interaction of contaminants in mixtures.

TABLE 5.1 Summary of Results from Sublethal and Chronic Toxicity Tests on Chemical Mixtures

Toxicants	Organism	Endpoint	Joint Action[1] (Action)	Reference
METALS				
1. Al, Cu, Fe, Mn, Ni, Pb, Zn, pH 5.8	Flagfish *Jordanella floridae*	Life cycle toxicity (survival, growth, reproduction [2])	Infra-additive; Cu, Zn and Al additive	Hutchinson and Sprague, 1986
2. As, Cd, Cu, Cr, Fe, Hg, Ni, Pb, Se, Zn	Mixed algal culture; *Ankistrodesmus falcatus*	Culture-primary production; *A.f.* - reproduction	Supra-additive in both tests[3]	Wong *et al.* 1982
3. As, Cd, Cu, Hg, Pb, Zn (all pairs and all 6)	Natural (Lake Ontario) copepod assemblage	Biomass production rate	Additive or supra-additive for most pairs, infra-additive for all 6	Borgmann 1980
4. As, Cd, Cr, Cu, Hg, Pb	Fathead minnow *Pimephales promelas; Ceriodaphnia dubia*	50% reduction growth for reproduction	Minnow - infra-additive; *Daphia* - additive	Spehar and Fiandt, 1986
5. Cd, Cu	*Campanularia flexosa*[4] (marine hydroid)	Growth (% of control)	Additive at low concentrations; at high concentrations, - infra - if Cu high, - supra - if Cd high	Stebbing and Santiago-Fandino, 1983
6. Cd, Cu, Pb (all combinations at various ratios)	Baltic herring	Eggs and larvae hatch and survival	Enhancement of toxicity	Westerhagen *et al.* 1979
7. Cd, Zn	Flagfish	Life cycle toxicity	Larval survival - reduced toxicity; reproduction - enhanced toxicity	Spehar 1976
8. Cd, Zn	*Lemna valdiviana*; *Salvinia natans* (aquatic vascular plants)	Frond growth	Enhanced toxicity	Hutchinson and Czyskra, 1972
9. Cd, Zn	Natural (Lake Michigan) zooplankton assemblage	Species density and diversity	Enhanced toxicity	Marshall *et al.* 1981
10. Cd, Hg, Zn	*Daphnia magna*	Reproduction	Enhanced toxicity	Biesinger *et al.* 1986
11. Cd, Cu, Zn	Fathead minnow	Life cycle toxicity	Enhanced toxicity	Eaton 1973
12. Cu, Ni	*Poecilia reticulata* (Guppy)	Growth	Addition	Muska and Weber, 1977
13. Cu, Zn	*Salmo salar* (Atlantic salmon)	Avoidance	Supra-additive	Sprague *et al.* 1965

TABLE 5.1 Summary of Results from Sublethal and Chronic Toxicity Tests on Chemical Mixtures, continued

Toxicants	Organism	Endpoint	Joint Action[1] (Action)	Reference
14. Cu, Zn	*Oncorhynchus tshawtscha* (Chinook salmon)	"Estimated safe" for early life stages	Enhanced toxicity, greater at higher Cu:Zn ratios	Finlayson and Verrue, 1980
15. Cu, Zn, Pb (at various ratios)	*Scenedesmus quadracauda*	Photosynthesis (% of control)	Mostly additive, some infra-additive	Starodub *et al.* 1987
METALS AND INORGANICS				
16. Cr, HCN; Zn, HCN	Fathead minnow, *Salmo gairdneri* (rainbow trout)	30-day survival and growth	No enhancement (Cr, HCN), or slight enhancement of toxicity (Zn, HCN)	Broderius and Smith, 1979
METALS AND ORGANICS				
17. Zn, pentachlorophenol	*Photobacterium phosphoreum*	Inhibited bioluminessence	Additive	Bois *et al.* 1986
18. Groups of 10 and 25	*Daphnia magna*	Growth (NOEC)[5]	Infra-additive for 10, supra-additive for 25	Hermens *et al.* 1985
ORGANICS				
19. 14 assorted organics	*Daphnia magna*	50% inhibition of reproduction	Infra-additive	Hermens *et al.* 1984
20. Endrin, malathion	Flagfish	Life cycle toxicity	Additive	Hermanutz *et al.* 1985
21. Groups of 5 and 10 similar acting organics	*Daphnia magna*	EC50 growth and reproduction; NOEC growth and reproduction	Both additive	DeWolf *et al.* 1988
22. Group of 9 non-similar acting organic chemicals	*Daphnia magna*	EC10 growth; NOEC growth	Both non-additive	Deneer *et al.* 1988

1. Definitions for joint action terminology used herein:

   a. Additive $\Sigma \frac{Ci}{Oi} = 1.0$

   b. Non-additive $Ci = Oi = 1.0$

   c. Infra-additive $1.0 > \Sigma \frac{Ci}{Oi} > \text{largest } \frac{Ci}{Oi}$

   d. Supra-additive $\Sigma \frac{Ci}{Oi} > 1.0$

   e. Enhanced or reduced toxicity - only nonquantitative increases or decreases from individual component toxicities were calculable.

