Environmental Assessment Tool for Cage Aquaculture in the Great Lakes Version 1.1

by

Deborah J. Brister [1,3]

and

Anne R. Kapuscinski [1,2,3]

[1]University of Minnesota, Department of Fisheries and Wildlife
[2] Minnesota Sea Grant College Program
[3] Institute for Social, Economic and Ecological Sustainability

***Part One*: Introductory Materials, Supporting Text and Summary Documentation**

DISCUSSION DRAFT

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Council of Lake Committees

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Preface

This draft addresses only within-lake aquaculture facilities. In other words, it only applies to cage aquaculture and other operations that are located within a Great Lake or a Great Lake tributary. It exemplifies the approach that will be taken in the land-based assessment tool (in preparation). *The responsible jurisdictional management agency is the assumed user*, although we hope that aquaculturists and other interested parties will also use this tool. Only management agencies, however, have the authority to make risk decisions on behalf of the environment. Because of the assessment tool's inherent transparency, it provides an opportunity for broad discussion—especially between management agencies and aquaculturists proposing to build a new aquaculture facility. For reference, we have attempted to include links to as many jurisdictional regulations as possible, but aquaculturists should always refer to their state or provincial management agency to ensure they receive the most up-to-date (federal, provincial, state and local) regulations.

Before starting a full assessment, the user should consider the following critical questions below and refer to the sections in parentheses for further information.

- Is the proposed species approved for culture by the managing agency (Question 9, Section 1)?

- Is the proposed facility close to or in: an area that is culturally significant to, or subject to a land claim by Native American or First Nations people; a historically significant area; an area that will impede navigational traffic; or an area that may adversely affect other lake users (Questions 12-15, Section III)? Does the facility comply with site regulations such as the Coastal Zone Management Act (Question 16, Section III)?

- Has the broodstock/production stock come from one of the Great Lakes or a tributary flowing into the Great Lakes (Question 19, Section IV)?

- Has a fish health specialist inspected production stock and/or broodstock following procedures and diagnostics in the (revised) Great Lakes Fish Disease Control Policy and Model Program (Question 24, Section IV)?

- Is the proposed aquaculture facility in the "zone of influence" of a designated Area of Concern" (Question 35, Section VI)?

- Does the facility meet water quality regulations (Question 46, Section IX)?

Introduction

An increasing interest in aquaculture development in the Great Lakes region has inspired the development of an aquaculture environmental assessment tool for aquaculture facilities in the Great Lakes. There are over 1200 aquaculture facilities in the Great Lakes basin (Sippel and Muschett, 1999; Garling, 1999) all under varying degrees of jurisdictional regulation. Jurisdictions include two countries (Canada and the United States), one province (Ontario), eight states (Minnesota, Wisconsin, Ohio, Illinois, Indiana, Pennsylvania, Michigan, New York) and numerous tribal agencies (Native American and First Nations), all of which have some control over how the Great Lakes basin is managed. Although agreements and plans such as the Great Lakes Water Quality Agreement (1987) and the Joint Strategic Plan for Management of the Great Lakes Fisheries (1997) call for agreement and collaboration between the management agencies with respect to water quality and fisheries management, the actual process for consensus is much more difficult. In addition, some managers and other Great Lakes stakeholders may be unaware of other jurisdictions' issues of concern. Because the Great Lakes are interconnected water bodies, organisms may move freely from one body of water to another, making aquaculture management a possible contentious issue between jurisdictions.

To best address the multitude of issues that need to be considered when determining the suitability and environmental effects of an aquaculture facility at a particular site, we have assembled an environmental assessment tool that methodically takes the user through these issues, identifies potential hazards and, when possible, makes risk management recommendations. *This is a tool and not a regulatory document*. It aims to assist decision-makers and other interested parties by providing a systematic and consistent process for assessing aquaculture facilities. Please note that economic effects and cost/benefit analyses were not in the scope of this project. This tool is comprised of three distinct components, the assessment pathway flowcharts, supporting text and summary documentation.

Each component of this environmental assessment tool serves a specific function. First, the assessment pathway guides the user through assessment of potential environmental effects. The user answers a series of carefully worded questions about the species (including genetic strains) and the accessible aquatic ecosystem, identifying whether or not the aquaculture operation under review poses any specific hazards. Should any hazards be identified, the user is led to consider risk management measures, including culture methods, facilities design and operations management. This would include whether or not measures capable of reducing the risk of the identified hazard currently exist.

Second, the supporting text provides: scientific background, including citations of relevant documents, for the questions and alternative decisions in the assessment pathway; more detail on risk management recommendations; a glossary of scientific terms; and other relevant appendices.

Third, the summary documentation traces the user's path through the assessment pathway and prompts the user to describe the rationale for any selected risk management measures. The summary documentation provides transparent documentation of the systematic assessment process, and will encourage more consistent and systematic use of available scientific and technical information, and regulatory decisions. This will hopefully reduce distrust and some sources of conflict between regulators, aquaculturists and other users.

This assessment tool is dynamic in that it will be periodically updated as new information is available. As stated earlier, this is not a regulatory document. To assist the user, however, links to specific jurisdictional regulations such as those for water quality and approved species lists are included. In addition, the document includes links for specific Great Lakes management plans to assist users in identifying whether or not a proposed aquaculture development conflicts with existing natural resource management plans.

Overview of the Environmental Assessment Tool

The current assessment tool only encompasses aquaculture facilities that are proposed to be located within a Great Lake. A future version will include land-based facilities, secured facilities, plant aquaculture and eventually shellfish culture. Figure 1. is an overview of the pathway through major sections of the assessment for lake-based aquaculture operations.

Determination of Assessment Pathway

The pathway is determined by questions regarding: type of organisms to be cultured (fish, shellfish or plant), collection or growout methods of organisms, and location (Great Lake-based or land-based facilities). Lake-based projects involving non-indigenous or non-naturalized species in the Great Lakes are directed to consult with relevant agencies, according to the Introductions in the Great Lakes Basin Procedures for Consultation (Council of Lake Committees, 1992), before proceeding further. Below is an overview of the lake-based pathway in the environmental assessment tool.

Assessment of Great Lakes-based Aquaculture Systems

Assessment of Suitable Environment
These questions assist the user in identifying whether an organism can survive and thrive in the surrounding aquatic ecosystem. Questions also address the structural integrity of the facility. Important factors include temperature, pH, degree of ice cover, wave heights, and currents (Beveridge, 1996). Additional factors are considered in later assessments.

Effects on Other Lake Users
These questions assist the user in identifying whether the facility or its related infrastructure are located in areas that may affect other lake users. Potential impacts on culturally, historically or navigationally sensitive sites are also considered. Users are prompted to refer to suggested agencies to make these determinations.

Disease Effects

These questions assist the user in identifying whether the cultured organisms have been certified to be free of emergency or restricted pathogens. If cultured organisms are salmonids, the user is instructed to evaluate the broodstock or production stock with the Great Lakes Fish Disease Control Policy and Model Program (Hnath, 1993). The user is also asked if emergency or restricted pathogens have been identified in wild fish populations in surrounding waters. These questions aim to minimize the possibility of spreading disease to cultured fish and further contaminating wild fish.

Impacts on Recovery or Rehabilitation Plans

These questions assist the user in identifying whether the cultured organisms or the facility could harm any listed endangered, threatened, special concern, or vulnerable species. The user is asked to identify species at risk and determine, with the assistance of the appropriate government agency, whether the cultured organism or the facility may adversely affect the species at risk. Questions also prompt the user to consider other recovery or rehabilitation plans that may be affected, e.g., recovery of wild lake sturgeon in Lake Ontario (Stewart et al., 1998).

Impacts on Areas of Concern

These questions assist the user in identifying whether the cultured organisms or the facility could harm Areas of Concern designated by the International Joint Commission. Clean-up and restoration plans have been identified in 42 areas of the Great Lakes (International Joint Commission, 1987). The user is asked to determine proximity of the aquaculture facility to Areas of Concern and possible effects on any recovery plans that include fish and wildlife rehabilitation, improvement of degraded benthos, or remediation of eutrophication or undesirable algae.

Effects of Settleable Solids on Benthos and Shellfish

These questions assist the user in identifying whether the cultured organisms or the facility could adversely affect benthic species or shellfish beds. Excessive wastes from culture facilities may cause smothering of benthic environments, a buildup of contaminants within the sediments, promote a higher level of resistant bacteria, change sediment chemistry, deplete oxygen levels, and cause a shift in community structure of benthic species (Weston, 1990; Gowen et al., 1994; Silvert, 1994; Sowles et al., 1994; Beveridge, 1996). Shellfish also may be vulnerable to contaminants and smothering. The user will be asked questions that help identify vulnerable benthic areas and significant shellfish beds. This section will also ask questions about the aquaculture facility's potential exposure to fouling agents (e.g., zebra mussels).

Impacts on Breeding Areas, Nurseries, and Fish-eating Animals

These questions assist the user in identifying whether the cultured organisms or the facility could harm breeding or nursery areas of wild organisms. Proximity to these areas will be the most important issue. The user is asked questions that will assist in identifying areas that are vulnerable. Questions also consider effects on fish-eating mammals and birds.

Water Quality and Cumulative Impacts

These questions assist the user in identifying whether the culture operation could adversely affect wild populations and pre-existing aquaculture operations through a higher cumulative waste load that could decrease dissolved oxygen levels and increase dissolved nutrients, thus promoting eutrophication. The objective of these questions is to assess cumulative impacts.

Impacts of Facility and Infrastructure

These questions assist the user in identifying whether the facility or its related infrastructure (e.g., construction of additional buildings or roads) could harm habitats for species at risk, or fisheries and wildlife restoration/rehabilitation projects listed in the Fish Community Objectives. Users are directed to suggested agencies to make these determinations.

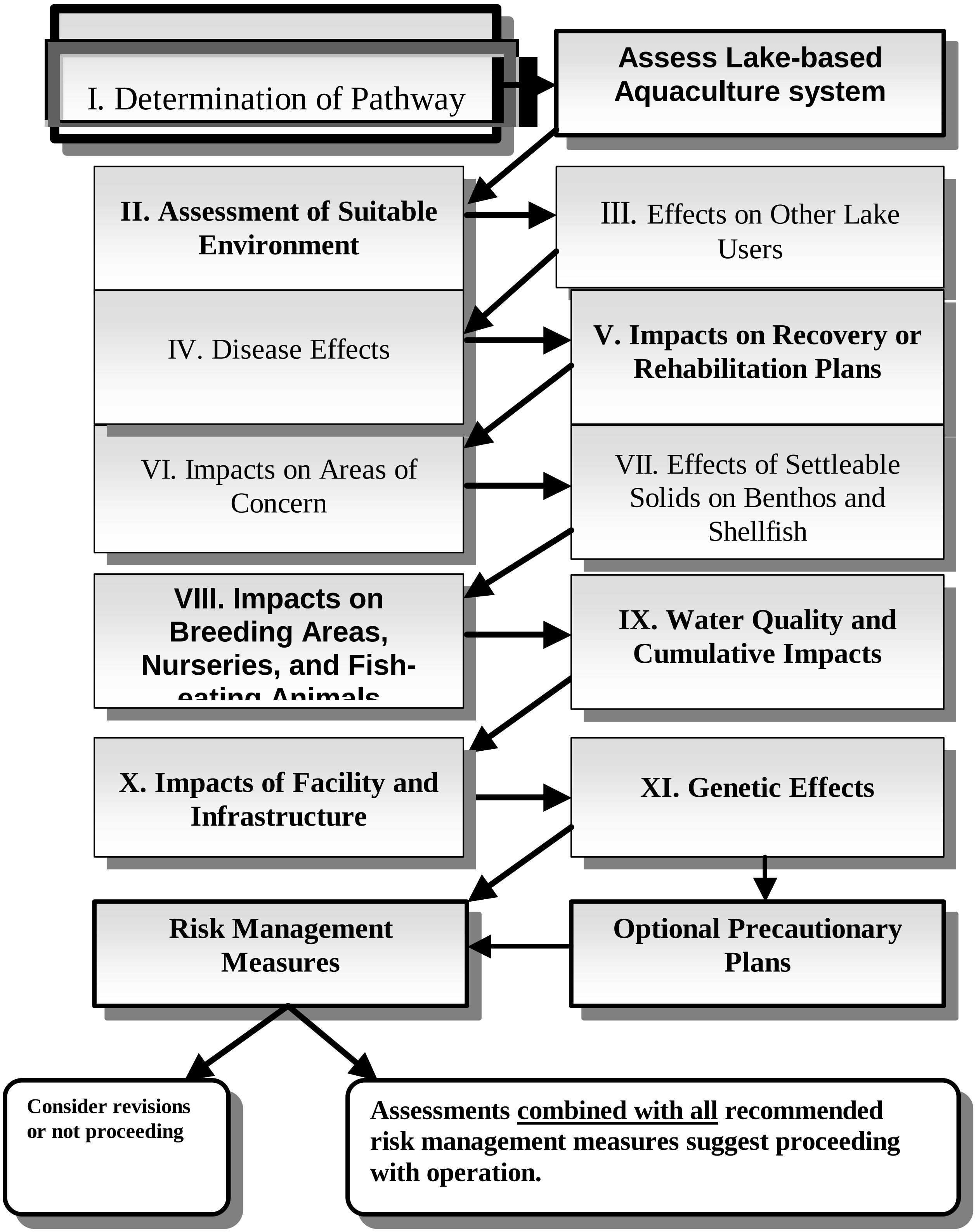
Genetic Effects

These questions assist the user in identifying whether an organism has been genetically engineered (involving deliberate gene changes, deliberate chromosomal manipulations or interspecific hybridization). Projects involving genetically engineered organisms are directed to the Manual for Assessing Ecological and Human Health Effects of Genetically Engineered Organisms (Scientists' Working Group on Biosafety, 1998). This manual is appropriate for assessing commercial-scale aquaculture of genetically engineered animals or plants. It is an expanded version of the Performance Standards for Safely Conducting Research with Genetically Modified Fish and Shellfish (ABRAC, 1995). Questions will also assist the user in assessing effects on the genetic makeup and fitness of wild populations due to interbreeding between wild populations and escaped aquaculture organisms derived from non-local genetic sources. The user is asked about known genetically distinct populations, sources of cultured organisms, and feasibility of sterilizing cultured organisms.

Optional Precautionary Plans

This section helps the user to develop additional ways of reducing or preventing specific environmental problems. Measures could include the development of an emergency response plan, a fish disposal plan, and a fish-eating predator prevention plan.

Figure 1. Overview of Sections in Assessment of Lake-based Aquaculture Systems



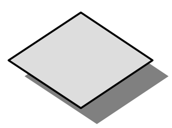
How to Use the Environmental Assessment Tool

The user is guided through a series of questions relating to a specific section (e.g. Genetic Effects, Disease Effects) of the assessment tool. These questions, usually answered with a yes or no, will assist the user in identifying potential hazards, which then allow the user to determine whether or not to accept the risk associated with each hazard.

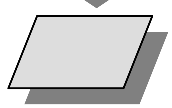
If the answer to a question is unknown, users should refer to the supporting text of the question at issue. The user is assisted in how to find the necessary answer with supporting information, useful links for documents and relevant addresses of people to contact. If the answer is still unknown, the assessment tool directs the user to follow the most precautionary path. This approach is based on the Precautionary Principle as stated in the preamble to the Convention on Biological Diversity (UNEP/CBD/94/1) which suggests that "…where there is a threat of significant reduction or loss of biological diversity, lack of scientific certainty should not be used as a reason for postponing measures to avoid such a threat".

The flowchart symbols consists of:

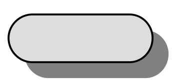
Questions



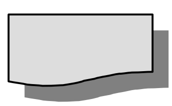
Potential Hazards



Terminal Points



Continuation Markers



This assessment tool uses both the terms hazard and risk. It is appropriate here to distinguish one from the other as they are sometimes used interchangeably in everyday language. For our purposes, *hazard* can be defined as a potentially adverse outcome of an event or activity. *Risk* is the probability of the hazard occurring (Smith, 1992). This assessment tool focuses on the *identification of hazards*. It does not provide guidance on the estimation of specific risks; users may instead consult the extensive literature on risk estimation (see e.g. Burgman et al., 1993 and Stern et al., 1996). The degree of acceptable risk a user is willing to take is left up to the users of this decision support tool. In this way, the assessment tool can be flexible and adaptive to unique circumstances of each case.

For most aquaculture proposals, the user will run through each section. An exception is projects involving harvest of wild organisms and confined holding, but no growout (e.g.

baitfish, ornamentals, feeder fish). In this case the user is directed to bypass the majority of the assessment and go to the section, *Impacts on Facility and Infrastructure*.

If a user suspects that a section in this assessment tool will identify a clear obstacle in their proposed project, it may be useful to work through the section of concern as a preliminary assessment. If a hazard has been identified and the user is unwilling to accept the risk, modifications to the proposal can then be made at this stage before running through the entire assessment tool. For example, navigational interference may be an issue that deserves immediate attention. If this is the case, users should first run through the section, *Effects on Other Lake Users.*

Although it may appear redundant, there are several places that ask nearly the same question, but are looking at different aspects of adverse effects. For example, while there is an entire section devoted to *Impacts of Facility and Infrastructure*, there are still questions regarding the infrastructure impacts on spawning areas in the *Impacts on Breeding Areas, Nurseries, and Fish-eating Animals* section. This ensures that adequate consideration is given to the possible impact of a facility's structure.

Throughout the assessment tool, supporting text is provided for almost every question and recommended risk management measures are provided for hazards that have been identified. **The Summary Documentation worksheet should be checked off as the user goes through the flowcharts.** Upon completion of the flowcharts, the user is directed to read supplemental information regarding voluntary *Precautionary Plans*.

Section I.
Determination of Pathway

The Determination of Pathway flowcharts identify which particular series of assessment flowcharts are applicable to the proposed aquaculture operation in question.

Question 1.

The organism at issue is what the aquaculturist proposes to culture. In the event of polyculture, or the rearing of multiple species, the user will need to run through the assessment for each species. As mentioned earlier, the plant and shellfish flowcharts will appear in a future version of the assessment tool.

If answer to this question is unknown, consult with operator.

Question 2.

In some instances, broodstock, eggs, fry or other marketable life stages may be collected from the natural environment prior to growout. In other cases, this collection, or harvesting requires no growout except for holding. Examples of this would include (but not limited to) harvesting of baitfish, feeder fish and species collected for aquaria. At issue are the possibilities of inadvertently collecting aquatic nuisance species (ANS) while collecting the desired target organisms, and the possibility of damaging habitat while collecting. Questions 3 and 4 deal with these issues specifically.

If no growout will take place after collection, the user is directed to bypass much of the assessment tool. Conversely, if growout of organisms is part of the operation, the user is directed through the entire assessment.

If organisms/gametes originate from outside the basin, operator should be aware of disease restrictions as outlined in the Protocol to Minimize the risk of Introducing Emergency Disease Agents with Importation of Salmonid Fishes from Enzootic Areas (Horner et al., 1993). To keep abreast of new disease restrictions, users should also contact the Great Lakes Fish Health Committee at: www.glfc.org/staff/health.htm .

