A TECHNICAL REVIEW OF THE LAKE ONTARIO FORAGE BASE ASSESSMENT PROGRAM

FINAL REPORT

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Introduction

The Importance of Fisheries Assessment Program Reviews

An essential component of successful fisheries management is an ongoing assessment program to monitor the condition of the fish community in the context of the ecosystem and the fisheries that are sustained by the fish community. Typical objectives of fish assessment programs include determinations of the relative abundance, age distribution, size-at-age relationships, and fish spatial distribution as well as values of environmental parameters that influence fish population dynamics.

Fish population indicators, such as catch rates collected from commercial, recreational (both are fisheries dependent data) and assessment fishing activities (fisheries independent data), are used to monitor changes in fish population abundance. Usually these sources are combined to present a more complete picture of fish abundance. Because fish are not directly observable and have large, complex spatial distributions over time, inferring fish population trends from fish catches taken over a short time interval is extremely challenging because of these inherent sampling difficulties. These difficulties all present particularly strong background "noise" in fisheries dependent data, which ranges from extremely difficult to nearly impossible to separate from real population trends. The trends can also be because of changes in vessel design, fishing gear, electronic fish-locating devices and socioeconomic trends.

Fisheries independent data (such as those collected by bottom-trawling) from well-designed assessment programs are collected in such a way to reduce some of this noise. For any parameter of the fish population or population component (age/size class) being assessed, the program should be consistent with respect to gear, sampling areas, and time period year-to-year. The sampling program should also cover the entire range of the population of interest. Keeping assessment features constant over a time series ensures that inter-annual changes in estimated abundance accurately reflect true changes in absolute or relative abundance. Sampling at the same time from year to year ensures that the diurnal regime of fish is comparable between years but does not adequately account for temperature-induced changes in fish distribution that can be independent of light regime and can vary considerably from year to year (Grosslein et al. 1982, NRC 1998).

It is important for assessment programs to undergo periodic and impartial evaluation of the sampling protocol, gear efficiency, data analysis and interpretation. A typical timeframe for these reviews is every five to 10 years, as new information or technologies become available. Stock assessment reviews are important, but especially so in situations in which the ecosystem and its fisheries undergo changes that increase the uncertainties in the fisheries dynamics. It is essential that the program review be conducted by an external, independent panel to ensure a more objective evaluation and to allow for the influx of new ideas for possible program improvement (NRC 1998, NRC 2000, NOAA 2001).

The Role of Stakeholder Perspectives

An important impetus for the periodic evaluation of fisheries assessment programs is the ongoing concern of fisheries stakeholders about the reliability of the stock assessment data, particularly how it relates to making management decisions. Such stakeholder concerns are commonplace on a global scale.

Based on many studies conducted in the world's oceans, fish catch data collected from a properly designed trawling program can provide less biased information than sampling programs in which different gear and techniques are continuously being adapted, resulting in poor agreement in fish abundance estimates from fisheries-dependent and fisheries-independent data. This situation often creates communication gaps between assessment biologists and fisheries stakeholders. Some of the primary factors that can contribute to these communication gaps include:

- Fisheries assessment gear and related sampling programs remain relatively constant over time to ensure that abundance estimate biases from sampling gear don't change, in contrast to recreational and commercial fishermen that continuously change their fishing gear to either maintain or increase catch rates.

- Fisheries assessment programs place extensive economic and manpower demands on agency resources. Assessment activities are limited in scope and are perceived as inadequate by stakeholders.

- Fisheries stakeholders often feel that assessment data are biased and regulations based on the data are politically motivated. Moreover, there are long timeframes between data collection and implementation of revised management plans.

- Fisheries stakeholders often operate in different time horizons than assessment biologists and are generally concerned with maintaining or increasing cash flow on an annual basis. Biologists focus on the long-term sustainability of fisheries.

- Different stakeholders may have different goals for the fisheries that may vary from the goals of fisheries managers. Some stakeholders prefer high catch rates whereas others prefer trophy sizes of the same fish species; managers cannot satisfy all stakeholder demands all the time.

- Stakeholders spend much time on the water and are often very skilled in locating fish. They either are unwilling to share this information with other stakeholders and biologists or become frustrated when biologists are reluctant to listen to them or utilize their expertise. On the other hand, scientists are reluctant to use stakeholder-generated information because the information can be biased because it is collected where fish densities are highest and is not representative of the entire distribution of the fish populations of interest.

- Biologists view assessment results as the best possible depiction of a fishery and operate with scientific sampling and analytical methods that are difficult to understand by stakeholders. Even if biologists utilize stakeholder information, the data are integrated into complex mathematical models that suggest management strategies that are often met with suspicion by stakeholders because stakeholders often see the assessment results as overly pessimistic about the status of a fishery.

- Restrictive management strategies designed to sustain individual fisheries (protection of spawning stock) and to maintain integrity of the ecosystem that supports these fisheries are implemented when considerable numbers of fish are observed by stakeholders. The rationale for these regulations is often misunderstood or misinterpreted by stakeholders.

These different frames of reference among biologists and varied stakeholders are at the core of controversy about fisheries management. They realistically reflect large uncertainties associated with making scientific predictions for future fish community trends and for establishing fisheries management strategies. Fisheries stakeholders often criticize the scientific data collection process and assessment estimates because of this uncertainty. As a result, fisheries stakeholders can lobby for less restrictive management actions and a more risk-prone strategy targeting the higher range of assessment estimates. This has sometimes resulted in over harvesting and collapse of the fishery. Examples include several ground fish stocks in the Western Atlantic, where fisheries were managed using anecdotal information. There are also situations where fisheries stakeholders are correct in their assertions based on factual information they possess.

Various assessment review panels recommend that fisheries stakeholders and biologists maintain, or open, lines of communication, share information, address misunderstandings, and develop more cooperative efforts. An important part in developing a more cooperative atmosphere and in improving the scientific quality (accuracy, precision, comparability, completeness and representativeness) of the data collection and analytical framework of the assessment program are periodic, independent peer reviews.

Suggested NMFS Assessment Guidelines

Despite constraints faced by assessment biologists, it is possible to make some adjustments to the assessment program to improve the efficiency and precision of the program, particularly should additional resources become available to support these activities.

While no standardized review guidelines exist, the National Marine Fisheries Service (NMFS) has developed a comprehensive series of tiered criteria that are often recommended for evaluating fisheries assessment programs (NOAA 2001). These NMFS criteria are catch level, abundance, life history, assessment level, and sampling frequency level. An assessment program can be assigned a numerical value corresponding to a performance level score in each of the five criteria. The numerical ranks extend from 0 as the lowest level upwards to higher levels of performance. These criteria and their characteristics are summarized in Appendix 1.

The NMFS tiers of excellence that can be used as targets for improvement of assessment programs are:

Tier 1: Improve stock assessments using existing data.

For target species, efforts should:

- make the assessment program more timely and comprehensive,
- integrate more quality control measures, and
- better communicate the results to fisheries managers and stakeholders.

These efforts entail more comprehensive characterization of the level of uncertainty associated within the state of the fisheries by stochastic modeling procedures. Such activities are time consuming and require additional staff support. For species of unknown status, additional data can be “mined” from archived datasets compiled by fisheries assessment or management agencies to serve as proxies of better-known species. The data must include information on catch by size or by strata.

Tier 2: Elevate stock assessment programs to new national standards of excellence.

To reach this tier, the frequency of assessments should be upgraded to at least level 3, the level at which changes in fish abundance for all managed species are estimated and monitored on a frequent, regular time scale (see Appendix 1). Achieving this level of assessment requires additional collection of fisheries-independent data, which imposes requirements for additional sampling time on cruises, prolonged sample processing and additional staff. This additional effort ensures that important information such as the association of fish and their habitat and how environmental features influence fish catches is collected and helps identify means of standardizing fish catches. This additional data does not simply entail an expansion of sampling effort but is an improvement of sampling mechanics (gear, sampling design, data analysis), including modifying existing mechanics or adoption of new mechanics. Reaching this tier also involves a greater interaction with other fisheries scientists (biometricians, modelers, ecologists). Although reaching this tier involves increased cost and effort, the likelihood of significant improvement to the assessment program is ensured.

Tier 3: Adopt the next generation of assessment methodology.
Additional improvements are possible by increasing the frequency and precision of fisheries surveys and by increasing the number of fish species for which data on age composition exists.

The next step is improving forecasting methods to more accurately predict future population trends, so that more focused protective management actions can be developed.

Such longer-term efforts include development of improved recruitment, biophysical (climactic), and ecosystem models that improve the ability to understand species interactions and utilization of high technology tools. Achievement of this tier requires additional time contributions of existing staff and hiring new staff as well as staff training on the use of new methodologies to expand the spectrum of available tools. Additional interactions between multidisciplinary scientists and assessment biologists are also needed.

