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Assessing Model-based Indices of Lake Trout Abundance in 1836 Treaty Waters of Lakes Huron, Michigan, and Superior

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Abstract.–Stock assessment models for lake trout in 1836 Treaty waters of the Great Lakes, located in Michigan, make use of annual indices of abundance derived from general linear mixed models (GLMMs) applied to fishery independent surveys. The GLMMs include categorical fixed effects of year, grid (spatial location), and depth, and a random year by grid interaction. Previously, a comprehensive evaluation of the distributional assumptions for the random effects and residual errors of these GLMMs, the sensitivity of the resulting indices to the constants added to catch per effort survey data before $\log_e$ transformation, and method of calculating denominator degrees of freedom had not been reported. Furthermore, alternative models to the current GLMM, based on the same dependent and categorical data, had not been systematically evaluated. To evaluate the validity of the distributional assumptions, we examined plots of the random effect estimates and residuals to see if frequency histograms were approximately normal (i.e., symmetric and bell-shaped) and if trends in the estimates exhibited any temporal (among years) or spatial (among adjacent grids) trends. We evaluated the sensitivity of the models to the constants that are added to catch per effort (CPE) values before $\log_e$ transformation by doubling and halving the constants currently used, and then comparing the values for the least square means and standard errors for each year (i.e., model output used in the stock assessments) among the models with different constants. The sensitivity of the models to the method of calculating degrees of freedom was evaluated by comparing the values for the least square means and standard errors for each year between the current method (Satterthwaite) and the Kenward-Roger's method. We evaluated the use of alternative models through the inclusion of different random effects in the model, as well as dropping depth and/or grid from the model. We found a lack of temporal independence in the year by grid effect in most assessment areas. Relative changes in the model output were nearly zero when the constant added to CPE values was altered and when the method of calculating degrees of freedom was changed. The combination of random effects in the status quo model provided the best or nearly best fit for almost all assessment areas in Lakes Huron and Michigan, except in one assessment area of Lake Michigan where a model with an autoregressive lag 1 error structure, *AR(1)*, in the year by grid effect provided the best fit. In Lake Superior large-mesh and graded-mesh surveys, the status quo model never provided the best fit or the most conservative estimates (i.e. larger standard errors), and the best model varied by assessment area and gear type. In assessment areas with a lack of temporal independence in the year by grid effect, modeling the year by grid effect as an *AR(1)* process significantly improved model fit, suggesting that this change was warranted. The fixed effect of depth improved model fit in all but one assessment area. The fixed effect of grid generally improved model fit in Lakes Huron and Michigan and for large-mesh surveys in Lake Superior, but not for graded-mesh surveys in Lake Superior. The status quo model often did not provide the best model fit and was often not the most conservative choice of models; so other models should be considered for some assessment areas.

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Introduction

Lake trout *Salvelinus namaycush* were historically one of the most highly valued Great Lakes fish species, and provided a stable fishery in Lakes Superior, Huron, and Michigan, prior to stock collapses in each of the lakes (Hansen et al. 1994; Hansen et al. 1995; Hansen 1999; Ward et al. 2000; Johnson et al. 2004). In Lake Superior, lake trout yield averaged 2.0 million kg annually during 1913-1950 (Hile et al. 1951a; Hansen et al. 1995), after which stocks collapsed to near extirpation (Hansen et al. 1995; Hansen 1999). In the U.S. waters of Lake Huron, yield averaged 0.77 million kg annually during 1895-1939 (Hile 1949), followed by a collapse to near extirpation beginning in 1935 (Hile 1949; Hansen 1999; Sitar et al. 1999; Johnson et al. 2004). Similarly, in Lake Michigan, where lake trout was the most valuable commercial species from 1890 to the mid-1940s, average yield was 3.18 million kg during 1912-1926 (Hile et al. 1951b; Wells and McLain 1973), but stocks collapsed to extirpation beginning at least by 1943 (Hile et al. 1951b; Hansen 1999). Lake trout stocks collapsed in each lake due to over-exploitation and sea lamprey *Petromyzon marinus* predation (Hile 1949; Hile et al. 1951a; Hile et al. 1951b; Wells and McLain 1973; Hansen et al. 1994; Hansen et al. 1995; Hansen 1999; Sitar et al. 1999; Ward et al. 2000; Johnson et al. 2004).

Lake trout restoration efforts have focused on sea lamprey control, protecting lake trout from commercial exploitation, and extensive stocking (Hansen 1999). The primary sea lamprey control tool was the lampricide 4-nitro-3-(trifluoromethyl) phenol, or TFM, which was first applied in Lakes Superior, Huron, and Michigan in 1958, 1960, and 1971, respectively, and reduced sea lamprey abundance by as much as 85% (Hansen 1999; Heinrich et al. 2003; Lavis et al. 2003; Morse et al. 2003). Recently, alternative control techniques have been applied, including barriers and sterile male release programs (Heinrich et al. 2003; Lavis et al. 2003; Morse et al. 2003). After TFM was shown to be effective, lake trout fisheries were closed in the upper Great Lakes in 1962, and since then, biologically based catch quotas, mandatory release, and refugia have facilitated rehabilitation (Hansen 1999). Lake trout stocking commenced in the early 1950s in Lake Superior, and during the 1960s in Lakes Michigan and Huron, and averaged over a million fish per year in some lakes (Hansen 1999). Despite these efforts, self-sustaining stocks have only been restored in Lake Superior (Hansen 1999) and isolated areas of Lake Huron (Dobiesz et al. 2005).

In order to sustain naturally reproducing stocks in Lake Superior and continue lake trout rehabilitation in the other lakes, target or limit total annual mortality rates have been set in most waters (Jonas et al. 2005; Woldt et al. 2005; Sitar et al. 2007). The target or limit annual mortality rates for lake trout are based on the work of Healey (1978) who concluded from a meta-analysis that lake trout populations were self-sustaining when total annual mortality was less than or equal to 50%, but that populations declined when mortality exceeded 50%. Consequently, in the 1836 Treaty waters of Michigan, lake trout are managed with the more conservative targets of 40% or 45% total mortality for mature fish depending upon the management area (United States vs. State of Michigan 2000; Sitar and Bence 2004).

In the 1836 Treaty waters of Michigan, estimates of abundance from statistical catch at age (SCAA) models are used in conjunction with the target total annual mortality rates to project recommended yield levels (Sitar and Bence 2004). The SCAA models are fit assuming expected survey gill-net catch per effort (CPE) will be proportional to population abundance:

$$E(CPE_{a,y}) = qS_aN_{a,y}$$

where q is catchability, S is selectivity, and N is abundance for age-a and year-y (Sitar and Bence 2004). For Lake Superior, this relationship is fit separately for each of two surveys, a large-mesh and graded-mesh gill-net survey.

The assumption that expected CPE is proportional to abundance may be violated if the spatial location or timing of sampling has varied over time or the capture efficiency of the gear varies. These complications can lead to trends in observed CPE that are not related to abundance. Weather conditions, operational problems, and budget limitations, can lead to short- and long-term changes in sampling locations (for fixed sampling designs) or incomplete sampling of strata (for stratified-random designs). We address this issue in the context of fixed-station sampling designs, where not all stations were necessarily sampled each year. For such designs, to account for changes in what stations are sampled, estimated CPE indices are often based upon output from a form of ANOVA such as a general linear mixed model (GLMM). This approach accounts for the spatial locations that were sampled so that the "year effect" is an appropriate index of abundance. In principle, such models adjust for potential biases such as a greater number of samples being taken at a station that generally has higher abundances. We note that models incorporating fixed station effects are useful even when stations are not truly fixed, provided samples are collected from fixed areas and these areas represent a subset of locations within the larger region about which inferences are being made.

This basic approach is used to generate lake trout indices of abundance in 1836 treaty waters of the Great Lakes, and similar techniques have been used in many marine fisheries and elsewhere in the Great Lakes, making this approach a widely accepted methodology. Krause (1999) used a GLMM to analyze trends in trawl survey data for bloater and alewife in Lake Michigan. Using similar approaches, Weeks (1997) analyzed lake trout survey data from a management area on Lake Superior, and Sitar et al. (1999) analyzed lake trout survey data from southern Lake Huron. Examples from marine fisheries include eastern Bering Sea walleye pollock (Battaile and Quinn 2004) and Australia's Penaeid trawl fishery (Bishop et al. 2004).

GLMM-based indices of abundance can be sensitive to various features of the model. In Michigan's 1836 Treaty waters, the GLMM are run on the $\log_e$ transformed CPE data with a constant added to each observation to avoid problems with $\log_e$ transformation of zero observations. The GLMM results can be sensitive to the constant added to the CPE observations (Maunder and Punt 2004) and use of an inappropriate constant can lead to violations of the usual normal, independent, and identically distributed (NIID) assumptions (Butterworth 1996; Cooke and Lankester 1996). Butterworth (1996) suggested choosing a constant that gives the "most normal-like" distribution of the residuals. Model output can also be sensitive to the method used to calculate denominator degrees of freedom, particularly with unbalanced data (Littell et al. 1996; Spilke et al. 2005). This sensitivity could lead to different trends in abundance or misspecification of uncertainty measures (e.g., standard errors) depending on which method of approximating denominator degrees of freedom was used in the GLMM, and ultimately different estimates from SCAA models. However, sensitivity of the GLMM results in 1836 Treaty waters to the added constant has not been systematically evaluated and sensitivity to the denominator degrees of freedom method (Satterthwaite approximation) has not been explored. Furthermore, the potential to improve model fit from the current form by including or excluding various factors has not been extensively evaluated for the GLMM used in the 1836 Treaty waters, nor have the distributional assumptions (normality, independence) been thoroughly examined.