If answer to this question is unknown, consult with operator.

Question 3.

Infested waters, or waters that have been found to contain aquatic nuisance species may be unsuitable for collection or harvesting of organisms. Determine first if the responsible government agency considers the water body to be infested. Some states prohibit the collection of organisms from infested waters (e.g. Minnesota State Statute 84D.11 Subd.2a).

Aquatic nuisance species may occur in the waters or substrate from which the target organism is collected or located on the collected target organism (e.g. parasite). These species can be collected and inadvertently sold with the desired baitfish. In a study by of baitfish purchased from 21 North Dakota and Minnesota dealers, 28% of the 21 samples contained a nonbait species (Ludwig et al., 1996). In a Toronto survey by Litvak et al. (1993), 6 species of illegal baitfish were identified in holding tanks of 4 dealerships.

The Great Lakes has many known aquatic nuisance species. Because live bait is harvested from Great Lakes waters, and then shipped to dealers for use in inland regions (Snyder, 1997), caution must be taken to minimize the spread of an accidentally harvested aquatic nuisance species. Indeed, bait bucket transfer and the release of unused bait after fishing is considered to be a major vector for the introduction of non-native species. Litvik et al. (1993) found that 41% of anglers interviewed would release extra, unused bait. Hence, prevention of these unwanted organisms should begin before they reach the anglers' live wells.

Additional information regarding Great Lakes aquatic nuisance species can be found on the Great Lakes Information Network at:
http://www.great-lakes.net/envt/exotic/exotic.html.

If answer to this question is unknown, encourage local natural resource agency to determine if body of water at issue is free from aquatic nuisance species. When the answer is unknown, it is recommended that the user take the precautionary approach and answer yes.

Question 4.

Harvesting wild organisms may have an impact on the ecosystem where collection takes place. Litvak et al. (1993) review possible effects of baitfish harvesting and consider population alteration, trophic alteration and habitat alteration. Population alteration may occur if forage fish are harvested without consideration of sustainable yields. For example, in Wisconsin, Vives (1990) observed that the horneyhead chub, *Nocomis biguttus*, is a keystone species. This is because the chubs' nests are used as spawning substrate by other cyprinids. Trophic alteration may occur if species dependent on the harvested organisms must shift to alternative prey species. Habitat alteration may occur if harvesting uproots vegetation and destroys cover for small or juvenile fish or if waterfowl breeding sites are disturbed.(Litvak et al., 1993).

Habitat damage due to the collection method may occur depending on the vulnerability of the specific environment and the type of equipment used. Factors to consider include but are not limited to: vulnerability of other organisms, type of substrate, vegetation, time period or season of collection and frequency of collection.

If answer to this question is unknown, take the precautionary approach and answer yes.

Question 5.

If growout (i.e., continued rearing) of organisms is included in the operator's plan, the user will be guided through the rest of the assessment. If operator plans to only hold and not feed organisms until they reach market, the user may bypass most of the assessment and go Section X., Impacts of Facility and Infrastructure, in order to assess the holding facility.

If answer to this question is unknown, consult with operator.

Question 6.

This question is aimed at those operations that exist within one of the Great Lakes, any connecting bodies of water, or any tributary of the Great Lakes excluding those that flow out of the Great Lakes, such as the Chicago Sanitary and Ship Canal. Aquaculture facilities of this kind are generally net cages that utilize the surface water of these water bodies and have direct water flow into and out of the cages or other rearing units.

If answer to this question is unknown, consult with operator.

Question 7.

An aquaculture facility located on land may still have effluents that reach a Great Lake, a connecting water body of a Great Lake or a tributary of a Great Lake. If this is the case, it is possible that the cultured organisms or pathogens may ultimately reach the Great Lakes. Even if there is no direct link to these water bodies, consideration should be given to levels of different flood events (e.g. 50 year flood events). If there is a high probability that the proposed aquaculture facility will be flooded, users should answer yes to this question. If the probability is low, the user should go to the Land-based Aquaculture Assessment (under construction).

If answer to this question is unknown, consult with flood level data.

Question 8.

A new introduction includes any species that does not (to the best of our knowledge) exist currently in the Great Lakes. To best determine this, go to Appendix 2, Checklist of the Extant, Established Fishes of the Great Lakes (Crossman and Cudmore, in press). If the proposed cultured species is not listed, the user should answer yes to this question.

If answer to this question is unknown, go to Appendix 2, Checklist of the Extant, Established Fishes of the Great Lakes (Crossman and Cudmore, in press).

Question 9.

The province of Ontario and each of the eight Great Lakes States has an approved species list. The linked approved lists are valid as of 1999. For a current approved list consult with the managing agencies.
Ontario (http://www.mnr.gov.on.ca/MNR/),
Michigan (http://www.dnr.state.mi.us/),
Wisconsin (http://www.dnr.state.wi.us/),
Minnesota (http://www.dnr.state.mn.us/fish_and_wildlife/fishsec.html),
New York, (http://www.dec.state.ny.us/index.html)
Illinois (http://dnr.state.il.us/),
Indiana (http://www.state.in.us/dnr/index.html),
Pennsylvania (http://www.state.pa.us/PA_Exec/Fish_Boat/mpag1.htm)
Ohio (http://www.dnr.ohio.gov/)
(Note: As of this printing, approved species lists are not known for Native American and First Nations tribal agencies. Consult with the Great Lakes Indian Fish and Wildlife Commission (http://www.glifwc.org/for) and Chippewa/Ottawa Treaty Fishery Management Authority (COTFMA) (http://home.northernway.net/~qitfap/) for more information.

If answer to this question is unknown, consult with agencies listed above.

Hazard 1.

Because aquatic nuisance species (ANS) are present in the collecting waters, measures must be taken to reduce the risk of transferring these ANS to other bodies of water that may not contain them. Although this task may be extremely difficult, it is possible, by means of inspecting collected organisms, to reduce this risk. The principles in the Hazard Analysis and Critical Control Point (HAACP) method (http://vm.cfsan.fda.gov/~lrd/bghaccp.html), developed by the Food and Drug Administration to identify and control the introduction of pathogens in food processing may be an appropriate model. Of its seven principles, four are directly relevant.

A modification of the HACCP method for the collecting of organisms, would be:

- **Analyze hazards.** Determine the specific aquatic nuisance species that are present in the collecting area.

- **Identify critical control points.** These are points in the collecting process and holding period. When it is feasible, identify and remove non-target organisms and known aquatic nuisance species.

- **Establish procedures to monitor the critical control points.** These procedures identify how and who should monitor critical control points. Examples include visual inspection and water changes.

- **Establish effective record keeping.** This would include records of hazards and their control methods, and action taken to correct potential problems. If operator is unwilling to do this, the area at issue may be unsuitable for collection of organism.

Note: As HACCP guidelines are developed for baitfish, revise this section and include link if appropriate.

Hazard 2.

Degrees of impact to the collection area depend on the type of harvesting equipment used. For instance, seining, which involves dragging the net along the bottom may have a greater impact than the use of traps. If the area is particularly vulnerable to the collecting activity, the operator should identify ways to minimize disturbance to the area.

Hazard 3.

Because the proposed culture species constitutes an introduction into the Great Lakes, the user must refer to Appendix 1, the Council of Lake Committee's Procedures for consultation for Introductions in the Great Lakes Basin (1992). This is currently under revision.

Section II
Assessment of Suitable Environment

Question 10.

The environmental conditions of the surrounding aquatic ecosystem should be one of the most important considerations when evaluating a location for a lake-based aquaculture facility. Fish reared in cages are directly exposed to water from the ambient environment so there is no easy way of manipulating the water quality to favor the requirements of cultured organisms. Temperature, dissolved gasses and pH are examples of factors that must be considered. Additional water quality criteria can be found in Wedemeyer (1997), however, these are general requirements. Optimal conditions are species-specific and should be known before much effort is put into a proposal to site the aquaculture facility in the Great Lakes basin.

Sub-optimal conditions may result in a stress response by the cultured organisms. Stress can be defined as a set of physiological events that result from biotic or abiotic challenges or forces that extend the homeostatic forces of an animal beyond its ability to control normal physiological function (Barton et al., 1991). A stimulus (the stressor) such as sub-optimal temperature or dissolved oxygen can result in a stress response, initially an adaptive response to adjust to the stressor. These primary stress responses include the release of hormones in the circulatory system. If the stressor is prolonged, the animal exhibits secondary, mal-adaptive stress responses that compromise its biological functions. These include, for example, increases in ion and water fluxes, heart rate and output, respiration rate and glycogen to glucose metabolism in the liver (Barton et al., 1991), all secondary responses that require additional energy input. If the organism cannot move to more optimal environmental conditions, tertiary stress responses occur. These affect the whole body's function and health and include decreased growth and reproductive potential, increased disease susceptibility and, finally, mortality (Alabaster et al., 1980; Pickering, 1981; Anderson, 1990; Schreck, 1990). For a thorough review of stress responses of cultured fish, see Pickering (1998).

Users should also consider other sub-optimal conditions such as seasonal runoff leading to a high concentration of non-point source contaminants. Possible sources include agricultural or marina runoff (Huguenin, 1997). Prior uses of the proposed site should also be known. The Great Lakes have an extensive history of iron and steel, pulp and paper, and chemical manufacturing. Industrial toxicants that are bound to sediments may inadvertently be released as sediment chemistry changes from excess food and feces build up which can create anoxic benthic areas (Refer to Section VII, Settleable Solids).

If the answer to this question is unknown, a detailed compilation of temperature requirement for Great Lakes fishes is given by Wismer and Christie (1987). Wind, wave, temperature and Great Lakes bathymetry maps are available from the Great Lakes Forcasting System on the Web at http://superior.eng.ohio-state.edu.

Question 11.

Currents must be fast enough for dispersion of aquaculture wastes, while slow enough so that cultured fish are able to retrieve food before it is drawn out of the cage or other rearing unit. Privolev (1975) determined that currents in excess of 20 cm/s inside cages resulted in adversely decreased growth and survival. Additionally, if currents are too fast, energy stores intended for growth may be spent on excessive swimming. Beveridge (1996) recommends that currents at the cage sites not exceed 60 cm/s to avoid deformation of nets, and excessive strain on moorings and cage collars.

Wave heights and ice may put excess stress on the containment facility resulting in (1) possible damage to the rearing units themselves, (2) potential for organisms to escape, or (3) putting facility employees at risk.

If answer to this question is unknown, consult Great Lakes-St. Lawrence Hydrology information at http://www.great-lakes.net/envt/water/hydro.html. A detailed compilation of temperature requirements for Great Lakes fishes is given by Wismer and Christie (1987). Wind, wave, temperature and Great Lakes bathymetry maps are available from the Great Lakes Forecasting System on the Web at http://superior.eng.ohio-state.edu. For cage culture design and considerations refer to Huguenin (1997).

Hazard 4.

A hazard to cultured organisms due to sub-optimal water quality conditions has been identified. If cultured organisms are forced to alter physiological functioning in order to compensate for these conditions over a prolonged period, decreased growth and increased susceptibility to disease and mortality may occur (see discussion in Question 10 supporting text). And the rearing of diseased organisms increases the risk of the disease spreading to wild populations in surrounding waters (especially since feed attracts wild organisms). For example, it is suspected that Infectious Salmon Anemia was recently transmitted from cage-cultured to wild Atlantic salmon in New Brunswick (Atlantic Salmon Federation, 1999). Unless the technology of the cage culture operation permits the manipulation of environmental conditions such that the rearing water meets the requirements of the cultured organisms, the proposed facility should be moved to an area with better water quality for culture.

Hazard 5.

A hazard to cultured organisms due to hydrological effects such as excessive current speed, wave height or ice has been identified. Historical hydrological data should be known for the proposed site, including storms such as 25, 50 or 100-year storms (Huguenin, 1997). The structural integrity of the facility should be appropriate for maximum storms to minimize the risk of structural damage and escape of organisms. The more exposed a facility is, the more vulnerable it is to a damaging storm, therefore the structural integrity of the facility must be greater for facilities in exposed areas. Submersible rearing cages are apparently under development (Huguenin, 1997). These would have the advantage of being lowered so that damage from waves would be minimal.

There are distinct tradeoffs between locations of the proposed facility that optimize maintenance of the structural integrity of the facility versus the overall health of the cultured organisms. On one hand, areas that are closer to shore have the advantage of protection from violent storms and can operate with less expensive structural equipment. These areas can also have the disadvantage of greater water quality fluctuations and thus expose cultured organisms to greater environmental variability. On the other hand, water quality fluctuations occur less in more open water, however hydrological conditions are more extreme, thus costs for stronger, more durable facilities will be greater. For an excellent review of cage culture design and considerations, refer to Huguenin (1997).

Section III.
Effects on Other Lake Users

Question 12.

The protection and preservation of Native American or First Nations sacred or culturally significant areas are at issue here. Consideration should be given to possible interference to sites where social or ceremonial activities take place. In addition, traditional hunting, gathering and fishing sites should remain unimpaired by aquaculture facilities infrastructure and their operations.

United States statutes that may be relevant include: National Historic Preservation Act of 1966, Archeological and Historic Preservation Act of 1974, National Environmental Policy Act of 1969, Archeological Resources Protection Act of 1979, American Indian Religious Freedom Act of 1979 and Native American Religious Freedom Act of 1978. To assist in identifying culturally significant areas, contact individual tribes, Chippewa/Ottawa Treaty Fishery Management Authority (COTFMA) at http://home.northernway.net/~qitfap/ and the Great Lakes Indian Fish and Wildlife Commission (GLFWC) at http://www.glifwc.org/default.htm. In the United States, contact the Tribal Historic Preservation Officers of the Advisory Council on Historic Preservation. Contact names and addresses for the United States are listed on the Web at http://www.achp.gov/thpo.html . In Canada, the Ontario Native Affairs Secretariat can be located on the Web at http://www.nativeaffairs.jus.gov.on.ca.

If answer to this question is unknown, refer to the contacts mentioned above.

Question 13.

To preserve the heritage of historically significant sites and structures, both Canada and the United States have promulgated preservation acts. In Canada, the Ontario Heritage Act, R.S.O. 1990, c.0.18 gives municipalities and the provincial government power to protect archaeological sites and heritage buildings. For more information, contact the Ontario Ministry of Citizenship, Culture and Recreation at http://www.gov.on.ca/MCZCR/. Additionally, users should also be aware of a new planning initiative in Ontario called the Great Lakes Heritage Coast Project (www.mnr.gov.on.ca/MNR/csb/news/jan27cfs00.html).

Historic properties are protected in the United States under the National Historic Preservation Act of 1966, National Environmental Policy Act of 1969, Archeological and Historic Preservation Act of 1974 and the Archeological Resources Protection Act of 1979. Listings for historical preservation status in the National Register Information System must meet criteria listed in 36 CFR Part 60 which is administered and maintained by the National Park Service. The National Register Information System database may be accessed at http://www.nr.nps.gov. For further assistance access the Advisory Council on Historic Preservation at http://www.achp.gov.

Information regarding identification of Great Lakes shipwrecks may be found on the State Underwater Archeologist Historic Preservation Division at www.seagrant.wisc.edu/shipwrecks.
Additional information can be found on the Great Lakes Information Network Historic Sites and Battlefields in the Great Lakes Region at http://www.great-lakes.net/tourism/historic.html.

If answer to this question is unknown, refer to the contacts mentioned above.

Question 14.

To prevent unauthorized obstruction or alteration of any navigable use of United States waters, the operator must obtain a permit from the United States Army Corp of Engineers. The criteria used when an application is evaluated include: (1) the relevant extent of public and private needs; (2) where unresolved conflicts of resource use exist, the practicability of using reasonable alternative locations and methods to accomplish project purposes; and (3) the extent and permanence of the beneficial or detrimental effects the proposed project may have on public and private uses to which the area is suited. See the U.S. Army Corps of Engineers Regulatory Program Overview 1998 http://www.usace.army.mil/inet/functions/cw/cecwo/reg/oceover.htm . Contact names and addresses of U.S. Army Corps of Engineers District Regulatory Offices can be found at http://www.usace.army.mil/inet/functions/cw/cecwo/reg/district.htm . Regulatory regulations for navigation and navigable waters can be found at http://www.lre.usace.army.mil/regu/html/regs/33cfr.html .

Under the Navigable Waters Protection Act (NWPA), Revised Statutes of Canada, 1985, the Canadian Coast Guard is responsible for impediments to navigation in Canadian waters. In the event that there may be a significant impact to navigable waters, formal approval must be given. If there is no significant impact, work assessment letters can be issued. The Fisheries and Oceans Canada Coast Guard website is: http://199.60.85.201/epages/NAVWAT/NAVWAT.HTM.

If answer to this question is unknown, refer to the contacts mentioned above.

Question 15.

To ensure that the neighboring community accepts the proposed facility, thus avoiding repercussions once the facility is built, other lake users should be identified and solicited to comment on the facility proposal. Berris (1997) in a report issued for the British Columbia Salmon Aquaculture Review noted that residents in the vicinity of salmon net cage operations are most concerned with smell, noise, aesthetics, impaired water and air quality, and garbage.
A comment period will be necessary if other users are likely to be affected by a new aquaculture facility. In the United States, it is possible that the Army Corps of Engineers would require an Environmental Impact Statement in which case public involvement in the form of a public notice and a public hearing will be required.

If answer to this question is unknown, consider local residents and businesses in proposed site area.

Question 16

The Coastal Zone Management Act of 1972 established a policy to "preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations" and to "encourage and assist the states to exercise effectively their responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the land and water resources of the coastal zone giving full consideration to ecological, cultural, historic, and esthetic values as well as the needs for compatible economic development." [16 USC § 1452]. Currently, seven of the eight Great Lakes States (Minnesota, Michigan, New York, Ohio, Pennsylvania, and Wisconsin. Indiana) and have approved or are in the process of approving state coastal management programs. (http://www.ocrm.nos.noaa.gov/).

If answer to this question is unknown, refer to http://www4.law.cornell.edu/uscode/16/1451.html and responsible managing agency.

Hazard 6.

A hazard to a Native American or First Nations culturally significant area due to proximity of the proposed aquaculture facility has been identified. Consultation with appropriate Native American or First Nations agencies is necessary to determine the degree of risk to the area. If the degree of risk has been determined to be unacceptable, determine first if lower production could lessen the risk to acceptable levels. If not, relocation of the proposed facility will be necessary. If the risk is accepted, a monitoring plan should be included to ensure minimal impact to area.

Hazard 7.

A hazard to a historically significant area due to proximity of the proposed aquaculture facility has been identified. Consultation with appropriate historical agencies is necessary to determine the degree of risk to the area. If the degree of risk has been determined to be unacceptable, determine first if lower production could lessen the risk to an acceptable level. If not, relocation of the proposed facility will be necessary. If the risk is accepted, a monitoring plan should be included to ensure minimal impact to area.

Hazard 8.

No additional text.

Hazard 9.

A hazard to other lake users due to proximity of proposed aquaculture facility has been identified. The responsible government agency should coordinate a commenting period to solicit input from all potentially affected users. If comments are unfavorable, meetings with opposing parties should be held. If there is no resolution, relocation of the proposed facility will be necessary.

