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Predicted Effects of Proposed New Regulation Plans on Sedge/Grass Meadows of Lake Ontario

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ABSTRACT. *Previously described models for predicting the percent of Lake Ontario wetlands that would be occupied by sedge/grass-dominated meadow marsh were used to test four proposed new plans for regulation of lake levels and to make comparisons with the current plan and unregulated conditions. The models for drowned river mouth, barrier beach, open embayment, and protected embayment wetlands assessed responses to lake levels that would be generated by each plan under net total supplies modified from those that occurred from1900 to 2000. In years when reduced supplies would allow meadow marsh regeneration, simulated unregulated lake levels produced the most meadow marsh in all wetland geomorphic types; current Plan 1958DD produced the least. Overall predicted percent meadow marsh under the test plans decreased in the order B+, 2007, D+, and A+, and the latter three plans produced rather similar results in many cases. Lower percentages of meadow marsh under some plans were due to insufficient low lake levels that could allow soils to dry and restrict invasion by cattails, as well as lack of periodic high lake levels that could kill invading upland plants. An assessment of seasonal lake-level characteristics demonstrated that Plan 2007 would reduce mean winter lake levels by 13 cm or more than Plan B+ and springtime lake levels by more than 10 cm. These seasonal differences could result in less winter habitat for muskrats and reduced access to spring spawning habitats for fish such as northern pike. Our model results provide important information for use in the process of selecting a new regulation plan for Lake Ontario.*

INDEX WORDS: *Lake-level-regulation plans, Lake Ontario, meadow marsh, wetlands.*

INTRODUCTION

Water levels in Lake Ontario and the upper St. Lawrence River have been regulated since about 1960 when the St. Lawrence Seaway began operation, largely through controls provided at the Moses-Saunders hydroelectric dam between Cornwall, Ontario and Massena, New York. The current regulation Plan 1958D with deviations (1958DD) attempts to reduce lake levels during high water-supply periods and raise levels during low supply periods; however, it requires human intervention in determining releases of water (deviations from the plan) to achieve its goals. Plan 1958DD has compressed the overall range of water-level fluctuations from approximately 2.0 m without regulation to 1.3 m in years following 1973 (when water supplies were very high). The range of growing season peak water levels was similarly reduced from approximately 1.5 m without regulation to 0.7 m after 1973 (Wilcox *et al*. 2005). In 2001, the International Joint Commission (IJC) appointed a Study Board to conduct the 5-year, bi-national Lake Ontario-St. Lawrence River study (LOSLR) to review the regulation plan and develop options for new plans that

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would better meet the needs of current interests. The interests of hydropower, shipping, municipal-industrial water supply, recreational boaters, riparian landowners, and the environment were considered as part of the study process, which also included the lower St. Lawrence River below the Moses-Saunders dam (International Lake Ontario-St. Lawrence River Study Board 2006).

Wetlands were a key component of the environmental interest because they provide important habitat for many species and even small changes in lake level can flood or dewater broad areas with shallow water. Wetland plant communities are very sensitive to these changes in environmental conditions, as they may result in death by flooding or in germination of the plant seed bank when exposed to the air (Keddy and Reznicek 1986, Wilcox 1995, Wilcox 2004, Wilcox and Nichols 2008). Regulation of lake levels has been shown to disrupt these natural processes and often results in development of large areas dominated by a few competitive species adapted to the new hydrologic regime, as well as concomitant alteration of faunal habitat (Wilcox and Meeker 1991, 1992). In Lake Ontario, regulation and a prolonged period of above-average water supplies resulted in a large increase in emergent wetland dominated by cattails (mainly *Typha angustifolia* L. and *T.* × *glauca* Godr.) and a decrease in meadow marsh at slightly higher elevations dominated by sedges (e.g., *Carex stricta* Lam.) and grasses (e.g., *Calamagrostis canadensis* (Michx) P. Beauv) (Wilcox *et al*. 1992, 2005, 2008; Wilcox and Meeker 1995). Meadow marsh requires periodic high lake levels to kill invading upland plants and succeeding periods of low lake levels to produce drier soils that are amenable to sedge and grass species but too dry to support cattails invading from lower elevations (Wilcox *et al*. 2008).

