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Aquatic Ecosystem Rehabilitation: Targets, Actions, Responses

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AQUATIC ECOSYSTEM REHABILITATION: TARGETS, ACTIONS, RESPONSES.

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MANAGEMENT PERSPECTIVE

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EC Priority/Issue: This work is part of the departments Nature, business line (Conservation of biodiversity in healthy ecosystems, Human impacts on the health of ecosystems are understood and reduced) and is relevant to the GL2000 Program and the Great Lakes Water Quality Agreement.

Current Status: Aspects of this work have been presented at a recent meeting of the Ecological Society of America. Rehabilitative measures continue to be implemented throughout the Great Lakes. It is imperative that the ecosystem response to these measures be followed and investigated in an effort to derive both general ecosystem rehabilitation principles and to effectively implement an "adaptive management strategy."

Next Steps: The response(s) of aquatic ecosystems to rehabilitative measures for the 14 beneficial use impairments described in Annex 2 of the Great Lakes Water Quality Agreement of 1987 will continue to be investigated.

Abstract

One effort to further define ecosystem health and integrity has been through the development and adoption of quantitative objectives for 14 beneficial use impairments associated with the Great Lakes Areas of Concern. Narrative descriptions of beneficial use impairments have been used to develop ecosystem type indicators and objectives, which are then used to set goals for rehabilitative actions. This process is both a technical and a social one. Implementation of rehabilitative actions, in addition to being socially, technically and economically challenging has yielded both encouraging and surprising results. The process and the results have reinforced the need for an adaptive management approach to the rehabilitation of aquatic ecosystems.

Keywords: Ecosystem objectives, Great Lakes, Adaptive management.

1. Introduction

Canada and the United States have signed a series of water quality agreements for the Laurentian Great Lakes in 1972, 1978 and 1987, as part of their 1909 Boundary Waters Treaty (USA and Canada, 1972; 1978; 1987). The purpose of these agreements is to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin ecosystem. As part of this process, the two countries adopted some general and specific objectives to assess water quality. The latest agreement adopts two ecosystem objectives, which address aspects of integrity, and requires the development of additional ones.

In addition, this agreement commits the governments to develop plans and take specific actions to address degraded nearshore areas, which are referred to as Areas of Concern (AOCs). These are areas that fail to meet the general or specific objectives of the Agreement, and where such failure has caused or is likely to cause impairment of beneficial use(s) or impairment of the areas' ability to support aquatic life. This approach attempts to reconcile the general and specific objectives employed in different parts of the Great Lakes, with an ecosystem, use-based approach to managing the resource. However, the Agreement does not provide detailed definitions of impairments or guidance on their quantification (USA and Canada, 1987).

One effort to define ecosystem integrity has been through the development and adoption of quantitative objectives for 14 beneficial use impairments associated with Great Lakes Areas of Concern. These targets were originally developed through a scientific symposium and were subsequently revised through both a peer and public review process. These guidelines are being used to assist the International Joint Commission to review Remedial Action Plans (RAPs), make recommendations on listing new AOCs and assist the governments of the United States and

Canada to reach consensus on the problems and clean-up benchmarks (Hartig and Zarull, 1992; United States and Canada, 1987; Hartig *et al.*, 1997).

Agreement on these listing/delisting guidelines represents a significant milestone in the process of assessing ecosystem health in the Great Lakes because they are scientifically defensible, sensitive to public concerns and pragmatic. These guidelines are being applied at the working level within regulatory and resource management programs and represent a practical application of ecosystem integrity theory. They recognize that the AOCs will not be restored to pristine conditions, but rehabilitated to a desired future state. Concurrence on problem definition and quantitative targets for each AOC provides clear direction for the selection of the remedial and preventative measures necessary for ecosystem rehabilitation.

This paper provides some examples of ecosystem objectives and quantitative targets for two AOCs, as well as the rehabilitative actions taken to achieve these targets and the aquatic ecosystem responses to these measures.

