STUDY PERFORMANCE REPORT

State: Michigan **Project No.:** F-81-R-5

Study No.: 230495 **Title:** Assessment of lake trout populations in Michigan waters of Lake Superior

Period Covered: October 1, 2003 to September 30, 2004

Study Objectives: (1) To annually (or semi-annually) determine relative abundance, length and age composition, sex and maturity, sea lamprey wounding, growth, and mortality for lean and siscowet lake trout in Michigan's Lake Superior lake trout management units. (2) To periodically determine relative abundance, diet, and biological variables (age, growth, etc.) of lake trout varieties, other predator fish, and forage fish at various depth strata in Lake Superior. (3) To calculate total allowable catch (TAC) for lake trout in Michigan's Lake Superior management units.

Summary: Lake trout surveys were conducted during the fall spawning period of 2003, and during the spring and summer of 2004. Spawner relative abundance has declined over the past few years on two of three reefs sampled in the Marquette area. Most of the spawning lake trout sampled were of wild origin. Spring survey relative abundance of lean lake trout increased in most areas in 2004. Spring lean lake trout relative abundance has increased in recent years in MI-4 and MI-6, and has declined in MI-3 and MI-5. Relative abundance of siscowet in the spring has been lower than leans in the last 10 years. The average percentage of hatchery leans in the spring survey was 6% in 2004. In the 2004 summer pre-recruit survey, lean relative abundance increased in all management units and by over 25% except in MI-6. Since 1995, summer lean abundance has increased in MI-2, MI-4, and MI-5. Summer lean abundance has declined in MI-3 and MI-6 since 2000. Siscowet abundance in the summer survey increased between 1995 and 2004 in all management units except MI-6. Siscowet abundance has declined in MI-6 by more than 50% since 2001. Siscowet relative abundance was equal to or higher than lean abundance in MI-2, MI-3, and MI-7. In general, the dominant prey fish in leans during the spring of 2004 was rainbow smelt and Mysis was the dominant invertebrate. Siscowet diet was more diversified with coregonines, burbot, sculpins, and rainbow smelt composing the prey fish component. The dominant invertebrates in siscowets were Mysis and terrestrial insects. Based on statistical catch-at-age models for wild leans in MI-5, MI-6, and MI-7, the 2001 to 2003 average instantaneous total mortality rates (Z) for ages 6 through 11 lake trout were: 0.30 year^{-1} in MI-5, 0.32 year^{-1} in MI-6, and 0.36 year^{-1} in MI-7. Sea lamprey predation was the dominant mortality source in all three populations. Sport fishing was the dominant fishing mortality source in MI-5 and MI-6, and commercial fishing was the principal fishing mortality source in MI-7. In collaboration with Michigan State University, preliminary genetic comparisons were made for four lake trout phenotypes in three spatial areas of Michigan waters of Lake Superior. The four lake trout phenotypes were: parental lean (LAT), parental siscowet (SIS), putative hybrid lean-dominant (LT?), and putative hybrid siscowet-dominant (FT?). The null hypothesis was that the frequency of alleles for all samples at all loci would not differ significantly, assuming that all three spatial groupings (MI-2/MI-3; MI-4/MI-5, MI-6/MI-7) and four phenotypes (parental types LAT and SIS and putative hybrid types FT? and LT?) were part of one panmictic and inter-breeding population. In general, parental lean lake trout and LT? phenotypes and SIS and FT? phenotypes exhibited greater genetic affinities to one another than to other samples, either within or between spatial groupings. There were no statistically significant differences in allele frequency among

sampling locales within each parental phenotype suggesting either high gene flow among populations within each phenotype and/or recent common ancestry.

Findings: Jobs 1 through 7 and 9 were scheduled for 2003-04, and progress is reported below.

Job 1. Title: Assess commercial-sized lake trout.–Between 27 October and 18 November 2003, Marquette Fisheries Research Station (MFRS) personnel conducted a lean lake trout (*Salvelinus namaycush*) spawning survey in the Marquette area (MI-5). The spawning sites sampled included: Presque Isle Harbor, Garlic Island Reef (new site), and Partridge Island Reef (Figure 1). There were 1,131 lake trout caught with 92.2% that were wild fish. There were 645 lake trout tagged with anchor tags and 75 recaptures from previous years.

Commercial-sized lean lake trout were sampled in the spring starting on 27 April and ending 20 May 2004. A contracted commercial fisher (Peterson Fisheries) under permit from GLIFWC fished six stations in management unit MI-3 (Figure 1). Six new stations were sampled in northern MI-3 by another GLIFWC permitted commercial fisher (Newago Fisheries). Personnel aboard the R/V Judy sampled 9 stations in MI-4, 7 stations in MI-5, and 12 stations in MI-6. Chippewa Ottawa Resource Authority personnel sampled eight stations in MI-7. Over two thousand fish were collected in the survey with about 1,700 lake trout.

All spring and fall data collected during this performance period were entered into a computer database and proofed for errors by MFRS personnel. Stratified-random subsamples of the total fish catch from each management unit from the spring survey will be assessed for age using scales and/or otoliths collected from each fish.

During this performance period, commercial-sized lean lake trout were also sampled in MI-1 (Isle Royale) by Sivertson Fisheries (September-October 2003) and the National Park Service (June-August 2004). These data are in the process of being entered in the database.

Job 2. Title: Assess pre-recruit lake trout.–Pre-recruit lake trout were sampled in the summer starting on 27 July and ending 02 September 2004. Personnel aboard R/V Judy sampled five stations in MI-2, seven stations in MI-3, eight stations in MI-4, four stations in MI-5, four stations in MI-6, and two stations in MI-7 (Figure 1). There were about 5,600 fish collected with approximately 3,000 lake trout. All data have been entered into a computer database and were proofed for errors. Fish ages will be assessed during the winter months using scales and/or otoliths collected during sampling.

Job 3. Title: Assess lake trout variety composition.–No field work was conducted during this performance period. Siscowet survey diet data from 2003 have been processed and entered into the database. Ages have been assessed for samples collected from this survey.

Job 4. Title: Analyze assessment data.

Spawner survey 2003–In 2003, relative abundance of spawning lake trout was three-fold higher at Garlic Island Reef than at the two other reefs (Figure 2). At Marquette Harbor, spawner relative abundance has declined by more than 50% since the survey was begun in 2000. At Garlic Island and Partridge Island reefs, over 97% of lake trout were of wild origin, whereas 80% of fish at Marquette Harbor were of wild origin. The percentage of lake trout that were male ranged from 78% to 100% at all three spawning areas. The length distributions of lake trout were significantly different at all three spawning reefs with Partridge Island Reef having higher proportion of smaller fish, and Garlic Island Reef with significantly higher proportion of larger fish (Kolmogorov-Smirnov Two-Sample test, $P < 0.001$ for all comparisons; Figure 3).

Spring survey 2004–During 2004, relative abundance of lean lake trout was higher in MI-4, MI-5, and MI-7 than in 2003 (Figure 4a). There were increasing trends in lean abundance since 1995 in MI-4 and since 2000 in MI-6. Declining lean abundance trends were observed in MI-3 and M-5. In MI-7, lean abundance fluctuated over years without any major trend. Generally, siscowet relative abundance was lower than lean abundance in all areas in the last 10 years (Figure 4b). Since 2000, siscowet abundance has declined in MI-3 and MI-5. In MI-7, siscowet abundance has declined since 1998. There has been an increase in siscowet abundance in MI-6 since 1995. There was no major trend in siscowet abundance in MI-4. Across all management units, the average proportion of lean lake trout that were of wild origin in 2004 was 0.94 (Figure 5). In MI-3, MI-5, MI-6, and MI-7, the proportion of wild fish has increased since 1999 to over 0.95 in 2004. In MI-4, the proportion of wild fish has declined since 1998 to 0.81 in 2004. The lower proportion of wild fish is MI-4 was due to continued stocking of hatchery fish in this management unit.

Pre-recruit survey 2004– Relative abundance of lean lake trout was higher in 2004 than 2003 in all management units (Figure 6a). In all areas except MI-6, lean lake trout abundance increased by over 25% from 2003 to 2004. Since 1995, lean abundance has increased in MI-2, MI-4, and MI-5. Lean abundance has declined in MI-3 and MI-6 since 2000. There were no temporal trends in lean abundance in MI-7 between 1995 and 2004. Siscowet abundance increased between 1995 and 2004 in all management units except MI-6 (Figure 6b). In MI-2, MI-3, and MI-7, siscowet relative abundance was equal to or higher than lean abundance. Since 2001, siscowet abundance has declined in MI-6 by more than 50%. Siscowet abundance in MI-7 fluctuated over time with no apparent trend.