The Lake Ontario Forage Base Assessment Program

The Lake Ontario Technical Review Process

Recent changes ascribed to nuisance species introductions and nutrient abatement in Lake Ontario have resulted in changes in fish distribution and alteration of the trawling assessment program. Sampling difficulties during the forage assessment program appeared during the mid-1990s as bottom trawls became clogged as dense dreissenid beds formed around the lake basin.

Moreover, there has been increasing concern from sport fishing stakeholders and local legislators about the accuracy of the assessment program. In particular, NYS Senator George Maziarz requested that NY Sea Grant organize a technical review of the forage base assessment program. The contentions from the lay community are that the stock assessment methodology is flawed and reflects poorly on the credibility of the involved agencies. Public criticisms largely stem from a general lack of familiarity with the process of scientifically-based sampling, and a disagreement between the sampling results and forage fish population status. Many stakeholders concluded that the Lake Ontario stocking policy was based on unreliable data.

The major stakeholder concerns could be summed up as:

1. Assessment biologists don't do enough transects and need to change the sampling program.

2. The trawling assessment is conducted where the fish are not present, hence many forage fish are missed and forage fish populations are thus underestimated.

3. Stakeholders spend more time on the lake than biologists and have knowledge that cannot be refuted with science.

4. The assessment data are not good enough or are wrong, so that the fishery cannot be properly managed. How can good decisions be made on stocking levels, if the forage base assessment program is so flawed?

Following Senator Maziarz's request, NY Sea Grant conducted an advisory meeting with biologists from the United States Geological Survey (USGS), the New York State Department of Environmental Conservation (NYSDEC), the Ontario Ministry of Natural Resources (OMNR) and Cornell University during October 2002 to discuss the evaluation strategy. All agencies were supportive of the review, feeling that it would be of great service to them as well as address stakeholder concerns. It was decided that the review would consist of three independent experts critiquing a seven-page white paper, written by USGS biologist Robert O'Gorman, outlining the sampling program. In addition, reviewers received supporting information in a technical report on Lake Ontario ecosystem changes by Dr. Edward Mills of Cornell University. The reviewers would base their evaluation on a series of evaluation criteria. USGS scientists Jim Johnson and Bob O'Gorman played a pivotal role in developing the workshop evaluation criteria:

- Is the level of sampling sufficient to statistically evaluate population trends?

- Does the program meet the goals/objectives of the sampling protocol?

- Are the data generated from the assessment program sufficient for modeling population dynamics of forage species?

- Are there sufficient data collected to develop a credible, predictive model?
- Does the assessment program adequately reflect changes in relative and absolute abundance of forage species?
- Is the sampling effort sufficient to capture spatial changes in fish abundance?
- Does the sampling program adapt to changes in fish behavior?
- Is the assessment program adequate to make good management decisions?
- What other data are needed to make better fisheries management decisions?

The review process was an externally facilitated, technical workshop for evaluating a written summary of the assessment protocol from USGS, using evaluation criteria (above and on page 8) developed by the USGS, NYSDEC and OMNR. The target audience of the workshop was fisheries managers and researchers. Three prominent scientists with expertise in fish assessment agreed to participate on the review: Dr. Jerald S. Ault, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami; Dr. Steve Murawksi, NMFS Woods Hole; and Steven Smith, Department of Fisheries and Oceans, Halifax (See Appendix 2 for review panel biographies).

Each of the reviewers was given two months to review the documents and was responsible for submitting comments directly to USGS and NYSDEC prior to the technical workshop. During the workshop, the evaluations were presented to Lake Ontario fisheries managers and researchers. This process allowed agencies time to prepare a response to reviewers as to how or if their recommendations could be integrated into the forage assessment program for Lake Ontario. The workshop facilitator was Dr. Lisa Kline of the Atlantic States Marine Fisheries Commission. Dr. Kline has extensive experience in fisheries assessment and in conducting assessment review processes. Every effort was taken to insure the objectivity of the review as well as to provide a safe, non-confrontational forum in which to conduct it.

A Brief History of the Lake Ontario Assessment Program

The present sampling frame in Lake Ontario consists of a series of systematic transects (fixed trawl stations), a model-based sampling design that is stratified or distributed over a range of depth strata. This sampling program has evolved over the years through a series of adjustments, including vessel changes and gear modifications. Assessment biologists have undertaken considerable efforts to standardize data collection and to preserve the integrity of the long-term data set for detection of changes in relative abundance of prey fishes.

The cooperative (USGS and NYSDEC) bottom trawl program to assess prey fishes was initiated in 1978 and formalized in 1980. Initially, there were two trawling transects: one fixed and one random, located near ports, but the random stations were quickly abandoned because of extensive net damage.

Bottom trawl assessments were timed to coincide with maximum availability of the prey fish of interest to the trawl based on spring through fall trawling conducted in 1972 (International Field Year on the Great Lakes). Alewife were assessed in late April – early May, rainbow smelt in late May – early June, and slimy sculpin in October. Each April - May, trawls were conducted on as near to the same day as practicable, usually +/- seven days, but there was more variation in the timing of sampling in the northeastern basin near Cape Vincent. Timing of rainbow smelt data collection by trawling was less variable than that for alewife data collection because stormy weather was infrequent in late May – early June.

From the late 1970s through the 1980s, alewife abundance increased dramatically following a large winterkill in 1976 and 1977. Because of the population upswing, and funding shortcomings, the number of trawl hauls that could be completed in one day declined even though efficiency of deck operations (sample processing) improved. Fishing all possible standard depths at a transect was abandoned in favor of concentrating sampling efforts in the depth range where alewife were abundant, only sampling outside the depth range of maximum abundance at a few transects, and assuming zero catches at standard depths deeper (shallower) after a catch of 50 or fewer alewives.

In May 1985, the NYSDEC obtained a new 46-foot, steel-hulled vessel, the *Seth Green*, and shortly thereafter side-by-side towing was conducted with the vessel *Kaho* to calibrate trawling speed and determine the fishing power of the *Seth Green* relative to that of the *Kaho*. About 50 side-by-side trials were completed during 1985-1989. Fishing power (paired *t*-tests of log transformed catches) did not differ for rainbow smelt (P=0.24) or lake trout (P=0.29), but was marginally different for adult alewives (P=0.12) and yearling alewives (P=0.07). Based on this analysis, a correction factor was applied to alewife catches made by the *Seth Green*.

During the early 1990s, zebra and quagga mussels (dreissenids) began to clog bottom trawls to the point where the efficiency of the gear was likely impacted. It was also known that the existing trawl doors were excessively large and tended to overpower the old 12-m (headrope) net that was the standard assessment net used for prey fish surveys. New trawl doors were installed and new 18-m (headrope) trawl nets, which fished lighter on the bottom, were deployed. The 12-m trawl net was stretched excessively, reducing the net height to less than 1 meter. In contrast, the 18-m trawl net maintained a headrope height of 2.5 to 3 m. USGS has mentioned that more net/vessel comparisons are needed, suggesting that additional gear would be purchased for use on Lake Ontario if sufficient funds were available.

To compare the fish catching ability of the two trawls, a series of paired tows was conducted during 1995-1998 using two vessels, *Kaho* and *Seth Green*. Regression analyses of depth versus the difference in log transformed catches indicated that the 18-m trawl was more efficient in capturing alewife and rainbow smelt at greater depths, perhaps because it opened higher. Conversion factors were developed to correct for the larger catches in the 18-m trawl at depths exceeding 50 m and to thus maintain comparability within the long-term dataset.

Much effort was placed in maintaining constant vessel speed when trawling and in maintaining winch speed when setting and retrieving the trawl. Digital tachometers were placed on propeller shafts and later use of GPS led to improved vessel speed determination.

Also during the 1990s, the alewife depth and geographic distribution changed. The fish moved further offshore and out of the areas off the eastern shore and northeastern basin. Trawling effort was reduced at depths less than 45 m and in the northeastern basin where catches were invariably zero. Changes in alewife distribution were coincident with zebra and quagga mussel colonization and may have been due to increased water transparency.

Sampling effort did not appreciably change over the years despite vessel breakdowns and funding shortfalls. Program continuity was maintained largely because two agencies, each with a research vessel, participated.

In Lake Ontario, salmonine stocking policy is developed from information on hatchery-return rates, salmonine growth rates, angler-catch data, and from prey fish abundance and biomass trends. The prey fish assessment program, primarily a bottom-trawling effort conducted jointly by USGS and NYSDEC, has been of particular value to fisheries managers because it not only provides an annual measure of forage fish relative abundance and biomass over a broad area but also provides annual measures of age composition and of fish growth, condition, and distribution. (*No such trawl survey exists on the Canadian side of the lake.*) Moreover, because these data were collected consistently for more than a quarter century, they are invaluable for understanding population dynamics and, most importantly, for building predictive models. For fisheries managers, data from the prey fish assessment is paramount in attempting to balance prey populations with salmonine stocking. Any means of either maintaining or improving the accuracy and precision of the assessment program is a high priority for managers.