The potential effects on wetlands of implementing a new regulation plan for Lake Ontario were evaluated as part of the LOSLR study (Wilcox *et al*. 2005, 2008; Hudon *et al*. 2006) and included development of GIS-based predictive models for each of four wetland geomorphic types (Wilcox and Xie 2007). In drowned river mouth, barrier beach, open embayment, and protected embayment wetlands, the models provide year-by-year predictions of percent of wetland that will be occupied by different plant communities, including meadow marsh. The purpose of this paper is to report and evaluate modeling results that predict changes in meadow marsh under the proposed new regulation plans for Lake Ontario.

METHODS

Regulation Plans Tested

Data sets containing 101-year, quarter-monthly water levels (four lake-level values per month) in the Lake Ontario-St. Lawrence River system were obtained for six different regulation plans from the International Joint Commission. These six sequences of lake levels were generated by simulating the operation of each plan to regulate releases of water from the lake to the river using the same 101-year set of net total supplies (the net amount of water entering Lake Ontario from its immediate watershed and from the upper Great Lakes, assuming present hydraulic characteristics of the system), ice conditions, and other inflows to the river. The net total supplies represent a modification of supplies from 1900 to 2000 that accounts for changes in upper lakes conditions and includes reconstructed ice conditions (D. Fay, Environment Canada, pers. comm.); hence, as was the practice in the LOSRL study, we refer to individual years using that time span.

Two of the plans were not new proposals. Pre-Project was a simulation of lake levels that would have occurred if no regulation had taken place, and 1958DD represented lake levels under the current regulation regime (Fig. 1a,b). Plans A+, D+, and B+ were developed during the LOSLR study (Fig. 1c,d,f). Each of these three plans was considered by the Study Board as meeting its three objectives of enhancing net economic benefits, increasing environmental integrity, and not causing any disproportionate losses to any interest (International Lake Ontario-St. Lawrence River Study Board 2006). However, the performance of each of the plans with respect to these objectives varied. Based on overall LOSLR comparisons of these three plans, Plan A+ produced the greatest net economic benefits, Plan B+ resulted in the best environmental performance, and Plan D+ provided a blend of economic and environmental benefits with the smallest loss of to any interest. Plan 2007 (Fig. 1e) is a later revision of Plan D+ that performs better than D+ with respect to all three of the Study Board's objectives.

Models Used for Testing

The predictive models for drowned river mouth, barrier beach, open embayment, and protected embayment wetlands developed by Wilcox and Xie (2007) were applied to each of the six plans. In summary, the models consist of four major compo-