Job 5. Title: Analyze diet data.–*Spring survey 2004*- The most frequent prey fish in the spring diet of small lean lake trout (≤ 600 mm) was rainbow smelt in all areas except MI-3 (Table 1). In MI-3, the most frequent prey fishes for small lake trout were coregonines. The most frequent invertebrate prey item for small lean lake trout was Mysis in all areas sampled. The most frequent prey fish observed for small siscowets were: slimy sculpins and ninespine sticklebacks in MI-5 and MI-6; rainbow smelt in MI-4; and coregonines, ninespine sticklebacks, and slimy sculpins in MI-3 (Table 1). As with leans, Mysis were observed in the most number of small siscowet stomachs. In large lean lake trout (>600 mm) stomachs, the most frequent prey fish was: coregonines in MI-3; rainbow smelt in MI-4; burbot and rainbow smelt in MI-5; and slimy sculpin in MI-6 (Table 2). Mysis was the dominant invertebrate observed in large lean lake trout in MI-5 and MI-6. Terrestrial insects were the most frequently observed invertebrate in large leans in MI-3. No invertebrates were observed in large lean stomachs in MI-4. Coregonines were the prey fish observed in the most stomachs of siscowets in MI-3 and MI-4 (Table 2). In MI-5 and MI-6, burbot were the most frequently observed prey fish in large siscowets. The most frequent invertebrate prey in large siscowets were: terrestrial insects MI-3 and MI-6; Mysis in MI-4; and both Mysis and terrestrial insects in MI-5.

The most numerically abundant prey fish in small leans were rainbow smelt in all management areas (Table 3). Rainbow smelt composed 44 to 98% of identifiable fish items in the small lean lake trout diet. In large leans, rainbow smelt were the most dominant prey fish in MI-4 and MI-5, making up more than 59% of identifiable prey fishes. In MI-3, coregonines were the most abundant prey fish in large lean stomachs. Sculpins were the dominant prey fish in the diet of large leans in MI-6. The dominant prey fish in small siscowets were: coregonines in MI-3; rainbow smelt in MI-4; and sculpins in MI-5 and MI-6. In the large siscowet diet, the most abundant prey fish were: coregonines in MI-3; rainbow smelt in MI-4; burbot in MI-5; and sculpins in MI-6.

Summer survey 2004–Over 1,400 stomachs were collected during the 2004 summer lake trout survey. The samples will be analyzed during the winter months of 2004-2005.

Job 6. Title: Model lean lake trout populations.–As mandated by the 2000 Consent Decree of the 1836 Great Lakes Fishing Treaty between the State of Michigan and Native American Tribes, statistical catch-at-age models were updated for wild lake trout populations in MI-5, MI-6, and MI-7 during 2004 (Figure 1). These models were used to develop the 2004 harvest quotas (also termed Total Allowable Catch or TAC) for lake trout.

The average instantaneous total mortality rates (Z) for ages 6 through 11 lake trout during 2001 to 2003 were: 0.30 year^{-1} in MI-5, 0.32 year^{-1} in MI-6, and 0.36 year^{-1} in MI-7. These rates were below the target maximum rate of 0.59 year^{-1} (A=45%). With the exception of background natural mortality (M), sea lamprey predation was the dominant mortality source in all three populations. The dominant fishing mortality source was sport fishing in MI-5 and MI-6, and commercial fishing in MI-7. Spawning stock biomass produced per recruit (SSBR) has been used to assess overall population health status, and is defined as the cumulative mature biomass produced per female recruit through its life given a set mortality schedule. The current SSBR was based on the average mortality rates, female maturity schedule, and weight at age estimates during 2001 through 2003. In all three models, current SSBRs were above target SSBRs indicating that the populations have mortality rates that are not likely inhibiting population growth and reproductive potential (Figure 7).

Job 7. Title: Prepare reports.–Draft reports on lake trout TAC recommendations for 2004 have been written for the 1836 Treaty Technical Fisheries Committee.

Job 9. Title: Analyze lake trout morphotypes.–We contracted with Dr. Kim Scribner, Michigan State University, to analyze tissue samples and allele frequencies of lake trout phenotypes. Caudal fin tissue samples were collected from four lake trout phenotypes during 2003 spring and summer surveys for genetic analyses. From those samples, 293 individual lake trout were genotyped at 10 microsatellite loci. Individuals were grouped into three spatial units (management units MI-2 and MI-3; MI-4 and MI-5; and MI-6 and MI-7), representing a west to east orientation (Figure 1). Within each spatial group, individual lake trout were assigned to one of four phenotypes (FT?, LT?, LAT, and SIS), where LAT and SIS were parental types for lean and siscowet lake trout, respectively. Phenotypes FT? and LT? were putative hybrids, where phenotypic affinities of FT? and LT? more closely resembled parental siscowet and lean lake trout, respectively.

Estimates of allele frequency for all 10 loci are presented in Table 4. The null hypothesis was that if all three spatial groupings (MI-2/MI-3; MI-4/MI-5, MI-6/MI-7) and four phenotypes (parental types LAT and SIS and putative hybrid types FT? and LT?) were part of one panmictic and inter-breeding population, the frequency of alleles for all samples at all loci would not differ significantly. Qualitatively, we found evidence for substantial differences in allele frequency (Table 4). Using quantitative measures (exact tests of analysis of variance), we estimated pair-wise inter-sample variance in allele frequency between phenotypes and spatial groupings (Tables 5 through 8). In general, parental lean lake trout and LT? phenotypes and SIS and FT? phenotypes exhibited greater genetic affinities to one another than to other samples, either within or between spatial groupings (Tables 5 and 6, Figure 8).

We conducted a hierarchical analysis of variance using parental phenotypes only (LAT vs. SIS), that apportioned variance in allele frequency into components associated with phenotype and with spatial sampling locations within phenotype (i.e., a hierarchical analysis of phenotype and spatial grouping within phenotype). We found that phenotype accounted for a statistically significant component of variation in allele frequency (Table 7). There was no statistically significant difference among sampling locales within phenotype (Table 8). Results support earlier findings that lake trout phenotypes in Lake Superior represent a statistically significant component of the genetic variation in the basin (Page et al. 2004). Page et al. (2004) found that across the Lake Superior basin there were statistically significant differences in allele frequency among locales within each recognized phenotypes. We found that within a more restricted segment of the basin, (Michigan waters of Lake Superior), there were no statistically significant differences in allele frequency among sampling locales within each parental phenotype (Table 8). These findings suggest either high gene flow among populations within each phenotype and/or recent common ancestry (e.g., Guinand et al. 2003).

When samples were divided into four phenotypes and three locales, genetic affinities among phenotypes were evident (Figure 8). Putative hybrid type FT? were more similar in allele frequency to SIS parental types. Putative hybrid type LT? were more similar in allele frequency to the parental LAT lake trout phenotype samples. Additional statistical analysis will be conducted to determine whether FT? and LT? phenotypes are intermediate and consistent with proposed hybridization between SIS and LAT types.

Literature Cited

Page, K.S., K.T. Scribner, and M.K. Burnham-Curtis. 2004. Assessing levels and partitioning of genetic diversity in wild and hatchery lake trout populations: relevance for lake trout management and restoration in the Great Lakes. Trans. Amer. Fish. Soc. 133: 674-691.

Guinand, B., K. T. Scribner, K. S. Page, and M. K. Burnham-Curtis. 2003. Genetic variation over space and time: analyses of extinct and remnant lake trout populations in the upper Great Lakes. Proc. Roy. Soc. Lond. 270: 425-434.

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Dated: September 30, 2004

Table 1.–Spring diet composition for lean and siscowet (sis.) lake trout ≤ 600 mm in Michigan waters of Lake Superior during 2004. Data expressed as percent frequency of occurrence of prey item observed across all non-empty stomachs sampled per management unit for lean or siscowet lake trout.