Our objectives were to determine 1) if the assumptions of NIID were grossly violated, 2) if the models are sensitive to the constant added to CPE observations or method of estimating degrees of freedom, and 3) if alternative models making use of the same categorical variables (i.e., defined depth categories, sampling locations, years) better fit the same data. To evaluate the validity of the NIID assumptions, we examined plots of the estimated best linear unbiased predictors of random effects (EBLUPs; i.e., estimates of the random effects from the GLMM) and residuals. If the NIID assumptions were not violated, we expected to see no trends through time or between adjacent sampling grids (locations). We evaluated the sensitivity of the accuracy and precision of the models to the constants that are added to CPE values before $\log_e$ transformation by doubling and halving the constants currently used and then comparing the relative change in the relevant model output (see below). We evaluated improving model fit through the inclusion of different random effects in the model, as well as potentially dropping all random effects and the fixed effects of depth and grid from the model.

Methods

Study Area

Our study area includes places where survey data are used for lake trout assessments in 1836 Treaty Waters, and in adjacent areas where the treaty has had management implications and similar lake trout assessment models have been developed. This area includes portions of Lakes Superior, Huron, and Michigan (Figure 1). Each lake is broken down into spatial reporting units, and analyses were performed on each reporting unit or for groups of reporting units, providing an index of abundance for each such assessment area. On lakes Michigan and Huron, reporting units are the statistical districts of Hile (1962). On Lake Superior, reporting units were lake trout management units (Hansen et al. 1995). Reporting units were grouped to correspond to assessment areas for which separate age-structured stock assessment models have been developed (by the 1836 Treaty water's Modeling Subcommittee within treaty waters and the Michigan Department of Natural Resources outside treaty waters). In Lake Huron, statistical districts MH3, MH4, MH5, and MH6 were combined into one assessment area (this assessment area is actually entirely outside treaty waters but the treaty influenced management in this region), while MH1 and MH2 each constituted separate assessment areas. In Lake Michigan, statistical districts MM1, MM2, and MM3 were combined into one assessment area, MM6 and MM7 were combined into another, while MM4 and MM5 were separate assessment areas. In Lake Superior, analyses were done separately for each of the three lake trout management units for which there is an assessment model within 1836 treaty waters (MI5, MI6, and MI7).

Data Collection and Analysis

We analyzed data for years that were being used in the SCAA assessment models as of 2005. These data were collected using standardized gill nets at what are treated as fixed locations (grids), and there has been variation in what stations were sampled and the sampling effort that occurred from year to year (Figure 2; Table 1 and 2). Grids represent defined areas 10 minutes of latitude and longitude on a side (Poff 1974). While there is variation in the sampling design among lakes and over time, with some randomization in some circumstances, sampling is generally done within a fixed subset of the region of interest and the sampled areas can be identified by grids, making the use of grids as a surrogate for sampling location in the statistical models (see next section) reasonable. In Lake Huron, these data were collected from 1984 to 2003 using graded-mesh gill nets (51 mm to 152 mm stretch measure) (Table 1 and 2; Johnson and VanAmberg 1995). In Lake Michigan, these data were collected from 1981 to 2003 also using graded-mesh gill nets (64 mm to 152 mm) (Tables 1 and 2; Holey et al. 1995). In Lake Superior, these data were collected from 1975 to 2004 using large-mesh gill nets (114 mm stretch measure) directed at adult lake trout, and from 1985 to 2004 using graded-mesh gill nets (51 mm to 89 mm stretch measure) directed at juvenile lake trout (Tables 1 and 2). Catch per effort values for Lake Superior large-mesh gill nets were also adjusted for net saturation following Hansen et al. (1998). Analyses for Lake Superior were conducted separately for large-mesh and graded-mesh gill-net surveys because of the different selectivity patterns between the two gears.

As of the writing of this report, estimates of least square means (LSM) of $\log_e$ (CPE + c) for each year from the GLMM were used as the observed index of abundance to fit the SCAA models, where c is the added constant, and uncertainty was described through the standard errors (SE) of these LSMs

(Sitar and Bence 2004). Log$_e$(CPE + *c*) was modeled with year, depth, and grid as fixed effects, except in Lake Michigan where there was no depth effect, and the interaction of year by grid as a random effect:

$$\log_e(CPE + c) = \mu + \alpha_y + \delta_d + \beta_s + \gamma_{ys} + \varepsilon_{iyds};$$

where μ is the overall mean, α_y is the year effect in year *y*, δ_d is the depth effect for strata *d*, β_s is the grid effect of grid *s*, γ_{ys} is the random interaction of year *y* and grid *s*, and ε_{iyds} is the measurement error for an individual gang of gill-net set, *i*, in year *y*, at depth *d,* and grid *s* (Sitar and Bence 2004). This model assumes that γ_{ys} and ε_{iyds} are independent and identically distributed as normal (NIID) with mean zero and variances σ_γ^2 and σ_ε^2 respectively. Depth, δ_d, was modeled as a fixed categorical effect, where in Lake Huron gill-net sets are classified as shallow (<30 m) or deep (≥30 m) based upon the minimum depth sampled by the net. In Lake Superior, spring large-mesh gill-net sets were classified as shallow (≤54.86 m) based on the maximum depth sampled by the gang of net, intermediate (min < 54.86 m; max > 54.86 m) if the sampled depths of the gang of net crosses 54.86 m, and deep (≥54.86 m) based on the minimum depth sampled by each gang of net. Lake Superior graded-mesh gill-net surveys were classified as shallow (≤41.15 m) based on the maximum depth sampled by the gang of net, intermediate (min < 41.15 m; max > 41.15 m) if the sampled depth of the gang of net crosses 41.15 m, and deep (≥41.15 m) based on the minimum depth sampled by each gang of net. We maintained these same definitions for each stratum throughout the analyses.

Evaluation of the Normal, Independent, and Identical Distribution (NIID) Assumption

To evaluate the validity of the NIID assumption for both random effects and random errors, we examined plots of residuals (ε_{iyds}) and EBLUPs (random effect estimates), and estimated the autocorrelation of the EBLUPs. To examine whether the assumption of normality was approximately met, we examined frequency histograms of the residuals and EBLUPS of the year by grid interaction (γ_{ys}) to see if the distributions were approximately symmetric and followed a bell-shaped curve. This approach is reasonable given that the GLMM models are robust to moderate non-normality (McCulloch and Searle 2001; Gelman and Hill 2007). To evaluate the assumption of temporal independence, we examined plots of residuals and EBLUPs of the year by grid interaction across years. To evaluate the assumption of spatial independence, we also examined plots of EBLUPS from adjacent grids. Lastly, we estimated the Prais-Winsten autocorrelation coefficient, $\hat{\rho}$, for the EBLUPs of the year by grid interaction within each grid, across years:

$$\hat{\rho} = \frac{\sum_{i=2}^{T} \hat{r}_i \hat{r}_{i-1}}{\sum_{i=2}^{T-1} \hat{r}_i^2};$$

where $\hat{r}_i$ is the EBLUP for year *i*, and *T* is total number of years (Bence 1995). If the independence assumption was approximately met, we expected that plots of residuals or EBLUPs would not have obvious longer-term trends, and expected estimates of the autocorrelation coefficient to be “small” (usually < 0.2 and > -0.2). Evidence that the assumption of temporal independence might not be a good approximation, through a number trends in the plots or frequent “high” estimates of the autocorrelation coefficient, led to our exploration of models that accounted for autocorrelation through a first order autoregessive process (AR(1)) for the random effects (see below).

Evaluation of Sensitivity to Constant Added to CPE Values

To evaluate how sensitive indices and their standard errors were to the constant added to CPE values before $\log_e$ transformation, we doubled and halved the constants currently in use for each lake. We compared the relative change in LSMs for each year, to evaluate accuracy, and SEs, to evaluate precision. The constant currently added to CPE values is 1.0 in Lake Superior, 0.01 in Lake Huron, and 1.25 in Lake Michigan. The reason for adding the specific constant in each lake is unclear, but is likely a consequence of independent decisions based on different methods and personal preferences of analysts who developed the preexisting GLMMs for each lake. We focused on relative changes in LSMs among years because the assessment models treat the LSMs as log-scale relative indices of abundance. Thus, we defined the relative changes as (LSM estimate from the models with double or halved constants in each year – [mean LSM estimates from the models with doubled or halved constants across years – mean LSM estimates from the status quo model across years]). With this definition, equal changes in LSMs for each year, relative to LSMs for the status quo model corresponds to no relative change. When there is relative change this means that LSMs for different years have responded differently to the change in the constant. We estimated the relative difference in SEs as the percent change in SEs of the models with “altered” constants to that of the status quo model ([[mean SE from altered models – mean SE from status quo]/mean SE from status quo] x 100). We used the percent difference in SEs because they provide a statistic that shows how much estimated precision changed from the status quo, and in which direction.

Evaluation of Sensitivity to Method of Calculating Degrees of Freedom

To evaluate the sensitivity of the models to the method used to calculate denominator degrees of freedom, we used the Kenward and Roger’s approximation for approximating degrees of freedom and compared the relative change in LSMs for each year and SEs to that produced by use of the Satterthwaite approximation. We chose these two methods because the Satterthwaite approximation is the default method, but the Kenward and Roger’s approximation has been suggested by some as a superior method for unbalanced data (Spilke et al. 2005), which the data are in the 1836 Treaty waters. We used the same method here to calculate relative changes as we described above for the responses to the constant added to CPE values before $\log_e$ transformation.

Consideration of Alternative Models

We evaluated several alternative models to see whether they better fit the data than the status quo model that has previously been used to create indices used in the assessment models. These alternative models included different random effects in the model, as well as potentially excluding all random effects and fixed effects from the model. Model fits were compared using corrected Akaike Information Criterion values (AICC). We began by exploring models with various combinations of random effects, which were fit using restricted maximum likelihood (REML). We considered the status quo model, models with all two- and three-way interactions added as random effects, and models with no random effects. Our analyses of EBLUPs and residuals (see above) provided evidence that the assumption of temporal independence for the year by grid effect, γ_{ys}, was violated , thus we also fit models where γ_{ys} had an AR(1) error structure:

$$\gamma_{ys} = \varsigma\gamma_{y-1,s} + \eta_{y,g} ,$$

where γ_{ys} is defined as above, ς is the estimate of the AR(1) parameter or level of autocorrelation, and η is distributed as NIID with mean of zero and variance σ_{η}^{2}. Once the best combination of random effects was selected, the best set of fixed effects was selected by comparing AICC values for all possible combinations of fixed effects, with models being fit using maximum likelihood (ML). Year was not evaluated during model selection because the objective is to estimate a yearly index of abundance, and so year must be retained in the final model. Our basic approach of first considering alternative models for random effects with all fixed effects included, followed by consideration of models with some fixed effects removed follows general recommendations, as did our use of REML to fit the alternative random effect models and ML for the alternative fixed effect models (Ngo and Brand 1997).

