GREAT LAKES FISHERY COMMISSION

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Pivotal Events in the History of Great Lakes Fisheries: The Effects of Environmental, Social, and Technological Changes

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PIVOTAL EVENTS IN THE HISTORY OF GREAT LAKES FISHERIES: THE EFFECTS OF ENVIRONMENTAL, SOCIAL, AND TECHNOLOGICAL CHANGES

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Abstract. Key socio-political decisions and environmental changes have shaped the history of the Laurentian Great Lakes since before the turn of the 19th century. Fishery exploitation (due to an unregulated commercial fishery), cultural eutrophication (due to deforestation, agricultural development, and population expansion), erosion and siltation, tributary and shoreline restructuring (through construction of dams, canals, and shoreline development), toxic substances, and establishment of nonindigenous species (NIS) have all had profound impacts on the ecology of each of the Great Lakes. We constructed timelines of pivotal events for each of the Great Lakes from the late 1700s to present based on findings in the published literature. The most recent events were compiled from published and unpublished SCOL II manuscripts for each of the Great Lakes. The timelines provide a powerful comparative tool for which one can assess the socio-political and environmental influences on the ecology of Great Lakes ecosystems.

keywords: Great Lakes, pivotal historical events, fisheries

Introduction

The Laurentian Great Lakes have experienced numerous ecological changes since their formation 10,000 years ago. However, the major perturbations they have experienced in the past 200 years have been entirely anthropogenic. Establishment of nonindigenous species (NIS), overfishing, and habitat degradation have each had varying degrees of impact on the ecology and fish community of each lake. Recent compilations have used timelines to illustrate events affecting the Great Lakes. Jude and Leach (1999) constructed a timeline divided into compartments for each of the five lakes showing arrival of NIS, increases and declines (sometimes to extirpation) of major fish species, and application of sea lamprey larvicide. Dann and Schroeder (2003) outlined social, technological, and environmental factors influencing Great Lakes fisheries. A timeline included with their report showed a breakdown of these factors within five time periods and the resulting changes in the fisheries. We sought to integrate and expand upon the works of Jude and Leach (1999) and Dann and Schroeder (2003) by creating tables of important events for each Great Lake, a table of socio-political events affecting all the lakes, and a timeline showing what we believe to be the most critical events affecting Great Lakes fish communities. It is hoped that the tables and timeline will provide a powerful comparative tool for evaluating past, current, and future influences of social, technological, and environmental changes on the ecology of Great Lakes ecosystems.

Methods

We developed timelines of pivotal events for each of the Great Lakes from the late 1700s to present by performing a literature search and compiling a chronological listing of events affecting each lake ecosystem. Much of the lake-specific information pertaining to the last 30 years was obtained from published manuscripts for Lake Ontario (Mills et al. 2003) and Michigan (Madenjian et al. 2002), a manuscript in preparation for Lake Superior (Bronte et al. 2004), and books for Lake

Erie (Munawar et al. 1999) and Lake Huron (Munawar et al. 1995). In addition, we constructed a table of socio-political events affecting all the Great Lakes, and a timeline that categorizes the most significant events based on the following three critical factors that have impacted Great Lakes fisheries: NIS introductions, overfishing, and habitat degradation. Socio-political decisions are included as a separate category to show the contrast in time of occurrence between negative events and institution of corrective measures.

Pivotal Events

Pivotal events affecting the fish communities of Lake Ontario (Table 1), Lake Erie (Table 2), Lake Huron (Table 3), Lake Michigan (Table 4), and Lake Superior (Table 5), include the decimation of lake trout populations due to commercial fishing, the destruction of spawning habitat due to watershed development, and the establishment of sea lamprey, alewife, and zebra mussel. However, the timing and degree to which each lake has been and continues to be affected by each event have varied greatly (Figure 1). For example, cultural eutrophication had early and severe effects on the Lake Ontario salmonid fish community, and problems were exacerbated by sea lamprey parasitism and overfishing. However, Lake Superior never experienced the same degree of nutrient loading as the lower lakes. Overfishing combined with the eventual establishment of sea lamprey were largely responsible for decreases in fish populations in Lake Superior, and similar declines had occurred decades earlier in the lower lakes. Alternatively, Wells and McLain (1973), in examining fish communities in Lake Michigan from 1880-1970, concluded that the invasion by sea lamprey and alewife between 1930 and 1950 had a greater effect on fish communities overall than either eutrophication or overfishing. We consider basin-wide development to be the primary factor in water quality and habitat degradation, with different degrees of overfishing and NIS invasion combining to elicit an overall negative effect on the fishery of each lake.

Canal construction, ballast water and the link to NIS. Construction of the Erie and Welland canals and the St. Lawrence Seaway have factored heavily in the proliferation of NIS throughout the Great Lakes. Coincident with the construction of the Erie Canal, which connected Lake Ontario to the Atlantic coast, was the arrival of two marine species, alewife (*Alosa pseudoharengus*) and sea lamprey (*Petromyzon marinus*), both of which ultimately established in all of the Great Lakes. The construction of the Welland Canal provided access to the upper lakes and effectively removed Niagara Falls as a natural barrier to the dispersal of NIS already present in Lake Ontario. Sea lamprey were established in all the lakes by the mid-1940s and quickly began devastating lake trout populations. The alewife invasion was complete shortly thereafter. Alewife replaced native forage fish (primarily coregonids) and negatively affected native lake trout and other fishes. The St. Lawrence Seaway, completed in 1959, provided access to the upper lakes by ocean-going vessels whose ballast water carried NIS from around the globe. The arrival and dispersal of the zebra mussel (*Dreissena polymorpha*) and many other organisms have been attributed to the ship vector (Mills et al. 1993a, Ricciardi 2001)

Overfishing. The establishment of European settlers in the basin ushered the beginning of overfishing in the mid-1800s. Growing demand for fish resulted in greater fishing effort and technological advancements in gear. The onset of the depletion of native fish stocks was not always evident since commercial catches remained stable or increased with improvements in gear. Atlantic salmon (present only in Lake Ontario) was the first casualty of an intensive commercial fishery, with stocks collapsing by 1840 (Christie 1973). Other species severely affected by overfishing include lake trout, lake whitefish, and lake herring, all of which have suffered declines in each lake at various times from the late 1800s through the 1970s (see Jude and Leach 1999; Table 23.3).

Habitat Degradation. Loss of fish habitat began with modifications to watershed drainage in the Great Lakes basin. Sawmill wastes and erosion resulting from deforestation and agricultural development destroyed spawning areas through increased sedimentation. Access to spawning habitat decreased with the construction of dams and development of shoreline areas. As a result, fish were concentrated in downstream areas where they were more vulnerable to harvest. Pollution began with the discharge of human wastes from growing cities and settlements. Nutrient loading through phosphorus inputs from the watershed and introduction of toxic substances from industries soon followed as major contributors to water quality degradation.

Socio-political influences. Several socio-political events have helped shape the history of all the Great Lakes (Table 6). In 1783, the Treaty of Paris established the boundary between the United States and British North America. The end result, a division of Great Lakes waters between two countries and eventually eight states (Bogue 2000), often made it difficult and sometimes impossible to regulate the commercial fishery. The International Joint Commission (IJC), established in 1909, was the first agency with the authority to investigate, offer recommendations, and make decisions on management issues relating to both U.S. and Canadian waters. The IJC's investigation of water quality problems in the mid 1960s led to the Great Lakes Water Quality Agreements (GLWQA) of 1972 and 1978. These agreements set permissible phosphorus loadings to each of the lakes and were instrumental in reversing the eutrophication process. The ratification of the 1955 Convention of Great Lakes Fisheries and formation of the Great Lakes Fishery

Commission (GLFC) provided a mechanism for fisheries rehabilitation initially through sea lamprey control, and more recently through coordination of research activities and regulatory efforts. Symposia supported by the GLFC have centered on key management issues and have given the opportunity for sharing of scientific advancements (see Table 6). The objective of the first symposium on Salmonid Communities in Oligotrophic Lakes (SCOL)(1971)(Loftus and Regier 1972) was to elucidate the effects of fisheries exploitation, cultural eutrophication, and NIS introductions on fish communities, with an emphasis on salmonines and coregonines. The Percid International Symposium (PERCIS)(1976)(Colby 1977) followed the SCOL model with an emphasis on percid communities. Next came the Stock Concept International Symposium (STOCS)(1980)(Berst and Simon 1981), with a focus on the concept that fish species are divided into distinct subpopulations or stocks that are affected individually by eutrophication, exploitation, and NIS introductions. STOCS was followed by the Assessment of Stocks and Prediction of Yield Symposium (ASPY)(1985)(Spangler et al. 1987), the emphasis of which was to gain a better understanding of the factors influencing the rate and direction of the rehabilitation process in the Great Lakes.

Discussion

Pivotal Great Lakes policy events associated with the GLWQA and control of sea lamprey have had a profound positive influence on improved water quality and restoring native lake trout. However, many challenges to maintain the integrity of the Great Lakes remain and we can only hope that future pivotal events and policy decisions will lead to reductions in new NIS, lessen the potential for ‘ecological surprises’, and greater sensitivity of user publics regarding the connection between a quality Great Lakes environment and the economic health of the region.

Fisheries Management and Ecosystem Health: Pivotal Policies

Jude and Leach (1999) listed ecosystem rebirth, management plans, recovery of native stocks, salmonine stocking programs, and control of nutrient and toxic substances as the successes in the recent history of Great Lakes fisheries. Water quality standards established under agreements between the United States and Canada were perhaps the greatest 'policy implementation' to positively affect the Great Lakes in the past 30 years. Under the GLWQA (1972) both governments agreed to reduce phosphorus inputs to the lakes. The GLWQA was amended in 1978 to include the goal of reducing toxic contaminant loads. Implementation of these policies has resulted in decreased phosphorus loads and improved water clarity in all the Great Lakes.

The formation of the GLFC in 1955 established a framework for sea lamprey control in the Great Lakes. Sea lamprey entered the upper Great Lakes in the early 1900s and contributed to the decline of several fish species, especially lake trout, lake whitefish and chubs. A variety of control measures, such as treatment of streams with lampricide (TFM), construction of barriers, and the sterile-male-release-technique have been developed with the support and guidance of the GLFC.

Finally, the implementation of ship ballast water exchange (BWE) has met with mixed success. Canada issued voluntary ballast water guidelines in 1989, and the United States followed suit in 1993 by implementing mandatory regulations (United States Coast Guard 1993). This legislation, specific to the Great Lakes, mandates that ocean-going vessels with declarable ballast water on board (BOB) to conduct open-ocean ballast exchange if the water is to be subsequently discharged within the Great Lakes system; post-exchange, ballast water must possess a salinity of no less than 30 parts per thousand (Locke et al. 1991, 1993; United States Coast Guard 1993). The premise behind ballast water exchange is that most freshwater organisms resident in ballast tanks would be purged while the remaining organisms would be killed by osmotic stress. The enacted legislation represents the most prescriptive ballast water law in the world, yet has fallen short in sufficiently protecting Great Lakes waters from new invasions.

Fisheries Management and Ecosystem Health: Future Challenges

Introduced species, disease outbreaks, global warming, and improved water quality: synergistic relationships. The introduction of NIS will be a continual management challenge in the coming years. Although ballast water exchange (BWE) laws were a step in the right direction, ships that arrive in the Great Lakes with no ballast on board (NOBOBs) currently pose the greatest introduction hazard (Colautti et al. 2003). These ships contain residual ballast water and sediment that can harbor NIS. In fact, most of the species discovered since the implementation of BWE have been euryhaline, benthic organisms or species with resting stages which possess the ability to tolerate the harsh conditions in the ballast tanks of NOBOB vessels. Since completion of the St. Lawrence Seaway in 1959, 73% of NIS introductions have been attributed to the release of ballast water from transoceanic ships (Grigorovich et al. 2003a). Other potential vectors of NIS to the Great Lakes include escape from aquaculture (Duggan et al. 2003), and sale of live species in retail pet, aquarium or bait fish stores. Some or all of these alternative vectors may pose greater risk in the future.