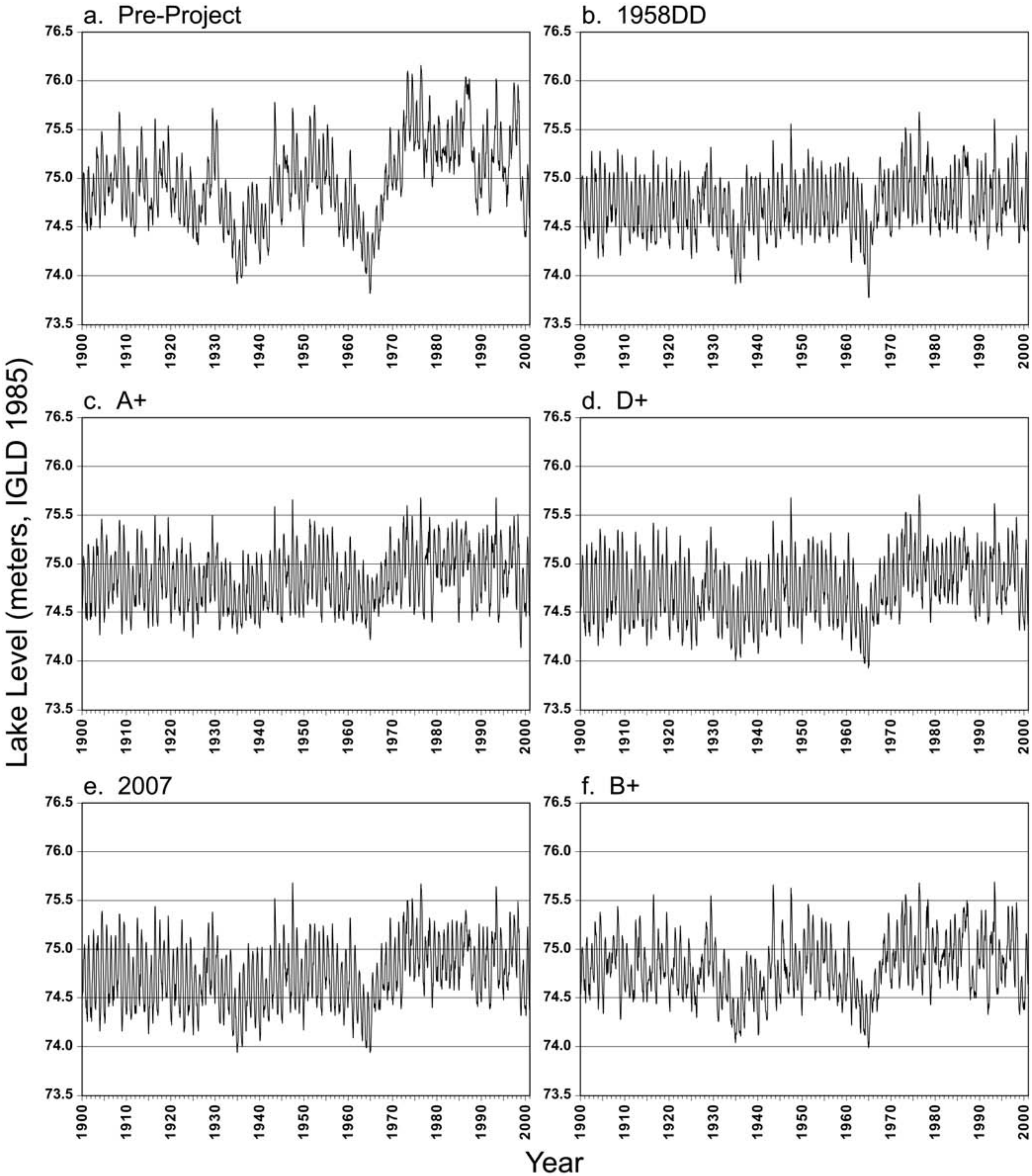

FIG. 1. Hydrographs provided by the International Lake Ontario-St. Lawrence River Study Board for Lake Ontario showing predicted lake levels for the period 1900-2000 based on total basin supplies with a) simulation of Pre-Project conditions with no regulation, b) regulation under Plan 1958DD, c) regulation under Plan A+, d) regulation under Plan D+, e) regulation under Plan 2007, and f) regulation under Plan B+.

nents: 1) three-dimensional geometric models for each of eight wetlands from each geomorphic type, 2) four generalized wetland geometric models representing each geomorphic type, 3) wetland plant profiles assigned to the generalized geometric models that identify associations between past flooding/dewatering events and the regulated water-level changes of a proposed plan, and 4) computer-coded routines that predict proportions of wetland plant communities within the geometric models and the time durations during which they would be affected under the proposed regulation plans. Based on this conceptual foundation, the predictive models were constructed using bathymetric and topographic wetland models and technical procedures operating on the platform of ArcGIS, as described in Wilcox and Xie (2007). For validation, the model results were tested against proportions of wetland plant communities derived from photointerpretation of historic aerial photographs (Wilcox and Xie 2007).

The model output of interest for each of the four wetland geomorphic types was percent of wetland predicted as meadow marsh (the upper portion of wetlands typically dominated by sedges and grasses that provide important faunal habitat), as this wetland type decreased substantially following regulation (Wilcox *et al*. 2008). Although the models present percent meadow marsh data in each year of the 101-year sequence, during periods of high net total supplies to Lake Ontario, all plans lack the ability to force lower lake levels that would promote increases in meadow marsh. From a meadow marsh perspective, the difference between plans is their ability to allow lower lake levels when supplies are low (Wilcox and Xie 2007). Therefore, based on determinations made from studies along transects with specific water-level histories (Wilcox *et al*. 2005), calculations to evaluate plan performance for meadow marsh were restricted to time spans that began four years after the average quarter-monthly total supply during the January-June period was less than 7,000 m^3/s and ended whenever the supply exceeded 8,000 m^3/sec (Wilcox and Xie 2007). This resulted in 22 individual years being selected for use in evaluating the plans: 1902–1903, 1924–1928, 1935–1942, and 1962–1968. Total supplies for years prior to the 1902–1903 time span were determined by appending a copy of the 101-year sequence of supplies, which followed the procedure used in model development (Wilcox and Xie 2007).