When comparison of AICC values resulted in no single set of random effects being clearly optimal (i.e., several models had similar AICC values), we also compared the relative change in LSMs for each year and SEs between the competing models and the status quo model. The relative changes in LSMs and SEs were estimated in a similar way as described above, with the status quo model always being treated as the full model. For each remaining set of competitive random effects, we also estimated the relative changes in LSMs for models without each fixed effect, where the status quo model was always treated as the full model. For example, if a model with no random effects was competitive, we estimated the change in LSMs for that set of random effects but with depth or grid removed from the model (reduced model) relative to the status quo model (full model). Lastly, we estimated the relative change in SEs for each remaining set of competitive random effects with (full model) and without (reduced model) each fixed effect. For example, if a model with no random effects was competitive, we compared the relative change in SEs between a model with no random effects that included all fixed effects (full model) to a model with no random effects but with one fixed effect (i.e., depth or grid) removed (reduced model). Models with larger standard errors would generally lead to a down weighting of the objective function used in fitting the SCAA models to the indices of abundance relative to objective functions for other data sources. So, we conclude that models with larger standard errors are more conservative because the estimates from the SCAA models would not be required to follow the trends from the surveys as rigidly.

Results

Evaluation of the Normal, Independent, and Identical Distribution (NIID) Assumption

We found no evidence for violations of the assumptions of NIID in the residuals or EBLUPs, except for a potential lack of temporal independence in the EBLUPs of the year by grid effect in several assessment areas. We only include example figures for each type of plot reported in this section because to display all the results would require a figure for each assessment area, type of plot, and gear type, which would be lengthy and redundant. Frequency histograms were roughly symmetric and bell-shaped for residuals and EBLUPs of the year by grid effect in nearly all assessment areas (Figure 3). Similarly, plots of residuals against years and EBLUPs of the year by grid effect from adjacent grids did not exhibit any discernable patterns in nearly all cases (Figure 4; Figure 5). Conversely, plots of EBLUPs of the year by grid effect across years exhibited trends for several grids (Figure 6). A lack of temporal independence was also supported by “high” values for the level of autocorrelation. Estimates of the autocorrelation coefficient were greater than 0.2 or less than -0.2 in 100% of grids for Lakes Huron and Michigan, and in 69% of grids for the large-mesh survey and 58% of grids for the graded-mesh survey in Lake Superior. Consequently, we explored the potential to improve model fit by including an AR(1) structure for the year by grid effect in each of the assessment areas. The results of these analyses are reported below (*Consideration of Alternative Models*).

Evaluation of Sensitivity to Constant Added to CPE Values

The relative values of LSMs were not sensitive to the constant added to CPE values, but the SEs changed modestly. The relative changes in the point estimates of LSMs for each year were nearly zero (i.e., <2%) in all assessment areas, regardless of whether the constant was doubled or halved. The relative changes in SEs of LSMs were positive in the case of halving the constant, and negative in the case of doubling the constant (Table 3). For the case of halving the constant, SEs of LSMs increased by at most 14% (Table 3). For the case of doubling the constant, SEs of LSMs decreased by at most -16% (Table 3).

Evaluation of Sensitivity to Method of Calculating Degrees of Freedom

The relative values of LSMs and SEs were not sensitive to the method used to calculate degrees of freedom. The relative change in the point estimates of LSMs for each year and SEs of LSMs were nearly zero in all assessment areas.

Consideration of Alternative Models

The combination of random effects included in the model with the lowest (best) AICC value differed by lake and assessment area. Depth was included in the best models in all but one area of Lake Huron (depth was not included in the Lake Michigan status quo model and we did not define a depth effect and evaluate models with depth added for Lake Michigan), and grid generally improved model fit except for Lake Superior graded-mesh surveys.

In Lake Huron, the combination of random effects in the status quo model produced the lowest or nearly the lowest AICC value in each assessment area, but a model with no random effects had a slightly better fit in a couple of assessment areas (Table 4). The relative changes in the point estimates of LSMs were nearly zero between the status quo model and the model with no random effects, and the changes in SEs were at most 1% (Table 5).

Models that included depth had lower AICC values than corresponding models without depth for all areas in Lake Huron, except MH2, for the status quo model, and any model whose combination of random effects improved model fit over the status quo model (Table 6). Regardless of the assessment area, the relative changes in the point estimates of LSMs for each year were nearly zero between the status quo model and models without depth. The percent changes in SEs between full and reduced models were the largest in MH2, where depth was not a significant effect (Table 7). Consequently, SEs were lower in MH2 when depth was excluded from the models. In other assessment areas, percent changes in SEs were 6% or less (Table 7).

Models that included grid had lower AICC values than corresponding models without grid for all areas in Lake Huron, except MH2, for the status quo model, and any model whose combination of random effects improved model fit over the status quo model (Table 6). The relative changes in the point estimates of LSMs for each year were nearly zero between the status quo model and models without grid, except in MH1, where changes were more substantial (Table 8). The percent changes in SEs between full and reduced models depended on assessment area and the set of random effects in the models (Table 9). Standard errors were higher in MH1 and lower in MH2 when grid was excluded from the models, and depended on the set of random effects in the model in MH3456 (Table 9).

In Lake Michigan, the model with the combination of random effects in the status quo model produced the lowest (best) or nearly lowest AICC value in each assessment area, but a model with an AR(1) error structure in the year by grid effect had a substantially lower AICC value in MM4 (Table 4). The relative changes in the point estimates of LSMs were nearly zero between the status quo model and the models with no random effects or an AR(1) error structure in the year by grid effect. The percent changes in SEs between the status quo model (full model) and the model with no random effects (reduced model) were all negative, and were at most -26% (Table 5). The percent changes in SEs between the status quo model (full model) and the model with an AR(1) error structure in the year by grid effect (reduced model) were all positive, and were all greater than 50%, with two changes at nearly 100%, and one change approaching 200% (Table 5).

Models that included grid had the lowest or nearly lowest AICC values than corresponding models without grid for all areas of Lake Michigan (Table 6). The relative changes in the point estimates of LSMs for each year were nearly zero between the status quo model and models without grid (Table 8). The percent changes in SEs between full and reduced models depended on assessment area and the set of random effects in the models (Table 9). The relative changes in SEs depended on the set of random effects in the models for MM123 and MM4, but were all lower in MM5 and MM67 when grid was excluded from the models (Table 9).

For large-mesh surveys in Lake Superior, the status quo model was outperformed (i.e., another model had a lower AICC value) in each assessment area, usually by a model with an AR(1) error structure in the year by grid effect (Table 4). The relative changes in the point estimates of LSMs were nearly zero between the status quo model and all other models with different combinations of random effects. The percent changes in SEs were as high as 16% between the status quo model (full model) and the model with all random effects, as high as 11% for the model with an AR(1) error structure in the year by grid effect, and as high as 21% for the model with all random effects and an AR(1) error structure in the year by grid effect (Table 5).

Models that included depth had lower AICC values than corresponding models that did not in all areas for large-mesh surveys in Lake Superior for the status quo model, and any model whose combination of random effects improved model fit over the status quo model (Table 6). Regardless of the area, the relative changes in the point estimates of LSMs for each year were nearly zero between the status quo model and models without depth. The percent changes in SEs between full and reduced models (i.e., with and without depth) were never greater than 4% for any assessment area (Table 7).

Models that included grid had lower AICC values than corresponding models without grid for all areas for large-mesh surveys in Lake Superior, except MS7, for the status quo model, and any model whose combination of random effects improved model fit over the status quo model (Table 6). The relative changes in the point estimates of LSMs for each year were nearly zero between the status quo model and models without grid (Table 8). The percent changes in SEs between full and reduced models depended on assessment area and the set of random effects in the models, but were never greater than 8% (Table 9).

For graded-mesh surveys in Lake Superior, the status quo model was outperformed in each assessment area by various models (Table 4). The relative changes in the point estimates of LSMs were nearly zero between the status quo model and all other models with different combinations of random effects. The percent changes in SEs were all positive and 15% or larger between the status quo model (full model) and the model with all random effects, they were all negative and as low as -18% for the model with no random effects, and were relatively small, except in MI5, for the model with an AR(1) error structure in the year by grid effect (Table 5).

Models with depth had lower AICC values than corresponding models that did not include depth in all assessment areas for the status quo model, and any model whose combination of random effects improved model fit over the status quo model (Table 6). Regardless of the assessment area, the relative changes in the point estimates of LSMs for each year were nearly zero between the status quo model and models without depth. The percent changes in SEs between full and reduced models (i.e., with and without depth) were never greater than 11%, and were generally 5% or less (Table 7).

Models that included grid never had lower AICC values than corresponding models without grid for all areas for graded-mesh surveys in Lake Superior for the status quo model, and any model whose combination of random effects improved model fit over the status quo model (Table 6). The relative changes in the point estimates of LSMs for each year were nearly zero between the status quo model and models without grid (Table 8). The percent changes in SEs between full and reduced models depended on assessment area and the set of random effects in the models, but were never greater than 5%, except for a model with an AR(1) error structure in the year by grid effect in MS5 (Table 9).

Discussion

The lack of evidence for severe violations of assumptions of normality in the residuals suggests that the constants added to each CPE observation may be appropriate, as suggested by Butterworth (1996) and Cooke and Lankester (1996). This conclusion is further supported by the “nominal” changes observed in the point estimates of LSMs when the constants were varied. Although SEs did change some when the constants were altered, we view these changes as modest. Consequently, we do not recommend substantial efforts exploring other ways of dealing with CPE observations of zero, like those suggested by Butterworth (1996) and Cooke and Lankester (1996).