NIS themselves, can be vectors of invasion for parasites and disease. For example, recent outbreaks of a rare strain of avian botulism in Lakes Erie and Ontario have resulted in the deaths of thousands of loons, mergansers and gulls. Botulin toxin is apparently accumulating in the tissue of these fish-eating birds whose diets have become increasingly dominated by round goby (*Neogobius melanostomus*) – an NIS that feeds primarily on introduced zebra and quagga (*Dreissena bugensis*) mussels (Ray and Corkum 1997). These mollusks concentrate the toxin as they filter water surrounding the sediments in which the *Clostridium* bacteria reside.

Ironically, the improved water quality conditions resulting from the GLWQA may be in part responsible for the recent surge in NIS discoveries. For example, some NIS may have been introduced repeatedly by the ship vector, but remained undetected until improving environmental conditions allowed populations to become established. Global warming may also be acting in concert with improving water quality, and the impacts on fish will depend on species-specific thermal requirements and changes in thermal habitat. Rising temperatures could positively affect salmonids by increasing the habitat volume for cold-water species in well-oxygenated lakes like Lake Ontario (Magnuson et al. 1990). Alternatively, increasing water temperatures in late fall and early winter may negatively affect fish survival and emergence, notably of lake trout and lake whitefish (Casselman 1995). A small increase in water temperature may also allow current NIS to expand their ranges in the Great Lakes.

Sustainability: Balancing public expectations with management of complex food webs. Rising stakeholder demand and the sustainability of Great Lakes fisheries will no doubt result in future conflicts. Pivotal events in the future in association with NIS, globalization, global climate warming, limited resources, and disease outbreaks will further stress Great Lakes ecosystems, thereby hampering goals associated with the sustainability of Great Lakes fisheries. We can only hope that the lessons learned from pivotal events over the last two centuries will provide the "guiding lights" for future policy and management of Great Lakes fisheries.

References

Beeton AM. 1969. Changes in the environment and biota of the Great Lakes. *In* Eutrophication: causes, consequences, correctives. Proceedings of symposium. Nat. Acad. Sci. Washington, D.C. 661 p.

Beeton AM, Sellinger CE, and Reid DF. 1999. An introduction to the Laurentian Great Lakes ecosystem. Pages 3-54 *in* Taylor WW and Ferreri CP (editors). Great Lakes fisheries policy and management: a binational perspective. Michigan State University Press, Lansing, Michigan.

Berst AH and Spangler GR. 1972. Lake Huron: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Board Can. 29: 877-887.

Berst AH and Spangler GR. 1973. Lake Huron: the ecology of the fish community and man's effects on it. Great Lakes Fishery Commission Technical Report No. 21.

Berst AH and Simon RC. 1981. Introduction to the proceedings of the 1980 stock concept international symposium (STOCS). J. Fish. Res. Board Can. 38 (12).

Bogue MB. 2000. Fishing the Great Lakes: an environmental history, 1783-1933. University of Wisconsin Press, Madison, Wisconsin.

Bronte CR, Selgeby JH, and Swedberg DV. 1993. Dynamics of yellow perch in western Lake Superior. N. Am. J. Fish. Manage. 13: 511-523.

Bronte CR, Ebener MP, Schreiner DR, DeVault DS, Petzold MM, Jensen DA, and Lozano SJ. 2004. Fish community change in Lake Superior, 1970-2000. Unpublished manuscript.

Carr JF and Hiltunen JK. 1965. Changes in the bottom fauna of western Lake Erie from 1930 to 1961. Limnol. Oceanogr. 10: 551-569.

Casselman, J.M. 1995. Survival and development of lake trout eggs and fry in eastern Lake Ontario — in situ incubation, Yorkshire Bar, 1989-1993. J. Great Lakes Res. **21** (Suppl. 1): 384-399.

Christie WJ. 1972. Lake Ontario: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Board Can. 29: 913-929.

Christie WJ. 1973. A review of the changes in the fish species composition of Lake Ontario. Great Lakes Fishery Commission Technical Report No. 23.

Christie WJ and Spangler GR (editors). 1987. International symposium on stocks assessment and yield prediction. Can. J. Fish. Aquat. Sci. 44 (Suppl. 2): 1-501.

Clapp DF, Schneeberger PJ, Jude DJ, Madison G, and Pistis C. 2001. Monitoring round goby (*Neogobius melanostomus*) population expansion in eastern and northern Lake Michigan. J. Gt. Lakes Res. 27:335-341.

Colautti RI, Niimi AJ, van Overdijk CDA, Mills EL, Holeck K, MacIsaac HJ. 2003. Spatial and temporal analysis of transoceanic shipping vectors to the Great Lakes. *In* Ruiz GM, Carlton JT, Mack RN, eds. Invasion Species: Vectors and Management Strategies. Island Press, Washington, DC.

Colby PJ. 1977. Introduction to the proceedings of the 1976 percid international symposium (PERCIS). J. Fish Res. Board Can. 34 (10).

Cook DG and Johnson MG. 1974. Benthic macroinvertebrates of the St. Lawrence Great Lakes. J. Fish. Res. Board Can. 31: 763-782.

Cucin D and Regier HA. 1966. Dynamics and exploitation of lake whitefish in southern Georgian Bay. J. Fish. Res. Board Can. 23: 221-274.

Dann SL and Schroeder BC. 2003. The Life of the Lakes: A Guide to the Great Lakes Fishery. Michigan Sea Grant. 54 pp.

Dermott, R., Witt, J., Um, Y.M., and González, M. 1998. Distribution of the Ponto-Caspian amphipod *Echinogammarus ischnus* in the Great Lakes and replacement of native *Gammarus fasciatus*. J. Great Lakes Res. 24: 442-452.

D'Itri F. 1988. Contaminants in selected fishes from the upper Great Lakes. Pages 51-84 *in* N.W. Schmidtke, editor. Toxic contamination in large lakes, vol. II, impact of toxic contaminants on fisheries management. Proceedings of a technical session of the world conference on large lakes. Lewis Publishers, Chelsea, Michigan.

Dochoda MR. 1999. Authorities, Responsibilities, and Arrangements for managing fish and fisheries in the Great Lakes ecosystem. Pages 93-110 *in* Taylor WW and Ferreri CP (editors). Great Lakes fisheries policy and management: a binational perspective. Michigan State University Press, Lansing, Michigan.

Duggan IC, Bailey SA, Colautti RI, Gray DK, Makarewicz JC, MacIsaac HJ. 2003. Biological invasions in Lake Ontario: past, present and future. *In* Munawar M, ed. State of Lake Ontario: Past, Present and Future. Backhuys Publishing, Netherlands. (in press).

Elrod, J.H., O'Gorman, R., Schneider, C.P., Eckert, T., Schaner, T., Bowlby, J.N., and Schleen, L.P. 1995. Lake trout rehabilitation in Lake Ontario. J. Great Lakes Res. 21(Suppl. 1): 83-107.

Grigorovich IA, Colautti RI, Mills EL, Holeck K, Ballert AG, MacIsaac HJ. 2003. Ballast-mediated animal introductions in the Laurentian Great Lakes: retrospective and prospective analyses. Canadian Journal of Fisheries and Aquatic Sciences 60: 740-756.

Groop R. 1999. Demographic and economic patterns in the Great Lakes region. Pages 73-92 *in* Taylor WW and Ferreri CP (editors). Great Lakes fisheries policy and management: a binational perspective. Michigan State University Press, Lansing, Michigan.

Hansen MJ (ed). 1990. Lake Superior: the state of the lake in 1989. Great Lakes Fishery Commission Special Publication 90-3.

Hartman WL. 1972. Lake Erie: effects of exploitation, environmental changes, and new species on the fishery resources. J. Fish. Res. Board Can. 29: 899-912.

Hartman WL. 1973. Effects of exploitation, environmental changes, and new species on the fish habitats and resources of Lake Erie. Great Lakes Fishery Commission Technical Report No. 22.

Hatch RW, Nepszy SJ, Muth KM, and Baker CT. 1987. Dynamics of the recovery of the western Lake Erie walleye (*Stizostedion vitreum vitreum*) stock. Can. J. Fish. Aquat. Sci. 44(Suppl 2): 15-22.

Heinrich JW, Mullet KI, Hansen MJ, Christie GT, Klar DA, Johnson DA, Young RJ, and Adams JV. 2003. Sea lamprey control and abundance in Lake Superior, 1957-1999. J. Great Lakes Res.(in press)

Howmiller RP and Beeton AM. 1970. The oligochaete fauna of Green Bay Lake Michigan. Proceedings of the Conference on Great Lakes Research. 13: 15-46.

International Joint Commission (IJC). 1918. Final Report of the International Joint Commission on the Pollution of Boundary Waters Reference. U.S. Government Printing Office. Washington, D.C.

International Joint Commission (IJC). 1951. Final Report of the International Joint Commission, United States and Canada, on the Pollution of Boundary Waters. U.S. Government Printing Office. Washington, D.C.

Jude, D., Reider, R.H. and Smith, G.R. 1992. Establishment of Gobiidae in the Great Lakes Basin. Can. J. Fish. Aquat. Sci. 49: 416-421.

Jude, DJ and Leach J. 1999. Great Lakes fisheries. Pages 623-664 *in* Inland Fisheries Management in North America, 2nd edition. *Edited by* CC Kohler and WA Hubert. American Fisheries Society, Bethesda, Maryland.

Kabre JA. 1993. Impact of *Renibacterium saloninarum* on non-lipid energy, lipid and water contents in liver of infected chinook salmon during fall and spring in Lake Michigan, 1990-1992. PhD thesis. Michigan State University, East Lansing.

Lanctot G. 1963. A history of Canada. Vol. 1. From its origins to the Royal Regime, 1663. Clarke, Irwin and Co. Ltd., Toronto and Vancouver. 393 pp.

Lange C. and Cap R. 1986. *Bythotrephes cederstroemi* (Schodler) (Cercopagidae: Cladocera): a new record for Lake Ontario. J. Great Lakes Res. 12: 142-143

Langlois TH. 1941. Two processes operating for the reduction in abundance or elimination of fish species from certain types of water areas. Trans. Amer. Wildl. Conf. 6: 189-201.

Lawrie AH, and Rahrer JF. 1972. Lake Superior: effects of exploitation and introduction on the salmonid community. J. Fish. Res. Board Can. 29: 765-776.

Lawrie AH, and Rahrer JF. 1973. Lake Superior: A case history of the lake and its fisheries. Great Lakes Fishery Commission Technical Report No. 19.

Leach JH. 1999. Lake Erie: passages revisited. Pages 5-22 *in* State of Lake Erie—Past, Present, and Future. *Edited by* Munawar M, Edsall T, and Munawar IF. Ecovision World Monograph Series. Backhuys Publishers, Leiden, Netherlands.

Lehman JT. 1987. Palearctic predator invades North American Great Lakes. Oecologia, 74: 478-480.

Locke A, Reid DM, Sprules WG, Carlton JT, van Leeuwen HC. 1991. Effectiveness of mid-ocean exchange in controlling freshwater coastal zooplankton in ballast water. Canadian Technical Report for Fisheries and Aquatic Sciences #1822. 93 p.

Locke A, Reid DM, van Leeuwen HC, Sprules WG, Carlton JT. 1993. Ballast water exchange as a means of controlling dispersal of freshwater organisms by ships. Can. J. Fish. Aquat. Sci. 50: 2086-2093.

Loftus KH and Regier HA. 1972. Introduction to the proceedings of the 1971 symposium on salmonid communities in oligotrophic lakes. J. Fish. Res. Board Can. 29 (6).

Lower AR. 1946. Colony to nation. Longmans, Green and Co., Toronto, London and New York. 600 pp.

Lozano, S.J., Scharold, J.V., and Nalepa, T.F. 2001. Recent declines in benthic macroinvertebrate densities in Lake Ontario. Can. J. Fish. Aquat. Sci. 58: 518-529.

MacIsaac, H.J., Grigorovich, I.A., Hoyle, J.A., Yan, N.D., and Panov, V.E. 1999. Invasion of Lake Ontario by the Ponto-Caspian predatory cladoceran *Cercopagis pengoi.* Can. J. Fish. Aquat. Sci. 56: 1-5.

Madenjian CP, Fahnenstiel GL, Johengen TH, Nalepa TF, Vanderploeg HA, Fleischer GW, Schneeberger, PJ, Benjamin DM, Smith EB, Bence JR, Rutherford ES, Lavis DS, Robertson

DM, Jude DJ, and Ebner MP. 2002. Dynamics of the Lake Michigan food web, 1970-2000. Can. J. Fish. Aquat. Sci. 59: 736-753.