2. Beneficial Use Goals

The 14 beneficial use goals, described in the Agreement, can be grouped into four aspects of ecosystem health or state: human health, societal value, economic value and biological or ecological performance. These groupings also indicate the diverse nature of the objectives and indicators and therefore, the need to have a variety of professionals and users collectively involved in the process (Hartig *et al.*, 1997; Zarull and Hartig, 1997). Under the Agreement, impairment of beneficial use means a change in the chemical, physical or biological integrity of the Great Lakes System sufficient to cause any of the following:

2.1 Human Health

Restrictions on fish and wildlife consumption.

- The use is deemed to be impaired when contaminant levels in fish or wildlife populations, due to contaminant input from the watershed, exceed current standards, objectives or guidelines, or public health advisories that are in effect for human consumption of fish or wildlife.

Restrictions on drinking water consumption, or taste and odour problems.

- This use is impaired when treated drinking water supplies are impacted to the extent that: 1) densities of disease causing organisms or concentrations of hazardous/toxic chemicals or radioactive substances exceed human health standards, objectives or guidelines; 2) taste and odour problems are present; or 3) the treatment needed to make raw water suitable for drinking is beyond the standard treatment used in comparable portions of the Great Lakes, which are not degraded (i.e. settling, coagulation, disinfection).

Beach closings.

- This use is deemed impaired when waters, which are commonly used for total body-contact or partial body-contact recreation, exceed standards, objectives, or guidelines for such use.

2.2 Societal Value

Eutrophication or undesirable algae.

- When there are persistent water quality problems (e.g. dissolved oxygen depletion of bottom waters, nuisance algal blooms or accumulation, decreased water clarity, etc.) attributed to cultural eutrophication, the use is considered impaired.

Degradation of aesthetics.

- When any substance in water produces a persistent objectionable deposit, unnatural colour or turbidity, or unnatural odour (e.g. oil slick, surface scum), this use is considered impaired.

2.3 Economic Value

Tainting of fish and wildlife flavour.

- The use is considered impaired when ambient water quality standards, objectives, or guidelines, for the anthropogenic substance(s) known to cause tainting, are being exceeded or survey results have identified tainting of fish or wildlife flavour.

Restrictions on dredging activities.

- When contaminants in sediments exceed standards, criteria, or guidelines such that there are restrictions on dredging or disposal activities, this use is viewed as impaired.

Added costs to agriculture or industry.

- This use is judged as impaired when there are additional costs required to treat the water prior to use for agricultural purposes (i.e., including but not limited to, livestock watering, irrigation and crop-spraying) or industrial purposes (i.e., intended for commercial or industrial applications and non-contact food processing).

3.4 Biological/Ecological Health

Degradation of fish or wildlife populations.

- This beneficial use is impaired when fish and wildlife management programmes have identified degraded fish or wildlife populations due to a cause within the watershed. In addition, this use will be considered impaired when relevant, field validated, fish or wildlife bioassays with appropriate quality assurance/quality controls confirm significant toxicity from water column or sediment contaminants.

Fish tumours or other deformities.

- When the incidence rates of fish tumours or other deformities exceed rates at unimpacted control sites or when survey data confirm the presence of neoplastic or pre-neoplastic liver tumours in bullheads or suckers (demersal fish), this use is declared impaired.

Bird or animal deformities or reproduction problems.

- When wildlife survey data confirm the presence of deformities (e.g., cross-bill syndrome) or other reproductive problems (e.g., egg-shell thinning) in sentinel wildlife species, this beneficial use is regarded as being impaired.

Degradation of benthos.

- This use is deemed impaired when benthic macroinvertebrate community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics. In addition, this use will be considered impaired when toxicity (as defined by relevant, field-validated, bioassays with appropriate quality assurance and quality controls) of sediment-associated contaminants at a site is significantly higher than controls.

Degradation of phytoplankton and zooplankton populations.

- When phytoplankton or zooplankton community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics, this use is impaired. In addition, this use will be considered impaired when relevant, field-validated phytoplankton or zooplankton bioassays (e.g., *Ceriodaphnia*; algal fractionation bioassays) with appropriate quality assurance/quality controls confirm toxicity in ambient waters.

Loss of fish and wildlife habitat.