		Management unit							
		MI-3		MI-4		MI-5		MI-6	
Category	Prey item	lean	sis.	lean	sis.	lean	sis.	lean	sis.
Burbot	Burbot		4.0			1.6	9.3	1.0	
Coregonine	Lake herring							1.0	
	Lake whitefish	1.9	4.0						
	Unidentified coregonine	23.1	24.0	6.6	6.3	3.2	4.7	2.0	1.5
Smelt	Rainbow smelt	19.2	4.0	82.0	56.3	21.0	7.0	33.3	9.0
Sculpin	Deepwater sculpin		4.0		6.3	1.6	7.0	3.0	4.5
	Sculpin (general)	1.9	8.0	1.6		4.8	11.6	4.0	13.4
	Slimy sculpin	1.9	24.0		6.3	8.1	41.9	11.1	28.4
Stickleback	Ninespine stickleback	7.7	24.0	1.6		9.7	27.9	24.2	28.4
	Threespine stickleback								1.5
Lake trout	Lake trout-unidentifiable morphotype								1.5
Other fish	Alewife			1.6					
	Fish egg	1.9	12.0					3.0	
	Fish entrails from human disposal								1.5
	Trout-perch					4.8	2.3	2.0	
	Unidentified fish or fish remains	50.0	40.0	16.4	12.5	29.0	27.9	42.4	43.3
Crustacean	Amphipod, diporeia	5.8		1.6		3.2	4.7	4.0	9.0
	Mysis, opossum shrimp	7.7	16.0	9.8	18.8	41.9	32.6	31.3	34.3
Insect	Ant, Formicidae							1.0	1.5
	Backswimmer								1.5
	Beetle, Coleoptera		4.0				2.3		3.0
	Caddis fly larvae, trichoptera				6.3			3.0	
	Chironomid (midge) pupae and larvae	1.9							
	Dragon fly adult		4.0						
	Flies, adult, Diptera					8.1		9.1	14.9
	Hymenoptera, bees and wasps							2.0	16.4
	Ladybug, Coccinellidae							1.0	7.5
	Mayfly larvae			1.6				1.0	1.5
	Plecoptera (stoneflies)		4.0	1.6					
	Stinkbug, Pentatomidae								1.5
	Unidentified aquatic insect					1.6			3.0
	Unidentified terrestrial insect	5.8	8.0			3.2	2.3	4.0	6.0
Mollusk	Clam, Pelecypoda						4.7	2.0	3.0
	Snail, Gastropoda								1.5
Other	Fish otoliths	1.9	8.0				4.7	1.0	1.5
	Frog								1.5
	Plastic					1.6			
	Rock, stone	1.9	4.0				4.7	9.1	4.5
	Sediments				6.3				1.5
	Spider, Arachnida							1.0	
	Vegetation	1.9	8.0			1.6	7.0	3.0	7.5
	Wood	3.9	12.0	1.6			4.7		1.5
	Number of stomachs	52	25	61	16	62	43	99	67

Table 2.–Spring diet composition for lean and siscowet (sis.) lake trout > 600 mm in Michigan waters of Lake Superior during 2004. Data expressed as percent frequency of occurrence of prey item observed across all non-empty stomachs sampled per management unit for lean or siscowet lake trout.

		Management unit							
		MI-3		MI-4		MI-5		MI-6	
Category	Prey item	lean	sis.	lean	sis.	lean	sis.	lean	sis.
Burbot	Burbot		16.7	5.9	13.3	19.2	46.7	9.3	35.3
Coregonine	Lake herring		5.6	5.9	6.7			1.9	
	Unidentified coregonine	57.1	44.4	11.8	46.7	11.5	6.7	7.4	
Smelt	Rainbow smelt	14.3		91.2	33.3	19.2		11.1	
Sculpin	Deepwater sculpin		5.6		6.7	7.7		9.3	5.9
	Sculpin (general)					7.7		14.8	5.9
	Slimy sculpin					7.7	6.7	16.7	17.7
Stickleback	Ninespine stickleback	14.3				11.5	6.7	13.0	5.9
Other fish	Fish egg				6.7			1.9	5.9
	Fish entrails from human disposal					3.9	6.7		
	Unidentified fish or fish remains	14.3	22.2	2.9	20.0	34.6	46.7	48.2	52.9
Crustacean	Amphipod, Diporeia		5.6						5.9
	Mysis, opossum shrimp		5.6		26.7	23.1	13.3	29.6	11.8
Insect	Ant, Formicidae							1.9	
	Backswimmer							3.7	5.9
	Beetle, Coleoptera						6.7	3.7	11.8
	Caddis fly larvae, Trichoptera					3.9			
	Flies, adult, Diptera	14.3	5.6			3.9	13.3	5.6	29.4
	Hymenoptera, bees and wasps	14.3						7.4	23.5
	Ichneumonidae wasps,	14.3							
	Ladybug, Coccinellidae							5.6	11.8
	Long horned beetle							1.9	
	Mayfly larvae							1.9	
	Midge, Diptera	14.3							
	Predacious diving beetle							1.9	
	Snout beetles, weevils							1.9	
	Stinkbug, Pentatomidae, Hemiptera							3.7	
	Unidentified aquatic insect					3.9		3.7	
	Unidentified terrestrial insects		11.1			3.9		7.4	11.8
Mollusk	Snail, Gastropoda								5.9
Other	Fish otoliths					3.9		1.9	5.9
	Plastic						6.7		
	Rock, stone		11.1					7.4	11.8
	Sediments				6.7			1.9	5.9
	Snake, Reptilia		5.6						
	Vegetation		5.6					3.7	11.8
	Wood					3.9		1.9	5.9
	Number of stomachs	7	18	34	15	26	15	54	17

Table 3.–Proportion of identified prey fish items sampled in the stomachs of lean and siscowet (sis.) lake trout collected during the spring of 2004 in Michigan waters of Lake Superior. The Other fish category includes: ninespine stickleback, threespine stickleback, alewife, and trout-perch; n is the number of stomachs that contained identifiable prey fish.

		Management unit							
Predator		MI-3		MI-4		MI-5		MI-6	
length	Prey fish	lean	sis.	lean	sis.	lean	sis.	lean	sis.
≤ 600 mm	Burbot		0.029			0.021	0.046	0.005	
	Coregonine	0.370	0.457	0.015	0.013	0.042	0.023	0.031	0.007
	Lake trout								0.007
	Other fish	0.087	0.171	0.006		0.188	0.284	0.276	0.362
	Sculpin	0.109	0.286	0.003	0.093	0.208	0.591	0.188	0.553
	Rainbow smelt	0.435	0.057	0.976	0.893	0.542	0.057	0.500	0.071
	n	25	18	54	11	27	28	64	39
> 600 mm	Burbot		0.235	0.006	0.037	0.151	0.786	0.048	0.389
	Coregonine	0.667	0.706	0.017	0.204	0.057	0.071	0.048	
	Other fish	0.167				0.057	0.071	0.295	0.111
	Sculpin		0.059		0.019	0.151	0.071	0.410	0.500
	Rainbow smelt	0.167		0.977	0.741	0.585		0.200	
	n	6	12	34	12	16	9	36	11

Table 4.–Allele frequencies for lake trout parental and putative hybrid phenotypes in Michigan waters of Lake Superior. Phenotypes were parental lean lake trout (LAT), parental siscowet lake trout (SIS), lean-dominant putative hybrid (LT?), and siscowet-dominant putative (FT?). Geographic areas were combined lake trout management units: MI-2 and MI-3; MI-4 and MI-5; and MI-6 and MI-7.