Results and Recommendations from the Technical Review

In this report, the technical expert reviews have been combined because of a general consensus on the evaluation in terms of the overall assessment program's strengths and suggested areas for improvement.

In general, the reviews were very favorable overall. Where suggested improvements were made, reviewers provided important background information to the Lake Ontario assessment biologists on recommended approaches and tools needed to make improvements. The panel's recommendations for program improvement have been compartmentalized into each of three primary components of the forage assessment program, namely:

- Sampling Design and Methods,
- Data Analytical Process, and
- Modeling Fish Population Dynamics and Fisheries Management Strategies.

Panel recommendations for program improvement will be discussed in the following section. It will be noted in this report that the section recommendations are more extensive than the overall program strengths identified by the review panel. This intent was to provide more background information to assessment biologists on alternative sampling, analytical and modeling methods that are less familiar to this audience. The larger emphasis on panel recommendations presented in this report is therefore *not indicative* of the weight of program strengths versus program recommendations in the overall review.

Overall Program Strengths

- All reviewers felt that the design of the existing assessment program in Lake Ontario was sufficiently robust to detect year-to-year variations in forage fish abundance*, by far and away one of the over-riding concerns of this review process*. During the spring prior to thermal stratification, the timing of the assessment program coincides with inshore movements of the alewife, when the spatial distribution of the species is most concentrated near bottom and vulnerable to sampling gear. (Over the last decade, effort has also been made to develop a pilot acoustic assessment program for Lake Ontario to provide another set of independent estimates of forage biomass and abundance.)

- Reviewers were impressed with the extensive inter-agency collaboration between USGS and NYSDEC, in terms of contributing comparable vessels, manpower and financial support of the field program both in development and refinement of the forage base assessment program. The data are also readily shared with OMNR, other agencies and academia.

- The review panel praised USGS and NYSDEC for maintaining the integrity of the long-term data set on relative abundance of Lake Ontario forage fish species. The forage base assessment data date back to 1978, a sufficient duration to detect changes in relative abundance of the three forage species. In addition, discussions between the review panel and USGS biologist Bob O'Gorman revealed that the Lake Ontario data set is readily adaptable to subsequent "data-mining" modeling exercises and trend re-analyses using alternative methods. Some modeling efforts recommended by the review panel to address system uncertainty will be discussed in the following section.

- According to review panel comments, the sampling intensity (effort) was a particular strong suit of the Lake Ontario program. Of USGS and State/Provincial assessment trawling field operations in the Great Lakes, the sampling effort expended on the Lake Ontario assessment program is proportionally the highest. Institutional memory of the assessment program and the sampling frame remain intact — important factors in maintaining sampling consistency. The review panel felt that considerable attention had been paid to detail on choice of sampling stations and to gear design by cooperating agencies.

- The reviewers positively commented on the adaptability of the sampling program and the responsiveness of participating agencies in adjusting sampling to maintain the integrity of the long-term data set. The assessment program was able to compensate in part for ecosystem changes in Lake Ontario by adjusting to fish distributional shifts reflected in a revised sampling frame and custom gear modification. Where gear or vessel changes have occurred out of necessity, for example, when dreissenids invaded the lake and created tearing hazards to trawl netting, sampling gear was custom designed by participating agencies to compensate for changes in fishing effort. In addition, numerous field trials were conducted to estimate correction factors between nets and vessels to help standardize trawl data since 1978. This archived data set can readily lend itself to data mining exercises for re-analyses.

- The panel commented on the strong academic partnerships with the assessment scientists on collaborative research projects. This collaboration has produced a noteworthy body of peer-reviewed research that has been published both separately by agency scientists and by scientists in conjunction with academic researchers (See Appendix 3). The data have also been compiled into several whole ecosystem level publications and have been utilized in the development of two predator-prey demand modeling efforts, albeit simplistic, to make predictions of the salmonine fisheries' sustainability.

- Over the years, the cooperating agencies have worked actively and very effectively with sportfishing stakeholders at annual educational forums. This improved dialogue with resource users has provided them with a better understanding of fisheries dynamics and the problems inherent in collecting fisheries data in assessment programs. Stakeholders are now much more supportive of the assessment program, despite being critical of the fish assessment data in the context of making fisheries management decisions. Again it should be noted, this is not a situation endemic exclusively to Lake Ontario fisheries management.

Review Panel Recommendations

Within the three content areas of the assessment program, the reviewers' recommendations focused on means of improving the precision of abundance/biomass estimates that could not only reduce variances around these point estimates, but could provide improved means of variance estimation and comparisons of variances calculated from disparate methodologies.

I. Sampling Design and Methods

1. Fixed versus random stratified sampling

In assessment programs, the sampling area should encompass the available sampling locations for the species of interest the same time each year. Within the sampling frame, sampling locations can be chosen randomly or are fixed over time within the survey area. In each case, however, a standardized sampling procedure in terms of fishing gear deployment (time or distance) is used at each sampling station to minimize sampling noise. The type of design chosen (fixed vs. random) influences the mean catch and total abundance calculations. The ongoing debates among assessment scientists on such issues as fixed (model based) versus random (design based) sampling have been widely reported in the literature (Grosslein et al. 1982, NRC 1988, NRC 2000, NOAA 2001).

In random sampling designs, properties of the estimates (precision and bias) are evaluated as functions of the sampling design and are therefore design based. Although completely random designs can offer lower transit distance between sampling locations, this approach can also result in reduced geographic coverage of the assessment area, since large areas may not be adequately covered and random stations can be close together (NRC 1988, NRC 2000, NOAA 2001). Random sampling is also unsuitable for Lake Ontario trawling due to heavy dreissenid beds and rough-bottom areas that would seriously damage trawl nets, creating excessive down time for vessels and crew.

Fixed sampling designs are considered model-based because they require a model for determining the properties of the mean and for estimating the variance around the mean. The use of fixed stations is most appropriate where a spatial model of fish distribution is an objective of the survey and spatial patterns are modeled as a function of distances between fixed points distributed over a broad range. This method, however, requires sophisticated statistics (NRC 1998, NRC 2000, NOAA 2001). Fixed station designs operate under the assumption that changes in relative abundance at persistently selected sampling sites reflect changes in absolute abundance of the entire population. Sampling stations are selected to ensure an adequate coverage of the system, however, fixed station designs are considered most appropriate for developing a spatial model of fish distribution. Although abundance trends can be biased, a fixed station design can provide useful inter-annual abundance if the same stations are selected (NRC 1998, NRC 2000, NOAA 2001).

There is consensus that the precision of the abundance estimates generated by either design is improved by sampling in discrete strata, with each stratum being defined by temperature, depth, latitude/longitude, species distributions or management zones. The majority of assessment programs incorporate a stratified random (design-based) approach where sampling stations are located randomly within each stratum. The only requirement of this design-based approach is that the sample be taken in accordance with the design at random. The mean catch from the strata is calculated and is weighted by the proportional area of each stratum to the overall survey area to calculate the total abundance in the survey area. In situations where spatial correlations between observations (individual trawl catches) are present, and the spatial structure of the assessment area can be modeled, the stratified fixed station design can provide more precise abundance estimates than those from a simple random design (NRC 1998, NRC 2000, NOAA 2001).

It is important during the review of a given assessment program to evaluate the assessment program's design efficiency and the degree of precision for one design relative to another (or to provide a measure of how much the survey design has contributed to increasing the precision of the survey estimates). There are different considerations in evaluating the precision of a stratified random design versus that of a stratified fixed design. Precision of the stratified random design is related to the strata overlap with the distribution patterns of the target species and whether the sampling intensities are increased in the more variable strata. Evaluation of a fixed station design's precision should be in the context of the adequacy of the number of sampling stations and their locations in estimating stock assessment model parameters.

The Lake Ontario forage assessment program consists of a fixed station or model-based stratified design, which, according to the review panel, should be examined more closely. Some statistical difficulties exist in obtaining precise variance estimates relative to those generated by stratified random designs from classic statistical methods, because there are no equivalent variance estimators for both fixed and random stratified designs.

***Specific panel recommendations for evaluating fixed versus random sampling*:**

- Accuracy of parameter estimates from a fixed station design, such as the Lake Ontario program, can be evaluated on the basis of the adequacy of sampling locations and their number. Using archived data from the Lake Ontario dataset, the panel recommended that USGS and NYSDEC evaluate the design efficiencies of a fixed versus stratified design through comparisons of abundance estimates and variances from fixed and hypothesized (using randomization techniques) random stratified designs to determine relative efficiency of one design to another.