The area of affected wetland in Lake Ontario and the upper St. Lawrence River differs by geomorphic type. Therefore, to obtain predicted area of meadow marsh resulting from each regulation plan during the selected 22 years, we multiplied the predicted percent meadow marsh by wetland area in each geomorphic type based on inventories produced by Wilcox *et al*. (2005).

Model Sensitivity and Error

A detailed discussion of the model sensitivity and error sources was presented by Wilcox and Xie (2007). The most important parameter used to assess the model sensitivity is the Root Mean Squared Error (RMSE), values for which were derived from Figure 7 in Wilcox and Xie (2007). RMSE is the square root of the mean squared error (MSE), which is a measure of how close a fitted line is to data points. RMSE is more sensitive than MSE to occasional large errors because the squaring process gives disproportionate weight to very large errors. When RMSE is measured in the same units, it is a good statistic to make comparisons of errors between different models (Nau 2008). Moreover, RMSE is known as the standard error of the estimate in regression analysis. This is the statistic that determines the width of the confidence intervals for predictions. If the data are assumed to be normally distributed, the sample mean and the standard error can be used to calculate confidence intervals for the mean. The 95% confidence intervals for one-step-ahead forecasts are approximately equal to plus or minus 2 standard errors (i.e., plus or minus 2 times the root-mean-squared errors).

RESULTS

Modeling results predicted that simulated Pre-Project lake levels would produce the greatest percent of meadow marsh in all four geomorphic wetland types during the periods of low net total supplies; the current regulation Plan 1958DD would produce the least meadow marsh (Table 1). In all geomorphic types, the mean predicted percent meadow marsh among the proposed new regulation plans decreased in the order: B+, 2007, D+, and A+. Across geomorphic types, the total wetland area in meadow marsh under Plan B+ was greater than under Plan 2007 by 3.6 to 5.3 percent, which translates to a substantial 14.7–17.4% difference in actual meadow marsh area. Although Plan 2007 resulted in more meadow marsh than Plan 1958DD, Plans D+, A+, and 2007 were within 0.5 to 3.7 percent of each other (Table 1).

TABLE 1. Model-derived predictions of mean percent meadow marsh that would occur in Lake Ontario wetlands in 22 years that follow low total basin supplies under simulated pre-regulation conditions and five lake-level-regulation plans. Percentages are presented by wetland geomorphic type: drowned river mouth (DRM), barrier beach (BB), open embayment (OE), and protected embayment (PE). The percentage range was calculated as (RMSE*1.96)*100 for a 95% confidence interval under the assumption of normal distribution.

	Modeled Mean Percent Meadow Marsh and Confidence Intervals					
PLAN	Pre	B+	2007	D+	A+	58DD
DRM	39.9 ± 0.04	32.2 ± 0.04	26.9 ± 0.05	26.3 ± 0.05	23.6 ± 0.06	18.5 ± 0.08
BB	48.3 ± 0.22	36.1 ± 0.29	30.8 ± 0.34	30.6 ± 0.35	27.1 ± 0.39	20.2 ± 0.53
OE	24.6 ± 0.23	23.2 ± 0.24	19.6 ± 0.29	19.0 ± 0.30	17.6 ± 0.32	15.1 ± 0.37
PE	33.2 ± 0.04	28.8 ± 0.04	23.8 ± 0.05	23.4 ± 0.05	23.3 ± 0.05	15.8 ± 0.08

Converting percentages to area of meadow marsh in each geomorphic type, the modeling results suggest that, across all geomorphic types in both U.S. and Canada, regulation under the current Plan 1958DD would reduce the area of meadow marsh during years with suitable hydrology by 5,479 ha when compared to natural conditions (unregulated Pre-Project hydrology) (Table 2; Total). Modeled reduction in meadow marsh would be 3,869 ha under Plan A+, 3,355 ha under Plan D+, 3,247 ha under Plan 2007, and 1,930 ha under Plan B+ during those years. When compared to the current regulation Plan 1958DD, Plan B+ would produce 3,549 ha additional meadow marsh, Plan 2007 would produce 2,232 ha, Plan D+ would produce 2,121 ha, and Plan A+ would produce 1,610 ha (Table 2; Total).