- This use is impaired when fish and wildlife management goals have not been met as a result of loss of fish and wildlife habitat due to a perturbation in the physical, chemical or biological integrity of the Boundary Waters, including wetlands.

3. Developing Specific Objectives and Quantifying Targets

The development of ecosystem objectives and their indicators is a two-stage process. The first step is the development of the objectives, which requires reaching agreement among all potential users of the ecosystem. The objectives will, in narrative form, describe desirable conditions and will reflect social values and long-term visions for the ecosystem state. The process is therefore, a social-political one, rather than technical; although, technical input is essential to ensure that the vision has a foundation in the realm of ecological possibilities and scales. Once agreement on the objectives has been reached, then measurable indicators can be considered and targets (that numerically represent the desired conditions) set. The selection of indicators and numerical targets is a technical process that requires expert input based on both historic and current knowledge of ecosystem structure, function and performance. In the Laurentian Great Lakes, some ecosystem objectives, along with their indicators have been proposed for individual lakes and large regions within a lake (Ryder and Edwards, 1985; Edwards and Ryder, 1990; Bertram and Reynoldson, 1992).

The statements of beneficial use impairment, contained in the Agreement, provide a common means of defining existing problems along with their causes and a standard way of assessing future conditions throughout the lakes. Earlier attempts to develop specific objectives and numerical targets for the fourteen beneficial use impairments set down in the Agreement, helped to focus both scientific and public opinion; however, the absence of a single numeric expression for each impairment acknowledges the need for site-specific indicators (Hartig *et al.*, 1990; Hartig and Zarull, 1992). Agreement on quantitative ecosystem-based targets also assists in; implementing an ecosystem approach, accounting for interrelationships among different programs; establishing a foundation upon which relative risk assessment can be performed and priorities set; and securing broad-based support for necessary actions.

In one Area of Concern (Hamilton Harbour, Ontario), the initial part of the process —

developing goals and principles for the development of a comprehensive Remedial Action Plan, was done by a stakeholder group. This group consisted of members from citizen groups, academics, industry, government agencies (federal, provincial and municipal), local politicians and other user group representatives. It was based on a round-table concept, with the objective of achieving consensus on the goals and principles for the future state of this particular aquatic ecosystem. A team of experts then provided quantification of these goals that identified the criteria that needed to be achieved for the goals to be realized. Below, is an example of the results of this process (Canada-Ontario, 1992).

One of the problems (impaired uses) was described as: 'A warmwater fishery population that is heavily stressed, unbalanced towards pollution -tolerant species, experiencing health problems (tumours, skin lesions) and subject to restrictions on their human consumption due to contaminant content of the fish fillets.' As a result of reaching agreement on the problem, the following water use goal was established: 'THAT water quality and fish habitat should be improved to permit an edible, naturally reproducing fishery fro warmwater species. Water and habitat conditions in Hamilton Harbour should not limit natural reproduction and the edibility of coldwater species.'

A series of delisting objectives or quantitative indicators of goal achievement were then developed by the scientific team and agreed to by the stakeholder group. These were: that the fish community has the following structure:

1. Shift from a fish community indicative of eutrophic environments, such as white perch, alewife, bullheads, and carp to a self sustaining community more representative of a mesotrophic environment, containing pike, bass, yellow perch, and sunfish.

2. Attain a littoral fish biomass of 200 - 250 kg/ha.

3. Increase the species richness from 4 species to 6-7 species per transect.

4. Increase the native species biomass from 37% to 80-90% of the total biomass.

5. Reduce the spatial variability in fish biomass within the harbour.

6. Proposed nearshore fish community of Hamilton Harbour:

Category	Littoral Biomass (kg/ha)
Piscivores (pike, bass)	40-60
Specialists (insectivores like pumpkinseeds and yellow perch)	70-100
Generalists (omnivores like carp and brown bullheads)	30-90

The percent of fisheries biomass allocated to the three trophic groups was based on the effects of improved water quality in the Bay of Quinte and Severn Sound, two other AOCs in the Great Lakes Basin. The littoral fish biomass of 200-250 kg/ha was based on electrofishing data collected from Hamilton Harbour, Bay of Quinte and Severn Sound in 1990.