Magnuson, J.J., Meisner, J.D., and Hill, D.K. 1990. Potential changes in the thermal habitat of Great Lakes fish after global climate warming. Trans. Am. Fish. Soc. **119:** 254-264.

Makarewicz, J.C., Bertram, P., Lewis, T., and Brown, E.H.J. 1995. A decade of predatory control of zooplankton species composition of Lake Michigan. J. Great Lakes Res. 21: 620-640.

Marsden, J.E., Krueger, C.C., and Schneider, C.P. 1988. Evidence of natural reproduction by stocked lake trout in Lake Ontario. J. Great Lakes Res. 14: 3-8.

Miller RR. 1957. Origin and dispersal of the alewife, *Alosa pseudoharengus*, and the gizzard shad, *Dorosoma cepedianum*, in the Great Lakes. Trans. Am. Fish. Soc. 86: 97-111.

Mills EL, Leach JH, Carlton JT, Secor CL. 1993a. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. J. Great Lakes Res. 19:1-54.

Mills, E.L., Dermott, R.M., Roseman, E.F., Dustin, D., Melinna, E., Conn, D.B., and Spidle, A.P. 1993b. Colonization, ecology, and population structure of the quagga mussel (Bivalvia: Dreissenidae) in the lower Great Lakes. Can. J. Fish. Aquat. Sci. 50: 2305-2314.

Mills, E.L., Casselman, J.M., Dermott, R., Fitzsimons, J.D., Gal G., Holeck, K.T., Hoyle, J.A., Johannsson, O.E., Lantry, B.F., Makarewicz, J.C., Millard, E.S., Munawar, I.F., Munawar, M., O'Gorman, R., Owens, R.W., Rudstam, L.G., Schaner, T., and Stewart, T.J. 2003. Lake Ontario: Food web dynamics in a changing ecosystem (1970-2000). Can. J. Fish. Aquat. Sci. 60(4): 471-490.

Munawar M, Edsall T, and Leach J (editors). 1995. The Lake Huron ecosystem: fisheries and management. Ecovision World Monograph Series. Academic Publishing, Amsterdam, Netherlands. 503 pp.

Munawar M, Edsall T, and Leach J (editors). 1999. State of Lake Erie: past, present, and future. Ecovision World Monograph Series. Backhuys Publishers, Leiden, Netherlands. 550 pp.

Nepszy SJ. 1999. The changing fishery regime in Lake Erie. Pages 233-239 *in* State of Lake Erie—Past, Present, and Future. *Edited by* Munawar M, Edsall T, and Munawar IF. Ecovision World Monograph Series. Backhuys Publishers, Leiden, Netherlands.

Nute GL. 1926. The American Fur Company's fishing enterprises on Lake Superior. The Mississippi Valley Historical Review 12: 483-503.

Nute GL. 1944. Lake Superior. *In* The American Lakes Series. *Edited by* MM Quaife. The Bobbs-Merrill Company, Indianapolis and New York. 376 pp.

O'Gorman, R., Elrod, J.H., Owens, R.W., Schneider, C.P., Eckert, T.H., and Lantry, B.F. 2000. Shifts in depth distributions of alewives, rainbow smelt, and age-2 lake trout in southern Lake Ontario following establishment of dreissenids. Trans. Am. Fish. Soc. 129: 1096-1106.

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

Owens, R.W., O'Gorman, R., Eckert, T.H., and Lantry, B.F. 2003. The offshore fish community in Lake Ontario, 1972-1998. *In* State of Lake Ontario: past, present and future. *Edited by* M. Munawar. Ecovision World Monograph Series, Aquatic Ecosystem Health and Management Society, Burlington, Ontario. In press.

Pearce, W.A., Braem, R.A., Dustin, S.M., and Tibbles, J.J. 1980. Sea lamprey (*Petromyzon marinus*) in the Lower Great Lakes. Can. J. Fish. Aquat. Sci. 37: 1802-1810.

Peck JW, MacCallum WR, Schram ST, Schreiner DR, and Shively JD. 1994. Other salmonines. Pages 35-52 *in* The state of Lake Superior in 1992. *Edited by* MJ Hansen. Great Lakes Fishery Commission Special Publication 94-1. Ann Arbor, MI.

Ray WJ and Corkum LD. 1997. Predation of zebra mussels by round gobies, *Neogobius melanostomus*. Env. Biol. Fish. 50: 267-273.

Regier HA and Applegate VC. 1972. Historical review of the management approach to exploitation and introduction in SCOL lakes. J. Fish. Res. Board Can. 29: 683-692.

Regier HA and Hartman WL. 1973. Lake Erie's fish community: 150 years of cultural stress. Science 180: 1248-1255.

Ricciardi A. 2001. Facilitative interactions among aquatic invaders: is an 'invasional meltdown' occurring in the Great Lakes. Can. J. Fish. Aquat. Sci. 58: 2513-2525.

Schaeffer, Jeffrey S., James S. Diana, and Robert C. Haas. 2000. Effects of long-term changes in the benthic community on yellow perch in Saginaw Bay, Lake Huron. J. Great Lakes Res. 26: 340-351.

Sly PG. 1976. Lake Erie and its basin. J. Fish. Res. Board Can. 33: 355-370.

Sly PG. 1991. The effects of land use and cultural development on the Lake Ontario ecosystem since 1750. Hydrobiologia, 213: 1-75.

Smith SH. 1970. Species interactions of the alewife in the Great Lakes. Trans. Amer. Fish. Soc. 99: 754-765.

Smith SH. 1972. Factors of ecologic succession in oliogotrophic fish communities of the Laurentian Great Lakes. J. Fish. Res. Board Can. 29: 717-730.

Smith BR and Tibbles JJ. 1980. Sea lamprey (*Petromyzon marinus*) in Lakes Huron, Michigan, and Superior: history of invasion and control, 1936-78. Can. J. Fish. Aquat. Sci. 37: 1780-1801.

Spangler GR and Peters JH. 1995. Fisheries of Lake Huron: An opportunity for stewardship. Pages 103-123 *in* The Lake Huron Ecosystem: Ecology, Fisheries and Management. *Edited by* M Munawar, T Edsall, and J Leach. Ecovision World Monograph Series. SPB Academic Publishing, Amsterdam, Netherlands.

Spangler GR, Loftus KH, and Christie WJ. 1987. Introduction to the international symposium on stock assessment and yield prediction (ASPY). Can. J. Fish. Aquat. Sci. 44(Suppl 2).

Starliper CE, Smith DR, and Shatzer T. 1997. Virulence of *Renibacterium salmoninarum* to salmonids. Journal of Aquatic Animal Health, 9: 1-7.

Stevens, R.J.J., and Neilson, M.A. 1987. Response of Lake Ontario to reductions in phosphorus load, 1967-82. Can. J. Fish. Aquat. Sci. 44: 2059-2069.

Stewart DJ and Ibarra M. 1991. Predation and production by salmonine fishes in Lake Michigan, 1978-1988. Can. J. Fish. Aquat. Sci. 48: 909-922.

Thwaites RG. 1968. France in America. Cooper Square Publ. New York. 320 pp.

United States Coast Guard. 1993. Ballast water management for vessels entering the Great Lakes. Code of Federal Regulations 33-CFR Part 151.1510.

Van Oosten 1940. Fishing industry in the Great Lakes. U.S. Dept. of Interior, Fish and Wildl. Serv. Memorandum, Mimeo: 1-63.

Van Oosten J. 1944. Mortality of smelt, *Osmerus mordax* (Mitchell), in Lakes Huron and Michigan during the fall and winter of 1942-1943. Trans. Am. Fish. Soc. 74: 310-337.

Vollenweider, R.A., Munawar, M., and Stadelmann, P. 1974. A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. J. Fish. Res. Board. Can. 31: 739-762.

Wells L and McLain AL. 1972. Lake Michigan: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Board Can. 29: 889-898.

Wells L and McLain AL. 1973. Lake Michigan: Man's effects on native fish stocks and other biota. Great Lakes Fishery Commission Technical Report No. 20.

Weseloh, D.V., and Ewins, P.J. 1994. Characteristics of a rapidly increasing colony of double-crested cormorants (*Phalacrocorax auritus*) in Lake Ontario: Population size, reproductive parameters and band recoveries. J. Great Lakes Res. 20: 443-456.

Weseloh DV, Ewins PJ, Struger J, Mineau P, Bishop CA, Postupalsky S, and Ludwig JP. 1995. Double-crested cormorants of the Great Lakes: changes in population size, breeding distribution and reproductive output between 1913 and 1991. Colon. Waterbirds, 18(Spec. Publ. 1): 48-59.

Tables.

Table 1. Management actions, socio-political influences, and unplanned events that have been pivotal to understanding ecological changes in the Lake Ontario ecosystem since the late 1700s.

Table 2. Management actions, socio-political influences, and unplanned events that have been pivotal to understanding ecological changes in the Lake Erie ecosystem since the 1669.

Table 3. Management actions, socio-political influences, and unplanned events that have been pivotal to understanding ecological changes in the Lake Huron ecosystem since 1831.

Table 4. Management actions, socio-political influences, and unplanned events that have been pivotal to understanding ecological changes in the Lake Michigan ecosystem since the 1830s.

Table 5. Management actions, socio-political influences, and unplanned events that have been pivotal to understanding ecological changes in the Lake Superior ecosystem since the early 1600s.

Table 6. Management actions and socio-political decisions pivotal to understanding ecological changes in all the Great Lakes since the 1700s.

Figure

Figure 1 (poster insert). Pivotal events affecting the fisheries of each of the Great Lakes categorized by NIS introductions, overfishing, habitat degradation, and socio-political decisions from 1800 to present.

Table 1 (Lake Ontario)

Time	Event	Reference
early 1800s	Deforestation and agricultural development reduce stream flows and increase stream temperatures	Smith 1972
1801	New York prohibits use of seines, nets, and weirs, in the Big Salmon, Little Salmon, Great Sandy, and Little Sandy Rivers that would prevent Atlantic salmon from reaching spawning grounds	Bogue 2000
1810	Canada introduces the idea of a closed season for Atlantic salmon for eastern Lake Ontario	Bogue 2000
1813	Dam owners must construct fishways, which did not work well; fish became easy targets at the bases of dams	Bogue 2000
1825	Opening of the Erie Canal	Sly 1991
1829	Welland Canal opened	Sly 1991
1830s	Introduction of pound nets	Sly 1991
1830-1840	Atlantic salmon stocks collapse	Christie 1973
1850s	Start of offshore fishing and use of commercial gill nets	Sly 1991
1873	First record of alewife	Smith 1972
1880s	Sea lamprey establishment	Smith 1972
1890s	Opening of Murray Canal	Sly 1991
1896	Extirpation of Atlantic salmon	Smith 1972
1931	First record of rainbow smelt	Smith 1972
1940s	Deepwater ciscoes, lake trout, burbot, and herring collapse; rainbow smelt colonize and dominate	Christie 1973
1950s	Disappearance of white bass, blue pike, and deepwater sculpin; walleye and whitefish abundant	Christie 1973
1950s	Start of sea lamprey control	Sly 1991
1950s	Start of salmonine stocking	Sly 1991

Table 1 cont.

Time	Event	Reference
1959	Opening of St. Lawrence Seaway	
1960s	White perch dominate; walleye decline; whitefish in Bay of Quinte collapse; yellow perch abundant in open waters	Christie 1973
1970	Canada limits phosphates in detergents	Stevens and Neilson 1987
1971	First treatment of Canadian tributaries to Lake Ontario with lampricide	Pearce et al. 1980
1972	New York limits phosphates in detergents	Stevens and Neilson 1987
1972	First treatment of New York tributaries to Lake Ontario with lampricide	Pearce et al. 1980
1973	First annual release of hatchery lake trout for population restoration	Elrod et al. 1995
1974	Twenty-two cormorant nests on Little Galloo Island	Weseloh and Ewins 1994
1982	First record of fry produced in lake by hatchery lake trout	Marsden et al. 1988
1982	First record of *Bythotrephes longimanus (previously B. cederstroemi)*	O. Johannsson, personal comm.
1983	Last record of bloater	Owens et al. 2003
1989	First record of zebra mussel (*Dreissena polymorpha*)	T. Schnaer, personal comm.
1991	First record of quagga mussel (*Dreissena bugensis*)	Mills et al. 1993
1992	Start of *Diporeia* collapse	Lozano et al. 2001
1993	Start of annual, successful reproduction by hatchery lake trout	O'Gorman et al. 2000
1993	Annual releases of trout and salmon sharply reduced	Owens et al. 2003
1995	First record of blueback herring	Owens et al. 1998
1996	First record of *Echinogammarus ischnus*	Dermott et al. 1998

Table 1 cont.

