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Bioenergetics Evaluation of the Fish Community in the Western Arm of Lake Superior in 2000 and 2004[1]

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Table of Contents

Figures

Abstract.— Lake Superior's fish community continues to change due to recovering lake trout *Salvelinus namaycush* populations, naturalization of introduced salmonids, declines in rainbow smelt *Osmerus mordax* populations, and fluctuating cisco *Coregonus artedii* year classes. This study used bioenergetics modeling of predator fish in the western arm of Lake Superior, including Minnesota and Wisconsin waters, to provide a comprehensive picture of community dynamics. Simulations of consumption by predators in 2000 and 2004 revealed current trends, and enabled comparisons to previous studies in the late 1980s and early 1990s. Modeling results are presented for nearshore and offshore areas, for three ecoregions representing geographically distinct areas, and for Minnesota and Wisconsin waters within the western arm. Results indicate that the western arm of Lake Superior is at or near carrying capacity for predators. Lean lake trout are responsible for most consumption of rainbow smelt and coregonines, while the deepwater form of lake trout known as siscowet ranks second in predatory consumption. Although individual Chinook salmon *Oncorhynchus tshawytscha* consumed more prey fish per unit time than did any other species, they along with other potadromous species played minor roles in total consumption. Hydroacoustic estimates of prey fish populations were generally sufficient to account for total consumption by all predators modeled, especially if supplemented by prey in adjacent ecoregions or Michigan waters. Chinook salmon appears to be an indicator species for inadequate forage, as it responded to declines in the rainbow smelt population with a dramatic diet shift to cisco and a decline in weight-at-age since the early 1990s. Because most predators in the western arm are wild fish, and survival of stocked predators has declined dramatically, managers no longer have the ability to control prey populations through stocking. Periodic hydroacoustic assessments of forage fish populations, predator diet monitoring, and bioenergetics analyses of predator consumption are warranted to track predator-prey dynamics, provide data for management of the fisheries, and quantify the allocation of prey species for the commercial fishery in the western arm of Lake Superior.

Introduction

The Lake Superior fish community has been changing continuously during the past century, but alterations have been most dramatic since the 1950s when sea lamprey *Petromyzon marinus* invaded the lake, native populations of lake trout *Salvelinus namaycush* and cisco (formerly called "lake herring") *Coregonus artedii* declined, introduced rainbow smelt *Osmerus mordax* became the dominant prey species, and several species of Pacific salmonid *Oncorhynchus* spp. predators were introduced to enhance recreational fishing. The recent rehabilitation of lake trout populations in much of Lake Superior, the naturalization of introduced salmonine species, and continued shifts in abundance of forage species (Bronte et al. 2003; Ebener, in press) have raised the concern of fisheries managers and public groups over the impacts of increased predation on the available forage base. Heist and Swenson (1983) warned that rainbow smelt production was insufficient to support the fisheries or predator populations previously supported by cisco, and recent declines in rainbow smelt populations appear to substantiate this claim. Stewart and Ibarra (1991) stated that overstocking predators could result in a catastrophic decline in a primary prey stock, and a rapid switch to other prey species could similarly depress those populations.

The concept of limited production capacity in Lake Superior is difficult to convey to public proponents of each favored predator species. Many user groups have opposed reductions in stocking, and have promoted the simultaneous restoration of both native and non-native species to historic high levels. This advocacy has only recently begun to falter as evidence of poor survival by stocked fish and indications of inadequate forage for some species increase. At the same time, sport anglers have historically opposed the commercial harvest of prey fish, fearing that food is being taken away from predatory game species. The emergence of hydroacoustics as an effective tool for quantifying pelagic prey biomass and the application of bioenergetics modeling to predator species enable managers to evaluate the capacity of Lake Superior to support current and potential abundances of wild, naturalized, and hatchery-reared predators, or commercial harvest.

In a previous study, bioenergetics modeling was applied to fisheries data from Minnesota waters in 1989 in an effort to coordinate available information and quantify predator consumption so that it could be compared with prey availability (Negus 1995). The Wisconsin bioenergetics model (Hanson et al. 1997) provided a useful format for compiling, cataloging, and organizing available data of various types. The model integrates these data, and can be used to investigate various management or growth scenarios so that quantifiable results can be documented and verified. Negus (1995) used simulation results to compare the relative impacts of predator consumption, commercial harvest, and sport fishing on a limited forage base, for both fisheries management purposes and public information. However, the results were compromised by incomplete or absent data, so this study functioned to highlight areas where information was most lacking, and assisted in directing future data acquisition. For example, the lack of adequate forage base estimates was used to justify a hydroacoustic study of forage populations in the western arm of Lake Superior (Johnson et al. 2004; Mason et al. 2005; Hrabik et al. 2006).

Since 1989, data required by the model have been updated or collected for the first time. Studies of Chinook salmon *Oncorhynchus tshawytscha* have shown that most of these fish are now naturally produced (Jones and Schreiner 1997; Peck et al. 1999; Schreiner et al. 2006). In addition, predator diet information from state and provincial agencies surrounding the lake have been compiled (Ray 2004), thermal and depth distributions of lake trout have been studied using archival tags (Mattes 2004), and models to estimate lake trout abundance using statistical catch-at-age with size-at-age and mortality rates have been generated (Bence and Ebener 2002; Schreiner et al. 2006; Linton et al. in press; M. Drake, Minnesota Department of Natural Resources [MNDNR], personal communication). Lean lake trout populations have rebounded sufficiently to warrant reduction or elimination of stocking in most areas (Schreiner and Schram 1997), and the dominance of the fat form of lake trout known as siscowet in deep water regions has been studied (Bronte et al. 2003; Ebener, in press). Trap return data in Minnesota's French and Knife rivers, and creel data during the 1990s also provided updated size-at-age and mortality information on lake-dwelling/stream-spawning (potadromous) species (Halpern 2002; Schreiner et al. 2006; MNDNR, unpublished data).

Few examples exist of bioenergetics studies that revisit previously modeled populations to evaluate earlier conclusions and determine if predictions were accurate. One such study in Lake Ontario (Rand and Stewart 1998) was used to evaluate shifts in predator diets and the forage base. Studies of this type can be useful for validating the predictive abilities of the Wisconsin bioenergetics model, while evaluating community dynamics within a lake. While several other studies have used models to address different aspects of the predator and prey communities in Lake Superior (Ebener 1995; Mason et al. 1998; Harvey and Kitchell 2000; Kitchell et al. 2000; Harvey et al. 2003), sufficient new data on predator and prey populations have only recently become available to allow an updated study to parallel the earlier one by Negus (1995).

Negus' (1995) preliminary study was limited in scope, and included primarily stocked fish within the bounds of Minnesota waters of Lake Superior. The current study includes stocked and naturally reproduced predator fish, and encompasses the western arm of the lake, which includes Minnesota and Wisconsin waters. The objectives of this study were to: (1) compile and catalog recent data on predator and prey species in the western arm of Lake Superior; (2) compare predator consumption estimates from bioenergetics simulations to the amount of available coregonine and rainbow smelt biomass; (3) compare commercial, sport, and assessment harvests to the amount of available biomass of coregonines (including cisco, kiyi *Coregonus kiyi*, and bloater *C. hoyi*) and rainbow smelt;

(4) compare the relative amounts consumed by predators in nearshore and offshore areas within three ecoregions, and in Minnesota and Wisconsin waters of the western arm, in 2000 and 2004; (5) compare the consumption by stocked predators to the consumption by naturally reproduced predators; (6) compare diets and cumulative consumption by individual fish of each predator species along with cumulative consumption by predator populations; and (7) compare predator and prey populations from 2000 to 2004.

Methods

The Wisconsin bioenergetics model (Hanson et al. 1997) was used to model consumption based on growth of the major predator species in the western arm of Lake Superior (Figure 1). Chequamegon Bay was not included in this study, due to its dissimilarity to the rest of the western arm and because that area was the focus of another study (Devine et al. 2005). The years 2000 and 2004 were modeled, including extant year classes of major predators both stocked and naturally reproduced. Predator species include lake trout (both the lean form and siscowet), Chinook salmon, coho salmon *Oncorhynchus kisutch*, rainbow trout *O. mykiss* (two migratory strains: the naturalized "steelhead" strain and the "Kamloops" hatchery strain stocked in Minnesota), brown trout *Salmo trutta*, burbot *Lota lota*, and walleye *Sander vitreus*. Minnesota and Wisconsin waters of Lake Superior have been divided into five lake trout management areas (Hansen 1996), but in this study the management areas were combined into three ecoregions of similar habitat types (Figure 1; Table 1). Simulations of nearshore and offshore species were also distinguished using 80 m (40 fathoms) as the dividing contour, to define the differing influences of the fish communities in the two depth zones.

We modeled only the time spent in Lake Superior by each species. For most species, the first simulation day was 1 June, and the final day was 31 May. Most migratory species enter the lake as smolts or are stocked about 1 June, and thus their predatory impact begins at that time. Age-0 lake trout simulations began on 1 July, to correspond to the approximate start of exogenous feeding (Bronte et al. 1995; Hudson et al. 1995).

Parameters supplied with the Fish Bioenergetics 3.0 (Hanson et al. 1997) documentation were used to model Chinook salmon, coho salmon, steelhead (including all strains of migratory rainbow trout), and walleye juveniles and adults. Energy densities in the lake trout model were modified to more accurately represent the lean and siscowet forms in Lake Superior (Johnson et al. 1999). Parameters for brown trout were supplied by Dieterman et al. (2004), and a burbot model developed by Rudstam et al. (1995) was modified for Lake Superior (Johnson et al. 1999) (Table 2). Additional data required by the model to tailor regional results for each predator species include: Abundance-at-age, diets, prey energy densities, weight-at-age, mortality rates, spawning date, age of maturity, average weight lost during spawning, and temperatures occupied.

Total consumption of coregonines and rainbow smelt by all predators was compared to biomass-plus-production ("availability") of these prey categories in the western arm as a whole, in nearshore and offshore areas of the western arm, and within three ecoregions. Consumption by predators was also compared to the commercial, sport, and assessment harvests. The availabilities of other diet items were not calculated for comparison with total consumption. The biomass of coregonines and rainbow smelt consumed by individual predators, and by entire populations of predators, were compared to determine which individuals or species had the most impact on these forage fish. Similar comparisons were made for total prey consumption by individuals and populations of predators. Much of the data for potadromous species came from MNDNR unpublished data collected at the French and Knife River traps, and from Wisconsin Department of Natural Resources (WIDNR) at the Bois Brule River fishway.

Study area

The western arm of Lake Superior includes both Minnesota and Wisconsin waters (Figure 1; Table 1). Surface areas within selected depth zones in the western arm were calculated from a bathymetric map supplied by the National Oceanographic and Atmospheric Administration (NOAA) in December 2006. The geographical breakdown for simulations was based on two management zones in Wisconsin (WI-1 and WI-2), and three zones in Minnesota (MN-1, MN-2, and MN-3). These management zones were regrouped to form three ecoregions based on geographic similarity. The three ecoregions are similar to those used in hydroacoustic studies of the forage base (Johnson et al. 2004; Mason et al. 2005), except that this study included Minnesota and Wisconsin waters in their entirety, and divisions between ecoregions incorporate the borders of the management zones. Ecoregion 1, which includes management zones MN-1 and WI-1, is the western tip of the lake, with low to moderate slope. Ecoregion 2, which is equivalent to management zone WI-2, is the Apostle Islands area (excluding Chequamegon Bay) and includes the largest area of shallow water. Ecoregion 3, which includes management zones MN-2 and MN-3 along Minnesota's steep, rocky north shore, represents the deep open lake. All surface areas were calculated using ArcView GIS (1996) software (Table 1).

Literature Review and Data Compilation

Predator population abundance

Predator abundances in the western arm of Lake Superior in 2000 (Table 3A) and 2004 (Tables 3B-3K) included naturally reproduced and stocked fish of each species. Predator population numbers within each ecoregion in 2000 and 2004 (Tables 3C-3E: 2004 values only) were compiled for bioenergetics simulations, and abundances within Minnesota and Wisconsin in 2004 are provided for comparison (Tables 3F and 3G: 2004 values only). (Population estimates within each subdivision in 2000 were not provided due to the excessive number of tables required.) Numbers of each species stocked into the western arm were supplied by Topel and Hulse (2001), WIDNR (unpublished data), and MNDNR (unpublished data). Lean lake trout are stocked primarily as yearlings bearing fin clips to identify year class, but most lean lake trout in Lake Superior are now naturally reproduced fish. Lean lake trout abundances, both wild and stocked fish, were estimated using statistical catch-at-age models developed for Minnesota waters (M. Drake, MNDNR, personal communication) and Wisconsin's Ecoregion 2 (Linton et al. in press). Wild lake trout of ages 0-2 were estimated by back-calculation from age-3 populations using the natural mortality rate. Wild lean lake trout populations in Wisconsin waters of Ecoregion 1 were estimated using densities equal to those in MN-1 based on total surface area. Lean lake trout primarily occupy water less than 80 m in depth, and siscowet primarily occupy areas deeper than 80 m. The distribution of lean lake trout in nearshore (<80 m) and offshore (>80 m) waters was determined using the proportion caught at various depths in population assessment gillnets set by MNDNR and WIDNR (Ebener 2003), weighted by the surface area within each depth zone. Siscowet populations were estimated based on the ratios of siscowet to lean lake trout caught in assessment nets set in each depth zone, weighted by the surface area of each depth zone within each region, and applied to the population estimates of lean lake trout from statistical catch-at-age models. This method assumes equal catchability of siscowet and lean lake trout, which seems reasonable.

Chinook salmon fingerlings are stocked into Minnesota tributaries, and nearshore in Wisconsin waters of Lake Superior in May and June, and these fish smolt and migrate to the lake soon after stocking at age 0. Most Chinook salmon live in Lake Superior for three to five years before returning to streams to spawn and die in September and October. From 2002 to 2004, stocked Chinook salmon that returned to the French River trap were age 2 to 4 only. Despite continued stocking, the percentage of wild Chinook salmon captured by anglers in Minnesota waters reached a mean of 94.3% in 2000-2002 (Schreiner et al. 2006). Estimates of stocked populations were expanded to include wild fish beginning at age 1, because spawning is minimal in Minnesota and Wisconsin streams and wild fish emigrate from other parts of the lake. The Chinook salmon population in WI-1 was expanded to include 94.3% wild fish similar to MN-1, and the population in WI-2 was expanded to include 76% wild fish as estimated by Peck et al. (1999). Chinook salmon are known to stray widely (Peck et al. 1999), and the Minnesota Chinook salmon population was divided 29% in Ecoregion 3 and 71% in Ecoregion 1 for simulations, based on the distribution of angler catch in 2000 and 2001.

Coho salmon have naturalized in Lake Superior and are not stocked in the western arm. They have a three-year life history, and their abundance fluctuates widely (Schreiner et al. 2006). Young coho salmon spend 16-18 months in streams, smolt and migrate to Lake Superior in spring, and spend 18-20 months in the lake before they return to spawn and die around 1 November. Coho salmon abundance was derived from annual harvest: 7,000 fish in 2000 and 4,400 fish in 2004 (37% less than in 2000) in the western arm. Mean annual return to the Bois Brule River from 1996 to 2001 was 2,600 coho salmon, and mean return from 2001 to 2004 was about 1,700 fish (35% less than in 2000). Population numbers used in 2004 simulations were 35% less than the number used in 2000, to reflect similar declines in angler harvest and returns to the Bois Brule River. Density was assumed to be equal within all nearshore (<80 m) waters. Population levels in Table 3 are sufficient to accommodate reported angler harvest and spawning runs in Minnesota tributaries (primarily French and Knife rivers) and Wisconsin tributaries (Bois Brule, Flag, and Cranberry rivers; North Fish, Whittlesey, and Pikes creeks; and Onion and Sioux rivers).

Populations of potadromous rainbow trout in the western arm include both naturalized steelhead that reproduce in the wild and are supplemented by fry and yearling stocking, and the Kamloops hatchery strain that is stocked as yearlings in MN-1. Based on angler catch rates of clipped rainbow trout (including all Kamloops and steelhead stocked as yearlings) from 1996 to 2004, about 80% of the Minnesota population was found in MN-1, and 20% of the population was in MN-2 and MN-3. Steelhead stocked as yearlings composed 8.5% of the clipped rainbow trout caught by anglers from 1999 to 2002.

Populations of steelhead lacking fin clips (including both wild and fry-stocked fish) in Minnesota waters were estimated based on the relative catch of unclipped steelhead versus fin-clipped rainbow trout in the spring creels from 1996 to 2002 (Ostazeski 2002), and the numbers of spawning fish returning to French and Knife River traps. Wild steelhead in Wisconsin waters were estimated based on the greater productivity in south shore tributaries, ensuring that populations were high enough to account for the average numbers of spawners (8,850 fish in tributaries listed above for coho salmon) from 1996 to 2000 for simulations of the year 2000, and average numbers of spawners (9,850 fish) from 2001 to 2004 for simulations of the year 2004 (WIDNR, unpublished data). Minnesota steelhead stocked as fry; Wisconsin steelhead stocked as fry, fingerlings, and yearlings; and wild steelhead were modeled together because these groups (all lacking fin clips) were indistinguishable as adults. Simulations began with age-2 smolts, because this was the life history pattern of the majority of steelhead that survived to adulthood.

Burbot stock size was estimated from the ratio of burbot to lake trout caught in Wisconsin graded-mesh nets set in July and August from 1976 to 1996 (WIDNR, file data). Stock size in WI-2 was estimated at 100,000 by Schram et al. (2006), but we expanded that number to approximately 200,000 age-1-and-older fish in the western arm. An equal density of burbot per unit surface area (including nearshore and offshore waters) was calculated.

Brown trout are a minor component of the predator population in Minnesota waters but are more abundant in Wisconsin waters, with an estimated sport harvest of 1,563 fish in 2000 and 526 fish in 2004. The largest known run of migratory brown trout in Lake Superior occurs in the Bois Brule River, averaging over 4,000 fish annually from 1996 to 1999, declining to 2,900 in 2004. Other rivers in Wisconsin, including the Flag, Cranberry, Sioux, and Onion rivers and North Fish Creek, have runs totaling about 1,200 brown trout. Most brown trout smolt at age 1 in the Bois Brule River and at age 2 in other rivers. Survival of stocked fish is currently very low, and wild fish compose at least 95% of the population in WI-1 and 60% of the population in WI-2 (WIDNR, unpublished data). Brown trout are stocked in WI-2, but population estimates include a 5% stray rate of stocked fish into WI-

1, 95% wild fish in WI-1, and 60% wild fish in WI-2. Estimated population numbers adequately account for known sport harvest and spawning runs.

The primary stock of walleye in the western arm spawns in the St. Louis River estuary. The abundance of spawning walleye in this stock, sampled by electrofishing and fyke netting in St. Louis Bay in 2002, was calculated using Bailey's modification of the Peterson mark and recapture method (Ricker 1975; WIDNR, unpublished data). Most males mature by age 6, and most females mature by age 7 (Schram et al. 1992), so age 7 was assumed to be fully represented in the 2002 population estimate. Ages 0 through 6 were estimated by back-calculations using mortality rates based on 2002 catch curves. Within Ecoregion 1, about 75% of this population was assumed to occupy Wisconsin waters, based on the higher sport and assessment catch in that area. Two other reproductively discrete stocks of walleye in the western arm inhabit Chequamegon Bay, and two additional stocks spawn in the Bad and Ontonagon rivers, located east of Chequamegon Bay (WIDNR, unpublished data). Little is known about these last two stocks, and they were not included in simulations.

Predator diets

All predator diet files, based primarily on data collected during the spring and summer, were modified for fall and winter to reflect seasonal availability of diet items (Tables 4-11; Figure 2). Rainbow smelt are a favored diet item and are most vulnerable in spring when they congregate in shallow nearshore areas, but consumption of this species was greatly reduced in other seasons. Cisco was the primary coregonine consumed by lean lake trout (Tables 4A and 4B), while kiyi, along with some bloater, were the primary coregonines consumed by siscowet (Table 5). The two forms of lake trout also consume different species of sculpins, with lean lake trout eating primarily slimy sculpin *Cottus cognatus* and siscowet eating primarily deepwater sculpin *Myoxocephalus thompsonii.* Burbot diets (Table 6) were modeled to reflect their widespread distribution in the lake, so the coregonine portion of their diet was equal parts *C. artedii* and *C. kiyi* or *C. hoyi*, and the sculpin portion was equal parts *C. cognatus* and *M. thompsonii.*

Prey energy densities

Prey energy densities were compiled from various sources (Table 12). The energy density for dace *Chrosomus* spp. was used for spottail shiner *Notropis hudsonius* and emerald shiner *Notropis atherinoides* in brown trout and walleye diets, and the energy density of bluegill *Lepomis macrochirus* was used for black crappie *Pomoxis nigromaculatus* in walleye diets. The energy density for larval and juvenile yellow perch *Perca flavescens* (Post 1990) was used in the diet of walleye of ages 1-3, and the energy density for older yellow perch was used in the diet of larger walleye. The indigestible portion of the diet was assumed to be 3.3% for fish and 10% for invertebrates (Stewart et al. 1983).

Weights-at-age; spawning weight loss

Weights-at-age of predators the western arm of Lake Superior in 2000 and 2004 (Tables 3A-3K; Figures 3-6) came primarily from MNDNR and WIDNR unpublished data. French and Knife river data came from spawning fish captured in traps; Bois Brule River data came from observations at the fishway. Weights-at-age for burbot were taken from Schram (1983) and Schram et al. (2006), and weights-at-age of walleye were reported by Mayo et al. (1998). Predator weights-at-age remained the same in simulations of all ecoregions and both states (Tables 3C-3K), with the exception of rainbow trout weights, which were adjusted for each ecoregion. Bois Brule River weights were used to model steelhead in Ecoregion 2, Knife River weights were used to model steelhead in Ecoregion 3, and intermediate values were used to model steelhead in Ecoregion 1.

A spawning weight loss of 7.5% (Devine et al. 2005) was used in simulations of lean lake trout, but the average egg production of siscowet is less than that of lean lake trout (Becker 1983), so a spawning weight loss of 6% was used for siscowet. A 12% weight loss at spawning (Scholl et al. 1984) was used for rainbow trout strains. Gamete weight in Chequamegon Bay brown trout was about 25% of total weight (Devine et al. 2005), but a

20% spawning weight loss was used in simulations of the open-lake fish. A spawning weight loss of 11% was used for burbot (Rudstam et al. 1995), and 10% was used for walleye (Devine et al. 2005).

Mortality rates

Lean lake trout mortality rates for Ecoregion 2 were taken from simulations of a statistical catch-at-age model developed for the Apostle Islands region of Wisconsin (Linton et al. in press), and mortality rates for Ecoregions 1 and 3 were taken from a similar model for Minnesota waters (M. Drake, MNDNR, personal communication) (Tables 3C-3K). Mortality rates for siscowet were assumed to equal the natural mortality plus sea lamprey mortality rates in the lean lake trout model. Siscowet are considered undesirable by sport anglers and commercial fishers, so fishing mortality was negligible.

Chinook salmon mortalities for ages 1, 2, and 3 were derived from a catch curve based on summer creel survey data from Minnesota, 1995 to 2000. Returns to the French River trap of the 1991-to-2004 year classes of stocked Chinook salmon were used to calculate the mean return rate of each age class relative to the number of fish stocked, and estimated mortality rates were applied to ages 0, 4, and 5 to achieve observed return rates. Coho salmon mortality rates were estimated to accommodate the sport catch and spawning population in Minnesota and Wisconsin.

An annual mortality rate for clipped rainbow trout of ages 4-8 (including Kamloops and steelhead stocked as yearlings) was determined from catch curves based on Minnesota spring creel surveys from 1996 to 2002. Similar mortality rates (67% and 72.5%) were determined using numbers-at-age of Kamloops that returned to the French River trap in 2000 and 2001. Returns to the French River trap through 2004 of clipped rainbow trout were used to estimate annual mortality rates for ages 1, 2, 3, and 9 that could accommodate the number of returning spawners plus the typical annual angler catch.

A mortality rate of 99% was estimated for steelhead stocked as fry and smolting at age 2 based on catch rates at the French River smolt trap (Tables 3A-3K). Mortality rates applied to Wisconsin fry (95%) were lower than those in Minnesota due to more favorable conditions in south shore streams. Even lower mortality rates were applied to Wisconsin fingerlings (90%) and 10-cm yearlings (85%). Returns of spawning fish to the Knife River from 1996 to 2000 and French River from 1998 to 2002 were used to create catch curves from which mortality rates could be determined for ages 5-9. Mortality rates were selected for fish of ages 2-4 to reflect the observed number of fish typically seen returning to the fish traps.

Mortality rates of brown trout (Tables 3A-3D, 3G, and 3K) in Wisconsin waters were calculated for ages 3-5 using a catch curve based on percentage return at each age of the spawning population in Bois Brule River from 1996 to 2001. Brown trout older than age 6 have become rare in recent years (WIDNR, file data). A 43% annual mortality rate was applied to burbot (Schram et al. 2006), and catch curves for walleye of ages 6-10 and 11-22 sampled in the St. Louis Bay in 2002 (WIDNR, file data) were used to estimate annual mortality rates (Tables 3A-3C, 3F-3H, and 3K).

Spawning dates

Lean lake trout in Minnesota waters of Lake Superior may first reach maturity as early as age 6 or 7 (males), or age 7 or 8 (females) (Halpern and Schreiner 2002), but 1 November at age 9 was used as the representative date of first spawning in simulations. Siscowet mature at about age 11, based on the sizes of mature siscowet reported in Becker (1983). Spawning siscowet have been found from April (Bronte 1993) through November (Hansen et al. 1995), but 1 November was used as the average date of spawning in simulations. Chinook and coho salmon stop eating prior to fall spawning, and they die after spawning, so simulations ended on 15 September for age-5 Chinook salmon and 15 October for age-2 coho salmon to correspond with the cessation of feeding.

Spawning by potadromous rainbow trout peaks about 1 May in Minnesota streams (Negus 1999). Most of the Kamloops spawners at the French River trap from 1996 to 2002 were ages 4 and 5 (73%), and most steelhead stocked as fry returned to the French River trap primarily at ages 4-6 (69%), so age 4 was used as the average age of first spawning for all rainbow trout. Simulations began on 1 June, so spawning was included in the age-3 cohorts on day 335.

Brown trout spawning peaks at about 14 October in the Bois Brule River, and from 1996 to 2001, 62% of the spawning runs were age-3 fish, so age 3 was used as the average age of first spawning in simulations. Spawning was included in burbot simulations on 1 January, beginning at age 6, based on data from the Nemadji and Amnicon rivers in Wisconsin (Schram 1983). Walleye spawning peaks at about 20 April in the St. Louis River estuary (MNDNR, unpublished data), and age 7 is the average age of maturity (Schram et al. 1992). Because simulations began on 1 June, spawning was included in the age-6 cohorts on day 324.