Terminal Point 4.

No additional text.

Section IV
Disease Effects

Question 17.

Disease control in the Great Lakes is essential for both cultured organisms and wild stocks. Due to the nature of culture conditions that are potentially stressful (refer to supporting text for Section II, Suitable Environment, question 10), the likelihood of a disease epidemic is greater than for wild fish because of a pathogen's ease of transmission in water from fish to fish. For example, Kingsbury (1961) found a correlation between furunculosis outbreaks and specific environmental conditions such as water temperature above 10º C, dissolved oxygen levels below 5.5-6.0 mg/l, handling for size and transportation, and excessive crowding.

Disease transmission has not only occurred within a single net cage operation, but has spread to neighboring facilities as well. This has been observed in countries that have well established cage culture facilities. For instance in 1985, furunculosis was found in Norwegian cage cultured Atlantic salmon after receiving smolts imported from Scotland. The disease was verified in 16 farms in Central Norway by the end of 1985 and, by 1991, 507 farms had been affected (Heggberget et al., 1993).

The Great Lakes Fish Health Committee of the Great Lakes Fishery Commission developed a Control Policy and Model Program (Hnath, 1993) in order to minimize the degree to which disease agents enter the Great Lakes. This document provides detailed inspection procedures and methods of diagnosis that a certified fish health specialist should follow. Note that this model program is currently under revision.
For information on the revised document, contact John Hnath at Hnathj@state.mi.us .
If answer to this question is unknown, consult with operator.

Question 18.

As defined by the Great Lakes Fish Disease Control Policy and Model Program, Annex IV, hatchery classifications are (Hnath, 1993):

Class A-1

The A-1 classification is assigned to those fish hatcheries meeting the following criteria:
1) All fish cultural water must be obtained from enclosed sources such as springs or wells that are free of fish.
2) Samples of all fish lots reared at the station must have been inspected (at least annually) as described in Annex VI (Inspection Procedures and Methods of Diagnosis) for all pathogens listed in Annex II (List of Disease Agents covered by the Model Program). Three successive, negative, inspections over a continuous two-year period are required.
3) To maintain A-1 status, hatcheries must assure that all fish (includes eggs) have been obtained only from properly inspected Class A-1 or A-2 sources.

Class A-2

The A-2 classification differs from A-1 only when the hatchery has an open water supply (such as a stream or lake) with resident fish. The A-2 classification is also assigned to discrete spawning populations of free-ranging fish that have met all other Class A-1 inspection requirements.

Class B

Hatchery and free-ranging spawning populations are assigned a B classification

when one or more of the pathogens listed in Annex II (List of Disease Agents covered by the Model Program) were found within the past two years.

Class C

Hatchery and free-ranging spawning populations that have an unknown

disease history, have not been inspected for all listed pathogens, or have undergone only one or two complete, annual inspections will be assigned a C classification.

If answer to this question is unknown, consult with operator.

Question 19.

The Chicago Sanitary and Ship Canal, a diversion that flows *out* of Lake Michigan, does not constitute a tributary of the Great Lakes. This diversion links Lake Michigan to the Illinois Waterway, the Des Plaines River and the Mississippi River (Manninen et al., 1999). Only those stocks that come from a Great Lake or a tributary flowing *into* a Great Lake should answer yes to this question.

If answer to this question is unknown, consult with operator.

Question 20.

Wild Fish Health Surveys are currently being conducted by the US Fish and Wildlife Service in partnership with individual states. These surveys will investigate all major watersheds throughout the United States and identify existing fish species, pathogens, number of sites, GPS coordinates and season/time of fish and pathogen collections.

A database is currently being set up on the Internet that will enable users to download information (http://wildfishsurvey.fws.gov). Comparable Canadian Data should be considered where available.

If answer to this question is unknown, consult Richard Nelson, Director, Lacrosse Fish Health Center, at 608-783-8441 for more information.

Question 21.

Currently (1999) the Great Lakes Fish Disease Control Policy and Model Program lists Emergency Fish Diseases which are caused by pathogens not yet detected within waters of the Great Lakes basin and Restricted Fish Diseases that are caused by pathogens which are enzootic within the Great Lakes basin but limited in range.

Emergency Diseases include:
Viral hemorrhagic septicemia (VHS)
Infectious hematopoietic necrosis (IHN)
Ceratomyxosis (CS)
Proliferative kidney disease (PKD)

Restricted Diseases include:
Whirling disease (WD)
Infectious pancreatic necrosis (IPN)
Bacterial kidney disease (BKD)
Furunculosis (BF)
Enteric redmouth (ERM)
Epizootic epitheliotropic disease (EED)

If answer to this question is unknown, consult the fish health specialist that examined broodstock/production stock. For a review of relevant Great Lakes diseases see Meyer et al.(1983).

Question 22.

Some breeding programs have been developed to enhance resistance to disease. For example, Kaastrup et al. (1991) developed Viral Hemorrhagic Septicemia resistance in some strains of rainbow trout (Plumb, 1994). Selecting fish that exhibit reduced corticosteroids elevations in response to culture-related stressors (see discussion on stress in Section II, Suitable Environment, question 10), may be one answer in selecting for disease resistance (Barton et al., 1991). It should be noted however that selecting for a reduction in capacity to respond to stress may be beneficial for organisms reared in a containment facility but not for those organisms that will ultimately be stocked in open waters (Barton et al., 1991).

If answer to this question is unknown, consult operator or broodstock manager otherwise take a precautionary approach and answer no.

Question 23.

It is now possible to vaccinate fish for a number of bacterial diseases, particularly those that affect salmonids (Beveridge, 1996). Prevention prior to an outbreak may be more economical than treatment once an outbreak has occurred. The alternatives include treating fish with antibiotics or destroying all fish and starting over with disease-free stock (Souter, 1983). Because antibiotics are often administered through feed, and sick fish often go off feed, there exists the possibility that excess food could 1)cause a buildup of settleable solids on benthic communities (see Section VII, Settleable Solids for further discussion), 2) allow wild populations of fish and shellfish to consume feed containing antibiotics (Samuelson et al., 1992), or 3) develop bacterial populations that become resistant to antibiotics (Pillay, 1992).
Further information regarding vaccines can be found in the Guide to Drug, Vaccine and Pesticide Use in Aquaculture (Federal Joint Subcommittee on Aquaculture, 1994) and can be found on the Web at:
http://ag.ansc.purdue.edu/aquanic/publicat/govagen/usda/gdvp.htm or contact the Great Lakes Fish Health Committee.

If answer to this question is unknown, answer no.

Question 24.

Consult with operator.

If answer to this question is unknown, answer no.

Question 25.

The complex relationships between host, pathogen and environment are not well known. A common thread however is stress. If an organism’s ability to maintain homeostasis is compromised by conditions such as temperature, dissolved gasses and current speeds that are sub-optimal for the specific species, mal-adaptive stress responses will result as the fish expends energy to compensate for the condition. Long-term or tertiary stress responses include decreased immunocompetence and can result in the organism succumbing to disease. There is an increased risk to cultured organisms if conditions are sub-optimal, and they are reared in waters that have had positively identified diseased fish.

If answer to this question is unknown, refer to Section II, Assessment of Suitable Environment, question 10.

Hazard 10.

No additional text.

Hazard 11.

No additional text.

Hazard 12.

A hazard to cultured organisms has been identified due to potential exposure to disease agents and suboptimal conditions. In addition, it is either not feasible to vaccinate fish or the operator is unwilling to vaccinate. These combined conditions increase the likelihood of cultured organisms succumbing to disease and possibly enhancing exposure to wild populations. Alternative recommendations include relocating facility to more optimal conditions or rearing organisms in a land-based facility.

Terminal Point 5.

A fish health specialist must examine broodstock/production stock. A list of Great Lakes fish health contacts may be accessed on the web at http://www.glfc.org.naol95.htm.

Terminal Point 6.

Class C fish from sources other than the Great Lakes or a Great Lakes tributary pose an unnecessary hazard to native or naturalized Great Lakes species. Transporting diseased fish encourages spread of the disease by exposing organisms in recipient waters to pathogens to which they are poorly or not well adapted. Thus these new pathogen-host relationships may result in detrimental effects to the host (Hindar et al., 1995).
The proposed culture organisms should not be reared in a Great Lake, unless they have followed the procedures outlined in the Protocol to Minimize the Risk of Introducing Emergency Disease Agents with Importation of Salmonid Fishes from Enzootic Areas (Horner et al., 1993). Many of these procedures may apply to non-salmonid fishes, but users should consult a fish health specialist for guidance.

Alternatively, these organisms should be reared in a secured, land-based facility that prevents organisms and effluent form reaching external water bodies.

Section V.

Impacts on Recovery or Rehabilitation Plans

Question 26.

Habitat preservation is critical in the recovery of species at risk. The United States Endangered Species Act (ESA) of 1973 (http://endangered.fws.gov/esa.html) states that "the purposes of this Act are to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved…" To identify habitat necessary for recovery, the Act requires determination and designation of critical habitat for listed species unless it is determined 1) that it would not be prudent for the species (for example, if the identification of critical habitat for an endangered species would increase the risk for that species to be taken or threatened by human activity); or 2) it is not determinable due to insufficient information. Unfortunately, as of August 1999, of the 1179 federally listed species, only 113 species have designated critical habitat (64 Federal Register 31871).

In the United States, federal species at risk in the Great Lakes basin are managed by Region 3 and Region 5 of the U.S. Fish and Wildlife Service (USFWS). (Contacts can be found at http://endangered.fws.gov/contacts.html.)

Region 3, the Great Lakes-Big Rivers Region, includes: Illinois (25 federally listed species), Indiana (24 federally listed species) , Michigan (21 federally listed species), Minnesota (12 federally listed species), Ohio (22 federally listed species), and Wisconsin (15 federally listed species). http://endangered.fws.gov/statl-r3.html.

Region 5, the Northeast Region includes: New York (15 federally listed species) and Pennsylvania (16 federally listed species). http://endangered.fws.gov/statl-r5.html.

The above include both terrestrial and aquatic species. In addition to federally listed species, each jurisdiction has its own state listed species at risk. Therefore, consultation with both the USFWS and state managing agencies should take place to identify if possible critical habitat may be affected by either the proposed aquaculture facility's infrastructure or by a large accidental release of cultured organisms.

In Canada, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (http://www.cosewic.gc.ca/) evaluates and designates the status of species considered to be at risk (currently 150 species have been listed for Ontario). The Committee on the Status of Species at Risk in Ontario (COSSARO), the provincial committee that evaluates and makes recommendations for at risk species is also a member of COSEWIC. Range maps, legal and management measures, overviews of biological traits and other important information for the endangered or threatened species of Ontario can be accessed by the Species at Risk Module, jointly assembled by the Royal Ontario Museum (ROM) and the Ontario Ministry of Natural Resources at http://www.rom.on.ca/ontario/risk.html.

If answer to this question is unknown, contact the agencies mentioned above. A formal risk assessment may be necessary.

Question 27.

In accordance with the Joint Strategic Plan for Management of Great Lakes Fisheries (Great Lakes Fishery Commission, 1997) (http://www.glfc.org/fishmgmt/sglfmp97.htm), fish community objectives are prepared by individual Lake Committees every 5 years. Management objectives for individual species, community and habitat plans are included. These can be found through the Great Lakes Fishery Commission Publications website at http://www.glfc.org/pubs/pub.htm#pubs . In addition, state and provincial agencies also have recovery plans.

If answer to this question is unknown, refer to documents mentioned above and consult with individual Lake Committees. Refer also to Section VII, Effects of Settleable Solids, Section VIII, Impacts on Breeding Areas, Section X, Impacts on Facility Infrastructure, and Section XI, Genetics when assessing potential impact to recovery or rehabilitation plans.

Hazard 13.

No additional supporting text.

Hazard 14.

No additional supporting text.

Section VI.

Impacts on Area of Concern
Question 28.

The scale of the zone of influence depends on the environmental effect at issue. For instance, a reduction in currents due to the physical structure of the aquaculture facility may pose adverse effects on spawning populations if the facility is located nearby spawning grounds. In this case, the zone of influence is relatively small. Pollution from the aquaculture facility may be close enough to spread to spawning grounds. In this case, the zone of influence is larger. In the event of organisms escaping from the aquaculture facility, and because of their ability to disperse easily, the zone of influence can be very large.

At issue are severely degraded geographic areas in the Great Lakes basin called Areas of Concern (AOCs). These areas have been defined by the Great Lakes Water Quality Agreement as geographic areas that fail to meet the general or specific objectives of the agreement where such failure has caused or is likely to cause impairment of beneficial use of the area's ability to support aquatic life (Annex 2 of the 1987 Protocol, http://www.ijc.org/agree/quality.html#ann2). An impaired beneficial use means a change in the chemical, physical or biological integrity of the Great Lakes system sufficient to cause any of the following:

- restrictions on fish and wildlife consumption
- tainting of fish and wildlife flavor
- degradation of fish wildlife populations
- fish tumors or other deformities
- bird or animal deformities or reproduction problems
- degradation of benthos
- restrictions on dredging activities
- eutrophication or undesirable algae
- restrictions on drinking water consumption, or taste and odor problems
- beach closings
- degradation of aesthetics
- added costs to agriculture or industry
- degradation of phytoplankton and zooplankton populations
- loss of fish and wildlife habitat

43 sites (Figure 2.) have been identified and Remedial Action Plans (RAPs) have been developed for each. Aquaculture facilities within a zone of influence may adversely affect recovery plans for a given Area of Concern.

Figure 2.

Environment Canada http://www.cciw.ca/glimr/raps/aoc-map-large.html

General information about AOCs can be found at http://www.great-lakes.net/places/aoc/aoc.html .Details including background, updates and contacts of each AOC can be located at: http://www.cciw.ca/glimr/raps/aoc-map.html

Note: In addition to Areas of Concern, Aquatic Biodiversity Inveestment Areas should also be considered. These are currently defined as “a specific location or area within a larger ecosystem that is especially productive, supports exceptionally high biodiversity and/or endemism and contributes significantly to the integrity of the whole ecosystem” (Koonce, et al., 1999). Presently, 168 sites within the Great Lakes basin have been identified with 49% of those sites identified as supporting ‘high biodiversity’ and 39 of the sites are located within IJC designated Areas of Concern (Koonce, et al., 1999).

If answer to the question is unknown, refer to map and web sites mentioned above.

Question 29.

Each Area of Concern has specific use impairments, which are identified at http://www.cciw.ca/glimr/raps/aoc-map.html. If an AOC has identified (1) loss of fish and wildlife habitat, (2) degradation of fish wildlife populations or (3) bird or animal deformities or reproduction problems, then answer of yes and initiate discussion between the AOC contact person(s) to identify possible adverse effects the aquaculture facility may have on recovering populations.

If answer to this question is unknown, information about specific areas of concern can be found on the Web at http://www.cciw.ca/glimr/raps/aoc-map.html.

Question 30.

If answer to this question is unknown, information about specific areas of concern can be found on the Web at http://www.cciw.ca/glimr/raps/aoc-map.html

Question 31.

It is difficult to determine the extent to which escaped organisms, will interact with and affect wild species. For a more extensive discussion, refer to Section III, Genetic Effects and Section VIII, Impacts on Breeding Areas, Nurseries and Fish-eating Animals. To answer no to this question, the user needs to have supporting evidence.

If answer to this question is unknown, refer to the sections mentioned above.

Question 32.

In addition to, and coordination with designated Areas of Concern are Lakewide Management Plans (LaMPs), developed for each of the Great Lakes as mandated by the Great Lakes Water Quality Agreement (revised 1987) (http://www.ijc.org/agree/quality.html). The purposes of these plans are to assess critical pollutants, set load reduction targets and develop remedial measures. For further information, refer to the following Lakewide Management Plans:

Lake Ontario (http://www.epa.gov/glnpo/lakeont/).
Lake Erie (http://chagrin.epa.ohio.gov/ohiolamp/)
Lake Michigan (http://www.lkmichiganforum.org/lkintro.html)
Lake Superior (http://www.epa.gov/grtlakes/lakesuperior/stage2lamp.html)

If answer to this question is unknown, information about specific areas of concern can be found on the Web at http://www.cciw.ca/glimr/raps/aoc-map.html

Question 33.

Refer to supporting text for Question 32.

If answer to this question is unknown, information about specific areas of concern can be found on the Web at http://www.cciw.ca/glimr/raps/aoc-map.html

Question 34.

Refer to supporting text for Question 32.

If answer to this question is unknown, information about specific areas of concern can be found on the Web at http://www.cciw.ca/glimr/raps/aoc-map.html

Hazard 15.

Fish-eating birds and mammals tend to be attracted to aquaculture facilities (Draulans, 1987; Stickley, 1990; Williams, 1992; APHIS, 1997; Littauer et al., 1997). In order to minimize this interaction between the aquaculture facility and piscivores, and subsequent harassment (or death) of these predators, the best response would be to relocate the facility to an area that would reduce these interactions. At the very least, protective, secure predator measures should be identified. Refer to supporting text for Section VIII, Impacts on Breeding Areas, Nurseries and Fish-eating Animals, Question 45.

Hazard 16.

No additional supporting text.

Hazard 17.

Refer to supporting text in Section VII, Effects of Settleable Solids on Benthos and Shellfish, Question 36.

Hazard 18.

Aquaculture effluent poses a hazard to recovery plans. Refer to the supporting text for Section IX, Cumulative Impacts, Question 48. A mass balance approach may be necessary. In a mass balance approach (as defined in the Lake Superior Lakewide Management Plan (http://www.epa.gov/grtlakes/lakesuperior/stage2lamp.html):

> The amount of contaminants entering the system, minus the amount stored, transformed, or degraded within the system, must equal the amount leaving the system. In its simplest form, the equation can be made by measuring these quantities at the various points where they enter and leave the system and the amount stored or changed in the system's compartments—the sediment, water,

and biota (such as fish and algae). If the resulting equation is balanced, it is a quantitative description of the movement of the contaminant through the system. If the result is unbalanced, it indicates more must be learned about the system's physical processes, or more accurate measurements are required. As a management tool, the mass balance approach is used to prioritize and allocate resources for research, remedial action, and regulatory efforts. This depends on the ability to predict the impacts of management actions on the compartments, such as the levels of contaminants in fish tissue. Mathematical calculations provide the tools for making such predictions.

For additional information and risk management recommendations, refer to the supporting text for Section IX, Water Quality and Cumulative Impacts, Question 47 and Hazard 28.

Hazard 19.

No additional supporting text.

Section VII.
Effects of Settleable Solids on Benthos and Shellfish

Question 35.

This question distinguishes aquaculture facilities physically located within a Great Lake or connecting body between two lakes from those that are using the Lake-based assessment tool because the facility's cultured organisms or effluent may reach a Great Lake.

If answer to this question is unknown, consult with operator regarding location of facility.

Question 36.