2. Where opposing effects on more than one lifestage were reported for a given mixture, only the net effect likely to influence viability in nature is given as the joint action.

3. Metals concentrations were selected on the basis of 1981 Water Quality Objectives or estimated "safe" concentrations; the zinc objective has recently been reduced to 30 from 10 µg/L. Redoing the test on the basis of 10 µg/L objective would probably have only a minor effect on the result.

4. Results from marine species are included as examples of types of joint action.

5. NOEC = No Observable Effect Concentration

5.4 References

Biesinger, K.E., G.M. Christensen and J.T. Fiandt, 1986. Effects of metal salt mixtures on *Daphnia magna* reproduction. Ecotoxicol. Environ. Safety 11:9-14.

Bois, F., M. Vaillant and P. Vasseur, 1986. Multiple regression analysis of toxic interactions: Application to the Microtox test and general comments. Bull. Env. Contam. Toxicol. 36:707-714.

Borgmann, 1980. Interactive effect of metals in mixtures on biomass production kinetics of freshwater copepods. Can. J. Fish. Aquat. Sci. 37:1295-1302.

Broderius J.J. and L.L. Smith, 1979. Lethal and sublethal effects of binary mixtures of cyanide and hexavalent chromium, zinc, or ammonia to the fathead minnor (*Pimephales promelas*) and rainbow trout (*Salmo gairdneri*). J. Fish. Res. Bd. Can. 36:164-172.

Deneer, J.W., W. Seinen and J.T.M. Hermens, 1988. Growth of *Daphnia magna* exposed to mixtures of chemicals with diverse modes of action. In: The toxicity of aquatic pollutants: QSARs and mixture toxicity studies. Ph.D. Thesis, University of Utrecht, Netherlands.

DeWolf, W., J.H. Canton, J.W. Deneer, R.C.C. Wegman and J.L.M. Hermens, 1988. Quantitative structure-activity relationships and mixture-toxicity studies of alcohols and chlorohydrocarbons: Reproducibility of effects on growth and reproduction of Daphnia magna. Aquatic Toxicol. 12:39-49.

Eaton, J.G., 1973. Chronic toxicity of a copper, cadmium and zinc mixture to the fathead minnow (*Pimephales promelas* Rafinesques). Water Res. 7:1723-1736.

Finlayson, B.J. and K.M. Verrue, 1980. Estimated safe zinc and copper levels for chinook salmon, *Oncorhynchus tshawytscha*, in the upper Sacramento River, California. Calififornia Fish and Game 66:68-82.

Hermanutz, R.O., J.G. Eaton and F.H. Mueller, 1985. Toxicity of endrin and malathion mixtures to flagfish (*Jordanella floridae*). Arch. Environ. Contam. Toxicol. 14:304-314.

Hermens, J., E. Broekhuyzen, H. Canton and R. Wegman, 1985. Quantitative structure activity relationships and mixture toxicity studies of alcohols and chlorhydrocarbons: Effects on growth on Daphnia magna. Aquatic Toxicol. 6:209-217.

Hermens, J., H. Canton, N. Steyger and R. Wegman, 1984. Joint effects of a mixture of 14 chemicals on mortality and inhibition of reproduction of Daphnia magna. Aquat. Toxicol. 5:315-322.

Hutchinson, T.C. and H. Czyrska, 1972. Cadmium and zinc toxicity on synergism to floating aquatic plants. Inst. Environm. Sci. Engin. Publ. No. ER-3. pp. 59-65.

Hutchinson, N.J. and J.B. Sprague, 1986. Toxicity of trace metal mixtures to American flagfish (*Jordanella floridae*) in soft, acidic water and implications for cultural acidification. Can. J. Fish. Aquatic Sci. 43:647-655.

Marshall, J.S., D.L. Mellinger and J.I. Parker, 1981. Combined effects of cadmium and zinc on Lake Michigan zooplankton community. J. Great Lakes Res. 7:215-223.

Muska, C.F. and F.J. Weber, 1977. An approach for studying the effects of mixtures of environmental toxicants on whole organism performances. In: R.A. Tubb, ed., Recent Advances in Fish Toxicology, A Symposium. U.S. EPA Ecological Research Series. EPA-600/3-77-085. pp. 77-87.

Spehar, R.L, 1976. Cadmium and zinc toxicity to flagfish, *Jordanella floridae.* J. Fish. Res. Board Can. 33:1939-1945.

Spehar, R.L. and J.T. Fiandt, 1986. Acute and chronic effects of water quality criteria-based metal mixtures on three aquatic species. Environ. Toxicol. Chem. 5:917-931.

Sprague, J.B., P.F. Elson and R.L. Saunders, 1965. Sublethal copper-zinc pollution in a salmon river - a field and laboratory study. IAPWA 9:531-543.

Starodub, M.E., P.T.S. Wong, C.I. Mayfield and Y.K. Chau, 1987. Influence of complexation and pH on individual and combined heavy metal toxicity to a freshwater green alga. Can. J. Fish. Aquatic. Sci. 44:1173-1180.

