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Assessment of Lake Trout Stocks in Michigan Waters of Lake Superior, 1998-2007

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Abstract.–Lake Trout *Salvelinus namaycush* is the dominant predator in Lake Superior and occupies nearly all depths in the lake. Management of Lake Trout populations is a major focus of most agencies on Lake Superior because it is important economically and socially. The two major morphotypes are the shallow water lean Lake Trout and the deepwater siscowet Lake Trout. Population dynamics statistics for lean and siscowet Lake Trout populations in management units from MI-2 in western Lake Superior waters to MI-7 in the east are reported based on Michigan Department of Natural Resources gill-net surveys conducted during 1998–2007. All populations of lean Lake Trout in MI-2 to MI-7 are wild, and hatchery fish comprised an insignificant portion of these stocks. Lean Lake Trout were more abundant east of the Keweenaw Peninsula and these populations generally increased slightly between 1998 and 2007. Lean Lake Trout populations west of the Keweenaw Peninsula were lower in abundance, though they increased slightly in MI-3 toward the end of the time period. Sea Lamprey *Petromyzon marinus* predation was the dominant source of mortality on all Lake Trout populations and increased over time in MI-4 and east. Commercial yield of lean Lake Trout was highest in MI-4, MI-5, and MI-7 with average annual landings above 10,000 kg in each unit during 1998–2007. Average annual recreational harvest of lean Lake Trout was highest in MI-5 (9,800 fish/year) and MI-6 (4,200 fish/year), and has declined in MI-5 and east in recent years. The diet of lean Lake Trout smaller than 600 mm consisted mostly of Rainbow Smelt *Osmerus mordax*, sculpins *Cottus cognatus, Myoxocephalus thompsoni*, sticklebacks *Gasterosteus aculeatus, Pungitius pungitius*, and aquatic macroinvertebrates *Diporeia* and *Mysis*. The diet of lean Lake Trout 600 mm and larger was dominated by Rainbow Smelt, coregonines *Coregonus* spp, and Burbot *Lota lota*. Fall lean Lake Trout surveys, conducted only in MI-5, indicate healthy spawning stocks with broad size and age distributions. Generally, growth of lean Lake Trout in Michigan management units has declined over the past 30 years and during 1998–2007 has either declined further or remained low. Lean Lake Trout female length at 50% maturity (L_{50}) ranged from 592 mm in MI-7 to 703 mm in MI-3. Lean male L_{50} ranged from 515 mm in MI-7 to 600 mm in MI-6. Lean Lake Trout populations west of the Keweenaw Peninsula are still in population recovery status and mortality rates need to be controlled. Siscowet Lake Trout were abundant in all areas in waters deeper than 37 m. Commercial landings of siscowet were only significant in MI-4 and MI-7 and averaged less than 8,200 kg/year for both units. Siscowet Lake Trout were only recreationally harvested in significant numbers in MI-4 (3,100 fish/year) and MI-7 (1,200 fish/year). The diet of siscowet Lake Trout smaller than 600 mm in shallow water comprised aquatic macroinvertebrates, sculpins, coregonines, and Burbot. Siscowet Lake Trout 600 mm and larger in shallow water mainly consumed Burbot and coregonines. In deep water (≥80 m), the diet of small siscowet Lake Trout comprised coregonines, sculpins, and insects. Large siscowet Lake Trout in deep water mainly consumed coregonines, sculpins, and Burbot. Siscowet female L_{50} ranged from 560 mm in MI-7 to 628 mm in MI-4. Siscowet Lake Trout male L_{50} ranged from 504 mm in MI-7 to 599 mm in MI-3. Siscowet Lake Trout populations in MI-2 through MI-7 are abundant, especially in deep waters and are generally healthy. Recommendations for future research include: expand existing

surveys of siscowet Lake Trout in deep water; conduct surveys to measure population dynamics of offshore lean and humper Lake Trout; find and describe siscowet Lake Trout spawning sites; map and quantify lean Lake Trout spawning reefs; and conduct surveys to measure age 0 or age 1 lean Lake Trout recruitment. It is also recommended that a Lake Superior Lake Trout management plan be developed and implemented for Michigan.

Introduction

Lake Trout *Salvelinus namaycush* is the keystone predator in Lake Superior, and there are three major forms[1]: the lean, the siscowet, and the humper (Eschmeyer and Phillips 1965; Lawrie and Rahrer 1973; Burnham-Curtis and Smith 1994). Lean Lake Trout are found generally in waters less than 100 m deep and exist in all of the Great Lakes. Siscowet Lake Trout are a deepwater form abundant at depths greater than 100 m, though they are commonly found in shallower waters (Bronte et al. 2003). The humper is an uncommon form of Lake Trout and derives its name from its habitat, which are offshore sea mount-like structures (humps) (Burnham-Curtis and Bronte 1996). Intense commercial fishing and predation by Sea Lampreys *Petromyzon marinus* caused the collapse of lean Lake Trout populations in the 1950s and caused major declines in siscowet populations starting in the mid-1940s (Hansen et al. 1995; Hansen 1999; Bronte and Sitar 2008). Subsequent recovery efforts have been successful in Michigan waters and self-sustaining lean Lake Trout populations approached historical levels in the 1990s (Wilberg et al. 2003). Siscowet relative abundance data are limited, and it is considered that siscowet populations have a similar status as lean Lake Trout (Bronte et al. 2003; Bronte and Sitar 2008). Although some descriptive biology has been published on humpers (Burnham-Curtis and Smith 1994; Burnham-Curtis and Bronte 1996; Moore and Bronte 2001), little is known about the status of humper populations, which have not been surveyed since the 1970s (Patriarche and Peck 1970; Michigan Department of Natural Resources, unpublished data). The current lakewide management goal for Lake Superior Lake Trout was established by a multi-agency committee and is to maintain genetically diversified, wild-producing populations of lean Lake Trout in near shore waters, siscowet Lake Trout in offshore waters, and humpers around Isle Royale and eastern offshore reefs that are similar to those prior to the 1940s (Horns et al. 2003).

Nearly all Lake Trout research and management in Lake Superior has focused on the lean form because they are preferred in fisheries. The descriptive biology of the lean form of Lake Trout is comprehensive and extensive (e.g., Martin and Olver 1980). Furthermore, long-term survey data monitoring Lake Trout population dynamics are also plentiful. Relative abundance indices for lean Lake Trout extend back to 1929 for Michigan waters of Lake Superior (Wilberg et al. 2003) and provide the fundamental inputs for quantitative stock assessments such as the development of statistical catch-at-age models that provide time-series estimates of mortality and abundance, which helped develop contemporary harvest quotas (e.g., Modeling Subcommittee, Technical Fisheries Committee 2009). Relative abundance indices and age compositions from survey data are used in age-structured models to estimate mortality rates, recruitment, and abundance (e.g., Modeling Subcommittee, Technical Fisheries Committee 2009). Furthermore, biological information from survey-caught Lake Trout is used to assess temporal and spatial trends in Sea Lamprey wounding rates, growth, diet, and maturation. In Lake Superior, the Marquette Fisheries Research Station (MFRS) routinely conducts three bottom gill-net surveys targeting lean Lake Trout and one survey for siscowet Lake Trout (Table 1). All surveys follow a fixed station design where sites are systematically sampled at various intervals (annually for spring and summer surveys; every 3 years for the siscowet Lake Trout survey; and periodically for fall surveys). The purpose of the spring Lake Trout survey was to index adult Lake Trout while they are aggregated and demersal during isothermal conditions. The summer survey was targeted at juvenile or

1 During the time this document was in the publication process, a fourth form, redfin, was documented (Muir et al. 2014).

prerecruit lean Lake Trout, which generally remain demersal after thermal stratification, while most adults become pelagic. The fall survey targeted spawning-condition lean Lake Trout near reefs to index the spawning stock and to support ongoing mark-recapture studies. The siscowet survey was conducted in all depth zones in MI-5 (2000, 2003, and 2006) and MI-6 (2003 and 2006), and provided relative abundance, growth, Sea Lamprey wounding rates, age structure, and diet composition data. In contrast, much basic descriptive biology of siscowet Lake Trout is still lacking (e.g., siscowet spawning sites have not been documented). Moreover, little has been known about siscowet population trends until the last 10 years. Limited modeling and time-series analyses of siscowet commercial catch-per-unit-effort data have provided some historic perspective on siscowet abundance (Ebener 1995; Bronte and Sitar 2008). Most data on siscowet Lake Trout have been collected from indirect sampling in lean Lake Trout surveys. However, concerted efforts since 1997 have been devoted to sampling siscowet Lake Trout in their principal habitat and have included a standardized, lakewide siscowet survey (e.g., Sitar et al. 2008).

Table 1.–Specifications of Lake Trout bottom gill-net surveys conducted in Lake Superior by the Michigan Department of Natural Resources (MIDNR) during 1998 to 2007. All gill nets were made of nylon, multifilament mesh material. The spring survey in MI-7 was conducted by the Chippewa/Ottawa Resource Authority in coordination with MIDNR.

	Survey			
Survey attributes	Spring	Summer	Fall	Siscowet
Management unit sampled	MI-3, MI-4, MI-5, MI-6, MI-7	MI-2, MI-3, MI-4, MI-5, MI-6, MI-7	MI-5	MI-5, MI-6
Sampling dates	3rd week in Apr to 1st week of Jun	End of Jul to 1st week of Sep	2nd week in Oct through 3rd week in Nov	Jun–Jul
Years conducted	1998–2007	1998–2007	2000–2004, 2006, 2007	2000, 2003, 2006
Gill net mesh (stretched cm)	11.4	5.1, 5.7, 6.4, 7.0, 7.6, 8.9	11.4, 12.7, 14.0, 15.2	5.1, 6.4, 7.6, 8.9, 10.2, 11.4, 12.7, 14.0, 15.2
Net dimensions (m) (length x height)	457.2 x 1.8	549 x 1.8	366 x 1.8	823 x 1.8
Hours fished	20–70	20	20	20
Bottom depth range (m)	24–90	24–90	5–24	30–399

In Lake Superior, Lake Trout stocks are managed at the management unit level (Hansen 1996). All Michigan waters of Lake Superior are contained within treaty territories defined in either the 1842 Treaty of La Pointe or the 1836 Treaty of Washington. The 1842 Treaty territory includes MI-1, MI-2, MI-3, MI-4, and the western half of MI-5. The 1836 Treaty territory encompasses the east half of MI-5 as well as MI-6, MI-7, and MI-8 (Figure 1). Consent decrees covering fishing stipulations in waters covered by the 1836 Treaty of Washington were issued in 1985 and again in 2000, with requirements for estimating Lake Trout quotas based on Lake Trout recovery plan reference points. Lake Whitefish *Coregonus clupeaformis* and Lake Trout fishery allocations between Native American tribes and the State of Michigan center on the status of Lake Trout populations and have essentially resulted in mandated comanagement via court orders in eastern Lake Superior (U.S. v. Michigan. 2000; Ebener et al. 2005). Currently, there are no consent decree agreements or specifications for comanagement of fish stocks in 1842 Treaty waters of Lake Superior.

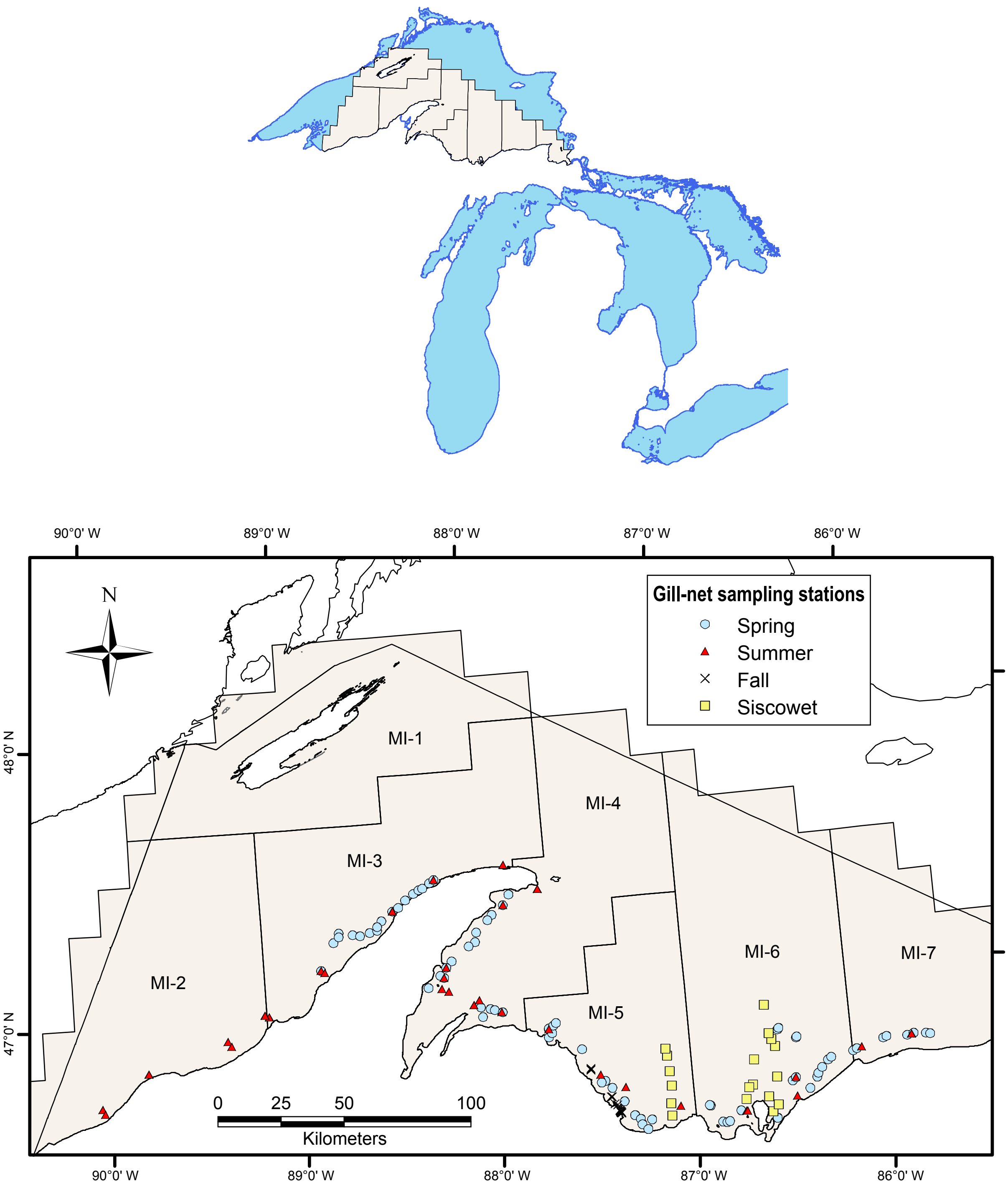

Figure 1.–Lake Trout management units and Michigan Department of Natural Resources gill-net sampling stations in Michigan waters of Lake Superior, between 1998 and 2007.

Commercial fishery harvest of lean Lake Trout is mostly considered as bycatch in commercial Lake Whitefish gill-net fisheries. However, the amount of Lake Trout harvested is significant enough to warrant careful regulation (Johnson et al. 2004). State of Michigan licensed commercial fishers are not permitted to retain Lake Trout, whereas tribal commercial fishers retain Lake Trout under a quota system. There is also occasional tribal subsistence harvest of Lake Trout. Generally, there has been little interest in harvest of siscowet Lake Trout due to its high fat content and low palatability (Bronte and Sitar 2008). However, there were short-term commercial fisheries for siscowet Lake Trout during the 1960s and again in the 1980s in offshore Michigan waters that supported some limited markets (Patriarche and Peck 1970; S. Sitar, Michigan Department of Natural Resources, unpublished data). More recently, there has been interest in extracting omega-3 oils from siscowet Lake Trout to make supplement pills for humans (R. Kinnunen, Michigan Sea Grant Extension, personal communication).

Lean Lake Trout are the most harvested sport fish in Lake Superior (Ebener and Schreiner 2007) and produce some of the highest Lake Trout catch rates in the Great Lakes. The majority of recreational Lake Trout harvest comes from anglers with personal vessels. There are a few professional charter fishing operators in Michigan waters of Lake Superior, and their catch rates of Lake Trout are much higher than those of noncharter anglers. Most anglers fish for Lake Trout in small vessels at depths ranging from a few meters to 90 meters by trolling with downriggers (Loftus et al. 1988) and drift-angling, known locally as bobbing. Some siscowet Lake Trout are harvested in the recreational fishery, but are incidental to targeting of lean Lake Trout.

The objectives of this report are to detail key population ecology variables, continuing the series of Michigan Department of Natural Resources (MIDNR) reports that assess the status of lean and siscowet Lake Trout populations in Michigan waters of Lake Superior (i.e., Peck and Schorfhaar 1991; Peck and Schorfhaar 1994; Peck and Sitar 2000), and to relate the population status to the fish community objective for Lake Trout (Horns et al. 2003). Specifically, lean and siscowet relative abundance, age and length compositions, Sea Lamprey wounding rates, fishery harvest, growth, body condition, maturity, sex ratios, and diet compositions from MIDNR surveys conducted from 1998 to 2007 are reported. During this report period, humpers were not sampled.

Methods

Most of the fishery-independent Lake Trout surveys were conducted in MI-2 through MI-7 by MFRS staff aboard the Research Vessel (R/V) *Judy* during 1998–2006 and aboard the R/V *Lake Char* in 2007. The Chippewa/Ottawa Resource Authority (CORA) conducted the spring lean survey in M-7 and provided all relevant data to MFRS. Under the direction of MFRS, four cooperator commercial fishers with gill-net boats were used to conduct spring surveys in MI-3, MI-5, and MI-6 in some years. Spring surveys were conducted in MI-3 through MI-7; summer surveys were conducted in MI-2 through MI-7; fall surveys were conducted at three spawning sites in MI-5 near Marquette; and siscowet surveys were conducted in MI-5 and MI-6 (Figure 1; Table 1). In general, the fall survey sampling stations were sampled multiple weeks during the spawning season (second week in October through the third week in November). Management units MI-1 and MI-8 are not reported because no surveys in MI-1 were conducted during 1998–2007 and Bay Mills Indian Community and CORA personnel actively survey and manage Lake Trout in MI-8.

Biological information was recorded from most Lake Trout and other fishes captured in gill-net surveys. Total length, weight, Sea Lamprey wounding, sex, stage of maturity, origin (examined for hatchery fin clip) were recorded from sampled fish. Maturity was based on visual examination of the gonads, classifying the reproductive state as mature or immature. A mature fish was defined as a fish that was judged likely to reproduce in the year of collection or that exhibited physical indications of prior reproduction. Mature fish also include skip spawners, which are fish that will not reproduce the year sampled, but exhibited indications of prior reproduction. An immature fish was one that exhibited no gonadal indications that it will reproduce in the year sampled or had previously reproduced.

Among all surveys, only otoliths were collected from siscowet Lake Trout for age determinations because siscowet Lake Trout are slow-growing and scales would underestimate ages. During 1998 to 2003 in spring surveys, 1998 to 2007 in summer surveys, and in 2000 and 2003 in siscowet surveys, scales were collected from lean Lake Trout smaller than 584 mm and otoliths were collected from larger fish for age determinations. After 2003, otoliths were collected from all lean Lake Trout in spring and siscowet surveys. In fall surveys, otoliths were collected from all lean Lake Trout that were not released. In spring 1998–2007 and summer 2002 to 2007 surveys, Lake Trout ages were determined from a stratified, random subsample of 20 Lake Trout per 25-mm length group from all fish collected.

For the years where fish were subsampled for age determinations, length-age matrices were constructed for each year and management unit to convert the survey length composition to age composition (described in Sitar 2010). First, the catch per unit effort (CPUE)-at-age at each station within a management unit and year was calculated by:

$$CPUE_{m,s,y,a} = L_{s,y} * K_{m,y,} \qquad (1)$$

where $L_{s,y,a}$ was a vector of the catch per 25 mm length group at a sampling station *s* in management unit *m* and year *y* and K was the age-length matrix developed for management unit *m* and year *y* based on the subset of fish that were assessed for age.

Then the overall proportion at age for a management unit and year (P) was calculated by summing CPUE-at-age across stations within a management unit and dividing by the overall CPUE for that unit:

$$P_{m,y,a} = (\sum_a CPUE_{m,s,y,a})/CPUE_{m,y.} \qquad (2)$$

This approach weighted each age class by its overall relative abundance in the survey catch and minimized the bias from systematic errors associated with only determining ages from a stratified, random subset of ages, which tends to over-represent less common ages (very young and very old) in determining the actual overall age composition (Sitar 2010). Prior to 2002 in summer surveys and in all years of the siscowet survey, age was determined for all Lake Trout collected, therefore survey age compositions were calculated as the overall proportions at age. Ages were not determined for the fall survey Lake Trout due to staff time limitations. Siscowet Lake Trout age data from spring surveys are not included because few samples were collected.

Ages were assessed from sagittal otoliths collected from Lake Trout. Sanded otoliths were soaked in mineral oil and annuli were enumerated visually using a compound scope with reflected light. From 1998 and later, age determinations were aided with a digital camera and computer image analysis system using the Hierarchical Discrete Correlation/Wallis Filter tool within the Optimas image analysis software (Optimas 6.5, Media Cybernetics 1999). Final age determinations were based on a single reading.

Sea lamprey wounding on Lake Trout was quantified following the classification system reported by King (1980), where Type A wounds were defined as those penetrating the musculature, and Type B wounds were those penetrating only through the scales and skin of the fish. Each wound type has four stages of healing with stage 1 being recent attacks and no healing, while stage 4 wounds are completely or nearly healed wounds. Wounding rates on fish caught in spring surveys were indexed as the total number of Type A (stages 1 through 3) wounds per 100 fish (Eshenroder and Koonce 1984) and were reported for standard groups by length: <432, 432–533, 534–635, 636–737, and >737 mm (Sitar et al. 1999). Sea Lampreys prefer larger hosts (e.g., Swink 1991) and infrequently attack Lake Trout smaller than 534 mm. Therefore, temporal trends in Sea Lamprey wounding rates were indexed for fish larger than 533 mm. Annual wounding rates were calculated for each length group for which sample sizes were 10 or more fish.

Diet compositions of lean and siscowet Lake Trout were determined from analysis of stomachs that were extracted from a length-stratified, random subsample of fish collected during the spring and summer surveys and from all fish in siscowet surveys. In the spring and summer surveys, approximately 100 lean and 100 siscowet stomach samples from each management unit were extracted and frozen for subsequent laboratory analyses. Based on the most common prey observed in Lake Trout stomachs (Table 2), diet items were grouped into nine prey categories: aquatic macroinvertebrates (AMI), insects (INS), Rainbow Smelt (SMT), sculpins (SCL), sticklebacks (STK), Burbot (BUR), coregonines (COR), salmonines (SAL), and unidentifiable fish remains (UFR). In addition, other uncommon prey items were grouped into the other (OTH) category (Table 2).

During 1998–2004, spring diet data were recorded as numerical frequencies of prey items. For prey fish that were not too digested, total lengths were also measured. From 2005 to 2007 in the spring survey and for all years of summer lean and siscowet Lake Trout surveys, diet data were based on wet weight measurements of prey items. Numerical frequency diet data can be biased in that it can overemphasize the importance of small prey (Hyslop 1980). Furthermore, the different prey items of Lake Trout vary widely in size and energetic value (e.g., Burbot vs. stickleback) and numerical frequency can be misleading in prey energetic importance, therefore diet data that were only measured as numerical frequencies were converted to biomass to standardize comparisons across years.