With a series of narrative objective or goals (developed by a consensus of users) and their accompanying quantified indicators of achievement (developed by technical experts) in hand, specific actions to realize these goals are then defined. In the case of Hamilton Harbour, a schedule (and order) of specific actions was developed and implemented to achieve the fish community goals:

- habitat construction/protection
- nutrient loading reductions
- oxygen demanding substances loading reductions
- toxic substances loading reductions

- erosion control/protection
- species stocking/control
- species (including humans) access/disturbance control

Other examples of the development of quantitative targets for ecosystem health and their application in protective and remedial actions in Great Lakes AOCs include benthic macroinvertebrate multi-metric goals using an extensive reference data base and the use of an Index of Biotic Integrity for fish communities (Reynoldson *et al.*, 1997; Yoder and Rankin, 1995).

4. Ecosystem Response to Rehabilitative Action

Historically, measures of biological community condition and habitat quality or amount have been used to describe ecological degradation and even as goals for preservation or rehabilitation. However, these quantitative targets have seldom been used in a prescriptive fashion for remedial and rehabilitative efforts (either regulatory or policy driven) until recently. The results for many of these specific actions, in response to consensus driven, quantitative ecological targets in the Great Lakes AOCs, have only recently become available. Two examples of specific actions driven by ecological targets and the ecosystem response to these actions are in the Black River, Ohio and Hamilton Harbour, Ontario.

4.1 Fish Tumours or Other Deformities

The Black River is one of four designated AOCs in the State of Ohio (USA); however, it is the only one that encompasses an entire watershed. Located in north-central Ohio, the Black

River watershed covers 1,210 km^2, most of which is used for agriculture. The river ultimately discharges into Lake Erie at the City of Lorain. The problem statements contained in the Black River RAP indicates a number of beneficial use impairments, including the presence of fish tumours and other deformities.

Data from the early 1980s and 1990s indicate a history of fish tumour and other deformities in the Black River (mainstem and near shore), Ohio. Research work established a link between high polyaromatic hydrocarbons (PAHs) concentrations in Black River sediment and liver cancers in bullheads. Further research documented a decline in sediment PAH(s) and fish tumours concurrent with the closure of the USS/KOBE coking facility on the river (Baumann and Harshbarger, 1997).

In 1990, approximately 38,000 m^3 of PAH-contaminated sediment was removed as part of the effort to restore beneficial uses and rehabilitate the aquatic ecosystem. Prior to dredging, PAH concentrations ranged from 4.8-390 mg/kg in these sediments. Table 1 shows pre- and post-dredging levels of four common PAHs found in these sediments.

Subsequent research on hepatic tissue types (cancer, non-cancer neoplasm and altered hepatocytes) in resident brown bullheads showed an initial, significant increase in the incidence of liver cancer cells after sediment removal, followed by a sharp decline in cancer and other abnormal cells (Figure 1). This increase in liver cancer cells is thought to be due to PAH redistribution that occurred during the 1990 dredging. No instance of liver cancer was found in 1994 samples (Baumann and Harshbarger, 1997).

4.2 Loss of Fish and Wildlife Habitat

Hamilton Harbour is located at the extreme western end of Lake Ontario and is one of 11 designated AOCs wholly within the Province of Ontario (five more are considered binational). Eleven of the fourteen beneficial uses are impaired, including degraded fish and wildlife populations, and loss of fish and wildlife habitat (COA, 1992). The rehabilitation of fish and wildlife communities in Hamilton Harbour is a three part process; i) reduce existing stressors (e.g., extreme oxygen demand, poor water clarity, presence of toxic substances, etc.,); ii) rehabilitate and create suitable habitat and; iii) restructure existing populations. Independent objectives and numerical targets were established for fish and wildlife. In the case of wildlife in Hamilton Harbour, the objectives focused on colonial waterbirds and the rehabilitative actions were directed at habitat.