Stebbing, A.R.D. and V.J.R. Santiago-Fandino, 1983. The combined and separate effects of copper and cadmium on the growth of *Campanularia flexuosa* (Hydrozoa) colonies. Aquat. Toxicol. 3:183-193.

Westernhagan, H.V., V. Dethlefsen and H. Rosenthal, 1979. Combined effects of cadmium, copper and lead on developing herring eggs and larvae. Helgolander Wiss. Meershenters 32:257-278.

Wong, P.T.S., Y.K. Chaw and D. Pate, 1982. Physiological and biochemical responses of several freshwater algae to a mixture of metals. Chemosphere 11:367-376.

6.0 ASSESSMENT OF COMPREHENSIVE TRACK CHEMICALS

6.1 Recommendation

EOC recommends to the Binational Objectives Development Committee that they examine the assembled data and references on the 272 nonpesticide, nonmetal compounds on the 1986 WQB Working List of Chemicals in the Great Lakes Basin Ecosystem (the comprehensive track chemicals). It is suggested that this database and the assessment scheme outlined in the 1987 reports of the EOC and of the Coordinating Committee for the Assessments of Chemicals in the Great Lakes Basin Ecosystem be used to develop the three lists required under the GLWQA (1987 Revision) Annex 1.

6.2 Discussion

In 1987, EOC completed to do the environmental part of the preliminary hazard assessment of the host of chemicals (1,000+) reported to be in the Great Lakes and which appeared in the 1983 Inventory of Chemicals in the Great Lakes Basin Ecosystem. The Coordinating Committee for the Assessment of Chemicals in the Great Lakes Ecosystem (CCAGLE), largely through the efforts of the U.S. Environmental Protection Agency, reduced the positive identifications to a more manageable 362 chemicals. This included some 32 metals and 68 pesticides, leaving a residual 262 potentially toxic organic chemicals which had never been assessed as to their significance in the system.

A workshop was held to determine the minimum information required to stimulate further new data acquisition. Such data would include some aspects of exposure to, and effects of, the chemicals. Included in this data are:

- the lethal dose to a mammalian species;
- the lethal concentration to sensitive aquatic species;
- a measure of the mutagenicity as indicated in tests with at least two cell lines, one of which must be mammalian; and
- the octanol/water partition coefficient.

In addition, it was determined that of equal importance, but not essential, is the following:

- the release of the chemical to the Great Lakes; and
- the concentrations in the system.

High, medium and low levels to differentiate concerns appropriate for each of the above were given at the workshop and several schemes suggested as to how the data might be combined to give a single parameter that assesses the environment and the human health significance of these chemicals.

References to these and other environmentally relevant data were obtained from the world's computerized literature. This search resulted in approximately 6,000 references and abstracts, which were to be evaluated for their possible significance for the Great Lakes system. The entire effort was intended as a coarse screen to identify compounds requiring more work on a priority basis using the limited resources available. Compounds for which data were not available were retained in the system. Unfortunately, the bulk of the abstracts did not include the numerical values required for the above parameters, although there is reference to their existence in the original citation.

The EOC focused its efforts on completing the indicator based mesotrophic objective and several other items prior to the Committee's dissolution, and agreed to provide the database for these chemicals to the U.S./Canada Binational Objectives Development Committee. In addition, EOC recommends that they consider two schemes to combine the data results and the data themselves in defining the three lists required for Annex 1. A requirement in the 1987 to the 1978 Agreement calls for the Parties to develop three lists of chemicals proven to be present in, and their possible effects on, the Great Lakes system. All 262 chemicals have some established presence in the system and the literature provides existing information on aquatic effects, as well as movement and accumulation in the system. A preliminary screening, based on the information collected, could provide a means to logically and consistently assign chemicals to one or another lists called for in Annex 1. The data provided on these compounds will soon be antiquated, therefore, the Parties are, through the Binational Objectives Development Committee, strongly urged to further examine the literature and complete the preliminary assessments.

7.0 THE USE OF QUANTITATIVE STRUCTURE ACTIVITY RELATIONSHIPS (QSAR) IN DEVELOPING OBJECTIVES: CHLOROPHENOLS AND CHLOROBENZENES

7.1 Background

The development of structure activity relationships between chemicals and their toxicity to aquatic organisms has been reported by many investigators over the past decade (Konemann 1981; Veith *et al.* 1983 1985; Hall *et al.* 1984; Hermens *et al.* 1985). Most investigators have attempted to predict acutely toxic effects (e.g., lethality, narcosis). Early work on a wide range of chemicals was based on physical/chemical properties, many of which were themselves predicted from other properties. Later, work on many of these same chemicals have reported other relationships for chronic endpoints (Call *et al.* 1985; McCarty 1986), although fewer data were available.