Temperatures

Temperatures used in simulations reflected depth zone and ecoregion differences (Table 13). Thermal stratification in nearshore areas of Lake Superior provided a range of temperatures from June through November, but nearly uniform cold temperatures occurred from about December through May, so all nearshore salmonines were assumed to occupy similar temperatures during the coldest months. Midwater temperatures available to salmonines in Ecoregion 1 were taken from the mean monthly temperatures of Lake Superior water that entered the French River Hatchery from 1996 to 2000 through an intake pipe at a lake depth of 18.3 m. The extent of thermal stratification was estimated from temperature profiles measured in Ecoregions 1 and 3 from June to October 2001-2003 (Large Lakes Observatory, University of Minnesota–Duluth, unpublished data) and in July 1996 (MNDNR, unpublished data), in Ecoregion 2 from June to October 2003 (B. Holbrook, University of Minnesota–Duluth, personal communication), and throughout the lake in fall and winter 1973-1979 (Assel 1986). Field measurements of temperatures occupied by fish were referenced whenever possible because temperatures that fish inhabit in Lake Superior are often colder than the preferred temperatures determined in a laboratory (McCauley and Tait 1970; Elrod and Schneider 1987). Temperatures used in simulations reflected species preferences when available.

Temperature and depth profiles recorded using archival tags implanted in lake trout in Lake Superior (Mattes 2004) provided monthly mean temperatures for fish in Ecoregion 2, and these means were modified for Ecoregions 1 and 3 based on available temperature ranges. Siscowet, which occupy the deep areas of the lake (>80 m) where temperature varies less, were modeled using temperatures that did not exceed 4.0°C during summer.

Chinook and coho salmon tracked with radio tags in Lake Ontario in spring and fall occupied temperatures of 6.5-13°C (Haynes and Gerber 1989), and a similar range (6.7-14.4°C) for coho salmon was reported by Becker (1983), so these temperatures were used when available. Rainbow trout tracked with radio tags in Lake Ontario in spring and fall occupied temperatures of 7.5-13.5°C (Haynes and Gerber 1989), so temperatures used in rainbow trout simulations were similar to those of coho salmon.

Optimum temperatures for brown trout occur in the 10-13°C range (Wismer and Christie 1987), so 13°C in September was the highest temperature used in simulations. Burbot were assumed to occupy water temperatures up to the physiological optimum of 12°C for juveniles and 10°C for adults (Rudstam et al. 1995). The walleye population occupies both the St Louis River and the lake, so temperatures used in simulations from April through November were the mean of temperatures in the St. Louis River (Mayo 1997)\ and at the French River Hatchery water intake. Hatchery intake temperatures were used from December through March.

Nearshore and offshore distributions

Distributions of predator populations were categorized as "nearshore" or "offshore" using the 80-m depth contour as the dividing line. Lean lake trout and siscowet distributions were based on siscowet assessment netting done at various depths by MNDNR and WIDNR. Burbot populations were assumed to distribute evenly in nearshore and offshore areas, so populations were calculated in equal proportion to the amount of nearshore and offshore areas within each ecoregion. Potadromous species were assumed to occupy the nearshore zones, based on their thermal and diet preferences.

Prey fish biomass estimates

Rainbow smelt and coregonine biomass estimates (Tables 14A and 14B) were based on hydroacoustic sampling of pelagic fish in western Lake Superior. Biomass estimates of both prey categories in 2004 were means calculated from hydroacoustic assessments conducted from 2003 to 2005 (Hrabik et al. 2006; additional data: T. Hrabik, University of Minnesota–Duluth, personal communication). Biomass estimates for 2000 were intermediate values calculated from assessments done in 1997 (Mason et al. 2005) and the 2004 estimates described above. Annual production was added to the biomass estimates to determine the total biomass of these forage species "available" to predators or harvesters within one year (Tables 14A and 14B). Annual production was calculated using production-to-biomass (P:B) ratios of 0.90 for juvenile cisco, 0.36 for adult cisco, and 1.90 for all age classes of rainbow smelt (Cox and Kitchell 2004).

Results

Prey consumption versus availability

Bioenergetics simulations of predator consumption, and calculations of prey biomass produced estimates within the same order of magnitude, enabling comparisons of prey use and availability. Predator fish consumed about 39% of the available coregonines (biomass + annual production), and about 47% of the available rainbow smelt in the western arm of Lake Superior in the year 2000, according to bioenergetics simulations in this study (Figure 7a). The portion of coregonines consumed relative to the biomass available in 2004 was similar (44%), but estimates of rainbow smelt consumption exceeded available biomass estimates. In nearshore areas, predator consumption of the available coregonines rose from 39% in 2000 to 68% in 2004, while estimated consumption of available rainbow smelt rose from 32% in 2000 to more than 100% of available rainbow smelt biomass in 2004 (Figure 7b). Predators in offshore areas consumed about 39% of the coregonines in 2000 and 28% in 2004, while consumption estimates of rainbow smelt equaled or exceeded the available biomass estimates in both years (Figure 7c). Coregonine biomass in the western arm was greater, and constituted a larger portion of the prey base than rainbow smelt. These two prey categories made up about 60% of the total prey biomass eaten by all predator species (Tables 15A and 15B). In both years, total consumption of all prey by all predators in the western arm was about 1,400 kg•km^{-2}, averaging 2,400 kg•km^{-2} in nearshore areas and 940 kg•km^{-2} in offshore areas, but this section of Lake Superior contained twice as much offshore area as nearshore area (Table 1). Total annual consumption of rainbow smelt and coregonines by all predators averaged 830 kg•km^{-2}.

Within Ecoregion 1, predators consumed an estimated 57% of available coregonines in both 2000 and 2004, while consumption estimates of the available rainbow smelt ranged from about 69% in 2000 to more than 100% in 2004 (Table 15C; Figure 8). In Ecoregion 2, predator consumption of available coregonines increased from 50% to 70% between 2000 and 2004, while consumption estimates of the available rainbow smelt increased from 58% to more than 100% (Table 15D, Figure 8). Within Ecoregion 3, predator consumption of available coregonines was about 14% in both years, while consumption estimates of the available rainbow smelt increased from 17% to slightly more than 100% (Table 15E; Figure 8). In general, rainbow smelt levels in 2004 were so low that even small changes in predator diet were sufficient to cause a discrepancy between use and availability.

In Minnesota waters, predators consumed about 22% of available coregonines in both 2000 and 2004, while consumption estimates of available rainbow smelt went from 26% to more than 100% (Table 15F; Figure 9). Predation was especially high in nearshore waters, where consumption of coregonines increased from about 24% in 2000 to nearly 50% in 2004. In Minnesota offshore waters, estimated coregonine consumption was close to 20% of available biomass in both years. Consumption estimates in Wisconsin waters revealed that 50% of available coregonine biomass and 60% of available rainbow smelt biomass was consumed in 2000, increasing to 69% of coregonine and more than 100% of rainbow smelt biomass in 2004 (Table 15G; Figure 9).

Biomass plus production of rainbow smelt in the western arm declined by an order of magnitude (from 4,901 MT to 549 MT) from 2000 and 2004 (Tables 14A and 14B; Figure 7), but these populations show fairly large annual fluctuations. Biomass plus production of coregonines declined 22% from 2000 and 2004. During this period, estimates of total consumption of rainbow smelt plus coregonines declined about 16% (Tables 15A and 15B; Figure 7), although some assumptions were made about dietary proportions of these prey fish based on known population declines. Predator population estimates used in simulations of lake trout, siscowet, coho salmon, and brown trout were also lower in 2004 than 2000, while other predators increased during that period (Tables 3A-3K).

Commercial, sport, and assessment harvests

Commercial harvest accounted for about 3-4% of the total consumption of coregonines in both years (Figure 10), but amounted to less than 2% of the available biomass in the western arm (Figure 7). The amount of rainbow smelt harvested commercially was 1% (in 2000) and less than 1% (in 2004) of the total consumption (Figure 10), and less than 1% of the available biomass in the western arm (Figure 7). The sport and assessment harvests of rainbow smelt and coregonines fell far below 0.01% of the total consumption or the available biomass in both years. The commercial harvest was assumed to occur nearshore, and in these areas the impact on coregonines increased slightly, to 5% of the total consumption (Figure 11), or 4% of the available biomass (Figure 7). The commercial harvest of nearshore rainbow smelt remained less than 1% of the total consumption or available biomass. In Minnesota waters, the commercial harvest of coregonines amounted to a higher portion (7%) of the total consumption, or less than 2% of the amount available, and harvest of rainbow smelt was less than 2% of the amount available (Figure 9). The impact of commercial harvest in Wisconsin waters was lower, accounting for about 1% of the total consumption or available biomass of coregonines, and less than 1% of the total consumption or available biomass of rainbow smelt (Figure 9).

Relative consumption by predator species

In the western arm, lean lake trout were the primary consumers of rainbow smelt and coregonines, and siscowet were the second highest consumers (Tables 15A and 15B; Figure 10). Chinook salmon and walleye were each responsible about 4% of the total rainbow smelt plus coregonine consumption in 2000 and 2004, tying for third place as consumers of these prey fish, with all of their impact occurring nearshore. The non-native predators modeled in this study, all of which are potadromous (Chinook salmon, coho salmon, rainbow trout, and brown trout), together were responsible for 6-7% of the total consumption of the rainbow smelt plus coregonines in both years. In terms of total prey consumption, however, rainbow trout were the third-highest consumer, with a high percentage of their diet composed of insects and invertebrates that contain less energy and higher indigestible material than prey fish. In all nearshore areas, lake trout were the primary predators, and the relative importance of other predator species varied by ecoregion or state. All non-native potadromous species occupied nearshore waters, and thus their predatory impact was confined to those areas. In all offshore areas of the western arm, siscowet were the dominant predators followed by lean lake trout, with burbot playing a relatively minor role (Tables 15A-15G; Figure 11).

In Ecoregion 1, lake trout were the primary predators of coregonines and rainbow smelt in 2000, and walleye were the second most important predator. By 2004 walleye consumption of rainbow smelt exceeded consumption by lake trout (Table 15C). As Chinook salmon numbers increased slightly from 2000 to 2004, they became the second-greatest consumer of coregonines in 2004.

Predator consumption within Ecoregion 2 as a whole resembles the consumption within the dominant nearshore areas, with lake trout as the primary consumer, followed by siscowet, and other species responsible for less than 6% of the total consumption (Table 15D). In Ecoregion 3, dominated by deep offshore water, siscowet were the primary predators overall, but in nearshore waters lake trout still consumed the most coregonines, followed by Chinook salmon (Table 15E).

In Minnesota waters, as in the western arm as a whole, lake trout were the primary predators of coregonines, siscowet were secondary, and Chinook salmon were third. In nearshore waters, the roles of rainbow trout and Chinook salmon exceeded that of siscowet. Wisconsin waters were dominated by the nearshore area of Ecoregion 2, with lake trout as the primary consumer of rainbow smelt and coregonines, followed by siscowet; potadromous species plus burbot were responsible for a relatively small percentage of the total consumption. Walleye were the third most important predators in Wisconsin waters as a whole, though they played a minor role in Ecoregion 2.

Consumption by stocked predators

Stocked fish in the western arm (which include some of the lean lake trout, Chinook salmon, rainbow trout, brown trout, and walleye) were responsible for 11% of the consumption of rainbow smelt and coregonines in 2000, and 8% in 2004. Stocked lake trout were responsible for most of the total coregonine consumption by stocked fish. Most of the stocked fish inhabited Minnesota waters, where this consumption pattern was most evident. Consumption by stocked fish in Wisconsin waters declined from 4% to less than 1% of the total consumption from 2000 to 2004.

Predator diets and consumption rates

Lake trout populations consumed more coregonines than rainbow smelt, but their diverse diet included sculpins, mysids, insects, and (seasonally) small salmonines (Tables 4A and 4B; Figure 2). Siscowet, rainbow trout, and walleye also had diverse diets, and were not completely dependent on coregonines or rainbow smelt (Tables 5, 10, and 11; Figure 2). On the contrary, the Chinook salmon diet lacked diversity, and they depended heavily on forage fish (Table 7; Figure 2).

Gross conversion efficiency (GCE), a measure of how well an animal converts ingested food into new tissue, was calculated for 3-kg individuals of each predator species as follows:

$$\text{GCE} = (\text{predator weight gained}) \bullet (\text{prey weight consumed})^{-1} \bullet 100$$

Chinook salmon had the highest GCE, followed by brown trout (Table 16). These higher GCEs are a reflection, in part, of diets composed primarily of prey items with high energy densities, especially rainbow smelt and coregonines. Despite their energy-rich diet, Chinook salmon growth has declined in recent years (Figure 12).

Consumption of cisco versus kiyi and bloater was derived from total consumption of coregonines, assuming that all coregonines consumed in nearshore areas were cisco, offshore lake trout were consuming cisco, and offshore siscowet and burbot were consuming kiyi and bloater. Based on these assumptions, 38% of the cisco and 63% of the kiyi and bloater in the western arm were consumed by predator fish (Figure 13). Nearshore populations consumed 70% of the ciscos and half of the kiyi/bloaters, but offshore only about 13% of the cisco were consumed along with 65% of the kiyi/bloaters.

The annual predatory impact by each year class within a population varied greatly, reaching a maximum at an age where population numbers and growth functioned together to cause the greatest consumption, followed by a decrease among older year classes (Figure 14). Lean lake trout consumption overshadowed that of all other species, and the maximum consumption occurred in the age-7 year class, which consumed about 600 metric tons of coregonines and rainbow smelt, and nearly 800 metric tons of total prey. The greatest impact by potadromous species occurred early in their lives, while the impact of siscowet was sustained over an extended period.

As individuals, Chinook salmon consumed a greater amount of rainbow smelt and coregonines per unit time than any other predator, but walleye and lean lake trout consumed more if they survived more than 13 or

16 years, respectively (Figure 15a). Individuals of all the potadromous species, including Chinook salmon, coho salmon, rainbow trout, and brown trout consumed more total prey per unit time at younger ages than the longer-lived species (Figure 15b). Considering the entire populations of predators in the western arm, however, lake trout and siscowet consumption of coregonines and rainbow smelt and total prey far exceeded that of other species (Tables 15A and 15B; Figure 16a and b)

Discussion

Prey consumption versus availability

Bioenergetics simulations of prey consumption by predators in this study, when compared to hydroacoustic estimates of pelagic prey species (Mason et al. 2005; Hrabik et al. 2006), reveal that adequate rainbow smelt and coregonines exist to support estimated populations of predator species in the western arm of Lake Superior (Figure 7), despite some localized rainbow smelt insufficiencies. However, a high proportion of these prey fish populations were consumed, and movement between ecoregions and depth zones by both predators and prey populations obviously occurs. In nearshore regions especially, 50% or more of the available coregonines and rainbow smelt may be consumed annually. An examination of results by ecoregion (Figure 8) reveals that predation levels in the Ecoregions 1 and 2 were extremely high relative to the prey fish available, especially in 2004. The high coregonine levels in Ecoregion 3, along with its size (50% of the western arm) make this region a prey refuge for the western arm. Hrabik et al. (2006) demonstrated that large cisco (>150 mm) and kiyi/bloater (>120 mm) were abundant in the offshore waters of Ecoregion 3, while consumption by predators was relatively low (Figure 8).

The large sizes attained by cisco, up to 495 mm (MNDNR assessments, 2006), cannot alone be considered a refuge from predation by lake trout or siscowet. In contrast, rainbow smelt in the western arm reach only about 210 mm (MNDNR assessments, 2006). Diet studies in Minnesota waters have shown that large lake trout will consume coregonines as large as 50% of their total length (MNDNR, unpublished data), and in 2006, cisco up to 460 mm total length were found in the stomachs of lake trout, although most prey fish consumed were smaller. Just 2% of the cisco captured in the commercial fishing nets and MNDNR assessment nets in 2006 exceeded 460 mm total length. The "average" lake trout modeled in this study reached only about 755 mm (3,944 g at the end of the 20^{th} year), and would theoretically consume cisco only up to 378 mm, but lake trout 755 mm and larger made up 7% of the those captured in MNDNR assessment nets in 2006. Spawning-size cisco (>305 mm) dominated total fish biomass in 2003 (86%) and 2004 (68%) (Hrabik et al. 2006); data in this study reveal that lake trout age 10 and greater could consume prey larger than 350 mm. Based on hydroacoustic surveys of coregonines, and a conservative judgment that siscowet will consume prey up to 40% of their total length, Hrabik (University of Minnesota–Duluth, personal communication) estimated that 75% of the coregonine population was vulnerable to siscowet predation.

Examination of the bioenergetics data by ecoregion reveals differences in population densities and consumption levels between habitats (Figure 8), but also demonstrates a problem when applying map delineations to mobile populations. In 2004, rainbow smelt populations were so low that even small changes in input data caused consumption estimates to exceed available levels. Five likely explanations for consumption estimates that exceed prey availability in this study include: (1) movement by predators or prey between or beyond ecoregion boundaries, and between nearshore and offshore areas; (2) inaccurate population estimates; (3) outdated and incomplete diet information for all seasons; (4) underestimation of available prey based on inaccurate production-to-biomass ratios; and (5) localized underestimation of rainbow smelt populations caused by their patchy or very nearshore distribution (where hydroacoustic sampling is impractical).

Foraging forays between depth zones or ecoregions can occur on a daily basis, or during various life stages of predators. Siscowet, for example, generally live in water deeper than 80 m (Becker 1983; Bronte et al. 2003) but are known to frequently forage briefly near the water surface. Stable isotope analyses of lean and siscowet lake trout in western Lake Superior suggest that these strains feed in similar locations at young ages, and small siscowet in this region may rely on nearshore prey for up to 25% of their production (Harvey et al. 2003). Chinook salmon stocked in each jurisdiction surrounding Lake Superior have been recaptured in every other jurisdiction (Peck et al. 1999), and rainbow trout are known to stray widely (Negus 2003).

Diet information used in simulations for this study came primarily from samples taken from 1996 to 2001, and modifications were made for 2004 based on known rainbow smelt population declines and occasional stomach samples examined by MNDNR Lake Superior Area. Rainbow smelt portions in the 2004 diets were likely overestimated in lake trout, siscowet, rainbow trout, and walleye.

The production-to-biomass (P:B) ratios used in this study (Cox and Kitchell 2004) may need reexamination. The 1.9 value used for rainbow smelt is higher than the P:B ratio used in 1989 (Negus 1995) and is at the high end of values determined by Lantry and Stewart (1993), but it is lower than the value used by Kitchell et al. (2000) in a Lake Superior food web model. The P:B ratios used for coregonines were similar to the values used by Negus (1995), but were lower than those of Kitchell et al. (2000). As these ratios translate directly into available prey biomass, they play an important role in forming our perspective on predator-prey interactions, and they warrant further study.

Rainbow smelt populations have declined dramatically since the mid-1980s (Bronte et al. 2003; Schreiner et al. 2006). By 2000, predator consumption estimates indicated that about 50% of the rainbow smelt biomass and production were consumed annually, and by 2004, consumption estimates exceeded availability. Under these conditions, competition for rainbow smelt likely exists between predators. Hydroacoustic estimates of available coregonine populations also indicate a decline between 2000 and 2004, which corresponds with a decline in several predator populations. Rainbow smelt and coregonine populations typically exhibit fairly large annual fluctuations, and annual estimates based on hydroacoustics from 2003 through 2006 varied considerably (Hrabik et al. 2006; T. Hrabik, University of Minnesota–Duluth, personal communication). Calculated estimates of rainbow smelt in 2006 were higher than during the previous three years, commercial harvest also increased that year (Geving 2007), and anecdotal reports from smelt netters corroborate that increase, indicating that some rainbow smelt congregations were able to elude predators and produce a relatively strong year class. Further hydroacoustic sampling is warranted in different seasons to establish a database sufficient to reveal annual variations and trends in biomass of both rainbow smelt and coregonines (Hrabik et al. 2006).

Commercial, sport, and assessment harvests

The commercial harvest of rainbow smelt and coregonines in the entire western arm is minor compared to the total consumption by predator fish and the total available biomass of prey fish. Because the harvest is concentrated nearshore in areas where predation pressure is already high and the harvest season typically corresponds with prespawning or spawning for rainbow smelt and coregonines, the local impacts on their populations may be somewhat greater than the overall totals imply. This is especially true in Minnesota waters, where commercial harvest is greater and the amount of nearshore water is much smaller than in Wisconsin (Table 1; Figures 9 and 11). The very low harvests by both sport anglers and assessment fishers are likely insignificant at current levels. With continually shifting abundances of predators, and fluctuating prey populations, the relative impact of commercial harvest will also change. This situation emphasizes the critical need for periodic hydroacoustic monitoring of prey populations and bioenergetics evaluation of predator impacts.

Relative consumption by predator species

Lean lake trout were the primary consumer of coregonines and rainbow smelt in this study, and siscowet played a secondary role. Other studies have demonstrated that siscowet and lean lake trout have minimal dietary overlap (Harvey and Kitchell 2000). Consumption by siscowet was considerably less than expected, based on predictions from a previous study by Ebener (1995) that included similar numbers of siscowet per unit area, higher growth rates, a greater reliance on coregonines, less consumption of sculpins and rainbow smelt at younger ages, and an older version of model parameters. Ecoregions 1 and 2 are relatively shallow compared to most of Lake Superior, which influences the habitat available for deep-dwelling siscowet and reduces their impact relative to that outside the western arm (Bronte et al. 2003).

Negus (1995) cautioned that the bioenergetics model does not account for behavior, and reduced prey availability may not equate to reduced rations for both lake trout and Chinook salmon if lake trout are more efficient predators. Lake trout are able to sustain high predation rates at low prey densities, so decreased availability of prey may have little affect on lake trout predation (Eby et al. 1995), and the composition of their relatively diverse diet may not reflect changes in relative abundance of the various items (Stewart and Ibarra 1991). Indeed, lake trout diets in the western arm of Lake Superior have changed only slightly since 1989, including more coregonine consumption by older fish (Ray 2004), and lake trout populations have increased through natural reproduction to levels that justified the reduction or cessation of stocking in most areas of the lake (Schreiner and Schram 1997; Bronte et al. 2003; Ebener, in press). Within the western arm, only lake trout in Ecoregion 2 showed some decline in growth rates between 1981 and 2003, although abundance of lake trout was high enough in four out of five management zones (MN-1, MN-3, WI-1, and WI-2) to cause density-dependent survival (Corradin 2004). In contrast, since 1989, Chinook salmon growth has decreased significantly—probably from a reduction in abundance of rainbow smelt populations. Chinook salmon diets have shifted dramatically from rainbow smelt to coregonines as the major component, and growth rates have declined (Figure 12). Despite high levels of stocking, returns of spawning Chinook salmon to the French River in Minnesota have shown a precipitous decline from over 1,600 fish in 1986 to 25 fish in 2001, although angler harvest rates have remained fairly constant in summer. Most of the Chinook salmon in the western arm are now wild fish that have been produced in other parts of the lake where tributaries contain better quality spawning habitat (Schreiner et al. 2006). In the 1980s and 1990s, Chinook salmon in Lakes Michigan and Huron showed a similar pattern of declining growth rates and condition, a diet shift to less preferred items, and (in Lake Michigan) lower survival of stocked fish, in response to major declines in alewife *Alosa pseudoharengus,* suggesting that they suffer from insufficient forage (Stewart and Ibarra 1991; Rand and Stewart 1998; Ebener 2005; Holey and Trudeau 2005).

Total consumption of rainbow smelt and coregonines by coho salmon, burbot, and brown trout was very low relative to that of lake trout and siscowet, and most of the diet of rainbow trout was composed of insects and invertebrates (Tables 15A-G; Figure 2). The consumption or rainbow smelt and coregonines by walleye may be overestimated in this study, as the diet information was collected in the early 1990s (Mayo et al. 1998). Since that time the availability of these prey fish has declined and several non-native species have entered into the assemblage of potential prey species in the St. Louis Bay near Duluth, Minnesota.

Consumption by stocked predators

Stocked fish in the western arm played a relatively minor role in the consumption of coregonines and rainbow smelt because their mortality was so high. The impact of rainbow trout on the rainbow smelt population in this study may be overestimated, as the diet information used was from the 1980s. Stocked fish, especially lake trout, play a bigger role in Minnesota waters and in Ecoregion 1 than in the rest of the western arm, because lake trout stocking is highest in this area. Based on rehabilitation of wild stocks and reduced survival of stocked fish, lake trout stocking was discontinued in WI-2 in 1996, in MN-3 in 2003, and in MN-2 in 2007. Stocking has also been reduced in WI-1and MN-1 (Topel and Hulse 2001; Schreiner et al. 2006). Because of reduced survival and low contribution to the sport fishery by stocked Chinook salmon, stocking in Minnesota was discontinued after 2006.

Predator diets and consumption rates

Gross conversion efficiency (GCE) is not a predictor of success for species inhabiting the cold unproductive waters of Lake Superior. Chinook salmon consumed more food per unit time, grew faster, and had the highest GCEs of any predator (Table 16), indicating that they were most efficient at converting forage into growth. Rainbow trout, brown trout, and coho salmon also emerged as rapid consumers, with rapid cumulative consumption shown in Figure 16b, although consumption of prey with lower energy densities did not support growth rates comparable to those of Chinook salmon. However, the impact on the forage base by all the introduced potadromous predators (including Chinook and coho salmon, rainbow trout, and brown trout) was small relative to that of lean lake trout (Tables 15A and 15B; Figures 14 and 16), which are native to Lake Superior. The lake trout preference for colder temperatures, its lower and slower individual consumption of prey fish, its slow growth, and its efficient predatory behavior despite fluctuations in the forage base, all indicate that this species is adapted to the cold, unproductive waters of Lake Superior. Kitchell et al. (2000) described these two types of predator-prey interactions as "fast" and "slow," with the "fast" set dominated by introduced predators and rainbow smelt. "Fast" fish have more rapid growth and maturation schedules, and fewer spawning year classes, than do the native "slow" species, which have emerged once again to dominate Lake Superior.

Comparison of current study to previous bioenergetics studies

A comparison of consumption estimates in Minnesota waters from this study (using a mean value for 2000-2004) to estimates from 1989 (Negus 1995) reveals a decline in rainbow smelt consumption and an increase in coregonine consumption, but the sum of rainbow smelt and coregonine consumption was just 14% lower in 2000-2004. An increase of more than 800% in consumption of other fish can be attributed to the inclusion of siscowet, walleye, and burbot. A 300% increase in mysids and other crustaceans as diet items is primarily due to higher proportions of these items in the diets of all predator species in the current study. Consumption of insects was similar in both studies.