- Statistically optimal methods such as kriging, a geostatistical technique, can help evaluate sampling adequacy as well as small-scale versus large-scale variations in fish abundance. Geostatistics is a branch of applied statistics used to detect and model spatial patterns, which can be used to compare variances between stratified random and stratified fixed sampling designs (as well as to evaluate catchabilities between different sampling gears/vessels on a time series). Using a non-parametric bootstrap technique, geostatistics has also been used to compare the precision of fish abundance estimates from fixed versus random sampling designs (Harbitz et al. 2003). The use of randomization tests such as bootstrapping in comparing variance estimates will be discussed later in this report.

- USGS and NYSDEC should expand efforts in collecting information to identify ancillary environmental and habitat variables that are correlated with fish catches and consider the adoption of a hybrid fixed adaptive design that accounts for ancillary variables related to fish abundance. See #2 sampling frame area recommendations on page 16 for details.

2. **Sampling frame area and geographic coverage**
A key consideration in the design of a trawl survey is the geographic coverage of the sampling program. Ideally, the sampling frame should encompass the complete range of the fish stock because fish stocks are highly mobile. In addition, the relationship between fish catches and other variables needs to be evaluated for modeling purposes (NRC 1998, NRC 2000, NOAA 2001). Because the sampling program covered only about one-eighth of the lake, reviewers questioned the assumption used in the Lake Ontario assessment program of equivalent proportions of fish inside and outside of transect — in other words are areas trawled truly representative of fish distribution patterns? If not, then, areas not trawled could be preferred habitats due to bottom type and trawl data could underestimate relative abundance.

Specific panel recommendations for evaluating the sampling frame area:

- The panel encouraged USGS and DEC to expand assessment efforts to better understand the relationship between fish distribution and ancillary variables, such as bottom type, depth etc. Hydroacoustic assessments should be improved and run coincident with trawling and in non-trawled areas to test the representativeness of the trawling stations of true population distribution. Existing bathymetric maps of Lake Ontario can be useful in quantifying different bottom types and their suitability for trawling.

- The panel recommended conducting bilateral trawls cooperatively with Canadians on the Canadian side of Lake Ontario or establishing agreements for New York boats to sample on the other side. Unfortunately, no comparable Canadian vessels are available and there are time and manpower limitations within USGS and NYSDEC that would restrict such an expansive effort.

- The panel suggested using an acoustic fish data viewer to describe spatial inter-relationships of fish shoals and plankton patches or fish in relation to habitat/bottom types combined with new image processing tools for distinguishing between fish shoals and plankton patches, and predator and prey relationships/aggregations.

- “Point and click method” imaging software for comparison of acoustic transects and other environmental and biological parameters using additive models (GAM) are now available. Effects of fish biomass indices or hydrologic parameters on confidence intervals can be determined by resampling as discussed in the next section.

- Another recommendation was related to the changing and largely unpredictable spatial distribution of alewife due to ecosystem changes observed by USGS and NYSDEC. The panel suggested that adaptive sampling approaches could be considered to address changing fish distributional patterns. Adaptive sampling can potentially improve sampling efficiency when parameters that influence fish abundance are incorporated into the sampling design through an adjustment of the assessment program to changing fish abundance patterns encountered during current sampling operations as opposed to historic locations. These designs may decrease site-to-site travel time if sampling effort is redirected into fewer locations (NRC 1998, NRC 2000, NOAA 2001). Adaptive sampling programs can be especially useful when fish habitat preferences and amount of preferred habitat are not well known, as in Lake Ontario.

- Known relationships between alewife catch/distribution and temperature/depth, etc. (refer to first specific recommendation for evaluating fixed versus random sampling on page 15) could be used to predict catches for un-trawled areas using ancillary variables of catch or by an empirical likelihood method. The panel, however, cautioned that although these approaches can optimize the collection of survey data, they are quite complex to implement and are error prone.

- Inevitably, if the same sampling intensity is utilized in all areas, sampling in areas within the sampling frame (strata) that contain higher fish densities will result in fish catches of higher variability, leading to a reduction in precision of abundance estimates. The panel considered the Lake Ontario sampling design as unbalanced — not proportional to the area occupied by strata in the sampling frame because some depth strata are larger than others. Although such designs are commonplace in many fisheries assessment programs, the panel recommended that the Lake Ontario program consider adopting a balanced sampling design by adding more fixed stations in certain strata so that all strata are sampled in proportion to the area occupied in the sampling frame.

  Alternatively, the panel suggested that USGS and NYSDEC could compensate for the existing unbalanced design by using predictive models that incorporate information of fish catches in relation to covariates such as temperatures or bottom types obtained from remote temperature probes on bottom trawls and expanded hydroacoustic assessment of fish abundance over different bottom types.

- Because different strata have different variances and different numbers of observations resulting in fractional degrees of freedom, the panel suggested the use of Satterthwaite's approximation, bootstrap method, or empirical likelihood method (used for very rare species). Satterthwaite's approximation is an interpolative function that is useful in accommodating fractional degrees of freedom in statistical analysis.

- While attempts should be made to maximize spatial coverage of the fish survey, at the same time, effort should be sought to make sampling efficient and minimize expenses of prolonged ship time (NRC 1998, NRC 2000, NOAA 2001). Such methods need to be evaluated extensively before and after adoption. USGS and NYSDEC employ a "stopping rule" that eliminates further sampling inshore (and offshore) stations when trawl catches decline to 50 individuals per haul and less. Although such stopping rules are commonly used in marine surveys (NRC 1998), reviewers suggested that the present Lake Ontario sampling frame does not address or factor in for portions of the stock inshore of the transect. Reviewers commented that fish abundance and biomass would be underestimated if fish catches were low and uniform in stations normally dropped under the stopping rule, and large numbers of fish could potentially remain uncounted if the inshore areas contain larger numbers of fish. The catch data would concomitantly provide overestimates of abundance and biomass, if stations that would have yielded zero catches are dropped from the stratum because of the rule. The panel recommended that either additional trawling assessment be conducted, or an integrated trawl/acoustic assessment be employed to evaluate the stopping rule.

3. Acoustic trawl assessment integration

Variability in trawl estimates may not reflect abundance changes but may be a function of statistical noise particularly with pelagic species such as the alewife. The panel suggested that Lake Ontario trawl data may be biased if fish abundance is correlated with bottom types, particularly if fish abundance is correlated with untrawlable bottom type. Data from USGS and NYSDEC suggest changes in trawl availability of Lake Ontario alewife that may be attributed to negative phototropic behavior.

Specific panel recommendations for integration of trawl and acoustic assessment data:

- As the panel pointed out, both acoustic and trawl assessment have inherent biases and cannot efficiently sample the entire water column. Both methods are considered either as independent estimates of the same population, tending to reflect similar population trends, or as measurements of different fractions of the same stock because of variable sampling efficiencies. Abundance estimates from the two techniques may vary considerably because they measure different fractions of the same stock, and reflect discrepancies from year to year due to variable growth rates, age composition, ontogenetic changes in distributional patterns, population densities and gear vulnerabilities. It is generally recommended that best estimates of stock abundance be obtained as a synthesis of trawl and acoustic survey results because both trawl and acoustic survey data are generally expected to exhibit high correlation and can also provide complementary information. Bottom trawls alone can be ineffective if pelagic fish are distributed far above the trawl headline and are less vulnerable to the gear, or if high population densities of target fish reduce trawl efficiency through gear saturation and successive fish losses. Ship noise can also force pelagic fish closer to the bottom in shallow waters (<200m), making them more vulnerable to bottom trawls (overestimation) and less so (underestimation) to acoustic sampling (Godo et al. 1993, Aglen 1996).

- The panel indicated that multiple indices of abundance, such as calibrated echosounding systems with acoustic signal integration, are not substrate limited and can be applied over a broad geographic area. The panel also recommended that measures be taken to better understand predator/prey distributions in Lake Ontario through acoustics and underwater videography.

II. Data Analytical Process

1. Precision of abundance estimates and reducing variances

The alewife is a pelagic species for which survey catch data are more variable than for demersal species as indicated by the large confidence intervals and by the use of smoothed geometric means in the Lake Ontario data set. Highly variable catches can be problematic for evaluating population trends without a model that relates trawl catches to population characteristics (demographics, predation rates, natural mortality, etc.) and to other covariates, such as depth, temperature and biological/chemical and physical parameters. Extreme catches result in outliers that considerably influence a statistical model's variance, often violating assumptions of least square models. (NRC 1998, NRC 2000, NOAA 2001). The panel commended USGS and NYSDEC for their efforts in collecting ancillary information during trawling operations.

Specific panel recommendations to address for addressing variability in trawl catches:

- Covariates of trawl catches, such as adult stock size, water temperature, and winter duration, may be autocorrelated, making standard techniques such as ANOVA or regression approaches unsuitable for analysis, because these techniques must

- operate under the assumption of independence among tows and ancillary variables. According to the review panel, a solution is to use a linear model with correlated errors (e.g. Fabrizio et al. 2000). Residual examination could help evaluate covariance structure of the data. A time series regression analysis can be conducted on residuals by utilizing results of process error model in place of dependent variable to correct the dependent variable.