As more compounds have been studied, the toxicity of individual families of chemicals have been identified as being related to solubility or other properties such as the position of various substituted groups. The concentrations that elicited a toxic response differed with each family of compounds and the changes in toxicity with substitution varied in a different manner depending on whether the response was being estimated by solubility or reactivity (Konemann and Musch, 1981; Schultz 1983; Schultz and Moulton, 1984; 1985a; 1985b; Schultz and Riggin, 1985; Schultz *et al.* 1986; Moulton and Schultz, 1986). As the precision of the descriptive relationships improved, no single relationship was observed to represent the general case of all organic chemicals.

Information regarding these structure toxicity relationships has grown over the years, and it appeared that sufficient data might have been published to develop water quality objectives for a family of chemicals. To do this, it would be necessary to follow the same principles as adopted for individual chemical objectives. These included scientific defensibility, subtle or nonlethal responses, sensitive organisms and other aspects outlined in EOC reports. An early effort to establ water quality objectives for chlorobenzenes using structure activity relationship information was conducted by the Ontario Ministry of the Environment (McCarty *et al.* 1984). However, that approach was considered insufficiently substantiated to be adopted as a provincial water quality objective.

7.2 Discussion

The IJC chemical water quality objectives rely on sublethal data for the most sensitive organisms, based on the observation that protection of sensitive stages of aquatic life or human health are usually the most sensitive designated uses for the Great Lakes. Applying safety factors to acute toxicity data to estimate chronic effect or no effect levels has not been considered acceptable (Kenaga 1982).

The extension of this approach to develop water quality objectives for a family of chemicals has meant using sublethal data and, for poorly documented compounds, extrapolating from more documented compounds using similar species, life stages and endpoints. In order to estimate an objective for a compound with insufficient toxicity information, it is necessary to have data on compounds that are related as to the number, position and type of substitutions. To estimate an objective value for a particular trichlorobenzene isomer, for example, requires information on structurally related di- and tetra- isomers as well as on some of the other trichlorobenzene isomers.

The above approach was applied in an attempt to develop water quality objectives for two families of candidate chemicals. The chlorophenols and chlorobenzenes were selected because of the extensive toxicity data published on these compounds. A literature review, excluding acute response data provided only a very limited number of sublethal reports that could be considered in the development of the two class objectives; these are presented in Table 7.1.

TABLE 7.1. Sublethal Effect Concentrations for Chlorinated Phenols and Chlorinated Benzenes

	Organism	Life Stage	Response	Concentration (ug/L)	Reference
CHLOROPHENOLS					
Phenol	Pimephales promelas	embryo-larvae	Impaired growth	3,570	Holcombe et al. 1982
		embryo-larvae	Impaired growth	2,500	DeGraeve et al. 1980
		embryo-larvae	No observed effect concentration	1,800	Holcombe et al. 1982
	Salmo gairdneri	larval fry	Impaired growth	200	DeGraeve et al. 1980
2,4-dichlorophenol	Pimephales promelas	embryo-larvae	Survival	460	Holcombe et al. 1982
		embryo-larvae	Impaired growth	1,240	Holcombe et al. 1982
	Notropia comutus	fry	Growth	320	Borgmann and Ralph, 1986
2,4,6-TCP	Pimephales promelas	embryo-larvae	Growth	720	U.S. EPA 1978a
Pentachlorophenol	Australorbis glabratus	Adult	Fecundity	50	Olivier and Hoskins, 1960
		Egg	Viability	100	Olivier and Hoskins, 1960
	Ceriodaphnia affinus/dubia	Adult	Reproduction	160	Hedtke et al. 1985
	Ceriodaphnia reticulata	Adult	Reproduction	<4	Hedtke et al. 1985
	Daphnia magna	Adult	Reproduction inhibition	250	Adams 1978
	Lepomis macrochirus	Fry	20% growth inhibition	40	Zischke et al. 1985
	Micropterus salmonides	Yolk sac to 53d	Threshold food conversion impairment	23.4	Johansen et al. 1987
	Notropis comutus	Fry	Growth	180	Borgmann and Ralph, 1986
	Oncorhynchus nerka	Fry	Growth inhibition	1.61	Webb and Brett, 1973
		Fry	Food conversion	1.66	Webb and Brett, 1973
	Physa gyrina	Juvenile	Growth	102	Hedtke et al. 1985
		Adult	Fecundity	26	Hedtke et al. 1985
	Pimephales promelas	Fry	Threshold growth inhibition	40	Zischke et al. 1985
		Fry	Threshold growth inhibition	59	Holcombe et al. 1982
		Embryo-larvae	Survival	144	Hedtke et al. 1985
	Salmo gairdneri	Embryo-larvae	Chronic threshold	14	Dominguez and Chapman, 1984
		180 g	Increased brain tryptophan	160	Sloley et al. 1986
		70-100 g	19% Oocyte atresia	22	Nagler et al. 1986
		Embryo-larvae	Survival/growth inhibition	11	Hodson and Blunt, 1981
		Embryo-larvae	Survival/growth inhibition	28	Hodson and Blunt, 1981
		Embryo-larvae	Survival/growth inhibition	21	Chapman and Shumway, 1978
		Fry	9% Growth inhibition	9.2	Chapman 1969
CHLOROBENZENES					
1,2-dichlorobenzene	Pimephales promelas	Embryo-larvae	Chronic value	2,000	U.S. EPA, 1978a
1,3-dichlorobenzene	Pimephales promelas	Embryo-larvae	Chronic value	1,510	U.S. EPA, 1978b
		32 d to juvenile	NOEC	1000	Carlson and Kosian, 1987
		32 d to juvenile	LOEC	2,300	Carlson and Kosian, 1987
1,4-dichlorobenzene	Pimephales promelas	32 d to juvenile	NOEC	570	Carlson and Kosian, 1987
		32 d to juvenile	LOEC	1,000	Carlson and Kosian, 1987
		Embryo-larvae	Chronic value	763	U.S. EPA 1973b
1,2,4-TCB	Pimephales promelas	Embryo-larvae	Chronic value	286	U.S. EPA 1978a
		Embryo-larvae	Chronic value	750	U.S. EPA 1980
	Daphnia magna	0 to 16 days	NOEC - growth	181	Hermens et al. 1985
1,2,3,4-TCB	Daphnia magna	0 to 16 days	NOEC - growth	55.5	Hermens et al. 1985
	Pimephales promelas	32 d to juvenile	NOEC	240	Carlson and Kosian, 1987
		32 d to juvenile	LOEC	410	Carlson and Kosian, 1987
		Embryo-larvae	Chronic value	318	U.S. EPA 1980
		Embryo-larvae	Chronic value	713	U.S. EPA 1978a
Pentachlorobenzene	Daphnia magna	0 to 16 days	NOEC - growth	18	Hermens et al. 1985
	Pimephales promelas	32 d to juvenile	Nontoxic	55	Carlson and Kosian, 1987
Hexachlorobenzene	Pimephales promelas	32 d to juvenile	Nontoxic	4.8	Carlson and Kosian, 1987