Diet data that were measured only as numerical frequencies were converted to biomass by multiplying the number of prey by a reference individual mean weight of that prey type (Table 2). The reference individual mean weight of a particular prey species was simply an overall average weight of that prey item from spring Lake Trout survey data collected during 2005–2007. For prey fishes were measured for length, the prey biomass (W) was estimated from a basic weight-length model:

$$W = \propto L^{\beta}, \tag{3}$$

where $\propto$ and β were coefficients, and L was length of prey item. Prey fish length-weight relationships were developed from data collected in prey fish surveys conducted during 1998–2007 (D. Yule, U.S. Geological Survey, unpublished data).

Overall diet composition for wild lean Lake Trout, siscowet Lake Trout, and hatchery lean Lake Trout was summarized as proportional biomass by management unit and length class (200 mm intervals). No temporal trends in diet compositions were detected in preliminary results and there were insufficient data to evaluate diets by season. Therefore, diet compositions reported in this paper were based on pooling spring and summer Lake Trout survey data. Siscowet Lake Trout survey diet data were pooled across years and reported separately.

Relative abundance of Lake Trout (CPUE) was indexed as the number of fish caught per kilometer of net-per-night fished at each sampling station. All gill-net surveys were based on a fixed station design, where gill-net stations were repeatedly sampled on an annual basis. Although this type of survey may be prone to systematic bias because it is nonrandom, there was broad spatial coverage of sampling stations within a management unit that lessened the bias of overemphasizing high and low Lake Trout density sites. In most years sampled, spring survey nets were set for multiple nights therefore CPUEs needed to be adjusted for net saturation using the function developed by Hansen et al. (1998), which was based on a study that measured the Lake Trout catch in MFRS spring gill-net surveys fished from one to five nights.

Table 2.–Lake Trout prey item length-weight parameters and reference mean weights used to convert diet items from numerical frequencies to biomass (in g). Length-weight parameters provided by U.S. Geological Survey.

Prey grouping	Prey item	α	β	Mean weight
OTH	Alewife (*Alosa pseudoharengus*)	6.170×10^{-06}	3.090	
RBS	Rainbow Smelt (*Osmerus mordax*)	6.290×10^{-07}	3.422	
BUR	Burbot (*Lota lota*)	1.460×10^{-06}	3.239	
STK	Threespine Stickleback (*Gasterosteus aculeatus*)	1.780×10^{-06}	3.332	
STK	Ninespine Stickleback (*Pungitius pungitius*)	1.780×10^{-06}	3.332	
OTH	Trout-perch (*Percopsis omiscomaycus*)	2.300×10^{-06}	3.296	
STK	Stickleback (general)	$1.780 \times 10\text{-}^{06}$	3.332	
COR	Lake herring/Cisco (*Coregonus artedi*)	3.990×10^{-06}	3.091	
COR	Lake Whitefish (*Coregonus clupeaformis*)	1.140×10^{-06}	3.329	
COR	Bloater (*Coregonus hoyi*)	7.740×10^{-06}	2.972	
COR	Kiyi (*Coregonus kiyi*)	5.330×10^{-06}	3.031	
COR	Round Whitefish (*Prosopium cylindraceum*)	4.000×10^{-06}	3.124	
COR	Unidentified coregonine (*Corgeonus* spp)	5.690×10^{-06}	3.031	
SAL	Salmonine (general)	3.170×10^{-06}	3.141	
SAL	Chinook Salmon (*Oncorhynchus tshawytscha*)	3.170×10^{-06}	3.141	
SAL	Brown Trout (*Salmo trutta*)	3.170×10^{-06}	3.141	
SAL	Lake Trout-lean (*Salvelinus namaycush namaycush*)	3.170×10^{-06}	3.141	
SAL	Lake Trout-siscowet (*Salvelinus namaycush siscowet*)	1.030×10^{-06}	3.339	
SAL	Coho Salmon (*Oncorhynchus kisutch*)	3.170×10^{-06}	3.141	
SAL	Splake (*Salvelinus namaycush x fontinalis*)	3.170×10^{-06}	3.141	
SAL	Lake Trout (general)	3.170×10^{-06}	3.141	
OTH	Longnose Sucker (*Catostomus catostomus*)	1.420×10^{-05}	2.959	
OTH	Common White Sucker (*Catostomus commersoni*)	1.420×10^{-05}	2.959	
OTH	Cyprinid (general)			2.000
OTH	Yellow Perch (*Perca flavescens*)			5.000
SCL	Sculpin (general)	8.490×10^{-06}	3.047	
SCL	Slimy Sculpin (*Cottus cognatus*)	7.640×10^{-06}	3.092	
SCL	Spoonhead Sculpin (*Cottus ricei*)	1.270×10^{-05}	2.925	
SCL	Deepwater Sculpin (*Myoxocephalus thompsoni*)	5.140×10^{-06}	3.125	
INS	Insect	6.170×10^{-06}		0.120
AMI	Mysis, Opossum Shrimp (*Mysis diluviana*)	6.290×10^{-07}		0.036
AMI	Amphipod, Diporeia (*Diporeia affinis*)	1.460×10^{-06}		0.017
OTH	Crayfish (*Decapoda)*	1.780×10^{-06}		0.132
OTH	Snail, (*Gastropoda*)	1.780×10^{-06}		0.263
OTH	Clam, (*Pelecypoda*)	2.300×10^{-06}		0.013
OTH	Bird remains	1.780×10^{-06}		5.084
OTH	Fish egg	3.990×10^{-06}		0.058

All other survey nets (summer, fall, and siscowet) were fished for one night, therefore net saturation adjustments were unnecessary. The annual index of relative abundance for each management unit was summarized as the geometric mean of the CPUEs (GMCPUE) for the stations in each year because survey catches were assumed to be log-normally distributed (Quinn and Deriso 1999). A small constant (0.1) was added to CPUEs before $\log_e$ transformation to account for stations with zero catches and then the constant was subtracted from the GMCPUE when back-transformed following the methods of Richards et al. (2004). Although more complex general linear mixed models have been developed for spring and summer survey CPUE data that adjusts for depth and site effects (Deroba and Bence 2011), the simple geometric mean CPUE was sufficient for the objectives of this report, which is supported by the findings of Nieland et al. (2007).

Recreational fishery harvest of Lake Trout and angler effort were estimated from standardized angler surveys conducted at major fishing ports in Lake Superior and from mandated charter fishing operator reports (Lockwood et al. 1999; Rakoczy and Wesander 2006). The major ports that angler surveys were conducted during 1998–2007 included: Black River Harbor, Ontonagon, Traverse Bay, Keweenaw Bay, Marquette, Au Train Bay, Munising, and Grand Marais. Recreational charter fishing operators licensed to fish in Michigan waters were based out of the following ports: Saxon Harbor (Wisconsin), Black River Harbor, Ontonagon, Isle Royale, Copper Harbor, Bete Grise, Huron Bay, Marquette, Shelter Bay, Au Train Bay, Munising, and Grand Marais.

Commercial fishery yield and effort data for Lake Trout were compiled from harvest reports provided by the Great Lake Indian Fish and Wildlife Commission and the Chippewa/Ottawa Resource Authority. During 1998 to 2007, nearly all commercial Lake Trout yield was from gill nets, though there was also limited Lake Trout yield from tribal commercial trap nets in MI-7. Tribal commercial catches of Lake Trout in MI-6 and MI-7 were pooled with no distinction between lean and siscowet Lake Trout; however, commercial monitoring by CORA provided proportions of the two forms that were used to estimate the composition of each morphotype.

Growth and body condition of Lake Trout were estimated annually for each management unit. Following the convention used by the Lake Superior Technical Committee of the Great Lakes Fishery Commission to index lean Lake Trout growth trends (Sitar et al. 2007; Sitar et al. 2010), annual mean length at age 7 from spring surveys was calculated for each management unit. This age was selected as the index because it is the first fully selected age in the spring survey gill nets. Mean length at age 7 for hatchery and siscowet Lake Trout was not estimated because insufficient numbers were collected in spring surveys. Index of Lake Trout condition was based first on the development of weight-length models and then using model parameters to estimate weight at two reference lengths of Lake Trout. Standard population length-weight relationships for each year-management unit combination were estimated with an allometric growth function using an additive error structure:

$$W = \alpha L^{\beta} + e^{\varepsilon}, \tag{4}$$

where W= weight, α was a coefficient, L was total length, and β was the exponent, and ε was random error with a mean of 0 and constant variance (Quinn and Deriso 1999). The length-weight models were based on data pooled from the spring and summer surveys in order to maximize size ranges and sample sizes. Trends in Lake Trout condition were indexed for each year and management unit by calculating weight at two reference lengths of Lake Trout: small (450 mm) and large (700 mm) sized fish using equation (4). These reference lengths were chosen to index fish below and above the midpoint of the length range of Lake Trout observed in survey catches in order to detect trends in condition should it differ between young and old fish (Mata 2009). Furthermore, these reference sizes generally correspond to lengths above and below length at 50% maturity (Sitar and He 2006).

Lean and siscowet length at maturity for each sex and management unit (from 1998 to 2007) was modeled using logistic regression (R Version 2.8.1, R Development Core Team 2010).

$$p = \frac{e^{(\beta_0+\beta_1 L)}}{1+e^{(\beta_0+\beta_1 L)}}, \quad (5)$$

where p is probability of being mature, L is total length, and β_0 and β_1 are regression coefficients. Length at which 50% of individuals were mature (L_{50}) was calculated with the following expression, assuming 100% as the maximum maturity (Quinn and Deriso 1999):

$$L_{50} = \frac{-\beta_0}{\beta_1}, \quad (6)$$

Bootstrap resampling based on 1,500 samples was conducted to generate 95% confidence intervals (R version 2.8.1, R Development Core Team 2010). Significant differences between L_{50} estimates were determined from nonoverlapping confidence intervals. Maturity data were based on Lake Trout observed in summer surveys when gonads were developmentally advanced than earlier in the year (i.e., spring survey).

Results

Lean Lake Trout

Spring Survey Relative Abundance, Age Composition, and Average Length

From 1998 to 2007, wild lean Lake Trout relative abundance (GMCPUE) increased nearly five-fold in MI-3, about six-fold in MI-4, about two-fold in MI-5, and more than four-fold in MI-7 (Figure 2). In MI-6, wild lean Lake Trout GMCPUE increased about 50% since 1998. In comparison with the previous ten-year period (1988–1997), the overall average GMCPUE of wild Lean Lake Trout during 1998–2007 in MI-5, MI-6, and MI-7 were at similar levels (Figure 2). In MI-3 and MI-4, overall average GMCPUE of wild lean Lake Trout for 1998–2007 was higher than the average GMCPUE for 1988–1997. In general, Wild lean Lake Trout were most abundant in MI-4, MI-5, and MI-6 and were least abundant in MI-3. Relative abundance of hatchery Lake Trout was extremely low (<1 fish • km^{-1} • $night^{-1}$) and was highest in MI-4, where stocking continues at low levels.

The age composition of wild lean Lake Trout in the spring survey was generally similar in all management units with about 30–38% of Lake Trout age 9 and older. The modal age was between 7 and 9 among all management units (Figure 3). During 1998 to 2007, the percentage of age 9 and older Lake Trout increased in MI-5, MI-6, and MI-7. In MI-5, the percent of age 9 and older fish increased from 31% in 1998 to 45% in 2007. In MI-6, this percentage nearly doubled from 35% in 1998 to 60% in 2007. In MI-7, more than 70% of wild lean Lake Trout were age 9 and older in 2007, as compared to only 14% in 1998.

The shift to older age distributions in MI-6 and MI-7 corresponded with an increase in average length of lean Lake Trout collected in the survey between 1998 and 2007 (Figure 4). Average length of lean Lake Trout in the spring survey was highest in MI-6 and MI-7. In MI-3, mean length of spring catch has declined by more than 10% between 1998 and 2007.

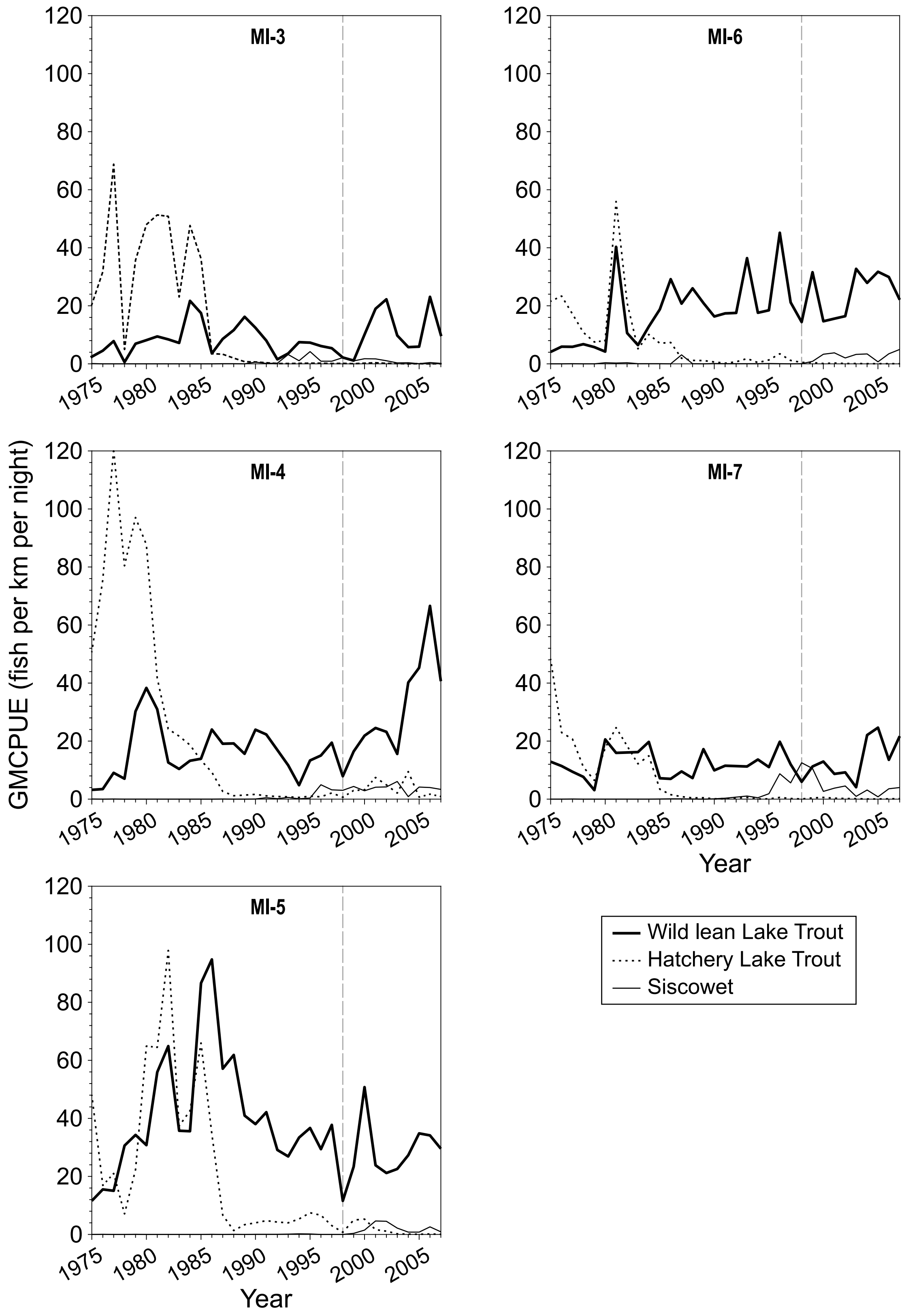

Figure 2.–Relative abundance of Lake Trout in spring gill-net surveys in Michigan waters of Lake Superior, 1998–2007. Vertical dashed line is a reference line to delineate current report period (1998–2007). Relative abundance was reported as annual geometric mean catch per unit effort (GMCPUE).

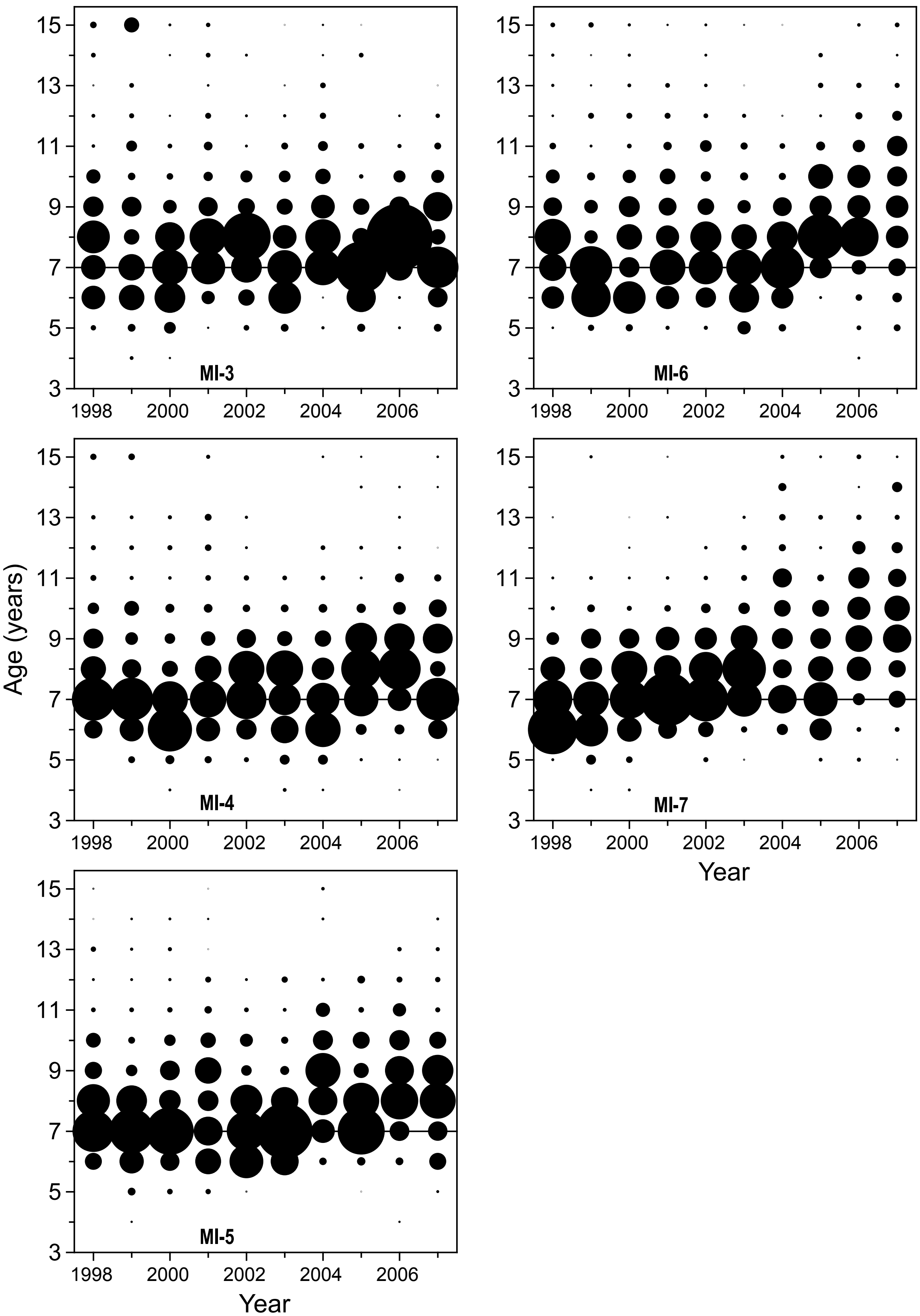

Figure 3.–Annual age composition of lean Lake Trout collected in the spring Lake Trout survey during 1998 to 2007 in Michigan waters of Lake Superior. The sizes of the circles represent the percent at age per year. Horizontal line at age 7 is provided for reference.

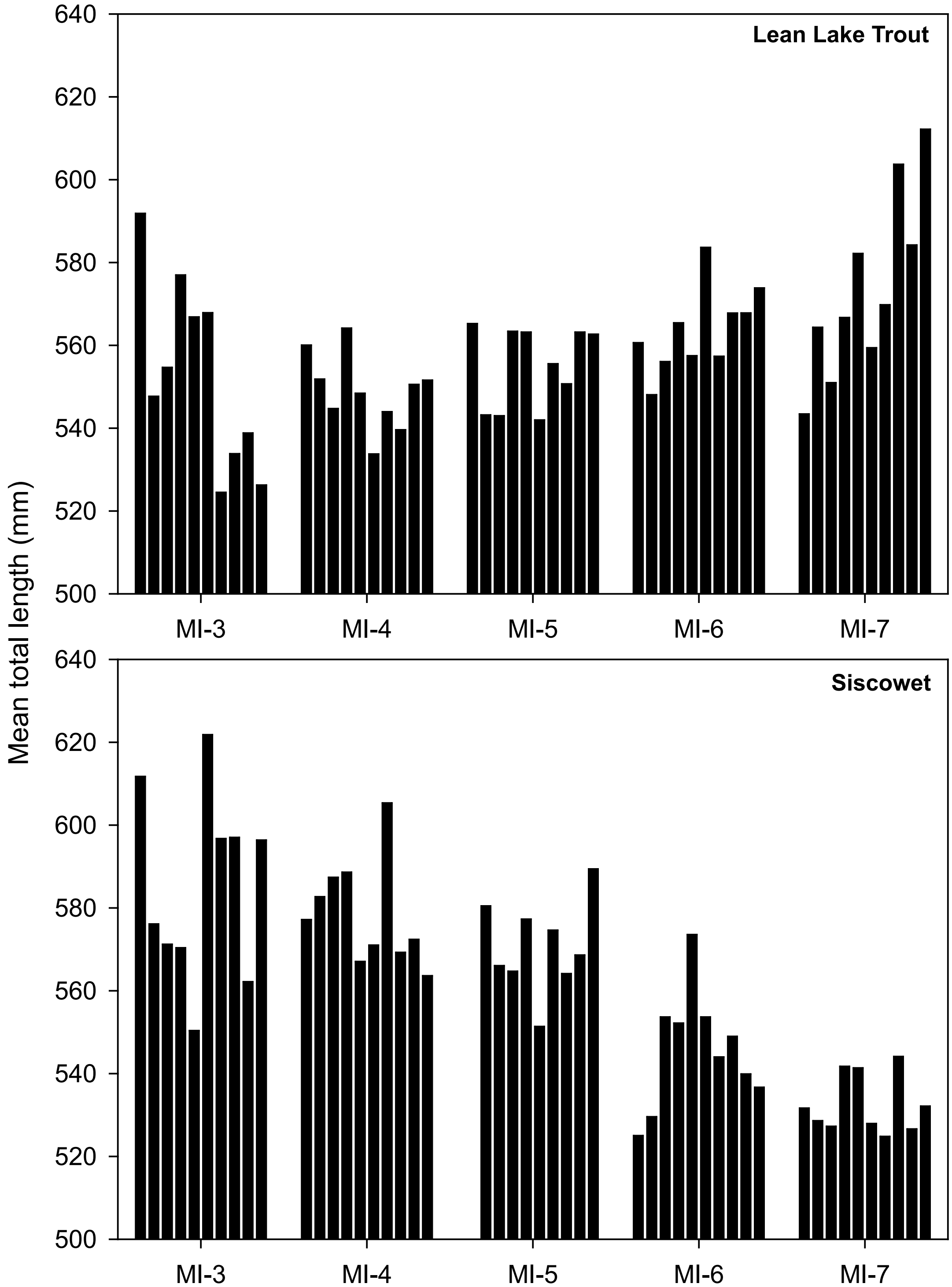

Figure 4.–Annual mean length of lean and siscowet Lake Trout collected in the spring Lake Trout survey during 1998 to 2007 (vertical bars in chronological order) in Michigan waters of Lake Superior.