- Multiplicative models can be used to evaluate the relative importance of annual covariate effects in trawl survey data. In addition, the panel suggested the use of a non-linear approach, called generalized additive models (GAM), to offer a more flexible way of relating covariates to abundance.

- The panel suggested the use of Kalman filters to conduct time series analyses of the survey catch data. This technique uses a linear (log-normal) model that differentiates between process errors around the population model and observation error associated with survey estimates. Errors are generally assumed to follow a normal distribution. This method has been found to be useful in predicting catch-per-unit-effort (CPUE) and trawl catch data. A more robust but non-linear approach called the generalized Kalman filter has been developed, and may offer more flexibility in modeling relationships.

- The review panel recommended that USGS and NYSDEC assessment biologists consider the use of bootstrapping and Monte Carlo simulations as approaches to provide less biased abundance estimated from trawl data. Derivation of bootstrap confidence intervals does not require distributional assumptions and is applicable to standard normal theory. These approaches are used to help estimate the sampling distributions of the parameter of interest, which are then used to assess the degree of uncertainties associated with different parameter estimates through repetitive resampling from a data set (Smith 1997). Smith (1997) compared three methods for estimating bootstrap confidence intervals for stratified random designs. Monte Carlo randomization tests are used to assess confidence intervals and significance of covariates. Data mining and reanalyses from long-term data sets can provide valuable information especially in highly variable data sets obtained from trawling.

- Fish catch data from trawling operations seldom exhibit a normal distribution and are usually highly positively skewed. Model-based abundance estimates can be improved either through data transformation or by fitting data to alternative statistical distributions (Stefansson 1996, Power et al. 1999). Robust regression methods such as least median of square can better detect outlying values and reduce the impact of outliers by downweighting outlying values. A robust linear method includes functional relationship regression that assumes the true independent variables are unknown constants with measurement error and natural variability instead of being normally distributed (Kimura 2000). In addition, the use of weighted means, windsorizing extreme values, smoothing techniques and geostatistics are valuable tools in accounting for skewed catch data and reducing estimator variance.

- Bayesian methods are useful in fitting abundance data and catch at age data to population models (Ellison 1996, NRC 1998, McAllister et al. 1998, Chen et al. 2000, NRC 2000, NOAA 2001). Bayesian models are useful in determining probabilities of alternative values or hypotheses from other models by either incorporating known information on fish stock of interest or with inferences from expert opinion. Bayesian analysis assigns prior distributions to parameters in a model and uses the likelihood function based on the data to update these priors as posterior probabilities. Bayesian models can be used with dynamic linear models that permit parameter values to change over time, in forecasting and provide forecast probabilities (Limon et al. 1998). (Meta analysis, which is becoming more widely used, provides information in an ideal form for Bayesian analysis). If a fisheries parameter has a distribution over a class of similar species that has been studied more completely, then a ready-made parameter distribution is available for a species of interest. Drawbacks of Bayesian methods are their mathematical complexity, overall unfamiliarity to many ecologists and a general reluctance of scientists to adopt methods outside the realm of traditionally used scientific tools. (Ellison 1996, NRC 1998, McAllister et al. 1998, Chen et al. 2000, Wade 2000, NRC 2000, NOAA 2001).

2. **Ecosystem induced fish distribution changes and target catchability**
   This issue is closely related to #1, Precision of abundance estimates and reducing variances. In Lake Ontario, large changes in the lake have resulted in an altered light regime and related distributional changes of alewives which could affect their vulnerability to trawl capture and could bias abundance and variance estimates. Data from USGS Oswego suggest that alewife catches in deeper offshore locations have increased in recent years and that alewife are also located closer to bottom in shallow inshore sites, coincident with increased water clarity resulting from dreissenid filtering activity. The changing light regime in the lake could be increasing the vulnerability of alewives to bottom trawl capture due to distributional shifts towards the lake bottom, increasing catchability, thereby inflating abundance and biomass estimates.

Specific panel recommendations to address for addressing variability in trawl catches:

- The review panel recommended that studies be conducted to further evaluate the catchability of target species in the Lake Ontario assessment program. Pelagic species, such as herring, have low catchabilities compared to benthopelagic species (Grosslein et al. 1982). The relationship between CPUE and stock abundance is a function of abundance and effort and is often non-linear. Therefore, catchability comparisons between ships should be made based on changes in the light regime and related fish distributional shifts in the lake. Catchability coefficients for each species should be compared against spatial distribution of ships and fish and effort. Depth effects should be evaluated by categorizing trawl tows into depth classes using a regression model with depth as covariate.

- The panel suggested the use of a non-linear approach, called generalized additive models (GAM, also see section II, p. 19), to incorporate covariates of catch with abundance. Catchability for several seasons, gear types and geographic areas can be evaluated with different models.

- The panel recommended that bulk catchability (Q), the ratio of swept area biomass and actual biomass, can be modeled using a Bayesian age-structured meta-analysis, with an assumed, underlying probability distribution for Q. The ratio will approach 1 if there is no trawl avoidance, herding occurs and the surveyed frame is representative of the population's habitat. If large areas of untrawlable areas exist and this habitat is preferred, then the ratio is further reduced (Millar et al. 2002). Swept area estimates of biomass obtained through standard methods can underestimate fish stock biomass due to spatial variations in trawl catches (Aglen 1996).

- The panel suggested the use of global positioning/plotting systems (GPS) to improve estimates of fishing effort and fishing power, a measure of a boat's effectiveness in catching fish. Fishing power has been found to increase among vessels adopting GPS (Robins et al. 1998).

- Because of the complex spatial distribution of the different forage species, the panel suggested that geostatistical methods be used to compare catchabilities of each target species in that the methods can provide an index of precision CV (coefficient of variation) of total abundance estimates as the basis of fishing power comparisons.

III. Modeling Fish Population Dynamics and Fisheries Management Strategies

Much of this forage base review has focused on Lake Ontario forage fish abundance data and the assessment protocol. Ideally, fish population parameters, life history information and other demographic information estimated from catch data should be integrated with predator-prey simulations and ecosystem production models to develop effective, long-term fisheries management models and to better ensure sustainable fisheries.

Population modeling aspects, however, impose the largest burden on fisheries managers in terms of networking with the research community. Previous modeling attempts for Lake Ontario have included the SIMPLE Model developed by Dr. Mike Jones during the early 1990s and the later RISK Model developed by a multi-disciplinary research team including academic researchers and biologists from USGS and NYSDEC. The review panel suggested that while contemporarily groundbreaking and reasonably intuitive, and capable of providing some useful information, these models were simplistic, as they inadequately incorporated components of limnology, stochasticity, seasonality and spatial scale. Also, these models had little empirical support as they exhibited some poor fits to the field data.

Accurately modeling fish population dynamics poses tremendous challenges for fisheries managers because of issues related to ecosystem complexity, conflicting management actions, and inherent uncertainties associated with biological processes, socioeconomics, and institutions (Lane et al. 1998, Cochrane 1999). Failure of many fisheries management systems is directly attributable to an inability to adequately account for uncertainty (Lane et al. 1998). The next generation of fisheries management strategies aspires to incorporate a suite of risk-sensitive options developed with associated uncertainties that are subsequently evaluated with decision analysis (NRC 1998, NRC 2000, NOAA 2001). Ultimately, the desired goal is to incorporate stakeholders' input based on their risk perceptions using human dimensions models. In particular, Bayesian modeling with decision analysis, discussed previously, is becoming more widespread among fisheries managers because of its straightforward approach to describe outcomes of alternative management actions in a probabilistic framework. This approach is useful in deliberations between fisheries managers in that the relative risks of several management actions are presented in an understandable format.

More attention is needed to improve modeling efforts for Lake Ontario fisheries management as per review panel recommendations:

- **Biophysical models**: The review panel recommended that more effort be expended to better understand the relationship between salmonine population dynamics and declines in lake productivity for making long-term ecosystem predictions in Lake Ontario. Environmental variables have a great deal of influence on system production and fish population dynamics, particularly in the rapidly changing biological and physical characteristics of the Great Lakes.

Maintaining long-term data sets and developing improved scientific techniques to identify/quantify ecosystem changes and their fisheries is essential. These data can be incorporated into various modeling efforts to make improved projections on fish growth, survival, recruitment and reproductive potential. In the marine environment, the effects of such natural regime shifts on fisheries have been a major research focus in the North Pacific. To understand biophysical linkages to fish demographics and their uncertainties, Monte Carlo simulations have been used to identify effects of ecosystem changes on fish population parameters (Rahikainen et al. 2003). The use of mass-balance approaches using ECOSIM and ECOPATH to reconstruct food webs over time and space, respectively, were discussed as a potential tool for Lake Ontario fisheries managers. These models provide descriptions of the average state of the lake, in terms of structure and function, as a means for detecting ecosystem changes (Pauly et al. 2000). Currently, modelers are comparing simulation results from the Bay of Quinte and Oneida Lake. These models, however, are extremely complex and have a steep learning curve.