	MI-2 & 3-FT?	MI-2 & 3-LAT	MI- 2 & 3-LT?	MI-2 & 3-SIS	MI- 4 & 5-FT?	MI- 4 & 5-LAT	MI- 4 & 5-LT?	MI-4 & 5-SIS	MI- 6 & 7-FT?	MI- 6 & 7-LAT	MI- 6 & 7-LT?	MI- 6 & 7-SIS
Sco19												
N	18	29	20	33	22	27	23	24	26	20	27	24
151	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.000
159	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
161	0.111	0.190	0.125	0.091	0.000	0.148	0.217	0.125	0.019	0.150	0.148	0.063
163	0.028	0.034	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
165	0.028	0.000	0.025	0.015	0.045	0.019	0.043	0.000	0.000	0.000	0.037	0.000
167	0.000	0.000	0.000	0.000	0.023	0.000	0.000	0.000	0.000	0.000	0.019	0.000
169	0.000	0.000	0.000	0.015	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000
171	0.139	0.276	0.375	0.197	0.205	0.278	0.196	0.167	0.154	0.375	0.167	0.063
173	0.028	0.000	0.025	0.045	0.045	0.111	0.000	0.000	0.000	0.050	0.019	0.042
175	0.583	0.431	0.425	0.545	0.591	0.333	0.435	0.604	0.750	0.375	0.556	0.708
177	0.028	0.034	0.000	0.015	0.023	0.074	0.087	0.042	0.038	0.025	0.000	0.083
179	0.056	0.017	0.025	0.061	0.068	0.019	0.022	0.042	0.038	0.025	0.056	0.042
Het obs	0.556	0.759	0.750	0.576	0.545	0.815	0.826	0.609	0.385	0.750	0.556	0.500
Het exp	0.640	0.711	0.678	0.659	0.613	0.785	0.731	0.592	0.419	0.710	0.648	0.490
Sfo18												
N	18	29	20	33	23	27	22	24	26	20	27	25
171	0.722	0.724	0.650	0.727	0.630	0.556	0.500	0.708	0.692	0.575	0.722	0.760
173	0.000	0.000	0.000	0.000	0.022	0.019	0.000	0.021	0.000	0.000	0.000	0.000
175	0.000	0.000	0.000	0.045	0.022	0.037	0.000	0.021	0.019	0.000	0.037	0.020
179	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.000	0.000	0.000	0.000	0.000
181	0.167	0.207	0.200	0.045	0.043	0.185	0.318	0.021	0.058	0.300	0.056	0.040
183	0.000	0.000	0.125	0.000	0.000	0.074	0.000	0.000	0.000	0.000	0.000	0.000
185	0.000	0.000	0.000	0.000	0.043	0.019	0.000	0.021	0.019	0.000	0.000	0.020
187	0.111	0.069	0.025	0.182	0.217	0.111	0.136	0.208	0.192	0.125	0.185	0.160
189	0.000	0.000	0.000	0.000	0.022	0.000	0.023	0.000	0.019	0.000	0.000	0.000
Het obs	0.389	0.448	0.650	0.424	0.478	0.741	0.455	0.522	0.462	0.450	0.407	0.440
Het exp	0.451	0.436	0.535	0.441	0.562	0.649	0.644	0.477	0.489	0.578	0.448	0.402
One9												
N	17	29	19	33	23	26	23	24	26	19	27	24
214	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
222	0.000	0.000	0.000	0.015	0.022	0.000	0.000	0.000	0.019	0.000	0.019	0.021
226	0.000	0.017	0.000	0.000	0.000	0.000	0.022	0.000	0.000	0.000	0.000	0.000
228	0.971	0.948	0.974	0.939	0.978	0.962	0.913	1.000	0.962	1.000	0.944	0.938
230	0.000	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.021
232	0.000	0.000	0.026	0.045	0.000	0.038	0.065	0.000	0.019	0.000	0.019	0.021
Het obs	0.059	0.103	0.053	0.121	0.043	0.077	0.174	0.000	0.077	0.000	0.111	0.125
Het exp	0.059	0.101	0.053	0.117	0.043	0.075	0.165	0.000	0.076	0.000	0.109	0.122
Sfo1												
N	18	29	20	33	24	27	23	24	26	20	27	25
108	0.111	0.000	0.000	0.197	0.146	0.056	0.130	0.146	0.077	0.025	0.074	0.100
110	0.806	0.948	0.900	0.788	0.792	0.926	0.826	0.771	0.788	0.900	0.870	0.760
116	0.083	0.052	0.100	0.015	0.063	0.019	0.043	0.083	0.135	0.075	0.056	0.140
Het obs	0.278	0.103	0.200	0.364	0.333	0.148	0.348	0.348	0.385	0.200	0.259	0.320
Het exp	0.341	0.100	0.185	0.345	0.355	0.142	0.305	0.399	0.361	0.188	0.238	0.401

Table 4.–Continued.

	MI-2 & 3-FT?	MI-2 & 3-LAT	MI- 2 & 3-LT?	MI-2 & 3-SIS	MI- 4 & 5-FT?	MI- 4 & 5-LAT	MI- 4 & 5-LT?	MI-4 & 5-SIS	MI- 6 & 7-FT?	MI- 6 & 7-LAT	MI- 6 & 7-LT?	MI- 6 & 7-SIS
Ogo1c												
N	17	27	19	27	21	25	20	22	26	20	24	23
213	0.029	0.019	0.000	0.000	0.024	0.000	0.050	0.091	0.058	0.025	0.000	0.022
219	0.559	0.556	0.579	0.500	0.524	0.560	0.550	0.523	0.462	0.600	0.583	0.326
221	0.412	0.426	0.421	0.500	0.452	0.440	0.350	0.386	0.481	0.350	0.417	0.652
223	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.025	0.000	0.000
Het obs	0.059	0.074	0.105	0.259	0.286	0.080	0.200	0.238	0.154	0.550	0.083	0.043
Het exp	0.533	0.519	0.501	0.509	0.533	0.503	0.585	0.577	0.563	0.529	0.496	0.478
Ogo1a												
N	18	29	20	33	24	27	23	24	26	18	27	25
144	0.000	0.086	0.025	0.091	0.104	0.056	0.152	0.229	0.077	0.028	0.093	0.080
150	0.778	0.655	0.700	0.591	0.604	0.630	0.674	0.563	0.615	0.694	0.704	0.560
152	0.222	0.259	0.275	0.303	0.292	0.296	0.152	0.208	0.308	0.278	0.204	0.360
154	0.000	0.000	0.000	0.015	0.000	0.019	0.022	0.000	0.000	0.000	0.000	0.000
Het obs	0.333	0.379	0.350	0.636	0.542	0.519	0.609	0.652	0.500	0.611	0.407	0.600
Het exp	0.356	0.505	0.445	0.559	0.551	0.522	0.510	0.598	0.531	0.452	0.463	0.562
Sfo12												
N	17	29	19	32	20	20	18	17	25	20	26	23
254	0.000	0.138	0.079	0.094	0.075	0.125	0.028	0.118	0.080	0.025	0.077	0.130
256	0.029	0.017	0.053	0.031	0.025	0.150	0.083	0.088	0.000	0.025	0.038	0.022
258	0.941	0.828	0.868	0.875	0.900	0.675	0.889	0.765	0.920	0.950	0.885	0.848
260	0.029	0.017	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000
262	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.000
Het obs	0.118	0.310	0.263	0.250	0.100	0.500	0.222	0.500	0.160	0.100	0.231	0.261
Het exp	0.116	0.301	0.243	0.228	0.188	0.517	0.208	0.425	0.150	0.099	0.214	0.270
Ssa85												
N	18	28	20	33	24	25	23	23	26	18	27	25
126	0.056	0.089	0.100	0.015	0.021	0.060	0.000	0.022	0.096	0.028	0.056	0.020
132	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.000
134	0.639	0.571	0.700	0.697	0.583	0.600	0.609	0.652	0.654	0.639	0.444	0.660
136	0.139	0.054	0.000	0.061	0.125	0.120	0.152	0.130	0.058	0.139	0.167	0.160
138	0.167	0.286	0.200	0.227	0.271	0.220	0.239	0.196	0.173	0.194	0.333	0.140
142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020
Het obs	0.556	0.607	0.450	0.455	0.667	0.600	0.565	0.318	0.538	0.500	0.519	0.440
Het exp	0.557	0.592	0.472	0.466	0.582	0.585	0.561	0.525	0.540	0.549	0.673	0.529
C24												
N	18	29	20	33	23	27	23	24	26	20	27	25
96	0.028	0.000	0.025	0.000	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.000
102	0.278	0.241	0.250	0.258	0.196	0.259	0.304	0.271	0.365	0.275	0.352	0.300
105	0.639	0.621	0.575	0.621	0.739	0.574	0.522	0.646	0.442	0.675	0.537	0.600
111	0.056	0.138	0.150	0.121	0.065	0.167	0.174	0.063	0.192	0.050	0.111	0.100
Het obs	0.611	0.483	0.650	0.667	0.522	0.519	0.609	0.522	0.615	0.350	0.519	0.520
Het exp	0.525	0.547	0.599	0.541	0.420	0.586	0.618	0.495	0.646	0.478	0.586	0.551
D75												
N	17	27	20	33	24	27	23	21	26	20	27	25
281	0.000	0.000	0.000	0.030	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.000
285	0.029	0.074	0.125	0.015	0.042	0.019	0.065	0.000	0.019	0.050	0.019	0.020
289	0.147	0.130	0.075	0.152	0.104	0.204	0.130	0.190	0.019	0.150	0.130	0.180
293	0.147	0.130	0.075	0.076	0.083	0.185	0.174	0.048	0.115	0.050	0.130	0.020
297	0.118	0.111	0.250	0.152	0.208	0.130	0.087	0.095	0.212	0.200	0.204	0.160
301	0.206	0.167	0.175	0.091	0.146	0.111	0.239	0.167	0.096	0.125	0.130	0.200

Table 4.–Continued.