The similarities in overall modeled results between Plans A+, D+, and 2007 prompted a review of the responses of all plans to each low supply period. Simulated Pre-Project lake levels resulted in more meadow marsh in all geomorphic types in all four time spans (Fig. 2). Plan 1958DD resulted in the least meadow marsh during the 1935–1942 time span in all geomorphic types, in protected embayments during the 1924–1928 and 1962–1968 time

TABLE 2. Model-derived predictions of mean area of meadow marsh that would occur in Lake Ontario wetlands in 22 years that follow low total basin supplies under simulated pre-regulation conditions and five lake-level-regulation plans. Meadow marsh area is presented by wetland geomorphic type separately for U.S. and Canada. Total wetland area U.S. and Canada: drowned river mouth (DRM) = 8,052 ha, barrier beach (BB) = 7,462 ha, open embayment (OE) = 2,020 ha, and protected embayment (PE) = 8,440 ha. Error term was calculated as (hectares of wetland type)*(95% confidence interval from Table 1) separately for each wetland type in the U.S. and Canada.

	Predicted Area of Meadow Marsh (hectares)					
PLAN	Pre	B+	2007	D+	A+	58DD
U.S.						
DRM	1,026 ± 1	828 ± 1	692 ± 1	676 ± 1	607 ± 2	476 ± 2
BB	1,976 ± 9	1,477 ± 12	1,260 ± 14	1,252 ± 14	1,109 ± 16	827 ± 22
OE	130 ± 1	122 ± 1	103 ± 2	100 ± 2	93 ± 2	80 ± 2
PE	609 ± 1	528 ± 1	437 ± 1	429 ± 1	428 ± 1	290 ± 1
CANADA						
DRM	2,187 ± 2	1,765 ± 2	1,474 ± 3	1,442 ± 3	1,294 ± 3	1,014 ± 4
BB	1,628 ± 7	1,217 ± 10	1,038 ± 11	1,032 ± 12	914 ± 13	681 ± 18
OE	367 ± ± 3	346 ± 4	293 ± 4	281 ± 4	263 ± 6	225 ± 6
PE	2,193 ± 3	1,903 ± 3	1,572 ± 3	1,546 ± 3	1,539 ± 3	1,044 ± 5
TOTAL	10,116	8186	6,869	6,761	6,247	4,637

spans, and in barrier beach wetlands during the 1962–1968 time span. It was comparable to plans A+, D+, and 2007 during the 1924–1928 time span in drowned river mouth and barrier beach wetlands but produced more meadow marsh than those plans in open embayments (Fig. 2). There were few marked differences among plans and pre-regulation conditions during the 1902–1903 time span. Plans A+, D+, and 2007 produced similar results in all geomorphic types during the 1924–1928 and 1935–1942 time spans; however, Plans D+ and 2007 resulted in more predicted meadow marsh than Plan A+ during the 1962–1968 time span, when they performed similarly to Plan B+ (Fig. 2). The latter plan consistently resulted in more predicted meadow marsh than all other proposed new regulation plans during the 1924–1928 and 1935–1942 time spans and more than A+ in the 1962–1968 time span (Fig. 2).

DISCUSSION

Plans under Consideration

A return to Pre-Project hydrology was not given strong consideration during the LOSLR study because it could result in disproportionate losses to some interests (ILOSLRSB 2006). The current Plan 1958DD was considered an option by the Study Board if other more suitable plans could not be developed, but it does not follow strict, pre-set rules and requires frequent decision-making (deviations) by the International St. Lawrence River Board of Control. Hence, from among many proposed alternatives, the Study Board presented the IJC with candidate plans A+, B+, and D+ (ILOSLRSB 2006). Plan 2007 (a revision of D+) was developed for the Commission after the conclusion of the LOSLR study as an additional candidate plan. Our assessment of these plans with regard to redevelopment and maintenance of lost meadow marsh (Wilcox *et al.* 2008) predicted that, across all geo-