We found no evidence for violations of spatial independence in the residuals or EBLUPs of the year by grid effect, but did find evidence for lack of temporal independence in the EBLUPs of the year by grid effect. Although samples appear to be spatially independent at this time, this assumption should be re-evaluated periodically as more data becomes available, particularly if the number or location of sampled grids changed. The lack of temporal independence in the EBLUPs of the year by grid effect was dealt with by adding autoregressive error. In this case, modeling year by grid effects as an autoregessive process (of order 1) significantly improved model fit in several assessment areas, suggesting that this change in the model was warranted due to lack of temporal independence.

Regardless of the combination of random effects or fixed effects included in the models, the point estimates of LSMs for each year were nearly unchanged in most assessment areas, so generally the effects of the factors in the models on SEs should dictate whether models other than the status quo should be considered. However, choices among models cannot be based solely on statistical grounds. Using a model that does not provide the best fit, but has larger SEs than the status quo model, would down weight the fit of the SCAA models to the indices of abundance relative to other data sources, and might be overly conservative. Conversely, continuing to use the status quo model, when the status quo model has smaller SEs than the best fit model, might place undue confidence in the indices of abundance. However, a model judged best on statistical grounds might not be considered plausible, either based on a priori grounds or because such a model differs from models selected for other areas. For example an analyst might prefer to keep random year by grid interactions in every region modeled, even when not judged statistically best, on the grounds that perfect tracking of abundance at different areas over time is not believable, and assuming this would tend to underestimate uncertainty. If models that improved fit over the status quo have SEs that are much different from the status quo, then assessment scientists using the resulting indices will have to decide whether the changes in the SEs are large enough to warrant using the “better” model, and whether models should be chosen on grounds of plausibility or to be conservative in terms of the error around LSMs for each year.

Each lake, and in some cases each assessment area, had a different set of random effects that provided the best fit or was most conservative (i.e., resulted in larger SEs than the status quo model). In Lake Huron, although the status quo model did not always provide the best fit, the difference in SEs between the status quo and models that provided a better fit were minimal. Consequently, the status quo model could be selected as providing nearly the best fit and also being most conservative in each assessment area. In Lake Michigan, a model with an AR(1) error structure in the year by grid effect would be more conservative than the status quo model across all assessment areas. The model with an AR(1) error structure also provided the best fit in MM4 and MM5. The status quo model provided the best fit in MM123, and a model with no random effects provided the best fit in MM67. However, using a model with no random effects would not be a conservative option. Conversely, using the model with AR(1) error structure in a assessment areas where it does not provide the best fit (e.g. MM123) may be overly conservative. In Lake Superior large-mesh surveys, the status quo model never provided the best fit and was not the most conservative option. The model with all two and three way interactions and an AR(1) error structure in the year by grid effect would improve model fit over the status quo model and provide the most conservative estimates across all assessment areas, but was never the best fit in any single assessment area. If a different model was selected for each assessment area for the large-mesh survey, the model with an AR(1) error structure in the year by grid effect would provide the best fit and be more conservative than the status quo model for MI5 and MI6, while a model with all two and three way interactions would be the best fit and most conservative in MI7.

In Lake Superior graded-mesh surveys, the status quo model never provided the best fit and was not the most conservative option. A model with all two and three way interactions would be more conservative than the status quo model across all assessment areas, and provide the best fit in MI6. If a different model was selected for each assessment area, the model with an AR(1) error structure in the year by grid effect provided the best fit and was most conservative in MI5 and a model with all two and three way interactions provided the best fit and was most conservative in MI6. In MI7, a model with no random effects provided the best fit, but this would not be a conservative option. The model with all two and three way interactions would be the most conservative option for MI7 and would not substantially reduce model fit from the status quo.

The depth effect improved model fit for all assessment areas in Lakes Huron and Superior (no depth effect was considered in Lake Michigan), and combinations of random effects that improved fit over the status quo, except in MH2. Consequently, depth should continue to be included in all these models. Including depth in the model for MH2 will only increase SEs from the status quo model making the model more conservative. Our finding that depth was consistently important is consistent with observations that lake trout preferentially seek out certain depths (Hansen 1999). If the depth distribution of lake trout changes through time, then adequately sampling various depths will remain an important survey design requirement, and what models should be used might change (e.g., a temporally correlated depth by year interaction might be needed).

The grid effect improved model fit for all lakes, assessment areas, and combinations of random effects that improved fit over the status quo, except in MH2, MS7 for large-mesh surveys, and all Lake Superior assessment areas for graded-mesh surveys. For the assessment areas where grid did not improve model fit, including grid in the models will generally increase SEs from the status quo model (Table 9), making the models more conservative. MH1 was the only assessment area where the differences in LSMs between the status quo and models without grid were greater than 2% (Table 8), but grid improved model fit in MH1 (Table 6), and so grid should likely be retained in the model. The graded-mesh surveys in Lake Superior sampled the fewest grids of all surveys (Table 1). Although this sampling design allowed samples to be taken from each grid in almost all years (Figure 2), our finding that grid did not improve model fit suggests that this design may not adequately sample the spatial variability in lake trout distribution. Alternatively, lake trout behavior may change systematically in the summer, when the Lake Superior graded-mesh survey is conducted, in a way that more evenly distributes fish among grids making sampling location less meaningful. Some possible explanations for these behavioral changes might include temperature preferences or responses to prey distributions that differ between the spring and summer timing of the two surveys.

In summary, the status quo models were generally reasonable. Alternative assumptions and models produced nearly the same point estimates and often only led to modest changes in estimated SEs for LSMs. In some cases, however, the data supported a change from the current status quo model, and resulting changes to SEs that were non-trivial. For these cases we suggest that these alternative models should be seriously considered or that the sensitivity of the assessment models be evaluated to this type of change in the estimated uncertainty associated with the survey indices of abundance.

We limited our evaluation to models fit to the same dependent data and using the same categorical explanatory variables as had been used in the GLMMs that were being used when our evaluation began. Our intent was to explore whether the current models were a justified treatment of these data, or whether they might be substantially improved through straightforward model changes. We did not explore changes in categorical variables, for example by changing definitions of deep or shallow, incorporating month effects to account for seasonal effects, or redefinition of what a location is (rather than using grids). We also did not consider incorporating entirely new effects (e.g., by acquisition and use of temperature data). While such efforts could potentially lead to better models and are worth pursuing in the future, we suspect they will require different approaches in different management areas, depending upon specifics of where and when samples have been collected and which additional data are available. Our analysis also did not evaluate alternative survey designs, but instead evaluated which models were best, given the data that exists. Evaluation of alternative survey designs would potentially provide substantial benefits, and results from GLMMs would be useful in such a study as they provide estimates of sources of variation that are typically used in such evaluations (e.g., Wagner et al. 2007).

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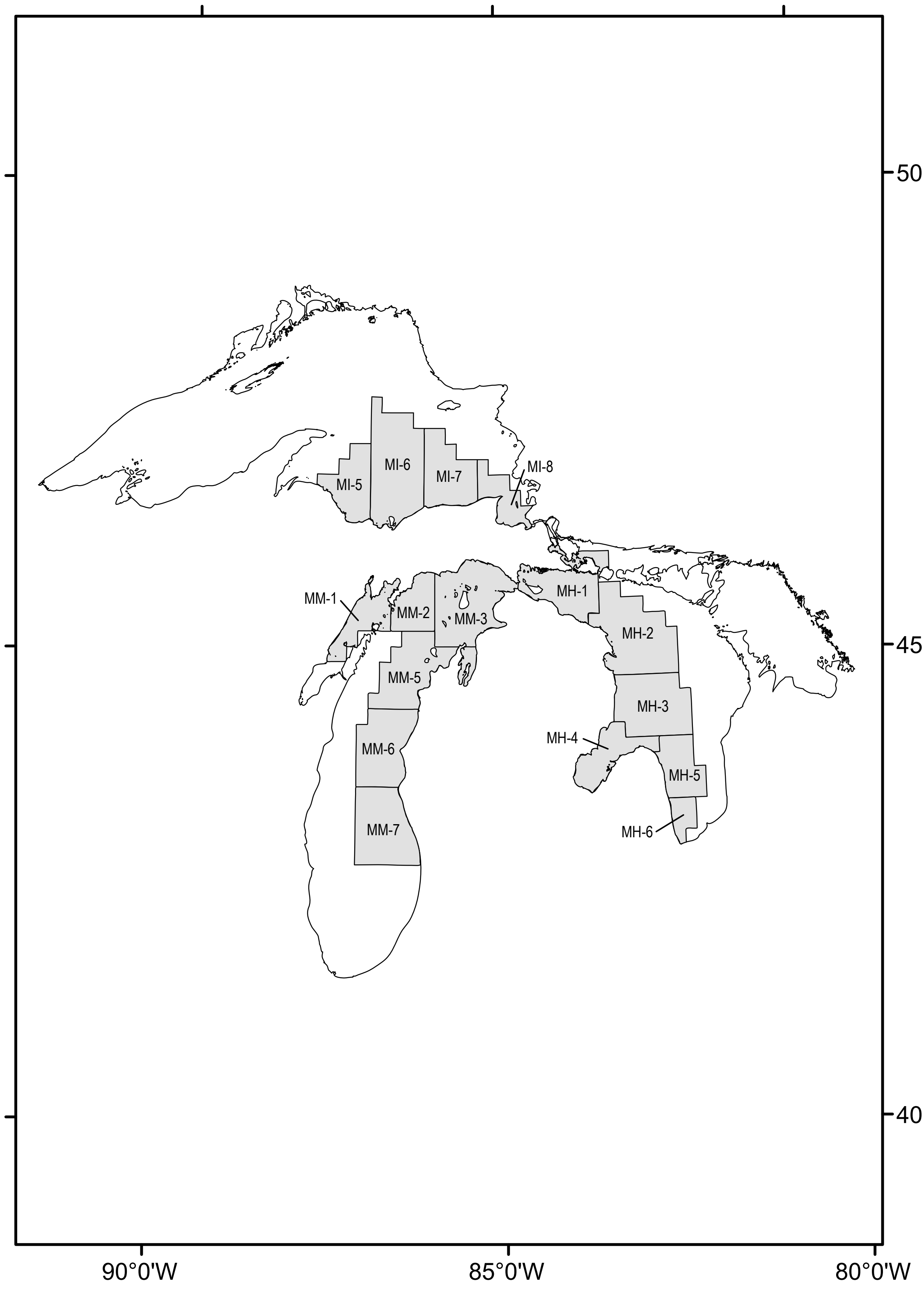

Figure 1.–Lake trout reporting units in the Michigan waters of Lakes Superior, Huron, and Michigan. Those labeled were used in this analysis.