	MI-2 & 3-FT?	MI-2 & 3-LAT	MI- 2 & 3-LT?	MI-2 & 3-SIS	MI- 4 & 5-FT?	MI- 4 & 5-LAT	MI- 4 & 5-LT?	MI-4 & 5-SIS	MI- 6 & 7-FT?	MI- 6 & 7-LAT	MI- 6 & 7-LT?	MI- 6 & 7-SIS
305	0.147	0.111	0.075	0.197	0.083	0.167	0.065	0.167	0.250	0.100	0.204	0.120
309	0.059	0.037	0.075	0.152	0.125	0.074	0.130	0.167	0.038	0.075	0.074	0.080
313	0.059	0.148	0.050	0.091	0.104	0.074	0.022	0.119	0.096	0.150	0.037	0.120
317	0.088	0.000	0.025	0.015	0.042	0.037	0.000	0.024	0.077	0.000	0.000	0.060
321	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.024	0.000	0.050	0.000	0.020
325	0.000	0.019	0.050	0.030	0.021	0.000	0.022	0.000	0.019	0.025	0.037	0.000
329	0.000	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.019	0.025	0.019	0.020
333	0.000	0.037	0.000	0.000	0.000	0.000	0.022	0.000	0.019	0.000	0.000	0.000
337	0.000	0.019	0.025	0.000	0.000	0.000	0.022	0.000	0.000	0.000	0.000	0.000
341	0.000	0.000	0.000	0.000	0.021	0.000	0.022	0.000	0.000	0.000	0.000	0.000
353	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000
Het obs	0.706	0.815	0.850	0.879	0.792	0.741	0.739	0.850	0.846	0.950	0.815	0.840
Het exp	0.889	0.899	0.885	0.881	0.898	0.871	0.879	0.886	0.868	0.897	0.874	0.879
	Number of alleles sampled											
Sco19	8	7	6	9	7	8	6	6	5	6	7	6
Sfo18	3	3	4	4	7	7	5	6	6	3	4	5
One9	2	3	2	3	2	2	3	1	3	1	4	4
Sfo1	3	2	2	3	3	3	3	3	3	3	3	3
Ogo1c	3	3	2	2	3	2	4	3	3	4	2	3
Ogo1a	2	3	3	4	3	4	4	3	3	3	3	3
Sfo12	3	4	3	3	3	4	3	4	2	3	3	3
Ssa85	4	4	3	4	4	4	3	4	5	4	4	5
C24	4	3	4	3	3	3	3	4	3	3	3	3
D75	9	12	11	11	12	9	12	9	13	11	11	11

Table 5.–Standardized variance in allele frequency among lake trout parental types, leans (LAT) and siscowets (SIS), and putative hybrids (LT? and FT?), in Michigan waters of Lake Superior. Geographic areas were combined lake trout management units: MI-2 and MI-3; MI-4 and MI-5; and MI-6 and MI-7.

	MI-2 & 3-FT?	MI-2 & 3-LAT	MI-2 & 3-LT?	MI-2 & 3-SIS	MI-4 & 5-FT?	MI-4 & 5-LAT	MI-4 & 5-LT?	MI-4 & 5-SIS	MI-6 & 7-FT?	MI-6 & 7-LAT	MI-6 & 7-LT?	MI-6 & 7-SIS
MI- 2 & 3-FT?	0	-0.0043	-0.0026	-0.0046	-0.009	0.0066	-0.0036	-0.0042	0.0006	-0.0038	-0.0095	0.0047
MI- 2 & 3-LAT	-0.0043	0	-0.0094	0.0064	0.0053	-0.0042	0.0016	0.007	0.0201	-0.0063	-0.0011	0.0246
MI- 2 & 3-LT?	-0.0026	-0.0094	0	0.0092	0.0076	-0.0019	0.0042	0.0174	0.018	-0.0101	0.0088	0.0315
MI- 2 & 3-SIS	-0.0046	0.0064	0.0092	0	-0.0088	0.0093	0.0144	-0.0073	0.0024	0.0131	0.0011	0.0013
MI- 4 & 5-FT?	-0.009	0.0053	0.0076	-0.0088	0	0.0112	0.0114	-0.0087	0.0055	0.0052	-0.0026	0.0025
MI- 4 & 5-LAT	0.0066	-0.0042	-0.0019	0.0093	0.0112	0	0.0006	0.0096	0.0288	0.0005	0.0074	0.0311
MI- 4 & 5-LT?	-0.0036	0.0016	0.0042	0.0144	0.0114	0.0006	0	0.0088	0.026	-0.0007	0.005	0.0345
MI- 4 & 5-SIS	-0.0042	0.007	0.0174	-0.0073	-0.0087	0.0096	0.0088	0	0.0075	0.0162	0.0004	0.0017
MI- 6 & 7-FT?	0.0006	0.0201	0.018	0.0024	0.0055	0.0288	0.026	0.0075	0	0.0312	0.004	0.0005
MI- 6 & 7-LAT	-0.0038	-0.0063	-0.0101	0.0131	0.0052	0.0005	-0.0007	0.0162	0.0312	0	0.0095	0.0393
MI- 6 & 7-LT?	-0.0095	-0.0011	0.0088	0.0011	-0.0026	0.0074	0.005	0.0004	0.004	0.0095	0	0.017
MI- 6 & 7-SIS	0.0047	0.0246	0.0315	0.0013	0.0025	0.0311	0.0345	0.0017	0.0005	0.0393	0.017	0

Table 6.–Estimates of statistical significance of pair-wise Fst values (unadjusted) for comparisons among lake trout parental types, leans (LAT) and siscowets (SIS), and putative hybrids (LT? and FT?) from Table 5. Geographic areas were combined lake trout management units: MI-2 and MI-3; MI-4 and MI-5; and MI-6 and MI-7.

	MI- 2 & 3-LAT	MI- 2 & 3-LT?	MI- 2 & 3-SIS	MI- 4 & 5-FT?	MI- 4 & 5-LAT	MI- 4 & 5-LT?	MI- 4 & 5-SIS	MI- 6 & 7-FT?	MI- 6 & 7-LAT	MI- 6 & 7-LT?	MI- 6 & 7-SIS
MI- 2 & 3-FT?	0.23258	0.18864	0.27273	0.77424	0.25303	0.35682	0.38485	0.24318	0.71742	0.63106	0.47045
MI- 2 & 3-LAT		0.52273	0.00303	0.00985	0.0303	0.05758	0.01364	0.0053	0.87955	0.09924	0.00303
MI- 2 & 3-LT?			0.00152	0.01818	0.36364	0.0053	0.00076	0.00379	0.53561	0.03106	0.00152
MI- 2 & 3-SIS				0.55000	0.10833	0.00076	0.40758	0.08258	0.04091	0.88106	0.19015
MI- 4 & 5-FT?					0.19015	0.00303	0.85909	0.70606	0.52727	0.79545	0.82273
MI- 4 & 5-LAT						0.01667	0.00833	0.00076	0.19242	0.10227	0.0053
MI- 4 & 5-LT?							0.01818	0.00152	0.40303	0.05682	0.00076
MI- 4 & 5-SIS								0.28636	0.37273	0.51439	0.93636
MI- 6 & 7-FT?									0.02879	0.53182	0.81364
MI- 6 & 7-LAT										0.39773	0.03409
MI- 6 & 7-LT?											0.15227

Table 7.–Standardized variance in allele frequency using only parental lake trout phenotypes, leans (LAT) and siscowets (SIS), in Michigan waters of Lake Superior. Geographic areas were combined lake trout management units: MI-2 and MI-3; MI-4 and MI-5; and MI-6 and MI-7.

	MI-2 & 3 LAT	MI-2 & 3 SIS	MI-4 & 5 LAT	MI-4 & 5 SIS	MI-6 & 7 LAT	MI-6 & 7 SIS
MI-2 & 3-LAT	0	0.0064	-0.0042	0.007	-0.0063	0.0246
MI-2 & 3-SIS	0.0064	0	0.0093	-0.0073	0.0131	0.0013
MI-4 & 5-LAT	-0.0042	0.0093	0	0.0096	0.0005	0.0311
MI-4 & 5-SIS	0.007	-0.0073	0.0096	0	0.0162	0.0017
MI-6 & 7-LAT	-0.0063	0.0131	0.0005	0.0162	0	0.0393
MI-6 & 7-SIS	0.0246	0.0013	0.0311	0.0017	0.0393	0

Table 8.–Probability values (uncorrected) associated with pair-wise population estimates for parental phenotype lean (LAT) and siscowet (SIS) lake trout in Michigan waters of Lake Superior. Geographic areas were combined lake trout management units: MI-2 and MI-3; MI-4 and MI-5; and MI-6 and MI-7.