'The overall objective is to have a self sustaining mixed community of colonial waterbirds generally with an increase of the rarer species and a reduction in the number of ring-billed gulls, which currently nest the harbour.' Management of colonial waterbirds is experimental and achieving specific populations of particular species is highly speculative (COA, 1992). The suggested interim targets for colonial waterbirds in Hamilton Harbour are presented in Table 2.

For other wildlife including waterfowl, no population targets were suggested, but a target for habitat has been suggested that will enhance wildlife populations generally. In addition, management of some species may be necessary as a result of habitat enhancement. These goals are to: increase quantity of emergent and submergent aquatic plants in specified areas to approximately 500 ha; create an additional 344 ha of lagoon habitat for waterfowl; create 20 ha of colonial nesting habitat.

One of the major rehabilitative actions taken to achieve these goals was the construction of three islands in the northeast corner of the harbour during the winter of 1995-1996 to provide secure nesting habitat for six species of colonial waterbirds — Double-crested Cormorants, Black-crowned Night Herons, Herring Gulls, Ring-billed Gulls, Caspian Terns and Common Terns. The three main islands (approximately 100 m x 30 m) were placed 125 m, 55 m and 95 m, respectively, from a restructured harbour shoreline. The islands were constructed to withstand the 25-50 year flood periods and elevated knolls and vegetation provide additional storm protection for birds nesting on the knolls and on the lee sides of the islands. Sections of the islands were specifically constructed (using soil, rock gravel, etc., and erecting artificial trees or nesting platforms) to attract and accommodate one of the six target species.

Five of the six target species nested on the created islands and substrates. At first, the Double-crested Cormorants did not nest on the new islands. Caspian Terns and Ring-billed Gulls occupied sub-areas and their accompanying substrates, which were designated for them. Whereas, Black-crowned Night Herons, Herring Gulls and Common Terns nested on the wildlife islands, but not on the substrates that were prepared for them and in the case of the gulls, measures had to be taken to keep them from interfering with the nesting habits of the terns. In both 1996 and 1997, all six species continued to occupy nesting sites elsewhere in the harbour.

The results of these habitat creation actions are encouraging since five of the six species established and maintained nesting colonies on the islands. However, only two of these species (Ring-billed Gulls and Caspian Terns) nested on the sub-areas specifically designed for their use. Temporal trends on the total number of nests for each of these six species throughout the harbour during the last ten years indicate that the number of Double -crested Cormorant nests increased significantly and the number of Black-crowned Night Heron nests declined significantly, while there have been no significant changes in the numbers of either Herring or Ring-billed Gull nests (Pekarik *et al.*, 1992).

There is a need for continued monitoring and adaptive management to ensure that the species are able to cohabit on the new islands in the long-term. The six species of colonial waterbirds are not exclusive to Hamilton Harbour, and their overall respective population trends will influence management efforts on the three constructed islands.

5. Conclusions

Quantitative, ecosystem-based targets are required to both adequately protect and rehabilitate aquatic environments.

The desired state or beneficial use should be identified, along with the main factors controlling the present conditions, prior to taking specific rehabilitative actions. This process requires both consensual objectives and technical targets, and should accommodate multiple uses of the resource.

Aquatic ecosystem responses to rehabilitation activities are frequently rapid, with the designated goals being achieved in surprisingly short periods of time. Occasionally, either the predicted response is not achieved, or surprising and unpredicted results are seen. This emphasizes the continuing experimental nature of ecological rehabilitation and the need to adopt an adaptive management approach.

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Figure 1: Percentage of age 3 brown bullheads (*Ictalurus nebulosus*) with various liver lesions, from the Black River, Ohio (from Baumann and Harshbarger, 1997).

Table 1: Pre- and post-dredging levels of four common PAHs found in the sediments of the Black River, Ohio.

PAH COMPOUND	1980	1984	1992
Phenanthrene	390.0	52.0	2.6
Fluoranthrene	220.0	33.0	3.7
Benzo(a)anthracene	51.0	11.0	1.6
Benzo(a)pyrene	43.0	8.8	1.7

Table 2: Interim targets for colonial waterbirds in Hamilton Harbour, Ontario.