NOEC = No Observed Effect Concentration
LOEC = Limited Observed Effect Concentration

The criteria originally set for this exercise could not be met. The data available for comparison were limited for chlorobenzenes; there were only five citations identified which referenced two organisms and four different end points. Data for chlorophenols included 17 citations which described the responses of 11 organisms exhibiting 11 different endpoints.

The confidence in water quality objectives that might be developed for a family of chemicals based on so few references, with such an inconsistent basis for comparison would be low. Furthermore, once sufficient data is available to meet the criteria set at the start of the exercise, many of the homologues may well be sufficiently documented that individual objectives could be developed following the traditional approach. It is probable that this data development would also take place mainly for the isomers of concern, and hence satisfy most of the need for the objectives.

Therefore, EOC concludes that data diversity and inadequacy currently precludes development of water quality objectives for chlorophenols and chlorobenzenes based on structure toxicity relationships. Since these compounds are among the best documented with regard to aquatic toxicity, the same limitations will likely apply to the development of water quality objectives for other groups of chemicals. The limitation is not the theoretical approach however, but the insufficiency of data to quantify and validate the process. Acquisition of such data will clarify the utility of this approach to establish water quality objectives in the future.

7.3 References

Adams, 1978. Table. 7.1

Borgmann, U. and K.M. Ralph, 1986. Effect of cadmium, 2,4-dichlorophenol and pentachlorophenol on feeding, growth and particle-size-conversion efficiency of white sucker larvae and young common shiners. Arch. Environ. Cont. Tox. 15: 473-480.

Call, D.J., L.T. Brooke, M.L. Knuth, S.H. Poirier and M.D. Hoglund, 1985. Fish subchronic toxicity prediction model for industrial organic chemicals that produce narcosis. Environ. Toxicol. Chem. 4: 335-341.

Carlson, A.R. and P.A. Kosian, 1987. Toxicity of chlorinated benzenes to fathead minnows (*Pimephales promelas*). Arch. Environ. Contam. Toxicol. 16: 129-135.

Chapman, G.A., 1969. Toxicity of pentachlorophenol to trout alevins. Oregon State University. Ph.D. Thesis 1969. Biology. University Microfilms 69-19,906. Ann Arbor, Michigan (as cited by Jones, 1981).

Chapman, G.A. and D.L. Shumway, 1978. Effects of sodium pentachlorophenate on survival and energy metabolism of embryonic and larval steelhead trout, pp. 285-299. <u>In</u>: Pentachlorophenol: Chemistry, Pharmacology and Environmental Toxicology. Ed. K.R. Rao. Plenum Press.

DeGraeve, G.M., D.L. Geiger, J.S. Meyer and H.L. Bergman, 1980. Acute and embryo-larval toxicity of phenolic compounds in aquatic biota. Arch. Environ. Contam. Toxicol. 9: 557-568.

Dominguez, S.E. and G.A. Chapman, 1984. Effect of pentachlorophenol on the growth and mortality of embryonic and juvenile steelhead trout. Arch. Environ. Contam. Toxicol. 13: 739-743.

Hall, L.H., L.B. Kier and G. Phipps, 1984. Structure-activity relationship studies on the toxicities of benzene derivatives: 1. An additivity model. Environ. Toxicol. Chem. 3:355-365.