Summer Survey Relative Abundance, Age Composition, and Average Length

Between 1998 and 2007, relative abundance of wild lean Lake Trout in the summer survey increased in MI-2, MI-4, MI-6, and MI-7 (Figure 5). In MI-3, lean GMCPUE declined by 40% from 1998 to 2006. In MI-5, wild lean GMCPUE nearly doubled between 1998 and 2004, but has declined since 2004 (Figure 5). Since the survey began in 1986, wild lean GMCPUE in MI-7 has more than doubled. However, much of the recent catch comprised older age classes than in earlier years of the survey (see below). Similar to the spring survey, hatchery Lake Trout composed a very small part of the summer survey catch. The highest hatchery GMCPUEs were in MI-4 and MI-5.

The modal age of wild lean Lake Trout collected in the summer survey was similar among all management units and mostly varied between age 5 and age 7 (Figure 6). In general, most fish sampled were less than age 7 in all management units except MI-7 and later years in MI-6. The percent of older wild lean Lake Trout in the summer survey has increased between 1998 and 2007 in all management units. The average percent of Lake Trout less than age 7 between 2005 and 2007 was lower than during 1998 and 2000 in all management units except MI-3. Comparing the same two time periods, the average percent of Lake Trout less than age 7 shifted from 74% to 57% in MI-2, from 74% to 54% in MI-4, from 71% to 63% in MI-5, from 65% to 37% in MI-6, and from 47% to 38% in MI-7. The increase in the percentage of older ages in the survey is partly related to increase in the average length of Lake Trout over the time series (Figure 7).

Mean length of lean Lake Trout in the summer survey during 1998–2007 has increased in MI-4, MI-6, and MI-7 (Figure 7). There were no trends in mean length of lean Lake Trout in MI-2, MI-3, and MI-5. Similar to trends in the spring survey, mean length of lean Lake Trout increased from western to eastern management units.

Fall Survey Relative Abundance and Size Structure in MI-5

The spawning season for lean Lake Trout in the Marquette area of MI-5 begins in early October and continues to the end of November. The highest relative abundance of spawning Lake Trout was during the last week in October and first week in November (Figure 8). Among the three spawning areas sampled, the highest relative abundance of spawners was at Garlic Island Reef (GIR) and the lowest was at Presque Isle Harbor (PIH). There were no changes in lean Lake Trout relative abundance at GIR or Partridge Island Reef (PIR) between 2000 and 2007, however, spawner relative abundance at PIH progressively declined during this period.

Fall survey catches were dominated by mature males with the percentage ranging from 56% to 100% per net lift. During the last week of October and the first week of November, the highest percentage of females was 31% and averaged 12% at GIR, 11% at PIR, and 21% at PIH (Figure 9). This was also the period of peak spawning as indicated by the highest proportion of ripe females (Figure 10). Spent females were observed as early as the 4th week in October, and most spent females were observed after the first week in November. During 2004, 2006, and 2007 at all three spawning sites, immature males composed less than 1% of total male catch and immature females made up between 1 and 6% of females caught. Only 12 siscowet or siscowet-like Lake Trout (11 were mature) were caught among 8,304 Lake Trout collected at the three spawning sites sampled during the fall surveys from 2000 through 2007.

Most Lake Trout sampled during the fall survey were of wild origin. At PIR and GIR, the highest proportion of hatchery fish was only about 5% of total weekly catch (Figure 11). At Presque Isle Harbor, where Lake Trout were stocked through 1996, hatchery Lake Trout composed as much as 28% of the spawning survey catch. Furthermore, the proportion of hatchery fish at Presque Isle Harbor increased as the spawning season progressed (Figure 11).

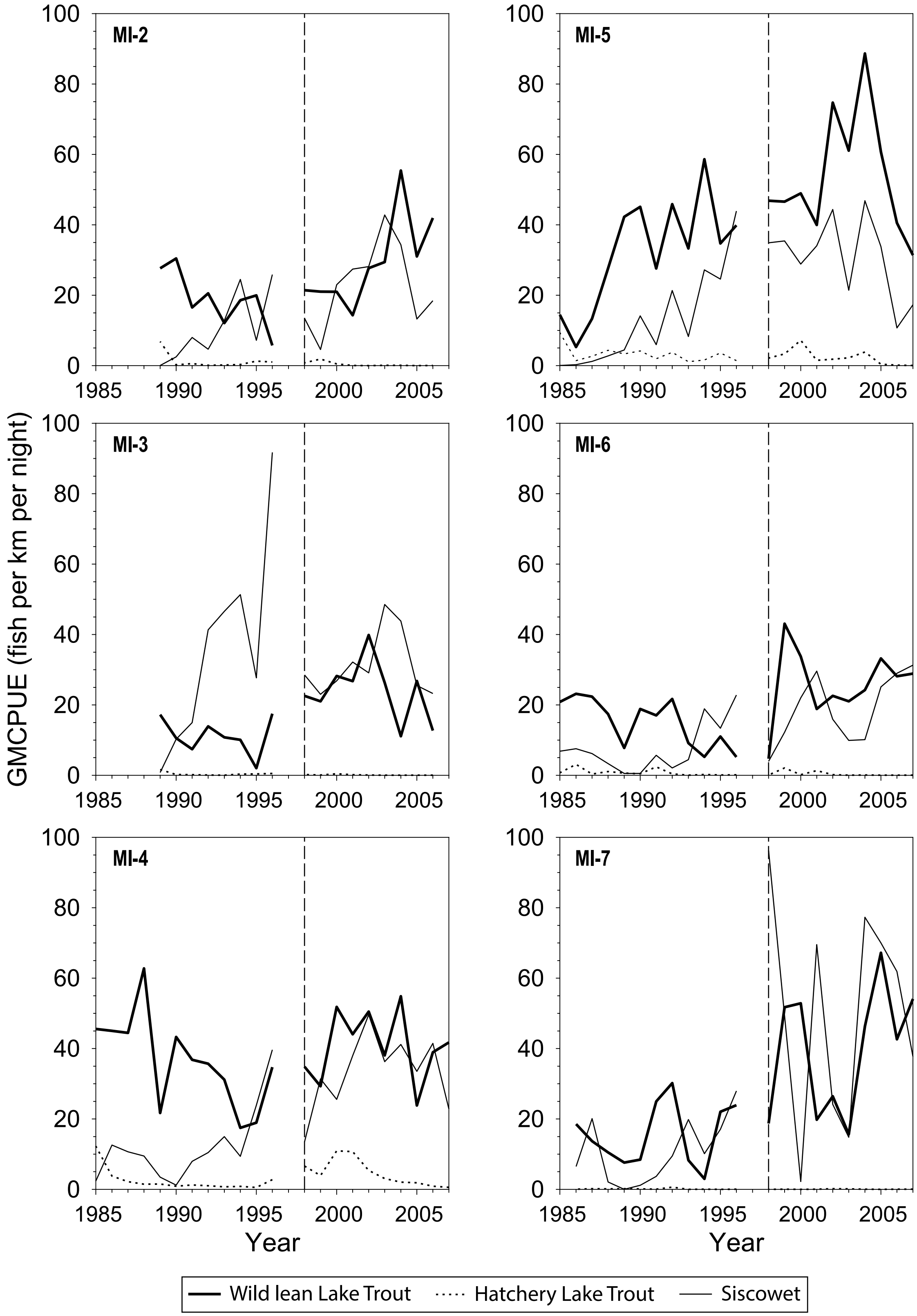

Figure 5.–Relative abundance of Lake Trout in summer gill-net surveys in Michigan waters of Lake Superior, 1985–2007. Vertical dashed line is a reference line to delineate current report period (1998–2007). Relative abundance was reported as annual geometric mean catch per unit effort (GMCPUE).

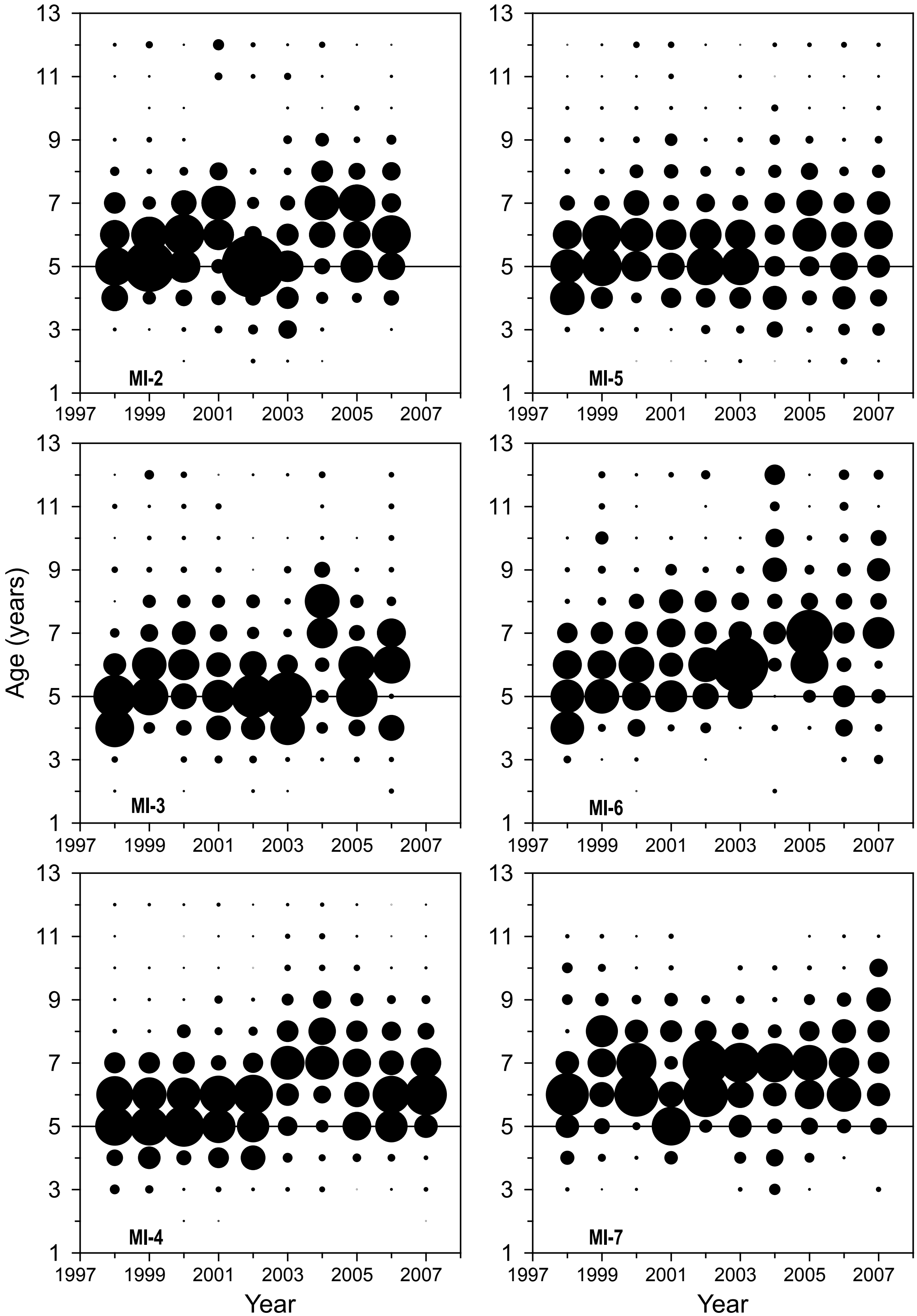

Figure 6.–Annual age composition of lean Lake Trout collected in the summer Lake Trout survey during 1998 to 2007 in Michigan waters of Lake Superior. The sizes of the circles represent the percent at age per year. Horizontal line at age 5 is provided for reference.

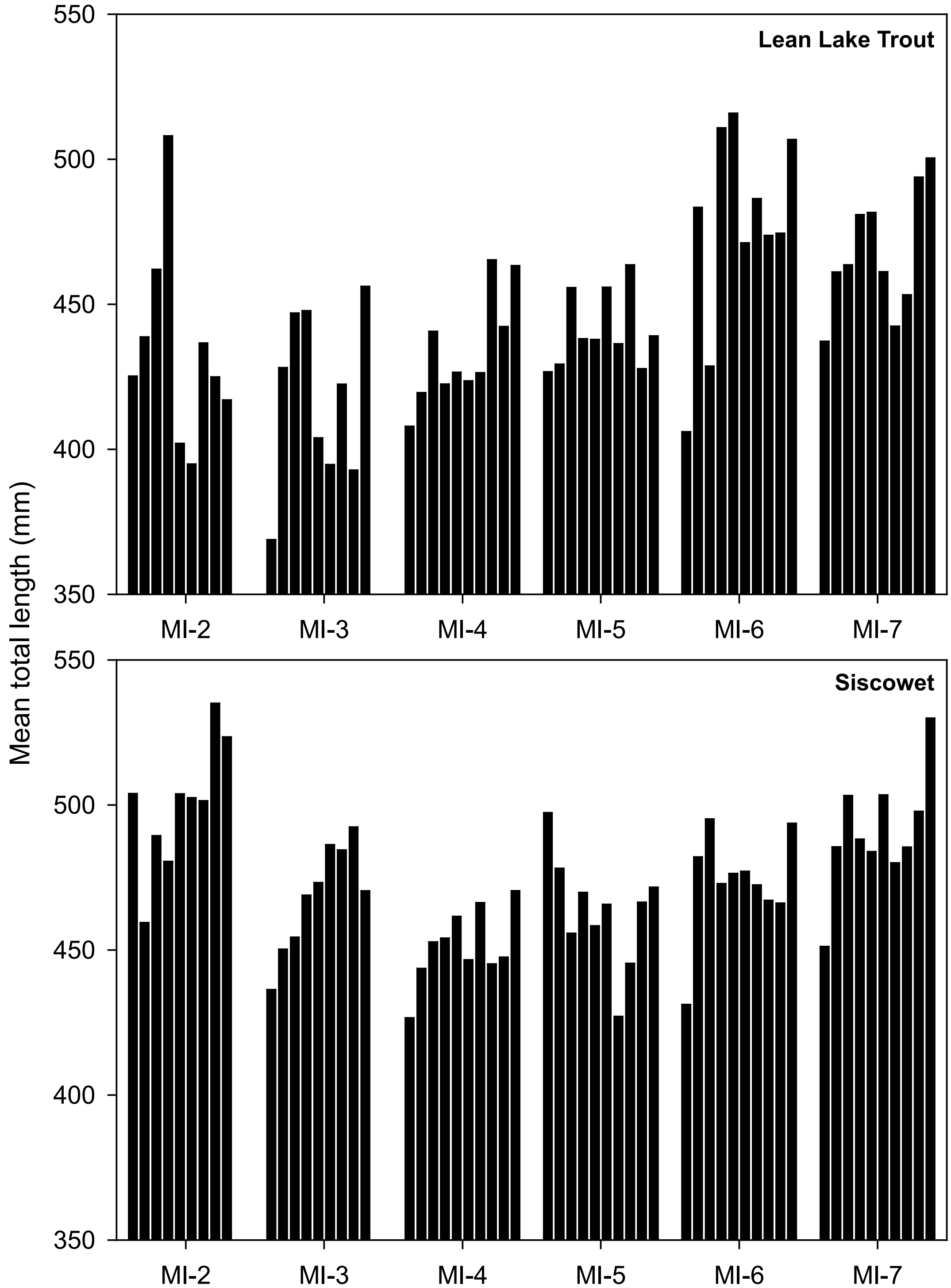

Figure 7.–Annual mean length of lean Lake Trout and siscowet collected in the summer Lake Trout survey during 1998 to 2007 (vertical bars in chronological order) in Michigan waters of Lake Superior.

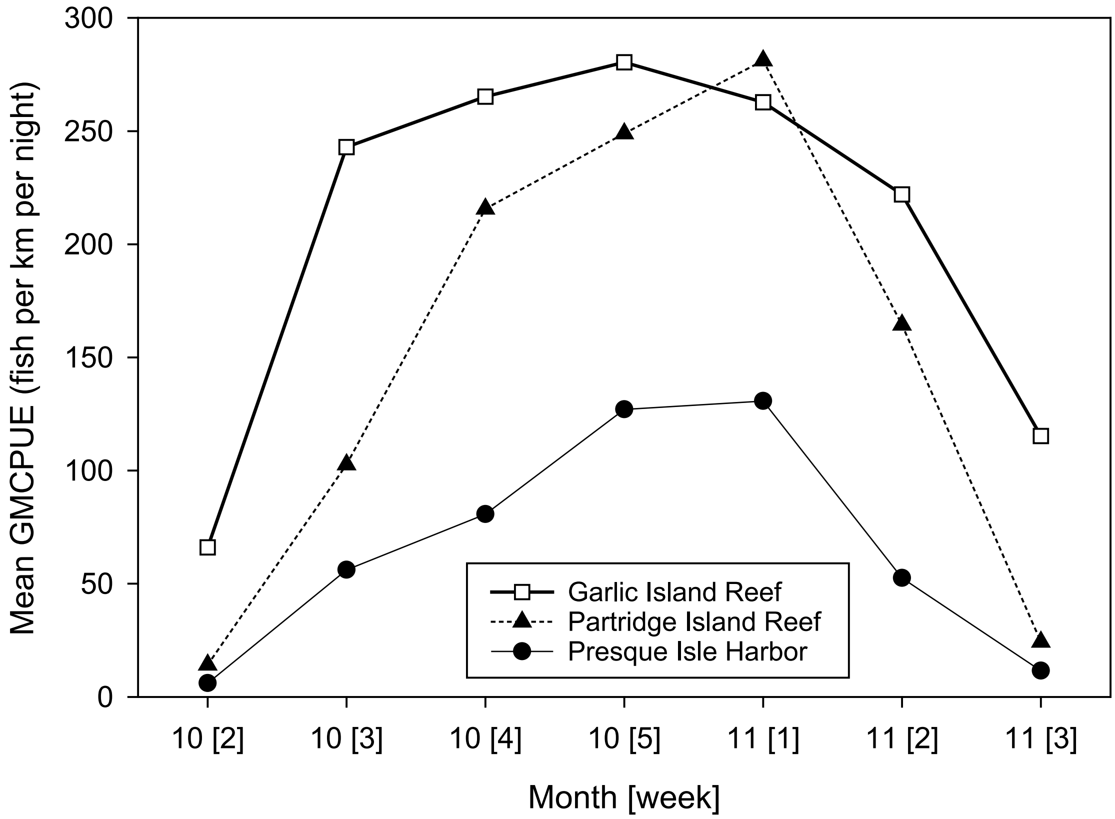

Figure 8.–Weekly relative abundance, expressed as the average geometric mean across years, of lean Lake Trout in fall gill-net surveys at three spawning sites near Marquette in MI-5 during 2000–2007. The x-axis was the week of sampling expressed as: numeric month [week number].

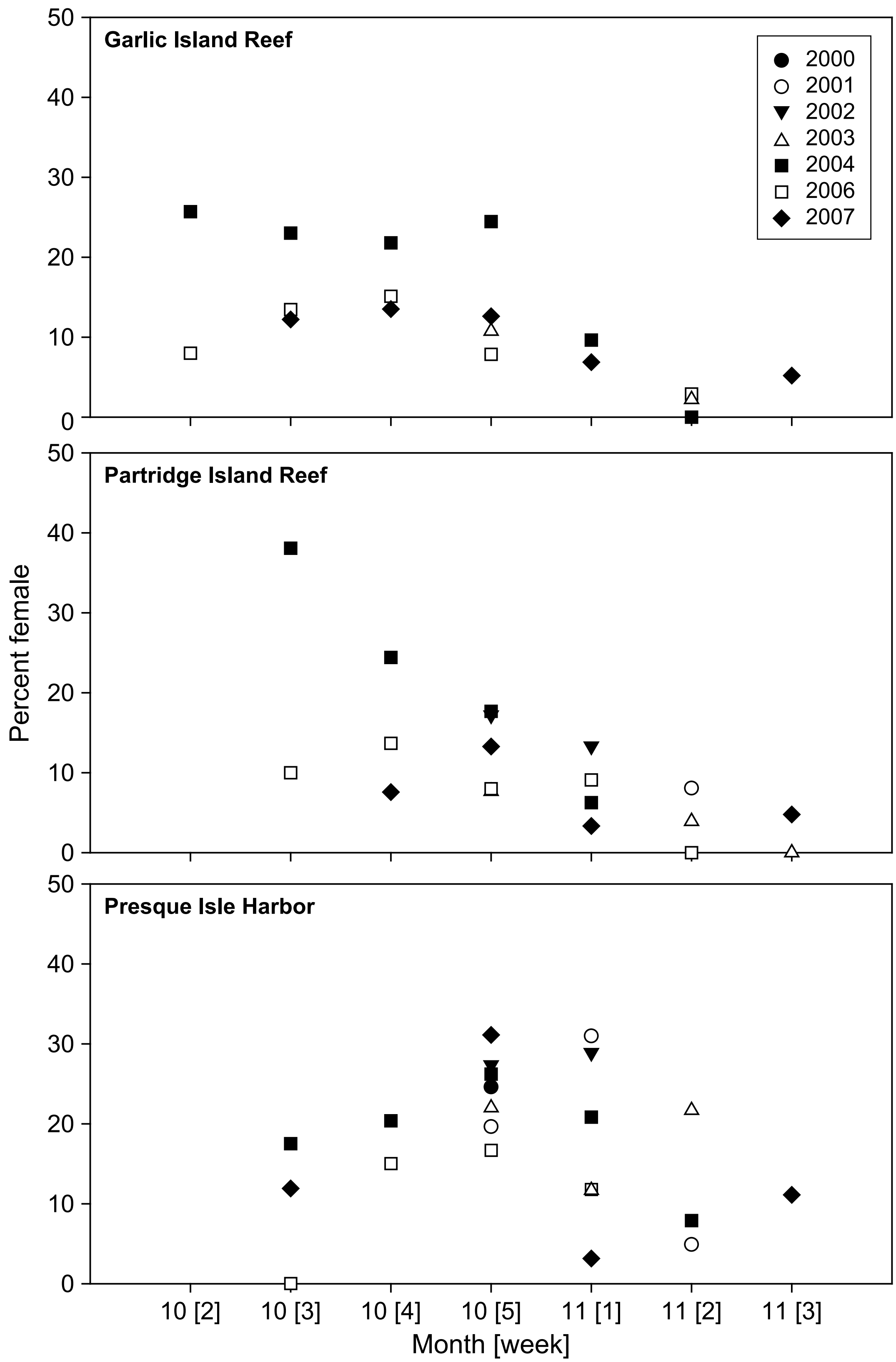

Figure 9.–Average percentage of female lean Lake Trout collected in fall gill-net surveys at three spawning sites near Marquette in MI-5 during 2000–2007.