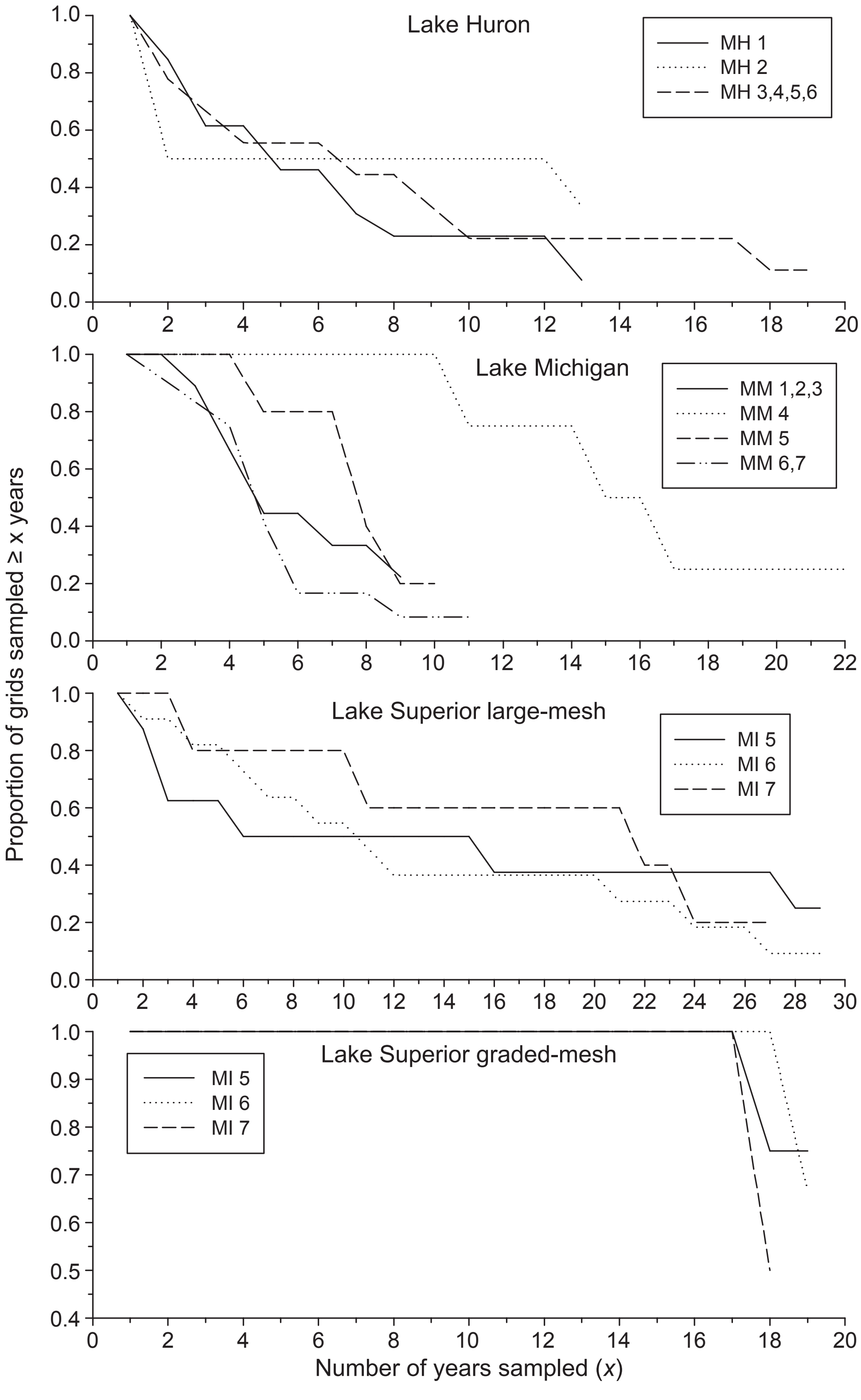

Figure 2.–The proportion of grids sampled for at least as many years as the number of years on the x-axis for lake trout surveys in 1836 Treaty waters of Lakes Huron, Michigan, and Superior. Data used here were from 1984-2003 in Lake Huron, 1981-2003 in Lake Michigan, 1975-2004 in Lake Superior large-mesh surveys, and 1985-2004 in Lake Superior graded-mesh surveys

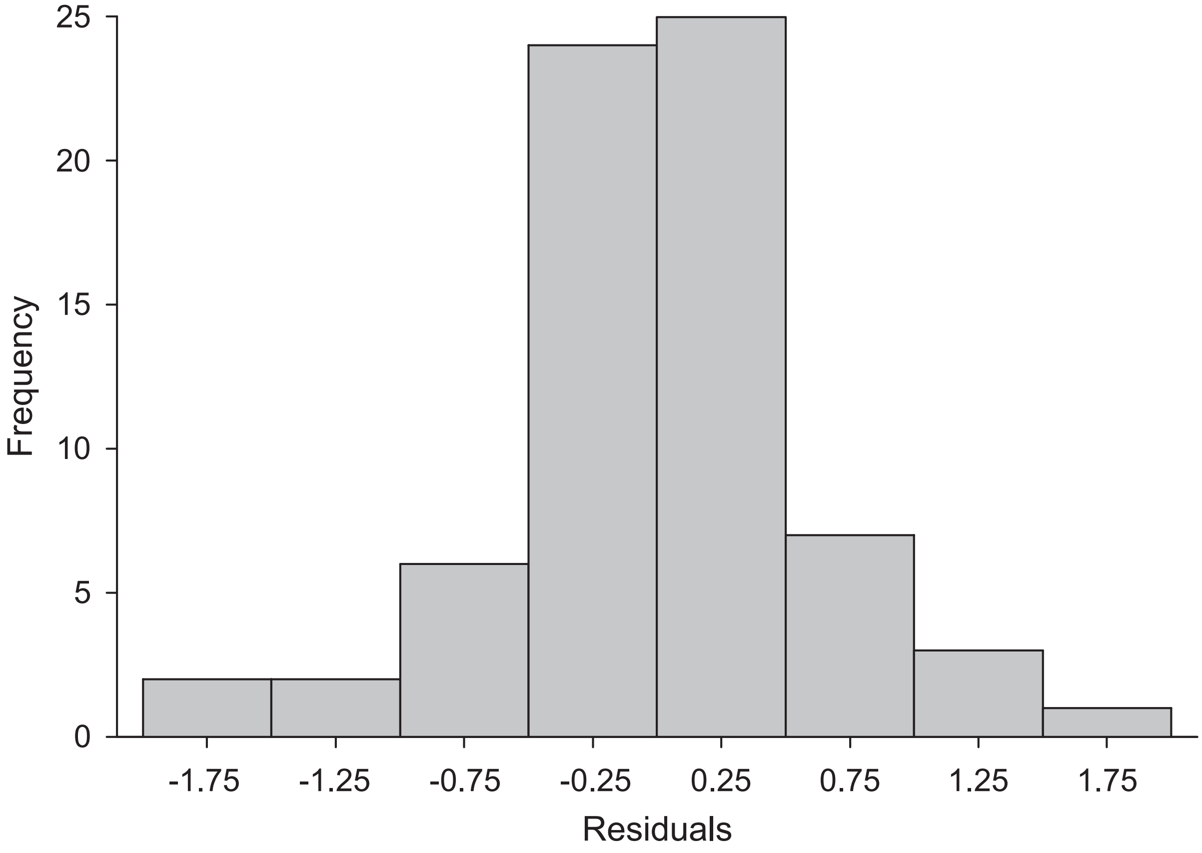

Figure 3.–Example frequency histogram used to show the normality of residuals and estimated best linear unbiased predictors of the random year by grid effect from status quo general linear mixed models used to create model-based indices of lake trout abundance in 1836 Treaty waters. The plot shown is for residuals in assessment area MH2 in Lake Huron.