Time	Event	Reference
1998	First record of *Cercopagis pengoi*	MacIsaac et al. 1999
1998	First record of round goby (*Neogobius melanostomus*)	Ontario Federation of Anglers and Hunters
1999	First annual oiling of cormorant eggs on Little Galloo Island	NYSDEC 2000

Table 2 (Lake Erie)

Time	Event	Reference
1669	Louis Joliet traversed north shore of Lake Erie	Sly 1976
1701	Early settlement of the Detroit area by the French	Sly 1976
1825	Completion of the Erie Canal	Regier and Hartman 1973
1829	Welland Canal opened	Regier and Hartman 1973
1832	Erie-Ohio Canal opened	Regier and Hartman 1973
mid 1800s	Steamboats began to operate	Regier and Hartman 1973
1850s	First use of gill nets and pound nets	Regier and Hartman 1973
1860s	American Civil War spurred development of the Lake Erie fishery	Regier and Hartman 1973
1860s	Lake sturgeon destroyed in large numbers as bycatch of gill net fishery	Regier and Hartman 1973
1867	Dawn of hatchery construction	Regier and Hartman 1973
1880s	Intensification of commercial lake trout fishery	Regier and Hartman 1973
1890s	Intensification of commercial lake whitefish fishery	Regier and Hartman 1973
1890s	Some commercial fishing enterprises collapse due to low catch rates	Regier and Hartman 1973
1900	Cessation of whitefish spawning in the Detroit River and Maumee Bay (pollution, silt loadings)	Hartman 1972
1905	Introduction of bull net use; selectively targeted immature whitefish	Regier and Hartman 1973
1913-1916	First comprehensive report on pollution	IJC 1918
1921	First record of sea lamprey	Smith 1972
1925	Collapse of lake herring	Hartman 1972
1928-1930	USFWS whole-lake studies of lower trophic levels	Regier and Hartman 1973

Table 2 (Lake Erie)

Time	Event	Reference
1929-1934	Bull net use outlawed	Regier and Hartman 1973
1931	First record of alewife	Smith 1972
1935	First record of rainbow smelt	Smith 1972
mid 1930s	Lake trout commercially extinct	Hartman 1972
1941	Suggestion that environmental stresses were the main reason for fishery decline	Langlois 1941
1946-1948	Research indicates inadequacy of domestic waste treatment facilities	IJC 1951
1948	Average phytoplankton density increased 3x from 1920-37 to 1944-63	Hartman 1973
early 1950s	Gill net efficiency improved dramatically through use of nylon	Regier and Hartman 1973
1950s	Decline of *Hexagenia*	Regier and Hartman 1973
1953	Catastrophic decline of larval mayfly due to oxygen degradation in western basin	Hartman 1972
1956	Walleye landings peak, then decline sharply	Hartman 1972
mid-late 1950s	Most intensive fishing in Lake Erie's history for walleye, blue pike, and yellow perch	Regier and Hartman 1973
1958	Collapse of blue pike fishery	Hartman 1972
1960	Collapse of *Hexagenia*	Schaeffer et al. 2000
late 1960s	Decline of rainbow smelt due to *Glugea hertwigi*	Anonymous 1970
1968	Initiation of Pacific salmon stocking	Regier and Hartman 1973
1968	The "Lake Erie Report - A Plan for Water Pollution Control"	Leach 1999
1969	IJC releases report describing severity of pollution problems and degraded state of the ecosystem	Leach 1999
1970	Project Hypo examines oxygen deficiency problem	Leach 1999

Table 2 (Lake Erie)

Time	Event	Reference
1971	Initiation of chinook salmon stocking	Regier and Hartman 1973
1985	First record of *Bythotrephes longimanus* (previously *B. cederstroemi*)	Lange and Cap 1986
1985	Target loads of phosphorus achieved in central and eastern basins	Leach 1999
1984	Western basin walleye stock rehabilitated	Hatch et al. 1987
1986	First treatment of tributaries to Lake Erie with lampricide	Elrod et al. 1995
1986	First record of zebra mussel (*Dreissena polymorpha*)	Mills et al. 1993
mid 1980s	Reduction in harvest of rainbow smelt	Nepszy 1999
1989	First record of quagga mussel (*Dreissena bugensis*)	Mills et al. 1993
1991	Significant recolonization of open waters of western basin by *Hexagenia*	Leach 1999
1990	First record of round goby	Jude et al. 1992
2002	"Lake Erie Dead Zone"; USEPA begins intensive study to determine the cause of the oxygen depletion in Central Lake Erie	http://www.epa.gov/glnpo/lakeerie/eriedeadzone.html

Table 3 (Lake Huron)

Time	Event	Reference
1831	Canadian seine net fishery established near Fishing Islands	Berst and Spangler 1972
1834	Commercial gill net fishery begun in Georgian Bay	Cucin and Regier 1966
1835	Gillnet use began near Alpena; lake trout and whitefish were main targets	Berst and Spangler 1972
1841	Seine use begins in US waters for targeting walleye and sucker	Berst and Spangler 1972
1845	Sawdust pollution adversely affects lake whitefish spawning in Saginaw Bay	Beeton 1969
1854	First use of pound nets in US waters	Van Oosten 1940
1855	Railroad reaches Collingwood and the fishery increases, especially in southern Georgian Bay	Berst and Spangler 1972
1870-75	Introduction of steam tugs	Berst and Spangler 1972
1880	First whitefish production hatcheries in operation (US)	Berst and Spangler 1972
1880s	First use of pound nets in Canadian waters	Berst and Spangler 1972
1890	Steam gill net lifter use begins	Berst and Spangler 1972
1892	Canadian commercial fish production reached a maximum of 6000 mt/y	Berst and Spangler 1972
late 1890s	First use of trap nets	Van Oosten 1940
late 1800s, early 1900s	Comparisons of whitefish plantings with production data show no significant correlation; results in closing of hatcheries	Berst and Spangler 1972
1900	US commercial fish production reached a maximum of 9000 mt/y	Berst and Spangler 1972
1904	First record of rainbow trout	Berst and Spangler 1975
1909	Lake sturgeon commercially extinct	Anonymous 1969
1912	Production hatcheries in operation (Canada)	Berst and Spangler 1972
1925	First record of rainbow smelt	Smith 1972

Table 3 (Lake Huron)

Time	Event	Reference
1925	Peak use of night lines by commercial fishermen on the Canadian side	Berst and Spangler 1972
1929	Deep water trap net use began targeting whitefish	Berst and Spangler 1972
1932	First record of sea lamprey	Smith 1972
1933	First record of alewife	Smith 1972
1935	Deep water trap net use limited by regulation	Berst and Spangler 1972
late 1930s	Lamprey predation evidence in the drop of whitefish, lake trout, and sucker landings	Berst and Spangler 1972
1946	Lake trout production in US waters commercially insignificant	Berst and Spangler 1972
1948	Height of lamprey abundance	Berst and Spangler 1972
1950	First use of nylon gill nets	Berst and Spangler 1972
1955	Lake trout production in Canadian waters commercially insignificant	Berst and Spangler 1972
1942-43	Massive die-off of rainbow smelt	Van Oosten 1944
late 1950s	Rainbow smelt decline due to alewife	Smith 1970
1956	Catch of cisco commercially insignificant	Berst and Spangler 1972
1950s, 1960s	Introduction of splake by Province of Ontario	Berst and Spangler 1972
1960	Elimination of *Hexagenia* in Saginaw Bay due to deteriorating water quality and oxygen depletion	Schaeffer et al. 2000
1960	Sea lamprey control initiated	Ebener et al. 1995
1964	Kokanee salmon introduced	Berst and Spangler 1972
1965	Lamprey abundance declines to 10% of that reported in 1948	Berst and Spangler 1972

Table 3 (Lake Huron)

Time	Event	Reference
1968	First chinook salmon stocking	Berst and Spangler 1972
1974	Hatchery-reared lake trout stocking begins	
1986-1992	Lake trout harvests are at less than 20% of the rehabilitation goal, and 10% of the historic harvest	Ebener et al. 1995
1992	Fishery objective for coregonid harvest is achieved; harvest dominated by lake whitefish; lake herring levels still extremely low	Ebener et al. 1995
1999	Successful application of lampricide to the St. Mary's River; results in ~85% reduction of sea lamprey	Dann and Schroeder 2003

Table 4 (Lake Michigan)

Time	Event	Reference
early 1830s	Beginning of rapid human population growth	Wells and McLain 1972
mid 1800s	Inshore areas affected by sawmills, dams, deforestation, and drainage	Wells and McLain 1972
1850	Fishing is a major industry	Wells and McLain 1972
1870s	Many fishermen hold the belief that high production of certain species is being only maintained by increased effort and efficiency of gear	Wells and McLain 1972
1885	Severe reduction in whitefish abundance (overfishing and pollution from sawmills)	Wells and McLain 1972
1893	First commercial production record of common carp	Wells and McLain 1972
1900	Completion of Chicago Sanitary and Shipping Canal; prior to this, raw sewage from Chicago was discharged directly into Lake Michigan	Beeton et al. 1999
1912	Rainbow smelt introduced into Crystal Lake which drains into Lake Michigan	Smith 1972
1923	First record of rainbow smelt	Smith 1972
1936	First record of sea lamprey	Smith 1972
1936	Rainbow smelt occupy entire lake	Wells and McLain 1972
1942-43	Massive die-off of rainbow smelt	Van Oosten 1944
1945	Beginning of a sharp decline in lake trout	Wells and McLain 1972
1949	First record of alewife	Smith 1972
1953	Alewife found throughout most of the lake	Miller 1957
1955	*Hexagenia* absent in Green Bay	Beeton 1969; Howmiller and Beeton 1970
1956	Lake trout extinct	Wells and McLain 1972
late 1950s	Collapse of blackfin cisco (*Coregonus nigripinnis*) and *C. johannae*; intermediate-size chubs uncommon; bloater common	Wells and McLain 1972

Table 4 cont.

Time	Event	Reference
late 1950s	Rainbow smelt decline	Smith 1970
1957-1967	Explosive increase in alewife catch (220,000 lbs in 1957 to 41.9 million lbs in 1967)	Wells and McLain 1972
1960	Sea lamprey control initiated	Wells and McLain 1972
early-mid 1960s	Abrupt decline in yellow perch, emerald shiner coincident with buildup of alewife population	Wells and McLain 1972
1965	Beginning of lake trout rehabilitation	Wells and McLain 1972
1966	Stocking of Pacific salmon (coho, *Oncorhynchus kisutch*) begins	Wells and McLain 1972
1967	Massive spring die-off of alewife estimated at 70% of population	Wells and McLain 1972
1967	Stocking of chinook salmon begins	Wells and McLain 1972
1971	Year-round study of primary production on a representative transect in Lake Michigan conducted by Fee (1971)	Vollenweider et al. 1974
1970s-early 1980s	Substantial decrease in alewife abundance	Jude and Tesar 1985; Eck and Wells 1987
1970s-1980s	Shift in phytoplankton composition from community dominated by blue-greens and greens to phytoflagellates	Fahnenstiel and Scavia 1987
1974-1991	Phosphorus loadings decreased by one-half	Madenjian et al. 2002
1986	First record of *Bythotrephes longimanus* (previously *B. cederstroemi*)	Lehman 1987; Makarewicz et al. 1995
1965-1986	Steady increase in salmonine population	Stewart and Ibarra 1991
1980-1993	Declines in abundance of *Diporeia*, oligochaetes, and sphaeriids in nearshore waters Reduced *Diporeia* abundance in nearshore areas coincident with zebra mussel establishment	Nalepa et al. 1998, 2000
1994	First record of round goby	Clapp et al. 2001
1997	Dramatic increase in cormorant populations (75 nests in 1977 to over 28 000 in 1997)	Weseloh et al. 1995
1998	Commercial yellow perch fishery closed	Madenjian et al. 2002

Table 4 cont.