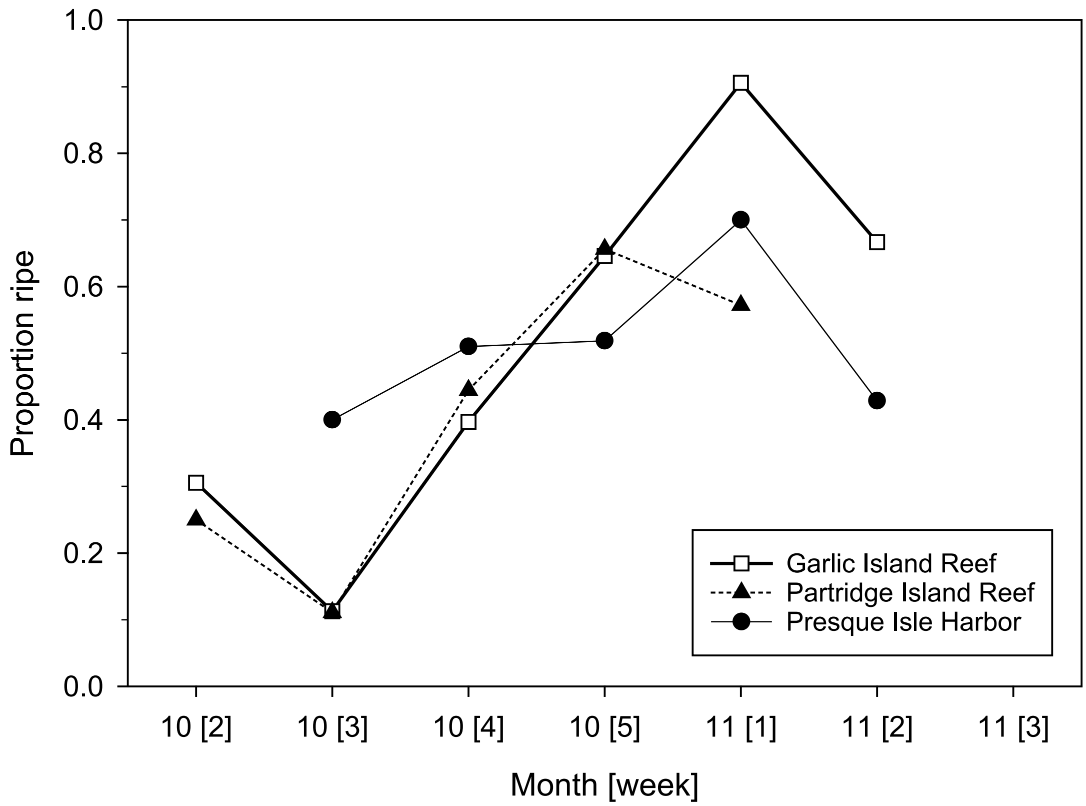

Figure 10.–Average proportion of ripe female lean Lake Trout at three spawning sites near Marquette in MI-5 during 2000–2007.

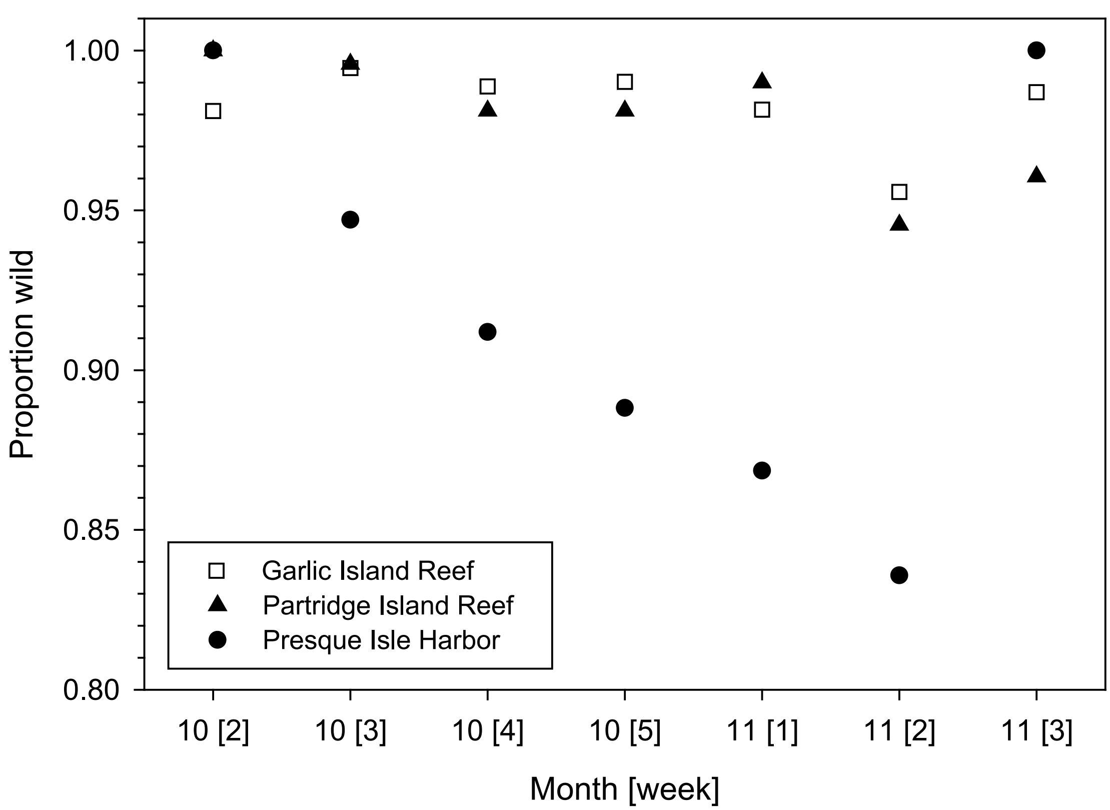

Figure 11.–Average weekly proportion of wild-origin lean Lake Trout collected in fall gill-net surveys at three spawning sites near Marquette in MI-5 during 2000–2007.

Among all spawning sites, the modal lengths of lean Lake Trout collected were between 600 and 700 mm (Figure 12). Very few Lake Trout smaller than 500 mm were caught in the nets among all sites and years sampled. Garlic Island Reef had the highest percentage of Lake Trout larger than 800 mm averaging 20% between 2003 and 2007. The percentage of fish larger than 800 mm averaged 12% at Presque Isle Harbor between 2000 and 2007 and 10% at Partridge Island Reef between 2001 and 2007. Mature male lean Lake Trout were consistently smaller on average than mature females at all spawning sites and years (Figure 13). During 2000 through 2007, mean length of mature males ranged between 687 and 737 mm at Garlic Island Reef, between 653 and 684 mm at Partridge Island Reef, and between 655 and 685 mm at Presque Isle Harbor. Average length of mature females during the same years was between 725 and 774 mm at GIR, between 703 and 741 mm at PIR, and between 700 and 726 mm at Presque Isle Harbor.

Sea Lamprey Wounding

Spring Survey

Regardless of management unit, Sea Lamprey wounding rates generally increased with length of Lake Trout (Table 3). Sea lamprey wounds were rare on Lake Trout smaller than 534 mm. During 1998–2007, average wounding rates for Lake Trout larger than 533 mm were highest in MI-6 and MI-7 and the lowest in MI-5. Between 1998 and 2007, Sea Lamprey wounding rates for lean Lake Trout larger than 533 mm has increased from 5.3 to 11 wounds/100 fish in MI-5, 3.4 to 19.6 wounds/100 fish in MI-6, and from 6.9 to 14.3 wounds/100 fish in MI-7 (Figure 14). In MI-3, MI-4, and MI-7, the average wounding rate for Lake Trout larger than 533 mm was equal to or less than the previous ten years. In MI-5 and MI-6, average wounding rates (fish > 533 mm) were higher during 1998–2007 than during 1988–1997.

Fall Survey in MI-5

Sea lamprey wounding rates on lean Lake Trout sampled during the fall were higher than those observed in the spring (Figures 14 and 15). This was due to the higher presence of fish larger than 650 mm that were in spawning aggregations, but are not represented in the spring survey. Furthermore, wounding rates in the fall could represent attacks from two differing cohorts of lampreys (previous and current year). Fall wounding rates for 534–635 mm Lake Trout were low and ranged from an average of 1.7 wounds/100 fish at Partridge Island Reef to 5.6 wounds/100 fish at Garlic Island Reef (Figure 15). The highest fall wounding rates were on Lake Trout larger than 737 mm and averaged 58 wounds/100 fish between 2003 and 2007 at Garlic Island Reef, 51.8 wounds/100 fish at Partridge Island Reef (2001–2007), and 42.3 wounds/100 fish at Presque Isle Harbor (2000–2007).

Fishery Harvest and Effort

Recreational

Between 1998 and 2007, average annual lean Lake Trout harvest ranged from 1,750 fish in MI-7 to 9,850 fish in MI-5. In MI-5, MI-6, and MI-7 lean Lake Trout harvest has declined between 1998 and 2007 (Figure 16). The only management unit where harvest has increased was MI-4. Recreational fishing effort (noncharter) was highest in MI-4, MI-5, and MI-6, ranging between 44,500 to 49,700 angler hours/year (Table 4). Effort was lowest in MI-7, averaging 18,100 angler hours/year. Recreational effort has declined in MI-5 and MI-6, but remained stable in MI-7. In MI-2 and MI-4, effort has increased over time (Table 4). Recreational charter effort was highest in MI-2 and MI-4, and made up less than 15% of all recreational fishery effort and averaged 6% of the total.

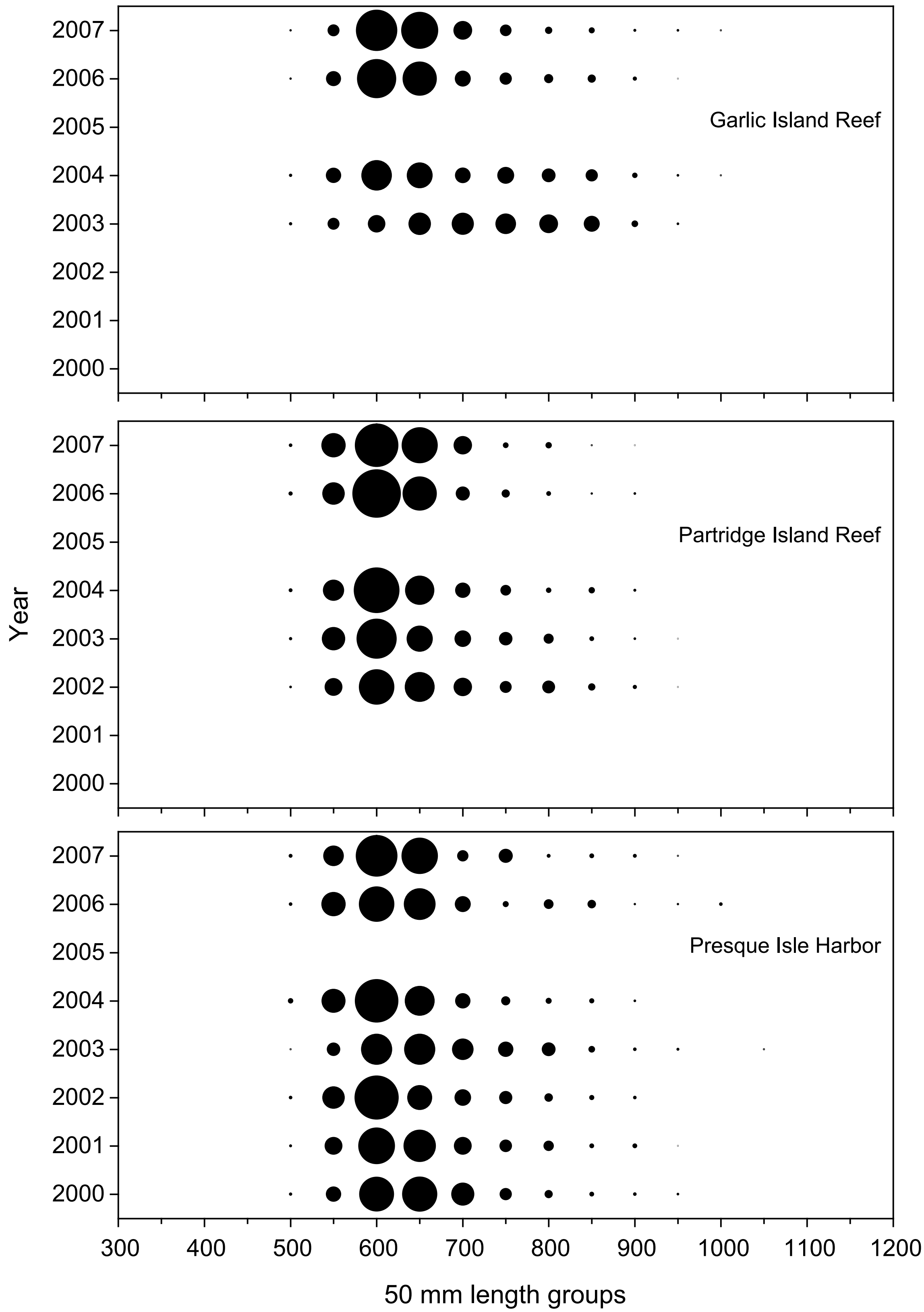

Figure 12.–Annual length composition of lean Lake Trout collected in fall gill-net surveys at three spawning sites near Marquette in MI-5 during 2000–2007. Circles are scaled percentage of fish per 50 mm length group per year.

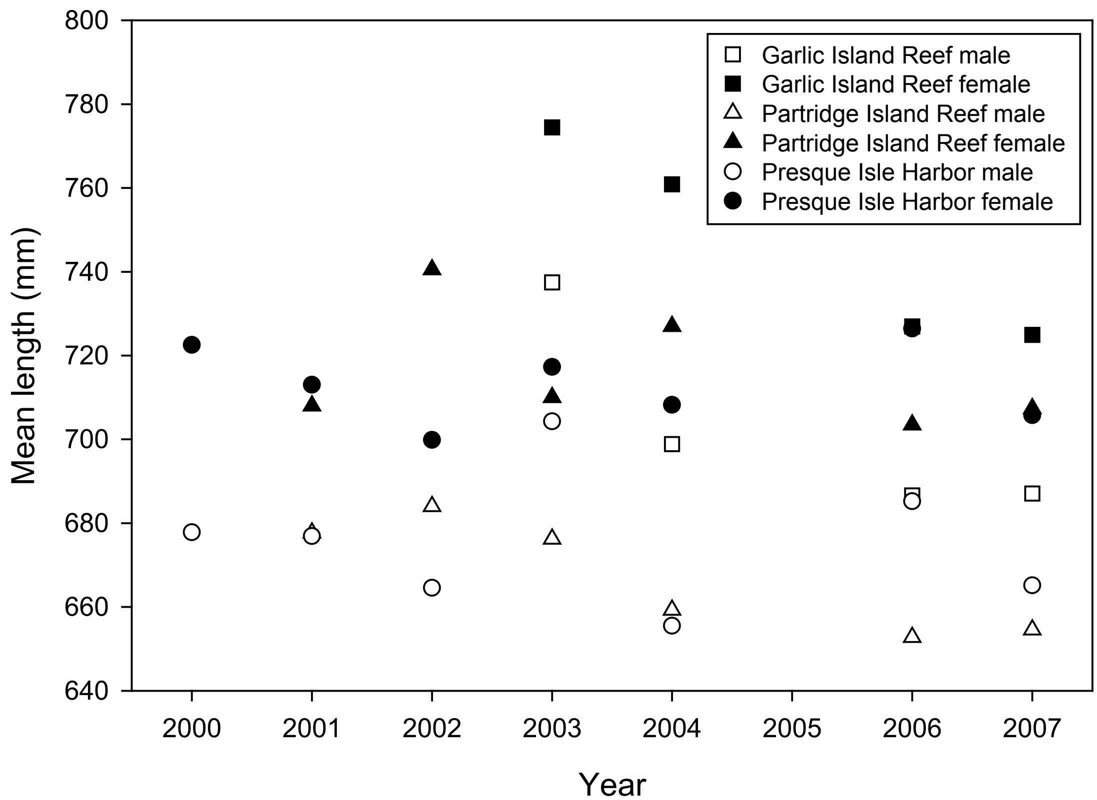

Figure 13.–Average length of mature Lake Trout sampled at three spawning sites near Marquette in MI-5 during fall gill-net surveys from 2000 to 2007.

Table 3.–Sea lamprey wounding rates on lean Lake Trout sampled in spring surveys from 1998 to 2007 in Michigan waters of Lake Superior. Wounding rates, expressed as wounds per 100 fish for designated length groups, were the total number of Type A (stages 1 through 3) wounds divided by the number of fish sampled multiplied by 100. Wounding rates were calculated only for sample sizes (in parentheses) of 10 or more fish.

Management unit	Year	Lake Trout length group (mm)				
		<432	432–533	534–635	636–737	>737
MI-3	1998		<0.1 (17)	11.2 (98)	21.7 (23)	
	1999	0 (11)	<0.1 (30)	10.7 (56)	<0.1 (12)	
	2000	0 (13)	1.5 (134)	3.8 (236)	15.4 (39)	
	2001		<0.1 (145)	3.0 (405)	12.6 (111)	
	2002	0 (15)	0.8 (120)	3.0 (366)	14.6 (41)	
	2003		<0.1 (64)	8.0 (112)	3.3 (30)	
	2004		1.9 (54)	5.6 (36)		
	2005		<0.1 (51)	11.6 (43)		
	2006		<0.1 (46)	4.6 (44)		
	2007		3.3 (60)	7.7 (52)		
MI-4	1998		1.1 (90)	1.8 (111)	18.5 (27)	
	1999	0 (27)	0.4 (275)	3.0 (365)	9.9 (81)	
	2000	0 (21)	0.6 (499)	4.1 (513)	33.8 (80)	60.0 (10)
	2001	0 (11)	<0.1 (329)	4.1 (459)	25.6 (121)	38.9 (18)
	2002	0 (10)	0.4 (278)	7.9 (340)	25.0 (36)	
	2003	0 (12)	0.7 (147)	5.9 (102)	37.5 (16)	
	2004		0.5 (218)	1.1 (180)	34.4 (32)	
	2005		<0.1 (149)	2.4 (165)	20.0 (10)	
	2006		1.3 (153)	3.8 (213)	27.8 (18)	
	2007		2.8 (107)	7.5 (187)	33.3 (12)	
MI-5	1998		<0.1 (282)	4.1 (461)	9.8 (112)	5.6 (18)
	1999	0 (32)	0.7 (456)	2.5 (519)	9.0 (67)	
	2000		0.9 (427)	6.4 (453)	9.8 (51)	
	2001		<0.1 (107)	2.1 (237)	24.2 (33)	
	2002		2.7 (111)	8.0 (224)	8.3 (24)	
	2003		<0.1 (85)	2.2 (90)	14.3 (14)	
	2004		<0.1 (102)	<0.1 (114)	18.2 (22)	
	2005		1.0 (98)	4.7 (128)	15.4 (13)	
	2006		<0.1 (61)	4.1 (121)	7.1 (14)	
	2007		<0.1 (38)	6.6 (61)	30.0 (10)	
MI-6	1998		<0.1 (152)	2.2 (182)	7.8 (51)	
	1999	0 (17)	1.5 (202)	4.5 (244)	15.9 (44)	
	2000	0 (11)	2.8 (176)	11.1 (262)	26.7 (45)	
	2001		0.9 (116)	6.9 (233)	14.0 (50)	
	2002		3.1 (162)	9.0 (223)	21.4 (84)	44.9 (49)
	2003		1.1 (90)	4.9 (185)	15.9 (63)	18.9 (37)
	2004		<0.1 (109)	8.0 (151)	37.0 (27)	26.3 (19)
	2005		1.0 (100)	13.3 (203)	23.6 (55)	46.7 (30)
	2006		<0.1 (93)	5.2 (192)	16.3 (49)	33.3 (15)
	2007		1.3 (75)	9.9 (151)	32.1 (56)	64.7 (17)

Table 3.–Continued.

Management unit	Year	Lake Trout length group (mm)				
		<432	432–533	534–635	636–737	>737
MI-7	1998		<0.1 (77)	8.5 (59)	<0.1 (14)	
	1999		1.0 (105)	4.4 (135)	33.3 (42)	
	2000		2.3 (128)	7.4 (148)	4.6 (22)	
	2001		<0.1 (67)	4.0 (126)	10.0 (30)	
	2002		<0.1 (44)	9.9 (121)	27.3 (33)	
	2003		<0.1 (58)	5.6 (89)	<0.1 (10)	
	2004		2.0 (98)	8.7 (115)	33.3 (18)	
	2005		1.3 (80)	12.4 (137)	33.3 (30)	
	2006		1.5 (69)	5.4 (111)	20.0 (20)	
	2007		5.3 (38)	14.7 (95)	15.0 (40)	

Table 4.–Recreational and commercial Lake Trout fishery effort in Michigan waters of Lake Superior, 1998–2007. Recreational data from Michigan Department of Natural Resources, commercial data provided by the Great Lakes Indian Fish and Wildlife Commission and Chippewa/Ottawa Resource Authority.