In a bioenergetics study of the "western U.S. waters" of Lake Superior (Ebener 1995), a region roughly twice the size of the western arm modeled in this study, consumption of rainbow smelt and coregonine prey was estimated to be approximately 40% higher than western arm estimates in this study. The higher percentage of deep water (>80 m) in Ebener's (1995) study, and presumably lower productivity, may explain the lower consumption per unit surface area. Ebener's (1995) simulations included lower numbers of most predator species per unit area, but higher densities of siscowet and Chinook salmon, greater consumption of coregonines by siscowet, and higher growth rates for most species, especially lake trout and siscowet.

A bioenergetics study of burbot (Schram et al. 2006) in the Apostle Islands region (Ecoregion 2) produced results similar to those obtained in this study. Both studies used an estimated population of 100,000 and 43% annual mortality; proportions of diet items were also similar.

One obvious advantage for this study over previous bioenergetics studies in western Lake Superior is that estimates of prey consumption and availability have been refined to the point where they fall within the same order of magnitude, lending credibility to our results. Earlier bioenergetics studies of the western basin (Ebener 1995) and Minnesota waters alone (Negus 1995) demonstrated large discrepancies between predator consumption and prey availability. Both of these earlier studies relied on estimates of forage fish derived from daytime bottom trawl surveys conducted annually in May-June (U.S. Geological Survey, Lake Superior Biological Station, Ashland, Wisconsin, file data). Bottom trawls have since been shown to greatly underestimate pelagic prey fish, especially cisco, compared with surveys conducted with night midwater trawls and hydroacoustic gear (Stockwell et al. 2006; Yule et al. 2007).

Management implications

This bioenergetics study of the western arm of Lake Superior, with the benefit of recent, comprehensive data on primary species, provides a more complete estimate of consumption by predators and a more coherent overview of predator and prey relationships than did previous studies. Since the 1989 study by Negus (1995), many data needs she outlined have been addressed, although continual updates will be necessary to follow community and environmental changes in Lake Superior. The value of this bioenergetics study lies in the ability to see general trends, compare the impact of various predator populations on the forage base, and make comparisons between prey consumption and availability in several geographic subunits, in different time periods, and under various management scenarios. The simulations reported here, though based on reasonable information from many sources, cannot predict the future with certainty. The precise consumption values and percentage changes reported are estimates based on many variables that continue to change. We must be cognizant of additional indicators such as changes in growth rates, relative population densities of predators and prey, dramatic and rapid changes in predator diet, disease outbreaks, changes in return rates of potadromous populations, or changes in catch rates, that may validate or challenge our model results.

Simulation results in this study, and supporting biomass densities and growth data, suggest that the western arm of Lake Superior is at or near carrying capacity for predators. Lake trout rehabilitation has progressed, but we should be alert to signs of inadequate forage such as reduced growth rates or lower population abundance, especially in Ecoregions 1 and 2 where lake trout densities are highest. Chinook salmon could be considered an indicator species that demonstrates early warning signs of reduced forage, although this species plays a less significant role than that of lake trout in the total fish community. The diet shift and declining growth rates of Chinook salmon reveal that this introduced species is not as well adapted as the native lake trout to this oligotrophic lake. Schram et al. (2006) felt that the high degree of burbot cannibalism and the diversity of fish in their diet may have been an indication of resource limitation in Ecoregion 2. Although whitefish were not part of this analysis, they include rainbow smelt as a diet item in Ecoregion 2 (WIDNR, unpublished data), and whitefish in Chequamegon Bay fed predominantly on rainbow smelt after age 6 (Devine et al. 2005). Lake trout are able to utilize non-native rainbow smelt or the native cisco even as these prey populations fluctuate in abundance, so consequences of reduced forage may not be as evident in this native predator until prey populations are quite low. Reduced lake trout growth reported in Ecoregion 2 may already indicate that competition for prey is intense, as does density-dependent survival in all management zones except MN-2 (Corradin 2004). Reduced survival of all stocked salmonids is an obvious and direct indicator that there is little capacity left in the western arm to support additional predators.

The term *predatory inertia* (Stewart 1980) refers to the time from stocking or hatching until the greatest predatory impact has occurred. Predatory inertia can indicate the suitability of a species for short-term management manipulations in response to forage fish fluctuations. Lake trout populations have the greatest predatory impact at age 7 (Figure 14), so the predatory inertia for this species is seven years for wild fish, or six years for stocked yearlings. Consumption by lean lake trout overshadowed consumption by all other species in this study, but their predatory inertia is too long for short-term management effects. Added to this delay is the fact that the majority (about 97%) of lake trout in the western arm are wild fish; thus recruitment of this species is beyond the control of fisheries managers. The greatest predatory effect of siscowet is spread over many years, and these populations are entirely self-sustaining. Non-native potadromous species generally have a shorter predatory inertia, with the greatest impact occurring early in their lives, but the majority of these fish are now naturally reproduced, and the survival and predatory impact of these populations is relatively low. Stocking is no longer the important issue that it once was in the western arm, and survival of stocked fish is greatly reduced (Schreiner et al. 2006). Thus manipulation of the forage base through stocking may have little impact, although reduced stocking may take immediate pressure off rainbow smelt and coregonines in some localized nearshore areas. Certainly, continued or increased predator stocking on the present forage base invites negative consequences and may be considered a waste of resources, as it will further suppress forage availability and thereby reduce predator growth and survival.

Bioenergetics modeling can assist in determining the allocation of prey fish to a commercial fishery, taking into account the portion consumed by predators and the amount needed for reproduction. The low levels of rainbow smelt available in the western arm, and the relatively small impact of commercial fishing on coregonine and rainbow smelt populations compared to the high consumption levels by predator fish, have already been factored into determinations of allowable commercial harvest in Minnesota waters. Commercial harvest of rainbow smelt is limited, and changes in coregonine harvest will be based on hydroacoustic estimates and Total Allowable Catch (TAC) models of these prey species, to maintain a productive fishery while adequately protecting the spawning stock (Schreiner et al. 2006).

Continual updates to the statistical catch-at-age models used to estimate lake trout populations are warranted. Further acquisition of temperatures and depths occupied by siscowet and potadromous species would increase our understanding of their habitat and migrations. Continued monitoring of diets throughout all seasons and life stages (especially those of lake trout, siscowet, Chinook salmon, rainbow trout, and walleye), is still a critical need for accurate bioenergetics model estimates. Refined estimates of mortality, natural reproduction, and growth for both stocked and naturally reproduced fish will increase the accuracy of future bioenergetics evaluations and help in development of demographic models incorporating density-dependent processes and species interactions. The development of bioenergetics models for different life stages, and analysis of the sizes of prey fish utilized by different life stages, may assist in determining where bottlenecks exist in both predator and prey populations. Additional and seasonal hydroacoustic sampling of the prey base will provide needed perspective on these populations and assist in the calculation of realistic P:B ratios. Finally, periodic use of these bioenergetics models can provide insight into population structure and community dynamics. Simulations can be used to evaluate the effect of various management strategies, and results can help to guide management actions and public education.

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Table 1.—Areas (km^2) within the western arm of Lake Superior, all calculated using ArcView GIS (1996) software. Depth contours were taken from a map supplied by NOAA in November 2005. Surface areas within Minnesota management zones reflect 2006 boundary definition changes.

Lake trout management zones and ecoregions	Nearshore: depth<80 m	Offshore: depth>80 m	Total area	Percentage of western arm area
MN-1	388	368	755	6.5%
MN-2	127	1,950	2,077	17.8%
MN-3	184	3,592	3,776	32.4%
Minnesota total	699	5,910	6,608	56.7%
WI-1	532	387	919	7.9%
WI-2[a]	2,662	1,467	4,130	35.4%
Wisconsin total	3,194	1,855	5,049	43.3%
Ecoregion 1 (western tip of lake)	920	755	1,674	14.4%
Ecoregion 2 (Apostle Islands)[a]	2,662	1,467	4,130	35.4%
Ecoregion 3 (north shore)	311	5,542	5,853	50.2%
Western arm total[a]	3,893	7,764	11,657	100.0%

[a] Minus Chequamegon Bay and land areas of the Apostle Islands. Chequamegon Bay encompasses about 145 km^2.

Table 2.—Physiological parameter values used in bioenergetics simulations of the western arm of Lake Superior.

Parameter	Lean lake trout[a]	Siscowet trout[a]	Brown trout[b]	Burbot[c]
Consumption				
Equation	1	1	3	2
CA-weight dependent intercept	0.0589	0.0589	0.2161	0.099
CB-weight dependent coefficient	-0.307	-0.307	-0.233	-0.195
CQ-temperature dependent coefficient	0.1225	0.1225	3.8	2.41
CTO-optimal temperature for consumption	*	*	17.5	13.7
CTM-maximum temperature for consumption	*	*	17.5	21
CTL-temperature for K4	*	*	20.8	*
CK1-proportion of maximum consumption at CQ	*	*	0.23	*
CK4-proportion of maximum consumption at CTL	*	*	0.1	*
Respiration				
Equation	1	1	1	2
RA-respiration intercept	0.00463	0.00463	0.0013	0.008
RB-respiration coefficient	-0.295	-0.295	-0.269	-0.172
RQ-temperature function	0.059	0.059	0.0938	1.88
RTO-swimming speed coeff. For optimum temperature	0.0232	0.0232	0.0234	21
RTM-swimming speed coeff. For max. temperature	0	0	0	24
RTL-cutoff water temperature	11	11	25	*
RK1-weight dependent intercept for swimming speed	1	1	1	*
RK4-weight dependent coefficient for swimming speed	0.05	0.05	0.13	*
ACT-swimming speed intercept	11.7	11.7	9.7	1.25
BACT-swimming speed coefficient	0.0405	0.0405	0.0405	*
SDA-Specific Dynamic Action	0.172	0.172	0.172	0.2
Egestion/Excretion				
Equation	3	3	3	1
FA-fecal loss intercept	0.212	0.212	0.212	0.17
FB-fecal loss coefficient	-0.222	-0.222	-0.222	*
FG-feeding level coefficient for fecal loss	0.631	0.631	0.631	*
UA-urinary loss intercept	0.0314	0.0314	0.026	0.09
UB-urinary loss slope	0.58	0.58	0.58	*
UG-feeding level coefficient for urinary loss	-0.299	-0.299	-0.299	*
Predator Energy Density				
Equation	2	2	2[d]	1
Energy density	*	*	*	5135
Alpha 1-intercept of first body-weight relation	4741	5383	5591	*
Beta 1-coefficient of first body-weight relation	2.28	3.77	7.7183	*
Cutoff-weight at change in body-weight equation	1500	1500	151	*
Alpha 2-intercept of second body-weight relation	7455	9767	6582	*
Beta 2-coefficient of second body-weight relation	0.4841	0.9216	1.1246	*

[a] References: Stewart et al. 1983; Johnson et al. 1999.
[b] Reference: Dieterman et al. 2004.
[c] References: Rudstam et al. 1995; Johnson et al. 1999.
[d] A constant predator energy density of 7,452 J • g^{-1} wet weight was used for brown trout age 3 and above (>810 g) as found in Hayes et al. (2000).

Table 3A.—Mean weight (W; grams) at age, abundance (N), and annual mortality (A) of each predator species modeled in the western arm of Lake Superior in 2000. Unclipped steelhead weights varied by ecoregion (Eco = Ecoregion). Mortalities listed for each species reflect values for Ecoregion 1.

	Lean lake trout (wild)[a]			Lean lake trout (stocked)[a]			Siscowet			Chinook salmon			Coho salmon		
Age	W	N	A	W	N[b]	A	W	N	$\bar{A}$	W	N	A	W	N	$\bar{A}$
0	0.02	7,586,014	0.897				0.02	21,447,943	0.898	6	769,338	0.995			
1	41	776,956	0.148	41	10,483	0.148	5	2,050,259	0.150	300	66,913	0.380	35	175,018	0.850
2	105	660,191	0.148	105	7,895	0.148	45	1,742,559	0.150	1,240	6,278	0.300	620	35,004	0.900
3	170	560,977	0.152	170	6,153	0.149	59	1,481,047	0.150	2,550	6,454	0.480	1,307		
4	362	431,019	0.164	362	37,551	0.154	125	1,259,059	0.159	4,100	5,445	0.800			
5	663	608,336	0.182	663	36,450	0.165	200	1,059,206	0.167	5,500	2,418	0.990			
6	910	264,587	0.203	910	155,804	0.188	250	881,826	0.175	5,500					
7	1,234	361,865	0.224	1,234	75,145	0.228	290	727,523	0.175						
8	1,600	179,127	0.280	1,600	63,664	0.262	350	600,545	0.196						
9	1,836	153,611	0.313	1,836	21,520	0.278	430	483,066	0.215						
10	2,100	79,121	0.289	2,100	21,678	0.273	500	379,202	0.215						
11	2,400	62,256	0.306	2,400	18,540	0.334	600	297,674	0.232						
12	2,695	54,444	0.317	2,695	15,956	0.363	700	228,724	0.228						
13	2,960	44,354	0.324	2,960	7,574	0.315	800	176,626	0.235						
14	3,213	26,161	0.327	3,213	1,731	0.338	950	135,067	0.243						
15	3,390	19,099	0.314	3,390	6,391	0.278	1,070	102,257	0.245						
16	3,543	14,169	0.328	3,543	4,430	0.295	1,210	77,230	0.252						
17	3,620	10,528	0.326	3,620	3,119	0.291	1,355	57,736	0.252						
18	3,732	7,834	0.324	3,732	2,065	0.283	1,540	43,174	0.252						
19	3,780	4,756	0.317	3,780	1,330	0.269	1,700	32,293	0.252						
20	3,861	248	0.317	3,861	2,781	0.269	1,900	24,160	0.252						
21							2,100	18,080	0.251						
22							2,300	13,534	0.251						
23							2,560	10,133	0.251						
24							2,750	7,588	0.251						
25+							3,000	20,992	0.251						
Total age 1+		4,319,639			500,260			11,909,560			87,508			210,022	

[a] Lean lake trout in Ecoregion 2 were modeled with higher weights-at-age after age 15, reaching 4,400 g at age 22.
[b] Numbers of stocked lake trout following initial stocking mortality.

Table 3A.—Western arm in 2000 continued.

	Unclipped steelhead				**Clipped rainbow trout**			**Brown trout**			**Burbot**			**Walleye**		
Age	W	N	A	Age	W	N	A	W	N	A	W	N	A	W	N	A
	Eco 1			0										2	635,710	0.950
2	48	146,469	0.750	1	150	133,066	0.850				91	121,494	0.430	25	31,785	0.400
3	800	36,505	0.500	2	782	19,819	0.400	21	86,846	0.800	138	69,252	0.430	121	19,071	0.165
4	1,649	18,012	0.450	3	1,548	11,321	0.450	425	13,863	0.700	213	39,474	0.430	250	15,930	0.165
5	2,260	9,792	0.540	4	2,310	6,360	0.720	905	6,292	0.700	317	22,500	0.430	423	13,307	0.165
6	2,735	4,497	0.540	5	2,577	1,235	0.720	1,444	4,416	0.700	452	12,825	0.430	619	11,115	0.165
7	3,089	1,979	0.540	6	2,850	392	0.720	2,042	2,844	0.900	619	7,310	0.430	844	9,284	0.165
8	3,296	1,115	0.540	7	3,133	121	0.720	2,698	2,089	0.950	820	4,167	0.430	1,074	7,755	0.165
9	3,476	502	0.900	8	3,250	48	0.900				1,055	2,375	0.430	1,301	9,736	0.165
				9							1,326	1,354	0.430	1,521	5,411	0.165
	Eco 2			10							1,635	772	0.430	1,733	5,510	0.165
2	67			11							1,982	440	0.430	1,931	3,050	0.323
3	777			12							2,369	251	0.430	2,120	5,288	0.323
4	1,545			13							2,797	143	0.430	2,282	4,559	0.323
5	2,340			14							3,267	81	0.430	2,426	1,275	0.323
6	2,851			15							3,781	46	0.430	2,562	5,061	0.323
7	3,188			16										2,689	6,047	0.323
8	3,499			17										2,791	450	0.323
9	4,098			18										2,880	734	0.323
				19										3,000	354	0.323
	Eco 3			20										3,120	207	0.323
2	29															
3	953															
4	1,542															
5	1,950															
6	2,449															
7	2,722															
8	2,767															
9	2,850															
Total age 1+		218,871				172,362			116,350			282,484			155,929	

Table 3B.—Mean weight (W; grams) at age, abundance (N), and annual mortality (A) of each predator species modeled in the western arm of Lake Superior in 2004. Unclipped steelhead weights varied by ecoregion (Eco = Ecoregion). Mortalities listed for each species reflect values for Ecoregion 1.

	Lean lake trout (wild)[a]			**Lean lake trout (stocked)[a]**			**Siscowet**			**Chinook salmon**			**Coho salmon**		
Age	W	N	A	W	N[b]	A	W	N	A	W	N	A	W	N	A
0	0.02	6,295,476	0.897				0.02	20,432,275	0.898	6	423,259	0.995			
1	41	644,046	0.151	41	27,226	0.148	5	1,729,044	0.150	300	24,469	0.380	35	114,011	0.850
2	105	546,938	0.151	105	22,461	0.148	45	1,469,466	0.150	1,240	33,237	0.300	620	22,802	0.900
3	170	464,475	0.157	170	21,887	0.149	59	1,248,866	0.150	2,550	24,540	0.480	1,307		
4	362	391,674	0.158	362	20,883	0.153	125	1,061,538	0.155	4,100	10,671	0.800			
5	663	305,393	0.167	663	5,507	0.168	200	899,549	0.163	5,500	3,020	0.990			
6	910	338,428	0.189	910	4,075	0.185	250	755,499	0.172	5,500					
7	1,234	285,522	0.209	1,234	2,957	0.204	290	627,957	0.169						
8	1,600	202,370	0.229	1,600	17,017	0.229	350	519,632	0.186						
9	1,836	151,682	0.233	1,836	14,931	0.251	430	423,684	0.197						
10	2,100	144,276	0.238	2,100	13,987	0.260	500	340,599	0.203						
11	2,400	112,971	0.247	2,400	7,026	0.302	600	272,059	0.212						
12	2,695	76,382	0.237	2,695	15,162	0.317	700	218,651	0.213						
13	2,960	47,265	0.243	2,960	4,322	0.285	800	173,106	0.218						
14	3,213	30,794	0.248	3,213	4,231	0.286	950	136,475	0.221						
15	3,390	22,202	0.254	3,390	3,487	0.290	1,070	107,595	0.233						
16	3,543	16,582	0.253	3,543	2,399	0.305	1,210	83,729	0.226						
17	3,620	12,389	0.253	3,620	1,668	0.303	1,355	65,667	0.226						
18	3,732	9,100	0.251	3,732	674	0.277	1,540	51,515	0.226						
19	3,780	6,261	0.250	3,780	363	0.255	1,700	40,424	0.225						
20	3,861	2,850	0.250	3,861	4,802	0.257	1,900	31,730	0.225						
21							2,100	24,913	0.225						
22							2,300	19,566	0.224						
23							2,560	15,371	0.224						
24							2,750	12,079	0.224						
25+							3,000	39,381	0.224						
Total age 1+		3,811,600			195,065			10,368,095			95,937			136,813	

[a] Lean lake trout in Ecoregion 2 were modeled with higher weights-at-age after age 15, reaching 4,400 g at age 22.
[b] Numbers of stocked lake trout following initial stocking mortality.

Table 3B.—Western arm in 2004 continued.

	Unclipped steelhead				**Clipped rainbow trout**			**Brown trout**			**Burbot**			**Walleye**		
Age	W	N	A	Age	W	N	A	W	N	$\bar{A}$	W	N	$\bar{A}$	W	N	$\bar{A}$
	Eco 1			0										2	635,710	0.950
2	48	152,040	0.750	1	150	133,313	0.800				91	121,494	0.430	25	31,785	0.400
3	800	42,378	0.500	2	782	30,339	0.400	21	41,287	0.850	138	69,252	0.430	121	19,071	0.165
4	1,649	21,002	0.450	3	1,548	15,485	0.450	425	14,173	0.700	213	39,474	0.430	250	15,930	0.165
5	2,260	11,579	0.540	4	2,310	8,792	0.720	905	8,190	0.700	317	22,500	0.430	423	13,307	0.165
6	2,735	5,298	0.540	5	2,577	2,459	0.720	1,444	6,545	0.700	452	12,825	0.430	619	11,115	0.165
7	3,089	2,430	0.540	6	2,850	684	0.720	2,042	4,300	0.900	619	7,310	0.430	844	9,284	0.165
8	3,296	1,105	0.540	7	3,133	182	0.720	2,698	3,280	0.950	820	4,167	0.430	1,074	7,755	0.165
9	3,476	503	0.900	8	3,250	52	0.900				1,055	2,375	0.430	1,301	9,736	0.165
				9	3,300						1,326	1,354	0.430	1,521	5,411	0.165
	Eco 2			10							1,635	772	0.430	1,733	5,510	0.165
2	67			11							1,982	440	0.430	1,931	3,050	0.323
3	777			12							2,369	251	0.430	2,120	5,288	0.323
4	1,545			13							2,797	143	0.430	2,282	4,559	0.323
5	2,340			14							3,267	81	0.430	2,426	1,275	0.323
6	2,851			15							3,781	46	0.430	2,562	5,061	0.323
7	3,188			16										2,689	6,047	0.323
8	3,499			17										2,791	450	0.323
9	4,098			18										2,880	734	0.323
				19										3,000	354	0.323
	Eco 3			20										3,120	207	0.323
2	29															
3	953															
4	1,542															
5	1,950															
6	2,449															
7	2,722															
8	2,767															
9	2,850															
Total age 1+		236,335				191,306			77,775			282,484			155,929	

Table 3C.—Mean weight (W; grams) at age, abundance (N), and annual mortality (A) of each predator species modeled in Ecoregion 1 of the western arm of Lake Superior.

	Lean lake trout (wild)			Lean lake trout (stocked)			Siscowet			Chinook salmon			Coho salmon		
Age	W	N	A	W	N[a]	A	W	N	A	W	N	A	W	N	A
0	0.02	1,104,336	0.897				0.02	1,989,452	0.898	6	149,927	0.995			
1	41	113,747	0.148	41	24,471	0.148	5	202,924	0.148	300	21,115	0.380	35	43,750	0.800
2	105	96,928	0.148	105	20,292	0.148	45	172,921	0.148	1,000	25,345	0.300	620	6,563	0.600
3	170	82,597	0.152	170	18,731	0.149	59	147,353	0.147	1,700	17,588	0.480			
4	362	69,970	0.156	362	18,018	0.153	125	125,675	0.151	3,000	7,177	0.800			
5	663	34,708	0.176	663	3,808	0.171	200	106,654	0.166	4,400	2,251	0.990			
6	910	80,560	0.205	910	2,621	0.190	250	88,908	0.179						
7	1,234	78,680	0.222	1,234	1,997	0.210	290	72,993	0.168						
8	1,600	45,867	0.275	1,600	8,892	0.239	350	60,696	0.194						
9	1,836	23,292	0.290	1,836	10,535	0.263	430	48,921	0.202						
10	2,100	20,213	0.281	2,100	10,744	0.272	500	39,016	0.192						
11	2,400	11,361	0.287	2,400	5,739	0.320	600	31,514	0.193						
12	2,695	7,825	0.306	2,695	12,480	0.334	700	25,446	0.205						
13	2,960	4,234	0.310	2,960	2,396	0.318	800	20,229	0.205						
14	3,213	2,547	0.306	3,213	2,689	0.314	950	16,084	0.201						
15	3,390	1,368	0.318	3,390	2,304	0.320	1,070	12,856	0.213						
16	3,543	945	0.309	3,543	1,519	0.334	1,210	10,116	0.204						
17	3,620	653	0.309	3,620	1,012	0.334	1,355	8,050	0.204						
18	3,732	302	0.309	3,732	186	0.334	1,540	6,406	0.204						
19							1,700	5,098	0.204						
20							1,900	4,057	0.204						
21							2,100	3,229	0.204						
22							2,300	2,569	0.204						
23							2,560	2,045	0.204						
24							2,750	1,627	0.204						
25+							3,000	2,025	0.204						
Total age 1+ in 2004.		675,797			148,434			1,217,412			73,476			50,313	

[a] Numbers of lake trout following initial stocking mortality.

Table 3C.—Ecoregion 1 continued.

Age	Unclipped steelhead			Clipped rainbow trout			Brown trout			Burbot			Walleye		
	W	N	A	W	N	A	W	N	A	W	N	A	W	N	A
0													2	635,710	0.950
1				150	105,584	0.800				10	17,495	0.430	25	31,785	0.400
2	48	57,610	0.750	782	24,029	0.400	21	9,482	0.850	79	9,972	0.430	121	19,071	0.165
3	800	18,771	0.500	1,548	12,264	0.450	425	1,969	0.700	194	5,684	0.430	250	15,930	0.165
4	1,649	9,198	0.450	2,310	6,963	0.720	905	619	0.700	277	3,240	0.430	423	13,307	0.165
5	2,260	5,087	0.540	2,577	1,948	0.720	1,444	474	0.700	459	1,847	0.430	619	11,115	0.165
6	2,735	2,311	0.540	2,850	541	0.720	2,042	86	0.900	662	1,053	0.430	844	9,284	0.165
7	3,089	1,054	0.540	3,133	144	0.720				870	600	0.430	1,074	7,755	0.165
8	3,296	473	0.540	3,250	41	0.900				1,072	342	0.430	1,301	9,736	0.165
9	3,476	212	0.900							1,261	195	0.430	1,521	5,411	0.165
10										1,434	111	0.430	1,733	5,510	0.165
11										1,589	63	0.430	1,931	3,050	0.323
12										1,724	36	0.430	2,120	5,288	0.323
13										1,842	21	0.430	2,282	4,559	0.323
14										1,944	12	0.430	2,426	1,275	0.323
15										2,030	7	0.430	2,562	5,061	0.323
16													2,689	6,047	0.323
17													2,791	450	0.323
18													2,880	734	0.323
19													3,000	354	0.323
20													3,120	207	0.323
Total age 1+		94,716			151,514			12,630			40,678			155,929	

Table 3D.—Mean weight (W; grams) at age, abundance (N), and annual mortality (A) of each predator species modeled in Ecoregion 2 of the western arm of Lake Superior in 2004.