If complete collection and containment measures are in place, the user can bypass this section upon providing satisfactory documentation. Note: in some jurisdictions such as Minnesota, all aquaculture facilities *must* collect, remove, treat, and properly dispose of unconsumed fish food and fish wastes (Minnesota Administrative Code 7050.0216). Organic enrichment from aquaculture facilities may result in a change in the macrobenthic community. Changes may include: (1) a decrease in species richness and an increase in total number of individuals as a result of the high densities of a few opportunistic species; (2) a general reduction in biomass, although there may be an increase in biomass corresponding to a dense assemblage of opportunists; (3) a decrease in body size of the average species or individual; (4) a shallowing of that portion of the sediment column occupied by infauna; and (5) shifts in the relative dominance of trophic guilds (Weston, 1990).

Oxygen levels may also change and with this so does the redox potential of the sediment. This is due to the continual deposition of organic waste and an imbalance between supply and consumption of oxygen (Gowen et al., 1992). In one study, 25 m from a fish farm, the boundary between aerobic and anaerobic processes (zero isovolt) occurred at a sediment depth of about 3.5 cm, suggesting that the main metabolic processes in the upper 3.5cm of sediment were aerobic. Below this, the redox potential was negative indicating that anaerobic processes were predominant. Under the net pen containment area, the zero isovolt was close to the sediment surface, which suggested that the entire sediment was anoxic. (Gowen et al.,1992).

The technology for waste containment and collection for net cage operations is quite new. There is some development of "bag technology" that may prove useful in the years to come (Berris, 1997). Instead of the permeable netting of cages, these funnel-shaped bags have solid walls and direct all waste materials to a narrow opening at the bottom. Tractable ways of collecting waste from the opening, in order to prevent its deposition in surrounding waters, are not yet commercially available. As of this writing, this technology is still in an experimental phase.

If answer to this question is unknown, consult with operator to determine waste containment and collection methods that will be taken.

Question 37.

The zone of influence here is the benthic area to be protected from settleable solids. Such solids may build up under an aquaculture facility and cause adverse effects (such as smothering, anoxic conditions, alteration of benthic communities, bacterial mats) to the area. Empirical studies in Puget Sound, Washington have shown that benthos may be affected as far as 150 m from a fish farm (Weston, 1990). It may be possible to determine the horizontal displacement of sedimenting particles from an aquaculture facility. Unfortunately, those models require fairly detailed input information (e.g. geometry of containment areas, current velocity, feed and faecal particle size and constitution, feed and faecal settling speed). For a good overview of models, see Hargrave (1994).

Other jurisdictions outside the Great Lakes region address proximity to sensitive areas in their guidelines for cage culture. Levings et al. (1995), for instance, reported: Washington does not allow aquaculture facilities within 91 m of habitats of special significance (including shellfish beds); Maine does not allow aquaculture facilities within 402 m of critical habitat and; Scotland recommends siting aquaculture facilities at least 3.7 km from shellfish farms.

Non-target organisms such as shellfish may be particularly vulnerable to food and faecal particles from aquaculture facilities. The primary issue here is the uptake of antimicrobials which may ultimately be consumed by humans. Beveridge (1996) cites observations where drugs have been detected in wild fish, crabs and mussels as far as several hundred meters from net cage sites up to two weeks following treatment of cultured organisms. Refer to Question 45 for discussion of additional effects of settleable solids.

If the answer to this question is unknown, assume the zone of influence for harvested shellfish beds is within at least 150 meters. Models such as those found in Silvert (1994) and Gowen et al. (1994) could provide a more accurate estimate of potential benthic impact provided that parameters such as cage configurations, area, depth, current and feed (volume, particle size and displacement) are known.

Question 38.

Water depth is one of the key variables that should be considered in siting aquaculture facilities directly within a water body. The distance between the bottom of the rearing units and the lake substrate must be far enough to allow maximum water exchange (Lawson, 1995) and dispersion of waste particles, especially when currents are low (Beveridge, 1996). If the units are placed too close to the substrate, food and faecal wastes, especially the larger particles, will settle near the units creating excessive levels of sedimentation that could contain high levels of antibiotics if used in feed (See Disease

Assessment supporting text for additional information), smother benthic organisms, alter macrobenthic community structure (Weston, 1990) favoring more pollution tolerant species, change sediment chemistry, create bacterial mats, and possibly create anoxic conditions (Gowen et al., 1992). Recommended depths in the literature vary. They include at least 2-3 m plus the depth of the rearing unit (Lawson 1995), a minimum of 10 m (Laird and Needham, 1988; Sedgewick, 1988) and at least 4-5 m (plus the depth of the containment unit) (Beveridge, 1996).

Other jurisdictions outside the Great Lakes region address water depth in their guidelines for cage-culture. These include Washington, which recommends net-pens have at least a minimum depth of 20 m between the bottom of the pens and the substrate (Levings et al., 1995) and Norway which recommends net pens be sited in at least 20 m of water (Levings et al., 1995).

If answer to this question is unknown, refer to Great Lakes bathymetry maps which are available from the Great Lakes Forcasting System on the Web at: http://superior.eng.ohio-state.edu.

Question 39.

Currents must not only be fast enough for dispersion of aquaculture wastes, they must be slow enough so that fish do not expend excessive energy swimming and are able to retrieve food before it is drawn out of the rearing unit. Current speed and direction are both important variables for determining how quicky material will fall out of suspension (Milne, 1979). Laird and Needham (1988) recommend that net cages be put in currents between 10 and 50 cm/sec.

Other jurisdictions outside the Great Lakes region address current speed in their guidelines for cage culture. Levings et al. (1995) notes that Washington's net-cages should be sited in an area with a minimum average velocity of 5 cm/sec. Ireland recommends that aquaculture facilities not be placed in embayments with low current velocities (<10 cm/sec).

Currents may also pose problems if they are in excess of 60 cm/sec. (Beveridge, 1996). This may result in net deformation, excessive strain on moorings and cage collars. Hazards to the cultured organisms include an increased energy expenditure along with poorer growth and survival. Privolnev (1975) recommended that flow rates *inside* the cages not exceed 20 cm/sec. The flow rate inside the cages will vary depending on variables such as the configuration of the net cages, and the amount of biofouling on the cages (Huguenin, 1997). Refer to the Question 41 supporting text for more information on biofouling.

If answer to this question is unknown, refer to information on Great Lakes currents at http://www.great-lakes.net/envt/water/flows.html

Question 40.

The zone of influence here is the area to be protected from settleable solids. Such solids may build up under an aquaculture facility and cause adverse benthic effects (such as smothering, anoxic conditions, alteration of benthic communities, bacterial mats). It may be possible to determine the horizontal displacement of sedimenting particles from an aquaculture facility. Unfortunately, these models require fairly detailed input information (e.g. geometry of containment areas, current velocity, feed and faecal particle size and constitution, feed and faecal settling speed). A good overview of models is given in Hargrave's Modelling Benthic Impacts of Organic Enrichment from Marine Aquaculture (1994). Generally, coarse particulates fall within 100 m of the net pens (Silvert, 1994), however, bacterial mats from an aquaculture facility in Puget Sound were found 150 m away from the facility.

Other jurisdictions outside the Great Lakes region include the site's distance from other aquaculture facilities in their guidelines. Recommended distances include ≥300 meters in New Brunswick, ≥ 1 km in Ireland, ≥ 8 km in Scotland, ≥ 3 km in British Columbia, and ≥ 2 km in Iceland (Levings et al., 1995)

If answer to this question is unknown, use a precautionary approach and assume settleable solids will be present at least 150 meters from the culture facility. Models such as those found in Silvert (1994) and Gowen et al. (1994) could provide a closer estimate of potential benthic impact provided that parameters such as cage configurations, area, depth, current and feed (volume, particle size and displacement) are known.

Question 41.

Fouling agents such as zebra mussels may have detrimental effects on aquaculture facilities. Fouling of rearing units can restrict water flow and thus deteriorate water quality, particularly dissolved oxygen resulting in increased stress and higher susceptibility to disease and mortality.

If answer to this question is unknown, several maps of zebra mussel distribution are available on the web. An animated map showing their rapid advancement can be found at http://www.nationalatlas.gov/zmussels1.html.

Hazard 20.

Settleable solids (i.e. food and feces) from proposed aquaculture facility pose a hazard to shellfish intended for harvest. Shellfish such as mussels and clams are filter-feeders, and can bioaccumulate pathogens which, upon consumption, can result in illnesses such as hepatitis A and Norwalk-like viruses (Jensen et al., 1997). Shellfish can also filter drug residue-bound particles from treated cultured organisms food and feces (Samuelsen, et al., 1992).

To reduce the amount of settleable solids, consider changes in feed management such as switching to high nutrient dense diets (Bureau et al., 1999) that are highly digestible and nutrient/energy dense. Bioenergetics models such as Fish-PrFEQ developed by Cho et al. (1998) are available as a computer program to assist users in predicting feed efficiency and waste outputs. A trial version can be found on the University of Guelph Fish Nutrition web site at: http://www.uoguelph.ca/fishnutrition/. This tool is currently being developed as a hatchery management tool for the Ontario Ministry of Natural Resources (Sippel et al., 1999).

New methods such as "bag technology" (Berris, 1997) are being tested for waste collection. Water pumped into a bag essentially encloses the culture area separating the cultured organisms from the external environment while allowing for the collection of wastes. These systems are still under development. Other waste collection methods such as those used in Minnesota mine pit lakes included using large funnel nets below net cages. Wastes were then collected and pumped out. Mechanical pump problems and clogging of the net panels prevented the operation from successfully removing wastes from the culture area (Hora, 1999).

A routine waste-monitoring program should also be included in the facility proposal. Underwater video cameras enable operators to observe feeding behavior as well as feed loss. If feed loss remains above the site's assimilative capacity, production volume should be reduced or the site should be relocated.

Hazard 21.

Water depth at this site poses a hazard to benthic organisms. To reduce the amount of settleable solids, consider changes in feed management such as switching to high nutrient dense diets (Bureau et al., 1999) that are highly digestible and nutrient/energy dense. Bioenergetics models such as Fish-PrFEQ developed by Cho et al. (1998) are available as a computer program to assist users in predicting feed efficiency and waste outputs. A trial version can be found on the University of Guelph Fish Nutrition web site at: http://www.uoguelph.ca/fishnutrition/. This tool is currently being developed as a hatchery management tool for the Ontario Ministry of Natural Resources (Sippel et al., 1999).

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Conditions of the benthos should be noted prior to operation production. Routine monitoring of benthic conditions should be implemented once the facility is in operation.

If waste management plans are unsuitable, production volume should be reduced or the proposed facility should be located further away from pre-existing aquaculture facilities.

Hazard 22.

Water current velocity at this site poses a hazard to benthic organisms. Refer to Hazard 21 for risk management measures.

Hazard 23.

An overlap of settleable solids from neighboring aquaculture facilities pose a hazard to benthic organisms. Additional aquaculture facilities at this site can cause an increase in the organic load to the benthic environment which can result in anoxia due to increased biological and chemical oxygen demand, outgassing (denitrification and methanogenesis) from the sediments, a change in sediment redox potential and re-release of previously bound compounds. Refer to Hazard 21 for risk management measures.

Hazard 24.

A hazard to cultured organisms due to aggressive fouling agents has been identified. As this area is known to be a suitable environment for zebra mussels, nets may be particularly vulnerable to colonization. Zebra mussel beds have been known to contain between 30,000 to 70,000 mussels per square meter in Lake Erie (Ohio Sea Grant, 1997). Water with calcium concentrations above 12 mg/L, alkalinity above 50 mg $CaCO_3$/L and pH above 7.2 are considered suitable for adult zebra mussels (Ohio Sea Grant, 1994). Biofouling on nets can cause impediments to water flow through the containment area, thus reducing the degree of water exchange and oxygen available for cultured organisms which can in turn stress or kill cultured organisms.

Net cleaning is part of routine maintenance for cage-culture operations. Additional cleaning of biofouled nets should be expected to maintain a suitable environment therefore, inclusion of methods for cleaning nets should be considered if culture facility is to be located in this area. Factors such as the location of cleaning (e.g., facility site or on land), what cleaning method (e.g. pressure spray, or chemical removal) and net exchange method (rotation or removal) should be considered. Because additional cleaning and handling will increase wear on nets, operator should plan on reduced life expectancy.

Section VIII
Impacts on Breeding Areas, Nurseries and Fish-Eating Animals

Question 42.

Cultured species whose life history traits include migration (e.g. salmon species, steelhead trout), may, upon escape from an aquaculture facility, utilize streams or rivers for spawning. Of concern are impacts on ecologically or economically important organisms that use streams or rivers for one or more life stages.

If unknown, consult primary literature for species at issue. A formal risk assessment may be necessary.

Question 43.

Interactions between cultured and wild organisms have not yet been well documented. Of the scientific literature available, most pertain to the interactions involving escaped Atlantic salmon, a species widely cultured in marine net cages in Norway, Scotland, Chile, and Canada. Table 1, reproduced from Gross (1998), summarizes the observations on the occurrence, survival, behavior and ecology of cultured Atlantic salmon in the wild.

Table 1.

Character	**Observation**	**Reference**
Abundance	25-48% of salmon on feeding grounds in NE Atlantic Ocean	Hansen et al. 1993
	50-80% of spawners in River Vosso, western Norway	Skaala and Hindar, 1997
	51-68% of all smolts leaving Magaguadavic River, New Brunswick have escaped from hatcheries	Stokesbury and Lacroix, 1997
	Over 2000 marine captures and 140 adult freshwater captures per year in NE Pacific Ocean between 1993 and 1997	Atlantic Salmon Watch, A. Thomson, personal communication)
	Positive correlations between smolts placed into Norwegian cages and percent Capture in fisheries and in Norwegian streams (7-year assessment)	Lund et al., 1997

Survival	*Two-fold lower marine survival (sea-ranched)*	*Jonsson et al.,* 1991
	20% lower juvenile survival in streams	Ferguson et al., 1997
Size, Feeding and Growth	Escaped smolts larger in size when migrating from Magaguadavic River, New Brunswick	Stokesbury and Lacroix, 1997
	Experimentally introduced farmed strain and hybrids grow faster than wild juveniles in rivers in Ireland	Ferguson et al., 1997
	Experimentally introduced farmed strain and hybrids grow faster than natives in Norwegian river	Einum and Fleming, 1997
	Naturally spawned farmed and hybrid offspring grow faster than native juveniles in Norwegian river	Fleming et al., 1997
	Adult farmed females entering Norwegian river are 10% smaller in size than wild females	Lura and Sægrov, 1991

Table 1. **Continued**

<u>**Character**</u>	<u>**Observation**</u>	<u>**Reference**</u>
	About 7% of marine captures of escaped farmed fish in NE Pacific Ocean have prey in stomach	McKinnell et al., 1997
	About 35% of marine captures of escaped Atlantic salmon in Scottish marine waters have prey in stomach	Hislop and Webb, 1992
	Farmed and hybrid offspring form natural breeding are scattered throughout Norwegian river during juvenile growth	Fleming et al., 1997
Reproductive Behavior	***<u>Norway</u>***	
	Later maturity and spawning than wild females	Heggberget, 1988
	Earlier maturity and spawning than wild females (3.5.weeks)	Lura and Sægrov, 1991
	Utilize similar spawning habitats	Okland et al., 1995; Fleming et al., 1997
	Males competitively inferior	Fleming et al., 1997
	Females show less breeding behavior and are less efficient	Fleming et al., 1996

at nest covering; males are less aggressive and court less

Iceland

Adults enter rivers later and spawn later than wild stock Gudjonsson, 1991

Scotland

Farmed adults stay lower in river and spawn later Webb et al., 1991

Eastern Canada

Adults enter river later than wild fish Carr et al., 1997

Reproductive Farmed progeny hatch and initiated feeding earlier in Lura and Sægrov, 1991
Success Norwegian streams
Females carry more unspawned eggs, have more nest Fleming et al., 1996
destruction, greater egg mortality, and overall less than
1/3 the success of wild females
Males have fewer spawnings, often do not ejaculate, and Fleming et al., 1996
overall have less than 3% the success of wild males
Successful spawning Lura and Sægrov, 1991
Unfertilized eggs Lura and Sægrov, 1991
Sucessful spawning in an eastern Canadian river in 1993 Carr and Anderson, 1997
55% of redds are of farmed origin in an eastern Canadian Carr and Anderson, 1997
river

Reproductive Interbreeding of a Scottish farmed strain with wild fish in Crozier, 1993
Interactions an Irish river and shift in wild gene pool
Farmed fish producing over 44% of the genes in the River Skaala and Hindar, 1997
Vosso, western Norway demonstrating that gene pool is
being replaced by farmed strain
Farmed fish contribute 21% of the genes in River Imsa, Fleming et al., 1997
southwestern Norway, mainly through hybridization,
after experimental release

	Farmed fish dig up wild fish’s eggs when making their own nest	Webb et al., 1991
Disease And Parasites	Sea lice in farms apparently contributing to increased wild stock mortality, reduced seawater growth and premature return	Dawson et al., 1997; McVicar, 1997; Todd et al., 1997

Table 1. **Continued**

Character	Observation	Reference
	More sea lice on sea-winter escaped farmed salmon than wild salmon in Norwegian sea	Jacobson and Gaard, 1997
	Gyrodactylis salaris carried into Eastern Atlantic drainage from Baltic Sea drainage by smolts from Swedish farm, killingover 35 Norwegian wild populations	Johnsen and Jensen, 1991
	Aeromonas salmonicida (furunculosis) carried to Norwegian aquaculture From Scottish smolts, probably spread by escapees to wild populations.	Johnsen and Jensen, 1994

The manner and degree of interaction will vary from species to species so it is difficult to know how much impact, if any, escapees will have. It should be assumed, however that escapes from net cage operations will occur. The magnitude and frequency of escapes of cultured fish varies between operations. Alverson and Ruggerone (1997) reported that up to 2% of annual production stock escape from salmon cage culture operations in British Columbia. Huge escape events also occur. For example, in 1997, 300,000 Atlantic salmon escaped from a cage-culture facility in Puget Sound. Another 100,000 more escaped from the same facility in 1999 (Anderson, 1999). For ecologically or economically important wild species, it may be more suitable to determine the maximum tolerable level of cultured fish “swamping” the stream or river at issue and then to estimate the acceptable production stock as escapes. If wild species have low or declining populations such that no allowable swamping is acceptable, then the aquaculture facility should be distanced from the stream or river at issue. An appropriate distance will depend on the typical distances the migratory species is capable of traveling to enter spawning streams. It is inappropriate and arbitrary to assign one distance, such as 1 km or 3 km from a stream, for all operations rearing migratory species. Because escapees from net cage operations do not have a natal stream, they may migrate to a suitable stream closest to the cage culture operation.

If the answer to this question is unknown, and there are ecologically or economically important species in the nearest streams or rivers to the proposed aquaculture facility, take the precautionary approach and answer yes.

Question 44.

The zone of influence varies across different environmental factors. A reduction in currents due to the physical structure of the aquaculture facility may harm spawning populations if the facility is nearby spawning grounds. In this case, the zone of influence is relatively small in scale. Pollution from the aquaculture facility may spread to more distant spawning grounds. In this case, the zone of influence is larger. In the event of escapes from the aquaculture facility, and because of the ability to translocate easily, the zone of influence can be very large-scale.