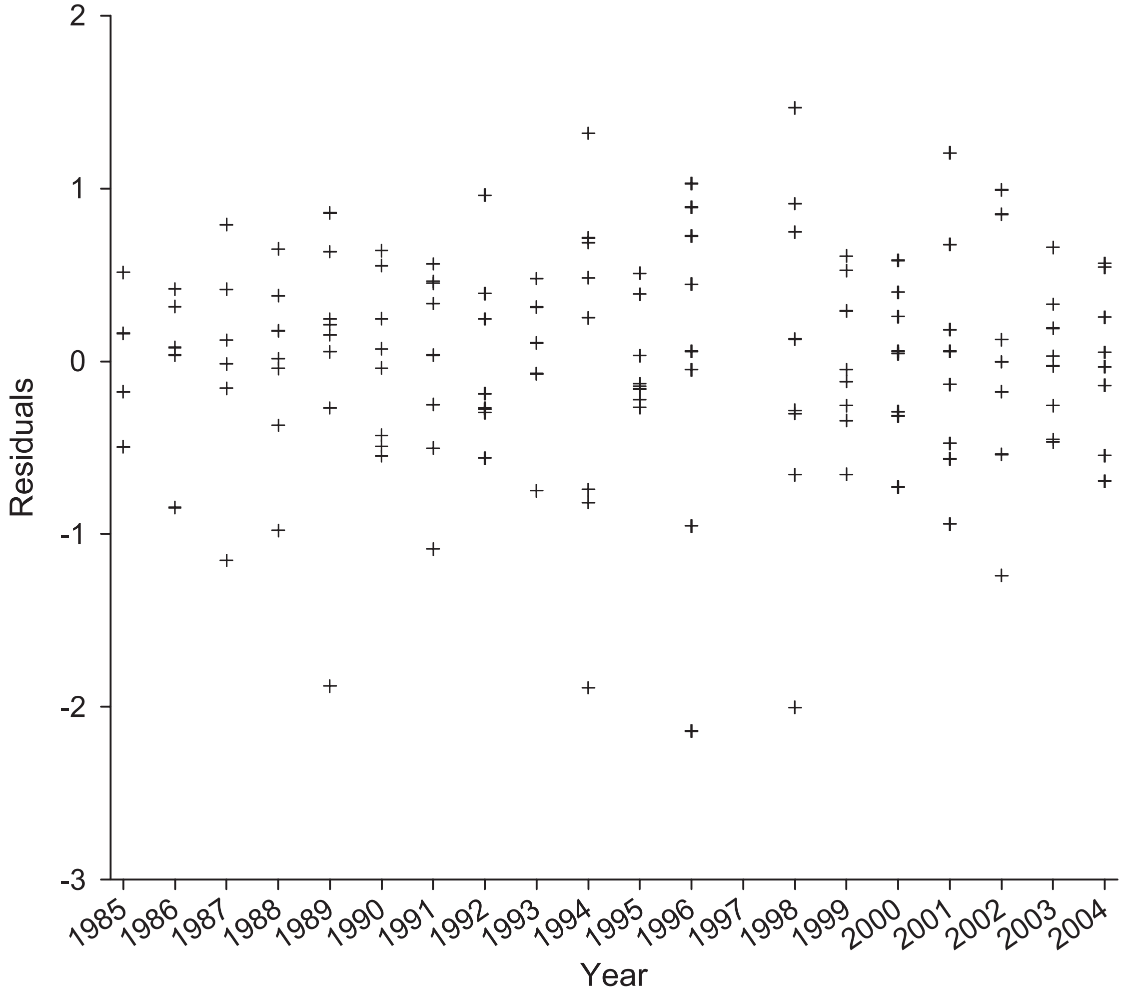

Figure 4.–Example plot used to show the temporal independence of residuals through time from status quo general linear mixed models used to create model-based indices of lake trout abundance in 1836 Treaty waters. The plot shown is for residuals in assessment area MI6 from Lake Superior graded-mesh surveys.

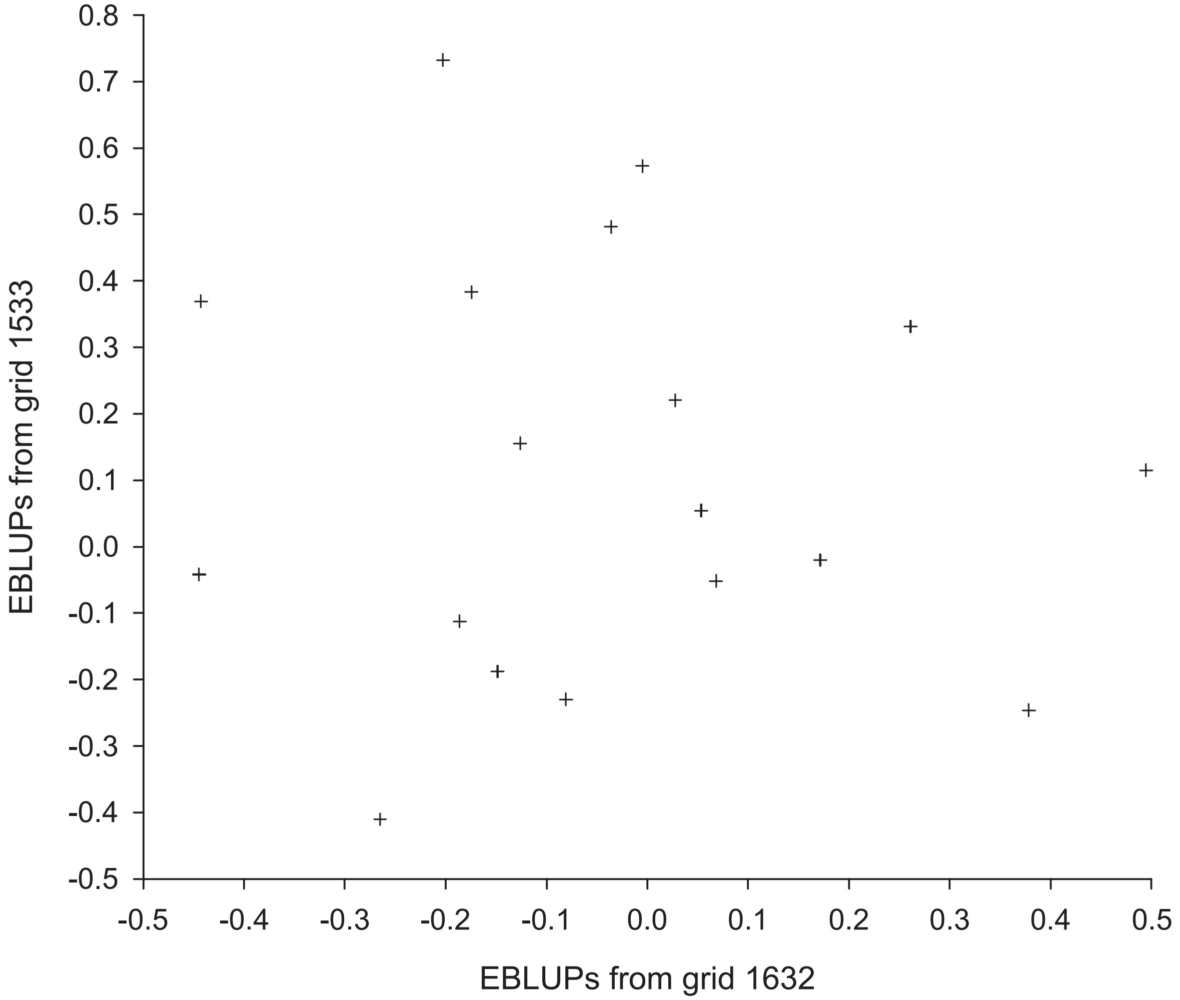

Figure 5.—Example plot used to show the spatial independence of estimated best linear unbiased predictors (EBLUPs) of the random year by grid effect for adjacent grids from general linear mixed models used to create model-based indices of lake trout abundance in 1836 Treaty waters. The plot shown is for EBLUPs in grids 1533 (y-axis) and 1632 (x-axis) from Lake Superior large-mesh surveys.

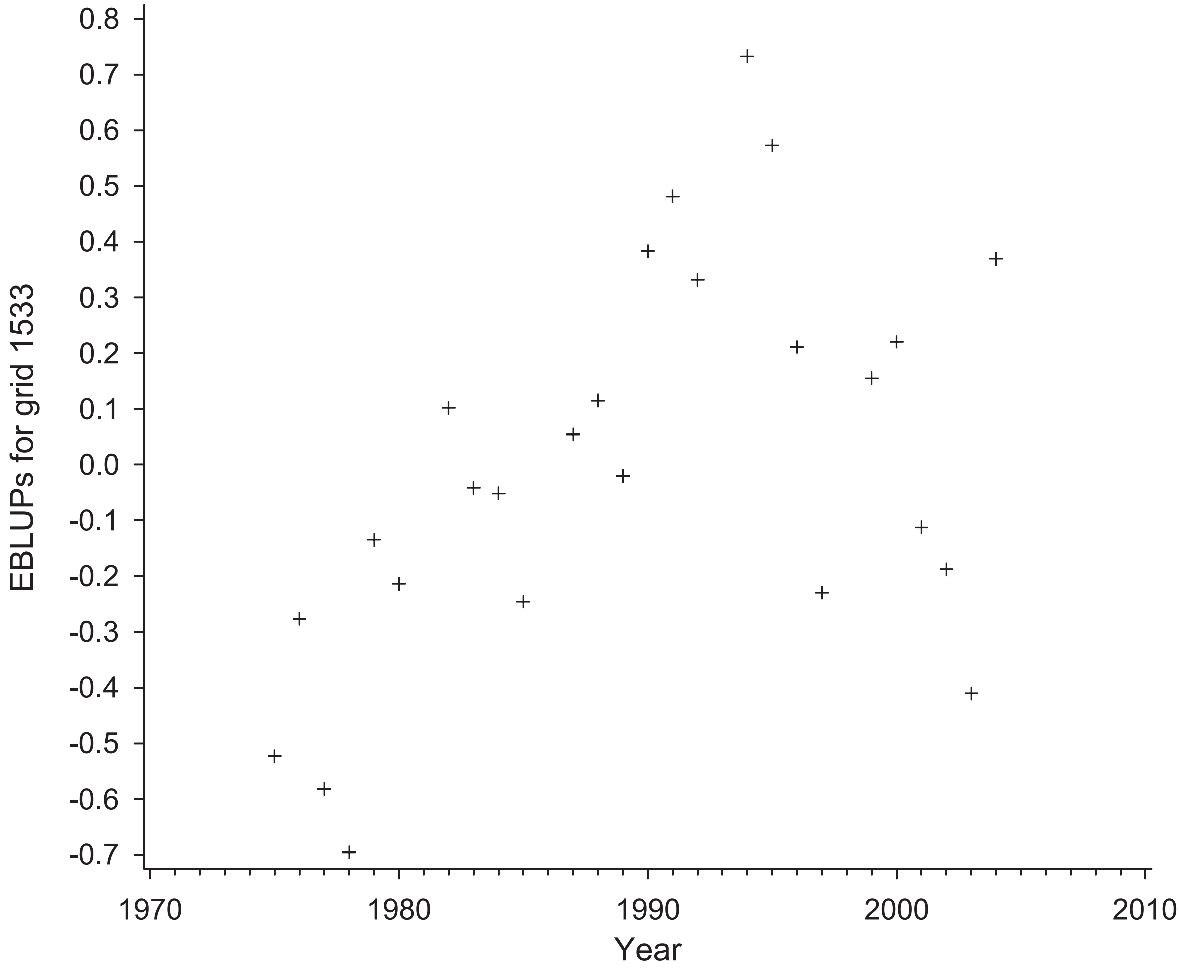

Figure 6.–Example plot used to show the lack temporal independence of estimated best linear unbiased predictors of the random year by grid effect from general linear mixed models used to create model-based indices of lake trout abundance in 1836 Treaty waters. The plot shown is for grid 1533 from Lake Superior large-mesh surveys.