Hedtke, S., C. West, K.N. Allen, T. Norberg and D. Mount, 1985. The toxicity of pentachlorophenol to aquatic organisms under naturally varying and controlled environmental conditions. Technical Report. U.S. Environmental Protection Agency, Monticello Ecological Research Station, Monticello, Minnesota. 34 pp.

Hermens, J., E. Broekhuyzen, H. Canton and R. Wegman, 1985. Quantitative structure activity relationships and mixture toxicity studies of alcohols and chlorhydrocarbons: Effects on growth on *Daphnia magna*. Aquat. Toxicol. 6:209-217.

Hodson, P.V. and B.R. Blunt, 1981. Temperature-induced changes in pentachlorophenol chronic toxicity to early life stages of rainbow trout. Aquat. Toxicol. 1: 113-127.

Holcombe, G.W., G.L. Phipps and J.T. Fiandt, 1982. Effects of phenol, 2,4-dimethylphenol, 2,4-dichlorophenol and pentachlorophenol on embryo, larval and early-juvenile fathead minnows (*Pimephales promelas*). Arch. Environ. Contam. Toxicol. 11: 73-78.

Johansen, P.H., R.A. Mathers and J.A. Brown, 1987. Effect of exposure to several pentachlorophenol concentrations on growth of young-of-year largemouth bass, *Micropterus salmonides*, with comparisons to other indicators of toxicity. Bull. Environ. Contam. Toxicol. 39: 379-384.

Kenaga, E., 1982. Predictability of chronic toxicity from acute toxicity of chemicals in fish and aquatic invertebrates. Environ. Toxicol. Chem. 1:347-358.

Konemann, H, 1981. Quantitative structure-activity relationships in fish toxicity studies. 1. Relationship for 50 industrial pollutants. Toxicology 19: 209-221.

Konemann, H. and A. Musch, 1981. Quantitative structure-activity relationships in fish toxicity studies. 2. The influence of pH on the QSAR of chlorophenols. Toxicology 19: 223-228.

McCarty, L.S., 1986. The relationship between aquatic toxicity QSARs and bioconcentration for some organic chemicals. Environ. Toxicol. Chem. 5: 1071-1080.

McCarty, L., M. Lupp and M. Shea, 1984. Provincial water quality objectives. Criteria development document for chlorinated benzenes. Ontario Ministry of the Environment, Toronto, Ontario.

Moulton, M.P. and T.W. Schultz, 1986. Comparisons of several structure-toxicity relationships for chlorophenols. Aquat. Toxicol. 8: 121-128.

Nagler, J.J., P. Aysola and S.M. Ruby, 1986. Effect of sublethal pentachlorophenol on early oogenesis in maturing female rainbow trout (*Salmo gairdneri*). Arch. Environ. Contam. Toxicol. 15: 549-555.

Olivier, L. and W.T. Hoskins, 1960. The effect of low concentrations of sodium pentachlorophenate on the fecundity and egg viability of *Australorbis glabratus*. Am. J. Trop. Med. Hyd. 9:199-105.

Schultz, T.W, 1983. Aquatic toxicology of nitrogen heterocyclic molecules: quantitative structure-activity relationships, pp. 579-612. In: Aquatic Toxicology. J.O. Nriagu (Ed.). John Wiley, New York.

Schultz, T.W., G.W. Holcombe and G.L. Phipps, 1986. Relationships of quantitative structure-activity to comparative toxicity of selected phenols in the *Pimephales promelas* and *Tetrahymena pyriformis* test systems. Ecotoxicology and Environmental Safety 12: 146-153.

8.0 CLASSIFICATION OF SPECIFIC OBJECTIVES: ANNEX 1

Article II of the Great Lakes Water Quality Agreement states: "... it is the policy of the Parties that:

> *The discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated."*

This policy statement, which is at the core of the Agreement, distinguishes between toxic and persistent toxic substances and prescribes different policies governing their discharge. Thus, the classification of substances into toxic and persistent toxic substances has an important bearing on the regulatory practices adopted by the Parties and jurisdictions and thus, on the success of what will be a multi-billion dollar cleanup.

In essence, the Agreement permits some discharge of toxic substances (the nonpersistent compounds) provided they are not discharged in a quantity which results in a concentration that causes toxicity in the receiving waters. That practice and the associated issuing of permits should be quite different from the policy and process required for persistent toxic substances.

The policy that was developed for persistent toxic substances in 1978 and which was reaffirmed in the 1987 Protocol is an extreme sanction: "... the discharge of any or all persistent toxic substances [should] be virtually eliminated." This policy is further elaborated on in Annex 12 where the principle states; "The philosophy adopted for control of inputs of persistent toxic substances shall be zero discharge." This approach is an appropriate response to the dangers posed to human health and resources by this class of compounds.