Concerns relevant for this question include the potential for spawning habitat damage either by *construction* of the proposed aquaculture facility, a *reduction in current speed* due to obstruction of the net cages, and the potential of aquaculture *pollutants* collecting on spawning grounds. Refer to the supporting text in Section VII. Effects of Settleable Solids on Benthos and Shellfish. Little is known regarding the impact of non-migratory cultured organisms on wild spawning sites, however caution should be exercised if facility is close to spawning areas.

If the answer to this question is unknown, use references such as the Atlas of Spawning and Nursery Areas of Great Lakes Fishes (Goodyear et al., 1982 available in a searchable format at http://www.glsc.usgs.gov/information/atlas/index.htm); other spawning habitat publications (Coberly et al.,1980; Nester, 1987; Thibodeau et al., 1990; Edsall et al., 1996; Dawson et al., 1997) or; jurisdictional spawning maps.

Question 45.

Aquaculture facilities close to land may be close to breeding or nesting areas for birds and mammals, some of which are piscivorous or bird-eating animals. This proximity to breeding or nesting areas can become a significant problem, as cultured fish are vulnerable to predation. Piscivorous birds such as egrets, cormorants, osprey and herons are well known to frequent fish farms. Mammals can also prey heavily on cultured fish in addition to damaging netting used to contain the fish thus increasing rates of escape (Draulans, 1987; Stickley, 1990; Williams 1992; Animal and Plant Health Inspection Service, 1997; Littauer, 1997).

If answer to this question is unknown, consult with the appropriate US Fish and Wildlife Service or the Canadian Wildlife Service.

Hazard 25.

A hazard to migratory wild populations resulting from interactions with escaped cultured fish has been identified. Jurisdictional regulations may require a minimum distance from a stream or river. Additional factors such as the proximity of suitable spawning streams for escapees should also be considered. Refer to the supporting text for Question 44. If unwilling to accept risk to ecologically or economically important species, consider culturing different species or relocating facility away from stream or river at issue.

Hazard 26.

A hazard to spawning areas due to potential habitat degradation from the proposed facility or from released effluent has been identified. Consider both the physical structure as well as land-based infrastructure needed for the operation (refer to supporting text in Section X. Impacts of Facility and Infrastructure, Question 49). Reduced water circulation because of net cages impeding currents may have an adverse effect on spawning areas. Measures for containment and removal of wastes from the proposed facility should be included in the proposal (refer to Section VII. Effects of Settleable Solids, Question 39). If these measures are unsatisfactory, the facility should be relocated to an area that will not adversely affect spawning grounds.

Hazard 27.

A hazard to breeding or nesting birds or mammals due to facility structure or operations has been identified. Various measures can be used to minimize impact from piscivorous predators. These include auditory deterrent devices, enclosures, lethal measures and locating facilities away from known breeding and nesting sites. Auditory deterrent devices considered to be only moderately effective include: pyrotechnics (or fireworks) such as Bird Bangers which have the explosive equivalent of an M-80 firecracker; ropes that ignite firecrackers along the rope and burn at a rate of 2.5 cm /10 min; automatic gas exploders or cannons, that emit variable numbers of blasts that can be heard over a 2 hectare area; and live ammunition from shotguns and rifles. To be effective at all, blasts need to be intermittent. (Littauer, 1990; Williams, 1992; Animal and Plant Health Inspection Service, 1997).

Unknowns include the extent to which auditory deterrent devices affect the breeding or nesting habits of neighboring birds and animals; and the effects these devices have on neighboring humans. Exclosures or barrier techniques are considered highly effective predator deterrents (Littauer, 1990). Examples include netting or overhead lines or wires. Lethal measures, which include the taking of predators, such as cormorants without obtaining a migratory bird take permit, are allowed in some states under the 1998 Double-crested Cormorant Depredation Order (50 Congressional Federal Register 21.47). Cormorant population size is increasing in the Great Lakes. For instance, the largest colony on Little Galloo Island in Lake Ontario had 5428 nests in 1991, an increase of 36% per year since 1974 (Weseloh et al., 1994). Minnesota is presently the only Great Lakes state permitted under the Cormorant Depredation Order.

The most effective defense against costly attacks by predators is to locate the facility away from known breeding or nesting areas. If unable to do so, a predator deterrent plan that does not adversely affect neighboring residents (animals and humans) will be necessary.

Section IX
Water Quality and Cumulative Impacts

Question 46.

National Pollutant Discharge Elimination System (NPDES) permits are required in the United States under the Clean Water Act. section 402 (Title 33, Chapter 26, § 1342, USC). For more information about NPDES permits, see the following:
Illinois: http://www.epa.state.il.us/about/org/bureau-of-water.html#dwpc
Indiana: http://www.state.in.us/idem/owm/npdes/guide/index.html
Michigan: http://www.deq.state.mi.us/swq/
Minnesota: http://www.pca.state.mn.us/water/permits.html
Ohio: http://chagrin.epa.ohio.gov/programs/permits.html
Wisconsin: http://www.dnr.state.wi.us/org/water/wm/ww/
New York: http://www.dec.state.ny.us/website/dow/index.html
Pennsylvania: http://www.epa.gov/reg3wapd/npdes/

Under Section 118(c)(2) of the Clean Water Act, the Water Quality Guidance for the Great Lakes System also known as the Great Lakes Initiative establishes minimum water quality standards and antidegradation policies for waters of the Great Lakes. (http://www.epa.gov/docs/great_lakes/wqggls.txt.html).

Canadian legislation such as the Ontario Water Resources Act and the Environmental Protection Act control waste material from fish farms. Contact the Canadian Ministry of the Environment and the Ontario Ministry of the Environment for current Canadian water quality regulations. Note: users should also be aware of other federal, provincial, state and municipal water quality regulations.

If answer to this question is unknown, contact state pollution control agencies, the Canadian Ministry of the Environment or Ontario Ministry of the Environment for assistance.

Question 47.

The nutrient of greatest concern in freshwater is phosphorous. This is the limiting nutrient that controls phytoplankton in freshwater lakes (Kelly, 1993; Ackerfors et al., 1994; Massik et al, 1995). Phosphorous is an essential nutrient found (usually in excess) in intensive fish food diets (Beveridge, 1996). Phosphorus readily leaches out from uneaten food and feces, forming one of several highly soluble ions in water.

The Great Lakes Water Quality Agreement's signatories committed themselves to restoring and maintaining the chemical, physical and biological integrity of the Great Lakes Basin. This document gives specific water quality guidelines. Refer to Appendix 3 for a reprint of the Great Lakes Water Quality Agreement (1972 amended 1987), Annex 3, Control of Phosphorus.

If answer to Question 47 is unknown, contact the Canadian Ministry of the Environment or State Pollution Control Agencies for assistance. The entire Great Lakes Water Quality Agreement can be found on the web at http://www.ijc.org/agree/quality.html .

Question 48.

Refer to the supporting text in Question 47.

If answer to this question is unknown, contact the Canadian Ministry of the Environment or State Pollution Control Agencies for assistance. The entire Great Lakes Water Quality Agreement can be found on the web at http://www.ijc.org/agree/quality.html .

Hazard 28.

A hazard to water quality due to cumulative effects of existing aquaculture facilities and the proposed introduction of excess nutrients, particularly phosphorous, into the Great Lakes has been identified. At the time of writing of the Great Lakes Water Quality Agreement, phosphorous, was the culprit behind massive algal blooms which eventually decay and cause anoxic areas and thus led to fish kills, especially in Lake Erie. The sources of phosphorous were primarily sewage treatment plants and non-point source agricultural runoff. Improved treatment methods and agricultural practices led to an overall decline of phosphorous entering into the Great Lakes. In addition, with the infamous introduction of the zebra mussel, an algal filter feeder, water clarity has improved considerably. How the Great Lakes will equilibrate with this latest biological introduction is unknown. Meanwhile, it should not encourage less concern about the introduction of excess phosphorous into the Great Lakes system.
Until the signatories of the Great Lakes Water Quality Agreement decide that phosphorous levels need not be limited, alternatives such as an overall reduction in the proposed aquaculture production, use of alternative feed such as high-nutrient dense, low pollution diets (Cho et al., 1994; Cho et al., 1999), or mechanisms to remove excess food and fecal waste should be implemented.

Hazard 29.

A hazard to water quality due to the proposed introduction of excess nutrients, particularly phosphorous into the Great Lakes has been identified. Refer to supporting text for Hazard 28.

Terminal Point 7.

No additional text.

Section X
Impacts of Facility and Infrastructure

Question 49.

Consider the need for additional structures or roads for the aquaculture facility as it is currently proposed *and also* if the operator intends to expand the operation in the future. Small-scale facilities will be able to utilize external sources for eggs, processing, maintenance, storage etc; however large-scale facilities tend to include economical, in-house divisions of these phases of production. Even if the rearing facility is located in a remote area, land access will still be necessary for a multitude of services. Huguenin (1997) lists operating and servicing functions that will be necessary for a cage-culture operation (Table 2), all of which require either roads for trucks and equipment, or land-based structures.

<u>Table 2.</u> Necessary cage unit operating and servicing functions (Adapted from Huguenin, 1997)

Stocking of organisms
Counting organisms
Measuring/weighing organisms
Grading organisms
Feed preparation and/or storage
Feeding of organisms
Prophylactic treatment of organisms
Monitoring water quality and flowrate
Monitoring and control of status and health of organisms
Harvesting and processing of organisms
Cleaning of system (biofouling control and good hygiene)
Logistical support for organisms and personnel (trucks, boats, etc.)
Mechanical maintenance (connections, moorings, equipment)
Support facilities and services for personnel (including shelter)
Storage for equipment and supplies

Municipal governments must be contacted to identify zoning by-laws and other planning documents.

If answer to this question is unknown, consult with operator.

Question 50.

This question revisits the issue of impact on species at risk or species involved with rehabilitation or recovery plans. Here, consider specifically the additional land-based infrastructure that accompanies the rearing facility. Habitat alterations can include filling or draining of wetlands and clearing of vegetation. These alterations can completely

eliminate species and biological communities, cause fragmentation of the ecosystem, increase edge effects, eliminate connectivity and reduce a natural area so that it is too small for a viable population (Nature Conservancy Great Lakes Program, 1994).
If you have already considered this aspect of the operation in Section V, Impacts on Recovery or Rehabilitation Plans, then proceed to Section XI, Effects on Other Lake Users.

If answer to this question is unknown, consult with U.S. fish and Wildlife Service, COSEWIC, COSSARO and Fish Community Objectives. Refer to Section V, Impacts on Recovery or Rehabilitation Plans.

Hazard 30.

A hazard to at risk species due to construction of additional infrastructure, such as land-based buildings or roads, has been identified. The responsible government agency for the species at issue should be consulted to seek approval. If approval is not granted, one solution is to relocate the facility away from critical habitat.

Section XI.
Genetic Assessment

Question 51.

The human capability to genetically modify organisms has expanded greatly with the advent of novel techniques of genetic engineering. A genetically engineered organism (GEO) is one that has been constructed by isolating nucleic acids molecules (molecules that encode genetic information) from one organism, and introducing these molecules into another organism in a manner that makes them part of the permanent genetic make-up of the recipient, i.e., capable of being inherited by offspring (Scientists' Working Group on Biosafety, 1998). This definition also includes those organisms constructed by the transfer of subcellular organelles from one cell to another, followed by the regeneration of an adult organism from the genetically altered cell, so long as the alteration can be transmitted to offspring.

In the case of aquatic organisms, interspecific hybridization and chromosome manipulations are so novel that they also warrant careful biosafety assessment (Agricultural Biotechnology Research Advisory Committee, 1995; Scientists' Working Group on Biosafety, 1998). Furthermore, many interspecific hybrids and chromosomal manipulated finfish, shellfish, or plants are derived from parental populations that are close to the wild-type, so these genetically engineered offspring will be ecologically competent if they escape into the wild (Kapuscinski and Hallerman, 1994).

If answer to this question is unknown, consult with operator.

Question 52.

The *Manual for Assessing Ecological and Human Health Effects of Genetically Engineered Organisms* is appropriate for assessing commercial-scale aquaculture of genetically engineered animals or plants (Scientists' Working Group on Biosafety, 1998, available at www.edmonds-institute.org). It is an expanded version of the USDA's *Performance Standards for Safely Conducting Research with Genetically Modified Fish and Shellfish* (Agricultural Biotechnology Research Advisory Committee, 1995), available at: www.nbiap.vt.edu/perfstands/psmain.html. The manual leads the user through a set of flowcharts, with each user following a case-specific pathway. The manual offers procedures for identifying potential hazards associated with the release of GEOs created from aquatic plants, finfish and shellfish. Where a specific hazard is identified, recommendations are made for minimizing the perceived risk (that is, minimizing the likelihood that a potential hazard will actually occur).

The scientific community has barely begun to conduct the appropriate studies to test for ecological risks of aquatic GEOs. Risk assessment tests need to address two broad issues. What is the ability and probability of a transgene to spread from escaped GEOs into a natural population through outbreeding of the GEO? What is the potential for ecological disruptions, for instance, excessive predation on a prey species or competitive displacement of a wild population, due to altered traits of organisms bearing the transgenes? In addressing both issues, one needs to search for altered traits of the GEO that could affect the outcome. For instance, large size at sexual maturity is known to give a mating advantage to males or females in many fish species. If growth-enhanced transgenic fish are larger than non-transgenics at sexual maturity, they would have a mating advantage that could increase the spread of transgenes into a wild population (discussed in further detail below).

The *Manual for Assessing Ecological and Human Health Effects of Genetically Engineered Organisms* (Scientists' Working Group on Biosafety) directs the user to first assess the potential for transgene spread and, depending on the outcome, then proceed to assess the potential for ecological disruptions. The user assesses the risk of transgene spread by taking a case-specific pathway through portions of flowcharts I through IV.B. In certain cases, the user goes on to assess the potential for ecological disruptions by taking a case-specific pathway through portions of flowcharts V through V.E. This priority order makes sense because conclusions about the potential spread of the transgene into wild populations will affect the range of situations for which one needs to assess ecological disruptions.

One should go on to assess the risk of ecological disruptions when any of three scenarios might apply:

(1) the escaped GEOs could survive and interbreed with wild relatives in the accessible ecosystems and the transgene could spread through the wild population;

(2) the escaped GEOs could survive and reproduce among themselves and establish a new population in an accessible ecosystem that lacks wild relatives; and

(3) the escaped GEOs cannot reproduce in the wild (e.g., rendered sterile via triploidy induction in fish) but could survive long enough in the wild to prey on, compete with, or otherwise displace wild organisms in the ecosystem.

The first and second scenarios are of concern for frequent leakage of relatively small numbers of escapees (e.g., small wear and tear holes in netting of farm cages) as well as infrequent but potentially very large numbers of escapees (e.g., storm damage destroying entire net cages). The third scenario is primarily of concern for infrequent, potentially large numbers of aquaculture escapees, particularly if these recur often enough so that a new wave of escapees tends to replace the earlier wave as it dies off.

The few existing scientific publications that might aid in ecological risk assessment of transgenic fish, although welcome in light of scanty support for such studies (Kapuscinski and Hallerman 1994), have important shortcomings. They have not estimated the probability of the transgene spreading in wild populations (except for the studies discussed in the next paragraph). Devlin et al. (1999) found that dramatically faster growing transgenic coho salmon (*Oncorhynchus kisutch*) had extraordinarily high plasma growth hormone (GH) levels and consumed 2.9 times more feed pellets than the non-transgenic controls in tanks. The elevated GH levels apparently increased feeding motivation or appetite, raising the possibility that escaped GH transgenic fish could compete successfully with wild fish for food. This study confirmed that genetic engineering usually changes non-target traits (feeding motivation, appetite) in addition to changing the target trait (growth rate), thus supporting the need to search for unintended trait changes when assessing the risk/safety of a GEO. This study was not designed to determine if changes in other behavioral traits, such as increased predation exposure due to increased foraging for natural prey, could counteract the higher feeding motivation of the transgenic fish. A second study examining critical swimming speed in tanks suggested that this same transgenic strain might have an inferior swimming ability (Farell et al., 1997). We are left, however, not knowing if swimming ability would offset any feeding-related competitive advantage were these transgenic salmon to escape into natural ecosystems. Also unclear is whether swimming ability and food competition are the most crucial traits to measure in order to assess the ecological impacts of these fish.

Stevens et al. (1998) found that a line of growth-enhanced transgenic Atlantic salmon had higher oxygen uptake (indicating higher metabolic rate) but similar critical swimming speed to similarly sized non-transgenic controls. The company that has developed these transgenic fish also attests that these fish have better food conversion than controls and produce growth-hormone in their tissues year-round (Entis, 1997, 1999; Yoon, 2000; A/F Protein unpublished brochures). These isolated bits of information, while potentially useful for demonstrating the desirability of these fish for aquaculture, do not provide the data needed to estimate the probabilities of transgenes spreading from escapees into wild populations and of ecological disruption.

We need a more effective and systematic means of testing aquatic GEOs for possible ecological risk or safety. A step in this direction is the methodology of Muir and Howard (1999, 2000) for assessing the risk of transgene spread to wild relatives (scenario 1 discussed above). Their approach focuses on estimating the overall fitness of a GEO by collecting data at critical "check points" in its life history (Muir and Howard, 2000; Prout, 1971a, 1971b). The first step is to conduct controlled experiments to test the transgenic organisms for changes in six fitness components: viability (survival to sexual maturity), longevity, age at sexual maturation, fecundity (clutch or spawn size), male fertility, and mating success of both females and males. Then, one integrates the fitness component data to predict gene flow from escapees to wild relatives. Integration of the fitness component data requires the use of simulation models (or multiple generation experiments in simplified, confined ecosystems) to estimate the *joint* effects of all altered fitness components on transgene spread and population size in the wild population. This methodology improves the chances of identifying one type of ecological disruption: major decreases or increases in wild population size resulting directly from a trade-off between the altered fitness components of transgenic individuals. Such information can then assist further assessment for other undesired ecological disruptions, for instance, changes in predation that might hurt biodiversity or economically important species or competitive displacement of native species by transgenic organisms that display invasive or pest characteristics.

Muir and Howard (1999), for instance, showed how critically important it is to examine *interactions* among different fitness components that can be changed by one transgene. They examined genetically engineered Japanese medaka (*Oryzias latipes*) containing extra growth hormone genes. The transgenic medaka grew faster, reached sexual maturity earlier, and had lower viability than non-engineered controls. Among medaka, as is true in many fish species, larger males have a substantial mating advantage over smaller males. Computer simulations combining the data on mating advantage and lower viability led to a troubling result called the Trojan gene effect. A transgene introduced into a wild population by interbreeding with a small number of transgenic fish spread quickly as a result of enhanced mating advantage; but the reduced viability of offspring drove the mixed population to one-half its size in less than six generations and to extinction in about 40 generations.