	Lean lake trout (wild)[a]			Siscowet			Chinook salmon			Coho salmon		
Age	W	N	A	W	N	A	W	N	A	W	N	A
0	0.02	4,388,262	0.898	0.02	12,974,495	0.898	6	302,000	0.995			
1	41	447,603	0.152	5	925,484	0.152	300	1,933	0.380	35	77,976	0.800
2	105	379,540	0.152	45	784,718	0.152	1,000	2,203	0.300	620	15,595	0.600
3	170	321,828	0.159	59	665,362	0.152	1,700	2,893	0.480			
4	362	270,676	0.159	125	564,161	0.159	3,000	1,420	0.800			
5	663	240,747	0.166	200	476,946	0.164	4,400	341	0.990			
6	910	211,043	0.184	250	401,248	0.173						
7	1,234	174,396	0.206	290	334,315	0.174						
8	1,600	135,493	0.214	350	274,121	0.185						
9	1,836	113,927	0.221	430	224,040	0.199						
10	2,100	109,826	0.232	500	179,928	0.215						
11	2,400	92,989	0.244	600	141,890	0.232						
12	2,695	62,397	0.227	700	113,308	0.218						
13	2,960	39,996	0.236	800	89,589	0.229						
14	3,213	26,117	0.243	950	70,256	0.238						
15	3,390	19,597	0.250	1,070	54,732	0.246						
16	3,543	14,705	0.250	1,210	42,415	0.246						
17	3,620	11,035	0.250	1,355	32,870	0.246						
18	3,732	8,280	0.250	1,540	25,473	0.246						
19	3,780	6,213	0.250	1,700	19,741	0.246						
20	3,861	2,850	0.250	1,900	15,298	0.246						
21				2,100	11,855	0.246						
				2,300	9,187	0.246						
23				2,560	7,120	0.246						
24				2,750	5,518	0.246						
25+				3,000	17,085	0.246						
Total age 1+		2,689,258			5,486,660			8,790			93,571	

[a] Lean lake trout in Ecoregion 2 were modeled with higher weights-at-age after age 15, reaching 4,400 g at age 22.

Table 3D.—Ecoregion 2 continued.

Age	Unclipped steelhead			Brown trout			Burbot		
	W	N	A	W	N	A	W	N	$\bar{A}$
0							10	43,009	0.430
1	67	25,000	0.750	21	22,519	0.850	79	24,515	0.430
2	777	6,250	0.500	425	4,676	0.700	194	13,974	0.430
3	1,545	3,125	0.450	905	1,469	0.700	277	7,965	0.430
4	2,340	1,719	0.540	1,444	1,125	0.700	459	4,540	0.430
5	2,851	791	0.540	2,042	205	0.900	662	2,588	0.430
6	3,188	367	0.540				870	1,475	0.430
7	3,499	167	0.540				1,072	841	0.430
8	4,098	77	0.900				1,261	479	0.430
9							1,434	273	0.430
10							1,589	156	0.430
11							1,724	89	0.430
12							1,842	51	0.430
13							1,944	29	0.430
14							2,030	16	0.430
15									
Total age 1+		37,496			29,994			100,000	

Table 3E.—Mean weight (W; grams) at age, abundance (N), and annual mortality (A) of each predator species modeled in Ecoregion 3 of the western arm of Lake Superior in 2004.

	Lean lake trout (wild)			Lean lake trout (stocked)			Siscowet			Chinook salmon			Coho salmon		
Age	W	N	A	W	N[a]	A	W	N	A	W	N	A	W	N	A
0	0.02	802,879	0.897				0.02	5,888,586	0.898	6	4,425	0.995			
1	41	82,697	0.148	41	2,755	0.148	5	600,636	0.148	270*	1,421	0.380	35	9,109	0.800
2	105	70,469	0.148	105	2,169	0.148	45	511,828	0.148	1,000	5,689	0.300	620	1,822	0.600
3	170	60,050	0.150	170	3,156	0.149	59	436,151	0.148	1,700	4,059	0.480			
4	362	51,028	0.153	362	2,865	0.151	125	371,703	0.150	3,000	2,074	0.800			
5	663	29,938	0.166	663	1,699	0.163	200	315,949	0.160	4,400	428	0.990			
6	910	46,825	0.184	910	1,454	0.176	250	265,343	0.168						
7	1,234	32,446	0.194	1,234	960	0.192	290	220,649	0.162						
8	1,600	21,010	0.229	1,600	8,125	0.218	350	184,815	0.184						
9	1,836	14,463	0.239	1,836	4,396	0.221	430	150,724	0.193						
10	2,100	14,237	0.228	2,100	3,243	0.218	500	121,655	0.189						
11	2,400	8,621	0.227	2,400	1,287	0.225	600	98,655	0.190						
12	2,695	6,160	0.247	2,695	2,414	0.223	700	79,897	0.208						
13	2,960	3,035	0.247	2,960	1,585	0.229	800	63,287	0.208						
14	3,213	2,130	0.242	3,213	1,334	0.224	950	50,135	0.202						
15	3,390	1,237	0.259	3,390	1,183	0.233	1,070	40,007	0.220						
16	3,543	932	0.247	3,543	881	0.255	1,210	31,198	0.207						
17	3,620	702	0.247	3,620	656	0.255	1,355	24,747	0.207						
18	3,732	517	0.246	3,732	488	0.255	1,540	19,636	0.206						
19	3,780	48	0.243	3,780	363	0.255	1,700	15,586	0.206						
20				3,861	4,802	0.257	1,900	12,375	0.206						
21							2,100	9,829	0.205						
22							2,300	7,809	0.205						
23							2,560	6,206	0.205						
24							2,750	4,934	0.205						
25+							3,000	16,767	0.204						
Total age 1+		446,545			45,815			3,660,521			13,671			10,931	

[a] Numbers of lake trout following initial stocking mortality.

Table 3E.—Ecoregion 3 continued.

	Unclipped steelhead			Clipped rainbow trout			Burbot		
Age	W	N	A	W	N	A	W	N	$\bar{A}$
0				150	27,729	0.800	10	60,990	0.430
1	29	69,430	0.750	782	6,311	0.400	79	34,764	0.430
2	953	17,358	0.500	1,548	3,221	0.450	194	19,816	0.430
3	1,542	8,679	0.450	2,310	1,829	0.720	277	11,295	0.430
4	1,950	4,773	0.540	2,577	511	0.720	459	6,438	0.430
5	2,449	2,196	0.540	2,850	142	0.720	662	3,670	0.430
6	2,722	1,010	0.540	3,133	38	0.720	870	2,092	0.430
7	2,767	465	0.540	3,250	11	0.900	1,072	1,192	0.430
8	2,850	214	0.900				1,261	680	0.430
9							1,434	387	0.430
10							1,589	221	0.430
11							1,724	126	0.430
12							1,842	72	0.430
13							1,944	41	0.430
14							2,030	23	0.430
15									
Total age 1+		104,125			39,792			141,807	

Table 3F.—Mean weight (W; grams) at age, abundance (N), and annual mortality (A) of each predator species modeled in Minnesota waters of the western arm of Lake Superior in 2004.

	Lean lake trout (wild)			Lean lake trout (stocked)			Siscowet			Chinook salmon			Coho salmon		
Age	W	N	A	W	N[a]	A	W	N	A	W	N	A	W	N	A
0	0.02	1,301,051	0.897				0.02	6,617,336	0.898	6	15,259	0.995			
1	41	134,008	0.148	41	24,564	0.148	5	674,968	0.148	300	4,900	0.380	35	20,463	0.850
2	105	114,194	0.148	105	21,345	0.148	45	575,170	0.148	1,000	19,616	0.300	620	4,093	0.900
3	170	97,310	0.151	170	20,904	0.149	59	490,128	0.148	1,700	13,996	0.480			
4	362	82,592	0.154	362	18,176	0.153	125	417,739	0.150	3,000	7,153	0.800			
5	663	45,595	0.170	663	3,911	0.167	200	355,017	0.161	4,400	1,476	0.990			
6	910	83,166	0.193	910	3,356	0.184	250	297,911	0.170						
7	1,234	67,939	0.209	1,234	1,978	0.201	290	247,387	0.163						
8	1,600	41,701	0.252	1,600	16,296	0.228	350	207,049	0.185						
9	1,836	24,970	0.260	1,836	14,309	0.250	430	168,644	0.194						
10	2,100	23,355	0.249	2,100	13,765	0.259	500	135,947	0.189						
11	2,400	13,746	0.249	2,400	6,710	0.301	600	110,199	0.190						
12	2,695	9,690	0.269	2,695	14,894	0.316	700	89,218	0.208						
13	2,960	4,945	0.271	2,960	3,981	0.282	800	70,698	0.208						
14	3,213	3,279	0.264	3,213	4,023	0.284	950	56,027	0.202						
15	3,390	1,854	0.279	3,390	3,462	0.290	1,070	44,716	0.219						
16	3,543	1,358	0.266	3,543	2,399	0.305	1,210	34,903	0.207						
17	3,620	996	0.265	3,620	1,668	0.303	1,355	27,696	0.206						
18	3,732	653	0.259	3,732	674	0.277	1,540	21,983	0.206						
19	3,780	48	0.243	3,780	363	0.255	1,700	17,453	0.206						
20				3,861	4,802	0.257	1,900	13,861	0.206						
21							2,100	11,011	0.205						
22							2,300	8,750	0.205						
23							2,560	6,955	0.205						
24							2,750	5,530	0.205						
25+							3,000	18,792	0.204						
Total age 1+		751,399			181,580			4,107,752			47,141			24,556	

[a] Numbers of lake trout following initial stocking mortality.

Table 3F.—Minnesota waters continued.

	Unclipped steelhead			**Clipped rainbow trout**			**Burbot**			**Walleye**		
Age	W	N	A	W	N	A	W	N	A	W	N	A
0										2	158,927	0.950
1				150	133,313	0.800	10	17,495	0.430	25	7,946	0.400
2	48	92,040	0.750	782	30,339	0.400	79	9,972	0.430	121	4,768	0.165
3	800	23,010	0.500	1,548	15,485	0.450	194	5,684	0.430	250	3,983	0.165
4	1,649	11,505	0.450	2,310	8,792	0.720	277	3,240	0.430	423	3,327	0.165
5	2,260	6,328	0.540	2,577	2,459	0.720	459	1,847	0.430	619	2,779	0.165
6	2,735	2,911	0.540	2,850	684	0.720	662	1,053	0.430	844	2,321	0.165
7	3,089	1,339	0.540	3,133	182	0.720	870	600	0.430	1,074	1,939	0.165
8	3,296	616	0.540	3,250	52	0.900	1,072	342	0.430	1,301	2,434	0.165
9	3,476	283	0.900				1,261	195	0.430	1,521	1,353	0.165
10							1,434	111	0.430	1,733	1,377	0.165
11							1,589	63	0.430	1,931	762	0.323
12							1,724	36	0.430	2,120	1,322	0.323
13							1,842	21	0.430	2,282	1,140	0.323
14							1,944	12	0.430	2,426	319	0.323
15							2,030	7	0.430	2,562	1,265	0.323
16										2,689	1,512	0.323
17										2,791	112	0.323
18										2,880	183	0.323
19										3,000	89	0.323
20										3,120	52	0.323
Total age 1+		94,716			151,514			40,678			43,973	

Table 3G.—Mean weight (W; grams) at age, abundance (N), and annual mortality (A) of each predator species modeled in Wisconsin waters of the western arm of Lake Superior in 2004.

	Lean lake trout (wild)			**Lean lake trout (stocked)**			**Siscowet**			**Chinook salmon**			**Coho salmon**		
Age	W	N	A	W	N[a]	A	W	N	A	W	N	A	W	N	A
0	0.02	4,994,425	0.897				0.02	10,334,072	0.898	6	241,853	0.995			
1	41	510,037	0.152	41	2,662	0.148	5	1,054,075	0.152	300	19,569	0.380	35	93,548	0.800
2	105	432,744	0.152	105	1,116	0.148	45	894,296	0.152	1000	13,621	0.300	620	18,710	0.600
3	170	367,165	0.158	170	983	0.149	59	758,739	0.151	1700	10,544	0.480			
4	362	309,082	0.159	362	2,707	0.153	125	643,800	0.158	3000	3,518	0.800			
5	663	259,798	0.167	663	1,596	0.171	200	544,532	0.165	4400	1,544	0.990			
6	910	255,262	0.188	910	719	0.190	250	457,588	0.173						
7	1234	217,583	0.209	1234	979	0.210	290	380,570	0.173						
8	1600	160,669	0.223	1600	721	0.239	350	312,584	0.186						
9	1836	126,712	0.228	1836	622	0.263	430	255,040	0.200						
10	2100	120,921	0.236	2100	222	0.272	500	204,652	0.212						
11	2400	99,225	0.247	2400	316	0.320	600	161,861	0.227						
12	2695	66,692	0.232	2695	268	0.334	700	129,433	0.217						
13	2960	42,320	0.240	2960	341	0.318	800	102,408	0.226						
14	3213	27,515	0.246	3213	208	0.314	950	80,449	0.234						
15	3390	20,348	0.252	3390	25	0.320	1070	62,879	0.242						
16	3543	15,224	0.252				1210	48,826	0.241						
17	3620	11,393	0.251				1355	37,971	0.241						
18	3732	8,446	0.251				1540	29,533	0.240						
19	3780	6,213	0.250				1700	22,971	0.240						
20	3861	2,850	0.250				1900	17,869	0.240						
21							2100	13,901	0.240						
22							2300	10,816	0.240						
23							2560	8,416	0.240						
24							2750	6,549	0.240						
25+							3000	20,589	0.239						
Total age 1+		3,060,199			13,485			6,260,347			48,796			112,258	

[a] Numbers of lake trout following initial stocking mortality.

Table 3G.—Wisconsin waters continued.

Age	Unclipped steelhead			Brown trout			Burbot			Walleye		
	W	N	A	W	N	A	W	N	A	W	N	A
0										2	476,782	0.950
1							10	52,607	0.430	25	23,839	0.400
2	67	60,000	0.750	21	32,001	0.850	79	29,986	0.430	121	14,303	0.165
3	777	19,368	0.500	425	6,645	0.700	194	17,092	0.430	250	11,948	0.165
4	1,545	9,497	0.450	905	2,088	0.700	277	9,742	0.430	423	9,980	0.165
5	2,340	5,251	0.540	1444	1,599	0.700	459	5,553	0.430	619	8,336	0.165
6	2,851	2,387	0.540	2042	291	0.900	662	3,165	0.430	844	6,963	0.165
7	3,188	1,092	0.540				870	1,804	0.430	1074	5,816	0.165
8	3,499	489	0.540				1072	1,028	0.430	1301	7,302	0.165
9	4,098	220	0.900				1261	586	0.430	1521	4,058	0.165
10							1434	334	0.430	1733	4,132	0.165
11							1589	190	0.430	1931	2,287	0.323
12							1724	109	0.430	2120	3,966	0.323
13							1842	62	0.430	2282	3,419	0.323
14							1944	35	0.430	2426	957	0.323
15							2030	20	0.430	2562	3,796	0.323
										2689	4,535	0.323
										2791	337	0.323
										2880	550	0.323
										3000	266	0.323
										3120	155	0.323
Total age 1+		98,304			42,624			122,313			131,917	

Table 3H.—Abundance (N) and annual mortality (A) of each predator species modeled in the MN-1 management zone in the Minnesota waters of Lake Superior in 2004.

	Lake trout (wild)		**Lake trout (stocked)**		**Siscowet**		**Chinook salmon**		**Coho salmon**		**Unclipped steelhead**		**Clipped rainbow trout**		**Burbot**		**Walleye**	
Age	N	A	N[a]	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A
0	498,173	0.90			728,750	0.90	10,834	0.995									158,927	0.95
1	51,312	0.15	21,809	0.15	74,333	0.15	3,479	0.38	11,354	0.80			105,584	0.80	7,897	0.43	7,946	0.40
2	43,725	0.15	19,176	0.15	63,342	0.15	13,927	0.30	2,271	0.60	22,610	0.75	24,029	0.40	4,501	0.43	4,768	0.17
3	37,260	0.15	17,748	0.15	53,976	0.15	9,937	0.48			5,653	0.50	12,264	0.45	2,566	0.43	3,983	0.17
4	31,564	0.16	15,311	0.15	46,036	0.15	5,079	0.80			2,826	0.45	6,963	0.72	1,462	0.43	3,327	0.17
5	15,657	0.18	2,212	0.17	39,068	0.17	1,048	0.99			1,554	0.54	1,948	0.72	834	0.43	2,779	0.17
6	36,341	0.21	1,902	0.19	32,568	0.18					715	0.54	541	0.72	475	0.43	2,321	0.17
7	35,493	0.22	1,018	0.21	26,738	0.17					329	0.54	144	0.72	271	0.43	1,939	0.17
8	20,691	0.28	8,171	0.24	22,233	0.19					151	0.54	41	0.90	154	0.43	2,434	0.17
9	10,507	0.29	9,913	0.26	17,920	0.20					70	0.90			88	0.43	1,353	0.17
10	9,118	0.28	10,522	0.27	14,292	0.19									50	0.43	1,377	0.17
11	5,125	0.29	5,423	0.32	11,544	0.19									29	0.43	762	0.32
12	3,530	0.31	12,480	0.33	9,321	0.21									16	0.43	1,322	0.32
13	1,910	0.31	2,396	0.32	7,410	0.21									9	0.43	1,140	0.32
14	1,149	0.31	2,689	0.31	5,892	0.20									5	0.43	319	0.32
15	617	0.32	2,279	0.32	4,709	0.21									3	0.43	1,265	0.32
16	426	0.31	1,519	0.33	3,705	0.20											1,512	0.32
17	294	0.31	1,012	0.33	2,949	0.20											112	0.32
18	136	0.31	186	0.33	2,347	0.20											183	0.32
19					1,867	0.20											89	0.32
20					1,486	0.20											52	0.32
21					1,183	0.20												
22					941	0.20												
23					749	0.20												
24					596	0.20												
25+					2,025	0.20												
Total age 1+	304,855		135,766		447,230		33,470		13,625		33,908		151,514		18,360		43,972	

[a] Numbers of lake trout following initial stocking mortality.

Table 3I.—Abundance (N) and annual mortality (A) of each predator species modeled in the MN-2 management zone in the Minnesota waters of Lake Superior in 2004.

	Lake trout (wild)		Lake trout (stocked)		Siscowet		Chinook salmon		Coho salmon		Unclipped steelhead		Clipped rainbow trout		Burbot	
Age	N	A	N[a]	A	N	A	N	A	N	A	N	A	N	A	N	A
0	268,446	0.90			2,177,300	0.90	1,611	1.00								
1	27,650	0.15	2,340	0.15	222,085	0.15	517	0.38	3,716	0.80			11,313	0.80	21,626	0.43
2	23,562	0.15	1,847	0.15	189,248	0.15	2,071	0.30	743	0.60	28,327	0.75	2,575	0.40	12,327	0.43
3	20,078	0.15	1,335	0.15	161,267	0.15	1,477	0.48			7,082	0.50	1,314	0.45	7,026	0.43
4	17,033	0.15	1,799	0.15	137,381	0.15	755	0.80			3,541	0.45	746	0.72	4,005	0.43
5	8,791	0.16	828	0.16	116,800	0.15	156	0.99			1,948	0.54	209	0.72	2,283	0.43
6	15,516	0.18	671	0.17	98,704	0.16					896	0.54	58	0.72	1,301	0.43
7	8,465	0.21	463	0.18	83,103	0.15					412	0.54	15	0.72	742	0.43
8	5,126	0.25	2,377	0.20	70,510	0.16					190	0.54	4	0.90	423	0.43
9	3,641	0.26	2,809	0.21	58,992	0.17					87	0.90			241	0.43
10	2,619	0.25	1,676	0.21	48,962	0.17									137	0.43
11	1,263	0.25	422	0.21	40,573	0.17									78	0.43
12	1,420	0.26	1,145	0.22	33,534	0.19									45	0.43
13	569	0.26	653	0.23	27,123	0.19									25	0.43
14	436	0.26	665	0.22	21,917	0.19									14	0.43
15	243	0.28	399	0.23	17,841	0.21									8	0.43
16	180	0.26	296	0.26	14,168	0.19										
17	133	0.26	220	0.26	11,460	0.19										
18	87	0.26	164	0.26	9,269	0.19										
19			122	0.26	7,496	0.19										
20			3,906	0.26	6,063	0.19										
21					4,904	0.19										
22					3,966	0.19										
23					3,208	0.19										
24					2,595	0.19										
25+					9,350	0.19										
Total age 1+	136,812		24,137		1,400,519		4,976		4,459		42,483		16,234		50,281	

[a] Numbers of lake trout following initial stocking mortality.

Table 3J.—Abundance (N) and annual mortality (A) of each predator species modeled in the MN-3 management zone in the Minnesota waters of Lake Superior in 2004.

	Lake trout (wild)		Lake trout (stocked)		Siscowet		Chinook salmon		Coho salmon		Unclipped steelhead		Clipped rainbow trout		Burbot	
Age	N	A	N[a]	A	N	A	N	A	N	A	N	A	N	A	N	A
0	534,433	0.90			3,711,286	0.90	2,814	1.00								
1	55,047	0.15	415	0.15	378,551	0.15	904	0.38	5,392	0.80			16,416	0.80	39,364	0.43
2	46,908	0.15	322	0.15	322,580	0.15	3,618	0.30	1,078	0.60	41,103	0.75	3,736	0.40	22,438	0.43
3	39,972	0.15	1,821	0.15	274,885	0.15	2,581	0.48			10,276	0.50	1,907	0.45	12,789	0.43
4	33,995	0.15	1,066	0.15	234,322	0.15	1,319	0.80			5,138	0.45	1,083	0.72	7,290	0.43
5	21,147	0.17	871	0.17	199,149	0.16	272	0.99			2,826	0.54	303	0.72	4,155	0.43
6	31,309	0.18	783	0.18	166,640	0.17					1,300	0.54	84	0.72	2,369	0.43
7	23,981	0.19	497	0.20	137,546	0.17					598	0.54	22	0.72	1,350	0.43
8	15,884	0.22	5,748	0.23	114,305	0.20					275	0.54	6	0.90	770	0.43
9	10,822	0.23	1,587	0.24	91,731	0.21					127	0.90			439	0.43
10	11,618	0.22	1,567	0.23	72,693	0.20									250	0.43
11	7,358	0.22	865	0.23	58,082	0.20									143	0.43
12	4,740	0.24	1,269	0.23	46,363	0.22									81	0.43
13	2,466	0.24	932	0.23	36,165	0.22									46	0.43
14	1,694	0.24	669	0.23	28,218	0.21									26	0.43
15	994	0.26	784	0.23	22,167	0.23									15	0.43
16	752	0.24	584	0.25	17,030	0.22										
17	569	0.24	435	0.25	13,287	0.22										
18	430	0.24	325	0.25	10,368	0.22										
19	48	0.24	242	0.25	8,089	0.22										
20			896	0.25	6,312	0.22										
21					4,925	0.22										
22					3,843	0.22										
23					2,998	0.22										
24					2,339	0.22										
25+					7,416	0.22										
Total age 1+	309,734		21,678		2,260,004		8,694		6,470		61,643		23,557		91,525	

[a] Numbers of lake trout following initial stocking mortality.

Table 3K.—Abundance (N) and annual mortality (A) of each predator species modeled in the WI-1 management zone in the Wisconsin waters of Lake Superior in 2004. [Note that management zone WI-2 is equivalent to Ecoregion 2, shown in Table 3D.]

	Lake trout (wild)		**Lake trout (stocked)**		**Siscowet**		**Chinook salmon**		**Coho salmon**		**Unclipped steelhead**		**Brown trout**		**Burbot**		**Walleye**	
Age	N	A	N[a]	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A
0	606,163	0.90			1,260,702	0.90	139,093	0.995									476,782	0.95
1	62,435	0.15	2,662	0.15	128,592	0.15	17,636	0.38	15,572	0.80					9,598	0.43	23,839	0.40
2	53,203	0.15	1,116	0.15	109,579	0.15	11,418	0.30	3,114	0.60	35,000	0.75	9,482	0.85	5,471	0.43	14,303	0.17
3	45,337	0.15	983	0.15	93,377	0.15	7,651	0.48			13,118	0.50	1,969	0.70	3,118	0.43	11,948	0.17
4	38,406	0.16	2,707	0.15	79,639	0.15	2,098	0.80			6,372	0.45	619	0.70	1,777	0.43	9,980	0.17
5	19,051	0.18	1,596	0.17	67,586	0.17	1,203	0.99			3,532	0.54	474	0.70	1,013	0.43	8,336	0.17
6	44,219	0.20	719	0.19	56,340	0.18					1,596	0.54	86	0.90	578	0.43	6,963	0.17
7	43,187	0.22	979	0.21	46,255	0.17					725	0.54	9	0.95	329	0.43	5,816	0.17
8	25,176	0.27	721	0.24	38,463	0.19					322	0.54			188	0.43	7,302	0.17
9	12,785	0.29	622	0.26	31,001	0.20					143	0.90			107	0.43	4,058	0.17
10	11,095	0.28	222	0.27	24,724	0.19									61	0.43	4,132	0.17
11	6,236	0.29	316	0.32	19,970	0.19									35	0.43	2,287	0.32
12	4,295	0.31	268	0.33	16,125	0.21									20	0.43	3,966	0.32
13	2,324	0.31	341	0.32	12,819	0.20									11	0.43	3,419	0.32
14	1,398	0.31	208	0.31	10,193	0.20									6	0.43	957	0.32
15	751	0.32	25	0.32	8,146	0.21									4	0.43	3,796	0.32
16	519	0.31			6,410	0.20											4,535	0.32
17	358	0.31			5,101	0.20											337	0.32
18	166	0.31			4,060	0.20											550	0.32
19					3,231	0.20											266	0.32
20					2,571	0.20											155	0.32
21					2,046	0.20												
22					1,628	0.20												
23					1,296	0.20												
24					1,031	0.20												
25+					3,504	0.20												
Total age 1+	370,941		13,485		773,687		40,006		18,686		60,808		12,639		22,316		131,917	

[a] Numbers of lake trout following initial stocking mortality.

Table 4A.—Lake trout diet by ecoregion in the western arm of Lake Superior in 2000, taken from MNDNR and WIDNR gillnet assessments, commercial permit fishermen, and stomachs obtained from angler-caught fish (Ostazeski et al. 1999; Ray 2004). Diets for ages 0-to-2 lake trout were combined from Swedberg and Peck (1984) and Hudson et al. (1995).