Time	Event	Reference
1986-1990s	Bacterial kidney disease (BKD) depletes stocks of chinook salmon	Kabre 1993; Starliper et al. 1997
1999	Successful application of lampricide to the St. Mary's River; results in ~85% reduction of sea lamprey in northern Lake Michigan	Dann and Schroeder 2003
1965-2000	Recovery of lake whitefish partially attributed to sea lamprey control	Madenjian et al. 2002
1965-2000	Overexploitation of fish populations appears to have played a minor role in shaping the food web in the last 30 years	Madenjian et al. 2002
1970-2000	Concentrations of most contaminants in biota decreased substantially (with the exception of toxaphene in lake trout)	Madenjian et al. 2002

Table 5 (Lake Superior)

Time	Event	Reference
1616	Lake Superior discovered, 24 years before Lake Erie this was due to the absence of hostile indians (Iroquois) of the lower lakes	Lower 1946; Lanctot 1963; Thwaites 1968
1835	American Fur Company establishes a number of commercial fishing stations (trout and whitefish); primary gear used was gillnets	Nute 1926, 1944
1850	Settlement of the south shore; lumbering begins	Lawrie and Rahrer 1972
1870	Construction of canal locks around the rapids in the St. Mary's River at Sault Ste. Marie	Groop 1999
1871	First intensive study of benthos undertaken by the U.S. Lake Survey	Cook and Johnson 1974
1871	First steam-driven vessel	Lawrie and Rahrer 1972
1885	Peak yield of lake whitefish	Lawrie and Rahrer 1972
1890	Steam-powered net lifters in use	Lawrie and Rahrer 1972
1895	First stocking of rainbow and brown trout	Lawrie and Rahrer 1972
1900	Blackfin cisco (*Coregonus nigripinnis*) landings peak probably as a result of depletion in Lake Michigan by the late 1800s	Lawrie and Rahrer 1972
1907	*C. nigripinnis* commercially extinct	Lawrie and Rahrer 1972
1920	South shore whitefish stocks commercially extinct	Lawrie and Rahrer 1972
1930	First record of rainbow smelt	Smith 1972
1941	Peak yield of lake herring; peak yield of total commercial catch (all species)	Lawrie and Rahrer 1972
1946	First record of sea lamprey	Smith 1972
1953	First record of alewife	Smith 1972
late 1950s	Use of lampricide to control sea lamprey begins	Bronte et al. 2004
1953-1962	Exponential decline in lake trout and whitefish catches; rapid increase and dispersal of sea lamprey	Lawrie and Rahrer 1972

Table 5 cont.

Time	Event	Reference
1956	Accidental introduction of pink salmon	Bronte et al. 2004
1962	De facto quotas restrict lake trout catches	Lawrie and Rahrer 1972
1962	Application of lampricide reduces lamprey abundance to 10% of the pre-control maximum	Lawrie and Rahrer 1972
1960s	Lake herring collapse	Bronte et al. 2004
1966	First stocking of coho salmon	Bronte et al. 2004
1967	First stocking of chinook salmon	Peck et al. 1994
1978	Peak abundance of rainbow smelt	Bronte et al. 2004
1978-81	90% decline in rainbow smelt	Bronte et al. 1993
early 1980s	Concern about competition between recovering lake trout and introduced salmonines leads to modeling efforts that result in rejection of competition hypothesis	Bronte et al. 2004
mid 1980s	Eurasian ruffe collected in the St. Louis estuary	Bronte et al. 1998
1992	Eurasian ruffe is the most abundant fish in the lower St. Louis River based on bottom trawl stock assessments	Bronte et al. 2004
1996	Eurasian ruffe population at 6,000,000 fish	Bronte et al. 2004
1999	Sea lamprey abundance declines from 800,000 in 1960 to less than 200,000 in1999	Heinrich et al. 2003
present	Recovering lean lake trout shows that sea lamprey control, limitations on fisheries, and protection of wild populations can work	Bronte et al. 2004
	Lean lake trout, lake herring and siscowet lake trout have recovered and are approaching pre-collapse levels of abundance	Bronte et al. 2004

Table 6 (all lakes)

Time	Event	Reference
17th century	Arrival of European settlers initiates the change from subsitence culture of Indians to that of European barter system	Bogue 2000
1783	Treaty of Paris established boundary between the U.S. and British N. America	Bogue 2000
1785	Land Ordinance of 1785	Bogue 2000
1787	Northwest Ordinance and Constitution drafted	Bogue 2000
1780s	British settlement in Kingston-Bay of Quinte and Niagara Peninsula	Bogue 2000
1791	Constitutional Act of 1791 encouraged development around Ontario and Erie to counter expanding American population	Bogue 2000
late 18th century	Overall goal of agricultural development led to population increase, removal of land cover, increase in erosion, and the damming of rivers and streams (began to impede the migration of fish)	Bogue 2000
early 19th century	Idea of managing fish for long-term use became common in statute books of NY and Upper Canada as Lake Ontario shorestransitioned from wilderness to agricultural/commercial economy	Bogue 2000
pre-1840	Gradual development of science and technology; intensification of exploitation	Regier and Applegate 1972
mid 1800s	Most land in the Great Lakes region suitable for farming had been settled	Beeton et al. 1999
mid 1800s	Railroad development expanded the market for fish	Regier and Hartman 1973
1840-1870	Artificial fish propagation and development of improved hatchery and stocking techniques	Regier and Applegate 1972
1870-1900	Extensive introduction of non-native species; market forces, technological advances lead to greater intensification of exploitation; great expansion of artificial propagation	Regier and Applegate 1972
1890-1910	Sharp declines in recorded catch of lake sturgeon in all lakes	Smith 1972
1871	Congress establishes the Commission of Fish and Fisheries; headed by Spencer F. Baird	Bogue 2000
1892	Joint Commission Relative to the Preservation of the Fisheries in Waters Contiguous to Canada and the U.S. formed based on the need to develop and enforce uniform, joint regulation; the Commission was charged with collecting information and making recommendations to U.S. and Canadian lawmakers; attempt #1 at cooperative management of Great Lakes fisheries and water resources.	Bogue 2000

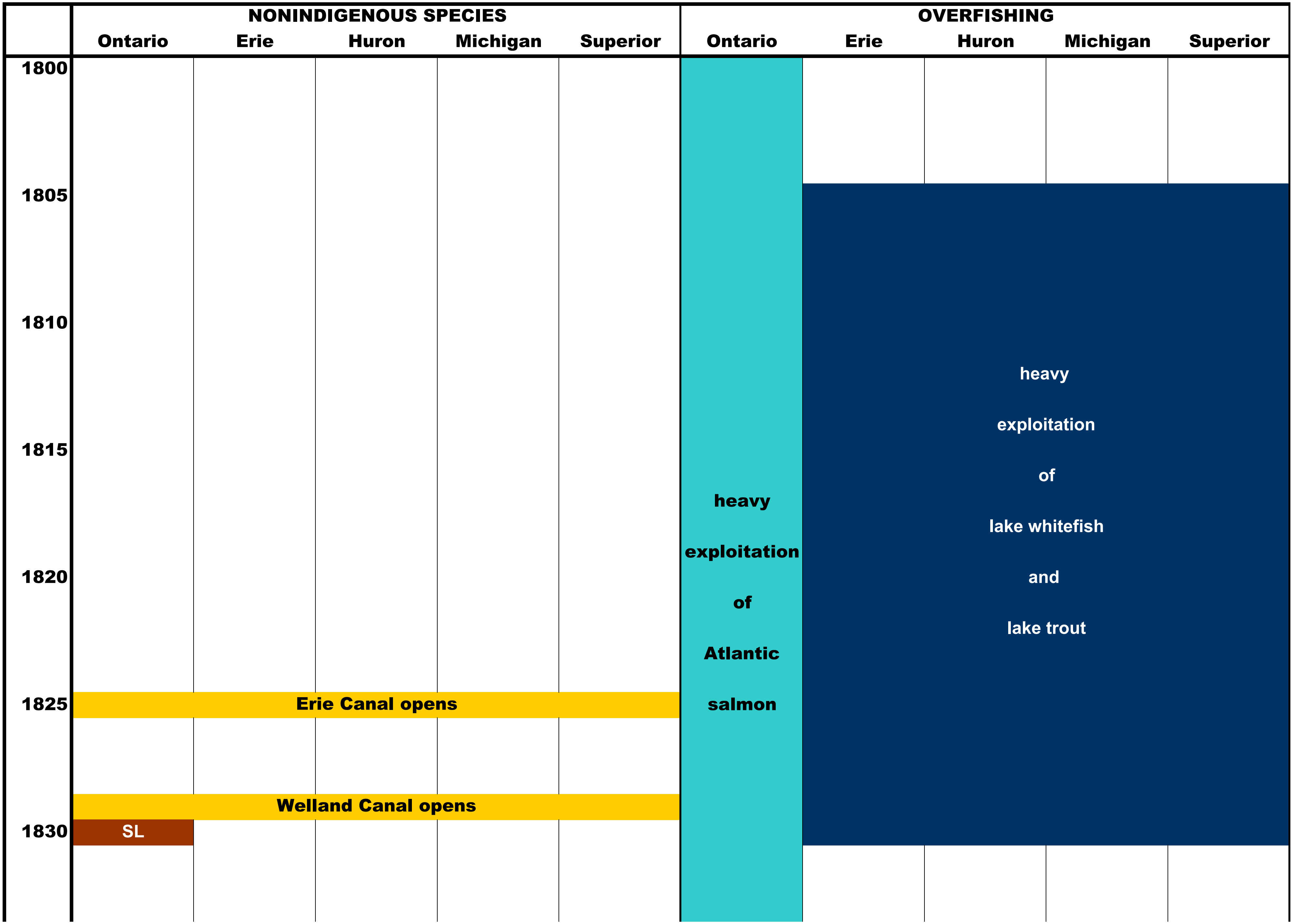
Table 6 (all lakes)

Time	Event	Reference
1893-1896	Appointed by the Joint Commission, William Wakeham (Canada) and Richard Rathbun (U.S.) investigate and report on effects of overfishing, water pollution, and obstructions in all Great Lakes waters except Lake Michigan.	Bogue 2000
1909	Boundary Waters Treaty drafted between the U.S. and Canada calls for the establishment of the International Joint Commission for joint regulation of fisheries in waters shared by the U.S. and Canada	Bogue 2000
1911	International Joint Commission established	Bogue 2000
1900-1945	Socionomic aspects of world wars partial cause of fluctuation in fish exploitation	Regier and Applegate 1972
1920-1930	Alewife and sea lamprey reach the upper lakes via the Welland Canal	Smith 1972
1945-1960	Conventional hatcheries close; technological advances increase fish exploitation; growing concerns about pollution and eutrophication	Regier and Applegate 1972
1955	Establishment of sea lamprey prompts drafting and ratification of the 1955 Convention on Great Lakes Fisheries; the convention established the Great Lakes Fishery Commission	Dochoda 1999
1965-1980	Concentrations of PCBs, total DDT, and mercury decreased significantly in lake trout, bloater, coho salmon, and chinook slamon	D'Itri 1988
1970-1973	Canadian Centre for Inland Waters initiated a year-round program to investigate primary production in Lake Ontario and Erie; extended to Lake Huron in 1971 and Lake Superior in 1973	Vollenweider et al. 1974
1971	Salmonid Communities in Oligotrophic Lakes (SCOL) symposium	Loftus and Regier 1972
1972	Drafting of the Great Lakes Water Quality Agreement (GLWQA) sets program in motion to control phosphorus discharges	
1976	Percid International Symposium (PERCIS)	Colby 1977
1978	Amendment of the 1972 GLWQA introduces the 'ecosystem approach' and focuses on reducing contaminant loading	
1979	Sea Lamprey International Symposium (SLIS)	Loftus et al. 1978
1980	Stock Concept International Symposium (STOCS)	Berst and Simon 1981
1981	Joint Strategic Plan for Management of Great Lakes Fisheries	Dochoda 1999

1987	43 Areas of Concern (AOCs) identified by the International Joint Commission (IJC)	Beeton et al. 1999

Table 6 (all lakes)