If the Trojan gene effect held true in a real situation, particularly whenever the wild population was already depleted, the local extinction of a wild population could have cascading negative effects on the biological community. It is possible that researchers will eventually identify biological factors that prevents the Trojan gene effect from happening in nature (and researchers are presently designing experiments to test the Trojan gene effect on fish populations in confined ecosystems). Meanwhile, taking a precautionary approach to any proposed aquaculture of a GEO would involve first requiring laboratory testing for a mating advantage and changes in other fitness components in the aquatic GEO. In the absence of such key information, the *Manual for Assessing Ecological and Human Health Effects of Genetically Engineered Organisms* (Scientists' Working Group on Biosafety) recommends to "consider disallowing the release" or to implement multiple types of barriers to escape of culture organisms; the latter will likely require relocation of cage aquaculture operations to land-based systems (see supporting text for question 53 and hazard 32).

If answer to this question is unknown, consult with operator.

Question 53.

If one or more hazards are identified, then the user needs to determine the feasibility of implementing risk reduction measures. A guiding principle is to apply a mix of different types of confinement measures, where each type has a fundamentally different vulnerability to failure (see flowchart VI.C and supporting text in Scientists' Working Group on Biotechnology, 1998). By mixing confinement measures with different vulnerabilities, one increases the chances that failure of one barrier will not breach all the barriers to escape of GEOs from the aquaculture operation. *Physical barriers* induce 100% mortality through such physical alterations as imposing lethal water temperatures or pH to water flowing out of fish tanks or ponds before the effluent is discharged to the environment. *Mechanical barriers* are devices, such as screens, that hold back any life stage of the GEO from leaving the aquaculture facility. *Biological barriers,* such as induced sterilization, are those that prevent any possibility of the GEO reproducing or surviving in the natural environment.

Within-lake aquaculture systems, such as cage aquaculture, pose a major challenge when it comes to trying to mix types of barriers. Physical barriers are not an option for cage farming of salmon because there is no “end of the pipe” effluent that can be so treated. Mechanical barriers are highly vulnerable to breaching in net cage farming. Materials such as extra predator barrier nets and rigid netting can help but cannot alone prevent large escapes of GEOs due to storm damage, predator damage, or wear and tear. Floating enclosed bags, a new technology, may work well in waters of the Great Lakes where potentially damaging physical force of tides are not an issue, but these bags need to be thoroughly tested for their ability to prevent fish escapes while providing cost-effective rearing conditions (Dodd, 2000).

The exclusive farming of monosex, triploid fish that are functionally sterile is a feasible biological barrier for cage culture of some transgenic fish species, such as salmon and trout (Solar and Donaldson, 1991; Donaldson et al., 1996; Cotter et al., 2000). But sole reliance on biological barriers in net cage farms would violate the risk management principle of applying multiple barrier types. Furthermore, biological barriers to reproduction are unknown for some aquaculture species. For a freshwater alga, there is no feasible way to make it sterile to prevent either sexual or asexual reproduction if some plants were to release propagules into aquaculture effluents or escape the culture facility. Sterilization of farmed genetically engineered algae, therefore, is not an option for helping to reduce establishment of a self-propagating population or to reduce gene flow to locally present wild relatives.

If answer to this question is unknown, seek assistance of the government agencies responsible for management of fisheries and environmental quality in the project area in reviewing the completed biosafety assessment.

Question 54.

At issue are *naturally* reproducing populations of the same species as the culture species or a closely related species with which the aquaculture escapees can interbreed. The natural populations of concern may be indigenous to the Great Lakes or naturalized descendants of an introduced species that has become socio-economically important (see example of genetically distinct steelhead trout populations discussed in the supporting text for question 55). Many aquaculture operations raise organisms from non-local broodstock sources. In most of these cases, organisms escaping from the aquaculture operation will be capable of surviving to reproduce and interbreed with natural populations in surrounding waters.

It is important to assess if the aquaculture escapees could cross with any closely related species in the accessible ecosystem. Interspecific hybridization among aquatic species is quite common, particularly among fishes (Hubbs, 1955; Lagler, 1977; Turner, 1984; Collares-Pereira, 1987), often yielding fertile hybrids that can backcross to wild populations of either parental species. Interspecific hybrids and their backcrossed descendants may occur naturally but usually at low frequencies; walleye containing introgressed sauger genes, for example, have been found in waters draining into Georgian Bay of Lake Huron (Billington et al., 1988). Frequent or large-scale escapes of fertile hybrids or either parental species from aquaculture operations can substantially increase these frequencies. This then poses a genetic hazard of losing a taxonomically distinct population of a native species. For instance, walleye x sauger hybrids have become a popular culture organism (Held and Malison, 1996). A wild population of walleye could lose its taxonomic and genetic distinctness if large numbers of walleye x sauger hybrids escaping from an aquaculture operation successfully out-crossed with the wild walleye.

It is in the long-term interest of parties interested in aquaculture or capture fisheries to prevent losses of taxonomically distinct populations in the wild. Taxonomically distinct, wild populations are an irreplaceable reservoir of genes (live gene bank) harboring coadapted gene and chromosomal complexes that aquaculture breeders can tap to improve economically important traits, such as disease resistance. Introgressive hybridization would disrupt these gene complexes as well as dilute rare alleles that could be crucially important for aquacultural performance traits. Furthermore, if one half of a hybrid cross comes from an introgressed rather than a pure parental species, the offspring will not show hybrid vigor for the target performance traits, thus undermining the very purpose of making interspecific hybrids in aquaculture. Indeed, Billington (1996a) found saugeye genes in some aquaculture broodstocks presumed to be pure walleye. The loss of coadapted gene and chromosomal complexes and of rare alleles also threatens the long-term sustainability of capture fisheries for reasons explained in greater detail in the remainder of the supporting text for question 54.

<u>Panmictic populations versus genetically distinct populations.</u> In cases where wild relatives belong to one panmictic population (probably a rarity in the Great Lakes), interbreeding with aquaculture escapees poses the genetic hazard of reducing the fitness, thus the productivity, of wild populations due to outbreeding depression. In cases where the wild relatives have a number of genetically distinct populations in the Great Lakes, their interbreeding with aquaculture escapees poses two hazards: (1) outbreeding depression that might reduce the near-term fitness and productivity of the wild fish; and (2) homogenization of the genetic differences between populations that might reduce the long-term sustainability of wild populations. Evidence of adverse effects of interbreeding between fish coming from genetically divergent sources has grown in recent years. For instance, see reviews in Kapuscinski and Jacobson (1987), Krueger and May (1991), Heggberget et al. (1993), Busack and Currens (1995:74-75), Leary et al. (1995), Allendorf and Waples (1996:253-254), Lynch (1996:491-493), National Research Council (1996), Reisenbichler (1997), Gross (1998), Youngson and Verspoor (1998), and Miller and Kapuscinski (2000). Further discussion of these potential problems appears under the three sub-headings below.

Although genetic population structure information is missing for many important species in the Great Lakes, substantial information exists for some species. Genetic data may be Great Lakes basin-wide or only lake-wide. For instance, there are data on population structure of lake trout (Ihssen et al., 1988, Krueger et al., 1989; Krueger and Ihssen, 1995), walleye (Billington and Hebert, 1988; Ward et al., 1989; Todd, 1990; Billington et al., 1992; Stepien, 1995), steelhead trout (Krueger et al. 1994; O'Connell et al., 1997), brook trout (Danzmann et al., 1991; Angers et al., 1995; Danzmann et al., 1998), and Northern pike (Senanan and Kapuscinski, 2000). Because new genetic studies are underway all the time, users need to actively seek out the most current information. This involves searching the scientific literature as well as consulting with practicing fisheries geneticists in the region to find out about unpublished results from the most recent studies (e.g., yellow perch population genetic analysis is currently underway for Lake Michigan).

Answers to this question should be based on appropriate genetic analyses of population structure conducted by a qualified population geneticist. Such analyses should examine genetic variation in at least one type of nuclear genetic marker that is polymorphic for the species in question. For example, protein electrophoresis is inadequate for assessing population structure in Northern pike (*Esox lucius*) because studies have shown virtually no variability in these genetic markers (Healy and Mulcahy, 1980; Seeb et al., 1987). Instead, one should use microsatellite DNA, a nuclear genetic marker that has much higher levels of variation and has been used to delineate distinct populations (Miller and Kapuscinski, 1996; Senanan and Kapuscinski, 2000). Likewise, proteins and mitochondrial DNA markers exhibit low variability in yellow perch and prior genetic studies with such markers found very little population structure across broad geographic regions (Todd and Hatcher, 1993; Billington, 1996). Yet, the existence of distinct breeding populations within single lakes has been proposed based on tagging studies, comparative growth and behavior studies, and patterns of egg mass deposition (Aalto and Newsome, 1990). Studies are presently underway to develop higher resolution nuclear DNA markers to search for genetic population structure in yellow perch (Miller and Kapuscinski, unpublished data). It is desirable to confirm population structure results by looking for concurrence between results from two or more types of genetic markers (nuclear or mitochondrial).

The objective of asking this question is to prevent declines in the near-term fitness and productivity and long-term sustainability of wild populations that could be wrought by interbreeding with aquacultural escapees. Genetic diversity is "part of the fabric of a biological resource" (National Research Council, 1996:146). The productivity of the resource, Great Lakes fish populations in this case, cannot be separated from its genetic basis. Escapees that survive and spread to the breeding grounds of a naturally reproducing population could interbreed with the wild organisms. If this happens on a large enough scale, genetic differences between the aquacultural and wild population are eroded, making all the populations simultaneously more vulnerable to environmental change (e.g., pathogens, contaminants, changes in water quality or temperature regimes). An additional outcome can be reduced fitness of the introgressed wild population resulting from outbreeding depression or maladaptive genes from the partially domesticated aquacultural broodstocks. For a review of the genetic basis for fitness and outbreeding depression in wild fish populations, see Busack and Currens (1995:74-77) and Campton (1995:341-342, 345-346).

<u>Increased vulnerability to environmental change due to loss of genetic differences between populations</u>. Genetic differences between naturally reproducing populations of a species provide an evolutionary "bet-hedging" strategy analogous to the adage: don’t put all your eggs in one basket. The “eggs” are the different alleles (total genetic variation) harbored within each species. The “basket” is each distinct population. As initially distinct populations become genetically homogenized, they develop the same vulnerability to stressful environmental conditions. The National Research Council (1996:148) expressed the critical importance of conserving between-population genetic differences as follows:

> Consider the extreme where no differences exist between local populations. In that case, a species consists of many copies of the same genetic population and is extremely vulnerable to environmental change. For example, a new disease might be introduced to which most individuals are genetically susceptible; the disease would jeopardize all populations and therefore the entire species. However, in the usual case, where genetic differences do exist between local populations, it is likely that some populations would have a higher frequency of genetically resistance individuals and thus would be relatively unaffected by the disease.

A graphic example of the extreme case was the widespread crash in yields of genetically uniform corn crops across North America in the 1970s due to rapid spread of corn blight disease. Following the precautionary principle, it is desirable to prevent erosion of any existing between-population genetic differences in naturally reproducing populations of fish and other aquatic species in the Great Lakes.

Decreased production and fitness of wild populations due to outbreeding depression. Outbreeding depression is a loss of fitness in the offspring produced as a result of interbreeding between two groups because the parents are too distantly related (Templeton, 1986). Local adaptation in naturally reproducing populations increases the probability that farmed fish x wild fish matings will yield outbreeding depression in the offspring. Outbreeding depression may result from the loss of local adaptation (i.e., through introduction of maladaptive genes) or a disruption in coadapted gene complexes that evolved through many generations of natural selection (Shields, 1993). Reductions in fitness due to loss of local adaptation may occur as soon as the first generation of outbred progeny (F_1). Reductions in fitness because of a disruption of coadapted gene complexes are more likely to occur in the next generation (F_2). For instance, Gharrett and Smoker (1991) documented severe outbreeding depression in F_2 hybrids between even- and odd-year pink salmon from the same stream in Alaska. The reduction in fitness could not be due to loss of local adaptation because both populations are native to the same stream. Instead, the appearance of outbreeding depression in the F_2, but not the F_1 generation, was likely due to breakdown of coadapted gene or chromosomal complexes (Allendorf and Waples 1996:254).
If a substantial proportion of wild fish secure matings with escaped farmed fish, outbreeding depression could cause declines in the wild population's abundance, posing a variety of ecological and socio-economic concerns. Reznick et al. (1997) found adaptive evolution of guppies to a new wild environment in only 7 generations (a mere 4 years for this species). It is thus reasonable to assume that populations of fish and other aquatic organisms in the Great Lakes have persisted in their local environments over enough generations that they have evolved local adaptation.

For example, two studies suggest that local adaptation is important in walleye, a native and economically important species of the Great Lakes. Fox (1993) compared the embryo hatching success of two populations of walleye from two neighboring rivers in Georgian Bay, Ontario. The rivers were 30 km apart and hatching success of both stocks was compared in both rivers. The native population showed significantly higher hatching rates than the non-native population in both rivers. Jennings et al. (1996) found that walleye recruitment to the spawning grounds had a heritable component. Walleye progeny from a river spawning population and a reef spawning population were stocked into an Iowa reservoir containing both river and reef spawning habitat. Upon reaching sexual maturity, the stocked walleye preferred the spawning habitat of their parental populations.

The effects of interbreeding and introgression between genetically divergent populations on the fitness and performance of fish in the wild have not been extensively studied (Campton, 1995; Leary et al., 1995). The published data show that interbreeding between genetically different populations and introgression seldom improve performance of fish in natural environments (reviewed by Krueger and May, 1991; Leary et al., 1995; Waples, 1991, 1995). In a recent study of genetic impacts of a non-indigenous hatchery stock of brown trout on two indigenous populations, Skaala et al. (1996) found that survival was nearly three times higher in wild trout than in hybrids of wild and introduced trout. McGinnity et al. (1997) compared the performance of wild, farmed, and hybrid Atlantic salmon progeny in a natural spawning stream. The progeny of farmed salmon had significantly lower survival to the smolt stage than wild salmon but they grew fastest and competitively displaced the smaller native fish downstream. A related study showed that progeny of farmed fish in this stream and other sites successfully migrated to the sea, homed to their river of escape, and interbred with wild salmon (Clifford et al., 1998). Such introgression is likely to reduce wild populations' fitness and productivity.

Negus (1999) examined the effects of interbreeding between two genetically distinct populations of *Oncorhynchus mykiss* from Lake Superior, a long-naturalized population of steelhead trout and a hatchery-propagated "kamloops" strain of rainbow trout. Embryo survival to hatching and the fright response behavior of fry were compared across progeny of four crosses: pure steelhead crosses, pure kamloops crosses, and the two reciprocal hybrid crosses (steelhead x kamloops, and kamloops x steelhead). Survival to hatching was greatest in the pure steelhead cross. Pure steelhead fry displayed a greater fright response than pure kamloops fry when startled by movements over their tanks. Survival to hatching and fry fright response of hybrids was intermediate to both pure crosses but more closely resembled the maternal source. These results confirm a genetic basis for traits affecting survival and productivity of fish in the wild. They also suggest that interbreeding between a partly domesticated strain (kamloops) and a naturalized strain (steelhead) could reduce the naturalized strain's near-term fitness in the wild. It is reasonable to expect similar fitness reductions in wild populations if partly domesticated strains of rainbow trout escaped from cage culture operations and hybridized with naturalized steelhead trout in the Great Lakes.

Some of the best evidence for outbreeding depression comes from studies comparing the post-stocking performance and introgression between genetically distinct populations of largemouth bass. Long-term studies documented genetic and physiological differences between Northern largemouth bass, *Micropterus salmoides salmoides*, and Florida largemouth bass, *Micropterus s. floridanus*. The non-native stocks exhibited poorer fitness and performance traits than the native stock (Philipp, 1991; Philipp and Whitt, 1991). Because these comparisons involved stocks that were very distant geographically, follow-up studies compared two much geographically closer stocks, a northern Illinois and a southern Illinois largemouth bass population (Philipp and Claussen, 1995). The Northern Illinois stock demonstrated better survival, reproductive success and growth than did the Southern Illinois stock in northern Illinois and the reverse was true in southern Illinois. This result strongly supports the existence of local adaptation and, consequently, outbreeding depression if non-native fish interbreed with a locally adapted population.

Outbreeding between genetically distinct populations is most likely to yield hybrids with improved fitness in the wild (outbreeding enhancement) when hybridization alleviates inbreeding depression that existed within one or both populations (Waples, 1995). However, inbreeding depression is unlikely in most naturally reproducing populations of aquatic species in the Great Lakes. Ferguson et al. (1988) did find some evidence for superior fitness of *first-generation hybrids* between two non-inbred populations of cutthroat trout. The *superior fitness of hybrids often disappears in subsequent generations* when the hybrids backcross to a parental population (Gharrett and Smoker, 1991). Non-native populations of organisms escaping from aquaculture operations would therefore pose a genetic risk to the wild population in the second and subsequent generations, even if offspring in the first hybrid generation exhibited superior fitness.

<u>Escapees from domesticated aquacultural stocks increase the hazard of outbreeding depression</u>. Most performance traits of aquacultural organisms are partly controlled by genes and, thus, are partly heritable (reviewed in Tave, 1993). Compared to wild-type ancestors, the aquacultural organisms will genetically adapt to the new natural selection forces in the aquaculture environment even when farmers do not actively practice selective breeding. As the organisms become domesticated by genetic adaptation to the aquaculture environment, their adaptation to natural environments declines. This does not mean, however, that aquaculture escapees will be so maladapted to the wild that natural selection will weed them out before they can cross with wild relatives and possibly trigger outbreeding depression (see further discussion below).

Domestication and the commensurate maladaptation to the wild can happen in a fairly small number of generations. Fleming and Einum (1997) documented differences in numerous morphological, behavioral, and physiological traits between a seventh-generation farm strain and its wild founder population of Atlantic salmon. These changes were adaptive responses to the farm environment but most are maladaptive to the natural environment. Another study confirmed that innate predator avoidance ability can be negatively altered through short-term domestication (Berejikian, 1995). Hatchery steelhead fry, whose parents were between one and seven generations removed from the wild population of the Quinault River, Washington survived predation significantly less than fry raised from fertilized eggs of wild Quinault River steelhead adults.

A growing number of studies reveal large differences in aggressive behavior between domesticated finfish and wild counterparts. Heritable changes in aggression in wild offspring of matings between aquaculture escapees and wild fish could make them less fit through various ecological mechanisms. Depending on the life history of the species and its interactions with other species in the wild, either increased or decreased aggression could reduce fitness in the wild. The precautionary approach to sustaining wild populations of aquatic organisms, therefore, is to avoid human-caused genetic changes in aggression.

Numerous studies have shown increased aggression in offspring of domesticated broodstocks, for example, in brook trout (Vincent, 1960; Moyle, 1969) and Atlantic salmon (Einum and Fleming, 1997). Increased aggression (or increased competitive ability) has also been found in hatchery fish including brown trout (Johnsson et al. 1996) and hatchery coho salmon and cutthroat trout (Swain and Riddell, 1990, 1991; Mesa, 1991; Ruzzante, 1991, 1992, 1994; Holtby and Swain, 1992). The reasons for different aggressiveness between hatchery and wild fish could be unintentional artificial selection (imposed when broodstock are chosen for broodstock) or natural selection to the more domestic hatchery environment (reviewed by Jonsson, 1997). For all these salmonine species, increased aggression in wild offspring of hatchery x wild matings would make them more vulnerable to predators (Johnsson and Abrahams, 1991).