		Dietary proportion (% by weight) of:						
Date	Simulation day	Rainbow smelt	Coregonines (cisco)	Salmonid juveniles	Burbot	Slimy sculpin	Mysids	Insects
Ecoregion 1 (western tip):				**Age 0**				
1 Jun	1	0	0	0	0	0	0.22	0.78
1 Jul	31	0	0	0	0	0	1.00	0
1 Oct	123	0	0	0	0	0.12	0.88	0
1 May	335	0	0	0	0	0.12	0.87	0.01
				Ages 1-5 (302-470 mm)				
1 Jun	1	0.15	0.30	0	0	0.20	0.32	0.03
1 Oct	123	0.05	0.50	0	0	0.30	0.15	0
1 Apr	305	0.05	0.50	0	0	0.30	0.15	0
1 May	335	0.75	0.10	0	0	0.13	0.01	0.01
				Ages $\geq$6 (>470 mm)				
1 Jun	1	0.11	0.75	0.10	0.01	0	0.03	0
1 Oct	123	0.07	0.90	0	0	0.03	0	0
1 Apr	305	0.07	0.90	0	0	0.03	0	0
1 May	335	0.76	0.12	0.10	0.01	0.01	0	0
Ecoregion 2 (Apostle Islands):				**Age 0**				
1 Jun	1	0	0	0	0	0	0.22	0.78
1 Jul	31	0	0	0	0	0	1.00	0
1 Oct	123	0	0	0	0	0.12	0.88	0
1 May	335	0	0	0	0	0.12	0.87	0.01
				Ages 1-5 (302-470 mm)				
1 Jun	1	0.16	0.30	0.06	0	0.19	0.27	0.02
1 Oct	123	0.08	0.42	0	0	0.30	0.20	0
1 Apr	305	0.08	0.42	0	0	0.30	0.20	0
1 May	335	0.60	0.25	0	0	0.15	0	0
				Ages $\geq$6 (>470 mm)				
1 Jun	1	0.15	0.70	0.08	0.01	0	0.04	0.02
1 Oct	123	0.07	0.90	0	0	0.03	0	0
1 Apr	305	0.07	0.90	0	0	0.03	0	0
1 May	335	0.58	0.30	0.01	0.10	0.01	0	0
Ecoregion 3 (north shore):				**Age 0**				
1 Jun	1	0	0	0	0	0	0.94	0.06
1 Jul	31	0.25	0	0	0	0.04	0.70	0.01
1 Oct	123	0	0	0	0	0.15	0.85	0
1 Apr	305	0	0	0	0	0.15	0.85	0
1 May	335	0	0	0	0	0	0.94	0.06
				Ages 1-5 (114-470 mm)				
1 Jun	1	0.04	0.18	0	0	0.21	0.57	0
1 Oct	123	0.09	0	0	0	0.34	0.57	0
1 Apr	305	0.09	0	0	0	0.34	0.57	0
1 May	335	0.27	0.09	0	0	0.06	0.55	0.03
				Ages $\geq$6 (>470 mm)				
1 Jun	1	0.20	0.70	0.05	0	0.05	0	0
1 Oct	123	0.10	0.79	0.01	0.04	0.05	0	0.01
1 Apr	305	0.10	0.79	0.01	0.04	0.05	0	0.01
1 May	335	0.80	0.12	0.07	0.1	0	0	0

Table 4B.—Lake trout diet by ecoregion in the western arm of Lake Superior in 2004, taken from MNDNR and WIDNR gillnet assessments, commercial permit fishermen, and stomachs obtained from angler-caught fish (Ostazeski et al. 1999; Ray 2004), with reduced rainbow smelt consumption to reflect population declines since 2000. Diets for ages 0-to-2 lake trout were combined from Swedberg and Peck (1984) and Hudson et al. (1995).

Date	Simulation day	Dietary proportion (% by weight) of: Rainbow smelt	Coregonines (cisco)	Salmonid juveniles	Burbot	Slimy sculpin	Mysids	Insects
Ecoregion 1 (western tip):				**Age 0**				
1 Jun	1	0	0	0	0	0	0.22	0.78
1 Jul	31	0	0	0	0	0	1.00	0
1 Oct	123	0	0	0	0	0.12	0.88	0
1 May	335	0	0	0	0	0.12	0.87	0.01
				Ages 1-5 (302-470 mm)				
1 Jun	1	0.01	0.06	0	0	0.35	0.53	0.05
1 Oct	123	0.03	0.15	0	0	0.35	0.45	0.02
1 Apr	305	0.03	0.15	0	0	0.35	0.45	0.02
1 May	335	0.05	0.10	0	0	0.35	0.50	0
				Ages ≥6 (>470 mm)				
1 Jun	1	0.04	0.63	0.03	0.09	0.01	0.12	0.08
1 Oct	123	0.04	0.65	0.03	0.10	0.03	0.13	0.02
1 Apr	305	0.04	0.65	0.03	0.10	0.03	0.13	0.02
1 May	335	0.20	0.23	0.40	0.11	0.02	0.04	0
Ecoregion 2 (Apostle Islands):				**Age 0**				
1 Jun	1	0	0	0	0	0	0.22	0.78
1 Jul	31	0	0	0	0	0	1.00	0
1 Oct	123	0	0	0	0	0.12	0.88	0
1 May	335	0	0	0	0	0.12	0.87	0.01
				Ages 1-5 (302-470 mm)				
1 Jun	1	0.80	0	0	0	0.18	0	0.02
1 Oct	123	0.03	0.70	0	0	0.25	0.02	0
1 Apr	305	0.03	0.70	0	0	0.25	0.02	0
1 May	335	0.90	0.03	0	0	0.06	0.01	0
				Ages ≥6 (>470 mm)				
1 Jun	1	0.50	0.30	0	0.15	0.03	0.01	0.01
1 Oct	123	0.03	0.80	0	0.10	0.05	0.02	0
1 Apr	305	0.03	0.80	0	0.10	0.05	0.02	0
1 May	335	0.50	0.30	0	0.15	0.02	0.02	0.01
Ecoregion 3 (north shore):				**Age 0**				
1 Jun	1	0	0	0	0	0	0.94	0.06
1 Jul	31	0.25	0	0	0	0.04	0.70	0.01
1 Oct	123	0	0	0	0	0.15	0.85	0
1 Apr	305	0	0	0	0	0.15	0.85	0
1 May	335	0	0	0	0	0	0.94	0.06
				Ages 1-5 (114-470 mm)				
1 Jun	1	0.01	0.16	0	0	0.14	0.38	0.31
1 Oct	123	0.01	0.3	0	0	0.27	0.40	0.02
1 Apr	305	0.01	0.3	0	0	0.27	0.40	0.02
1 May	335	0.01	0.16	0	0	0.14	0.38	0.31
				Ages ≥6 (>470 mm)				
1 Jun	1	0.01	0.64	0.04	0	0.01	0.13	0.18
1 Oct	123	0.02	0.72	0.05	0.06	0.06	0.08	0.01
1 Apr	305	0.02	0.72	0.05	0.06	0.06	0.08	0.01
1 May	335	0.11	0.43	0.05	0.22	0.03	0.15	0.01

Table 5.—Siscowet diet by ecoregion in the western arm of Lake Superior in 2000, taken from MNDNR and WIDNR gillnet assessments and commercial permit fishermen (Ostazeski et al. 1999; Ray 2004), and an Ecoregion 2 diet study (WIDNR, unpublished data). Diet in 2004 was modified by cutting rainbow smelt consumption in half and adding that portion to coregonines.

		Dietary proportion (% by weight) of:						
Date	Simulation day	Rainbow smelt	Coregonines (*C. kiyi & hoyi*)	Salmonids	Burbot	Deepwater sculpin	Mysids	Insects
Ecoregion 1 (western tip):			**Age 0-10 (<454 mm)**					
1 Jun	1	0.10	0.13	0	0	0.75	0.02	0
1 Jul	31	0.02	0.14	0	0	0.75	0.07	0.02
1 May	335	0.10	0.13	0	0	0.75	0.02	0
			Ages 11-16 (454 – 566 mm)					
1 Jun	1	0.10	0.77	0	0	0.11	0.02	0
1 Jul	31	0.02	0.75	0	0	0.21	0	0.02
1 May	335	0.10	0.77	0	0	0.11	0.02	0
			Ages 17 and older (> 566 mm)					
1 Jun	1	0.05	0.87	0	0.07	0.01	0	0
1 Jul	31	0	0.80	0	0.20	0	0	0
1 May	335	0.05	0.87	0	0.07	0.01	0	0
Ecoregion 2 (Apostle Islands):			**Age 0-10 (<454 mm)**					
1 Jun	1	0.10	0.60	0	0	0.26	0.02	0.02
1 May	335	0.66	0.10	0	0	0.20	0.02	0.02
			Ages 11-16 (454 – 566 mm)					
1 Jun	1	0	0.65	0	0	0.35	0	0
1 May	335	0.20	0.50	0	0	0.30	0	0
			Ages 17 and older (> 566 mm)					
1 Jun	1	0	0.90	0	0.09	0.01	0	0
1 May	335	0.02	0.60	0	0.30	0.08	0	0
Ecoregion 3 (north shore):			**Age 0-10 (<454 mm)**					
1 Jun	1	0.07	0.16	0	0	0.68	0.07	0.02
1 May	335	0.07	0	0.01	0	0.61	0.12	0.19
			Ages 11-16 (454 – 566 mm)					
1 Jun	1	0	0.65	0	0	0.35	0	0
1 May	335	0.07	0.60	0.02	0	0.31	0	0
			Ages 17 and older (> 566 mm)					
1 Jun	1	0	0.65	0	0	0.35	0	0
1 May	335	0	0.65	0.03	0.18	0.14	0	0

Table 6.—Burbot diet in the western arm of Lake Superior, taken from MNDNR and WIDNR gillnet assessments and commercial permit fishermen (Ostazeski et al. 1999; Ray 2004; Schram et al. 2006).

		Dietary proportion (% by weight) of:					
Date	Simulation day	Rainbow smelt	Coregonines[a]	Burbot	Sculpins[b]	Mysids	Insects
Ecoregion 1 (western tip) and Ecoregion 2 (Apostle Islands)			**Ages 0-2 (<360 mm)**				
1 Jun	1	0.05	0	0	0.36	0.47	0.12
1 Aug	62	0	0.14	0	0.42	0.44	0
1 May	335	0.05	0	0	0.36	0.47	0.12
			Age 4 and older (>360 mm)				
1 Jun	1	0	0.70	0	0.23	0.07	0
1 Aug	62	0.12	0	0	0.75	0.13	0
1 Sep	93	0.13	0	0.87	0	0	0
1 Oct	123	0	0	0	1.00	0	0
1 May	335	0.34	0.62	0	0	0	0
Ecoregion 3 (north shore):			**Ages 0-2 (<360 mm)**				
1 Jun	1	0	0	0	0.80	0.19	0.01
1 Oct	123	0	0.14	0	0.42	0.44	0
1 May	335	0	0	0	0.80	0.19	0.01
			Age 4 and older (>360 mm)				
1 Jun	1	0	0.46	0	0.47	0.07	0
1 May	335	0	0.46	0	0.47	0.07	0

[a] equal parts *C. artedii* and *C. kiyi* or *C. hoyi.*
[b] equal parts *C. cognatus* and *M. thompsonii*.

Table 7.—Chinook salmon diet by ecoregion in the western arm of Lake Superior, taken from stomachs obtained from angler-caught fish from 1997 to 2001 (Ostazeski et al. 1999; Ray 2004). Diets of age-0 Chinook salmon were estimated based on a greater use of small prey (mysids and terrestrial insects) in the first spring and greater availability of rainbow smelt near shore in spring.

		Dietary proportion (% by weight) of:			
Date	Simulation day	Rainbow smelt	Lake herring	Mysids	Insects
Ecoregion 1 (western tip) and Ecoregion 2 (Apostle Islands):					
		Age 0			
1 Jun	1	0.05	0.05	0.80	0.10
1 Oct	122	0.10	0.50	0.40	0
1 May	335	0.10	0.80	0.10	0
		Ages 1-5			
1 Jun	1	0	0.94	0.04	0.02
1 Oct	122	0.04	0.89	0.07	0
1 May	335	0.04	0.89	0.07	0
Ecoregion 3 (north shore):					
		Age 0			
1 Jun	1	0	0.05	0.85	0.10
1 Oct	122	0	0.30	0.70	0
1-May	335	0	0.70	0.22	0.08
		Ages 1-5			
1 Jun	1	0	0.94	0.04	0.02
1 Oct	122	0	0.50	0.50	0
1 May	335	0	0.50	0.42	0.08

Table 8.—Coho salmon diet by ecoregion in the western arm of Lake Superior, taken from stomachs obtained from angler-caught fish from 1997 to 2001 (Ostazeski et al. 1999; Ray 2004).

		Dietary proportion (% by weight) of:			
Date	Simulation day	Rainbow smelt	Lake herring	Crustaceans	Terrestrial insects
Ecoregion 1 (western tip) and Ecoregion 2 (Apostle Islands):					
1 Jun	1	0	0.83	0.02	0.15
1 Oct	122	0	0.90	0.10	0
1 May	335	0	0.83	0.02	0.15
Ecoregion 3 (north shore):					
1 Jun	1	0	0.55	0.44	0.01
1 Oct	122	0	0.56	0.44	0
1 May	335	0	0.55	0.44	0.01

Table 9.—Brown trout diet in the western arm of Lake Superior (Ecoregions 1 and 2 only); data from Ray (2004) and Devine et al. (2005), eliminating prey items not likely to occur outside Chequamegon Bay.

		Dietary proportion (% by weight) of:			
Date	Simulation day	Rainbow smelt	Cisco	Emerald shiners	Insects
1 Jun	1	0.25	0.25	0.10	0.40
1 Oct	122	0.35	0.55	0.10	0
1 May	335	0.25	0.25	0.10	0.40

Table 10.—Rainbow trout diet in the western arm of Lake Superior, from fish collected in Wisconsin and Minnesota waters of Lake Superior from 1981 to 1987 (Conner et al. 1993), modified to reflect reduced rainbow smelt populations in recent years and rainbow trout stomachs examined by MNDNR in 2006.

		Dietary proportion (% by volume) of:		
Date	Simulation day	Rainbow smelt	Crustaceans	Insects
		First lake year		
1 Jun	1	0.01	0	0.99
1 Jul	31	0.01	0.05	0.94
1 Oct	122	0	0.78	0.22
1 Apr	305	0	0.78	0.22
1 May	335	0.01	0.10	0.89
		> One lake year		
1 Jun	1	0.10	0.10	0.80
1 Jul	31	0.05	0.10	0.85
1 Apr	305	0	0.60	0.40
1 May	335	0.10	0.10	0.80

Table 11.—Walleye diet in the western arm of Lake Superior (Mayo et al. 1998; Ray 2004).

		Dietary proportion (% by weight) of:						
Date	Simulation Day	Rainbow smelt	Lake herring	Black crappie	Yellow perch	Emerald shiner	Spottail shiner	Ruffe
				Ages 0-5				
1 Jun	1	0.34	0	0.13	0.17	0.14	0.11	0.11
31 May	365	0.34	0	0.13	0.17	0.14	0.11	0.11
				Ages 6-18				
1 Jun	1	0.20	0.70	0	0.06	0	0.02	0.02
31 May	365	0.20	0.70	0	0.06	0	0.02	0.02

Table 12.—Energy densities (Joules • g^{-1} wet weight) of prey species. (Note: one calorie = 4.1862 Joules.)

Prey species	J • g^{-1} wet weight	Reference
Burbot	5,135	Lake Superior: Johnson et al. 1999
Coregonines		
Cisco	About 6,500	Laboratory: fish from L. Superior; Pangle et al. 2004
Bloater (*C. hoyi*)	9,879	Lake Michigan: Rottiers & Tucker 1982
Insects (aquatic & terrestrial)	3,138	Great Lakes: Lantry & Stewart 1993
Other small fish		
Nine-spine stickleback	4,396	Apostle Isl., L. Superior; Fisher & Swanson 1996
Bluegill	4,186	Kitchell et al. 1974
Dace	5,007	Hanson et al. 1997
Yellow perch	5,700	adults: Hartman and Margraf 1992
	2,512	larvae and juveniles: Post 1990
Ruffe	4,843	Mayo et al. 1998
Salmonines, small	5,442	Lake Michigan: Stewart 1980
Sculpins	5,582 (mean)	Lake Michigan: Rottiers & Tucker 1982
Slimy Sculpin	5,743	Lake Michigan: Rottiers & Tucker 1982
Deepwater Sculpin	5,421	Lake Michigan: Rottiers & Tucker 1982
Rainbow smelt	3,549 (3,197-4,266)	small (<100 mm); Lake Ontario: Rand et al. 1994
	4,865 (4,457-5,771)	large (100-169 mm); Lake Ontario: Rand et al. 1994
	5,702	large; Lake Michigan: Foltz 1974
	6,656	average; Lake Michigan: Rottiers & Tucker 1982
	5,000	intermediate value used in this study
Zooplankton		
Mysis relicta	3,537	Gardner et al. 1985

Table 13.—Water temperatures (ºC) used in bioenergetics simulations of predators in three ecoregions of Lake Superior. Preferred temperatures of each species were used when available in the environment.

Month	Lake trout			Siscowet	Chinook salmon.			Coho salmon .			Rainbow trout (Steelhead & Kam-loops strains)			Brown trout.		Burbot[a] .			Walleye
	Eco 1	Eco 2	Eco 3	Eco 1-3	Eco 1	Eco 2	Eco 3	Eco 1	Eco 2	Eco 3	Eco 1	Eco 2	Eco 3	Eco 1	Eco 2	Eco 1	Eco 2	Eco 3	Eco 1
January	2.2	2.5	2.8	3.2	2.2	2.6	3.0	2.2	2.6	2.8	2.2	2.6	2.8	2.2	2.6	2.2	2.6	2.8	2.2
February	1.5	1.0	2.2	2.7	1.5	1.1	2.5	1.5	1.1	2.2	1.5	1.1	2.2	1.5	1.1	1.5	1.1	2.2	1.5
March	1.3	0.4	1.6	2.4	1.3	0.3	2.0	1.3	0.3	2.0	1.3	0.3	2.0	1.3	0.3	1.3	0.3	1.6	1.3
April	2.0	1.4	2.0	2.2	2.0	1.4	2.0	2.0	1.4	3.0	2.0	1.4	3.0	2.0	1.4	2.0	1.4	2.0	3.0
May	3.4	3.4	3.0	1.5	3.4	3.4	3.0	3.4	3.4	3.0	3.4	3.4	3.0	3.4	3.4	3.4	3.4	3.0	7.7
June	5.4	6.0	3.5	3.0	5.4	6.0	4.0	6.0	6.0	4.0	6.0	6.0	4.0	5.5	6.0	5.4	5.4	3.5	11.5
July	8.2	7.9	4.0	3.8	9.5	9.5	5.0	10.0	10.0	5.0	10.0	10.0	5.0	10.0	10.0	8.5	8.5	4.0	13.8
August	8.3	8.0	5.5	3.8	11.5	12.0	7.0	12.0	14.0	7.0	12.0	12.0	7.0	12.0	12.0	10.0	10.0	5.5	16.8
September	8.2	8.5	6.0	4.0	11.5	12.0	8.0	14.0	15.0	8.5	13.5	13.5	8.5	13.0	13.0	10.0	10.0	6.0	13.1
October	7.9	8.5	6.7	4.0	7.9	7.9	8.0	8.0	8.0	7.0	8.0	8.0	7.0	8.0	8.0	7.9	7.9	6.7	8.5
November	5.6	6.9	5.5	4.0	5.6	5.6	6.0	6.0	7.1	5.5	6.0	7.1	5.5	6.0	7.1	5.6	5.6	5.5	4.0
December	3.8	4.7	3.9	4.0	3.8	3.8	4.0	3.8	4.9	3.9	3.8	4.9	3.9	3.8	4.9	3.8	3.8	3.9	3.8
Mean	4.8	4.9	3.9	3.2	5.5	5.5	4.5	5.9	6.2	4.5	5.8	5.9	4.5	5.7	5.8	5.1	5.0	3.9	7.3

[a] Temperatures shown were used for adult burbot. Juveniles were modeled using 12°C in August and September, 9°C in October, and 7°C in November.

Table 14A.—Biomass (B) and production (P) of prey species in the western arm of Lake Superior in 2000. Intermediate values for the year 2000 were calculated from densities measured using hydroacoustics in 1997 by Mason et al. (2005) and from 2003 to 2005 by Hrabik et al. (2006 and unpublished data). Production (P) was calculated using production:biomass (P:B) ratios of 0.90 for juvenile cisco, 0.36 for adult cisco, and 1.90 for all age classes of rainbow smelt (Cox and Kitchell 2004). (Note: One metric ton= 1,000 kg.)

	Prey species available in 2000 (metric tons)			
Area of Lake Superior	Coregonine B	Coregonine B+P	Rainbow smelt B	Rainbow smelt B+P
Total ecoregion areas				
Ecoregion 1 (tip of lake)	2,526	3,518	239	694
Ecoregion 2 (Apostle Islands)	7,643	10,643	910	2,638
Ecoregion 3 (north shore)	4,949	6,926	541	1,569
Minnesota waters	6,083	8,502	649	1,881
Wisconsin waters	9,035	12,585	1,041	3,020
Western arm total	15,118	21,087	1,690	4,901
Nearshore areas (<80 m depth)				
Ecoregion 1 (tip of lake)	2,182	3,015	229	664
Ecoregion 2 (Apostle Islands)	6,302	8,710	813	2,358
Ecoregion 3 (north shore)	1,660	2,277	290	840
Minnesota waters	2,621	3,639	391	1,134
Wisconsin waters	7,523	10,363	940	2,727
Western arm total	10,144	14,002	1,331	3,861
Offshore areas (>80 m depth)				
Ecoregion 1 (tip of lake)	345	486	11	31
Ecoregion 2 (Apostle Islands)	1,341	1,890	97	280
Ecoregion 3 (north shore)	3,289	4,613	251	729
Minnesota waters	3,463	4,808	258	747
Wisconsin waters	1,512	2,181	101	293
Western arm total	4,975	6,989	359	1,040

Table 14B.—Biomass (B) and production (P) of prey species in the western arm of Lake Superior in 2004. Data for Ecoregions 1 and 3 were averages of hydroacoustic estimates from 2003 to 2005 (Hrabik et al. 2006 and unpublished data). Data for Ecoregion 2 were from nearshore hydroacoustic estimates collected in this region in 2004 along with offshore estimates from contiguous areas in MN-3 (Hrabik et al., unpublished data). Production was calculated using production:biomass (P:B) ratios of 0.90 for juvenile cisco, 0.36 for adult cisco, and 1.90 for all age classes of rainbow smelt (Cox and Kitchell 2004).

	Prey species available in 2004 (metric tons)			
Area of Lake Superior	Coregonine B	Coregonine B+P	Rainbow smelt B	Rainbow smelt B+P
	Entire ecoregion areas			
Ecoregion 1 (tip of lake)	1,900	2,645	40	115
Ecoregion 2 (Apostle Islands)	4,415	6,132	135	391
Ecoregion 3 (north shore)	5,413	7,563	15	43
Minnesota waters	6,258	8,752	32	92
Wisconsin waters	5,471	7,587	157	457
Western arm total	11,729	16,339	189	549
	Nearshore areas (<80 m depth)			
Ecoregion 1 (tip of lake)	1,230	1,700	32	94
Ecoregion 2 (Apostle Islands)	2,795	3,864	133	386
Ecoregion 3 (north shore)	556	763	1	2
Minnesota waters	1,075	1,500	14	42
Wisconsin waters	3,507	4,827	152	440
Western arm total	4,582	6,327	166	482
	Offshore areas (>80 m depth)			
Ecoregion 1 (tip of lake)	671	945	7	21
Ecoregion 2 (Apostle Islands)	1,620	2,268	2	5
Ecoregion 3 (north shore)	4,857	6,800	14	40
Minnesota waters	5,183	7,252	17	50
Wisconsin waters	1,964	2,761	6	17
Western arm total	7,147	10,013	23	67

Table 15A.—Consumption (metric tons) in 2000 by major predators in the entire western arm of Lake Superior, in nearshore areas, and in offshore areas (divided at the 80-m contour). Metric tons of rainbow smelt and coregonines are followed by percentages of the total amount of that diet item consumed by each predator species. Prey species abbreviations are: RBS = rainbow smelt, COR = coregonines, SAL = salmonines, BUB = burbot, SCU = sculpins, MYS = mysids, INS = insects.

	Prey species consumed										
Species	RBS	(%)	COR	(%)	SAL	BUB	SCU	MYS	INS	Total by predator	% of total consumption by all predators
					Western arm totals						
Lake trout (lean)	1,020	45%	5,377	65%	158	37	611	911	39	8,153	48%
Siscowet	1,042	45%	1,982	24%	13	59	2,511	238	229	6,074	35%
Chinook salmon	11	<1%	320	4%	0	0	0	52	4	387	2%
Coho salmon	0	0%	203	2%	0	0	0	23	13	239	1%
Rainbow trout	46	2%	0	0%	0	0	0	583	1,008	1,637	10%
Brown trout	35	2%	48	1%	0	0	0	0	20	103	1%
Burbot	5	<1%	30	<1%	0	1	78	40	3	157	1%
Walleye	133	6%	254	3%	0	0	0	0	0	388	2%
TOTAL	**2,292**	**100%**	**8,214**	**100%**	**171**	**97**	**3,201**	**1,847**	**1,316**	**17,139**	**100%**
Stocked fish only	174	8%	877	11%	29	8	52	283	393	1,815	11%
					Nearshore areas of the western arm						
Lake trout (lean)	771	63%	4,258	78%	126	26	423	597	27	6,229	62%
Siscowet	227	19%	385	7%	0	12	302	19	13	958	10%
Chinook salmon	11	1%	320	6%	0	0	0	52	4	387	4%
Coho salmon	0	0%	203	4%	0	0	0	23	13	239	2%
Rainbow trout	46	4%	0	0%	0	0	0	583	1,008	1,637	16%
Brown trout	35	3%	48	1%	0	0	0	0	20	103	1%
Burbot	3	<1%	9	<1%	0	0	25	16	2	54	1%
Walleye	133	11%	254	5%	0	0	0	0	0	388	4%
TOTAL	**1226**	**100%**	**5478**	**100%**	**126**	**38**	**750**	**1,290**	**1,088**	**9,995**	**100%**
Stocked fish only	124	10%	620	11%	20	3	28	248	389	1,432	14%
					Offshore areas of the western arm						
Lake trout (lean)	250	23%	1,119	41%	32	11	188	314	11	1,924	27%
Siscowet	814	76%	1,596	58%	13	47	2,209	220	216	5,116	72%
Burbot	2	<1%	21	1%	0	1	54	24	1	103	1%
TOTAL	**1,066**	**1**	**2,736**	**1**	**45**	**58**	**2,451**	**558**	**229**	**7,143**	**100%**
Stocked fish only	50	5%	257	9%	8	5	24	35	4	383	5%

Table 15B.—Consumption (metric tons) in 2004 by major predators in the entire western arm of Lake Superior, in nearshore areas, and in offshore areas (divided at the 80-m contour). Metric tons of rainbow smelt and coregonines are followed by percentages of the total amount of that diet item consumed by each predator species. Prey species abbreviations are: RBS = rainbow smelt, COR = coregonines, SAL = salmonines, BUB = burbot, SCU = sculpins, MYS = mysids, INS = insects.