Effort type and management unit	Year									
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Recreational (non-charter, angler hours)										
MI-2	26,921								37,417	
MI-4	38,983	51,911	43,767	53,951	38,895	49,554	61,227	68,548	40,806	
MI-5	52,152	57,111	55,739	51,910	50,598	39,506	36,122	34,067	33,944	35,684
MI-6	41,424	57,533	52,862	58,834	40,247	46,558	47,195	41,045	38,243	39,674
MI-7				15,732	20,030	17,361	19,404	16,700	19,657	18,022
Recreational (charter, angler hours)										
MI-2	5,280	5,497	5,089	5,116	5,449	5,431	5,529	5,837	4,732	4,475
MI-3	200			60	64	214	280	148	20	122
MI-4	3,125	7,425	6,512	4,909	2,700	5,459	2,883	3,320	3,496	3,222
MI-5	2,512	1,677	566	2,186	5,344	6,055	3,193	3,310	3,052	1,805
MI-6	1,556	1,710	491	613	783	848	1,418	1,861	1,434	1,444
MI-7							189	122	95	118
Commercial gill net (km)										
MI-2	26	52	119	29	113	80	166	176	501	357
MI-3	782	520	491	522	573	536	383	380	528	447
MI-4	759	760	616	680	834	523	569	507	490	413
MI-5	108	64	153	91	180	139	213	255	225	252
MI-6	282	198	310	289	129	416	260	10	1	66
MI-7	675	634	1,098	951	790	634	1,286	673	312	73
Commercial trap net (lifts)										
MI-7							4	100	58	

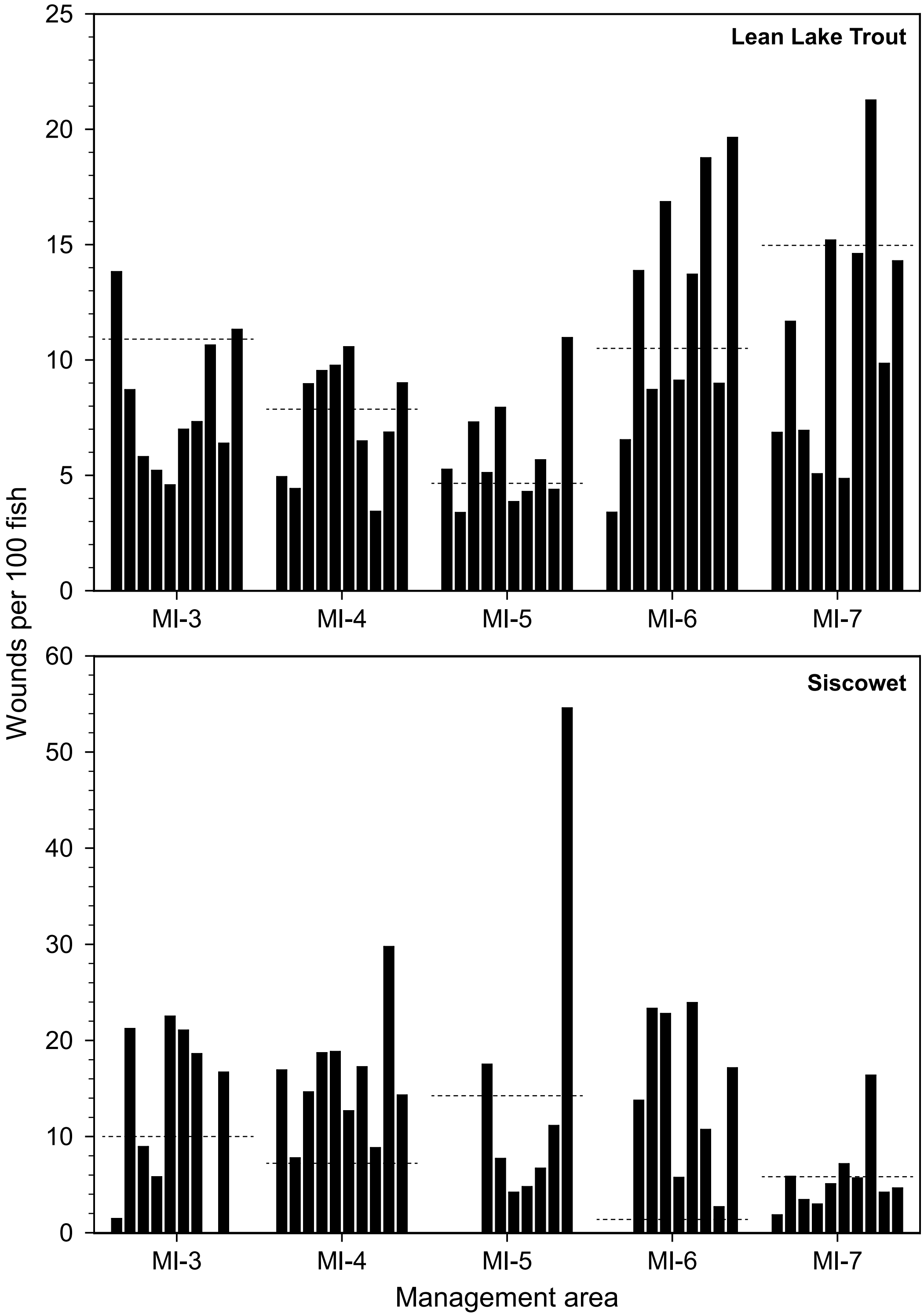

Figure 14.–Spring Sea Lamprey wounding rates for lean and siscowet Lake Trout > 533 mm in Michigan waters of Lake Superior during 1998 to 2007 (vertical bars in chronological order). Horizontal dashed line represents the average wounding rates during 1988 to 1997. Wounding rates were the sum of A1 to A3 wounds.

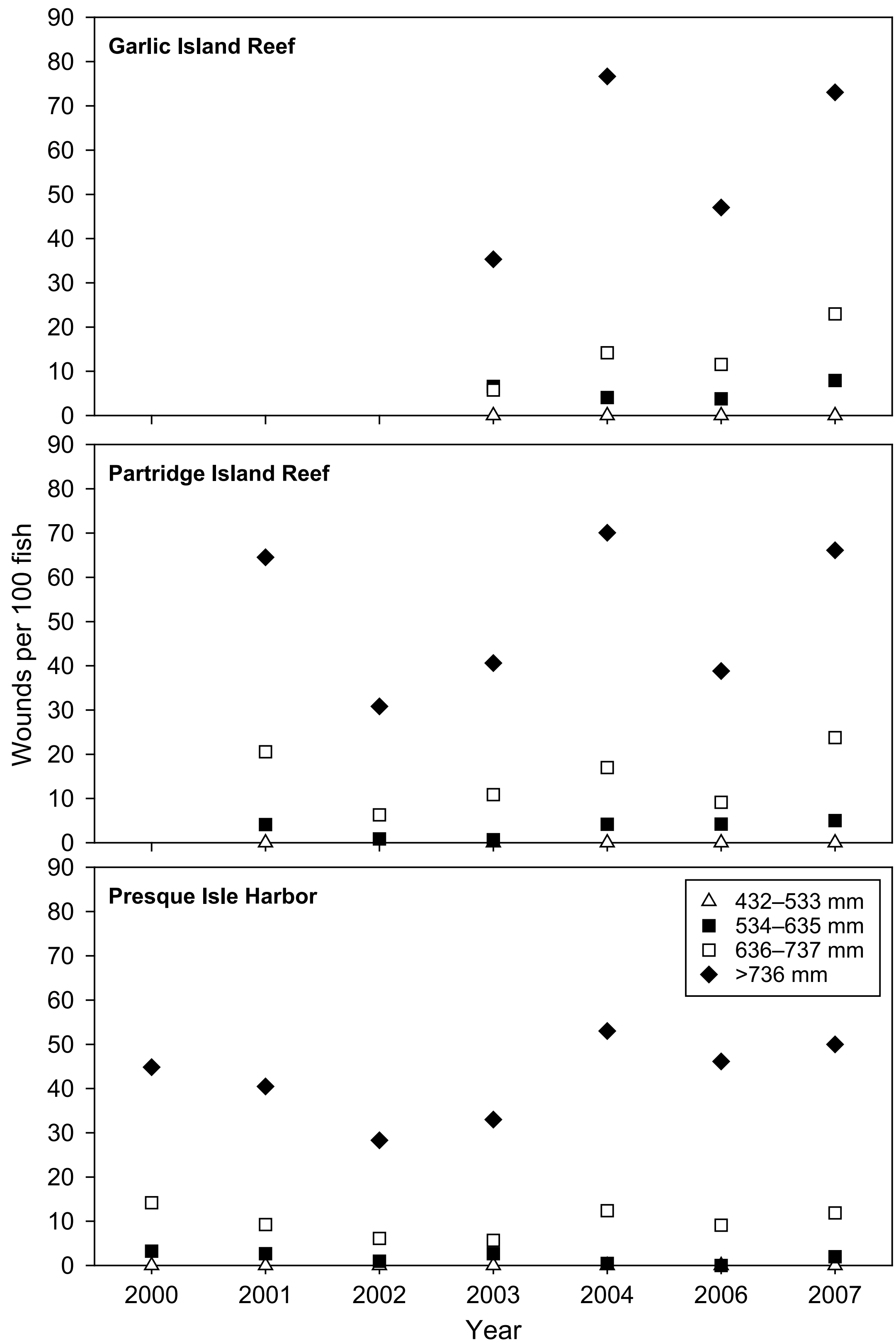

Figure 15.–Sea lamprey wounding rates by length-class of lean Lake Trout at three spawning sites near Marquette in MI-5 during fall gill-net surveys from 2000 to 2007. Wounding rates were based on the sum of Type A, stages 1–3 wounds.

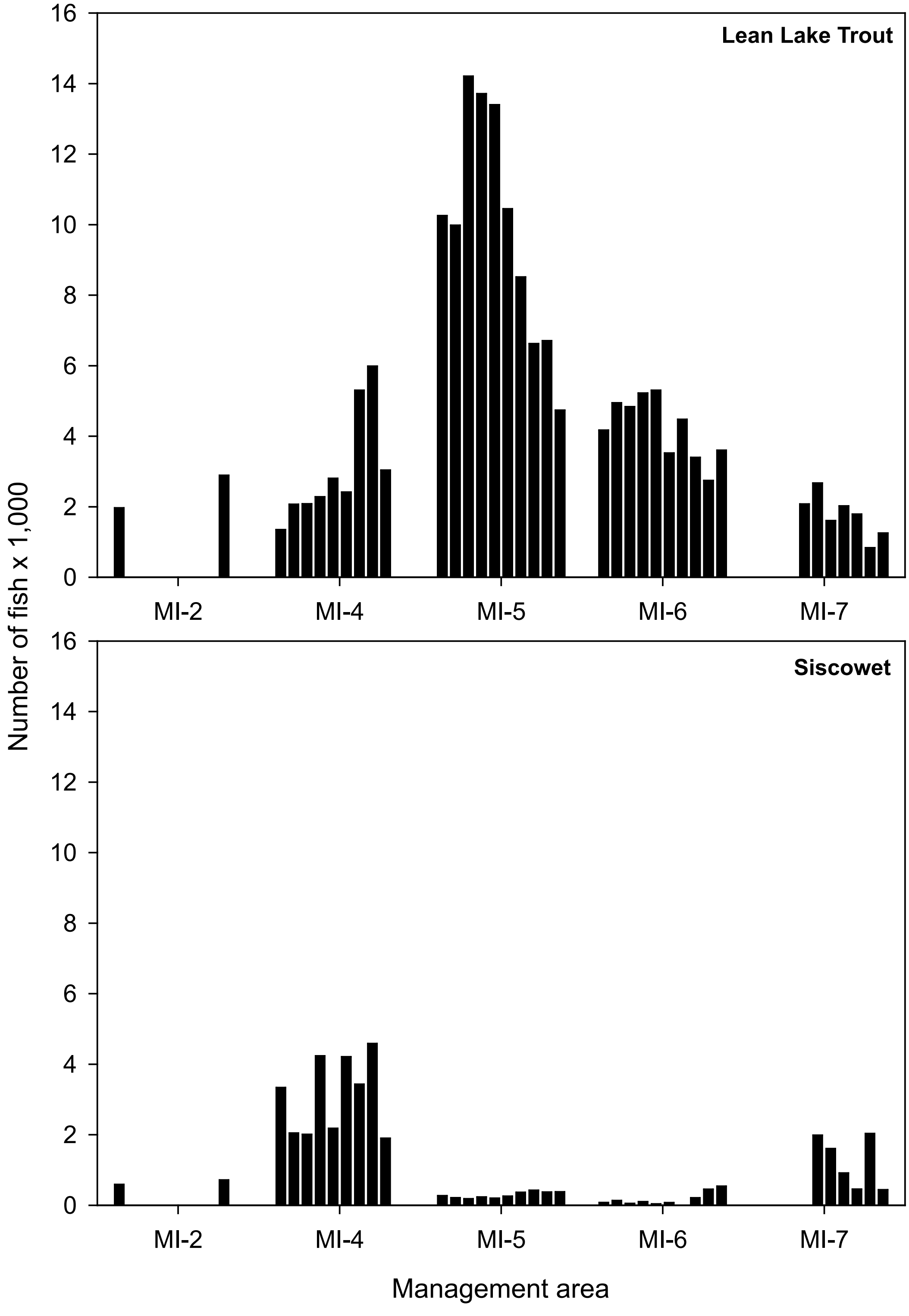

Figure 16.–Recreational fishery harvest of lean and siscowet Lake Trout in Michigan waters of Lake Superior during 1998 through 2007 (vertical bars in chronological order). Data from Michigan Department of Natural Resources

Commercial

Tribal commercial yield of lean Lake Trout was highest in MI-4 (Figure 17), averaging 22,900 kg/year. The lowest commercial yield was in MI-2 and MI-6, where annual averages were less than 4,000 kg/year. Increasing trends in commercial yield of lean Lake Trout were observed in MI-2 and MI-5, whereas declines were observed in MI-3, MI-6, and MI-7.

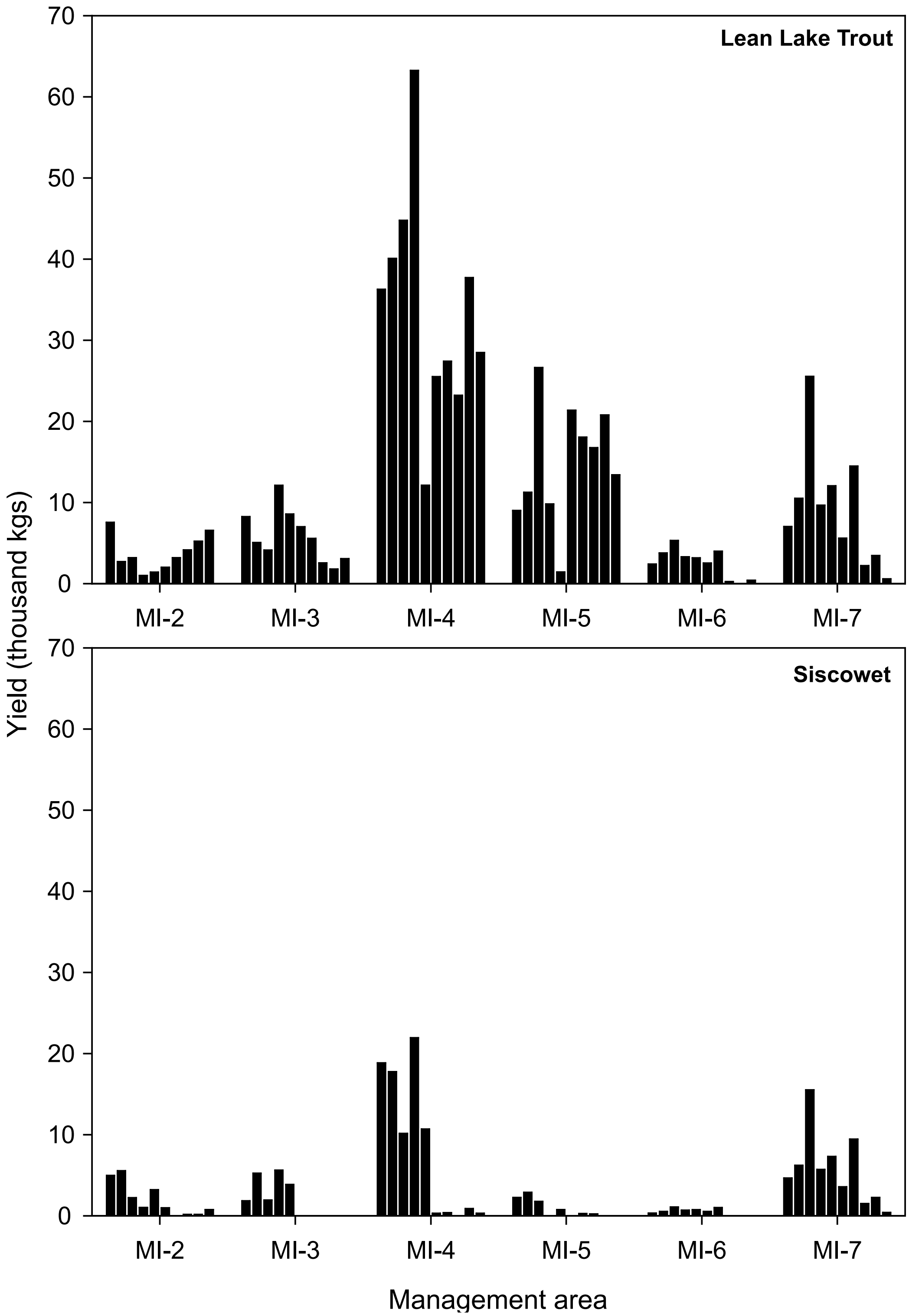

Figure 17.–Tribal commercial fishery yield of lean and siscowet Lake Trout in Michigan waters of Lake Superior 1998 to 2007 (vertical bars in chronological order). Data from Chippewa/Ottawa Resource Authority and Great Lakes Indian Fish and Wildlife Commission.

During 1998 to 2007, tribal commercial gill-net effort was highest in MI-3, MI-4, and MI-7 (Table 4). Average effort during this period was 516 km/year in MI-3, 615 km/year in MI-4, and 713 km/year in MI-7. During the same period, gill-net effort doubled in MI-5 (108 to 252 km/year) and increased 10-fold in MI-2 (26 to 357 km/year). Effort has declined during the last three years in MI-4, MI-6, and MI-7. Tribal trap nets were only fished in MI-7 at low effort levels during 2004–2006 (Table 4).

Diet Composition

Spring and Summer Surveys

During 1998 to 2007, nearly 5,800 nonempty lean Lake Trout stomachs were analyzed with wild lean Lake Trout comprising 90%, and hatchery lean Lake Trout making up 10% of samples (Table 5). Most Lake Trout collected were between 400 and 799 mm total length. Fish 800 mm or larger made up less than 1% of all samples. Most hatchery fish were collected in MI-4 and MI-5.

Table 5.–Number of nonempty Lake Trout stomachs analyzed for diet composition in Michigan waters of Lake Superior during 1998 to 2007. Fish were stratified into 200 mm length intervals and collected from spring and summer bottom gill-net surveys.

		Management unit					
Morphotype	Length (mm)	MI-2	MI-3	MI-4	MI-5	MI-6	MI-7
Wild lean	200: 399	110	160	162	187	102	42
	400: 599	90	525	794	814	837	336
	600: 799	8	156	211	205	382	48
	≥800		5	6	6	21	3
Hatchery lean	200: 399	11		49	14		
	400: 599	7	32	207	83	54	12
	600: 799		12	40	19	10	5
	≥800				3		
Siscowet	200: 399	54	122	191	125	91	35
	400: 599	169	324	681	423	807	495
	600: 799	24	164	247	87	125	26
	≥800		5	10		2	

Among all areas, the diet of small lean Lake Trout (200–399 mm) comprised mainly Rainbow Smelt and sculpins (Figure 18). Aquatic macroinvertebrates, *Diporeia* and *Mysis,* comprised less than 30% of small lean diet except in MI-7 where it made up 60% of the diet. In the small hatchery Lake Trout diet, aquatic macroinvertebrates, Rainbow Smelt, and sculpins were the most important prey items (Figure 19). The diet of medium (400–599 mm) lean Lake Trout was dominated by Rainbow Smelt in MI-2, MI-5, and MI-6 (Figure 18). In MI-3 and M-6, both coregonines and Rainbow Smelt were most prevalent in medium lean diet. In MI-7, sticklebacks, aquatic macroinvertebrates, and Rainbow Smelt were the most important prey items.

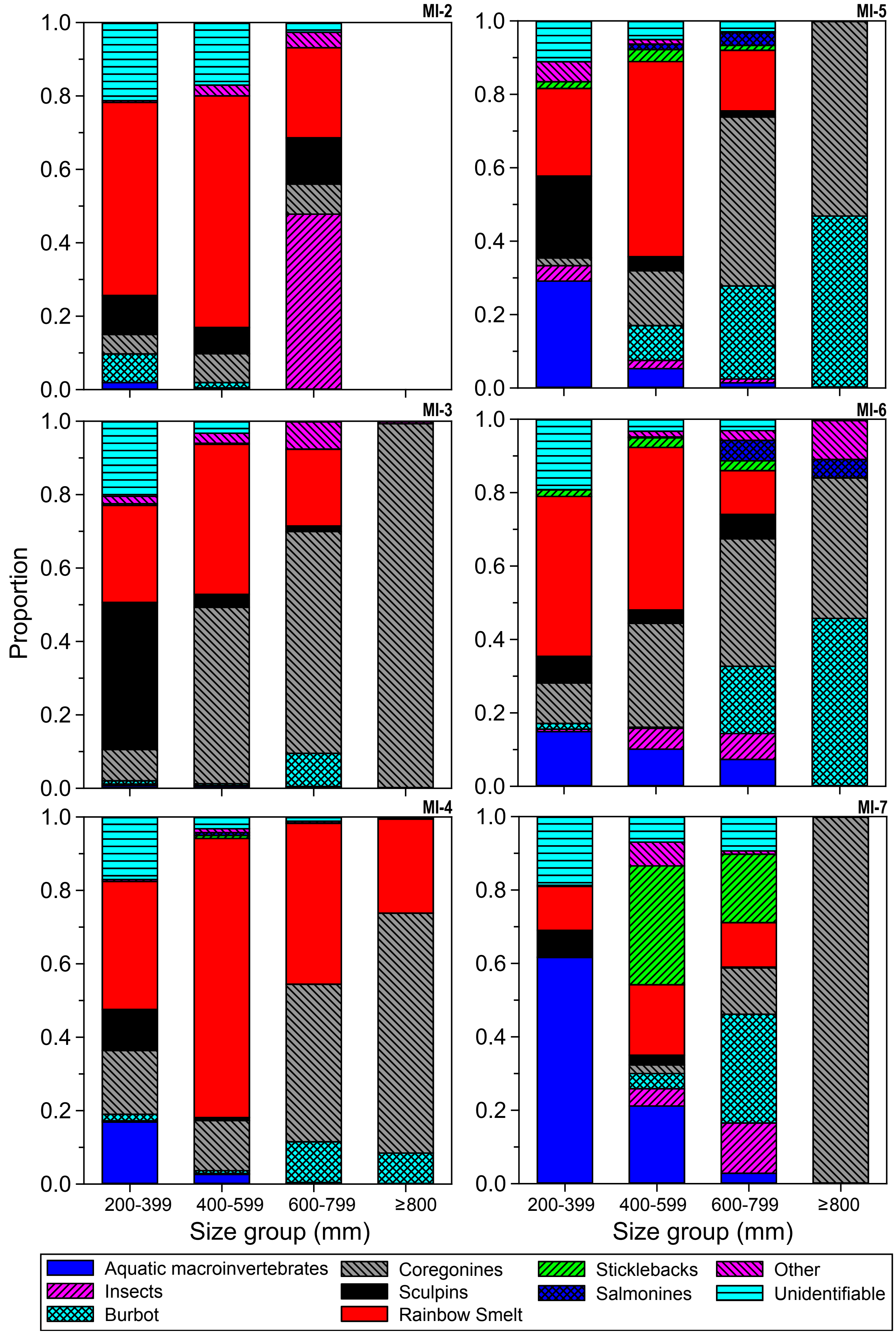

Figure 18.–Diet composition of wild-origin lean Lake Trout during 1998 to 2007 in Michigan waters of Lake Superior. Data were from spring and summer Lake Trout gill-net surveys.