The classification of substances in Annex 1 into "persistent toxic substances" and "toxic substances" has an important effect on the way in which these respective classes of substances are controlled and thus, on the effectiveness of cleanup programs. Misclassification of compounds could undermine the value of these policy statements and even bring them into disrepute. Likely, the drafters of the policy were particularly concerned about organic substances when they referred to persistent toxic substances. The 1970s were a period of time when information about the deleterious effects of DDT and its metabolites, aldrin and dieldrin, and polychlorinated biphenyls was becoming widespread and these organic substances were not only persistent and toxic but were also biomagnified through food chains and widely dispersed in the environment. They pose very severe threats to the Great Lakes Basin Ecosystem and by 1970 had caused widespread injury to fish and wildlife resources and likely also to human health. This class of substances seems to require treatment with a special policy; recent information on polychlorinated dibenzo-*p*-dioxins and furans indicates that these compounds should also be included in this special class.

Unfortunately, total dissolved solids and inorganic substances such as iron and fluoride have also been included in Annex 1, under the heading of "persistent toxic substances." The threats posed by dissolved solids, iron and fluoride are in no way related to the dangers posed by PCBs and dioxins. The inclusion of iron and fluoride and other inorganic compounds under the class that requires extreme sanction undermines the policy of virtual elimination and the philosophy of zero discharge for persistent toxic substances as originally intended by the drafters of the Great Lakes Water Quality Agreement. There is therefore a requirement to review the present classification of compounds under Annex 1 of the Agreement. The meaning of the term "persistent toxic substance" should be clarified and substances such as "total dissolved solids" and "iron" should be moved to other sections. Careful attention should be given to the proper categorization of elements (fluoride, metals, etc.). Elements are persistent in the sense of being completely nonbiodegradable, but with some exceptions (e.g. Hg) are not biomagnified in food chains and do not pose the same threat to ecosystem health as do persistent <u>organic</u> compounds.

5.0 CLASSIFICATION OF SPECIFIC OBJECTIVES: ANNEX I

Article II of the Great Lakes Water Quality Agreement states: "...it is the policy of the Parties that:

> *The discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated.*

This policy statement, which is at the core of the Agreement, distinguishes between toxic and persistent toxic substances and prescribes different policies governing their discharge. Thus, the classification of substances into toxic and persistent toxic substances has an important bearing on the regulatory practices adopted by the Parties and jurisdictions and thus, on the success of what will be a multi-billion dollar cleanup.

In essence, the Agreement permits some discharge of toxic substances (the nonpersistent compounds) provided they are not discharged in a quantity which results in a concentration that causes toxicity in the receiving waters. That practice and the associated issuing of permits should be quite different from the policy and process required for persistent toxic substances.

The policy that was developed for persistent toxic substances in 1978 and which was reaffirmed in the 1987 Protocol is an extreme sanction: "...the discharge of any or all persistent toxic substances [should] be virtually eliminated." This policy is further elaborated on in Annex 12 where the principle states; "The philosophy adopted for control of inputs of persistent toxic substances shall be zero discharge." This approach is an appropriate response to the dangers posed to human health and resources by this class of compounds.

The classification of substances in Annex 1 into "persistent toxic substances" and "toxic substances" has an important effect on the way in which these respective classes of substances are controlled and thus, on the effectiveness of cleanup programs. Misclassification of compounds could undermine the value of these policy statements and even bring them into disrepute. Likely, the drafters of the policy were particularly concerned about organic substances when they referred to persistent toxic substances. The 1970's were a period of time where information about the deleterious effects of DDT and its metabolites, aldrin and dieldrin, and polychlorinated biphenyls was becoming widespread and these organic substances were not only persistent and toxic but were also biomagnified through food chains and widely dispersed in the environment. They pose very severe threats to the Great Lakes basin ecosystem and by 1970 had caused considerable injury to fish and wildlife resources and likely also to human health. This class of substances seems to require treatment with a special policy; recent information on polychlorinated dibenzo-p-dioxins and furans indicates that these compounds should also be included in this special class.

Unfortunately, total dissolved solids and inorganic substances such as iron and fluoride have also been included in Annex 1, under the heading of "persistent toxic substances." The threats posed by dissolved solids, iron and fluoride are in no way related to the dangers posed by PCBs and dioxins. The inclusion of iron and fluoride and other inorganic compounds under the class that requires extreme sanction undermines the policy of virtual elimination and the philosophy of zero discharge for persistent toxic substances as originally intended by the drafters of the Great Lakes Water Quality Agreement. There is therefore a requirement to review the present classification of compounds under Annex 1 of the Agreement. The meaning of the term "persistent toxic substance" should be clarified and substances such as "total dissolved solids" and "iron" should be moved to other sections. Careful attention should be given to the proper categorization of elements (fluoride, metals, etc.). Elements are persistent in the sense of being completely nonbiodegradable, but with some exceptions (e.g. Hg) are not biomagnified in food chains and do not pose the same threat to ecosystem health as do persistent organic compounds.