	Prey species consumed										
Species	RBS	(%)	COR	(%)	SAL	BUB	SCU	MYS	INS	Total by predator	% of total consumption by all predators
					Western arm totals						
Lake trout (lean)	1,080	64%	4,018	56%	81	520	786	889	128	7,502	47%
Siscowet	395	23%	2,277	32%	15	87	2,119	200	198	5,290	33%
Chinook salmon	11	1%	381	5%	0	0	0	54	4	450	3%
Coho salmon	0	0%	132	2%	0	0	0	13	11	156	1%
Rainbow trout	55	3%	0	0%	0	0	0	661	1,221	1,938	12%
Brown trout	12	1%	23	<1%	0	0	0	0	10	45	<1%
Burbot	5	<1%	30	<1%	0	4	79	40	3	162	1%
Walleye	133	8%	254	4%	0	0	0	0	0	388	2%
TOTAL	**1,693**	**100%**	**7,115**	**100%**	**96**	**611**	**2,984**	**1,858**	**1,575**	**15,931**	**100%**
Stocked fish only	40	2%	266	3.7%	18	29	45	353	515	1,267	8%
				Nearshore areas of the western arm							
Lake trout (lean)	897	75%	3,080	72%	45	168	278	399	53	4,920	57%
Siscowet	86	7%	413	10%	1	9	212	20	20	761	9%
Chinook salmon	11	1%	381	9%	0	0	0	54	4	450	5%
Coho salmon	0	0%	132	3%	0	0	0	13	11	156	2%
Rainbow trout	55	5%	0	0%	0	0	0	661	1,221	1,938	22%
Brown trout	12	1%	23	1%	0	0	0	0	10	45	1%
Burbot	3	<1%	9	<1%	0	0	7	5	0	25	<1%
Walleye	133	11%	254	6%	0	0	0	0	0	388	4%
TOTAL	**1,198**	**100%**	**4,293**	**100%**	**46**	**178**	**497**	**1,152**	**1,319**	**8,682**	100%
Stocked fish only	35	3%	163	4%	1	392	483	716	858	2,650	31%
				Offshore areas of the western arm							
Lake trout (lean)	183	37%	938	33%	36	352	508	490	75	2,582	35%
Siscowet	310	63%	1,863	66%	15	85	2,065	196	195	4,730	64%
Burbot	2	<1%	21	1%	0	1	71	36	1	131	2%
TOTAL	**495**	**100%**	**2,822**	**100%**	**51**	**438**	**2,644**	**722**	**271**	**7,443**	100%
Stocked fish only	5	1%	102	4%	4	4	7	36	8	166	2%

Table 15C.—Consumption (metric tons) in 2004 by major predators in all of Ecoregion 1 (western tip) in the western arm of Lake Superior, in Ecoregion 1 nearshore areas, and in Ecoregion 1 offshore areas (divided at the 80-m contour). Metric tons of rainbow smelt and coregonines are followed by percentages of the total amount of that diet item consumed by each predator species. Prey species abbreviations are: RBS = rainbow smelt, COR = coregonines, SAL = salmonines, BUB = burbot, SCU = sculpins, MYS = mysids, INS = insects.

	Prey species consumed										
Species	RBS	(%)	COR	(%)	SAL	BUB	SCU	MYS	INS	Total by predator	% of total consumption by all predators
					Ecoregion 1 totals						
Lake trout (lean)	66	25%	718	47%	55	104	207	413	50	1,613	38%
Siscowet	18	7%	231	15%	0	10	359	21	5	639	15%
Chinook salmon	9	3%	296	19%	0	0	0	23	2	330	8%
Coho salmon	0	0%	32	2%	0	0	0	3	2	36	1%
Rainbow trout	36	13%	0	0%	0	0	0	397	781	1,213	28%
Brown trout	0	0%	7	<1%	0	0	0	0	3	10	<1%
Burbot	2	1%	4	<1%	0	1	12	8	1	27	1%
Walleye	133	51%	254	17%	0	0	0	0	0	388	9%
TOTAL	**264**	**100%**	**1,542**	**100%**	**55**	**115**	**577**	**864**	**845**	**4,262**	**100%**
Stocked fish only	64	19%	176	11%	12	23	36	403	276	961	23%
				Nearshore areas of Ecoregion 1							
Lake trout (lean)	54	23%	586	48%	39	73	145	289	35	1,220	37%
Siscowet	4	2%	54	4%	0	1	36	2	1	98	3%
Chinook salmon	9	4%	296	24%	0	0	0	23	2	330	10%
Coho salmon	0	0%	32	3%	0	0	0	3	2	36	1%
Rainbow trout	36	15%	0	0%	0	0	0	397	781	1,213	37%
Brown trout	0	0%	7	1%	0	0	0	0	3	10	<1%
Burbot	1	<1%	2	<1%	0	0	5	3	0	12	<1%
Walleye	133	56%	254	21%	0	0	0	0	0	388	12%
TOTAL	**237**	**100%**	**1,232**	**100%**	**39**	**74**	**185**	**717**	**824**	**3,308**	**100%**
Stocked fish only	31	13%	138	11%	0	391	481	848	490	2,379	72%
				Offshore areas of Ecoregion 1							
Lake trout (lean)	12	45%	132	43%	17	31	62	124	15	393	41%
Siscowet	14	52%	176	57%	0	9	323	19	5	546	57%
Burbot	1	3%	2	1%	0	1	7	5	1	15	2%
TOTAL	**27**	**100%**	**310**	**100%**	**17**	**41**	**392**	**148**	**21**	**954**	**100%**
Stocked fish only	3	13%	38	12%	0	0	0	32	2	76	8%

Table 15D.—Consumption (metric tons) in 2004 by major predators in all of Ecoregion 2 (Apostle Islands region) in the western arm of Lake Superior, in Ecoregion 2 near-shore areas, and in Ecoregion 2 offshore areas (divided at the 80-m contour). Metric tons of rainbow smelt and coregonines are followed by percentages of the total amount of that diet item consumed by each predator species. Prey species abbreviations are: RBS = rainbow smelt, COR = coregonines, SAL = salmonines, BUB = burbot, SCU = sculpins, MYS = mysids, INS = insects.

	Prey species consumed										
Species	RBS	(%)	COR	(%)	SAL	BUB	SCU	MYS	INS	Total by predator	% of total consumption by all predators
					Ecoregion 2 totals						
Lake trout (lean)	1,000	74%	2,846	64%	0	391	481	275	18	5,012	63%
Siscowet	325	24%	1,435	32%	0	55	561	32	32	2,440	31%
Chinook salmon	2	<1%	41	1%	0	0	0	5	0	48	1%
Coho salmon	0	0%	94	2%	0	0	0	7	6	108	1%
Rainbow trout	6	<1%	0	0%	0	0	0	66	123	195	2%
Brown trout	12	1%	16	<1%	0	0	0	0	7	35	<1%
Burbot	4	<1%	9	<1%	0	3	27	17	2	62	1%
Walleye											
TOTAL	**1,348**	**100%**	**4,442**	**100%**	**0**	**449**	**1,069**	**403**	**189**	**7,900**	**100%**
Stocked fish only	0	0%	3	<1%	0	0	0	0	0	4	<1%
					Nearshore areas of Ecoregion 2						
Lake trout (lean)	840	89%	2,391	82%	0	90	111	63	4	3,499	79%
Siscowet	81	9%	359	12%	0	5	56	3	3	508	12%
Chinook salmon	2	<1%	41	1%	0	0	0	5	0	48	1%
Coho salmon	0	0%	94	3%	0	0	0	7	6	108	2%
Rainbow trout	6	1%	0	0%	0	0	0	66	123	195	4%
Brown trout	12	1%	16	1%	0	0	0	0	7	35	1%
Burbot	2	<1%	6	<1%	0	0	1	1	0	10	<1%
Walleye											
TOTAL	**943**	**100%**	**2,907**	**100%**	**0**	**96**	**168**	**146**	**144**	**4,403**	**100%**
Stocked fish only	0	0%	2	<1%	0	0	0	0	0	3	<1%
					Offshore areas of Ecoregion 2						
Lake trout (lean)	160	40%	455	30%	0	301	371	212	14	1,513	43%
Siscowet	244	60%	1,077	70%	0	54	555	32	32	1,993	56%
Burbot	1	<1%	3	<1%	0	3	26	17	2	51	1%
TOTAL	**405**	**100%**	**1,535**	**100%**	**0**	**358**	**952**	**260**	**47**	**3,558**	**100%**
Stocked fish only											

Table 15E.—Consumption (metric tons) in 2004 by major predators in all of Ecoregion 3 (north shore/open lake) in the western arm of Lake Superior, in Ecoregion 3 nearshore areas, and in Ecoregion 3 offshore areas (divided at the 80-m contour). Metric tons of rainbow smelt and coregonines are followed by percentages of the total amount of that diet item consumed by each predator species. Prey species abbreviations are: RBS = rainbow smelt, COR = coregonines, SAL = salmonines, BUB = burbot, SCU = sculpins, MYS = mysids, INS = insects.

	Prey species consumed										
Species	RBS	(%)	COR	(%)	SAL	BUB	SCU	MYS	INS	Total by predator	% of total consumption by all predators
					Ecoregion 3 totals						
Lake trout (lean)	15	18%	453	40%	26	26	98	200	59	877	23%
Siscowet	52	64%	611	54%	15	22	1,199	147	160	2,206	59%
Chinook salmon	0	0%	44	4%	0	0	0	27	1	71	2%
Coho salmon	0	0%	6	1%	0	0	0	3	2	12	<1%
Rainbow trout	14	18%	0	0%	0	0	0	199	317	530	14%
Brown trout											
Burbot	0	0%	17	2%	0	0	40	15	0	73	2%
Walleye											
TOTAL	**81**	**100%**	**1,131**	**100%**	**41**	**47**	**1,337**	**591**	**541**	**3,768**	**100%**
Stocked fish only	6	7%	87	8%	6	6	9	56	64	233	6%
					Nearshore areas of Ecoregion 3						
Lake trout (lean)	3	19%	103	67%	6	6	22	46	14	200	21%
Siscowet	0	0%	0	0%	1	2	120	15	16	154	16%
Chinook salmon	0	0%	44	28%	0	0	0	27	1	71	7%
Coho salmon	0	0%	6	4%	0	0	0	3	2	12	1%
Rainbow trout	14	81%	0	0%	0	0	0	199	317	530	55%
Brown trout											
Burbot	0	0%	1	1%	0	0	2	1	0	3	0%
Walleye											
TOTAL	**18**	**100%**	**154**	**100%**	**7**	**8**	**144**	**290**	**350**	**971**	**100%**
Stocked fish only	8	18%	23	15%	1	1	2	43	59	133	14%
					Offshore areas of Ecoregion 3						
Lake trout (lean)	11	18%	350	36%	20	20	75	154	46	676	23%
Siscowet	52	82%	611	62%	15	22	1,187	145	159	2,190	75%
Burbot	0	0%	16	2%	0	0	39	15	0	70	2%
TOTAL	**63**	**100%**	**977**	**100%**	**35**	**41**	**1,301**	**314**	**205**	2,936	**100%**
Stocked fish only	2	3%	64	7%	4	4	7	13	6	100	3%

Table 15F.—Consumption (metric tons) in 2004 by major predators in the entire Minnesota waters of Lake Superior, in nearshore areas, and in offshore areas (divided at the 80-m contour). Metric tons of rainbow smelt and coregonines are followed by percentages of the total amount of that diet item consumed by each predator species. Prey species abbreviations are: RBS = rainbow smelt, COR = coregonines, SAL = salmonines, BUB = burbot, SCU = sculpins, MYS = mysids, INS = insects.

	Prey species consumed										
Species	RBS	(%)	COR	(%)	SAL	BUB	SCU	MYS	INS	Total by predator	% of total consumption by all predators
Minnesota water totals											
Lake trout (lean)	51	27%	854	46%	57	84	206	418	87	1,757	29%
Siscowet	59	31%	695	38%	15	26	1,330	155	162	2,442	40%
Chinook salmon	4	2%	196	11%	0	0	0	37	2	239	4%
Coho salmon	0	0%	20	1%	0	0	0	4	3	27	<1%
Rainbow trout	38	21%	0	0%	0	0	0	484	867	1,389	23%
Brown trout											
Burbot	1	0%	19	1%	0	1	46	19	1	86	1%
Walleye	33	18%	64	3%	0	0	0	0	0	97	2%
TOTAL	**187**	**100%**	**1,847**	**100%**	**71**	**110**	**1,583**	**1,116**	**1,123**	**6,038**	**100%**
Stocked fish only	39	21%	244	13%	17	28	41	462	318	1,183	20%
Nearshore areas of Minnesota waters											
Lake trout (lean)	31	28%	404	58%	28	47	99	199	33	839	30%
Siscowet	1	1%	8	1%	1	3	133	15	16	177	6%
Chinook salmon	4	4%	196	28%	0	0	0	37	2	239	9%
Coho salmon	0	0%	20	3%	0	0	0	4	3	27	1%
Rainbow trout	38	36%	0	0%	0	0	0	484	867	1,389	50%
Brown trout											
Burbot	0	0%	2	<1%	0	0	4	2	0	9	<1%
Walleye	33	31%	64	9%	0	0	0	0	0	97	3%
TOTAL	**108**	**100%**	**692**	**100%**	**29**	**49**	**236**	**741**	**922**	**2,777**	**100%**
Stocked fish only	33	31%	143	21%	9	17	24	313	506	1,046	38%
Offshore areas of Minnesota waters											
Lake trout (lean)	20	26%	451	39%	29	37	108	220	54	919	27%
Siscowet	58	74%	687	60%	15	25	1,305	152	161	2,404	71%
Burbot	0	0%	17	1%	0	0	42	17	0	77	2%
TOTAL	**79**	**100%**	**1,155**	**100%**	**44**	**62**	**1,455**	**389**	**215**	**3,399**	**100%**
Stocked fish only	5	7%	101	9%	8	11	16	32	9	181	5%

Table 15G.—Consumption (metric tons) in 2004 by major predators in the entire Wisconsin waters of Lake Superior, in nearshore areas, and in offshore areas (divided at the 80-m contour). Metric tons of rainbow smelt and coregonines are followed by percentages of the total amount of that diet item consumed by each predator species. Prey species abbreviations are: RBS = rainbow smelt, COR = coregonines, SAL = salmonines, BUB = burbot, SCU = sculpins, MYS = mysids, INS = insects.

	Prey species consumed										
Species	RBS	(%)	COR	(%)	SAL	BUB	SCU	MYS	INS	Total by predator	% of total consumption by all predators
Wisconsin waters totals											
Lake trout (lean)	1,029	68%	3,163	60%	24	437	579	471	41	5,744	58%
Siscowet	336	22%	1,582	30%	0	61	788	45	35	2,848	29%
Chinook salmon	6	<1%	186	4%	0	0	0	17	2	211	2%
Coho salmon	0	0%	113	2%	0	0	0	9	7	129	1%
Rainbow trout	17	1%	0	0%	0	0	0	178	354	549	6%
Brown trout	12	1%	23	<1%	0	0	0	0	10	45	<1%
Burbot	5	<1%	11	<1%	0	3	33	21	3	76	1%
Walleye	100	7%	191	4%	0	0	0	0	0	291	3%
TOTAL	**1,506**	**100%**	**5,268**	**100%**	**24**	**501**	**1,401**	**741**	**451**	**9,893**	**100%**
Stocked fish only	1	<1%	22	<1%	1	1	4	8	1	38	<1%
Nearshore areas of Wisconsin waters											
Lake trout (lean)	866	80%	2,676	74%	17	122	179	200	20	4,081	70%
Siscowet	85	8%	406	11%	0	6	79	5	4	584	10%
Chinook salmon	6	1%	186	5%	0	0	0	17	2	211	4%
Coho salmon	0	0%	113	3%	0	0	0	9	7	129	2%
Rainbow trout	17	2%	0	0%	0	0	0	178	354	549	9%
Brown trout	12	1%	23	1%	0	0	0	0	7	42	1%
Burbot	3	<1%	7	<1%	0	0	4	2	0	16	<1%
Walleye	100	9%	191	5%	0	0	0	0	0	291	5%
TOTAL	**1,089**	**100%**	**3,601**	**100%**	**17**	**128**	**262**	**411**	**394**	**5,902**	**100%**
Stocked fish only	1	0%	20	1%	1	1	3	6	1	33	1%
Offshore areas of Wisconsin waters											
Lake trout (lean)	163	39%	487	29%	7	315	400	271	21	1,663	41%
Siscowet	252	60%	1,176	71%	0	60	760	44	35	2,326	57%
Burbot	2	<1%	4	<1%	0	3	29	19	2	59	1%
TOTAL	**416**	**100%**	**1,667**	**100%**	**7**	**378**	**1,189**	**333**	**58**	**4,049**	**100%**
Stocked fish only	0	0%	1	<1%	0	0	1	2	0	6	<1%

Table 16.—Gross conversion efficiencies (GCEs) of predators weighing 3 kg, considering total cumulative consumption of all diet items.

Predator species	Age	GCE
Lean lake trout	13	8.8%
Siscowet	25	10.5%
Chinook salmon	2	21.4%
Steelhead (wild)	5	7.6%
Kamloops	5	5.8%
Brown trout	6	19.2%
Burbot	13	6.5%
Walleye	18	3.1%

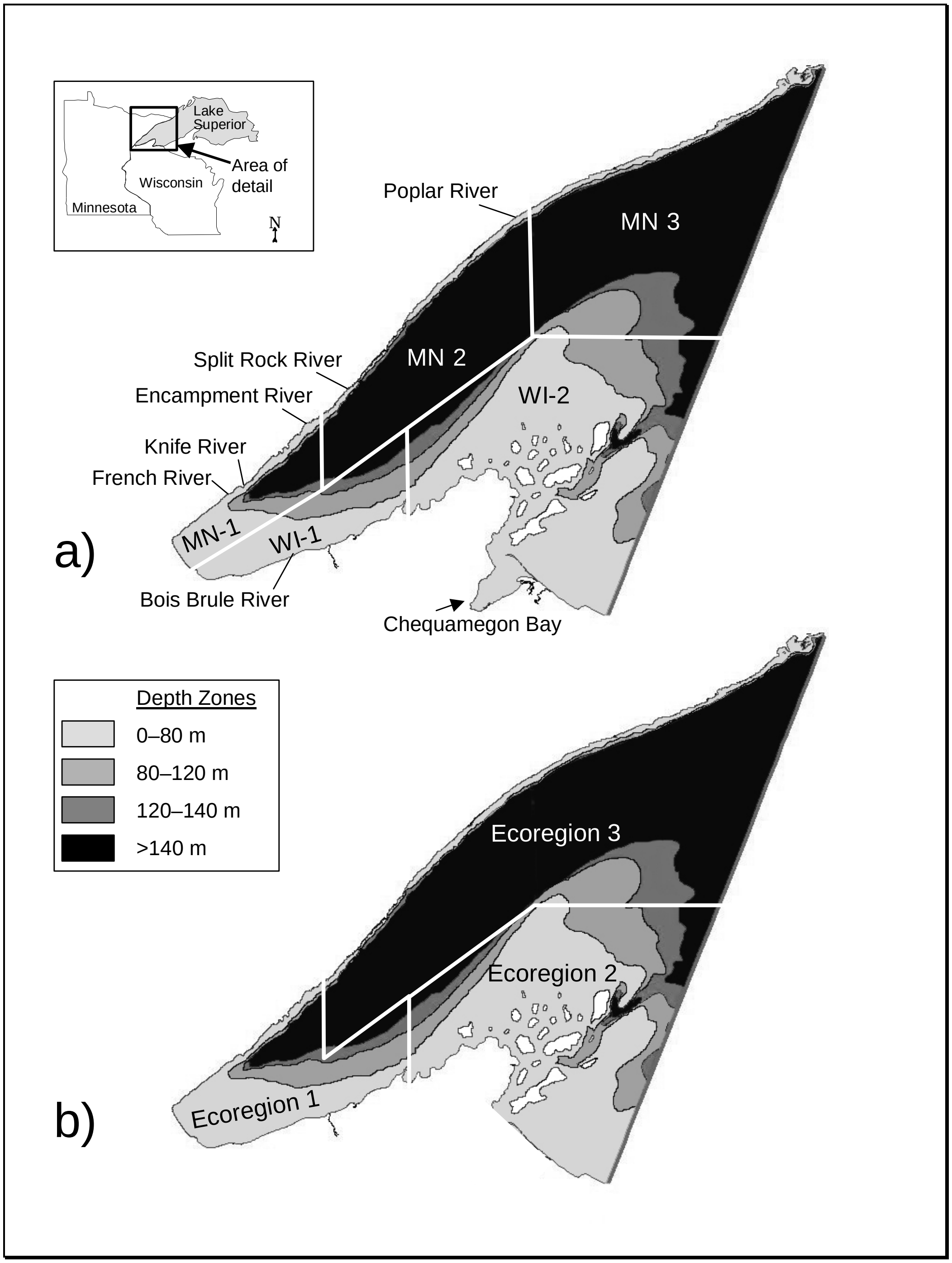

Figure 1.—The western arm of Lake Superior showing: a) Minnesota lake trout management zones and b) Ecoregions. Management zone boundaries in Minnesota waters represent changes made in 2006 to reflect current and historic management practices.

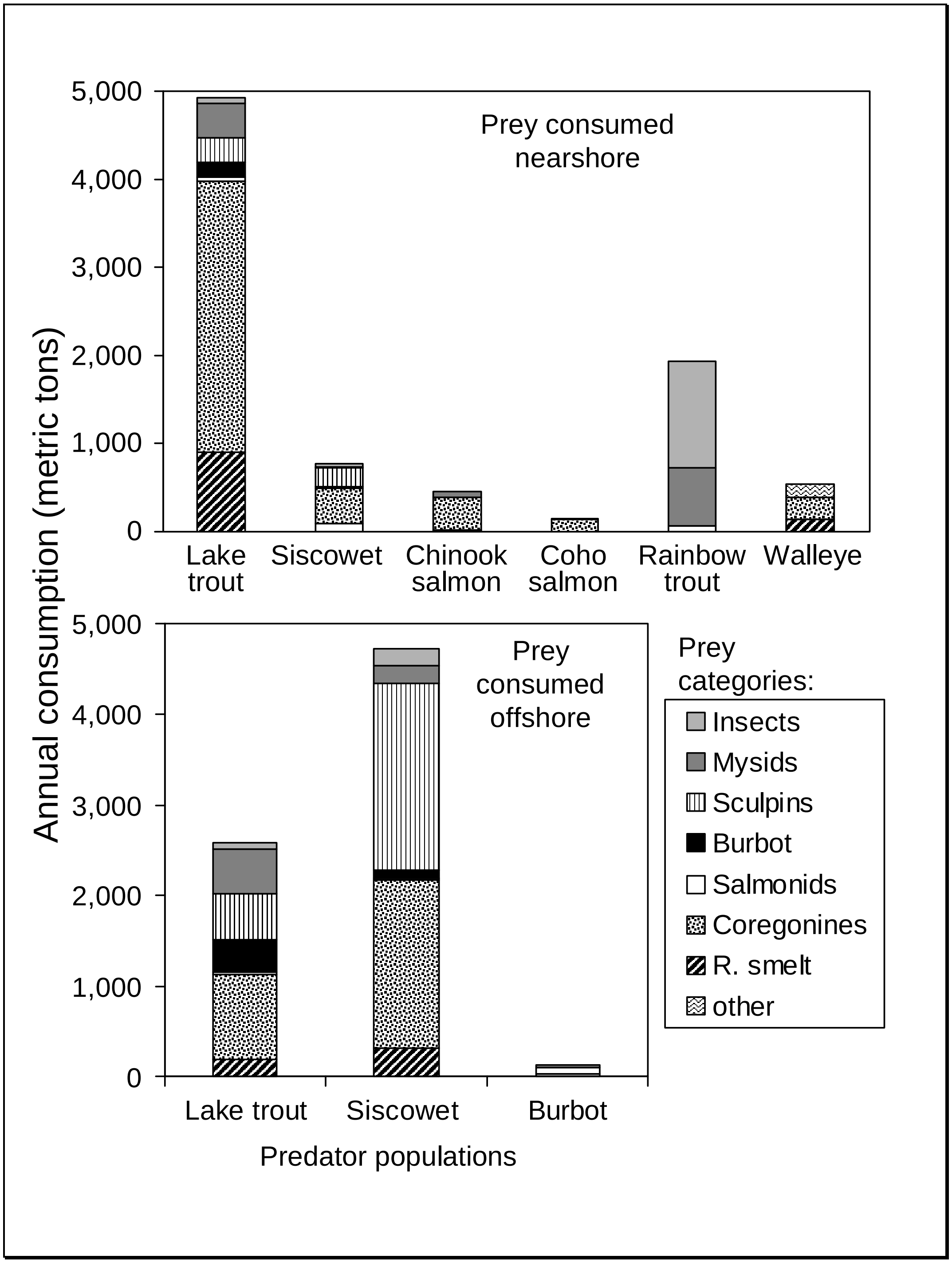

Figure 2.—Prey consumed by nearshore and offshore predator populations in the western arm of Lake Superior. Brown trout and burbot are not shown with the nearshore predators due to their low total consumption.

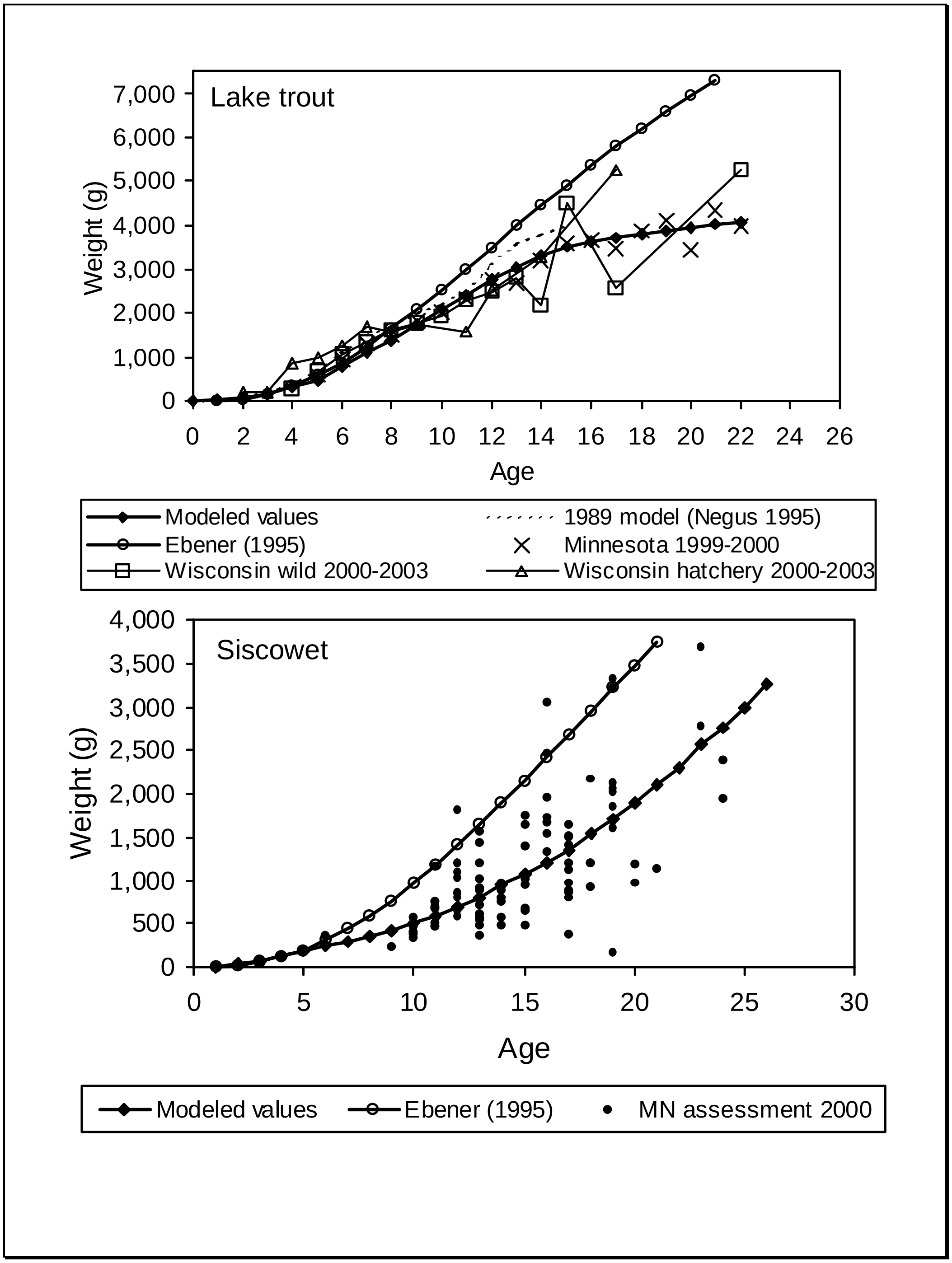

Figure 3.—Weights-at-age of lake trout and siscowet.