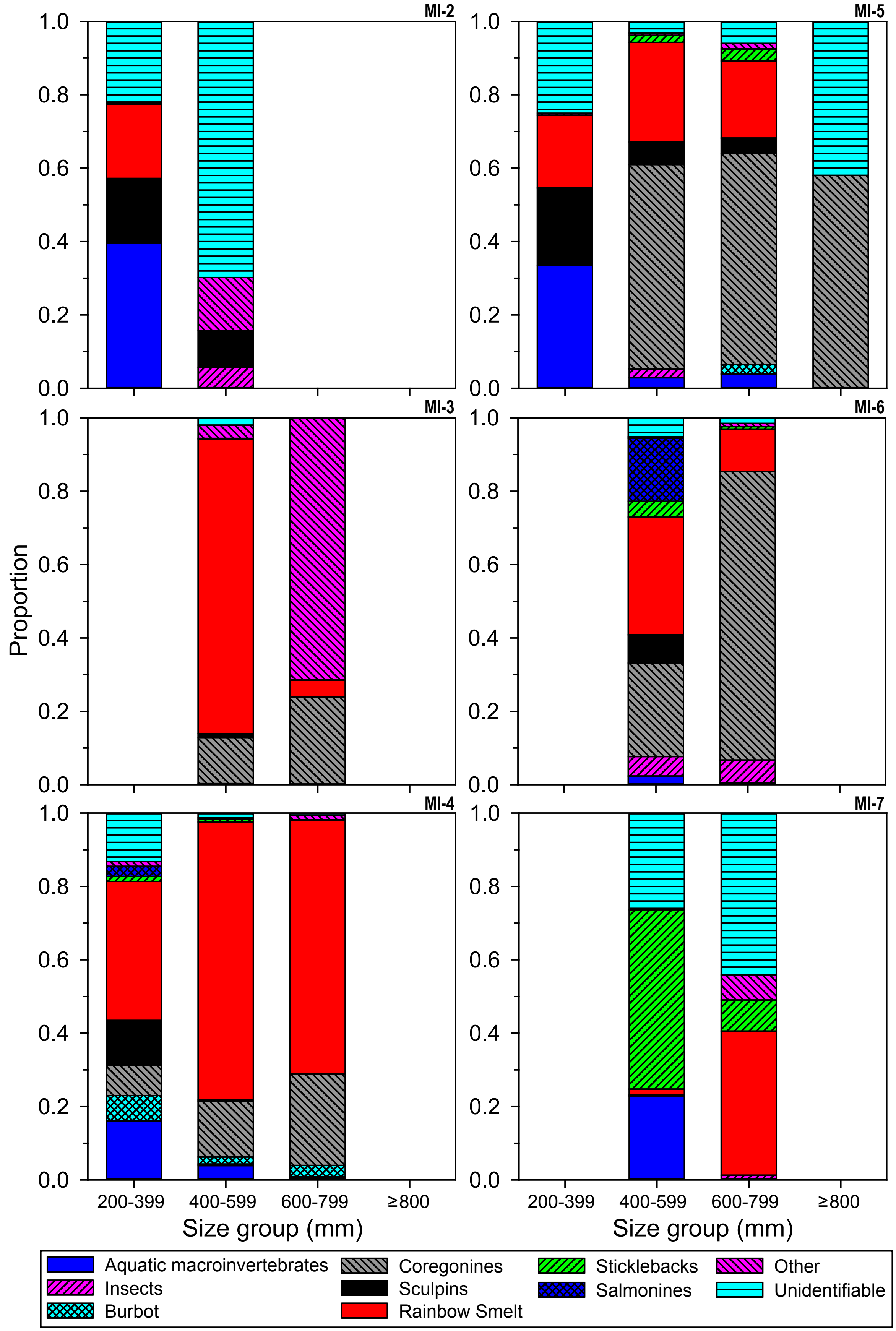

Figure 19.–Diet composition of hatchery-origin lean Lake Trout during 1998 to 2007 in Michigan waters of Lake Superior. Data were from spring and summer Lake Trout gill-net surveys.

Large lean Lake Trout (600 to 799 mm) diet was dominated by coregonines in MI-3 and MI-5 (Figure 18). In MI-6, both Burbot and coregonines were important in large lean diet. In MI-4, Rainbow Smelt and coregonines composed the majority of diet. In MI-7 and MI-2, large lean diet was diverse, though may not be well characterized because samples sizes were very low—8 fish in MI-2 and 48 fish in MI-7. In both of these units, insects composed a large proportion of the diet. In MI-2, Rainbow Smelt, coregonines, and sculpins were also prevalent. Few large hatchery Lake Trout were collected and there was none in MI-2 (Table 5). In MI-3, large hatchery diet was dominated by coregonines and other prey (Figure 19). In MI-4 and MI-7, Rainbow Smelt composed the greatest proportion of large hatchery Lake Trout diet. Coregonines were also prevalent in hatchery Lake Trout diet in MI-4. Both Rainbow Smelt and coregonines were most prevalent in the diet of large hatchery fish in MI-5 and MI-6.

The diet of the largest Lake Trout (≥ 800 mm) should be interpreted with caution because of low samples sizes (Table 5). Coregonines were the key prey item in the largest lean Lake Trout in all areas (Figure 18). In MI-4, Rainbow Smelt was also prevalent. In MI-5 and MI-6, Burbot was also important in largest lean diet. For the few largest hatchery fish collected, which all were in MI-5, coregonines were the prevalent prey item.

Body Condition

Between 1998 and 2007 average predicted weight of 450 mm lean Lake Trout ranged from 687 g in MI-2 to 751 g in MI-7. During the same period, condition declined slightly in MI-2, MI-5, and MI-7 (Figure 20). In all areas, condition of 450 mm lean Lake Trout increased between 2005 and 2007. Average predicted weight of 700 mm lean Lake Trout during 1998 to 2007 ranged from 2,786 g in MI-5 to 3,057 g in MI-7. Overall, condition of 700 mm lean Lake Trout in all areas has declined since 2000 (Figure 21). The greatest decline in 700 mm lean Lake Trout condition was west of the Keweenaw Peninsula, where predicated weight decreased 16 % in MI-2 and 11% in MI-3.

Mean Length at Age 7

During 1998–2007, there were no major trends in mean length at age 7 of wild lean Lake Trout in MI-4, MI-6, and MI-7 (Figure 22). Mean length at age 7 in MI-3 has progressively declined from 561 mm in 1998 to 490 mm in 2007. In comparison to the average for 1988–1997, overall mean length at age 7 during 1998–2007 was lower in MI-3 and MI-5. In MI-7, mean length at age 7 increased from 523 mm in 1998 to 564 mm in 2007. Overall, mean length at age 7 in MI-4, MI-6, and MI-7 remained about the same during 1998–2007 as during the previous 10-year period.

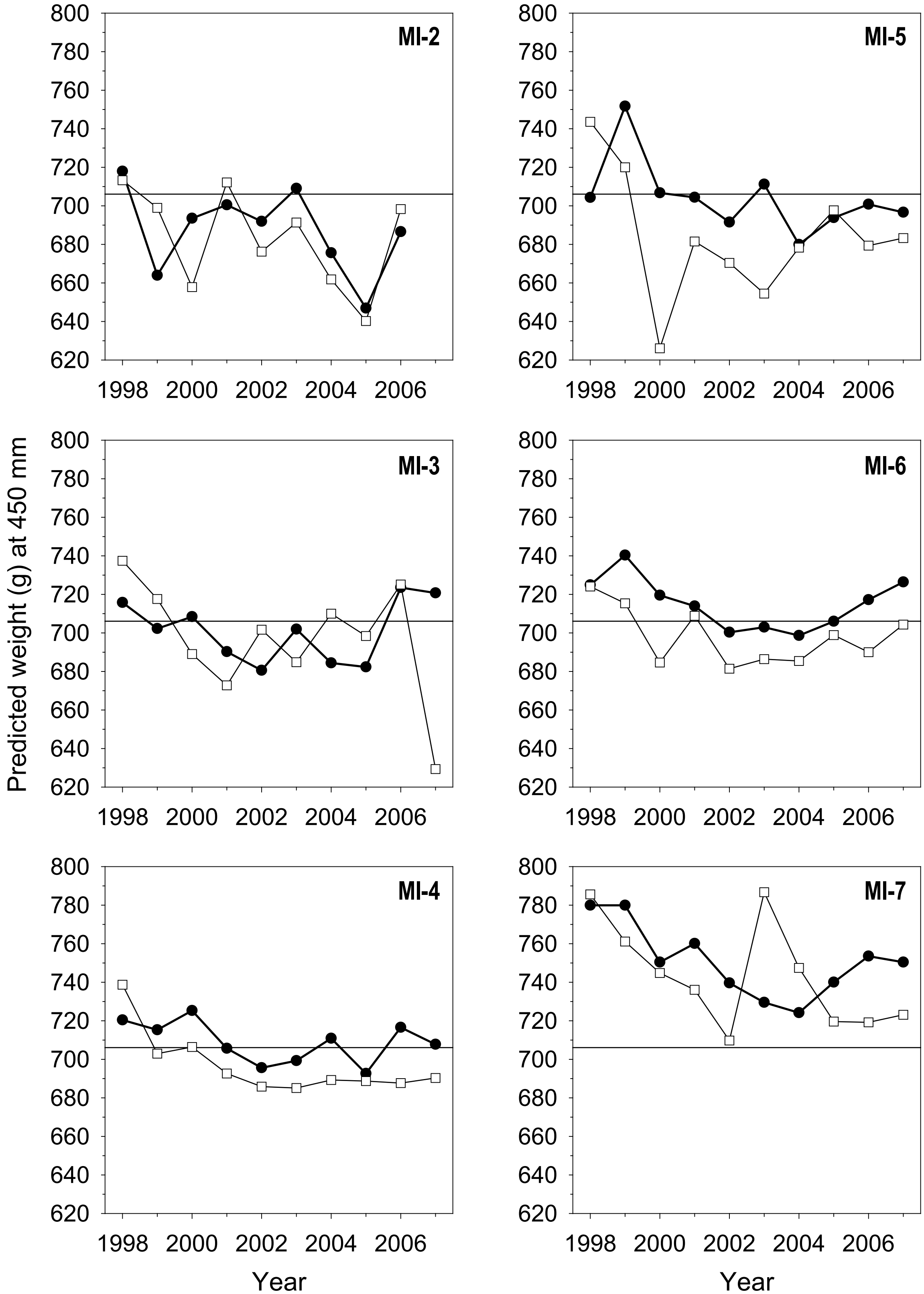

Figure 20.–Predicted weight at 450 mm for lean (circles) and siscowet (squares) Lake Trout in Michigan waters of Lake Superior, 1998–2007. Horizontal line represents overall average weight (across all areas and years) of both lean and siscowet Lake Trout.

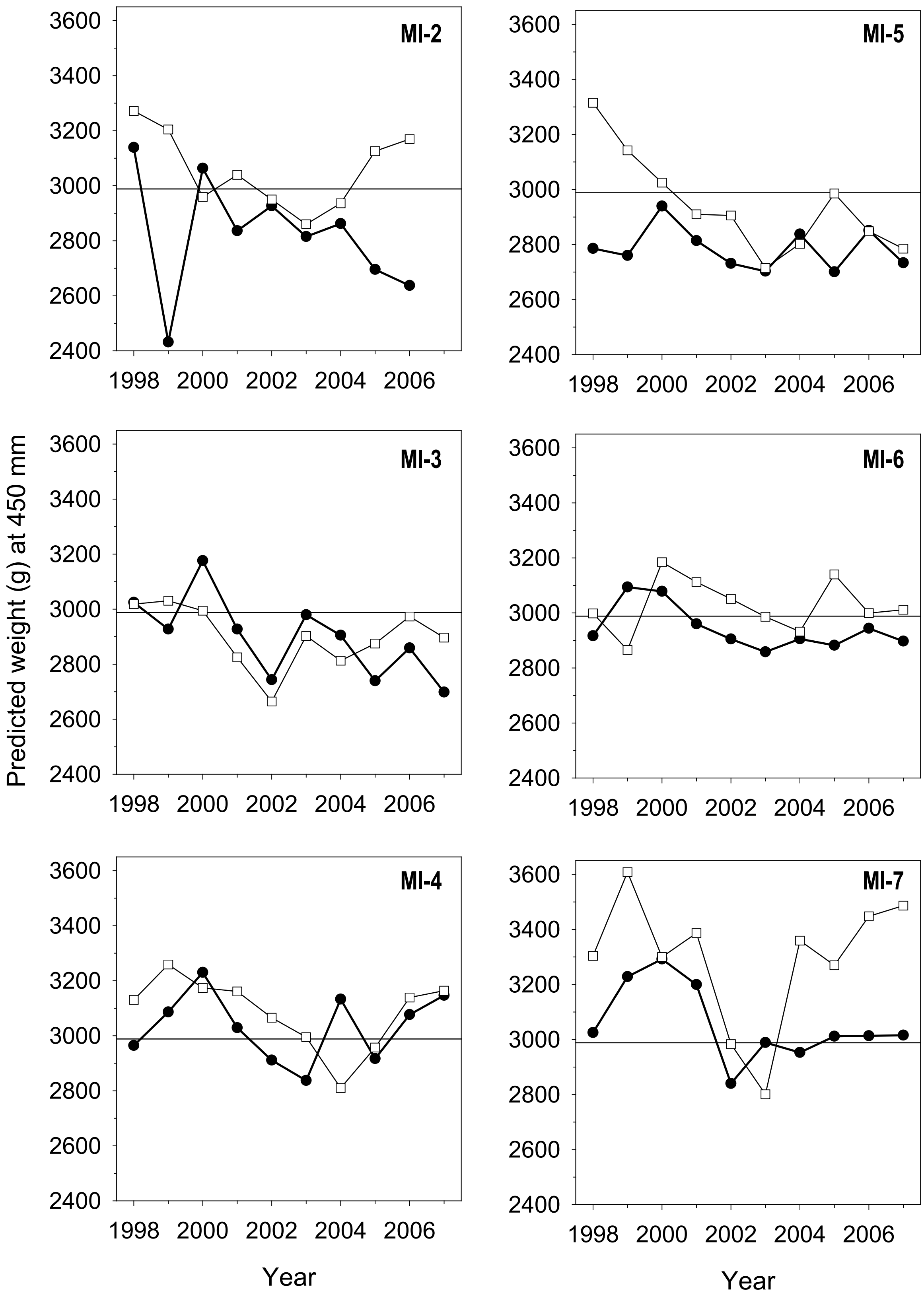

Figure 21.–Predicted weight at 700 mm for lean (circles) and siscowet (squares) Lake Trout in Michigan waters of Lake Superior, 1998–2007. Horizontal line represents overall average weight (across all areas and years) of both lean and siscowet Lake Trout.

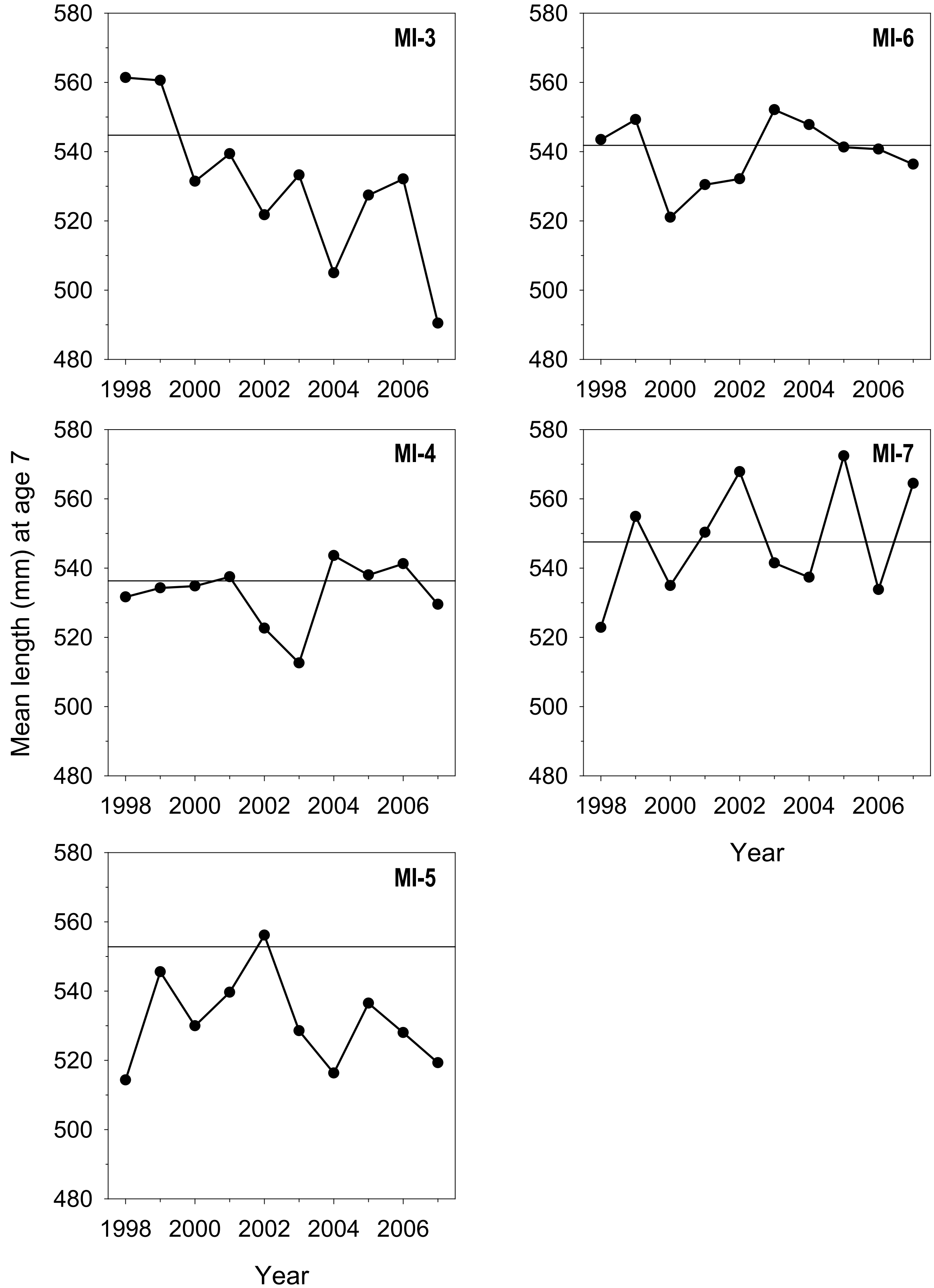

Figure 22.–Mean length at age 7 for wild lean Lake Trout collected during spring surveys in Michigan waters of Lake Superior, 1998-2007. Horizontal line represents the mean length at age 7 during 1988 to 1997 for that management unit.

Maturity and Sex Ratio

Male lean Lake Trout consistently reached 50% maturity at shorter lengths than females in all management units (Table 6). Male lean Lake Trout length at 50% maturity (L_{50}) averaged 79 mm less than females across all areas. Lean female L_{50} ranged from 592 mm in MI-7 to 703 mm in MI-3. Lean male L_{50} ranged from 515 mm in MI-7 to 600 mm in MI-6. Female L_{50} estimates were generally higher for lean than siscowet Lake Trout, though were only significant in MI-3 and MI-5. Lean male L_{50} was significantly higher than siscowet L_{50} in MI-4 and MI-5 (Table 6).

Table 6.–Logistic regression model estimates of length (mm) at 50% maturity (L_{50}) for lean and siscowet Lake Trout in Michigan waters of Lake Superior, 1998–2007. Data were based on Lake Trout collected during August–September in summer surveys. Confidence intervals (CI) were generated from bootstrapping (1,500 samples).

Management		Female		Male	
unit	Statistic	Lean	Siscowet	Lean	Siscowet
MI-2	L_{50}	633	597	543	558
	95% CI	(597, 683)	(577, 618)	(531, 556)	(545, 571)
	n	396	207	457	351
MI-3	L_{50}	703	610	589	599
	95% CI	(629, 792)	(596, 626)	(568, 614)	(587, 612)
	n	409	612	547	1,010
MI-4	L_{50}	651	628	598	568
	95% CI	(623, 695)	(610, 651)	(585, 615)	(559, 578)
	n	1,312	751	2,099	1,483
MI-5	L_{50}	679	602	595	567
	95% CI	(646, 723)	(587, 622)	(580, 611)	(557, 580)
	n	913	663	1,375	1,100
MI-6	L_{50}	657	609	600	577
	95% CI	(629, 694)	(590, 636)	(582, 622)	(563, 595)
	n	428	403	596	747
MI-7	L_{50}	592	560	515	504
	95% CI	(565, 629)	(543, 588)	(504, 530)	(495, 514)
	n	301	284	443	537

The sex ratio of lean Lake Trout was marginally male-biased during 1998–2007 based on data from spring and summer surveys (Table 7). The only area where the sex ratio was female-biased was in MI-3. The lowest percentage of lean females measured was in MI-5 (47%) and MI-6 (46%) during the summer survey.

Table 7.–Average percent of female lean and siscowet Lake Trout collected in Michigan Department of Natural Resources spring and summer gill-net surveys in Lake Superior during 1998 to 2007. No spring survey data were available for MI-2.

	Lean		Siscowet	
Management unit	Spring	Summer	Spring	Summer
MI-2		47.9		46.2
MI-3	51.8	48.1	52.2	47.7
MI-4	49.4	47.7	44.9	48.0
MI-5	49.2	46.9	50.2	47.2
MI-6	48.7	46.4	46.3	49.3
MI-7	47.7	48.6	46.3	49.4

Siscowet Lake Trout

Spring Survey Relative Abundance and Average Length

Relative abundance of siscowet Lake Trout in the spring survey was low (<10 fish • km • night^{-1}) in all management units (Figure 2). The greatest abundance of siscowet Lake Trout in the spring survey was in MI-7, and siscowet GMCPUE declined by 3-fold in this management unit between 1998 and 2007. In MI-6, siscowet GMCPUE increased gradually between 1998 and 2007. During the same period in MI-3, MI-4, and MI-5, siscowet GMCPUE was variable without trend.

Average length of siscowet Lake Trout was highest in western management units and was lowest in MI-6 and MI-7 (Figure 4). Further, mean length of siscowet Lake Trout was higher than lean Lake Trout in MI-3 to MI-5, but lower than lean Lake Trout in MI-6 and MI-7. There were no major temporal trends in average length of siscowet Lake Trout in the spring survey.

Summer Survey Relative Abundance and Age Composition

Relative abundance of siscowet Lake Trout from the summer survey was higher during 1998–2007 than earlier years in all management units except MI-3 (Figure 5). In MI-2, MI-4, MI-6, and MI-7, siscowet Lake Trout CPUE has generally increased between 1998 and 2007. During the same period, siscowet Lake Trout CPUE declined in MI-3 and MI-5. Siscowet Lake Trout collected in the summer survey were most abundant in MI-7 and least abundant in MI-2.

The age structure of siscowet Lake Trout in the summer survey was much broader and older than that for lean Lake Trout (Figure 23). In most management units, the age distribution of siscowet Lake Trout extended past age 20. Among all management units during 1998–2007, more than 60% of siscowet Lake Trout were age 10 and older. The only temporal trend in age composition was in MI-7, where the age structure became older in recent years with more than 80% of siscowet Lake Trout older than age 10. This corresponds with the increase in the mean length of siscowet Lake Trout caught in the survey (Figure 7). Mean length of siscowet Lake Trout in the summer survey increased during 1998 to 2007 in MI-2, MI-3, and MI-4.