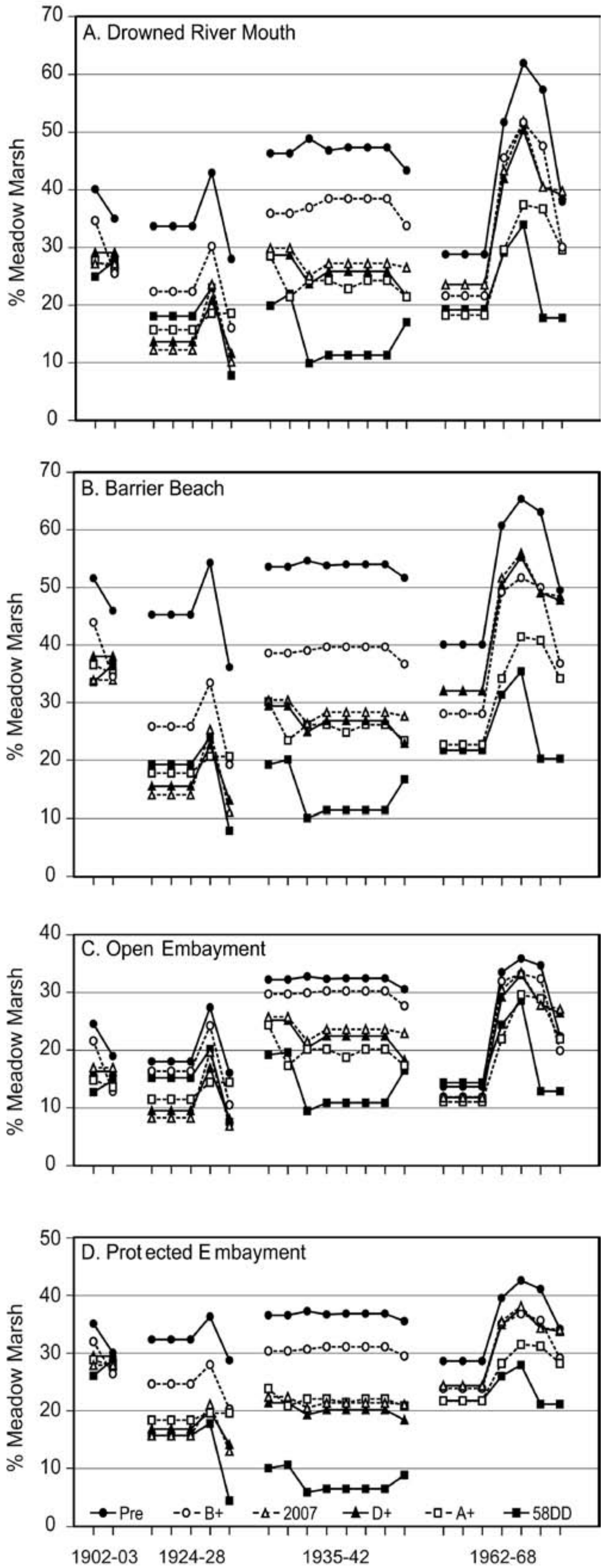

FIG. 2. Model-derived predictions of mean percent meadow marsh that would occur in Lake Ontario wetlands in years following low total basin supplies (1902–1903; 1924–1928; 1935–1942; 1962–1968) under simulated pre-regulation conditions and five lake-level-regulation plans. Wetland geomorphic types are a) drowned river mouth, b) barrier beach, c) open embayment, and d) protected embayment.

morphic types, all plans would result in more meadow marsh than Plan 1958DD during drought conditions such as those that occurred in the 1930s. However, the results were mixed in other time spans, when Plans A+, D+, and 2007 sometimes performed in a manner similar to Plan 1958DD.

As our results show, if the confidence intervals are applied to the mean percent meadow marsh of each wetland type, the error ranges of the mean percent meadow marsh are very limited. In other words, the errors in our wetland geomorphic models are very small, likely due to strong similarities among sites of a given geomorphic type in geomorphology at the elevations modeled. Hence, the model results and our analyses are statistically reliable. However, it should be pointed out that the mean percent meadow marsh of each wetland type is the sample mean based on the eight wetlands of that type surveyed in field. In reality, the true value of "mean percent meadow marsh" does not exist because of the limitation of field data collection. Therefore, any statement about the model sensitivity or reliability is only applicable to the sampling we conducted in this research.