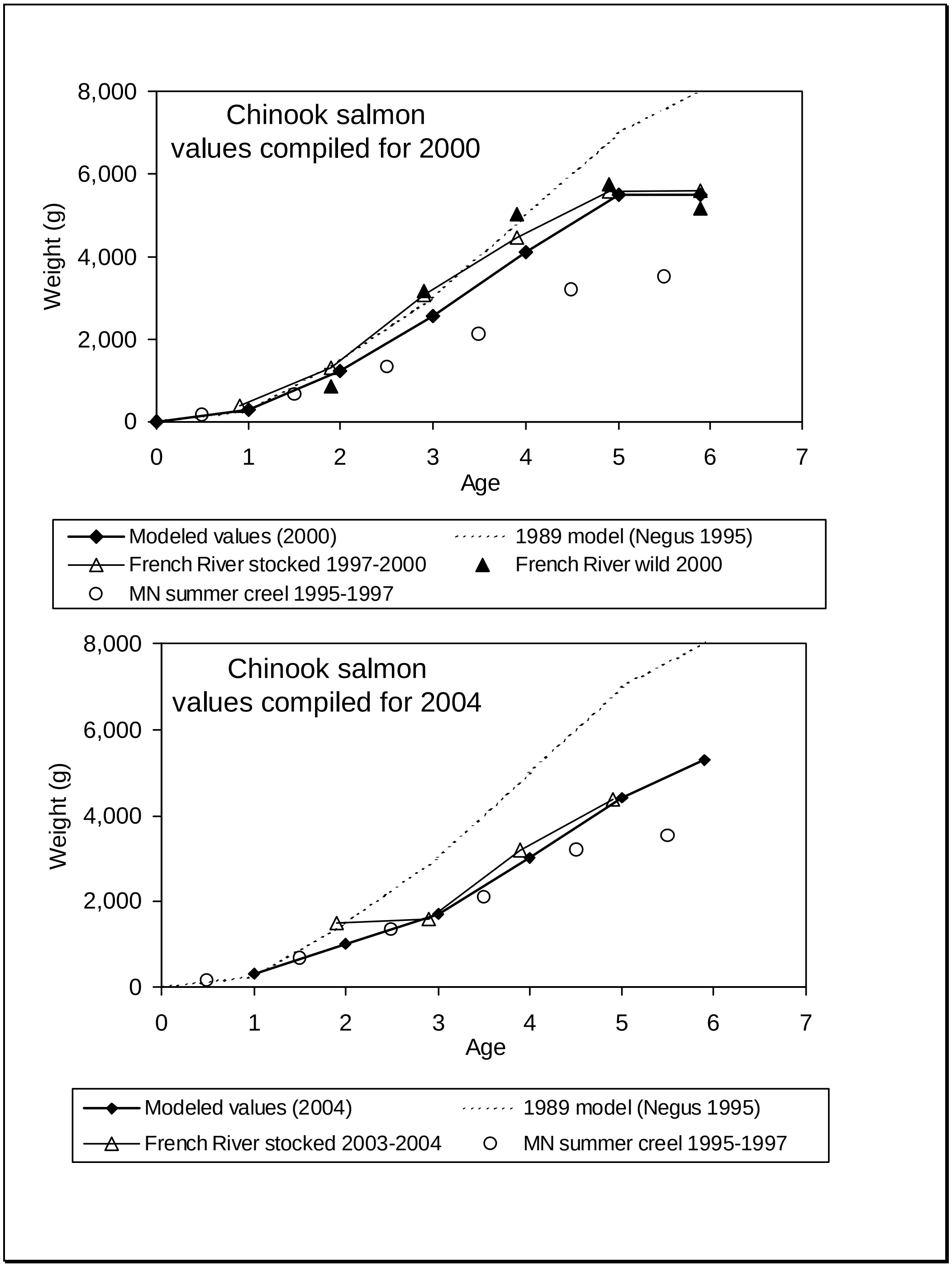

Figure 4.—Chinook salmon weights-at-age came from fish measured in Minnesota summer creel surveys and captured at the French River trap from 1997 to 2000 (2000 simulations), and fish captured at the French River trap in 2003 and 2004 (2004 simulations). Weights-at-age were unavailable from Wisconsin, but lengths of Chinook salmon spawning in the Bois Brule River were similar to lengths of Minnesota fish.

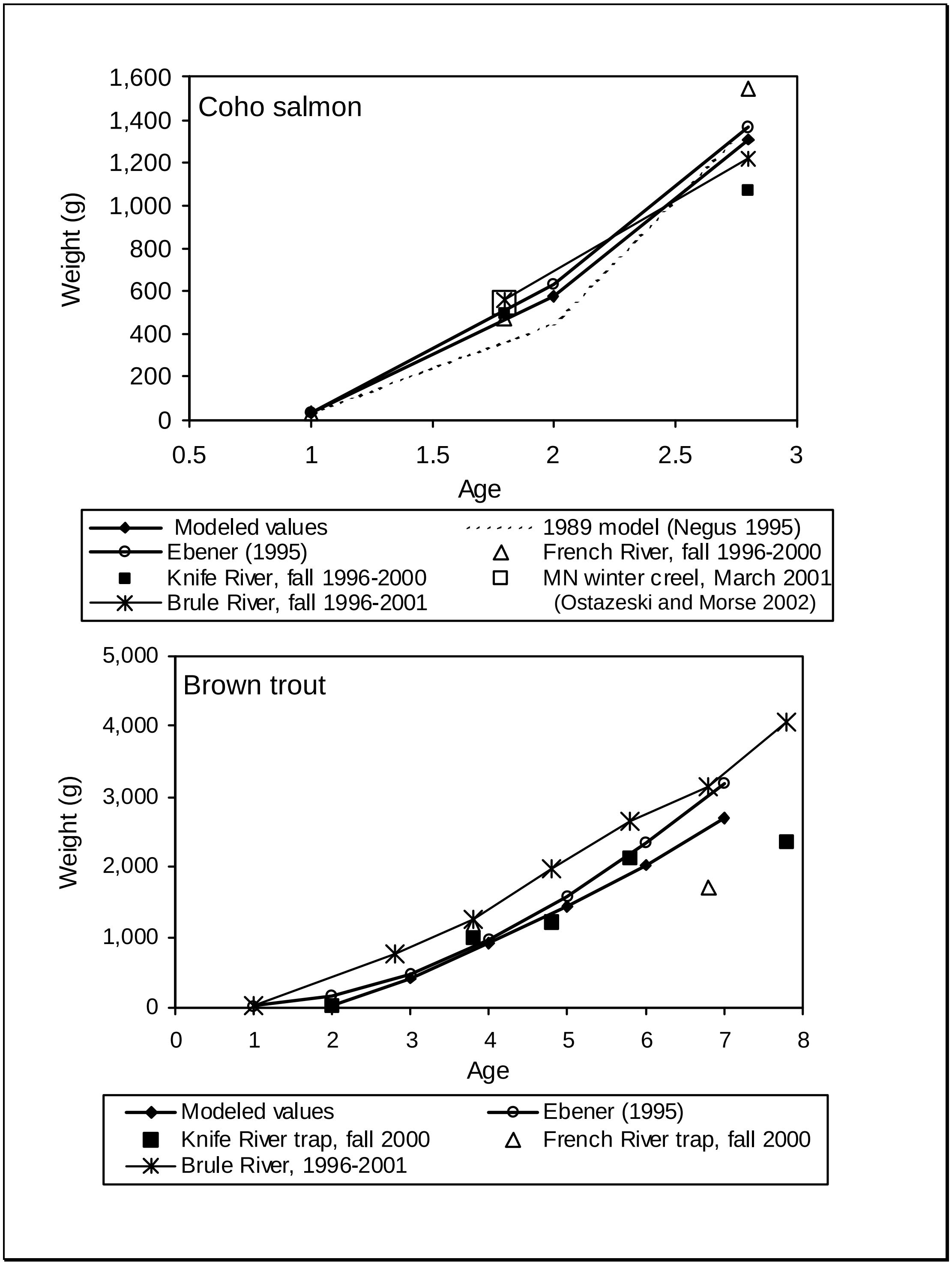

Figure 5.—Weights-at-age of coho salmon and brown trout. Brown trout smolt at age 1 in the Bois Brule River, while brown trout in other rivers typically smolt at age 2.

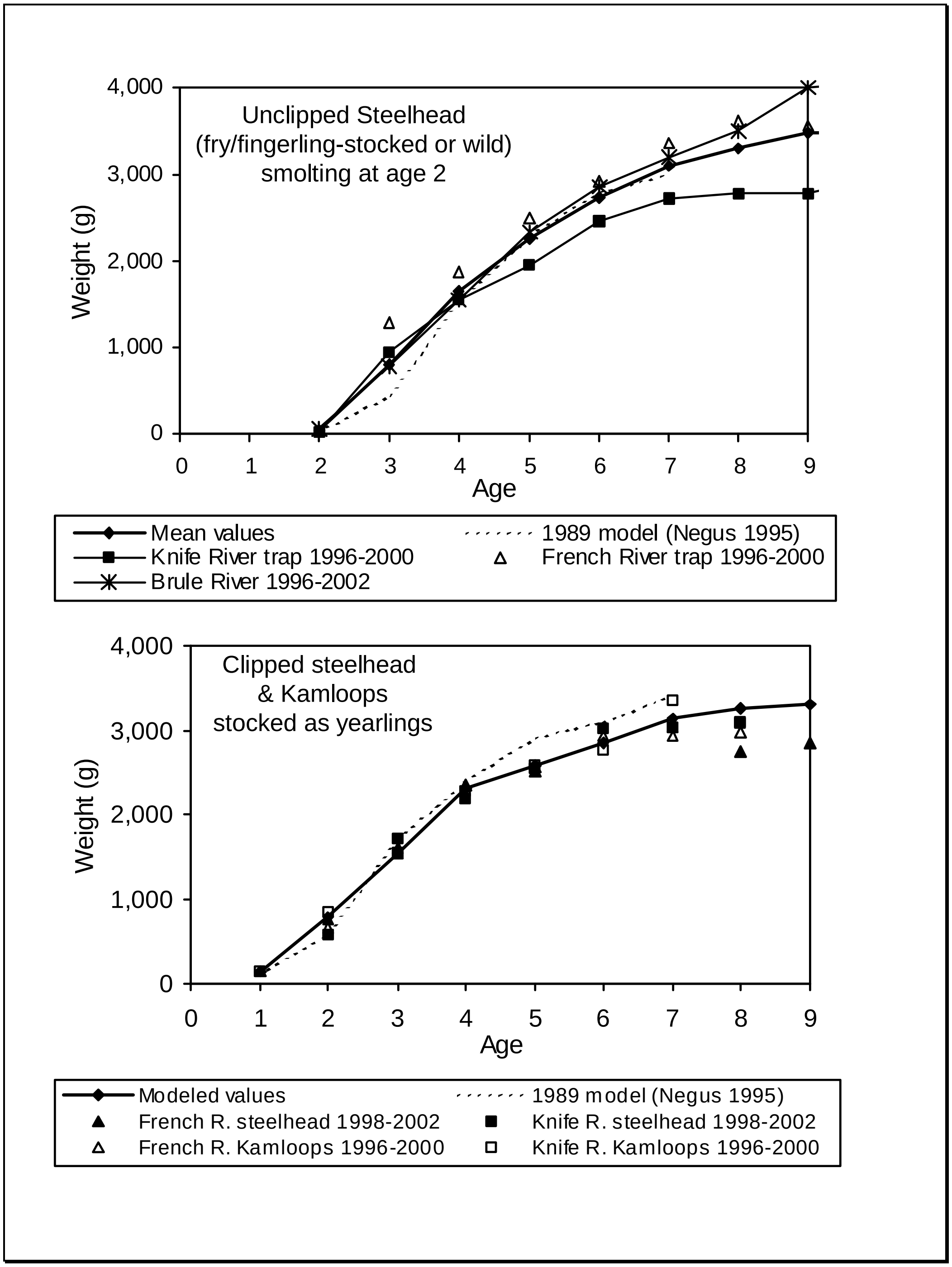

Figure 6.—Unclipped steelhead (fry-stocked and fingerling-stocked, or wild) weights-at-age came from fish returning to the French and Knife River traps and the Bois Brule River fishway in 1996-2002. Bois Brule River weights were used to model steelhead in Ecoregion 2, Knife River weights were used to model steelhead in Ecoregion 3, and intermediate values were used to model steelhead in Ecoregion 1. Clipped steelhead and Kamloops (stocked as yearlings) weights-at-age were taken from fish returning to the French and Knife River traps in 1996-2002.

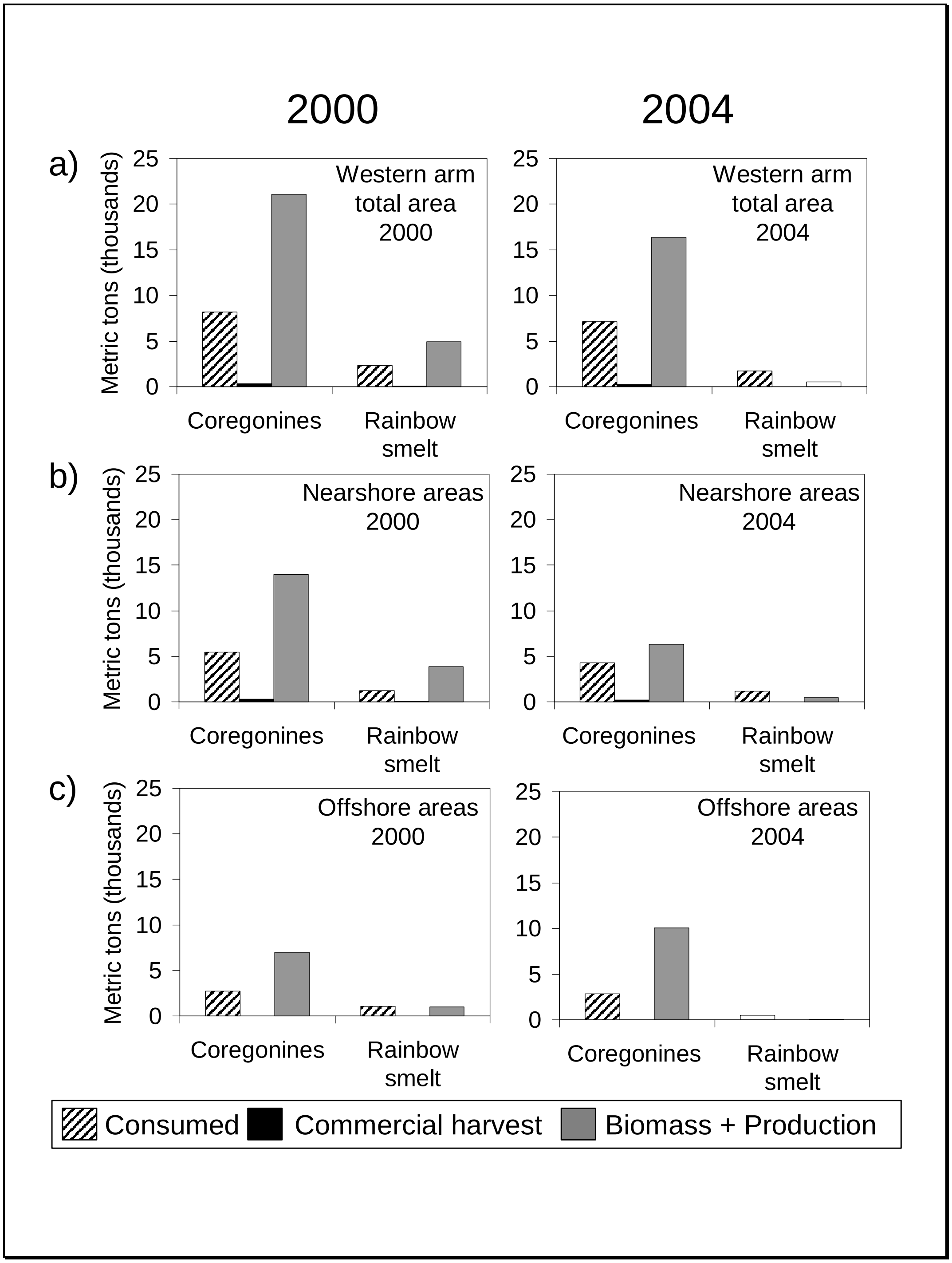

Figure 7.—Metric tons of coregonines and rainbow smelt consumed by predator fish, harvested commercially, and available biomass + annual production of these prey species in 2000 and 2004, in a) the western arm of Lake Superior; b) nearshore areas only; and c) offshore areas only.

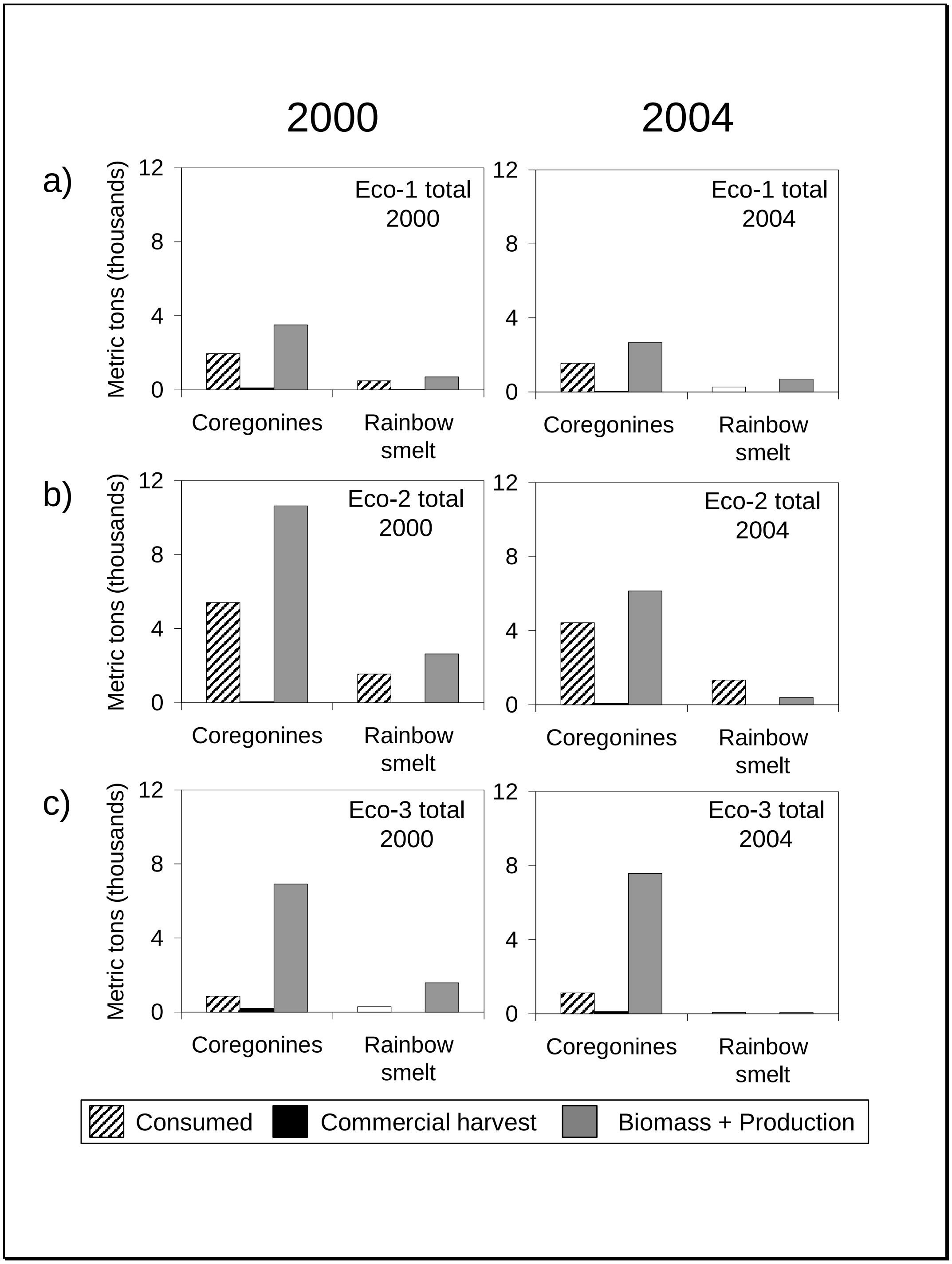

Figure 8.—Metric tons of coregonines and rainbow smelt consumed by predator fish or harvested commercially, and available biomass + annual production of these prey species in 2000 and 2004 in three ecoregions in the western arm of Lake Superior.

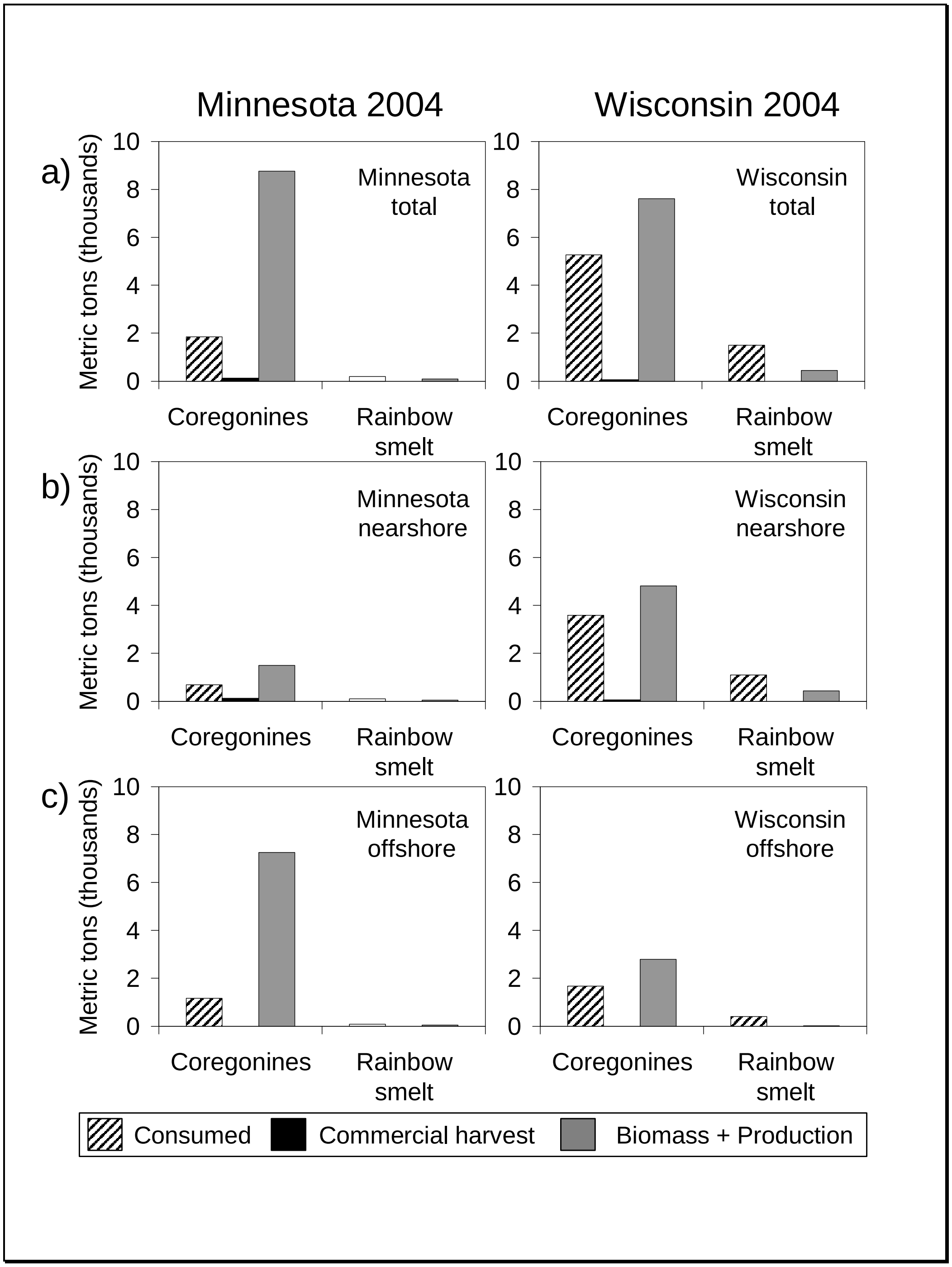

Figure 9.—Metric tons of coregonines and rainbow smelt consumed by predator fish, harvested commercially, and available biomass + annual production of these prey species in Minnesota and Wisconsin waters of Lake Superior: a) total area; b) nearshore areas only; and c) offshore areas only

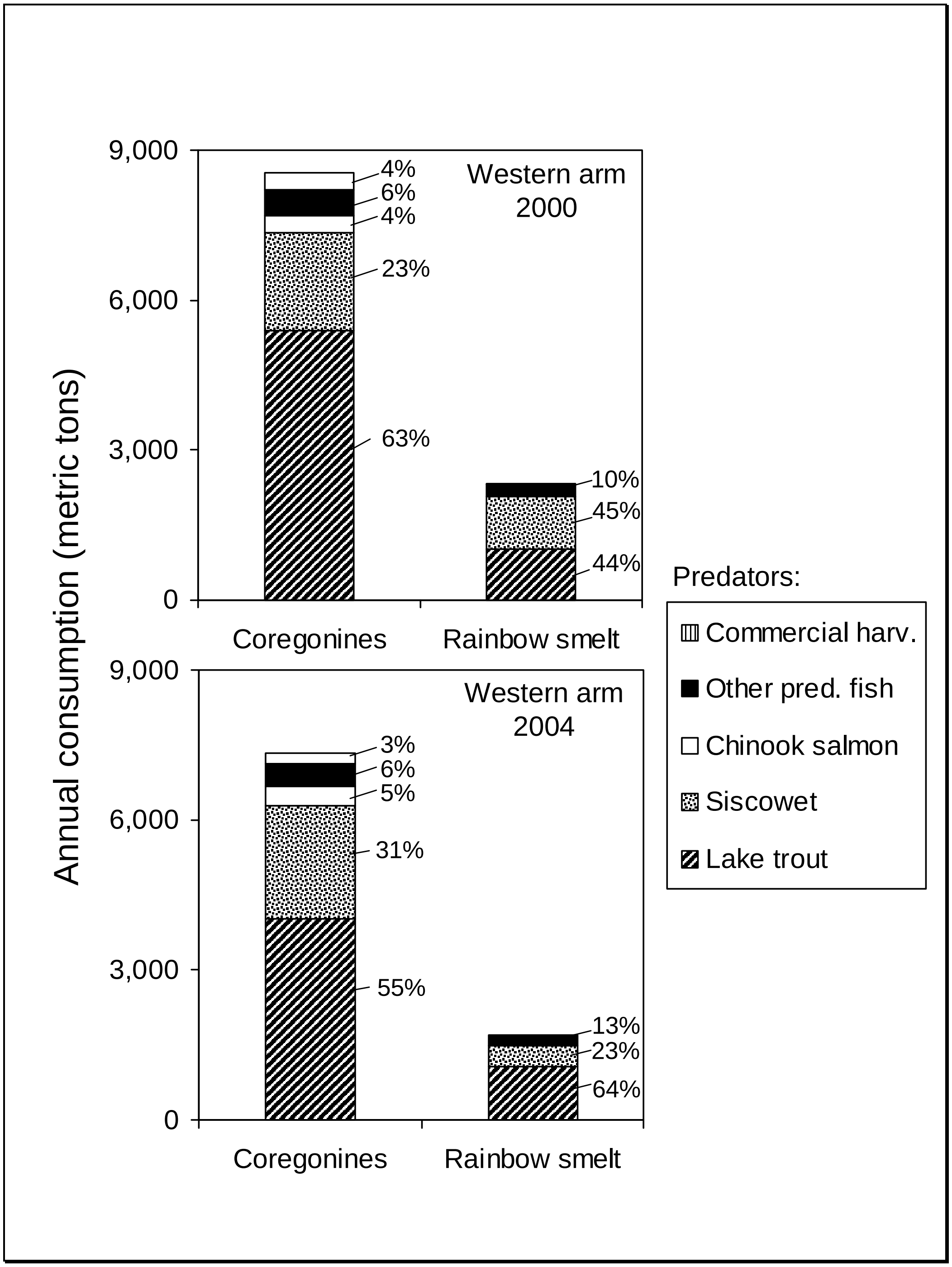

Figure 10.—Percentages of the total annual consumption of coregonines and rainbow smelt attributable to various predator fish and commercial harvest in the western arm of Lake Superior: 2000 and 2004.