	MI-2 & 3-SIS	MI-4 & 5-LAT	MI-4 & 5-SIS	MI-6 & 7-LAT	MI-6 & 7-SIS
MI-2 & 3-LAT	0.00333	0.04333	0.00667	0.81667	0.00333
MI-2 & 3-SIS		0.11000	0.65667	0.03000	0.34667
MI-4 & 5-LAT			0.00667	0.19333	0.00333
MI-4 & 5-SIS				0.24000	0.74667
MI-6 & 7-LAT					0.01000

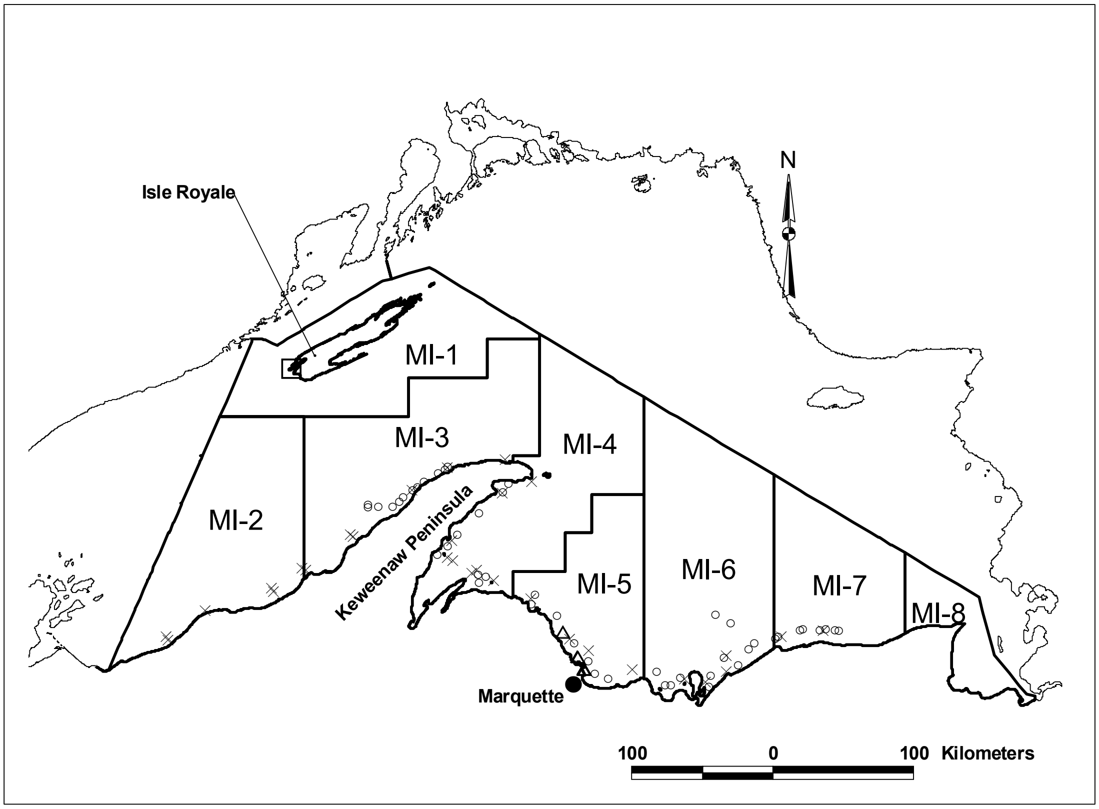

Figure 1.–Lake trout management units and lake trout survey sampling stations in Michigan waters of Lake Superior from October 2003 through August 2004. Open circles represent spring survey stations, Xs represent summer pre-recruit survey stations, open triangles represent fall spawning survey stations, and open square represents Isle Royale survey stations.

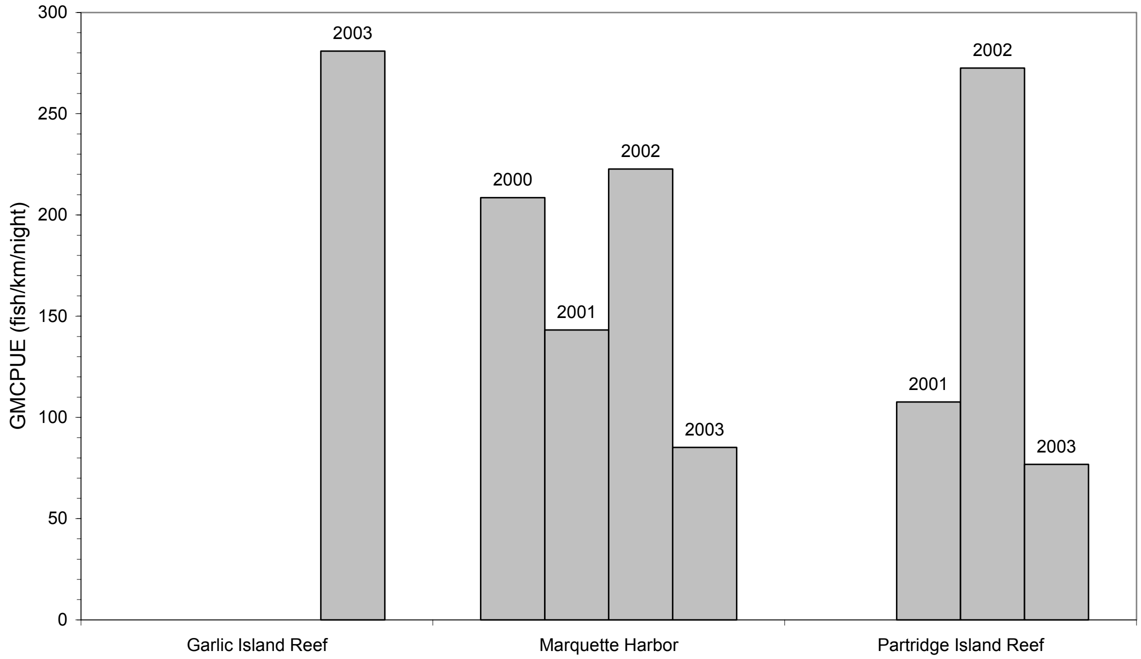

Figure 2.–Relative abundance of lean lake trout sampled during fall spawning surveys from 2000 to 2003 in the Marquette area (MI-5) of Michigan waters of Lake Superior. The graphs are presented with vertical bars in chronological order from left to right for each spawning area and the year indicated at the top of each bar. Relative abundance index based on the Geometric Mean Catch-Per-Unit-Effort (GMCPUE) expressed as the number of fish per km of net per night based on graded-mesh bottom gill nets (stretched mesh sizes: 11.4, 12.7, 13.0, 15.2 cm).

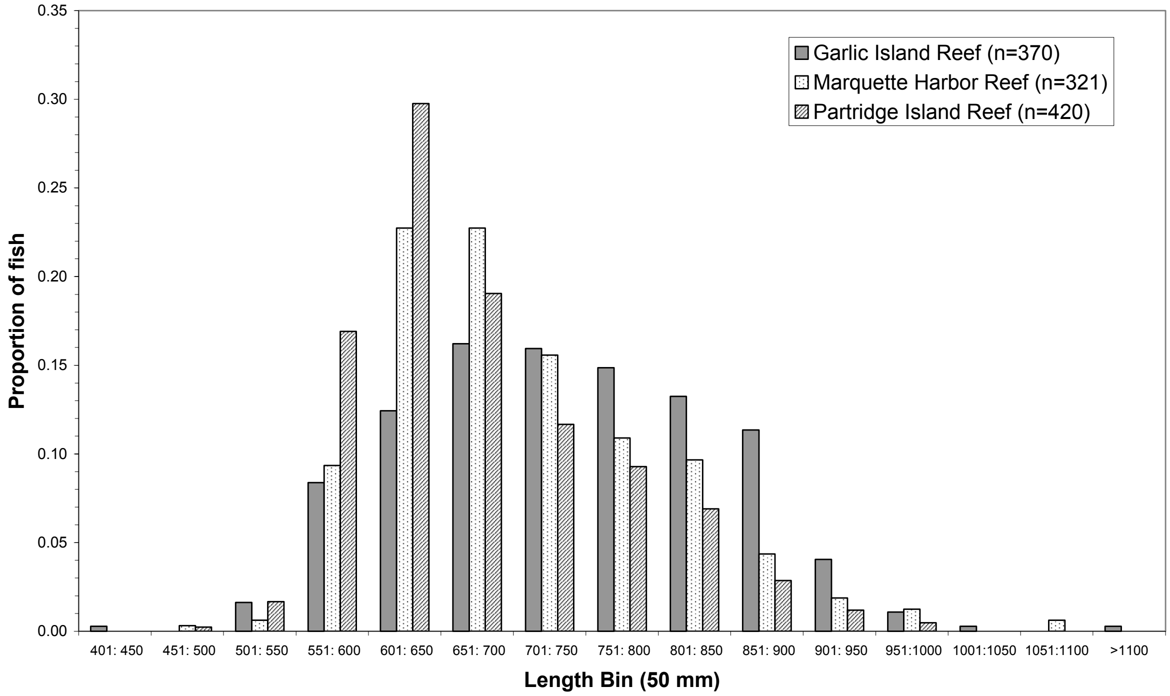

Figure 3.–Length distributions of lean lake trout sampled at three spawning areas in the Marquette area of Lake Superior during the fall of 2003.