Response of Plans to Low Water-supply Years

Although Plans A+, D+, and 2007 predicted increasing percent meadow marsh in that order when all time spans were combined (Tables 1, 2), most of the differences occurred in the 1960s (Fig. 2). A high lake level in 1947 under all plans (Fig. 1c–f) would have flooded much of the higher wetland elevations and reduced the area to be categorized as "transition to upland" by the models (Wilcox and Xie 2007), making it available for meadow marsh colonization if lake levels were low during low net total supplies of the 1960s. During 2 years in the 1960s, Plans D+ and 2007 allowed summertime peak lake levels to drop 33 to 46 cm lower than did Plan A+ (Fig. 1c-e), providing more dewatered area at those higher elevations for meadow marsh development.

The differences between Plans A+, D+, and 2007 were less marked in the low supply period of the 1930s. Plan A+ allowed lake levels to rise 12 cm above Plans D+ and 2007 when supplies were high in 1929 (Fig. 1c-e), resulting in less area as nonflooded "transition to upland" and more area available for meadow marsh colonization in the 1930s. Although Plans D+ and 2007 provided summertime peak levels 3 to 28 cm lower than Plan A+ across 2 years in the 1930s (Fig. 1c-e), the increase in meadow marsh was restricted by upland plant invasion at those higher elevations, making the difference between plans much less than in the 1960s.

Plan B+ most closely approximated a return to natural conditions during all time spans across all geomorphic types. During the 1960s, it reacted similarly to Plans D+ and 2007. In the 1930s, it took advantage of both a higher lake level in 1929 and lower lake levels in the mid-1930s (Fig. 1f) to increase the area of predicted meadow marsh. In the 1920s, Plan B+ produced more meadow marsh because it created lake levels 12 to 15 cm higher in 1916 than under Plans D+ and 2007, thus reducing "transition to upland" (Fig. 1d-f). Although Plan B+ created 1916 lake levels only 6 cm greater that under Plan A+ (a minor reduction in "transition to upland"), it also created lake levels as much as 27 cm lower than Plan A+ in the mid-1920s (Fig. 1c,f), thus making more wetland at lower elevations suitable for meadow marsh.

Predicted meadow marsh under the current regulation Plan 1958DD was substantially less than all other plans in the 1930s (Fig. 2) despite low lake levels in some of those years (Fig. 1b). Plan 1958DD, however, kept lake levels low even in preceding years with increased net total supplies, such as 1908, 1916, and 1929. Therefore, much of the higher elevation had not been flooded for more than 30 years prior to the 1930s and was categorized by the models as "transition to upland" (Wilcox and Xie 2007). The poor performance of Plan 1958DD in the 1930s points out the importance of occasional high lake levels, as well as lows, in creation of meadow marsh. The highs are needed to recover wetland area from invading upland species; a succeeding period of low lake levels is needed to allow meadow marsh colonization (Keddy and Reznicek 1986; Wilcox 1995, 2004). If not for the lack of high levels in 1908, 1916, or 1929 under Plan 1958DD, the overall differences between Plans 2007, D+, A+, and 1958DD (Tables 1, 2) would be much reduced.

Plans 2007 and B+

More recent deliberations by the International Joint Commission focused primarily on Plans 2007 and B+. As described above, the meadow marsh indicator ranked Plan B+ well ahead of Plan 2007. However, other environmental considerations separate the plans further. Following regulation under Plan 1958DD, muskrat (*Ondatra zibethicus* L.)

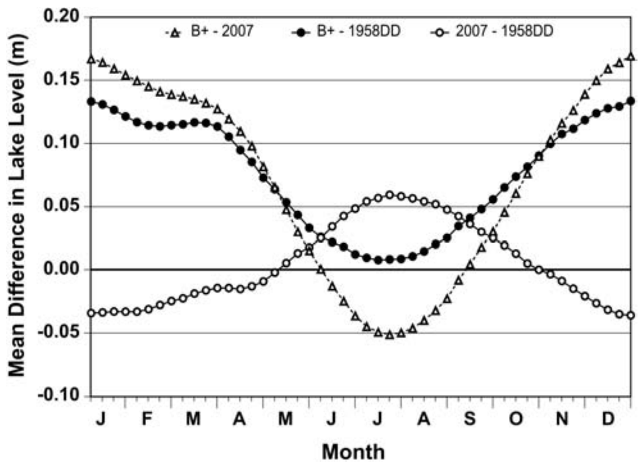

FIG. 3. Difference in mean water level of Lake Ontario by quarter months across 101 years (1900-2000) of total basin supplies when regulated by Plan B+ vs. Plan 2007 (B+ minus 2007 levels); Plan B+ vs. Plan 1958DD; and Plan 2007 vs. Plan 1958DD. In each evaluation, positive values reflect greater levels under the first plan, and negative values reflect greater levels under the second plan.