SPECIES	NUMBER OF PAIRS
Ring-billed gulls (*Larus delawarensis*)	5,000
Common terns (*Sterna hirundo*)	> 600
Herring gulls (*Larus argentatus*)	350
Caspian terns (*Sterna caspi*)	> 200
Double-crested cormorants (*Phalacrocorax auritus*)	200
Black-crowned night herons (*Nycticorax nycticorax*)	200

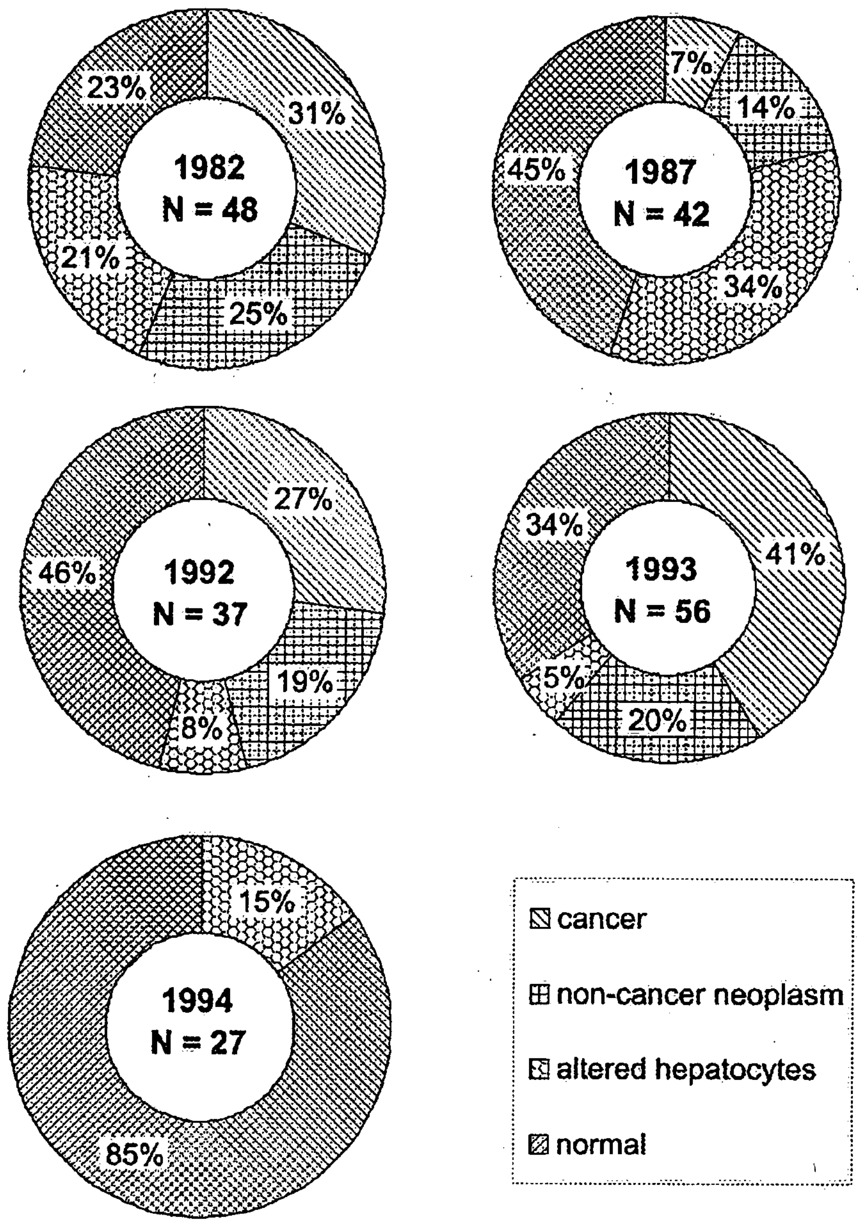

Figure 1: Percentage of age 3 brown bullheads from the Black River having various liver lesions, during (1982) and post (1987) after operation of the coking facility and post contaminated sediment dredging
(from BAUMANN & HARSHBARGER 1997)

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