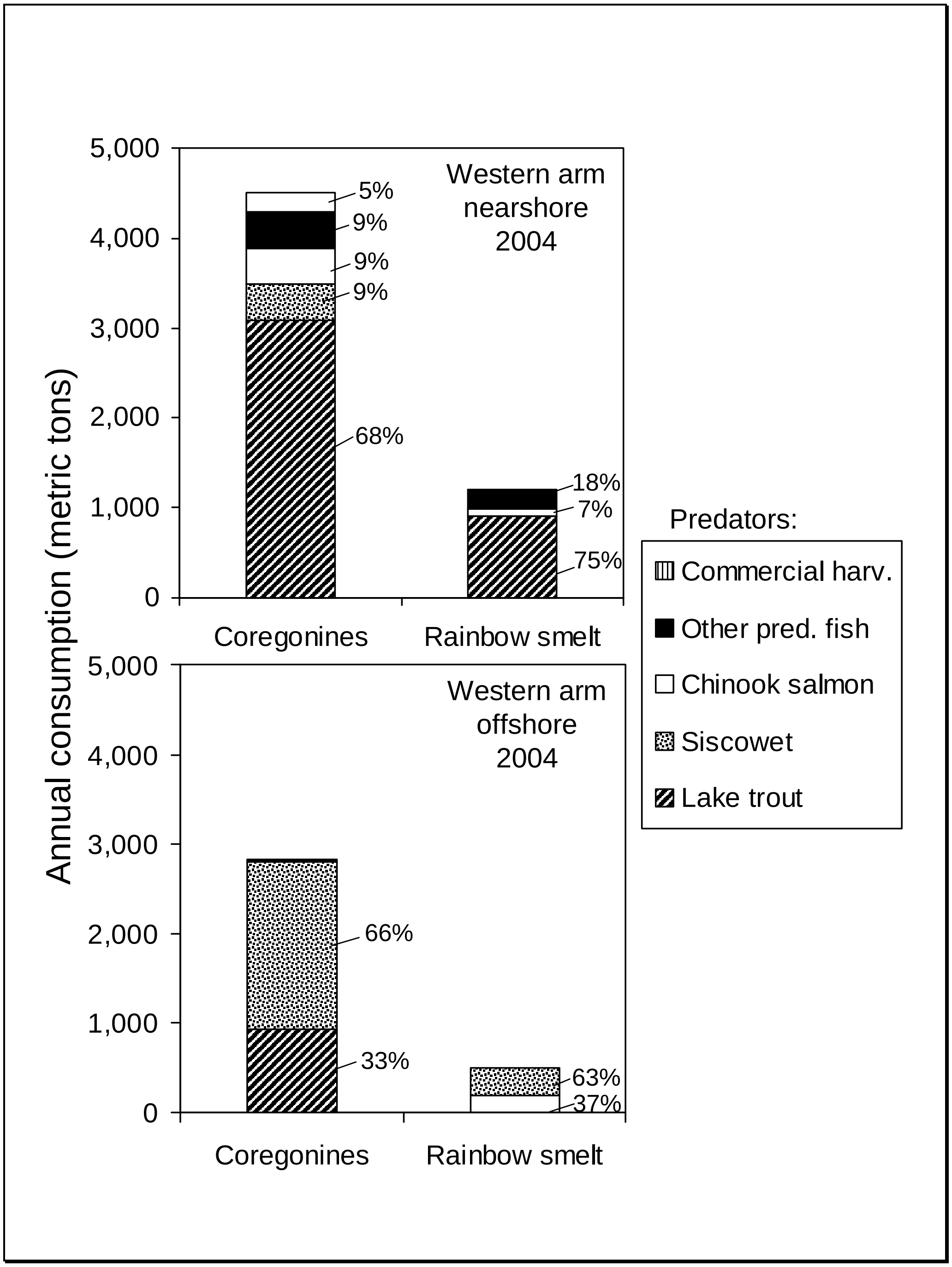

Figure 11.—Percentages of the 2004 total annual consumption of coregonines and rainbow smelt attributable to various predator fish and commercial harvest in the western arm of Lake Superior: nearshore waters and offshore waters.

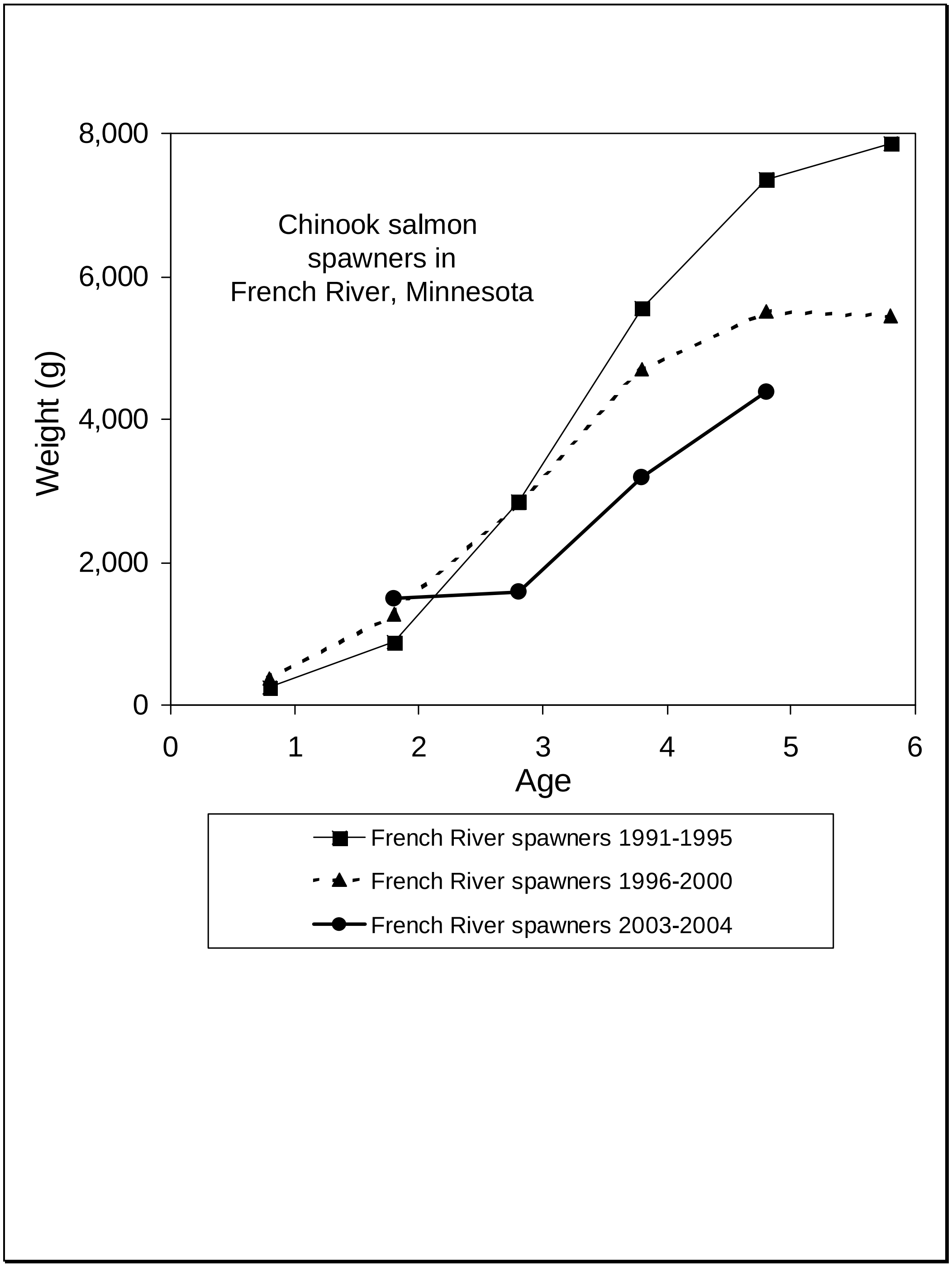

Figure 12.—Mean weight-at-age of Chinook salmon returning to spawn in the French River, Minnesota, in 1991-1995, 1996-2000, and 2003-2004.

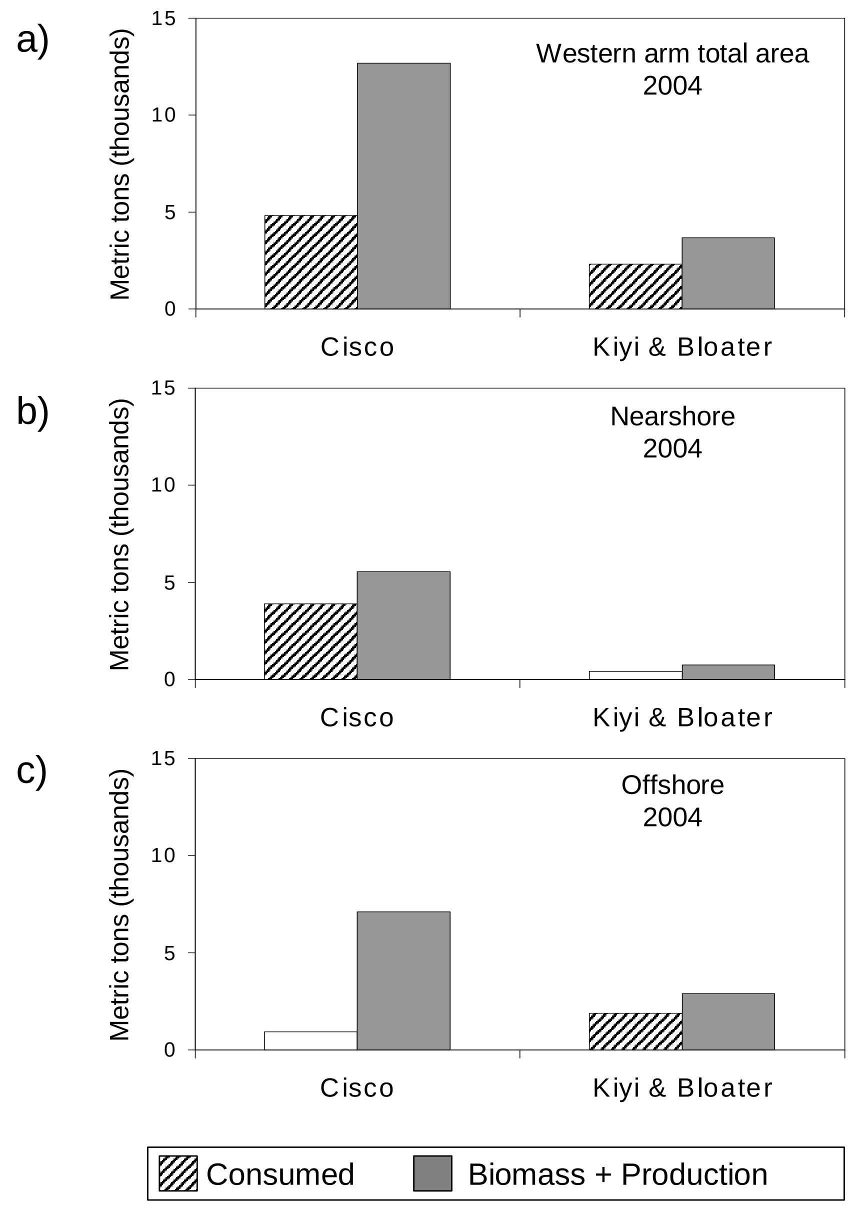

Figure 13.—Annual consumption versus availability (biomass + production) of shallower water coregonines (cisco) and deeper water coregonines (kiyi and bloater) in 2004. Note that the relative amounts of cisco and kiyi and bloater were similar in 2000 (not shown).

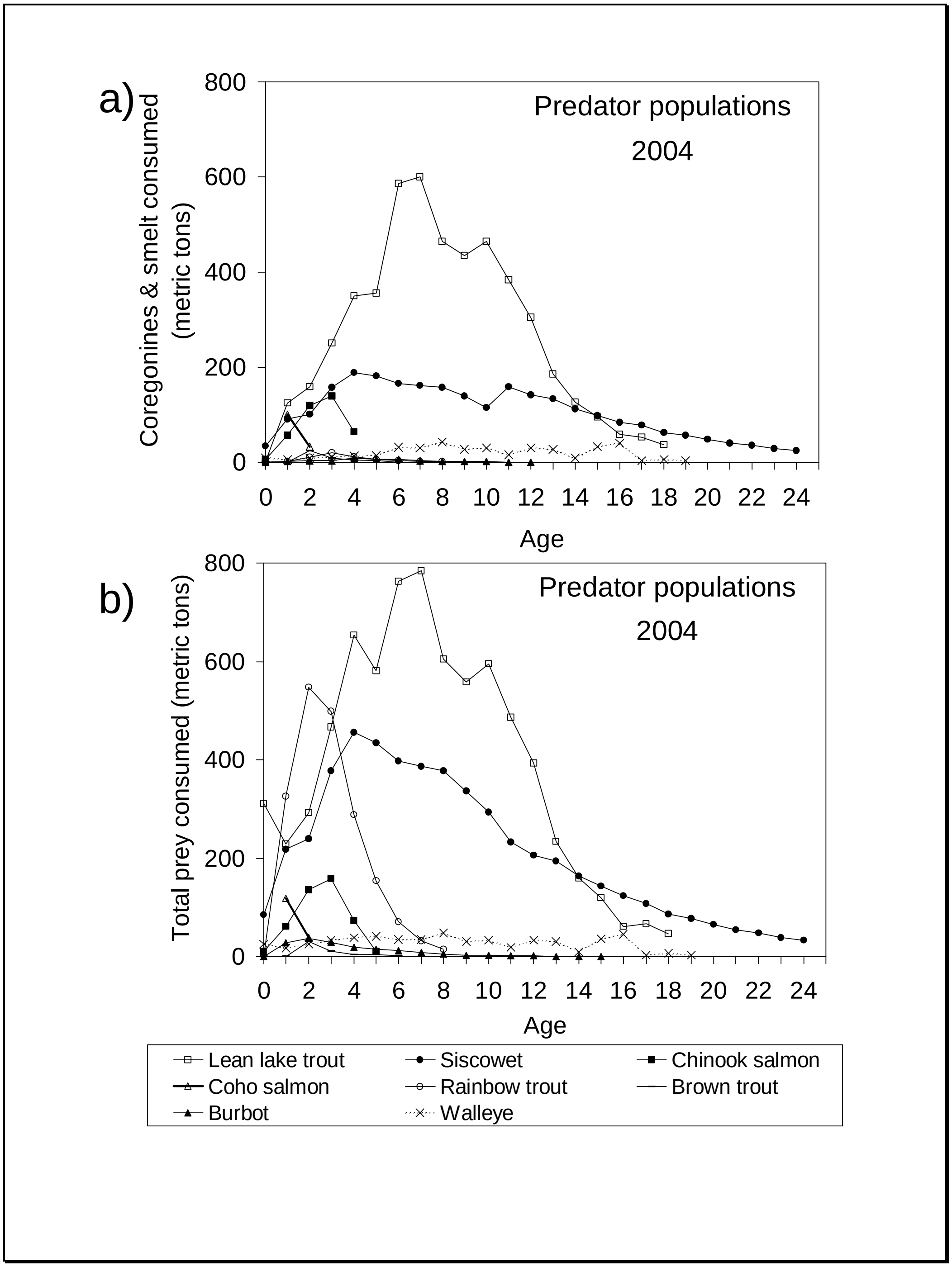

Figure 14.—Annual consumption in 2004 of a) coregonines and rainbow smelt, and b) all prey items by each year class of predator fish modeled, demonstrating the predatory inertia of various species.

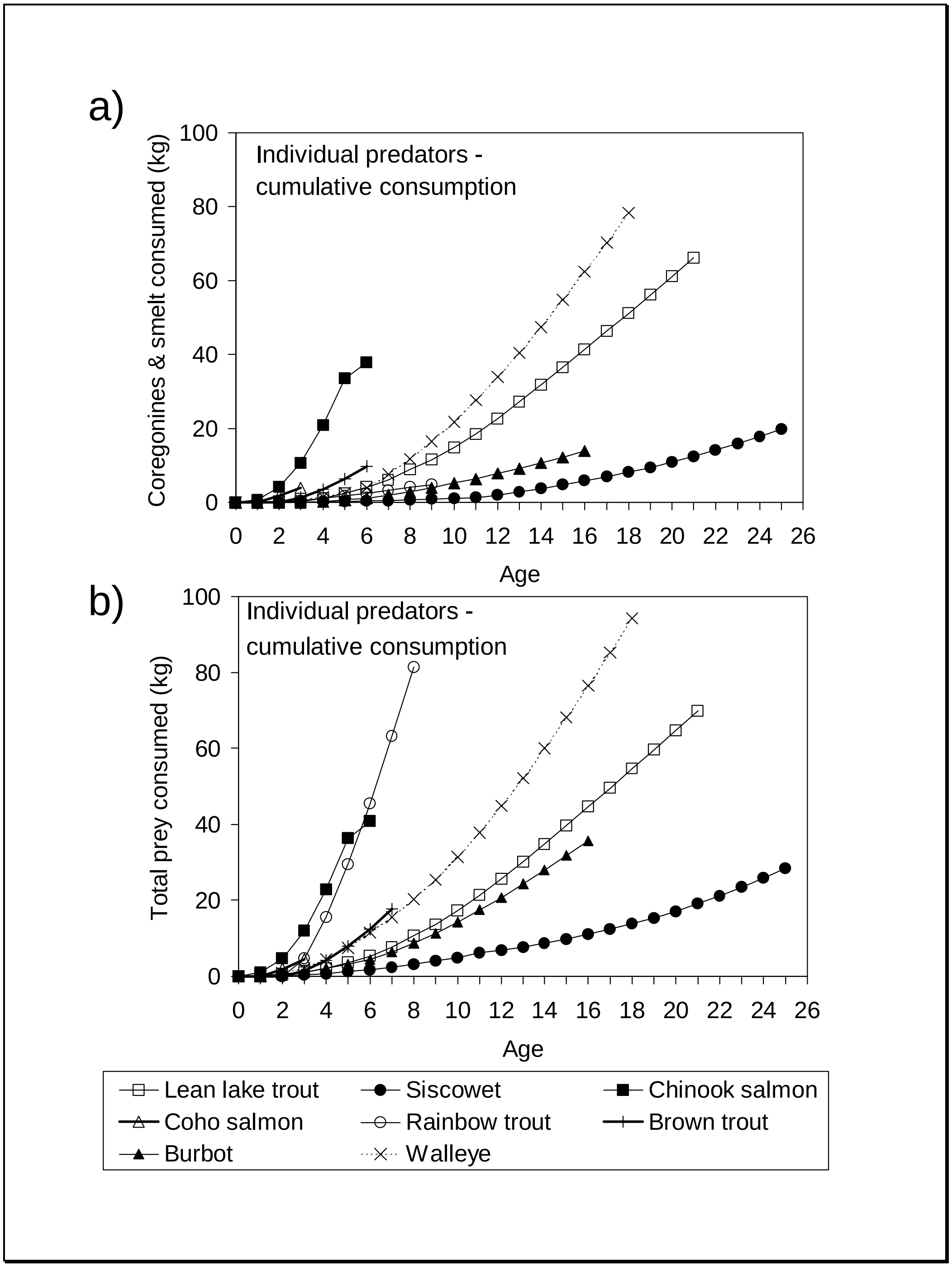

Figure 15.—Cumulative consumption of a) coregonines and rainbow smelt, and b) all prey items by individual predator fish over their lifespan.

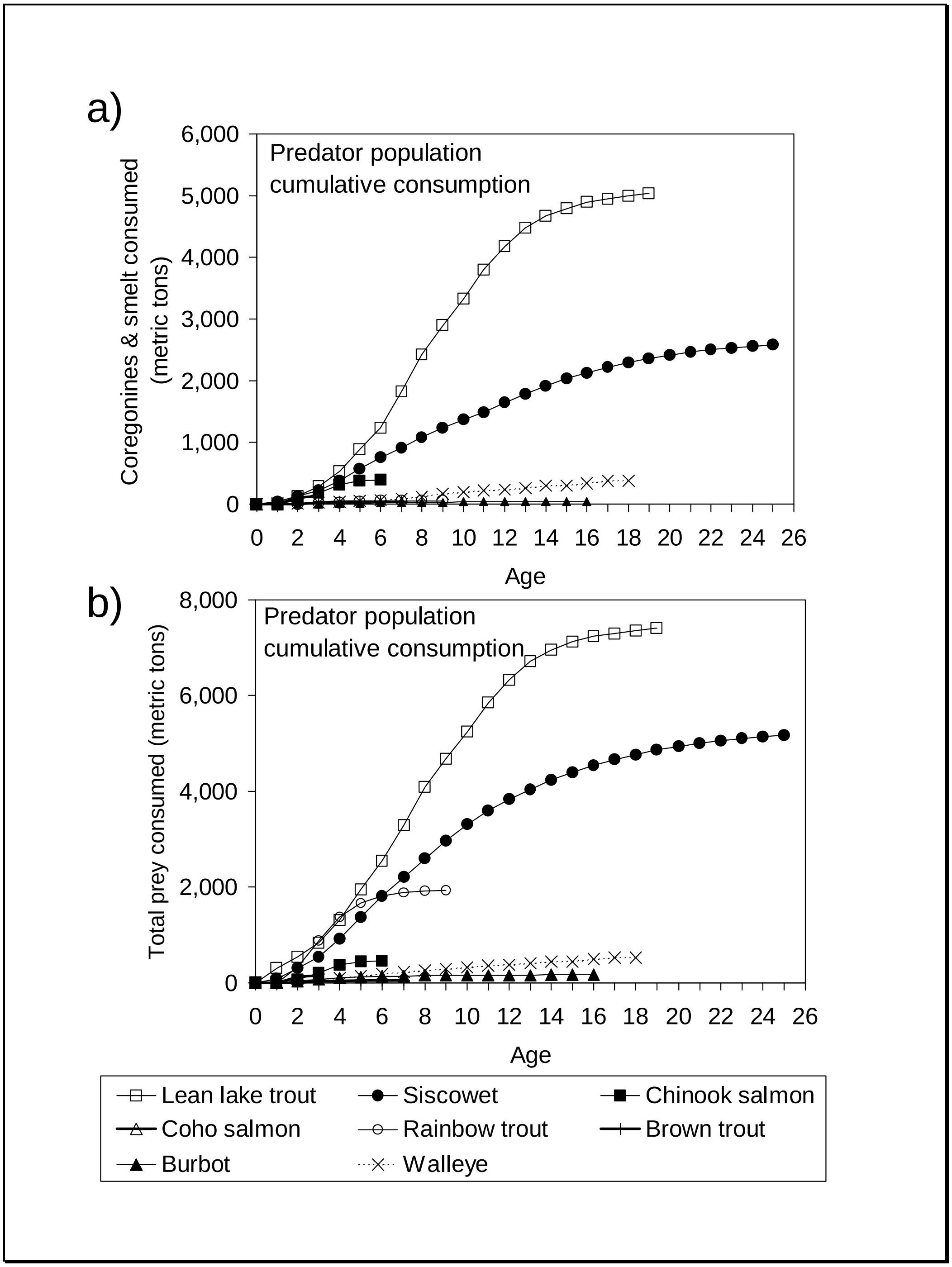

Figure 16.—Cumulative consumption of a) coregonines and rainbow smelt, and b) all prey items by predator fish populations over their lifespan.