Table 1.–Number of grids sampled in each assessment area by lake trout surveys for years used in this analysis. All samples on lakes Michigan and Huron were taken with graded-mesh gill nets. On Lake Superior samples were taken both with graded-mesh (denoted GM-) and by large-mesh (LM-) gill nets.

	Assessment area												
	Lake Huron			Lake Michigan				Lake Superior					
Year	MH1	MH2	MH3456	MM4	MM5	MM123	MM67	LM-MI5	LM-MI6	LM-MI7	GM-MI5	GM-MI6	GM-MI7
1975	–	–	–	–	–	–	–	5	5	5	–	–	–
1976	–	–	–	–	–	–	–	6	4	5	–	–	–
1977	–	–	–	–	–	–	–	5	4	3	–	–	–
1978	–	–	–	–	–	–	–	6	4	4	–	–	–
1979	–	–	–	–	–	–	–	4	5	2	–	–	–
1980	–	–	–	–	–	–	–	3	4	3	–	–	–
1981	–	–	–	3	2	3	4	3	2	3	–	–	–
1982	–	–	–	3	2	4	5	3	4	–	–	–	–
1983	–	–	–	3	2	2	1	4	4	2	–	–	–
1984	4	1	3	3	2	2	2	4	5	3	–	–	–
1985	4	1	3	3	2	4	–	4	3	1	4	3	–
1986	1	1	2	2	2	4	2	4	3	3	4	3	2
1987	1	2	2	2	2	4	5	4	4	3	4	3	2
1988	1	1	2	2	2	3	4	3	4	4	4	3	2
1989	1	1	2	2	2	3	3	4	5	4	4	3	2
1990	–	1	2	2	–	3	2	4	5	4	4	3	2
1991	1	2	2	–	–	–	–	3	6	4	3	3	2
1992	4	2	3	4	–	–	–	4	5	–	4	3	2
1993	3	1	2	3	–	–	–	3	4	2	3	2	2
1994	3	1	2	4	–	–	–	3	7	2	4	3	2
1995	4	3	5	4	–	–	–	3	4	3	4	3	2
1996	3	3	4	4	–	–	1	3	4	3	4	3	2
1997	3	3	3	4	1	–	3	3	5	3	–	–	–
1998	4	3	4	2	4	1	2	–	–	–	4	3	2
1999	5	3	5	2	2	2	1	3	4	3	4	3	2
2000	8	3	5	3	1	1	3	2	7	3	4	3	1
2001	8	3	5	2	3	4	2	4	7	3	4	3	2
2002	7	3	5	2	3	5	8	4	8	3	4	3	2
2003	7	3	5	3	4	4	8	4	6	3	4	3	2
2004	–	–	–	–	–	–	–	5	10	3	4	3	2

Table 2.–Average number of samples taken within grids for lake trout surveys in each assessment area for years used in this analysis. All samples on Lakes Michigan and Huron were taken with graded-mesh gill nets. On Lake Superior, samples were taken both with graded-mesh (denoted GM-) and large-mesh (LM-) gill nets.

	Assessment area												
	Lake Huron			Lake Michigan				Lake Superior					
Year	MH1	MH2	MH3456	MM4	MM5	MM123	MM67	LM-MI5	LM-MI6	LM-MI7	GM-MI5	GM-MI6	GM-MI7
1975	–	–	–	–	–	–	–	2.0	3.0	1.0	–	–	–
1976	–	–	–	–	–	–	–	5.2	6.0	6.4	–	–	–
1977	–	–	–	–	–	–	–	4.4	6.5	6.7	–	–	–
1978	–	–	–	–	–	–	–	4.5	7.5	8.0	–	–	–
1979	–	–	–	–	–	–	–	4.0	5.2	7.0	–	–	–
1980	–	–	–	–	–	–	–	4.0	5.0	3.0	–	–	–
1981	–	–	–	4.0	5.0	2.0	1.8	3.3	1.5	3.3	–	–	–
1982	–	–	–	1.7	4.0	1.8	2.0	3.3	2.5	–	–	–	–
1983	–	–	–	5.0	4.0	2.0	2.0	4.0	3.0	3.5	–	–	–
1984	1.8	4.0	2.0	4.0	2.5	1.5	1.5	2.0	1.6	2.0	–	–	–
1985	1.5	4.0	1.7	2.0	1.5	2.0		1.3	2.7	6.0	1.0	1.3	–
1986	2.0	4.0	3.0	2.5	1.0	1.5	2.5	1.3	1.0	4.0	2.0	1.7	2.0
1987	2.0	2.0	3.0	1.5	2.0	1.5	1.2	2.0	2.0	3.7	2.5	2.0	2.0
1988	1.0	4.0	3.5	1.0	2.0	1.0	1.5	4.7	3.0	6.5	2.5	2.7	2.0
1989	2.0	3.0	4.0	1.5	1.5	1.3	1.7	5.5	2.8	4.8	2.0	2.7	2.0
1990	–	4.0	3.0	1.0	–	1.3	2.0	5.5	6.4	4.0	2.0	2.7	2.0
1991	2.0	1.5	3.0	–	–	–	–	6.0	4.7	6.0	1.7	2.7	2.0
1992	4.0	2.0	2.0	3.0	–	–	–	6.0	5.2	–	2.0	2.3	2.0
1993	2.0	3.0	2.5	3.0	–	–	–	8.0	4.0	8.0	1.7	2.5	2.0
1994	1.7	4.0	2.5	3.0	–	–	–	6.7	3.7	4.0	2.0	2.7	2.0
1995	1.5	1.0	2.0	3.3	–	–	–	6.7	3.0	5.3	2.0	2.7	2.0
1996	1.7	1.0	2.5	4.3	–	–	2	7.3	1.5	5.3	2.0	2.7	2.0
1997	1.7	1.0	2.0	5.3	2.0	–	3.0	6.7	2.2	5.3	–	–	–
1998	1.5	1.0	2.0	1.5	1.5	1.0	4.0	–	–	–	2.0	2.7	2.0
1999	1.4	1.0	2.0	5.0	3.5	3.0	3.0	9.3	3.0	5.3	2.0	2.7	2.0
2000	1.5	1.0	2.0	2.3	3.0	5.0	4.0	8.0	3.1	5.3	2.0	2.7	2.0
2001	1.8	1.0	2.0	5.0	2.0	2.3	3.0	3.0	2.6	5.3	2.0	2.7	2.0
2002	1.6	1.0	2.0	3.5	3.7	2.6	3.1	3.0	2.6	5.3	2.0	2.7	2.0
2003	1.7	1.0	2.2	6.3	5.0	2.5	3.9	3.0	3.0	5.0	2.0	2.7	2.0
2004	–	–	–	–	–	–	–	2.8	2.1	5.3	2.0	2.7	2.0

Table 3.–Percent changes in the standard errors of estimates of least square means of log$_e$ catch per effort for each year from lake trout survey mixed models when the constant added to catch per effort values before log$_e$ transformation was doubled or halved. All samples on Lakes Michigan and Lake Huron were taken with graded-mesh gill nets. On Lake Superior samples were taken both with graded-mesh (denoted GM-) and by large-mesh (LM-) gill nets. Data used here were from 1984–2003 in Lake Huron, 1981–2003 in Lake Michigan, 1975–2004 in Lake Superior large-mesh surveys, and 1985–2004 in Lake Superior graded-mesh surveys.

	Assessment area												
	Lake Huron			Lake Michigan				Lake Superior					
Constant	MH1	MH2	MH3456	MM123	MM4	MM5	MM67	LM-MI5	LM-MI6	LM-MI7	GM-MI5	GM-MI6	GM-MI7
doubled	-8	0	0	-15	-16	-14	-14	-5	-8	-13	-5	-11	-10
halved	9	0	0	14	13	13	14	3	6	11	3	10	9

Table 4.–Corrected Akaike Information Criterion values for lake trout survey mixed models fit with restricted maximum likelihood in each assessment area of Lakes Huron, Michigan, and Superior. All samples on Lakes Michigan and Huron were taken with graded-mesh gill nets. On Lake Superior samples were taken both with graded-mesh (denoted GM-) and by large-mesh (LM-) gill nets. Data used here were from 1984–2003 in Lake Huron, 1981–2003 in Lake Michigan, 1975–2004 in Lake Superior large-mesh surveys, and 1985–2004 in Lake Superior graded-mesh surveys. DNC indicates the model did not converge.

	Assessment area												
	Lake Huron			Lake Michigan				Lake Superior					
Random effects	MH1	MH2	MH3456	MM123	MM 4	MM 5	MM67	LM-MI5	LM-MI6	LM-MI7	GM-MI5	GM-MI6	GM-MI7
year by grid (status quo)	394.5	135.6	354.1	184.2	395.1	241.6	381.9	1,025.7	949.6	939.1	333.2	331.5	129.6
all 2 and 3 way interactions	394.7	DNC	355.7	–	–	–	–	1,027.4	952.1	933.6	334.2	327.4	130.9
none	392.4	133.4	354.1	188.8	393.8	243.5	379.8	1,053.0	1,008.2	942.2	339.8	333.6	127.6
year by grid AR(1)	DNC	137.2	356.1	186.1	392.9	241.2	383.8	1,023.4	931	941.1	324.6	333.6	131.8
all 2 and 3 way interactions with year by grid AR(1)	DNC	140.3	357.8	–	–	–	–	1,025.2	932.8	935.6	DNC	329.4	133.3

Table 5.–Percent changes in the standard errors of estimates of least square means of $\log_e$ catch per effort for each year from lake trout survey mixed models for various combinations of random effects. The percent changes are all calculated relative to the standard errors produced by the status quo model (full model), which only includes the interaction of year by grid as a random effect. All samples on Lakes Michigan and Huron were taken with graded-mesh gill nets. On Lake Superior samples were taken both with graded-mesh (denoted GM-) and by large-mesh (LM-) gill nets. Data used here were from 1984–2003 in Lake Huron, 1981–2003 in Lake Michigan, 1975–2004 in Lake Superior large-mesh surveys, and 1985–2004 in Lake Superior graded-mesh surveys. A dash (–) indicates that the model did not improve model fit from the status quo model based on comparison of Corrected Akaike Information Criterion values.