Some analysts have argued that maladaptation of escaped farmed fish ensures that their genes would be quickly purged from wild populations by natural selection. Unfortunately, virtually no aquacultural broodstocks have become so intensively domesticated to assure a high death rate in the wild and, thus, rapid purging of maladaptive genes. Furthermore, the ability of natural selection to purge wild populations of maladaptive traits will be severely hindered whenever there is year-after-year escapes and interbreeding of farmed fish with wild fish. Frequent and relatively large escapes of partially domesticated organisms that successfully interbreed with wild organisms would lead to a chronic reduction (genetic load) in the wild population's fitness and productivity. The decline in the wild population's well being will be in proportion to the frequency of individuals in the mixed population that carry genes from the domesticated farmed fish. Quantification of this frequency is a key step towards quantifying the possible genetic load; see the discussion starting on page 25 of Part I. of the *Performance Standards for Safely Conducting Research with Genetically Modified Fish and Shellfish* (Agricultural Biotechnology Research Advisory Committee, 1995), available at: www.nbiap.vt.edu/perfstands/psmain.html. Although natural selection is expected to remove maladaptive genes from a population, the number of generations required for the process to be completed can be very large (Hartl 1988).

If answer to this question is unknown, consult with fish population geneticists familiar with information for the Great Lakes. They can be reached through fisheries management agencies (sometimes there is a staff geneticist), the Genetics Section of the American Fisheries Society (www.afs.org) or one of the universities in the region. Additionally, the responsible fisheries management agency should conduct a formal estimation of the risk of increased vulnerability to environmental change and decreased productivity and fitness in wild populations. See question 54, supporting text on estimation of genetic load and supporting text for hazard 33 for further guidance on risk estimation.

Question 55.

Responses to this question should be based on appropriate genetic analyses of population structure conducted by a qualified geneticist. Such analyses should examine genetic variation in at least one type of nuclear genetic marker (proteins or nuclear DNA genes). Whenever possible, it is desirable to confirm population structure results by comparing results from analysis of two or more genetic markers (nuclear or mitochondrial); one looks for concurrence in population structure between different types of markers.

Be sure to consider distinct populations of native species as well as naturalized populations of introduced species that have become socioeconomically important and are endorsed by the Fish Community Objectives for the different Great Lakes (Stewart et al., 1998). For instance, assessment of a proposed rainbow trout cage culture operation in Lake Superior should include consideration of naturalized genetically distinct populations of steelhead trout (*Oncorhynchus mykiss*). This migratory form of rainbow trout was introduced to Lake Superior approximately 100 years ago through hatchery stockings and quickly became established in several parts of the Lake Superior basin. Genetic analyses of fish collected along the North Shore of Lake Superior showed that these fish have evolved into genetically distinct populations that breed in different tributary streams (Krueger et al., 1994).

In the 20 generations of natural reproduction since introduction, steelhead trout populations have had adequate opportunity to evolve local adaptation to Lake Superior streams. Reznick et al.

(1997) found adaptive evolution of guppies to a new wild environment in only 7 generations (a mere 4 years). Local adaptation in naturalized steelhead trout would increase the probability that farmed rainbow trout x wild steelhead trout matings in streams generate hybrid offspring with reduced fitness. These steelhead populations form the basis of a recreational fishery but have recently experienced declines in abundance. The declines have heightened angler concerns and focused Minnesota DNR attention on gaining the information needed to successfully rehabilitate naturalized steelhead populations. The current policy of the Minnesota Department of Natural Resources (DNR) is to protect the genetic differences among these naturalized steelhead populations (Schreiner 1992, 1995). Thus, the DNR would be interested in preventing introgressive hybridization caused by farmed rainbow trout escaping into the wild and mating with wild steelhead. Note: ongoing field research in two Lake Superior streams is measuring the fitness of hybrids compared to pure steelhead trout (Miller and Kapuscinski, unpublished data).

If answer to this question is unknown, consult with fish population geneticists familiar with information for the Great Lakes. They can be reached through fisheries management agencies (sometimes there is a staff geneticist), the Genetics Section of the American Fisheries Society (www.afs.org) or one of the universities in the region. See question 54, supporting text on estimation of genetic load and supporting text for hazard 33 for further guidance on risk estimation.

Question 56.

No additional supporting text.

Question 57.

Users have reached this question either because wild relatives of the culture species exist as one panmictic population in the Great Lakes or because the population genetic structure of wild relatives is unknown.

<u>Panmictic populations versus genetically distinct populations.</u> In cases where wild relatives belong to one panmictic population (probably a rarity in the Great Lakes), interbreeding with aquaculture escapees poses the genetic hazard of reducing the fitness, thus the productivity, of wild populations due to outbreeding depression. In cases where the genetic structure of wild relatives is unknown, the precautionary approach is to assume the existence of genetically distinct populations until genetic data become available. Following a precautionary approach, one should then assume that the interbreeding of aquaculture escapees with wild relatives poses two hazards: (1) outbreeding depression that might reduce the near-term fitness and productivity of the wild fish; and (2) homogenization of the presumed genetic differences between populations that might reduce the long-term sustainability of wild populations.

Evidence of adverse effects of interbreeding between fish coming from genetically divergent sources has grown in recent years. For instance, see reviews in Kapuscinski and Jacobson (1987), Krueger and May (1991), Heggberget et al. (1993), Busack and Currens (1995:74-75), Leary et al. (1995), Allendorf and Waples (1996:253-254), Lynch (1996:491-493), National Research Council (1996), Reisenbichler (1997), Gross (1998), Youngson and Verspoor (1998), and Miller and Kapuscinski (2000). Further discussion of these potential problems appears under the three sub-headings in the supporting text for question 54.

Question 58.

Refer to the discussion of permanent sterility in the supporting text for Hazard 35.

Question 59.

Refer to the discussion of permanent sterility in the supporting text for Hazard 35.

Question 60.

Refer to the supporting text for questions 54 and 55 for a discussion of genetic hazards posed by possible outbreeding between aquaculture escapees coming from a different genetic background than local populations in the Great Lakes.

Question 61.

Refer to the discussion of permanent sterility in the supporting text for Hazard 35.

Question 62.

Refer to the discussion of permanent sterility in the supporting text for Hazard 35.

Hazard 31.

Lack of a systematic biosafety assessment of the genetically engineered organisms proposed for aquaculture poses a hazard to aquatic biological communities. Although few empirical risk assessments have been conducted on genetically engineered aquatic organisms, a number of studies indicate possible ecological risks (see supporting text for Question 52). Modern evolution and ecology further point to the complex ways in which genetically engineered organisms could harm aquatic communities (Kapuscinski and Hallerman, 1991; Kapuscinski et al., 1999). Users should conduct a biosafety assessment using the *Manual for Assessing Ecological and Human Health Effects of Genetically Engineered Organisms* (Scientists Working Group on Biosafety, 1998) available at www.edmonds-institute.org.

Hazard 32.

One or more specific ecological hazards of the genetically engineered organisms proposed for aquaculture have been identified. Although few empirical risk assessments have been conducted on genetically engineered aquatic organisms, a number of studies indicate possible ecological risks (see supporting text for Question 52). Modern evolution and ecology further point to the complex ways in which genetically engineered organisms could harm aquatic communities (Kapuscinski and Hallerman, 1991; Kapuscinski et al., 1999).

Consider disapproval of the project in any lake-based facility because of the impossibility of deploying an effective mix of physical, mechanical, and biological barriers to escape (see barrier definitions in supporting text for question 53). Physical barriers are not an option for cage farming of salmon because there is no "end of the pipe" effluent that can be so treated. Mechanical barriers are highly vulnerable to breaching in net cage farming. Materials such as extra predator barrier nets and rigid netting can help but cannot alone prevent large escapes of GEOs due to storm damage, predator damage, or wear and tear. Floating enclosed bags, a new technology, may work well in waters of the Great Lakes where potentially damaging physical force of tides are not an issue, but these bags need to be thoroughly tested for their ability to prevent fish escapes while providing cost-effective rearing conditions (Dodd, 2000). The exclusive farming of monosex, triploid fish that are functionally sterile is a feasible biological barrier for cage culture of some transgenic fish species, such as salmon and trout (Solar and Donaldson, 1991; Donaldson et al., 1996; Cotter et al., 2000). But sole reliance on biological barriers in net cage farms would violate the risk management principle of applying multiple barrier types. Furthermore, biological barriers to reproduction are unknown for some aquaculture species such as algae.

If considering relocation to a land-based facility, the operation should include back up mechanical, physical, or biological barriers. For further information on mechanical and physical barriers, refer to the risk management sections of existing biosafety assessment guides (Agricultural Biotechnology Research Advisory Committee, 1995; Scientists' Working Group on Biosafety, 1998). For biological barriers to reproduction, refer below to the remaining supporting text for hazard 32. Users should also proceed to the assessment of land-based aquaculture facilities in this guide in order to examine other environmental hazards that can be posed by land-based facilities. (Pathway is under construction.)

<u>Biological barriers: triploid induction and production of all-female lines.</u>
Triploidy induction is widely accepted as the most effective method for producing sterile fish for aquaculture (Tave, 1993; Benfey, 1999). Triploidy induction disrupts gonadal development to *some* extent. Typically, gonadal development is more fully disrupted in females than in males. In general, ovarian growth is greatly retarded whereas testes grow to near normal size. Triploid males often produce viable sperm but at greatly reduced numbers and with aneuploid chromosome numbers and other abnormalities. In most though not all species, fertilization of eggs with milt from triploid males produces progeny that die at embryonic or larval stages. Typically, triploid females do not produce mature oocytes, although several studies that went beyond the normal first time of sexual maturation in diploids did report the occasional production of mature oocytes by triploid females. In summary, the production of all-female lines of triploids in fish and shellfish (Benfey, 1999; Thorgaard and Allen, 1992) is the best way to maximize disruption of gonadal development as a biological barrier to reproduction of aquacultural escapees. The commercial culture of all-female lines is now widespread in chinook salmon farming in British Columbia and rainbow trout farming North America, Europe and Japan. Monosex triploid trout are also widely grown and monosex triploid Atlantic salmon are grown commercially in Tasmania and possibly in Scotland (reviewed by Donaldson and Devlin, 1996:980).

Methods of triploidy induction are well described (see reviews in Benfey, 1999 and Thorgaard, 1995). Triploidy has been induced in numerous aquaculture species such as channel catfish, African catfish, various trout species, various salmon species, common carp, grass carp, various tilapia species, yellow perch, red sea bream, and various loach species (Benfey, 1999:51). The methods for production of all-female lines of fish vary depending on whether the species has an XY sex-determining system or a WZ sex-determining system, are also well described and have been used successfully on a broad variety of aquacultural species (reviewed by Tave, 1993:268-277).

Donaldson et al. (1996: figure 5) summarized the production cycle for integrating triploidy induction into a monosex line with additional detail provided by Donaldson and Devlin (1996a) for salmon, trout and other species with an XY sex-determining system. Applying this production cycle to transgenic fish involves initially developing an all-female line of transgenic fish, then fertilizing transgenic eggs with milt from the sex-reversed females and inducing triploidy on the newly fertilized eggs. Triploidy induction must occur every time the all-female transgenic line is bred to produce offspring for growout. Under experienced hands, one can expect rates of successful triploidy in the 90th percentile in large-scale production but this will vary with fish strain, egg quality, age of spawners, and induction conditions.

The critical risk management issue is whether to screen every individual destined for growout for the all-female triploid condition or only a sub-sample of each production lot. Screening for the all-female condition only needs to occur once in the development process. The most common screening method is progeny testing, although male-specific DNA probes provide a faster alternative in chinook salmon and perhaps someday in other species (Devlin 1994, Donaldson et al. 1996, Clifton and Rodriguez, 1997). Screening for triploidy must occur in every generation of production fish.

Individual screening has long been required for large-scale stocking of grass carp in Florida (Wattendorf and Phillippy 1996, Griffin 1991). The most effective screening method involves particle size analysis of fish blood samples with a Coulter Counter and Channelyzer (Wattendorf 1986, Harrell and Van Heukelem 1998). Estimated labor and supply costs in 1986 were $0.08 to $0.20 U.S. per screened fish (Wattendorf 1986). It should be possible to maintain or lower this cost at year 2000 prices through economies of scale and the application of computer automation technology. In any event, the cost of individual screening is a small fraction of the current market price of salmon smolts, trout fingerlings, or other early life stages purchased by grow-out farmers.

It is hypothetically possible to induce sterility in fish through gene transfer that aims to disrupt the production of a key enzyme or hormone involved in gonadal development. Some fish research in this direction is at a very early stage of development (e.g., Alestrom et al. 1992). The feasibility of this approach has not yet been proven. Induction of sterility solely by gene transfer might not be a good option because of vulnerabilities known to be inherent to gene transfer. Expression of the transgene responsible for sterility induction could be turned off at any time through methylation, something that genetic engineers do not know how to prevent. The transgene could also undergo rearrangement in the founders or descendants, thus possibly disrupting the expression needed to induce sterility.

If cage culture operations ever produce transgenic fish, the most secure biological barrier would be to raise transgenics that are exclusively all-female, triploid fish and to provide individual confirmation of triploidy. However, these biological measures alone would not fit well with the principle of multiple barrier types. Land-based farming of transgenic salmon fits this principle much better because it allows use of effective mechanical and physical barriers in addition to sterilization of production fish. The diversity and number of barriers may need to be higher in flow-through systems than in recirculating aquaculture systems. The risk of fish escaping is typically lowest in recirculating systems because no more than 10% of the rearing water is discharged daily and many upstream components of the system (such as solids removal) also act as mechanical barriers to fish escape.

Hazard 33.

Possible hazards of increased vulnerability to environmental change and decreased productivity and fitness of wild populations have been identified. The genetic bases of these hazards are loss of genetic differences between aquacultural stocks and wild populations or outbreeding depression. (See supporting text for question 54 for further explanation of these genetic hazards.) The risk of increased vulnerability to environmental change is the product of the probability of interbreeding between escapees and wild fish x the probability of loss of genetic differences between the aquacultural and wild stocks. The risk of decreased production is the product of the probability of interbreeding between escapees and wild fish x the probability of outbreeding depression.

Factors to consider in estimating the probability of interbreeding include, but are not limited to:

- Entry potential - frequency of farmed fish escaping at different seasons; travel distance to all areas harboring wild fish with which they can mate; probability of surviving in transit to these areas. Consider the presence or absence of physical, mechanical, and environmental barriers to such transit. In general, this potential is higher when the aquaculture operation and the populations of wild relatives occur in the same Great Lake than when they occur in different bodies of the Great Lakes. However, each situation should be assessed on a case-by-case basis.

- Introgression potential - probability of surviving to reproduction stage; degree of similarity in reproductive development, timing of spawning and mating behaviors between aquacultural and wild fish; fecundity and gamete viability of aquacultural escapees.

The probability of loss of genetic differences increases as the genetic distance between the aquacultural and wild populations increases. Estimation of this probability requires knowledge of the genetic population structure of wild populations with which the aquacultural escapees could interbreed, as well as these populations' genetic distance from the aquacultural stock, as was discussed in the supporting text for question 54. Assessment cases that have reached this part of the decision tool are missing information on population genetic structure of wild relatives.

The responsible fisheries management agency should determine population genetic structure in order to allow complete estimation of the risk of increased vulnerability to environmental change. Refer to the supporting text for question 55 for general recommendations regarding genetic analyses. In the absence of population genetic data, it may be possible to identify major groupings of genetically divergent populations based on knowledge of adult fish movements between spawning grounds, geographical distances and geographical barriers to gene flow. However, geographical distance does not always parallel genetic distances. For example, chinook salmon (*Oncorhynchus tshawytscha*) in California's Klamath River appear to be descended from a lineage quite distinct from that of chinook in the adjacent coastal populations (Utter et al., 1989; Bartley and Gall, 1990). In another example, Tessier et al. (1997) discovered greater genetic differences between land-locked Atlantic salmon (*Salmo salar*) populations from two tributaries of a single river than between them and a population from a neighboring river. Thus, any attempt to delineate genetically different groups solely on the basis geographical proximity should expect surprises (i.e., large error terms).

The probability of outbreeding depression will increase as the number of generations of domestication of the farmed broodstock increases and the genetic distance between the farmed and wild populations increases. Laboratory or adequately confined field experiments conducted to test directly for outbreeding depression between the populations at issue can greatly assist in estimation of this probability.

In the total absence of outbreeding data, one might turn to a cruder estimation of the risk of outbreeding depression. This involves assessing the degree of similarity (or difference) in life history patterns and ecology of originating environments between the aquaculture production stock (including its founding source) and the wild populations (Miller and Kapuscinski, 2000). As the degree of similarity increases, the potential for outbreeding depression because of introduction of maladaptive genes from the aquaculture stock should decrease. Similarity in life history patterns partly reflects similarity in genetic makeup for these evolutionarily important traits (Ricker, 1972) and increases the chances that the life history patterns of outbred individuals will remain locally adaptive. Similarity in ecology of originating environment is indicative of similarity in evolutionary history, also increasing the chances that outbred individuals will remain locally adapted. This albeit crude approach fits with principles of evolution but is unproven as a risk estimation technique.

Hazard 34.

Possible hazards of increased vulnerability to environmental change and decreased productivity of wild populations have been identified. The genetic bases of these hazards are loss of genetic differences between aquacultural stocks and wild populations and/or outbreeding depression. Refer to the supporting text for Hazard 33 for guidance on factors to consider in estimation of these risks. Refer to the supporting text for questions 54 and 55 for extensive discussion of why one should avoid loss of between-population genetic differences and outbreeding depression as well as for guidance regarding determination of population genetic structure of wild populations.

Hazard 35.

To date, the most reliable sterilization method involves producing all-female, triploid lines. For further background, guidance and discussion of potential pitfalls, see the supporting text for hazard 32 under the sub-heading, "biological barriers: triploid induction and production of all-female lines". Screening production animals for the triploid condition before selling or stocking them into a cage aquaculture system is necessary because it may be hard to achieve 100% percent triploidy in large batches and small batch-to-batch deviations in biological characteristics and operator handling can reduce the success rate. It may be wise to monitor for permanent sterility in triploids; reversion to the diploid and fertile condition was recently discovered in a group of triploid oysters much to the surprise of shellfish biologists (Blankenship, 1994). To date, no one has reported reversion in fish.

Some interspecific hybrids of fish are sterile, but not all are. For instance, hybrid walleye (walleye x sauger) are of increasing interest in private aquaculture but these hybrids are fertile. Finally, the exclusive farming of monosex fish populations (Solar and Donaldson, 1991) is inappropriate as a *sole* risk management measure if wild relatives exist in the Great Lakes because escapees can still interbreed with wild males of the same or related species. Exclusive farming of monosex stocks could be part of a larger risk management program in cases where there are no wild relatives of the same or potentially hybridizing species in the Great Lakes. For this to be true, the proposed culture species constitutes an introduction into the Great Lakes. In this event, the user should refer to Appendix 1, the Council of Lake Committees Procedures for Consultation for Introductions in the Great Lakes Basin (1992). This document is currently under revision. The user is expected to seek endorsement from the Council of Lake Committees before proceeding with this introduction.