- **Bayesian decision analysis models:** Universally, scientists and managers need to develop improved predictive tools that can be utilized to develop proactive strategies to maintain sustainable fisheries. Stock assessments are conducted to provide information useful in the decision-making process, yet many complex fisheries models are difficult to fit because relationships are highly nonlinear and important model parameters are often unknown. Among fisheries managers and researchers, there is growing use of precautionary approaches to managing fish stocks that incorporate uncertainty estimates of fish stock abundance (Ellison 1996). As described earlier, Bayesian models assign unknown parameters a known probability distribution, which can be useful in determining probabilities of consequences from alternative management scenarios (treated as alternative hypotheses). The probabilities permit the evaluation of consequences of management alternatives through decision analysis in an understandable and useful format. Essentially, modelers can simulate the full range of environmental/physical uncertainty collected from observational data (field studies) for comparing results of varied management actions. This approach prompts close examination of historical data to assess what is known about the parameters and processes in the system of interest (Ellison 1996, McAllister et al. 1998, Wade 2000). The advent of more powerful personal computers has made these techniques more available for use in fisheries management (Ellison 1996, McAllister et al. 1998).

- **Integrated fisheries models:** Current biologically-based models, including ecosystem-based models, used to develop management strategies can fail because they do not incorporate institutional and socioeconomic uncertainty. They cannot directly incorporate stakeholder demand into the management policy and they cannot adequately account for competing objectives. Integrated fisheries models are complex modeling approaches that incorporate ecological, socioeconomic, legal and institutional aspects of fisheries in dynamic outlines of strategies within which goals and expectations of managers and stakeholders converge. The integrated models include interactive components of ecosystem complexity/dynamics, management objectives, stakeholder values/behavior and institutional framework, each with feedbacks. They are designed to address complex problems and allow managers to select from an array of management options. STELLA simulation models are often used as the model format. The review panel suggested that more research is needed to quantify sport fishing socioeconomic indicators in Lake Ontario.

- **Other decision analysis simulations:** Because fisheries management faces a complex decision-making environment, interest is growing for developing modeling efforts that incorporate a number of management objectives. The FINMAN (Fisheries Institution Management-training simulation model) model developed by Dr. Jerald S. Ault, Rosenstiel School of Marine and Atmospheric Sciences (RSMAS), can be used in situations in which competing management objectives exist and can be used to select an effective and risk-aversion management strategy to attain maximal and sustainable benefits over time. FINMAN is a microcomputer-based, discrete-time, multi-objective decision model that simulates decision-making responses based on different level of agency constraints (general, assessment and research budgetary constraints) as well as for the current management environment of the designated regulating authority. The simulations yield a suite of management rules, authority levels and alternative fisheries that can be used to evaluate the efficacy of different strategies and to identify sensitive areas of the system. Risk levels are evaluated as low, medium or high risk. The model contains six pre-programmed fish stock life history models (representing six marine fish families) that can incorporate the specific socioeconomic and biological endemic to a particular fishery. The FINMAN model is also an excellent teaching tool.

- **Human dimensions (uncertainty, risk assessment, risk communication and management):** Rapid and whole ecosystem changes are making fisheries sustainability predictions extremely difficult, suggesting that uncertainty in future modeling exercises and in the decision making process should be considered. Some reviewers suggested that efforts could be expanded to attempt to model the ecosystem and understand how changes are influencing fish production and population dynamics of predator and prey species as integrated with current socioeconomic data. Human dimensions techniques could be integrated with decision analysis models for communicating competing management strategies and their effects to the public because stakeholders should be involved with deliberations about fisheries management options. A suite of possible management options could be developed by fisheries managers or by contractual agreements with appropriate modeling experts to include a range of possible management scenarios, each presented with a simulated probabilistic sphere of expected outcomes to stakeholders.

- **Fuzzy logic models:** Fuzzy logic models are based on algorithms that can overcome some biological uncertainties since they model real-world inputs to real-value outputs in a non-subjective manner These models have been found to be universal non-linear estimators for functional relationships such as stock-recruitment. Fuzzy logic approaches can be developed to model effects of environmental changes in stock recruitment. This technique has been used effectively in identifying changes in stock production from environmental changes (Chen 2001).

- **Neural networks:** These models offer utility in forecasting stock recruitment relationships and available biomass by evaluating the key variables that influence population dynamics in long-term data series. They can have higher predictive power than traditional fisheries assessment models. Neural networks are computer algorithms that can find patterns in complex (linear and non-linear) data by mimicking the information processing of the human brain using input data layers, hidden (unknown interactions) layers and output (forecasts) by a weighting function of mode inputs. The networks “learn” patterns of ecological data from previous experience through repeated learning runs. The knowledge is compiled by a variable weighting process in the neural network that minimizes the differences between model predictions and observations. In a sense, neural networks are similar to multiple regression analysis, but generally perform better. Networks can also be developed for each year class separately. The neural networks can improve the accuracy of stock-recruitment forecasts especially for short-lived fish such as alewives that are especially impacted by abrupt ecosystem changes. The disadvantage of neural networks (typical for most modeling approaches) is that they provide little understanding of the underlying mechanisms driving population dynamics (Chen et al. 1999, Huse et al. 1999).

- **Meta-analysis:** Data across multiple studies are often used in reviews and synthesis studies by combining treatment effects (tests of statistical significance) from different studies that examine identical or similar treatments (treatment magnitude) using a common scale, due to overall lack of long-term data for any one population. Meta-analysis, similar to empirical Bayesian methods, can reduce some biological uncertainty. Both methods can be used in decision analysis under uncertainty and can lead to similar conclusions. However, by incorporating data from other studies (populations) a biased result can still result due to inherent biases within each dataset.

Summary

In response to a request from NYS Senator Maziarz and to stakeholder concerns, NY Sea Grant organized an external, objective review of the Lake Ontario Forage Fish Assessment Program with the cooperation of USGS and NYSDEC. Four prominent scientists with expertise in the field of fisheries assessment participated in the review (three as technical reviewers, one as workshop facilitator). The review process consisted of evaluating the assessment program in the context of review criteria developed by an advisory panel of Lake Ontario scientists and fisheries managers. The basis of the review was a series of documents developed by USGS and NYSDEC outlining the program's history, sampling design, analytic and modeling framework and data trends and provided to the review panel. USGS and NYSDEC were provided with an opportunity to develop responses to reviewers' critiques prior to a workshop forum at which reviews and responses were presented to NYSDEC field staff, academic researchers and select members of stakeholder sport fishing interest groups.

Review panel suggestions for refining the Lake Ontario assessment program did not reflect any unique deficits to the assessment protocol or to the management process. The program received an overall positive review in terms of the reliability of the population trends of the major forage species in Lake Ontario, despite some recommendations for improvement made by the external review panel. The panel lauded USGS and NYSDEC for the intensive effort paid to not only maintaining but also improving the Lake Ontario assessment program, given operational constraints and the need for adapting to a rapidly changing sampling environment. The review panel was very favorably impressed with the quality of the extensive body of published peer-review research based on the Lake Ontario assessment program's data and the close academic linkages with the assessment program. The panel also commended USGS and NYSDEC on their frequent interactions with stakeholders and their efforts to present updated assessment and management information to this audience.

Panel recommendations to USGS and NYSDEC were constructive and fair appraisals of the program. The panel recognized the impracticality of implementing all recommendations into the assessment program. The panel's commentary was well received by both agencies, and several of the review panel's recommendations were incorporated into the assessment program for 2003.

A summary of the review panel recommendations is as follows:

Sampling Design and Methods

- Evaluate fixed versus random sampling design using archived data.
- Utilize geostatistics to evaluate sampling adequacy and spatial variations in fish abundance.
- Collect data to identify ancillary environmental and habitat variables correlated with fish abundance.
- Expand the hydroacoustic assessment program to better understand fish distribution patterns on various bottom types and sampling effectiveness of trawls.
- Use an acoustic data viewer with image analysis tools to describe spatial patterns of fish abundance related to predator/prey overlap.
- Evaluate point-and-click imaging software combined with general additive models to be used to compare fish abundance/biomass estimates from acoustic transects.
- To compensate for broad scale ecosystem changes, develop an adaptive sampling approach that can adjust to changes in spatial fish distribution patterns.

- Investigate methods for predicting trawl catches in untrawled areas.
- Adopt a balanced sampling design by increasing the number of sampling stations or compensate for unbalanced design using predictive models that incorporate data on fish spatial distributions.
- Investigate non-parametric methods for estimating confidence intervals (i.e. bootstrap).
- Integrated trawling and acoustic assessment or expanded trawling effort can be used to evaluate the "stopping rule."
- Recognize limitations of both trawling and acoustic assessment when combining data from the two sources and regression models of catches from each source are best fit using multiplicative models to provide conversion factors.