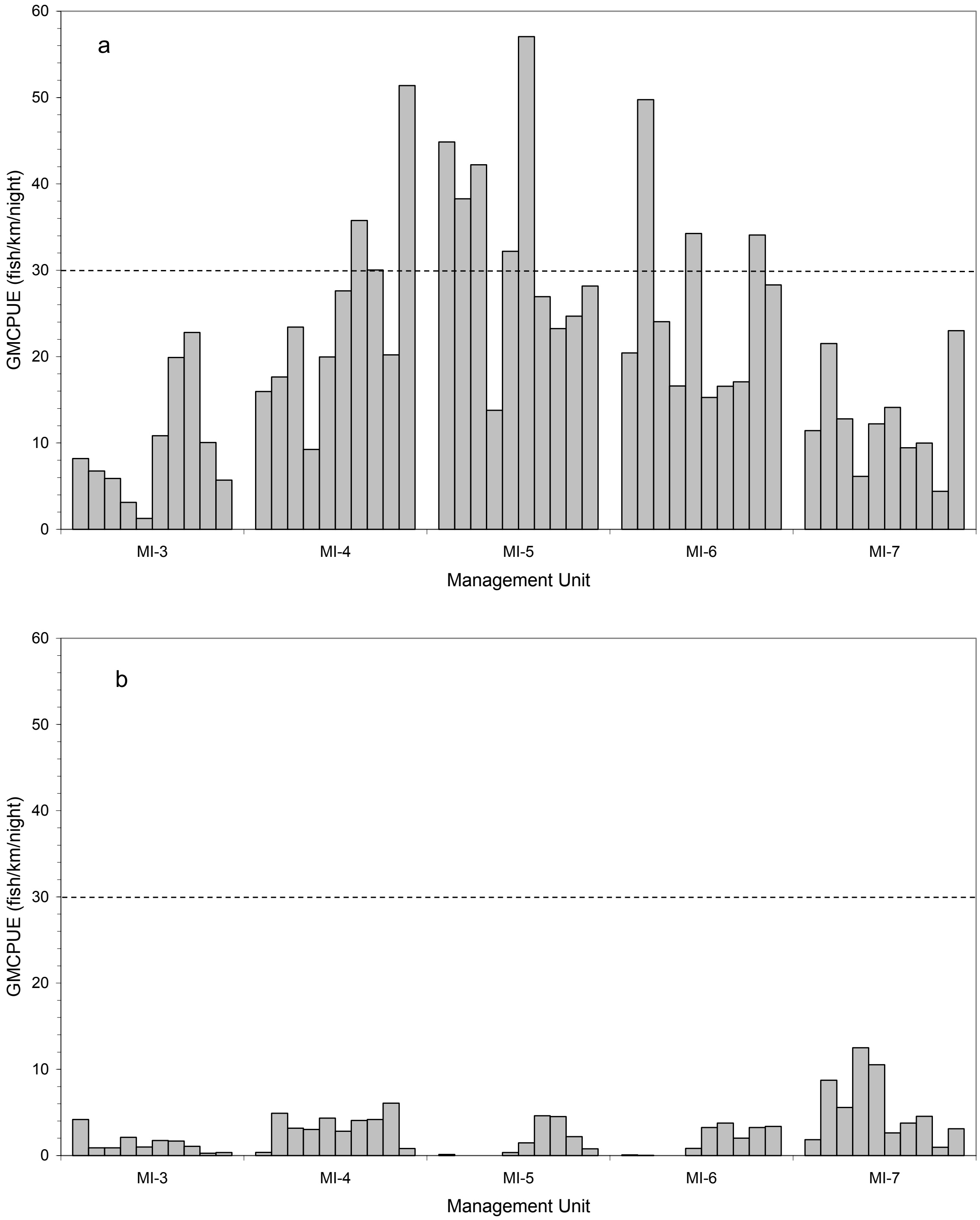

Figure 4.–Relative abundance of (a) lean and (b) siscowet lake trout sampled in spring surveys from 1995 to 2004 in Michigan waters of Lake Superior. The graphs are presented with vertical bars in chronological order from left to right for each management unit. Horizontal dashed line is a reference line (30 fish/km/night) for comparing the two graphs. Relative abundance index based on the Geometric Mean Catch-Per-Unit-Effort (GMCPUE) expressed as the number of fish per km of net per net night based on 11.4 cm stretched-mesh bottom gill nets.

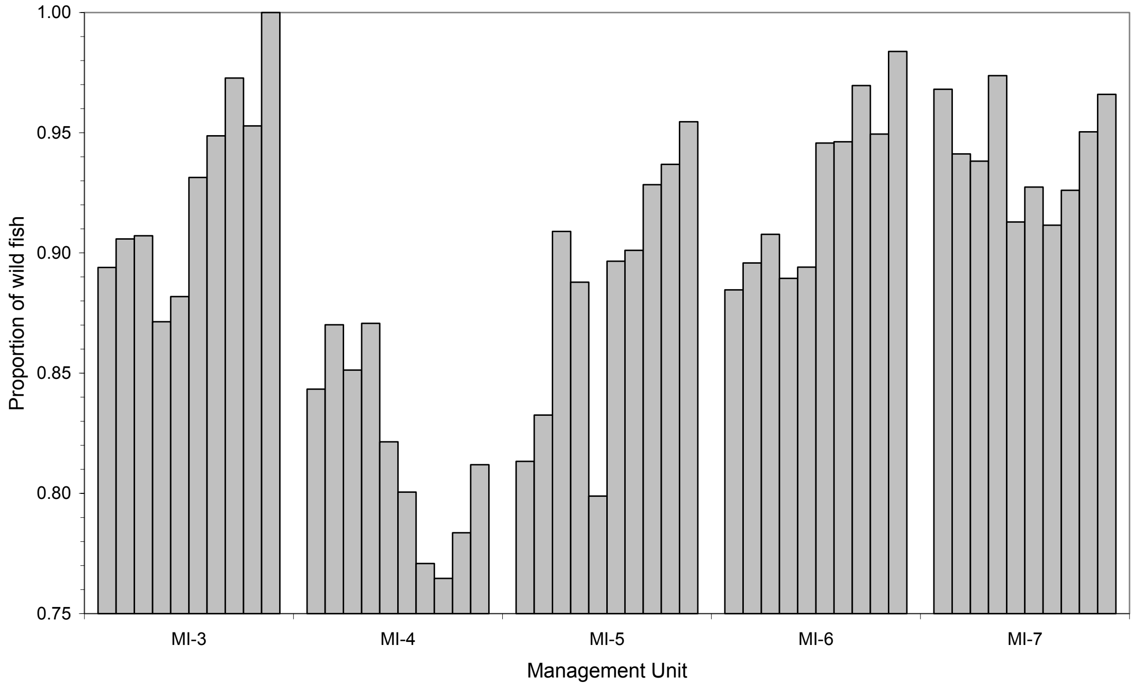

Figure 5.–Proportion of wild lean lake trout collected in annual spring lake trout surveys from 1995 to 2004 in Michigan waters of Lake Superior. The graph is presented with vertical bars in chronological order from left to right for each management unit.