populations in Lake Ontario/upper St. Lawrence River wetlands are believed to have declined significantly to their current low numbers (Farrell *et al.* 2006, Toner 2006). Under regulation, fewer muskrat houses are constructed in autumn due to lower lake levels, and those that are built become isolated from water during winter as a result of increased drawdown of lake levels to provide storage capacity for spring runoff (Farrell *et al.* 2006, Toner 2006). In addition, spring-spawning fish, such as northern pike (*Esox lucius* L.), that require access to wetlands in early spring are often excluded because regulated lake levels are kept lower than under natural conditions. Lack of low lake levels during the growing season has also resulted in conversion of preferred meadow-marsh spawning habitat to cattail dominance (Farrell 2001, Farrell *et al.* 2006, Cooper *et al.* 2008, Wilcox *et al.* 2008), and loss of muskrats has reduced natural herbivory on cattails, allowing even greater ability for lakeward cattail invasion (Toner 2006).

A comparison of mean lake levels generated under Plans B+, 2007, and 1958DD (Fig. 3) shows some of the seasonal differences among those plans. On average, across the 101-year record of supplies used for analysis, Plan B+ would hold lake levels more than 13 cm above Plan 2007 during winter, thus providing more wintering habitat for muskrats. Plan B+ would also hold lake levels more than 10 cm above Plan 2007 during early spring, thus providing greater access to wetland spawning habitat by fish such as northern pike. In addition, poor northern pike year-class formation has been linked with high summer lake levels under Plan 1958DD (Smith *et al.* 2007), and Figure 3 demonstrates the propensity for Plan 2007 to hold lake levels higher than Plan B+ during the summer. This is also a primary reason for poorer performance in creating and maintaining meadow marsh. The pattern shown for Plan B+ vs. Plan 1958DD is similar to that with Plan 2007, but with average higher lake levels during summer under 2007 than 1958DD (Fig. 3). Comparison of Plan 2007 with Plan 1958DD indicates that, on average across the 101-year record, Plan 2007 would produce winter and early spring lake levels as much as 4 cm lower than Plan 1958DD and summer lake levels more than 5 cm higher (Fig. 3). Thus, from the perspective of muskrat wintering habitat and access to fish spring spawning habitat, on average, Plan 1958DD performs better than Plan 2007, despite the strong negative effect it has had on those habitat functions. The Integrated Ecosystem Response Model (IERM) developed during the LOSLR study (LimnoTech 2005) showed an improvement in the muskrat house indicator for Plan 2007 vs. Plan 1958DD; however, that result may have been an artifact of only a few specific years during the 101-year record evaluated—similar to improvement in meadow marsh scores described above. Indeed, experimental studies conducted in controlled marshes with water-level management showed an increase in muskrats without the fall/winter drawdown (Farrell *et al.* 2005, Toner 2006).

CONCLUSIONS

Over the 22 years responding to low net basin supplies, Plan B+ would provide an increase in total meadow marsh from 1958DD levels that is 1.6 times greater than Plan 2007 (Table 2). The increase would be 1.7 times greater than under Plan D+ and more than double (2.2) that under Plan A+. Comparisons with Plan 1958DD levels can be misleading, however, because extremely low percentages of meadow marsh in the 1930s would be due largely to invasion of upland species, since no high lake level would have occurred for more than 30 years under Plan 1958DD.

The algorithms that drive Plan B+ provide both high and low lake levels across the 101-year study period. The algorithms behind the other plans, including Plan 2007, lack steps to recognize both components consistently. They also restrict the range of fluctuations. Thus, Plan B+ would create 1,317 ha more meadow marsh than Plan 2007 in response to low net basin supplies. Seasonal high and low lake levels that affect habitat for muskrats and fish represent still further differences between Plans B+ and 2007. Our evaluations demonstrated that increases in meadow marsh require periodic high lake levels followed by a period of several years with low lake levels, which is consistent with photointerpretation studies of Lake Ontario wetlands (Wilcox *et al.* 2008) and current general knowledge of Great Lakes wetland processes (Keddy and Reznicek 1986; Wilcox 1995, 2004; Wilcox and Nichols 2008).

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