Data Analytical Framework

- Because of autocorrelation of trawl catch covariates, ANOVA and regression may be unsuitable, necessitating the evaluation of linear models with correlated errors, multiplicative models to evaluate the covariate effects, or general additive models to incorporate catch covariates with abundance.
- Investigate Kalman filters for time series analysis of survey indices.
- Evaluate Bootstrapping and Monte-Carlo simulations to help minimize bias from trawl data and help assess the amount of variability in abundance/biomass estimates from trawl data.
- Catchability coefficients for each forage species should be determined for different seasons, gear types, and geographic areas and compared against spatial distribution of sampling effort to better understand depth effects using linear models.
- Bayesian methods are recommended to evaluate potential models for the data.
- Evaluate whether Bayesian meta-analysis is useful to model actual versus swept area estimates and provide information on possible trawl avoidance.
- Utilize geostatistical techniques to compare catchabilities of target species and to assess precision of total abundance estimates.
- Determine in estimates of fishing power/effort can be improved by using GPS.

Modeling Fish Population Dynamics and Evaluating Fisheries Management Strategies

- Evaluate/improve use of biophysical models – relating biophysical parameters to fish catches, incorporating a spatial component to better understand the relationship between changes in production to forage fish and predator population dynamics.
- Evaluate the use of Bayesian decision analysis models – to simulate ecosystem uncertainty and to develop a suite of management actions with probability components.
- Evaluate integrated fisheries models – to incorporate biological uncertainty with institutional and socioeconomic uncertainty.
- Examine other decision analysis models – to incorporate/account for multiple competing management objectives.
- Evaluate or improve the use of human dimension tools – incorporate uncertainty with decision analysis to present alternative management strategies to the public.
- Evaluate fuzzy logic models – can be useful to account for uncertainty by classifying biophysical relationships in a non-subjective manner.
- Evaluate neural network models – models that "learn" patterns of ecological data to improve forecasting abilities.
- Evaluate meta-analysis – permit combining treatment effects across different data sets using a common scale to reduce biological uncertainty.

In an ideal world, incorporation of all recommendations made by the review panel could improve the precision of fish abundance estimates. In reality, however, implementation of all recommendations is impractical due to existing manpower and budgetary restrictions incurred by agencies responsible for the forage fish assessment mandate. A balance will have to be struck that meets management needs and stakeholder expectations. To attain this balance a dialogue between stakeholders, fisheries managers and assessment biologists must be maintained. It is clear that this review verified the credibility of the assessment program but made valuable recommendations that have improved the program and have helped stakeholders better understand the complexities involved with sampling fisheries.

Epilogue

Since the prey fish assessment review in October 2003, the participating agencies embarked on a restructuring of the alewife assessment database and a re-examination of forage fish population trends during the long history of the alewife assessment program. In response to suggestions provided by the reviewers, the latest statistical procedures were used to examine the effect of changes in vessels and gear, to change the stratification scheme, and to modify rules for incorporation of zero catches in statistical analyses. Sampling was expanded to greater depths and further expansion is scheduled for 2005. Additional resources were provided to the USGS Lake Ontario Biological Station that funded additional sampling in spring 2004 and participation in an international workshop on survey analysis and design in summer 2004. Hydroacoustic sampling was incorporated into the 2004 alewife assessment thanks to the gracious assistance of the Ontario Ministry of Natural Resources. Additional hydroacoustic sampling is scheduled for future alewife assessments. A similar re-examination of the rainbow smelt assessment is scheduled to begin in 2005.

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Appendix 1. NMFS Fisheries Assessment Guidelines

Evaluation Criterion 1: *Catch data* Performance level	Characteristics
0	No catch data
1	The fisheries assessment catch provides a minimum estimate of abundance and predator removal (commercial, recreational or prey demand from stocked predators) based on a statistically based sampling program used to expand assessment catches to a relative or absolute abundance/biomass estimate.
2	Catch size composition serves as an index of body sizes of fish in fisheries, and over a time series, can provide information on recruitment and mortality
3	Information on fish spatial orientation provides information on fish range expansion or reduction.
4	The age distribution of assessment catches requires accurate age determination and development of a sub-sampling program of catches for the age analysis. This provides a greater degree of age-class distribution than from size frequency information in tier 2.
5	Accurate and complete data on fish removal by predators and catches in assessment program provides accurate abundance/biomass information.

Evaluation Criterion 2: *Abundance data* Performance level	Characteristics
0	No abundance data, assessment begins at level 1 and above
1	Relative abundance derived from fishery or catch per unit effort from an infrequent, imprecise survey (or, from a single survey from which an estimate of absolute abundance is calculated) results in a limited ability to monitor changes in fish abundance.
2	Precise, frequent surveys that generate data on age composition in the fish population that provides more accurate tracking of changes in abundance/biomass and recruitment.
3	Research surveys with good estimates of fish catchability, acoustic surveys of known target strength, can provide estimates of absolute abundance, especially useful when the time series of the assessment is so short that no trend is detectable.
4	Habitat-specific surveys refine the concept of stratified random sampling so that the survey results are associated with some habitat feature (depth, temperature, bottom type etc.) that entails the use of alternative methodologies to extend survey coverage into a variety of habitats, resulting in improved information on the relationship of fish populations to their habitat.

Evaluation Criterion 3: ***Life history data*** **Performance level**	**Characteristics**
0	No life history data.
1	The size distribution of assessment catches provides an index of a fish population's demographic growth potential and vulnerability to over harvesting or over predation.
2	Basic demographic parameters (age composition, growth rates, age at maturity) provide information for estimating mortality and productivity of the fisheries of interest.
3	Spatial and temporal patterns of fish movements and variability in life histories, provides information on a how fisheries respond to environmental changes.
4	Food habits of the target species describe the predator-prey and competitive environment of the species, and provide a first step in estimating natural mortality and biologically driven management recommendations.

Evaluation Criterion 4: ***Assessment models*** **Performance level**	**Characteristic**
0	Existing data collected from a fishery has not been examined beyond a simple time series or catch summaries.
1	Either: **a.)** A time-series abundance index calculated from raw catches or standardized catch-per-unit effort data from assessment, commercial or recreational fisheries, **or** **b.)** A onetime estimation of absolute abundance from tagging studies, or a calibrated survey.
2	Simple equilibrium models (i.e. yield per recruit, spawner per recruit) applied to life history information (mortality, growth, cohort analysis, reproductive age and potential), and catch curves.
3	Equilibrium and non-equilibrium production models applied in spatial and age/size-based contexts (i.e. Schaefer, Pella-Tomlinson models).
4	Size, life history stage, or age structured models such as cohort analysis and virtual population analysis, age-structured production models, CAGEAN, stock synthesis, size/age structured Bayesian models, modified DeLury models or size/age based recapture models.
5	Assessment models incorporating ecosystem-based information (multiple target species or biological ecosystem components other than target fish species, plus spatial and temporal analyses in addition to levels 3 and 4.

Evaluation Criterion 5: ***Sampling frequency*** **Performance level**	**Characteristic**
0	No assessment has ever been conducted.
1	Infrequent, the most recent assessment was conducted three years ago.
2	Frequent or recent, the most recent assessment was conducted within the last three years but not annually.
3	Annual or more, assessments are conducted at least annually.

Appendix 2. The Workshop Faculty

Workshop Facilitator:
Dr. Lisa Kline, Atlantic States Marine Fisheries Commission, Washington, D.C.
Lisa Kline received her Bachelor's of Science Degree from Millersville University of Pennsylvania and her Ph.D. from the Virginia Institute of Marine Science, College of William and Mary. After receiving her Ph.D., Lisa worked for the Maryland Department of Natural Resources for three years as a fisheries statistician. In 1993, Lisa accepted a position with the Atlantic States Marine Fisheries Commission. Lisa has been with the Commission for more than ten years and has been Director of Research and Statistics for eight of those years.

Technical Reviewers:
Stephen Smith: Department of Fisheries and Oceans Canada (DFO), Bedford Institute of Oceanography (BIO), Halifax, Nova Scotia, Canada
Stephen Smith is a research scientist and head of the Molluscan Fisheries Section of the Invertebrate Fisheries Division at Bedford Institute of Oceanography in Halifax, Nova Scotia. He Joined DFO in 1979, working on groundfish surveys in St. John's, Newfoundland. He then moved to the Marine Fish Division at BIO and worked on groundfish surveys and population dynamics models from 1981 to 1996. Since 1997, he has been working on scallop population dynamics and benthic ecology with the Invertebrate Fisheries Division at BIO. Stephen was the associate editor of the ICES Journal of Marine Science from 1991 to 1997 and is currently the associate editor with the Canadian Journal of Fisheries and Aquatic Sciences.