Time	Event	Reference
1985	International Symposium on Stocks Assessment and Yield Prediction (ASPY)	Christie and Spangler 1987
1989	Canadian voluntary ship ballast water exchange regulations	
1993	U.S. mandatory regulations for ship ballast water exchange	United States Coast Guard 1993
2003	SCOL II synthesizes 30 years of research since SCOL I	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heavy exploitation of lake whitefish and lake trout
Erie Canal opens
Welland Canal opens
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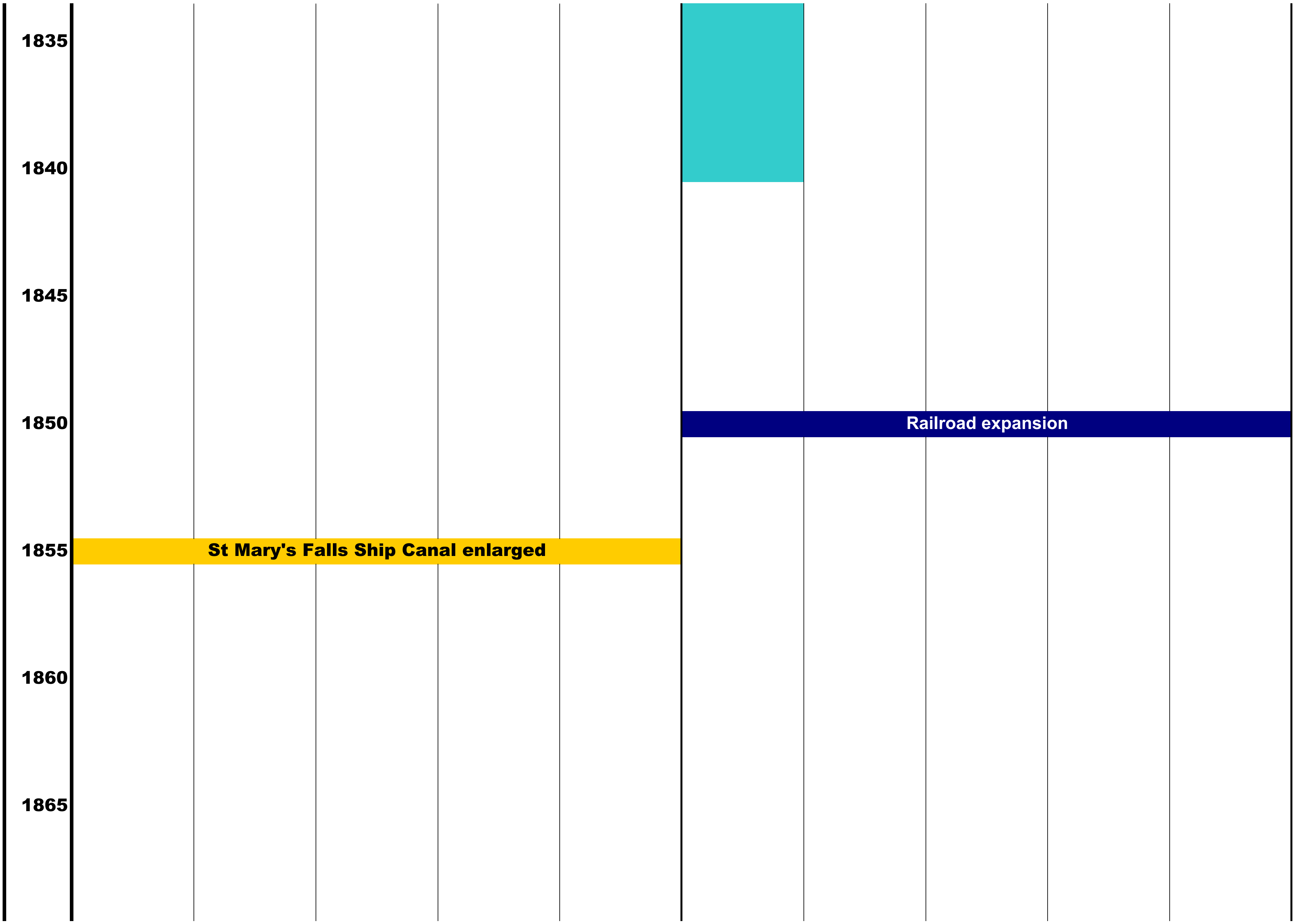
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Railroad expansion