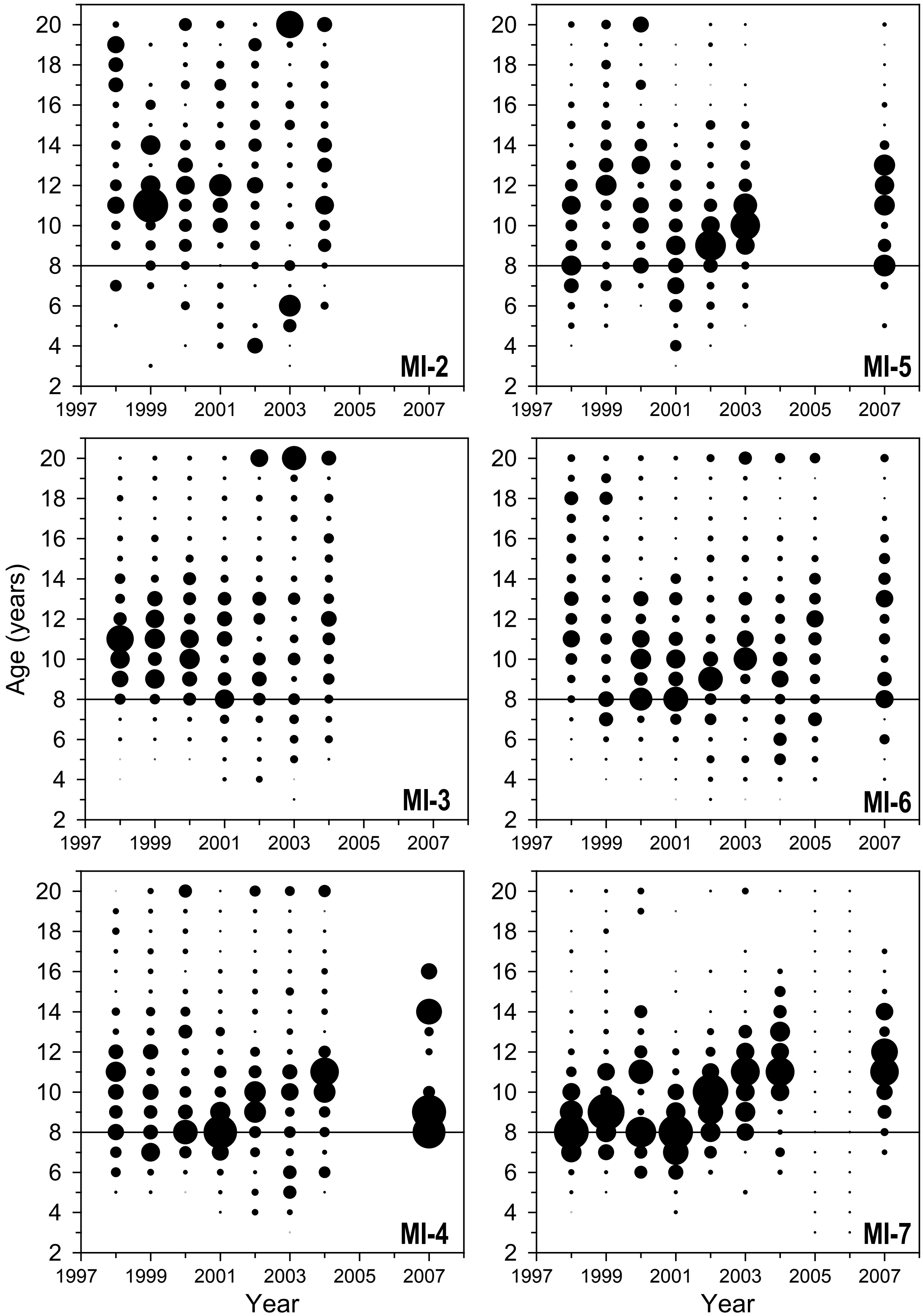

Figure 23.–Annual age composition of siscowet Lake Trout collected in the summer Lake Trout survey during 1998 to 2007 in Michigan waters of Lake Superior. The sizes of the circles represent the percent at age per year. Horizontal line at age 8 is provided for reference.

Siscowet Survey Relative Abundance and Size Structure in MI-5 and MI-6

The siscowet survey was conducted in 2000, 2003, and 2006 in MI-5, and during 2003 and 2006 in MI-6. The maximum depth sampled in MI-5 was 198 m and 399 m in MI-6, which was the greatest depth sampled for fish in Lake Superior and the Great Lakes. The maximum depth that lean Lake Trout were found was 195 m, though most were caught in less than 73 m. Siscowet Lake Trout were caught at nearly every depth interval sampled in both MI-5 and MI-6, and generally outnumbered lean Lake Trout (Figure 24). In MI-5, siscowet Lake Trout were most abundant beyond 183 m. In MI-6, siscowet Lake Trout were most abundant at depths greater than 37 m.

Siscowet Lake Trout between 250 and 950 mm were collected in both MI-5 and MI-6. Length distributions were variable among depth intervals in MI-5. However, in MI-6, siscowet length distributions skewed towards larger fish at depths greater than 146 m (Figure 25). More than 70% of siscowet Lake Trout collected deeper than 73 m were larger than 500 mm in MI-6. In both management units, very few siscowet Lake Trout smaller than 400 mm were observed beyond depths of 220 m and no fish of these lengths were observed deeper than 330 m.

Sea Lamprey Wounding

Spring Survey

Sea Lamprey wounding rates on siscowets in the spring survey were higher than lean Lake Trout in all management units except MI-7 (Figure 14). Among management units, siscowet wounding rates were lowest in MI-7 and highest in MI-4 during 1998–2007. There were no temporal trends in Sea Lamprey wounding on siscowet Lake Trout among all management units. With the exception of MI-5 and MI-7, siscowet wounding rates were higher during 1998–2007 than during the previous 10-year period.

Siscowet Survey in MI-5 and MI-6

Similar to lean Lake Trout, there were virtually no Sea Lamprey wounds on siscowet Lake Trout smaller than 534 mm. However, for siscowet Lake Trout larger than 533 mm, wounding rates sampled in this survey were much higher than those measured in the spring survey in shallower waters (<100 m). Sea lamprey wounds were found on siscowet Lake Trout (>533 mm) at nearly all depths that were sampled and wounding rates ranged from 0 in shallow depth intervals to 88.2 wounds/100 fish in deeper waters (Figure 26). In general, wounding rates were greater than 20 wounds/100 fish at depths beyond 220 m. Wounding rates were lowest at depths less than 74 m in both management units and generally increased over time during 2000 to 2006.

Fishery Harvest and Effort

Recreational

During 1998–2007, annual recreational harvest of siscowet Lake Trout was less than 1,000 fish/year in MI-2, MI-3, and MI-6 (Figure 16). Siscowet composed less than 5% of recreational harvest of all Lake Trout (lean and siscowet) in MI-5, and MI-6. In MI-2, siscowet Lake Trout made up about 21% of total Lake Trout harvest. In MI-7, the average percentage of siscowet Lake Trout in the recreational harvest of Lake Trout was 40%. In MI-4, siscowet Lake Trout made up about half of recreational harvest of all Lake Trout forms. In some years, siscowet harvest was higher than lean harvest in MI-4 (Figure 16).

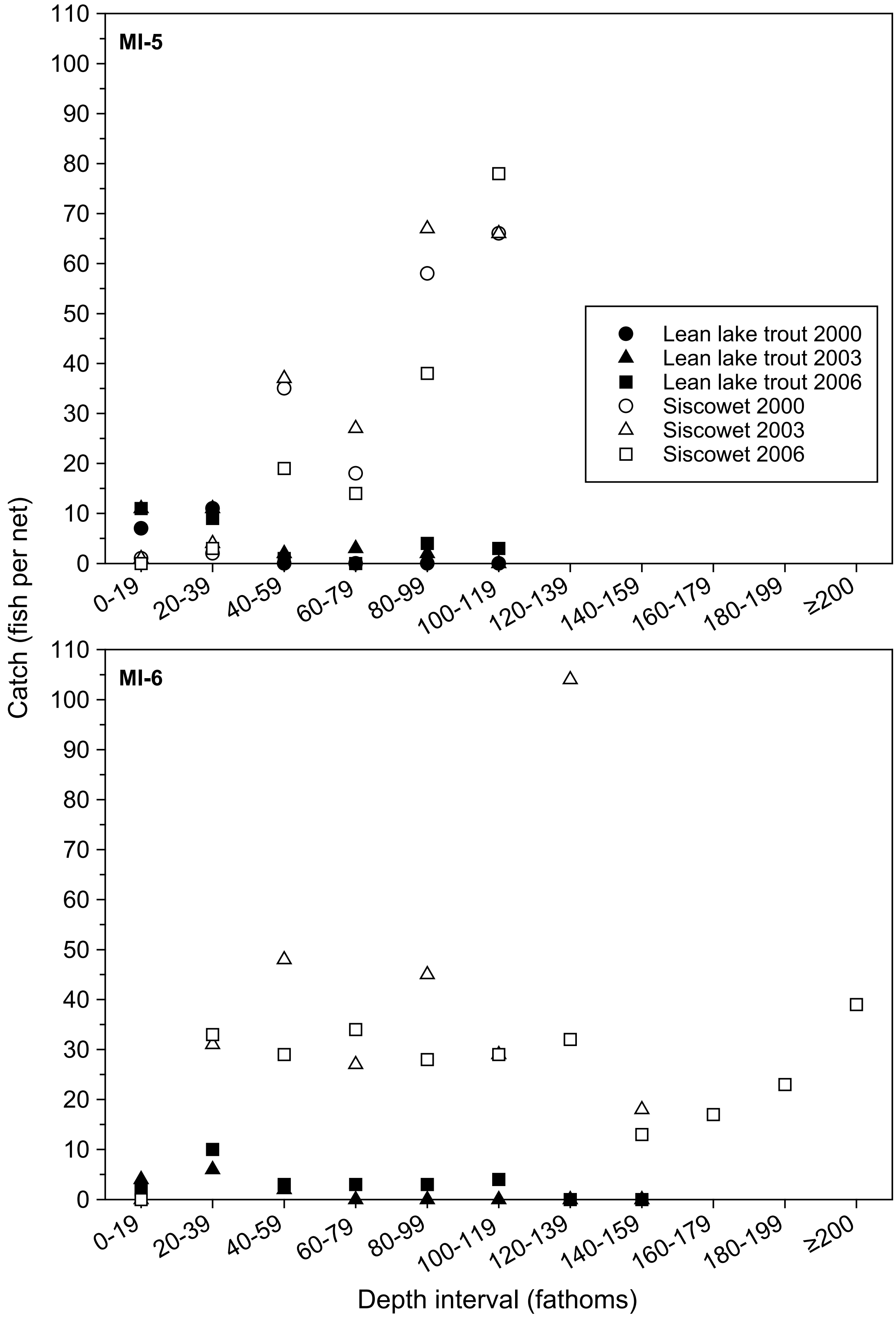

Figure 24.–Catch of siscowet and lean Lake Trout during the tri-annual siscowet survey in MI-5 and MI-6 during 2000 through 2006. The survey was conducted in MI-5 in 2000, 2003, and 2006. In MI-6, the survey was conducted in 2003 and 2006. Each symbol represents catch per 823 m of multi-mesh bottom gill net comprising the following stretched mesh sizes: 5.1, 6.4, 7.6, 8.9, 10.2, 11.4, 12.7, 14.0, 15.2 cm.

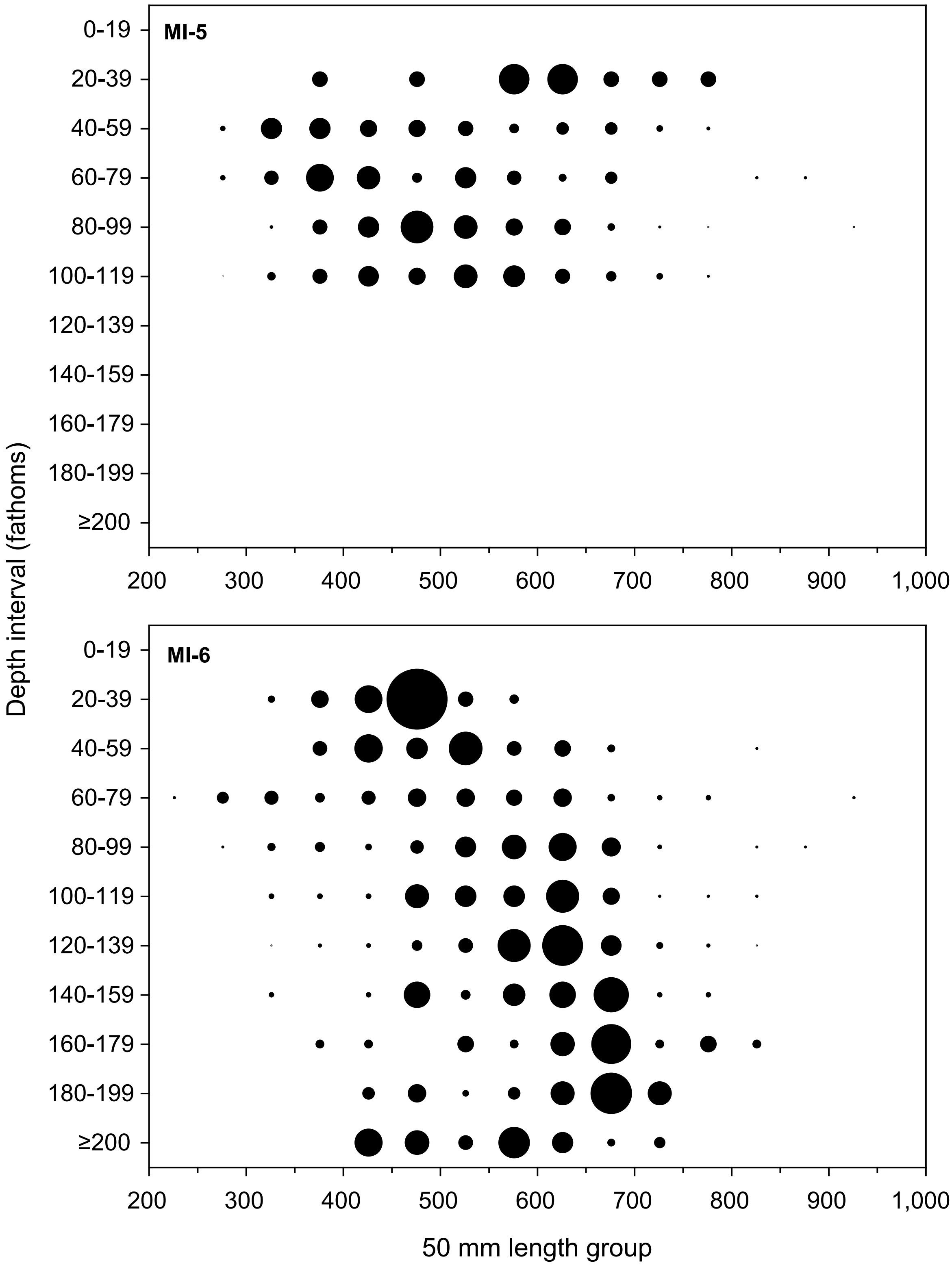

Figure 25.–Length composition of siscowet Lake Trout sampled during the tri-annual siscowet survey in MI-5 and MI-6 during 2000 through 2006. Circles are scaled percent of fish per 50 mm length group per depth-interval across all years sampled.

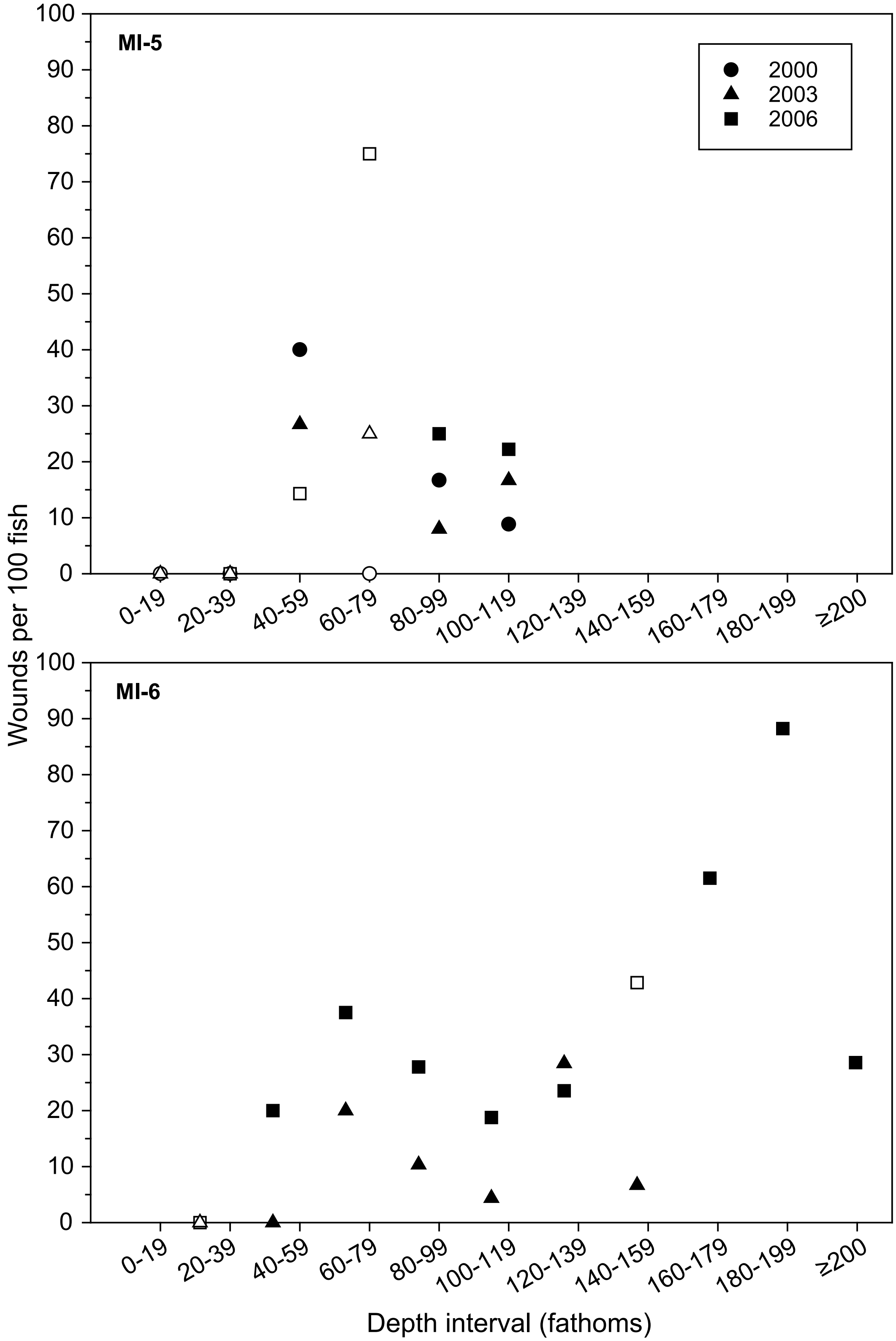

Figure 26.–Sea lamprey wounding rates by depth interval for siscowet Lake Trout (>533 mm) sampled during the tri-annual siscowet survey in MI-5 and MI-6 during 2000 through 2006. The survey was conducted in MI-5 in 2000, 2003, and 2006. In MI-6, the survey was conducted in 2003 and 2006. Open symbols represent wounding rates with low sample sizes of less than 10 fish.

Commercial

During 1998 to 2007, siscowet yield was highest in MI-4, averaging 8,100 kg/year and composing about 20% of total landing of Lake Trout in MI-4 (Figure 17). In MI-7, siscowet Lake Trout composed about 38% of Lake Trout yield and averaged 5,600 kg/year. In the earlier part of the time series in MI-2 and MI-3, siscowet Lake Trout composed about 35% of commercial yield, but has dropped to insignificant levels. In MI-5 and MI-6, siscowet Lake Trout were an insignificant component of the tribal commercial yield.

Diet Composition

Spring and Summer Surveys

Approximately, 4,200 nonempty siscowet stomachs were analyzed from 1998–2007 (Table 5). Sculpins and aquatic macroinvertebrates were most important in small siscowet (200–399 mm) diet (Figure 27). Rainbow Smelt composed less than 35% of small siscowet diet except in MI-2 where it made up 43% of the diet. In MI-5 and MI-7, Rainbow Smelt were absent in small siscowet diet.

Medium siscowet (400–599 mm) diet was diverse and varied geographically. Rainbow Smelt were a minor component in medium siscowet Lake Trout except in MI-4 (Figure 27). In MI-2 and MI-3, sculpins and coregonines dominated the diet. In MI-4, Rainbow Smelt and coregonines were most important. In MI-5, Burbot and sculpins were most prevalent in medium siscowet diet. Diet was most diverse in MI-6 for medium siscowet Lake Trout, which included coregonines, sculpins, Rainbow Smelt, sticklebacks, and insects. Similar to medium lean Lake Trout, sticklebacks were prevalent in the diet of medium siscowet Lake Trout. Aquatic macroinvertebrates were also in high proportion in MI-7 medium siscowet Lake Trout.

In MI-7, large siscowet (600–799 mm) diet comprised Burbot, coregonines, sticklebacks, and Rainbow Smelt (Figure 27). The largest-sized siscowet (≥ 800 mm) diet was dominated by coregonines in MI-3 and Burbot in MI-6 (Figure 27). In MI-4, largest siscowet diet was dominated by Burbot and lean Lake Trout (categorized as salmonines).

Siscowet survey

In MI-5, the maximum depth sampled was the 100–119 fathom interval (Table 8). In MI-6, stomach samples from siscowet Lake Trout were collected for the first time at the maximum depth (~400 m) in Lake Superior (and Great Lakes) in 2006.

In small siscowet (200–399 mm) diet, aquatic macroinvertebrates were the dominant prey at depths out to 40 fathoms in both MI-5 and MI-6 (Figures 28, 29). In MI-6, aquatic macroinvertebrates persisted in importance out to 100 fathoms. In MI-5, sculpins and coregonines became more dominant with increasing depth in the diet of small siscowet Lake Trout. In MI-6, sculpins and insects were in high proportion in small siscowet diet as depth increased beyond 80 fathoms.

The diet of medium siscowet Lake Trout (400–599 mm) was mostly dominated by coregonines or sculpins across all depth strata, except at depths less than 60 fathoms in MI-6 where aquatic macroinvertebrates were important (Figures 28, 29). The other exception was in MI-5, where aquatic macroinvertebrates dominated at the 20–39 fathom depth strata (Figure 28). Predation on salmonines was significant in MI-6 between 60 and 100 fathoms (Figure 29).

Large siscowet (600–799 mm) diet was variable at depths less than 80 fathoms because of low samples sizes (n < 20 fish; Table 8; Figures 28, 29). Burbot, sculpins, and coregonines were prevalent at depths less than 80 fathoms in both MI-5 and MI-6. Predation on salmonines (including Lake Trout) was predominant in the 60–79 fathom interval in both management units, based on only five fish in MI-5 and six fish in MI-6. At depths greater than 80 fathoms, large siscowet Lake Trout mostly consumed coregonines, Burbot, and sculpins.