Dr. Steven Murawski, National Marine Fisheries Service, Woods Hole, Massachusetts
Since 1990, Steve Murawski has been the Chief Stock Assessment Scientist for the Northeast Region with the National Marine Fisheries Service, located at Woods Hole Oceanographic Institute in Massachusetts. Steve is responsible for coordinating stock assessment research on more than 50 fishery populations off the Northeast USA (including groundfish, invertebrates, sport fish and small pelagic species). This research supports management efforts by the New England and Mid-Atlantic Fishery Management Councils, Atlantic States Marine Fisheries Commission, the North Atlantic Salmon Conservation Organization, the Northwest Atlantic Fisheries Organization the International Commission the Conservation of Atlantic Tunas, and the International Council for the Exploration of the Sea. His research interests include ecosystem effects of mixed-species harvesting, methods of fish stock assessment, and use of Maine Protected Areas for fisheries management. He holds a Ph.D. from the University of Massachusetts (Amherst).

Dr. Jerald S. Ault, Rosenstiel School of Marine and Atmospheric Sciences (RSMAS), University of Miami, Miami, Florida
Dr. Jerry Ault is an Associate Professor of Marine Biology and Fisheries, specializing in theoretical population dynamics and fisheries management systems in tropical marine systems. at the RSMAS. He holds a Ph.D. from RSMAS. His research includes fisheries independent studies on a variety of vertebrate and invertebrate species that is focused on the relationship to migration patterns of theses species as means of identifying optimal sampling surveys and understanding the mechanisms in population dynamics and spatial patterns of the species of interest. His interests also include the application of population and community modeling efforts to understand recruitment variability for developing improved resource forecasting for sustainable management. Jerry has received national and international recognition for his research excellence.

Appendix 3. Peer-Reviewed Publications by USGS Staff Using Data Collected During Bottom Trawl Surveys in U.S. Waters of Lake Ontario

Elrod, J.H. and R. O'Gorman. 1991. Diet of juvenile lake trout in southern Lake Ontario in relation to abundance and size of prey fishes, 1979-1987. *Transaction of the American Fisheries Society* 120: 290-302.

Elrod, J.H., R. O'Gorman, and C.P. Schneider. 1996. Bathythermal distribution, maturity, and growth of lake trout strains stocked in U.S. waters of Lake Ontario, 1978-1993. *Journal of Great Lakes Research* 22: 722-743.

Johannsson, O.E., E.L. Mills, and R. O'Gorman. 1991. Changes in the nearshore and offshore zooplankton communities in Lake Ontario: 1981-88. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 1546-1557.

Johannsson, O.E. and R. O'Gorman. 1991. Roles of predation, food, and temperature in structuring the epilimnetic zooplankton populations in Lake Ontario, 1981-1986. *Transactions of the American Fisheries Society* 120(2): 193-208.

Jones, Michael L., J.F. Koonce, and R. O'Gorman. 1993. Sustainability of hatchery-dependent salmonine fisheries in Lake Ontario: The conflict between predator demand and prey supply. *Transactions of American Fisheries Society* 122(5): 1002-1018.

Madenjian, C.P., D.M. Whittle, J.H. Elrod, R. O'Gorman, and R.W. Owens. 1995. Use of a simulation model to reconstruct PCB concentrations in prey of Lake Ontario lake trout. *Environmental Science and Technology* 29: 2610-2615.

Mills, E.L., R. O'Gorman, J. DeGisi, R.F. Heberger, and R.A. House. 1992. Food of the alewife (*Alosa pseudoharengus*) in Lake Ontario before and after the establishment of *Bythotrephes cederstroemi*. *Canadian Journal of Fisheries and Aquatic Sciences* 49(10): 2009-2019.

Mills, E.L. and 17 others, including R. O'Gorman and R. Owens. 2003. Lake Ontario: Food web dynamics in a changing ecosystem (1970-2000). *Canadian Journal of Fisheries and Aquatic Sciences* 60: 471-490.

Mills, E.L. and 17 others, including R.W. Owens, and R. O'Gorman. 2003. A synthesis of ecological and fish community changes in Lake Ontario, 1970-2000. *Great Lakes Fishery Commission Technical Report XX*: In press.

O'Gorman, R., B.F. Lantry, and C.P. Schneider. 2004. Effect of stock size, climate, predation, and trophic status on recruitment of alewives in Lake Ontario, 1978-2000. *Transactions of the American Fisheries Society* 133(4): 855-867.

O'Gorman R. and C.P. Schneider. 1986. Dynamics of alewives in Lake Ontario following a mass mortality. *Transactions of the American Fisheries Society* 115(1): 1-14.

O'Gorman, R., D.H. Barwick, and C.A. Bowen. 1987. Discrepancies between ages determined from scales and otoliths for alewives from the Great Lakes. Ed. R.C. Summerfelt and G.E. Hall. Age and Growth of Fish. Iowa State University Press, Ames, Iowa. 203-210.

O'Gorman, R., E.L. Mills, and J.S. DeGisi. 1991. Use of zooplankton to assess the movement and distribution of alewife (*Alosa pseudoharengus*) in south-central Lake Ontario in spring. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2250-2257.

O'Gorman, R., J.H. Elrod, R.W. Owens, C.P. Schneider, T.H. Eckert, and B.F. Lantry. 2000. Shifts in depth distributions of alewives, rainbow smelt, and age-2 lake trout in southern Lake Ontario following establishment of dreissenids. *Transactions of the American Fisheries Society* 129(5): 1096-1106.

O'Gorman, R., O.E. Johannsson, and C.P. Schneider. 1997. Age and growth of alewives in the changing pelagia of Lake Ontario, 1978-1992. *Transactions of the American Fisheries Society* 126(1): 112-126.

O'Gorman, R., R.A. Bergstedt, and T.H. Eckert. 1987. Prey fish dynamics and salmonine predator growth in Lake Ontario, 1978-84. *Canadian Journal of Fisheries and Aquatic Sciences* 44(Supplement 2): 390-403.

O'Gorman, R. and R.W. Owens. 2001. Establishment of dreissenids in Lake Ontario: implications for the endemic fish community. Ed. D. F. Pavlov and G. Kh. Scherbina. Invasion of alien species in Holarctic: proceedings of U.S.-Russia Invasive Species Workshop. I.D. Papanin Institute of Biology of Inland Waters, Borok, Yaroslavl, Russia. 546-553.

O'Gorman, R. and T.J. Stewart. 1999. Ascent, dominance, and decline of the alewife in the Great Lakes: food web interactions and management strategies. Ed. W.W. Taylor and P. Ferreri. Great Lakes Policy and Management: A Binational Perspective. Michigan State University Press. 489-514.

Owens, R.W. and D.E. Dittman. 2003. Shifts in the diets of slimy sculpin (*Cottus cognatus*) and lake whitefish (*Coregonus clupeaformis*) in Lake Ontario following the collapse of the burrowing amphipod, *Diporeia*. *Aquatic Ecosystem Health and Management* Vol 6(3): 311-322

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Owens, R.W. and P.G. Weber. 1995. Predation on *Mysis relicta* by slimy sculpins (*Cottus cognatus)* in southern Lake Ontario. *Journal of Great Lakes Research* 21: 275-283.

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Owens, R.W., R. O'Gorman, E.L. Mills, L.G. Rudstam, J.J. Hasse, B.H. Kulik, and D.B. MacNeill. 1998. Blueback herring (Alosa aestivalis) in Lake Ontario: First record, entry route, and colonization potential. *Journal of Great Lakes Research* 24(3): 723-730.

Owens, R.W., R. O'Gorman, T.H. Eckert, B.F. Lantry, and D.E. Dittman. 2004. Recovery and decline of lake whitefish in U.S. waters of eastern Lake Ontario, 1980-2001. *Great Lakes Fishery Commission Technical Report 66*: In press.

Owens, R.W., R. O'Gorman, T.H. Eckert, and B.F. Lantry. 2003. The offshore fish community in southern Lake Ontario, 1972-1998. Ed. M. Munawar. The State of Lake Ontario: Past, Present, and Future. *Ecovision World Monograph Series*, Aquatic Ecosystem Health and Management Society, Burlington, Ontario, Canada. 407-442.

Rand, P.S., B.F. Lantry, R. O'Gorman, R.W. Owens, and D.J. Stewart. 1994. Energy density and size of pelagic prey fishes in Lake Ontario, 1978-1990: implications for salmonine energetics. *Transactions of the American Fisheries Society* 123: 519-534.

Rand, P. S., D.J. Stewart, B.F. Lantry, L.G. Rudstam, O.E. Johannsson, A., Goyke, S.B. Brandt, R. O'Gorman, and G.W. Eck. 1995. Effect of lake-wide planktivory by the pelagic prey fish community in Lakes Michigan and Ontario. *Canadian Journal of Fisheries and Aquatic Sciences* 52:1546-1563.