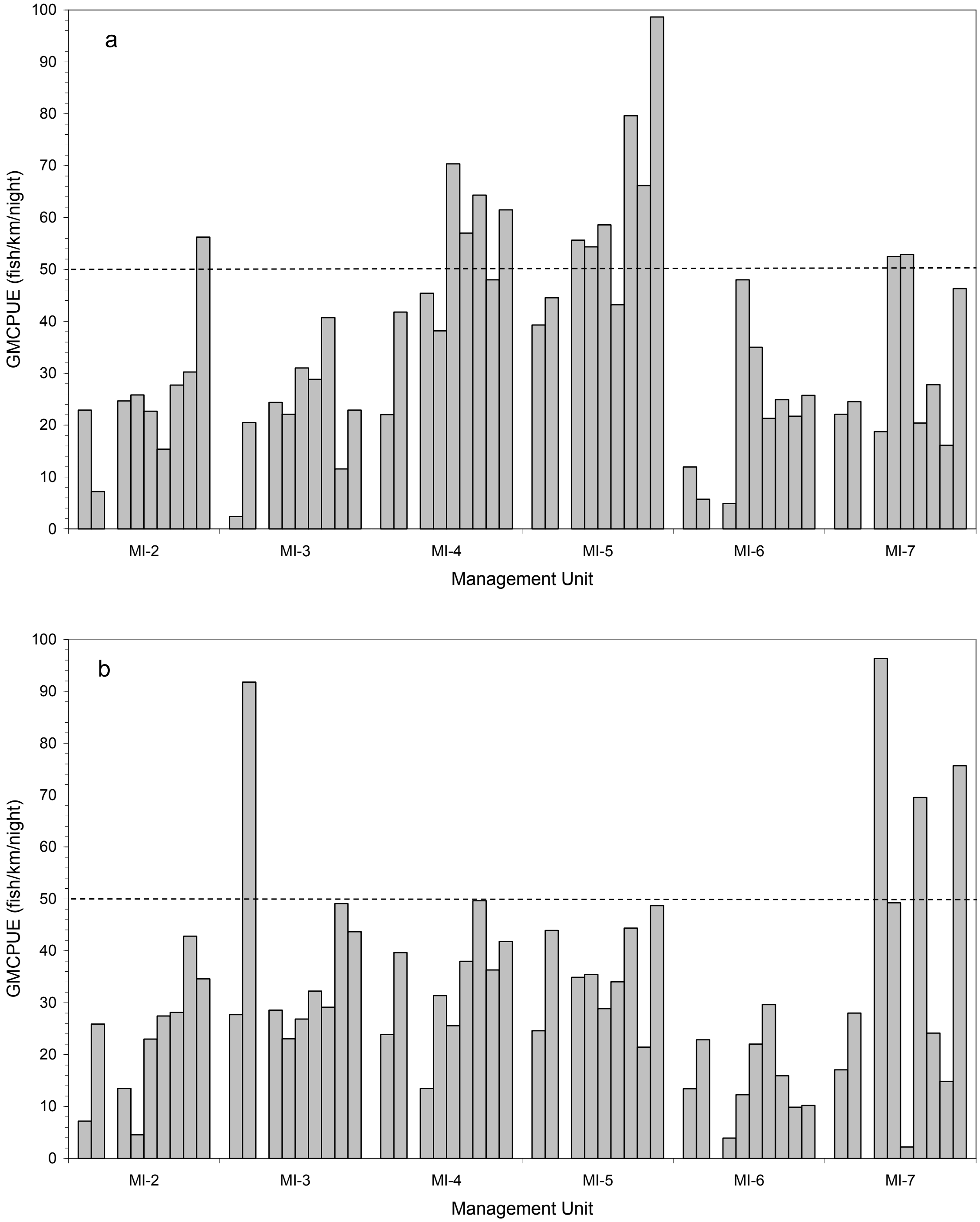

Figure 6.–Relative abundance of (a) lean and (b) siscowet lake trout sampled in summer pre-recruit surveys from 1994 to 2003 or 1995-2004? in Michigan waters of Lake Superior. The graphs are presented with vertical bars in chronological order from left to right for each management unit. Horizontal dashed line is a reference line (50 fish/km/night) for comparing the two graphs. Relative abundance index based on the Geometric Mean Catch-Per-Unit-Effort (GMCPUE) expressed as the number of fish per km of net per net night based on graded-mesh bottom gill nets (stretched mesh sizes: 5.1, 5.7, 6.4, 7.0, 7.6, 8.9 cm). No pre-recruit survey was conducted in 1997 1996? as indicated by gaps for each management unit in the figure.

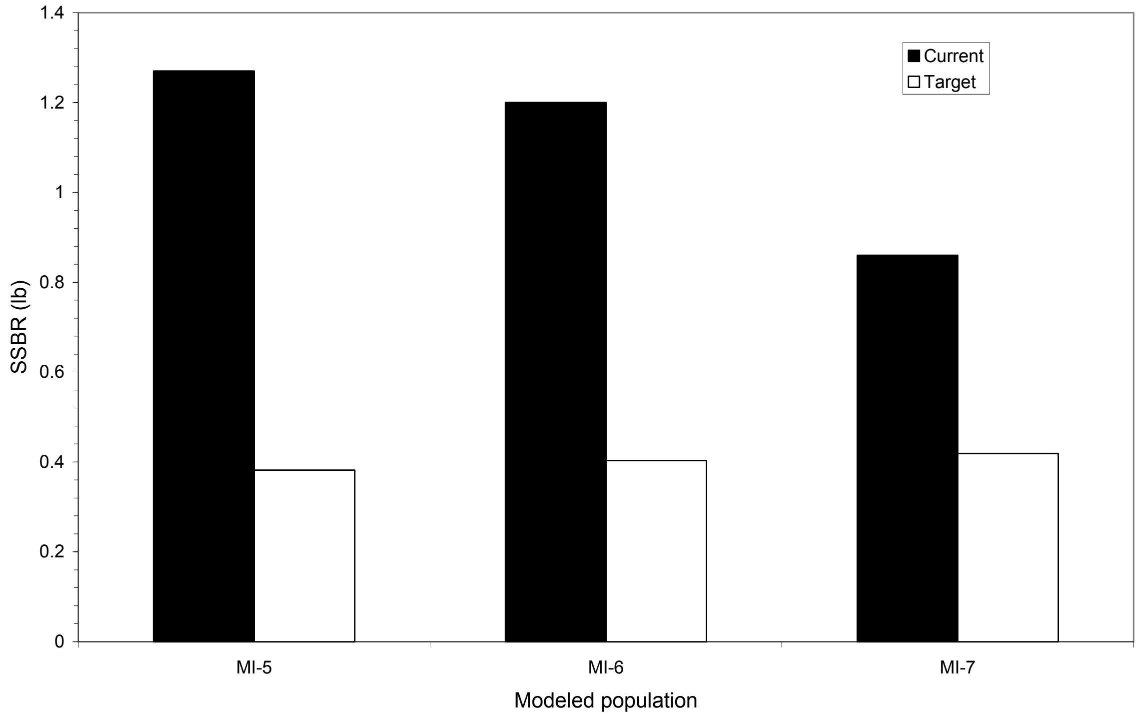

Figure 7.–Spawning Stock Biomass produced per Recruit (SSBR) values for wild lake populations in MI-5, MI-6, and MI-7 based on results from statistical catch-at-age models. The target minimum SSBR value was based on the Great Lakes Fishery Commission target maximum total annual mortality rate of 45%.

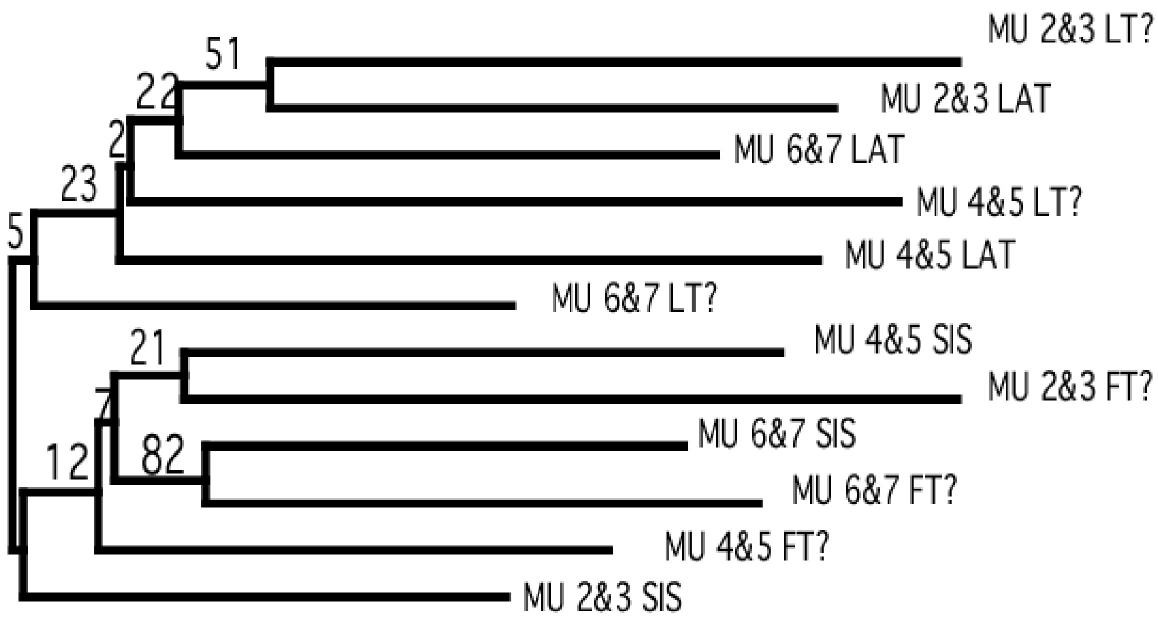

Figure 8.–Genetic affinities Cavalli-Sforza and Edwards chord distance for four defined lake trout phenotypes from Michigan waters of Lake Superior. Phenotypes were parental lean lake trout (LAT), parental siscowet lake trout (SIS), lean-dominant putative hybrid (LT?), and siscowet-dominant putative (FT?).