	Assessment area												
	Lake Huron			Lake Michigan				Lake Superior					
Reduced random effects model	MH1	MH2	MH3456	MM123	MM4	MM5	MM67	LM-MI5	LM-MI6	LM-MI7	GM-MI5	GM-MI6	GM-MI7
all 2 and 3 way interactions	–	–	–	–	–	–	–	4	0	16	15	26	16
no random effects	-1	0	0	-24	-6	-26	-2	–	–	–	-15	-18	-5
year by grid AR(1)	–	–	–	195	55	99	92	4	11	-3	28	0	1
all 2 and 3 way interactions with year by grid AR(1)	–	–	–	–	–	–	–	6	21	6	–	–	–

Table 6.–Corrected Akaike Information Criterion values for lake trout survey mixed models fit with maximum likelihood in each assessment area of Lakes Huron, Michigan, and Superior. All samples on Lakes Michigan and Huron were taken with graded-mesh gill nets. On Lake Superior samples were taken both with graded-mesh (denoted GM-) and by large-mesh (LM-) gill nets. Data used here were from 1984–2003 in Lake Huron, 1981–2003 in Lake Michigan, 1975–2004 in Lake Superior large-mesh surveys, and 1985–2004 in Lake Superior graded-mesh surveys. A dash (–) indicates that the combination of random effects in that row did not improve model fit from the status quo model based on comparison of Corrected Akaike Information Criterion values, and consequently was not of interest in terms of fixed effects.

		Management unit												
		Lake Huron			Lake Michigan				Lake Superior					
Random effects	Fixed effects	MH1	MH2	MH3456	MM123	MM4	MM5	MM67	LM-MI5	LM-MI6	LM-MI7	GM-MI5	GM-MI6	GM-MI7
year by grid	year, depth, grid	499.2	223.5	411.0	–	–	–	–	1,065.0	990.5	960.7	371.8	369.3	174.6
year by grid	year, grid	505.3	220.4	438.8	228.7	406.5	285.6	437.2	1,073.9	1,021.1	969.9	378.4	370.7	185.6
year by grid	year, depth	561.2	203.3	426.8	–	–	–	–	1,089.0	1,070.6	958.3	367.1	369.1	170.4
year by grid	year	565.1	201.1	441.6	255.7	507.2	284.3	454.5	1,096.9	1,097.5	965.2	373.0	367.5	184.8
none	year, depth, grid	499.2	223.5	411.0	–	–	–	–	–	–	–	372.3	369.3	174.6
none	year, grid	505.3	220.4	438.8	225.4	406.5	285.6	437.2	–	–	–	377.2	370.7	185.6
none	year, depth	581.5	203.3	426.8	–	–	–	–	–	–	–	368.8	366.3	170.4
none	year	579.2	201.1	441.6	287.7	555.5	281.3	459.8	–	–	–	372.7	367.5	184.8
all 2 and 3 way interactions	year, depth, grid	–	–	–	–	–	–	–	1,065.0	988.8	957.6	377.5	375.3	179.1
all 2 and 3 way interactions	year, grid	–	–	–	–	–	–	–	1,076.3	1,009.0	962.8	381.8	375.6	183.1
all 2 and 3 way interactions	year, depth				–	–	–	–	1,085.8	1,024.0	954.2	371.2	371.2	174.7
all 2 and 3 way interactions	year				–	–	–	–	1,085.5	1,024.4	956.4	373.7	370.6	179.6
year by grid AR(1)	year, depth, grid	–	–	–	–	–	–	–	1,064.1	974.4	963.0	371.6	378.4	183.7
year by grid AR(1)	year, grid	–	–	–	231.5	409.0	288.8	440.2	1,072.7	1,007.5	971.9	371.8	378.5	187.3
year by grid AR(1)	year, depth	–	–	–	–	–	–	–	1,069.7	977.9	960.5	358.1	372.0	174.7
year by grid AR(1)	year	–	–	–	239.3	422.3	286.4	441.8	1,077.1	1,010.5	967.3	365.3	370.3	188.8
all 2 and 3 way interactions with year by grid AR(1)	year, depth, grid	–	–	–	–	–	–	–	1,064.1	974.0	960.0	–	–	–
all 2 and 3 way interactions with year by grid AR(1)	year, grid	–	–	–	–	–	–	–	1,075.0	992.7	965.2	–	–	–
all 2 and 3 way interactions with year by grid AR(1)	year, depth	–	–	–	–	–	–	–	1,071.8	979.3	956.6	–	–	–
all 2 and 3 way interactions with year by grid AR(1)	year	–	–	–	–	–	–	–	1,079.6	990.4	958.8	–	–	–

Table 7.–Percent changes in the standard errors of estimates of least square means of $\log_e$ catch per effort for each year from lake trout survey mixed models with and without a fixed depth effect for models with various combinations of random effects. The percent changes are all calculated relative to the standard errors produced by the model with depth (full model). All samples on Lakes Michigan and Huron were taken with graded-mesh gill nets. On Lake Superior samples were taken both with graded-mesh (denoted GM-) and by large-mesh (LM-) gill nets. Data used here were from 1984–2003 in Lake Huron, 1981–2003 in Lake Michigan, 1975–2004 in Lake Superior large-mesh surveys, and 1985–2004 in Lake Superior graded-mesh surveys. A dash (–) indicates that the combination of random effects in that row did not improve model fit from the status quo model based on comparison of Corrected Akaike Information Criterion values, and consequently was not of interest in terms of the fixed effects.

Random effects	Assessment area								
	Lake Huron			Lake Superior					
	MH1	MH2	MH3456	LM-MI5	LM-MI6	LM-MI7	GM-MI5	GM-MI6	GM-MI7
year by grid	-1	-24	6	1	5	1	-1	-1	5
none	0	-23	6	–	–	–	1	0	11
all 2 and 3 way interactions	–	–	–	-1	4	2	1	0	5
year by grid AR(1)	–	–	–	2	-1	1	2	-1	4
all 2 and 3 way interactions with year by grid AR(1)	–	–	–	0	3	4	–	–	–

Table 8.–Percent changes in the least square means of $\log_e$ catch per effort for each year from lake trout survey mixed models with and without a fixed grid effect for models with various combinations of random effects. The percent changes are all calculated relative to the least square means produced by the status quo model (full model). All samples on Lakes Michigan and Huron were taken with graded-mesh gill nets. On Lake Superior samples were taken both with graded-mesh (denoted GM-) and by large-mesh (LM-) gill nets. Data used here were from 1984–2003 in Lake Huron, 1981–2003 in Lake Michigan, 1975–2004 in Lake Superior large-mesh surveys, and 1985–2004 in Lake Superior graded-mesh surveys. A dash (–) indicates that the combination of random effects in that row did not improve model fit from the status quo model based on comparison of Corrected Akaike Information Criterion values, and consequently was not of interest in terms of the fixed effects.

	Management unit												
	Lake Huron			Lake Michigan				Lake Superior					
Random effects	MH1	MH2	MH3456	MM123	MM4	MM5	MM67	LM-MI5	LM-MI6	LM-MI7	GM-MI5	GM-MI6	GM-MI7
year by grid	65	1	2	0	0	0	-1	0	0	0	0	0	0
none	-10	1	2	-1	0	0	-1	–	–	–	0	0	0
all 2 and 3 way interactions	–	–	–	–	–	–	–	0	0	0	0	0	0
year by grid AR(1)	–	–	–	2	0	-1	0	0	1	0	0	0	0
all 2 and 3 way interactions with year by grid AR(1)	–	–	–	–	–	–	–	0	0	0	–	–	–

Table 9.–Percent changes in the standard errors of estimates of least square means of $\log_e$ catch per effort for each year from lake trout survey mixed models with and without a fixed grid effect for models with various combinations of random effects. The percent changes are all calculated relative to the standard errors produced by the model with grid (full model). All samples on Lakes Michigan and Huron were taken with graded-mesh gill nets. On Lake Superior samples were taken both with graded-mesh (denoted GM-) and by large-mesh (LM-) gill nets. Data used here were from 1984–2003 in Lake Huron, 1981–2003 in Lake Michigan, 1975–2004 in Lake Superior large-mesh surveys, and 1985–2004 in Lake Superior graded-mesh surveys. A dash (–) indicates that the combination of random effects in that row did not improve model fit from the status quo model based on comparison of Corrected Akaike Information Criterion values, and consequently was not of interest in terms of the fixed effects.

	Management unit												
	Lake Huron			Lake Michigan				Lake Superior					
Random effects	MH1	MH2	MH3456	MM123	MM4	MM5	MM67	LM-MI5	LM-MI6	LM-MI7	GM-MI5	GM-MI6	GM-MI7
year by grid	62	-13	8	-24	-6	-26	-2	1	5	1	-1	-1	5
none	37	-13	-3	22	36	-6	-1	–	–	–	0	0	-1
all 2 and 3 way interactions	–	–	–	–	–	–	–	-8	5	-6	-2	-2	-3
year by grid AR(1)	–	–	–	-57	15	-53	-43	-1	2	-3	-23	-1	-3
all 2 and 3 way interactions with year by grid AR(1)	–	–	–	–	–	–	–	-3	-5	0	–	–	–

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