APPENDICES

A. Terms of Reference for the Ecosystem Objectives Committee of the Science Advisory Board

B. Membership List for the Ecosystem Objectives Committee of the Science Advisory Board

C. Terms of Reference for the Mesotrophic Indicators Workgroup of the Ecosystem Objectives Committee

D. Membership List for the Mesotrophic Indicators Workgroup of the Ecosystem Objectives Committee

Membership

Membership of the Aquatic Ecosystem Objectives Committee will be limited to fourteen active members plus corresponding members as required and deemed advisable to accomplish the above Terms of Reference. Active members will be selected to provide a broad range of expertise in the physical, chemical and biological fields of environmental science. Corresponding membership is intended to provide for continuing involvement of former active members whose available time is temporarily restricted or whose expertise is not immediately required. It may also be a membership category offered to persons who can assist the Committee on a continuing basis but not at the same level of intensity as active members must provide. All members are appointed by the Great Lakes Science Advisory Board after considering the recommendations of the Committee.

Reporting

The Aquatic Ecosystem Objectives Committee will report to the Science Advisory Board at such times as are appointed for the International Joint Commission's biennial meeting on the Great Lakes. Such formal reporting does not preclude the submission to the Board of Objectives appropriately reviewed and will indicate the nature of such review at the time of submission.

The Committee will, at the same time as it submits its Objectives to the Science Advisory Board, transmit the Objectives to the Water Quality Board. This is to permit the Board to evaluate the socio-economic and analytical impacts of the recommendations and to make such evaluation available to the International Joint Commission at the same time as the Objectives are formally presented.

APPENDIX B

Membership List for the Ecosystem Objectives Committee of the Science Advisory Board

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APPENDIX C

Terms of Reference for the Mesotrophic Indicators Workgroup of the Ecosystem Objectives Committee

An ecosystem objective by definition, infers a broad scientific approach encompassing all aspects of the environment and the indigenous biota. Such an objective framed as an ultimate goal for ecosystem management in the Laurentian Great Lakes may be philosophically satisfying, but pragmatically intractable.

Alternatively, the establishment of an ecosystem objective using a single species (a seeming contradiction of terms) may be justified, provided that the niche characteristics and habitat requirements of that species can be adequately described and compared with the former environments provided by a major portion of both the biotic and abiotic subsystems of the Great Lakes, thus ensuring adequate habitat diversity for other desirable community components of the system.

With the specific task of developing an Ecosystem Objective for the Great Lakes Basin, a designated work group (formerly task force) shall proceed to investigate the following charges:

Appraise, evaluate and critique the feasibility of using an indicator (integrator) organism as a suitable surrogate for depicting a "healthy" Great Lakes;

If feasible, produce an objective with supporting rationale applicable for inclusion into the 1978 Great Lakes Water Quality Agreement and in accordance with the Terms of Reference for the Aquatic Ecosystem Objectives Committee;

In the course of performing these specific charges the following additional charges shall be considered;

Identify and recommend appropriate system variables for future monitoring based on these concepts; and

Explore and develop, if appropriate, other ecosystem approaches with potential application to the Great Lakes basin.

Work Group Membership

The Work Group should be kept small and flexible. A first-line working group will consist of no more than eight members. Alternates or resource people may be selected to participate on an *ad hoc* basis as required. These may represent a particular discipline such as epidemiology, toxicology, physical limnology or any other for which a specific input is needed.

Twelve individuals, including four from the EOC and the IJC professional staff agreed to participate as full members of the Mesotrophic Indicators Work Groups.

APPENDIX C

Terms of Reference for the
Mesotrophic Indicators Work group
of the Ecosystem Objectives Committee

An ecosystem objective by definition, infers a broad scientific approach encompassing all aspects of the environment and the indigenous biota. Such an objective framed as an ultimate goal for ecosystem management in the Laurentian Great Lakes may be philosophically satisfying, but pragmatically intractable.

Alternatively, the establishment of an ecosystem objective using a single species (a seeming contradiction of terms) may be justified, provided that the niche characteristics and habitat requirements of that species can be adequately described and compared with the former environments provided by a major portion of both the biotic and abiotic subsystems of the Great Lakes, thus ensuring adequate habitat diversity for other desirable community components of the system.

With the specific task of developing an Ecosystem Objective for the Great Lakes Basin, a designated work group (formerly task force) shall proceed to investigate the following charges:

> Appraise, evaluate and critique the feasibility of using an indicator (integrator) organism as a suitable surrogate for depicting a "healthy" Great Lakes;
>
> If feasible, produce an objective with supporting rationale applicable for inclusion into the 1978 Great Lakes Water Quality Agreement and in accordance with the Terms of Reference for the Aquatic Ecosystem Objectives Committee;
>
> In the course of performing these specific charges the following additional charges shall be considered;
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The Work Group should be kept small and flexible. A first-line working group will consist of no more than eight members. Alternates or resource people may be selected to participate on an *ad hoc* basis as required. These may represent a particular discipline such as epidemiology, toxicology, physical limnology or any other for which a specific input is needed.

Twelve individuals, including four from the EOC and the IJC professional staff agreed to participate as full members of the Mesotrophic Indicators Work Groups.

APPENDIX D

Membership List for the Mesotrophic Indicators Workgroup of the Ecosystem Objectives Committee

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