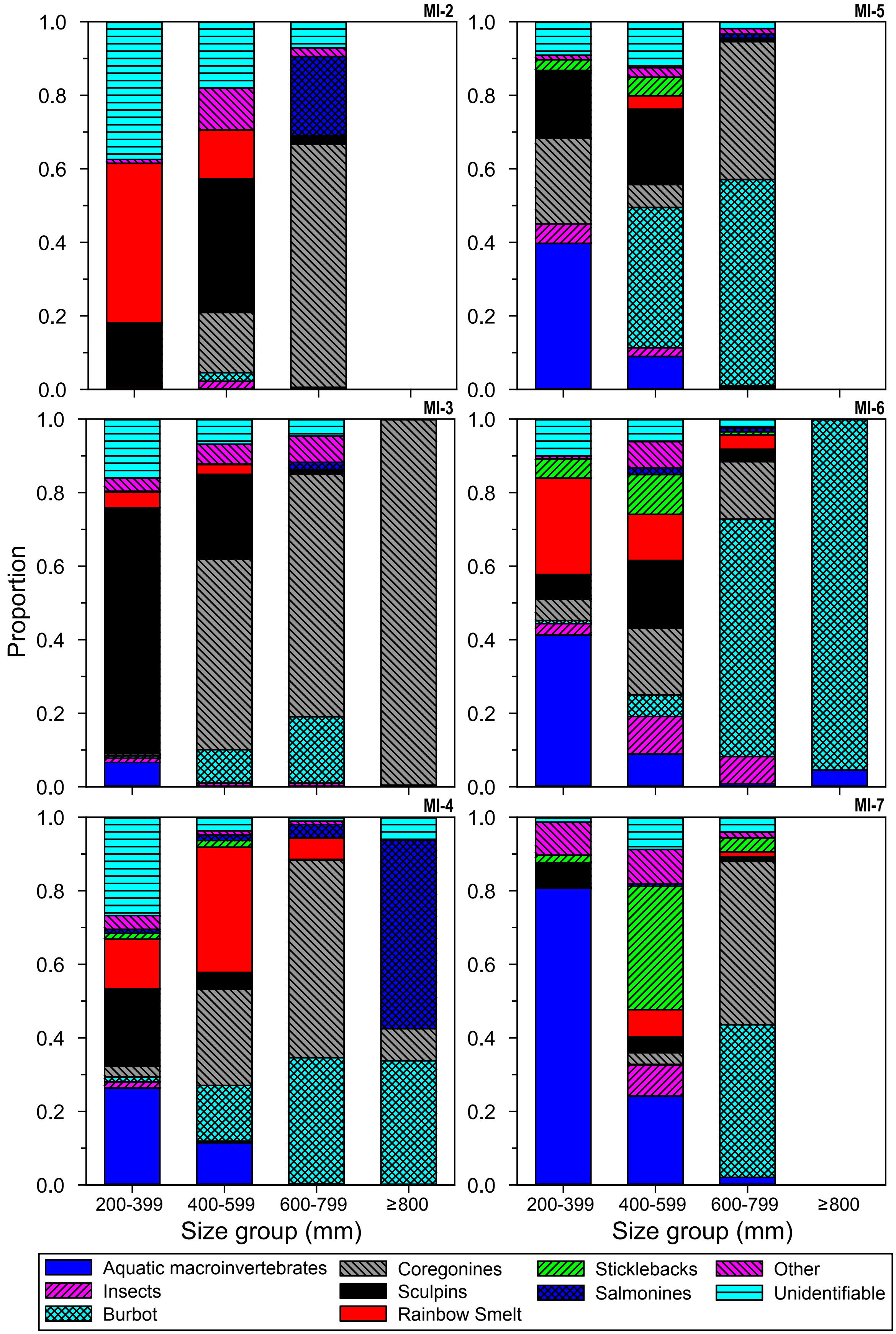

Figure 27.–Diet composition of siscowet Lake Trout during 1998 to 2007 in Michigan waters of Lake Superior. Data were from spring and summer Lake Trout gill-net surveys.

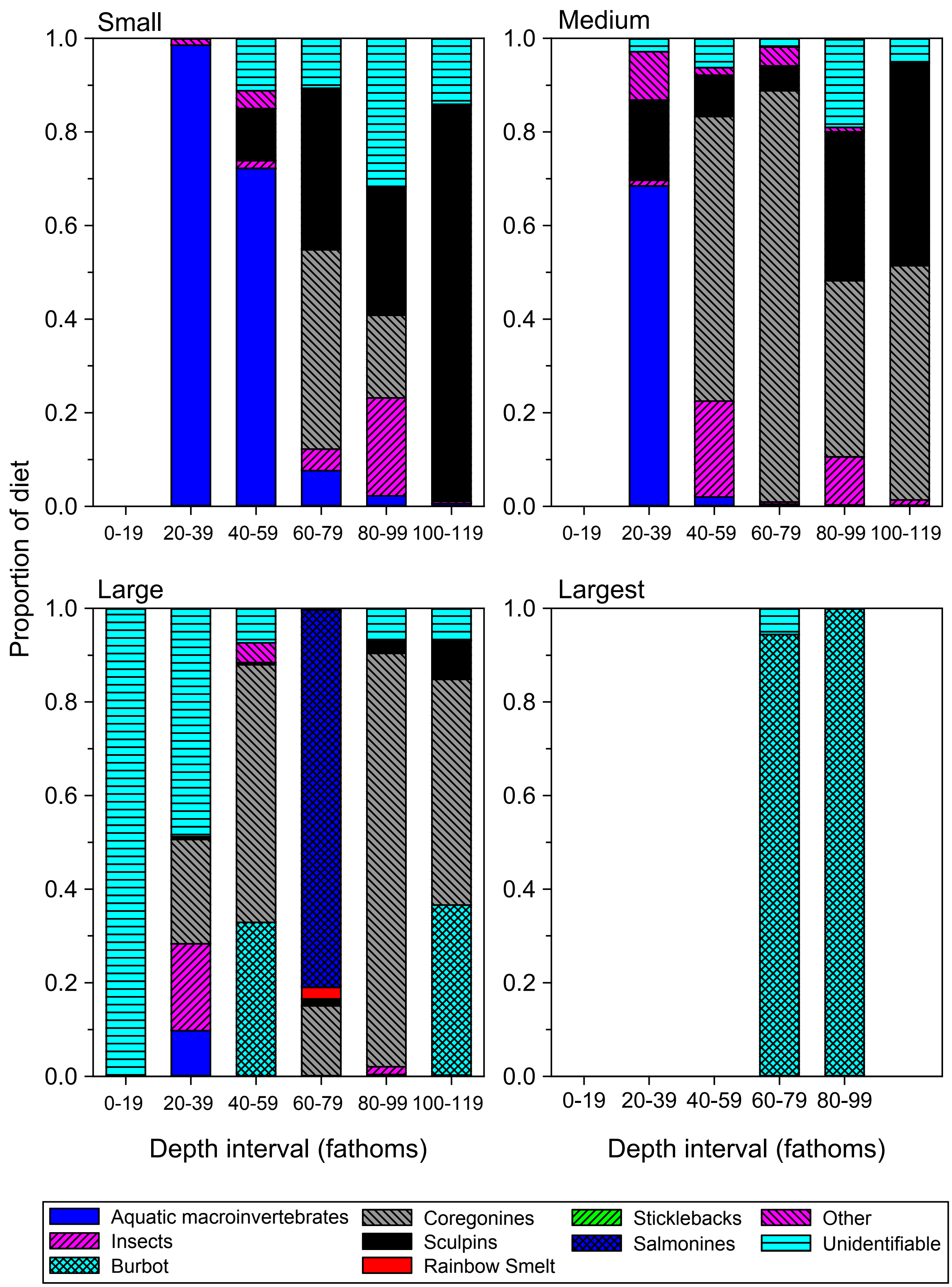

Figure 28.–Diet composition of siscowet Lake Trout collected in siscowet surveys in 2000, 2003, and 2006 in MI-5 in Michigan waters of Lake Superior.

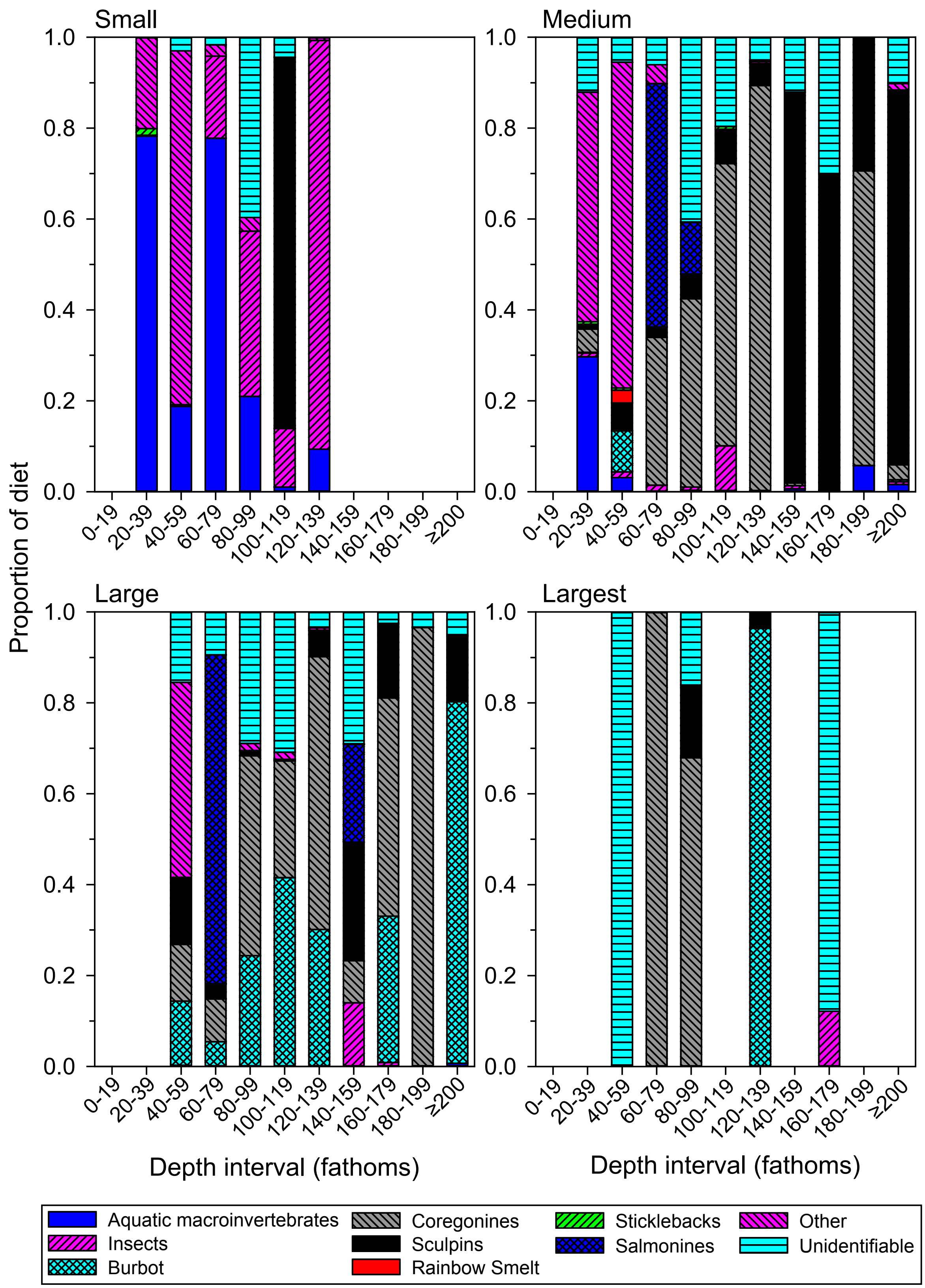

Figure 29.–Diet composition of siscowet Lake Trout collected in siscowet surveys in 2003 and 2006 in MI-6 in Michigan waters of Lake Superior.

Table 8.–Number of nonempty siscowet stomachs analyzed for diet composition in south-central Michigan waters of Lake Superior. Data were from siscowet/deepwater surveys conducted during the summers of 2000, 2003, and 2006. Data were stratified into 200 mm length groups and siscowet Lake Trout were collected in 20-fathom depth strata.

Management unit	Depth (fathoms)	Length (mm)			
		200–399	400–599	600–799	≥800
MI-5	0–19			1	
	20–39	1	2	5	
	40–59	29	27	18	
	60–79	16	21	5	1
	80–99	16	85	19	1
	100–119	29	86	35	
MI-6	0–19				
	20–39	10	46		
	40–59	6	45	13	1
	60–79	15	6	6	1
	80–99	7	21	19	2
	100–119	2	20	15	
	120–139	3	31	47	1
	140–159		12	12	
	160–179		2	11	1
	180–199		3	2	
	≥200		16	8	

There were only eight stomach samples for the largest siscowet group (≥ 800 mm) among all depth intervals from the siscowet surveys (Table 8). In MI-5, there were only two largest-category siscowet Lake Trout sampled, and their diet was dominated by Burbot (Figure 28). In MI-6, largest siscowet diet was dominated by coregonines and Burbot (Figure 29).

In summary, aquatic macroinvertebrates, sculpins, and coregonines were important in the diet of small siscowet Lake Trout out to 100 fathoms. Beyond 100 fathoms, small siscowet Lake Trout consumed sculpins and insects. Sculpins, Burbot, and coregonines dominated the diet of larger siscowet Lake Trout out to the deepest waters in MI-5 and MI-6. Cannibalism and predation on other salmonines were detected at various depth strata. Virtually no Rainbow Smelt or Alewives were present in the diet of siscowet Lake Trout in this survey.

Body Condition

Condition of small (450 mm) siscowet Lake Trout declined from 1998 to 2007 in MI-2, MI-4, MI-5, and MI-7 (Figure 20). The highest condition for small siscowet Lake Trout was MI-7. The lowest condition of small siscowet Lake Trout was in MI-2. There were no overall trends in condition of large (700 mm) siscowet Lake Trout during 1998–2007 except for a decline in MI-5 (Figure 21). Condition of large siscowet Lake Trout was highest in MI-7 and lowest in MI-3.

Maturity and Sex Ratio

Female siscowet Lake Trout reached 50% maturity at greater lengths than males in all management units (Table 6). Male siscowet L_{50} averaged 39 mm less than females. Siscowet female L_{50} ranged from 560 mm in MI-7 to 628 mm in MI-4. Siscowet male L_{50} ranged from 504 mm in MI-7 to 599 mm in MI-3. Lean male L_{50} was significantly higher than siscowet L_{50} in MI-4 and MI-5.

In most management units, sex ratios of siscowet Lake Trout were slightly skewed towards males in both spring and summer survey catches (Table 7). The lowest percentage of siscowet females was in measured in the spring survey in MI-4 (45%). The highest percentage of female siscowet Lake Trout was in MI-3 during the spring survey.

Assessment of Individual Stocks

MI-2

Although recruitment of lean Lake Trout has increased between 1998 and 2007, adult lean populations in MI-2 are at low abundance levels and have declined since the 1990s (Sitar et al. 2010). Commercial yield of lean Lake Trout has been increasing since 1999, and the proportion of lean Lake Trout larger than 600 mm has declined from 25% of spring survey catch in 1998 to 3% in 2006 (M. Symbal, Red Cliff Fisheries Department, personal communication). Sea lamprey wounding rates were below the Great Lakes Fishery Commission target levels for Lake Superior of five wounds/100 fish (Steeves et al. 2010). Hence, fishery exploitation of lean Lake Trout in MI-2 may be excessive on current stocks and caution is recommended in issuing harvest quotas. It is important that fishing and total mortality rates be estimated for lean Lake Trout in MI-2 in order to accurately gauge the status of population recovery.

Little is known about adult siscowet populations in MI-2 from lean Lake Trout surveys, though siscowet surveys conducted by Red Cliff Fisheries Department report comparable siscowet relative abundance as in other Michigan management units (Ebener et al. 2010). Siscowet recruitment (from summer survey) in MI-2 has trends similar to lean lake Trout and has increased since 1998. Given the low fishery exploitation of siscowet Lake Trout because of their deeper distribution, it is reasonable to presume that siscowet stocks are healthy in MI-2.

MI-3

Relative abundance of adult lean Lake Trout stocks in MI-3 has steadily increased since 1998, though recruitment has declined in recent years. Sea lamprey mortality was slightly above the target level, though lower than during the 1990s. Commercial gillnetting has been the only significant source of fishery exploitation on this stock and has declined to low levels in recent years. Growth and body condition of adult lean Lake Trout in MI-3 has declined in the last 10 years. Although abundance of lean Lake Trout in MI-3 is higher than the 1990s, it is still considered in the recovery process, and fishery exploitation should be monitored and controlled. As in MI-2, estimating fishing and total mortality rates will be important in effectively managing lean Lake Trout recovery in MI-3.

Siscowet populations in MI-3 appear to be in good health, with relative abundance estimates from siscowet surveys higher than populations east of the Keweenaw Peninsula (Ebener et al. 2010). Summer survey estimates of siscowet recruitment have increased since the 1980s and are at similar levels as lean Lake Trout. There is very little fishery harvest of siscowet Lake Trout in MI-3. Sea lamprey wounding rates on siscowet Lake Trout has been modest and has increased during the last 10 years. Condition of siscowet Lake Trout in MI-3 has declined between 1998 and 2007, and may be related to population density-dependent factors.

MI-4

The MI-4 lean Lake Trout stock is the most productive in Michigan waters of Lake Superior. Relative abundance of adult lean Lake Trout in MI-4 has increased in the last 10 years with consistent levels of recruits, which has supported the highest levels of commercial harvest in Michigan. Recreational harvest of lean Lake Trout was modest in MI-4. Growth and condition of lean Lake Trout is stable in MI-4. Given the strong fishery exploitation in this management unit, it is important that fishing and total mortality be estimated and monitored.

This is the only management unit that had measurable levels of hatchery lean Lake Trout because stocking by the Keweenaw Bay Indian Community continues even though the Lake Trout restoration plan criteria to cease Lake Trout stocking has been met more than 10 years ago (Hansen 1996). Fishery and survey data indicate that the importance of hatchery Lake Trout has diminished to an insignificant level. Continued stocking may have a negative effect on the genetic integrity of extant wild lean Lake Trout populations in MI-4.

The siscowet stock appears to be stable in MI-4. Siscowet harvest in MI-4 was the highest among all siscowet stocks in Michigan and it appears to be proportional to the amount of fishing effort expended for lean Lake Trout. Therefore, if lean Lake Trout harvest quotas are carefully monitored, then siscowet populations should be protected from excessive fishing.

MI-5

Overall, the MI-5 lean Lake Trout stock is abundant and exhibiting effects from density-dependent factors such as reduced growth and condition. This stock supports the highest level of sport harvest and modest levels of commercial harvest of lean Lake Trout in Michigan waters. Total mortality and SSBR (spawning stock biomass per recruit, a measure of reproductive potential) estimates from a statistical catch-at-age (SCAA) model developed for this stock were at satisfactory levels (Sitar and Netto 2009a). Sea lamprey predation persists as the dominant mortality source in MI-5. Fall spawning reef surveys found abundant large fish (> 700 mm), high Sea Lamprey wounding on large fish (not measured in other surveys), and consistent peak spawning occurs between the last week in October and first week in November. Commercial fishery exploitation on the local lean spawning stock near Presque Isle Harbor reef has been excessive; it is advised that a seasonal fishing closure be issued for MI-5 from 15 October through at least 15 November.

Siscowet populations are abundant in MI-5 (deeper than 75 m) and exhibit depressed growth and condition, possibly due to density-dependent effects. Fishery exploitation on siscowet Lake Trout in MI-5 was minimal. The major source of mortality on siscowet Lake Trout is likely Sea Lamprey predation. Overall, siscowet populations in MI-5 are considered stable and healthy.

MI-6

Abundance of lean Lake Trout in MI-6 has generally remained at the same average level since the mid-1980s, though recruitment of young age classes has declined slightly since 1998. This lean Lake Trout stock supports the second highest level of sport harvest in Michigan waters. Overall, growth and body condition of lean Lake Trout has remained stable in MI-6. Statistical catch-at-age model estimates of total mortality and SSBR for MI-6 were at satisfactory levels (Sitar and Netto 2009b). However, Sea Lamprey-induced mortality has been high, above the target maximum rate, and increasing in MI-6.

Siscowet Lake Trout are abundant in MI-6, which is the management unit that contains the deepest waters in the Great Lakes. There is virtually no fishery exploitation on siscowet Lake Trout in MI-6. The key source of mortality on siscowet Lake Trout is likely from Sea Lamprey predation. Observed Sea Lamprey wounding rates on siscowets in MI-6 were modest and have increased significantly since the mid-1980s. Body condition of siscowet Lake Trout in this unit was stable and recruitment has increased in recent years. Siscowet populations are healthy and stable in MI-6.

MI-7

Lean Lake Trout abundance, size (and age) structure has been increasing in this unit. Furthermore, body condition and growth were above average in MI-7. Recreational harvest of lean Lake Trout has been low and declining. Commercial yield, which was at modest levels in the early 2000s, has declined to very low levels in recent years. Sea lamprey predation was the dominant mortality source and has been increasing to pre-1998 high levels. Statistical catch-at-age model estimates of total mortality and SSBR for lean Lake Trout in MI-7 were at acceptable levels (Sitar and Netto 2009c).

Siscowet populations are abundant in MI-7. Recruitment has increased in recent years. Siscowet Lake Trout compose a modest part of both the recreational and commercial fishery. Body condition for siscowet Lake Trout in MI-7 was the highest in Michigan waters. Sea lamprey wounding rates on siscowets during the last 10 years in MI-7 were relatively low and have remained lower than the prior 10-year period. Siscowet populations in MI-7 are stable and healthy.

Discussion

Lean Lake Trout populations in Michigan waters of Lake Superior east of the Keweenaw Peninsula to Whitefish Point are abundant, self-sustaining, and meet the fish community objective for Lake Trout (Horns et al. 2003). In Michigan waters on the west side of the Keweenaw Peninsula, lean Lake Trout populations are self-sustaining, but low in abundance and are still in the recovery process, and are not considered to meet the Lake Trout fish community objective. Overall in Michigan waters, decreased length at age, reduced condition of adults, shifting length at maturity (Sitar and He 2006), and increases in the proportion of older fish indicates density-dependent responses in lean Lake Trout populations.

Siscowet populations are self-sustaining and abundant in all deepwater areas of Michigan waters of Lake Superior. Siscowet populations are likely at or near equilibrium levels, though continuous relative abundance indices (like those available for lean Lake Trout) are not available to gauge recent trends. Fishing mortality on siscowet populations has been low, but prospective commercial fishery interests could affect sustainability if potential increased harvest is not quantitatively evaluated.

Sea lampreys continue to be the dominant mortality source for all lean Lake Trout populations. Sea lampreys prefer larger Lake Trout and wounding rates can be very high as indicated from the fall lean Lake Trout spawning surveys conducted in MI-5. Furthermore, high wounding rates on siscowet Lake Trout, which have deeper (and offshore) distribution than lean Lake Trout, indicate that Sea Lampreys are pervasive. Sea lamprey control efforts need to be continued and improved in order to benefit Lake Trout populations.

Fishery exploitation is also an important force on lean Lake Trout stocks in many management units. Fishing mortality rates for those lean Lake Trout populations that have been estimated by statistical catch-at-age models were at acceptable levels. Further work is necessary to complete the development of statistical catch-at-age models for other stocks in order to estimate total and component mortality rates in comparison to target values.

Lake Superior Lake Trout populations provide a model of success for other Great Lakes in the process of Lake Trout recovery. Lake Superior Lake Trout are part of a natural ecosystem that exemplifies how native species food webs self-regulate and compensate to disturbances such as nonnative species or environmental change. The existence of sympatric morphotypes in Lake Superior illustrates the dynamic ability that Lake Trout have to adapt to habitat complexity in large, North American lakes. Improved understanding of these adaptations will improve efforts to recover Lake Trout populations in the Great Lakes

Long-term stock assessment programs conduct surveys, carry out research studies, and develop quantitative models that are important tools supporting management of fish populations. Assessment of Lake Trout stocks in Michigan waters of Lake Superior has been ongoing since the collapse of populations in the 1950s and would not have been possible without its research vessels. Hence, it is important that support for the MIDNR research vessel and long term Lake Trout stock assessment programs be continued and enhanced with new technologies.

Recommendations for Research and Management

Future research needs include:

- Expanded surveys of siscowet Lake Trout in deep water areas of Lake Superior,
- Surveys to measure relative abundance and life history characteristics of offshore Lake Trout populations,
- Location and characterization of siscowet and humper spawning sites,
- Quantifying lean Lake Trout spawning habitat,
- Improved estimates of lean Lake Trout recruitment at young ages (age 0 or age 1).

In order to properly and effectively manage Lake Trout stocks and monitor the status of populations, a MIDNR management plan for fish populations in Lake Superior needs to be developed with time-lined biological, fishery, and socially-accepted reference points. Public input coupled with stock assessments can be used to guide management actions and plans to better manage Lake Trout populations and other fishes in Lake Superior.

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