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St Mary's Falls Ship Canal enlarged
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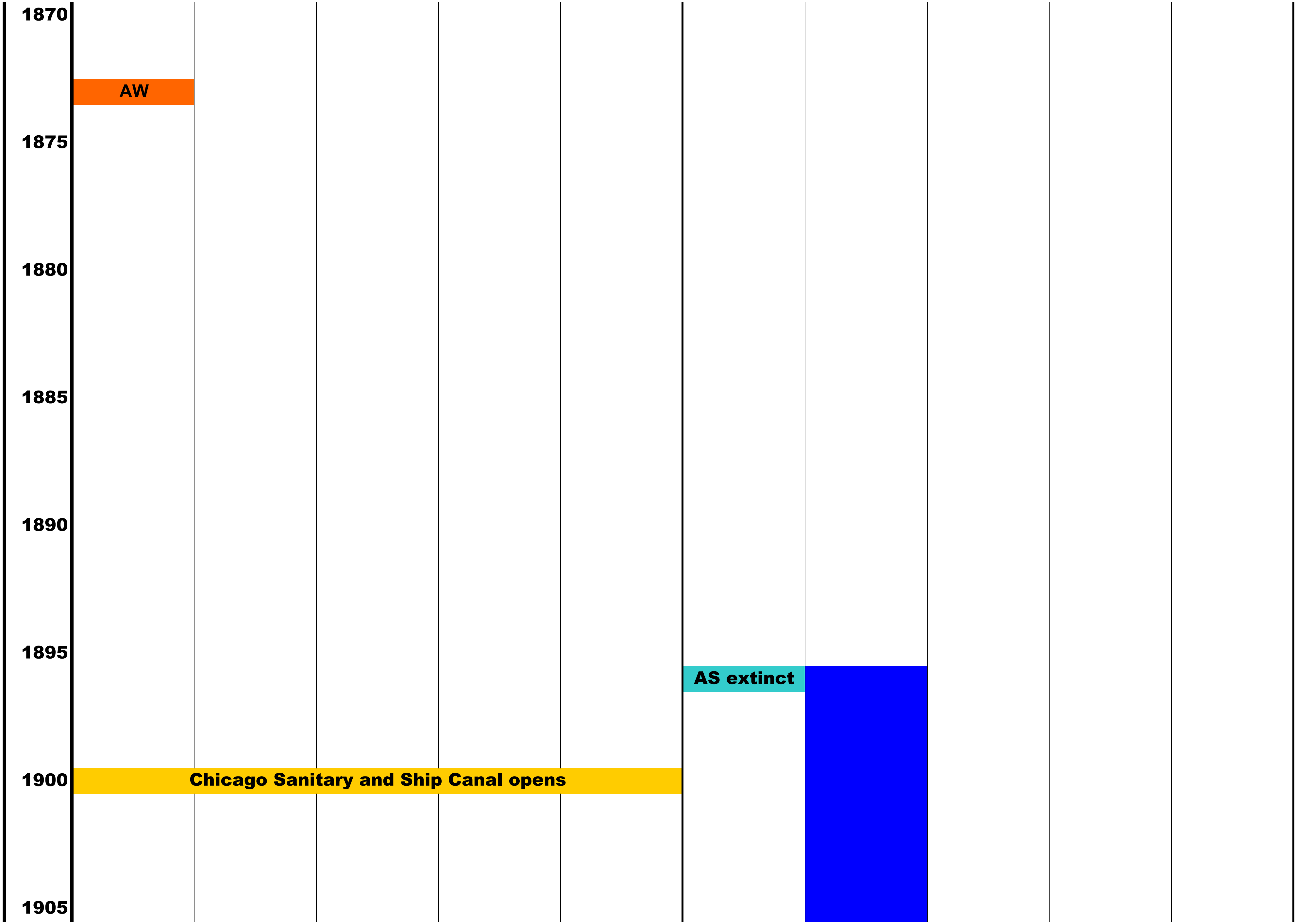
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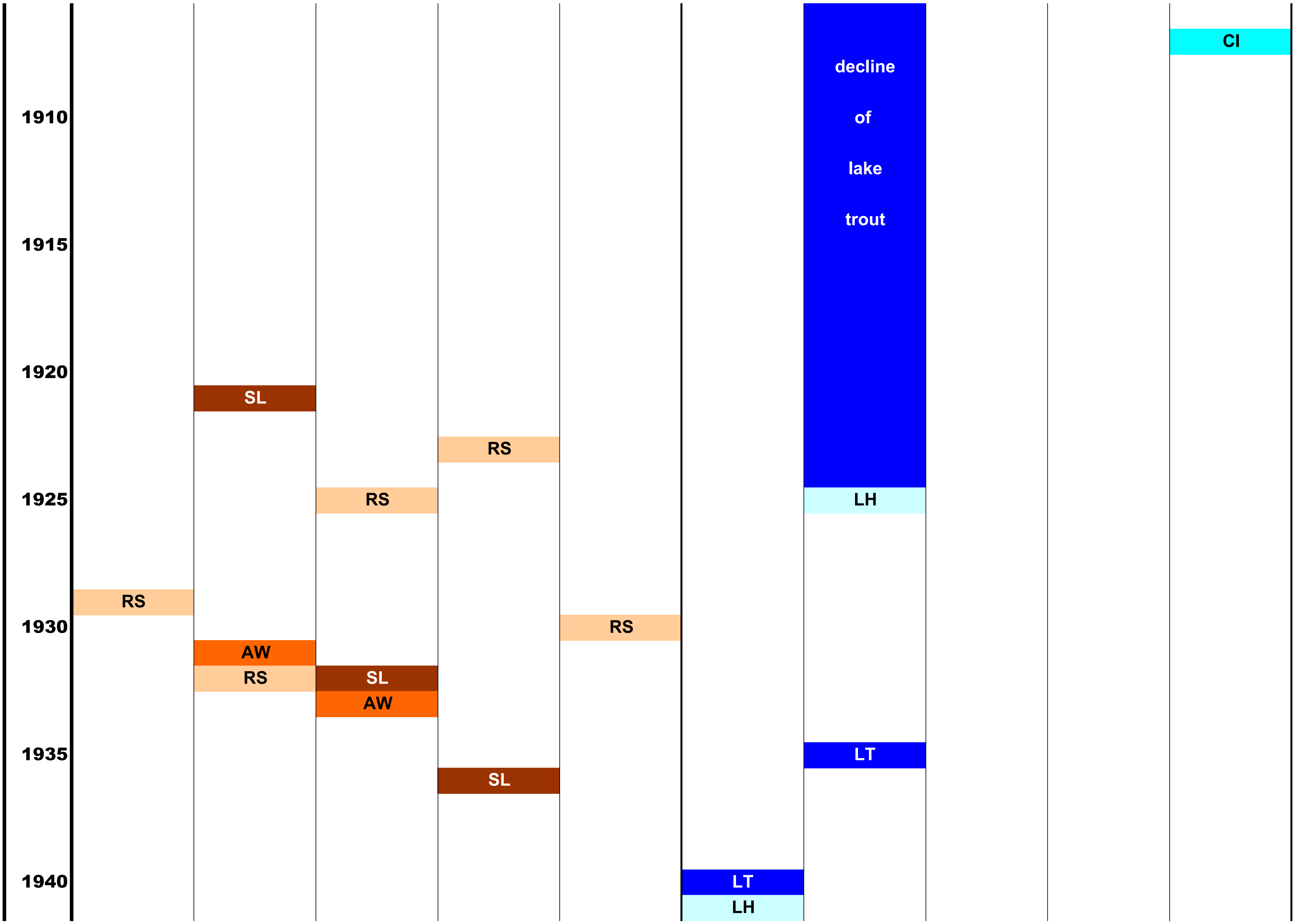
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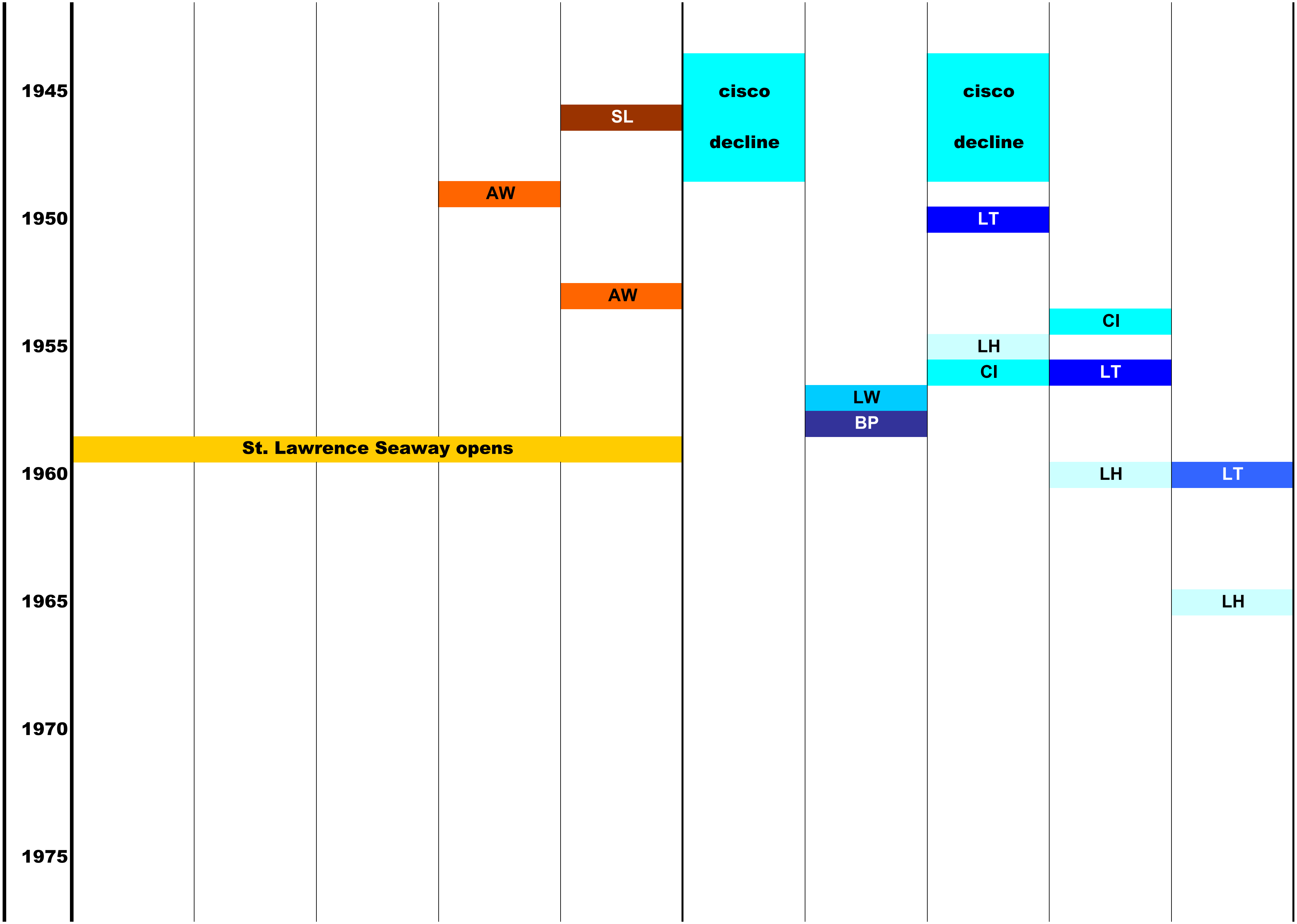
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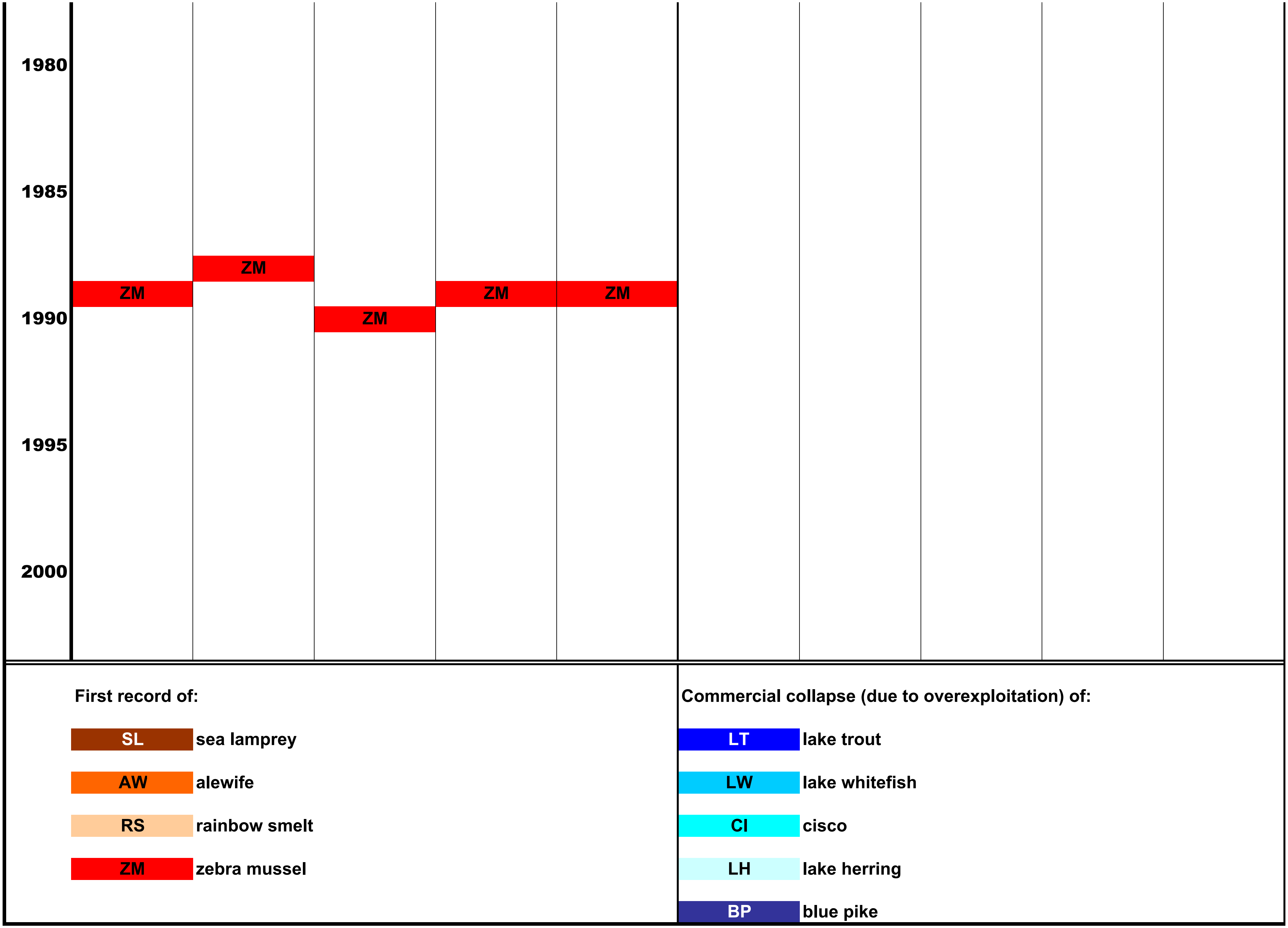
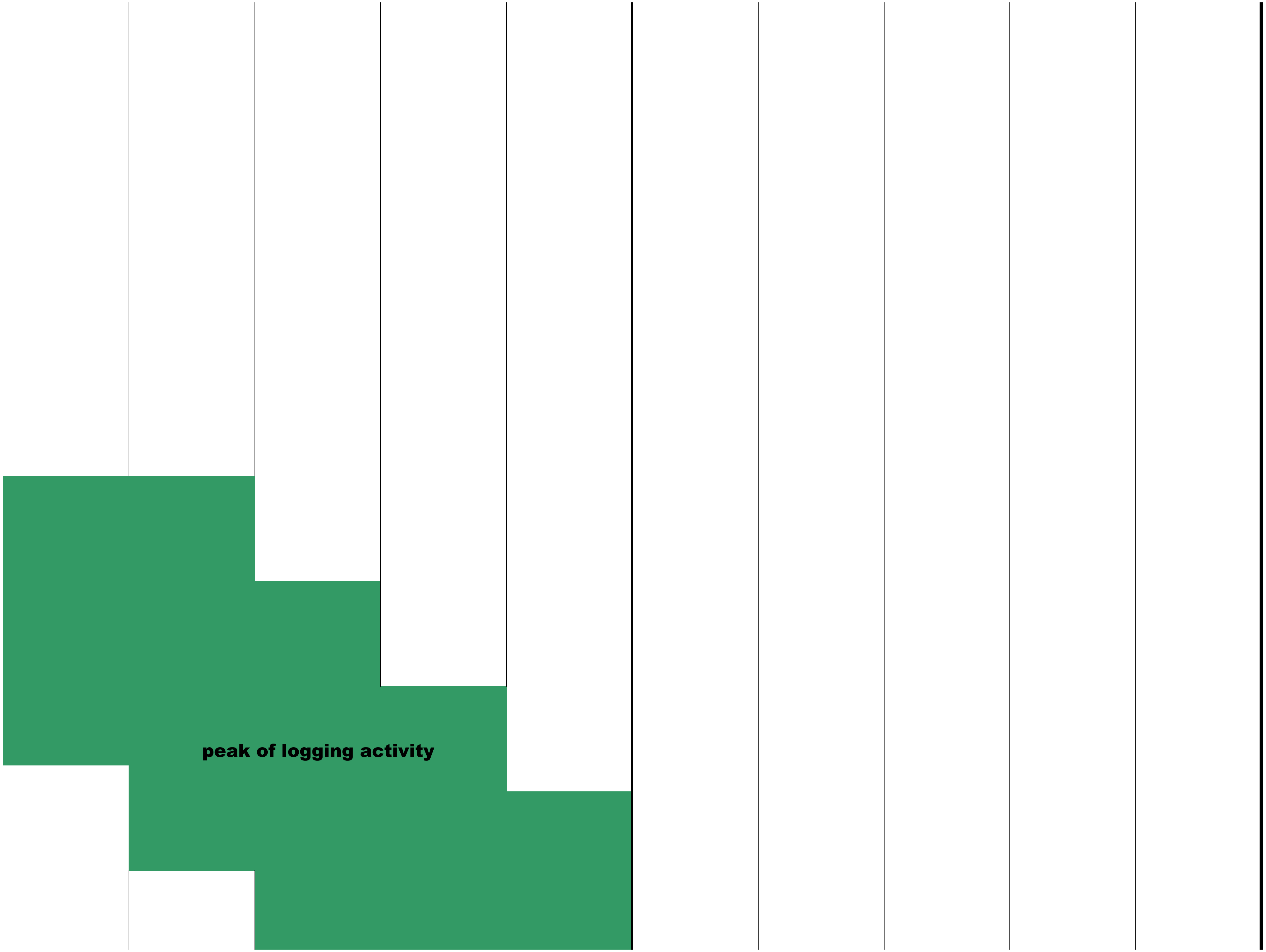
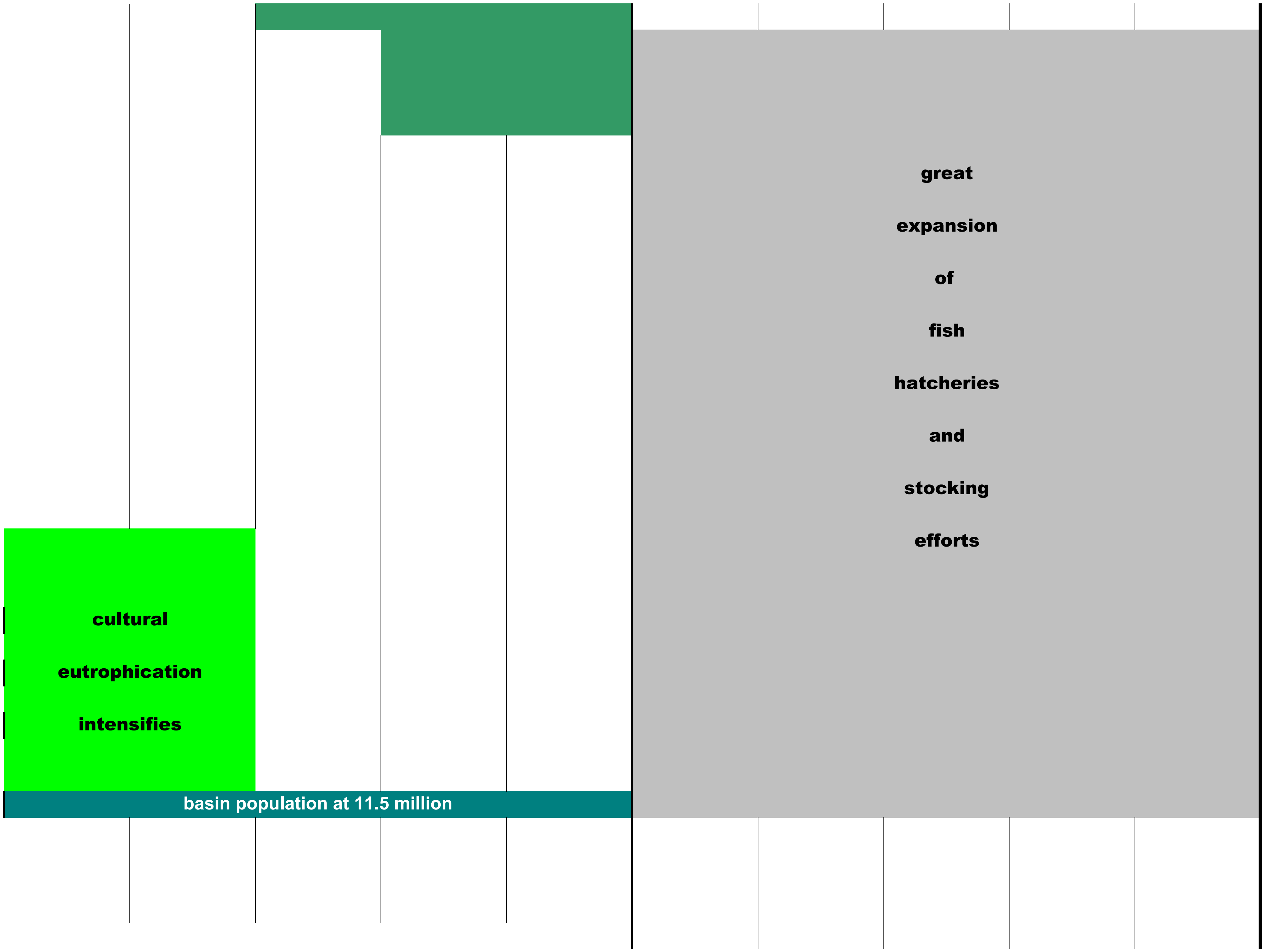
1960
1965
1970
1975
cisco
decline
cisco
decline
SL
AW
LT
AW
CI
LH
CI
LT
LW
BP
St. Lawrence Seaway opens
LH
LT
LH