Hazard 36.

A possible hazard of increased vulnerability to environmental change and decreased production of wild populations has been identified. The genetic bases of these hazards are loss of genetic differences between aquacultural stocks and wild populations and/or outbreeding depression. (Note: in cases where the wild relatives constitute one panmictic population in the Great Lakes, outbreeding depression is the hazard of concern; see supporting text for question 57.) All other factors being equal, using non-local broodstocks for aquaculture will generally increase these risks. An exception would be if population genetic studies show a high degree of genetic relatedness and many similarities in life history traits between the aquacultural broodstock and local wild populations. Refer to the supporting text for Hazard 33 for guidance on factors to consider in estimation of these risks.

Hazard 37.

A possible hazard of increased vulnerability to environmental change and decreased production of wild populations has been identified. The genetic bases of these hazards are loss of genetic differences between aquacultural stocks and wild populations and/or outbreeding depression. For guidance on risk estimation, see the supporting text for Hazard 33. For guidance on sterilization, see the supporting text for Hazard 35.

Optional Precautionary Plans

Optional plans include an emergency recovery plan for escaped fish, a fish health contingency plan, a fish disposal plan, and a predator prevention plan. To be truly useful, aquaculture facility managers should have written versions of these plans and train staff to implement the plans.

Emergency Recovery Plan

The purpose of this plan is to define the most common types of emergencies that might occur at a facility and outline measures to prevent loss of the cultured fish.

Responsible party. The facility operator or designated proxy must be available in person or by phone at all times to respond to emergency problems.

Notification of loss of confinement. In the event of loss of confinement, the responsible party must notify responsible local agencies. In most cases, the first local agency to contact is the local office of the state or provincial fisheries management agency.

Mitigation or recovery plan. The emergency response plan should include a plan for mitigation or recovery of escaped cultured fish in cases where the facility site and biological features of the cultured fish allow recovery or mitigation. The state or provincial fisheries management agency should be involved in development of such a plan because it will probably have oversight authority over any recovery or mitigation actions that occur in natural waters. (Agricultural Biotechnology Research Advisory Committee, Working Group on Aquatic Biotechnology and Environmental Safety, 1995: 46-47).

Fish Disposal Plan

The purpose of this plan is to identify the method of disposal of dead organisms found in the rearing units.

Removal of sick and dead animals can minimize the spread of pathogenic populations. The disposal of infected fish directly into a Great Lake is hazardous to both wild and cultured fish. Methods for storage and transfer of dead fish should be identified and detailed in a written plan. The nearest land-based disposal site should also be identified here. Any additional construction of structures necessary for waste disposal should also be included in the disposal plan.

Predator Prevention Plan

The purpose of this plan is to minimize the impact that piscivorous birds and mammals have on cultured fish. Mortalities, infection as a result of injury caused by piscivores, and rearing unit damage from predator actions, (leading to escape of cultured fish), all may result in serious economic loss. Many piscivores exist in the Great Lakes and this plan should identify populations that may prey on fish reared in the proposed facility as well as preventative measures that will be taken to minimize encounters between predators and cultured fish.

Monitoring

In the event that a hazard has been identified and the risk accepted, effective monitoring for the specific hazard and its environmental effects should be part of the plan. Before an aquaculture facility begins operation, baseline measurements of the site's relevant biological, chemical, and physical variables should be taken to allow valid comparison of changes against pre-operation conditions. Threshold limits should be identified and agreed upon before the start of production, thereby reducing the need for emergency measures. The operator should know what specific actions to take if monitoring suggests conditions are approaching threshold limits. For example, if escapes exceed a specified percentage of production stock, additional safeguards such as stronger netting, improved methods of handling, or better predator control may be suitable actions to reduce the risk of reaching a threshold limit.

In another example, if the assessment tool has identified a hazard to benthic organisms, it would be appropriate to take a baseline measurement of sediment chemistry and benthic biota. Monitoring of sediments can assist operators in identifying whether an operational change such as different feeding strategies or if a reduction in production volume will be necessary to adjust to the assimilative capacity of the local environment. Fallowing, although accepted in many marine production areas, should be considered only as an emergency measure, for instance, to break a disease cycle. The preferred solution to excessive organic buildup from aquaculture food and feces is to achieve a production volume that matches the assimilative capacity of the local environment. Because it takes much longer for a benthic environment to recover than it does to load the site with organic wastes, fallowing merely increases the areas impacted by an aquaculture facility (Black, 1998). Thus, it is not appropriate as a routine method of managing overproduction of waste. Operating at an appropriate production volume combined with relevant monitoring can better minimize the hazard to the benthic environment.

Although often costly and logistically difficult to carry out, monitoring that employs feasible data collection methods, with sufficient statistical power to detect change, should be considered for any hazards identified in the assessment tool. Conclusions drawn from statistical analysis of monitoring results might involve one of two types of error. A type I error occurs when the statistical analysis indicates that the aquaculture facility has an adverse effect when in fact no such harm exists. A type II error occurs when the analysis indicates that the aquaculture facility has no adverse effect when in fact it does cause environmental harm. The potential for harm is greater when a type II error occurs than when a type I error occurs. Most environmental harms involve long time lags before recovery and some environmental damage is irreversible (Dayton, 1998). Type I errors, in contrast, are usually limited to short-term economic costs (Dayton, 1998). Monitoring activities should therefore seek to minimize type II errors.

Flowchart Summary Documentation Worksheet

No. ***Flowchart Section***

I. Determination of Assessment of Pathway led to:

___Hazard 1: Harvesting organisms in these infested waters may pose a hazard to the Great Lakes aquatic ecosystem if aquatic nuisance species were accidentally released. Operator must demonstrate acceptable specific points during processing that enable the operator to identify and remove aquatic nuisance species organisms.

___Risk accepted. Demonstration is acceptable.

___Risk not accepted. Demonstration is not acceptable. Harvest in water bodies that do not contain aquatic nuisance species.

___Hazard 2: Collection methods may pose hazard to habitat. Operator must identify methods to minimize impact of collecting or harvesting in this area.

___ Risk accepted. Methods have been identified.

___Risk not accepted. Harvest in areas less vulnerable to collection methods.

___Hazard 3: Introducing a new species poses a hazard to the Great Lakes. Refer to the Council of Lake Committee's Procedures for Consultation for Introductions in the Great Lakes Basin (1992).

___Approved

___Unapproved. Revise operation proposal so that cultured organisms and effluent will not reach a tributary that flows into the Great Lakes, a connecting water body of the Great Lakes or one of the Great Lakes.

___Terminal Point 1: Go to Plant Assessment Tool

___Terminal Point 2: Go to Shellfish Assessment Tool

___Terminal Point 3: Contact managing agencies for approved species

___Go to Plant Assessment Tool.

___Go to Shellfish Assessment Tool.

___Go to Land-based Assessment Tool.

___Go to Section II, Assessment of Suitable Environment.

___Go to Section X, Impacts of Facility and Infrastructure.

II. Assessment of Suitable Environment led to:

___Hazard 4: A sub-optimal environment poses hazards to cultured organisms including reduced growth, higher susceptibility to disease or mortality.

___Risk accepted.

___Risk not accepted. Relocate facility.

___Hazard 5: Excessively rapid currents pose hazards to cultured species including reduced feed retrieval, excessive energy use, increased susceptibility to injury and excessive stress. Another hazard is damage to structural integrity of facility leading to escape of cultured organisms.

___Risk accepted. Go to Section III, Effects on Other Lake Users.

___Risk not accepted. Relocate to more suitable environment.

___Go to Section III, Effects on Other Lake Users.

III. Effects on Other Lake Users led to:

___Hazard 6: Proximity of aquaculture facility poses a hazard to a culturally significant area. Consult with Native American or First Nations agencies to determine if facility will be suitable for area.

___Risk accepted.

___Risk not accepted. Relocate facility to area outside of culturally significant area.

___Hazard 7: Proximity of aquaculture facility poses a hazard to a historically significant area. Consult with designated historical agency to determine if facility will be suitable for area.

___Risk accepted.

___Risk not accepted. Relocate facility to area outside of historically significant area.

___Hazard 8: Location of this facility poses a hazard to navigation. Consult with the Army Corp. of Engineers or Canadian Coast Guard to determine if navigational traffic will be adversely affected.

___Risk accepted.

___Risk not accepted. Relocate facility to area where navigational traffic will not be impeded.

___ **Hazard 9: Proximity of aquaculture facility poses a hazard to other lake users.** Therefore, other users, if any, must be identified and solicited for comments on proposed facility. Contact relevant government agency to coordinate such public input.

    ___Risk accepted.

    ___Risk not accepted. Relocate facility to area where other users will not be adversely affected.

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___ Terminal Point 4: Regulatory guidelines for coastal zone management must be met.

___ Go to Section IV. Disease Effects

<u>IV. Disease Effects led to:</u>

___Hazard 10: A "B" Classification poses a hazard when one or more pathogens are found within the past two years.

- ___Risk Accepted
- ___Risk Not Accepted.
  - ___Use different broodstock/production stock.
  - ___Rear organisms in land-based facility

___Hazard 11: A "C" Classification from stocks of the Great Lakes of tributaries flowing into the Great Lakes poses a hazard because there have been less than 3 consecutive and complete annual inspections.

- ___Risk Accepted
- ___Risk Not Accepted
  - ___Use different broodstock/production stock
  - ___Rear organisms in land-based facility

___Hazard 12: Culturing fish in sub-optimal conditions and exposing them to disease agents pose a hazard to both the cultured fish and subsequently to wild fish if a disease outbreak occurs.

- ___Risk accepted.
- ___Risk not accepted.
  - ___Relocate facility to more optimal conditions.
  - ___Rear organisms in land-based facility.

___Terminal Point 5: Broodstock/Production stock must be evaluated by a fish health specialist following the (revised) Great Lakes Fish Disease Control Policy and Model Program.

___Evaluated stock.

___Did not evaluate stock. Do not culture organisms in a lake-based facility.

___Terminal Point 6: A C classification from a source other than the Great Lakes or a Great Lakes tributary poses new disease hazards to native or naturalized Great Lakes species.

___ Procedures implemented in Protocol to Minimize the Risk of Introducing Emergency Disease Agents with Importation of Salmonid Fishes from Enzootic Areas (Horner et al., 1993).

___Procedures not implemented. Do not culture organisms in a lake-based facility.

___Go to Section V, Impacts on Recovery or Rehabilitation Plans.

V. Impacts on Recovery or Rehabilitation Plans led to:

___Hazard 13: The operation poses a hazard to wild organisms that are already "at risk" of decline or extinction.

___Approval granted.

___Disapproved. Relocate to area that will not adversely affect "at risk" organisms.

___ Hazard 14: The proposed operation is a hazard to species targeted for rehabilitation.

___Risk accepted. Operator has identified methods that will avoid adverse effects on recovery or rehabilitation.

___Risk not accepted. Relocate facility.

___Go to Section VI, Impacts on Areas of Concern.

VI. Impacts on Areas of Concern led to:

___Hazard 15: Fish-eating predators may be at risk from harassment.

___Risk accepted. Ensure protective, secure predator apparatus is included in proposal.

___Risk not accepted relocate facility to area not heavily populated with fish-eating predators.

___Hazard 16: The recovery species in the AOC plan may be at risk from interspecific hybridization, predation or competition for food or habitat. More information is needed about the recovery species before a decision can be reached.

- ___Lead person contacted. Risk accepted.
- ___Lead person contacted. Risk not accepted. Culture different species or relocate to a site where adverse interactions with recovery species are less likely to occur.
- ___Lead person not contacted. Do not proceed with operation.

___Hazard 17: Benthic organisms may be at risk unless measures are in place for the removal of excess food, feces and mortalities.

- ___Risk accepted. Measures are in place.
- ___Risk not accepted. Relocate facility.

___Hazard 18: Recovery plans may be hampered by the addition of an aquaculture facility in this area. A mass balance analysis may be necessary to quantify risk. Contact appropriate federal, state or provincial agency for assistance.

- ___Risk accepted. Consultation determined that water quality will not be adversely affected.
- ___Risk not accepted.
  - ___Relocate facility.
  - ___Reduce production volume.
  - ___ Use alternative feed (e.g. high-nutrient dense, low polluting feed (Cho et al., 1994).
  - ___Use alternative mechanisms for removing waste.

___Hazard 19: Contaminated sediments may pose a hazard to cultured organisms due to possible exposure to contaminants. This may also pose a hazard to food safety.

- ___Risk accepted.
- ___Risk not accepted. Relocate facility.

___Go to Section VII, Effects of Settleable Solids on Benthos and Shellfish.

VII. Effects of Settleable Solids on Benthos and Shellfish led to:

___Hazard 20: This poses a hazard to shellfish that are intended for harvest. Operator should develop plans minimize release of settleable solids.

- ___Risk accepted. Plans are acceptable.
- ___Risk not accepted.
  - ___Relocate facility.
  - ___Reduce production volume.

___Use alternative mechanisms for removing waste.

___Hazard 21: Water distance between bottom of cages and lake substrate poses a hazard to benthic organisms. Operator should develop plans minimize release of settleable solids.

___Risk accepted. Plans are acceptable.

___Risk not accepted.

___Relocate facility.

___Reduce production volume.

___Use alternative mechanisms for removing waste.

___Hazard 22: Water current velocity poses a hazard to benthic organisms. Operator should develop plans minimize release of settleable solids.

___Risk accepted. Plans are acceptable.

___Risk not accepted.

___Relocate facility.

___Reduce production volume.

___Use alternative mechanisms for removing waste.

___Hazard 23: Addition of this facility to other neighboring facilities poses a hazard to benthic organisms. Operator should develop plans minimize release of settleable solids.

___Risk accepted. Plans are acceptable.

___Risk not accepted.

___Relocate facility.

___Reduce production volume.

___Use alternative mechanisms for removing waste.

__Hazard 24: Fouling agents pose a hazard to culture operation.

___Risk accepted.

___Risk not accepted. Relocate facility.

___Go to Section VIII, Impacts on Breeding Areas, Nurseries and Fish-eating Animals.

VIII. Impacts on Breeding Areas, Nurseries and Fish-eating Animals led to:

___Hazard 25: Culturing this particular species poses a hazard to wild populations.

___Risk accepted.

___Risk not accepted.

___Culture different species.

___Relocate facility away from spawning habitat.

___Hazard 26: Facility structure or released effluent poses hazards to spawning areas due to the potential of habitat degradation.

___Risk accepted.
___Risk not accepted.
___Relocate facility away from spawning grounds.

___Hazard 27: The location of this facility poses a hazard to breeding or nesting mammals or birds due to the structure of the *facility* or its *operations.* This also poses a hazard to cultured organisms due to possible increased exposure of piscivorous breeders or nesters. Operators must identify methods of minimizing interference with wild nesters including a predator deterrent plan.

___Risk accepted.
___Risk not accepted. Relocate facility to area that is not close to mammal or bird breeding or nesting habitats or colonies.

___Go to Section IX, Water Quality and Cumulative Impacts.

<u>IX . Water Quality and Cumulative Impacts led to:</u>

___Hazard 28: This poses a risk to water quality by introducing excess nutrients, especially phosphorus into a Great Lake.

___Risk accepted.
___Risk not accepted.
 ___Reduce production volume.
 ___ Use alternative feed (e.g. high-nutrient dense, low polluting feed (Cho et al., 1994).
 ___Use alternative mechanisms for removing waste.
 ___Relocate facility.

___Hazard 29: Cumulative effects pose a risk to water quality by introducing excess nutrients, especially phosphorus into a Great Lake.

___Risk accepted.
___Risk not accepted.
 ___Reduce production volume.
 ___ Use alternative feed (e.g. high-nutrient dense, low polluting feed (Cho et al., 1994).
 ___Use alternative mechanisms for removing waste.
 ___Relocate facility.

___Terminal Point 7: Do not proceed with approval unless water quality standards are met.

___ Go to X, Impacts of Facility and Infrastructure.

X. Impacts of Facility and Infrastructure led to:

___Hazard 30: Facility Infrastructure or roads pose hazards to "at risk" species or to species undergoing recovery or rehabilitation plans. User should consult with responsible government agency for the species at issue.

___Risk accepted. Approval is granted.

___Risk not accepted. Relocate facility to area that is less vulnerable to additional construction of buildings or roads.

___ Go to Section XI, Genetic Effects.

XI. Genetic Effects led to:

___Hazard 31: Culture of genetically engineered organisms poses a significant hazard to Great Lakes aquatic communities. Go to the Manual for Assessing Ecological and Human Health Effects of Genetically Engineered Organisms.

___Completed.

___Not yet completed.

___ Hazard 32: This poses a significant hazard to the Great Lakes aquatic environment. Consider disapproval of project as lake-based aquaculture.

___Project disapproved.

___Relocate to a secure land-based facility where GEOs and effluent cannot reach a Great Lake, Great Lakes connecting body or Great Lakes tributary.

___ Switch to culture of non-engineered organisms.

___Hazard 33: This may pose hazards of increased vulnerability to environmental change and decreased production for genetically distinct populations.

___ Fish management agency should assess genetic structure of the species in the Great Lakes and estimate risk. Continue with assessment.

___ Hazard 34: Reproduction by escaped organisms may pose a hazard of increased vulnerability to environmental change and decreased production of genetically distinct populations in *other Great Lakes bodies*.

___ Consult with the fish population/conservation geneticists to assess genetic risks from escapees.

___ No consultation. Do not culture in lake-based facility.

___ Hazard 35: Consultation with population/conservation geneticists has found this poses a hazard to other genetically distinct populations.

___Induce permanent sterility in all production organisms.

___ Relocate to a land-based facility where organisms and effluent cannot reach a Great Lake, G.L. connecting body or G.L. tributary.

___Culture different species.

___ Hazard 36: Escapees from non-local and fertile aquaculture stocks may pose a genetic hazard to populations of wild relatives in the Great Lakes.

___Consult with fish population/conservation geneticists to estimate the risk of increased vulnerability to environmental change and decreased production, then proceed to Optional Precautionary Plans.

___Revision of proposal to make risk acceptable:

- ___Use local stock.
- ___Use non-local stock and induce permanent sterility.
- ___Use different species (and return to beginning of assessment tool).
- ___ Relocate facility to a land-based facility where organisms and effluent cannot reach a Great Lake, Great Lake connecting body or Great Lake tributary.

___ Hazard 37: Using non-local and fertile populations poses hazards of increased vulnerability to environmental change and decreased production for known genetically distinct populations.

___Consult with fish population/conservation geneticists to estimate these risks then proceed to Optional Precautionary Plans.

___Revision of proposal to make risk acceptable:

- ___Use local stock.
- ___Use non-local stock and induce permanent sterility.
- ___Use different species (and return to beginning of assessment tool).

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___ Relocate facility to a land-based facility where organisms and effluent cannot reach a Great Lake, Great Lake connecting body or Great Lake tributary.

___Go to Land-based Assessment.

***___Go to Optional Precautionary Plans, page 56*.**

Upon completion of Assessment Pathway flowcharts and Summary Documentation Worksheet, proceed to Monitoring, page 58.

References

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