1980
1985
1990
1995
2000
ZM
ZM
ZM
ZM
ZM
First record of:
SL sea lamprey
AW alewife
RS rainbow smelt
ZM zebra mussel
Commercial collapse (due to overexploitation) of:
LT lake trout
LW lake whitefish
CI cisco
LH lake herring
BP blue pike

HABITAT DEGRADATION					POLICY AND MANAGEMENT				
Ontario	**Erie**	**Huron**	**Michigan**	**Superior**	**Ontario**	**Erie**	**Huron**	**Michigan**	**Superior**
Great Lakes basin population is 300,000; mostly around Lakes Erie and Ontario (prior to arrival of Europeans, basin population is estimated at 60,000-120,000)									

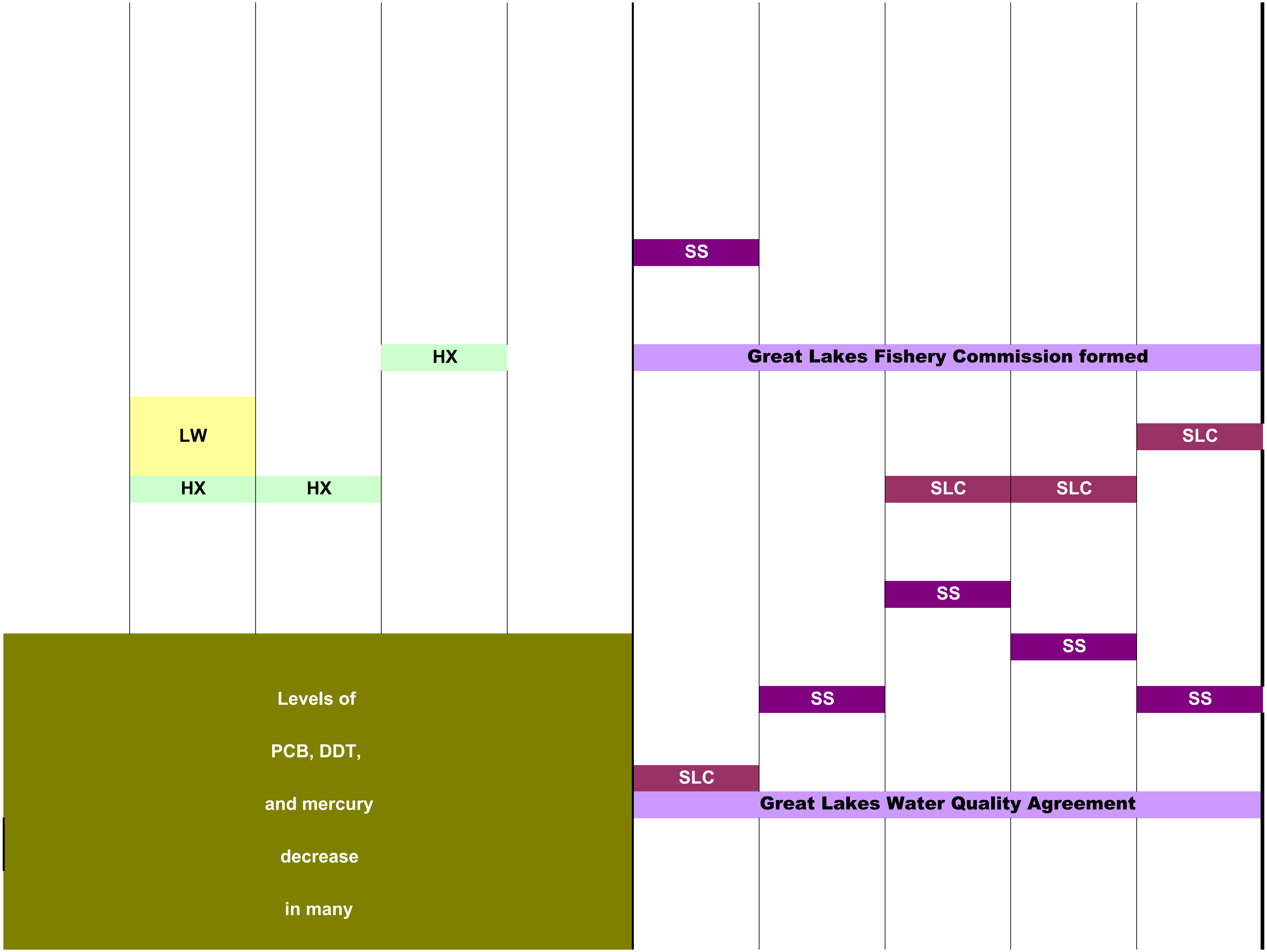

peak of logging activity

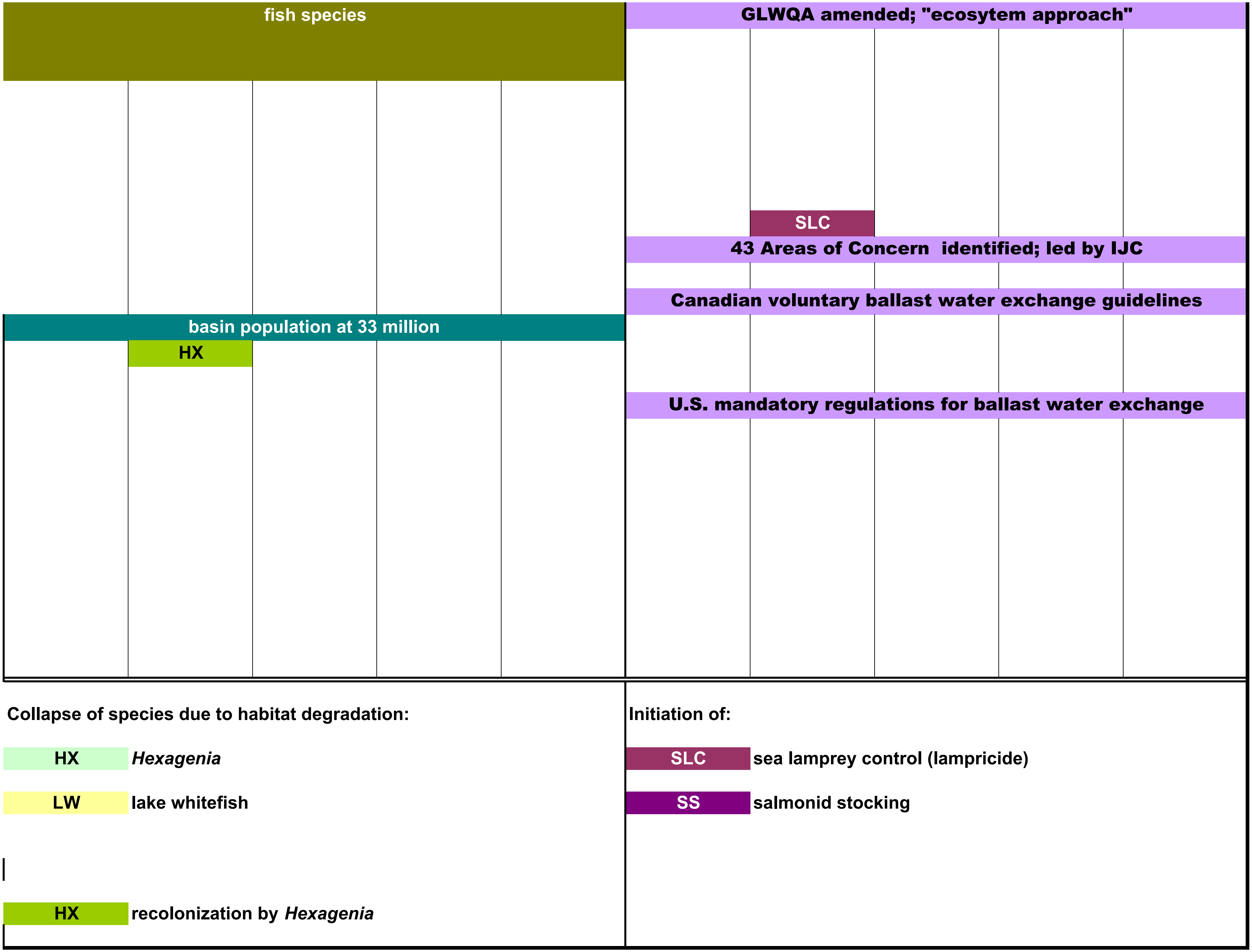

great expansion of fish hatcheries and stocking efforts
cultural eutrophication intensifies
basin population at 11.5 million

**losses of river-run lake trout, lake whitefish,
and lake herring due to modification of
river drainages from logging, sawmills, and dams**

Boundary Waters Treatly establishes the IJC

basin pop at 23 million


SS
HX
Great Lakes Fishery Commission formed
LW
SLC
HX
HX
SLC
SLC
SS
SS
SS
SS
SLC
Great Lakes Water Quality Agreement
Levels of PCB, DDT, and mercury decrease in many


fish species
GLWQA amended; "ecosytem approach"
SLC
43 Areas of Concern identified; led by IJC
Canadian voluntary ballast water exchange guidelines
basin population at 33 million
HX
U.S. mandatory regulations for ballast water exchange
Collapse of species due to habitat degradation:
HX Hexagenia
LW lake whitefish
HX recolonization by Hexagenia
Initiation of:
SLC sea lamprey control (lampricide)
SS salmonid stocking