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Causes of Variable Survival of Stocked Chinook Salmon in Lake Huron

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Abstract.–We investigated several cohorts of Chinook salmon in Lake Huron with emphasis on factors contributing to post-stocking survival. Stocked Chinook salmon were marked with oxytetracycline and/or coded-wire tags (CWT). Returns of CWT Chinook salmon to the recreational fishery were 2.5 times higher for fish pen-acclimated at the Au Sable River than for those stocked there conventionally. Return rates were only slightly enhanced by pen acclimation at Harbor Beach where the fish were probably stressed by excessive acclimation temperatures in most or all years of the study. Acclimation pens also appeared to better imprint fish to the Au Sable River where returns in fall spawning runs were 6.4 times higher for acclimated than conventionally-stocked fish. Transporting pen-acclimated Chinook salmon to the beach at the mouth of the Au Sable River enhanced performance of the 1995 cohort relative to acclimated fish stocked in the river, but beach stocking produced little improvement in survival in subsequent years when alewives were scarce. Returns of CWT Chinook salmon from all stocking sites generally decreased after 1995, as did alewife abundance. Survival of juvenile Chinook salmon and growth, condition, and survival of adult Chinook salmon appear to be positively correlated with adult alewife abundance. One-fourth of spawning-phase Chinook salmon in the Au Sable River were in critically low physical condition in fall 2004, suggesting a significant proportion of the adult population was succumbing to malnutrition. Age-0 Chinook salmon occupied the nearshore waters of Lake Huron for their first 6 months of lake residence. During May and June, both hatchery and wild juvenile salmon were taken by beach seining, particularly at the mouths of the Au Sable and Tawas rivers. Adult alewives were the most abundant of 46 species of fish sampled with beach seines while targeting Chinook salmon, and lake whitefish were caught in beach seines at many locations, especially in the Thunder Bay area. Age-0 Chinook salmon were found in stomachs of walleyes, lake trout, and other predators sampled near the beach seining sites, particularly when alewives were scarce. Pen acclimation appeared to minimize exposure of stocked Chinook salmon to predation in the beach zone because the acclimated fish were larger and appeared to migrate offshore more quickly than smaller conventionally stocked Chinook salmon. Juvenile Chinook salmon were sampled later in the summer with small-mesh gill nets in waters less than 20 m deep where water temperatures were frequently near 18°C. These juveniles fed on terrestrial and aquatic invertebrates until September when they began switching to fish, principally age-0 alewives. Growth rates were rapid, averaging 1.3 mm per day, probably driven by the relatively warm temperatures occupied. Adult alewives were the leading incidental catch in the small-mesh gillnets while targeting juvenile Chinook salmon. Age-0 Chinook salmon appeared to be buffered from predation in years when alewives were abundant. Conversely, their similar size and appearance and spatial association with alewives may have contributed to increased predation on age-0 Chinook salmon when alewives were scarce. Adult alewife abundance declined sharply after 2002, which renders the future of Lake Huron's Chinook salmon fishery highly uncertain.

Introduction

In 1967, the first successful Chinook salmon introduction to the Great Lakes was made by stocking fingerlings in two tributaries of Lake Michigan. The egg source for these stockings was a Puget Sound stock from Green River, Washington (Weeder 2005). Two Lake Huron tributaries, the Ocqueoc and Thunder Bay rivers, were stocked in 1968. By 1970 there were sufficient eggs available from spawning runs in Lake Michigan tributaries in Michigan to supply the stocking needs of all Great Lakes agencies. Today, the egg sources for Michigan's Lake Huron Chinook salmon stocking program are principally Swan River, a small tributary of northwest Lake Huron, and the Little Manistee River, tributary to eastern Lake Michigan.

Michigan waters of the Great Lakes supported an estimated 14.9 million angler hours or 3.9 million angler days in 1987 (Rakoczy and Rogers 1988). Valued at $77 per angler day (USFWS and USCB 2002), this fishery generated 302 million dollars annually in direct angler expenditure. By 1991 angler use of Michigan's Great Lakes had declined to 1.5 million days (Rakoczy 1992), less than half the 1987 level. This amounted to an estimated loss of $186 million in angling expenditures for Michigan waters alone. It is believed that the reduction in use was principally due to a Chinook salmon collapse in Lake Michigan, which began in 1988. About that same time, Chinook salmon catches in southern and central Lake Huron also declined. Seventy-two percent of Lake Michigan anglers and 47% of Lake Huron anglers reported they were seeking salmonids in 1988 (Rakoczy and Rogers 1988). Stocking was the primary source of salmonid recruitment of Michigan's Great Lakes (Carl 1982; Hesse 1994). This was particularly so for the Michigan side of Lake Huron, where few tributaries are available for spawning and rearing of anadromous salmonids. Hence, changes in survival and stocking rates of salmonids in the Great Lakes can have serious ramifications to the success rates of anglers and the economies of coastal communities of Michigan.

A number of factors can contribute to post-stocking survival:

1) *Health of the fish at stocking (Goede and Barton 1990)*.–Mortalities of Chinook salmon in Lake Michigan have been attributed to bacterial kidney disease, a pathogen that is now endemic to Michigan's feral egg sources, and thus to its anadromous salmonid hatchery products (Nelson and Hnath 1990). Similarly, furunculosis is carried by fish stocked from certain hatcheries and can be especially prevalent in brown trout. Both of these diseases are stress mediated and they can express themselves in the wild. Other fish health characteristics that can influence performance in the wild include fin erosion, fat reserves, and secondary infections.

2) *Genetics*.–Reisenbickler and McIntyre (1977) documented differences in growth and survival of hatchery and wild steelhead. Johnson and Rakoczy (2004) demonstrated that, for brown trout, Plymouth Rock strain produced consistently inferior growth and return to creel when compared with two other strains in Lake Huron and Lake Charlevoix. Fielder (1987) showed that certain strains of anadromous rainbow trout ascended streams earlier and produced better catch rates on the open waters of the Great Lakes than the "Michigan" strain. Weeder et al. (2005) found that, after 30 years of naturalization and culture, genetic drift had affected allelic variation in the founded population of Chinook salmon in the Great Lakes by comparing genetic diversity with the Puget Sound source.

3) *Size and age of stocked fish*.–Seelbach (1989) determined that a large percentage of steelhead yearlings were stocked prematurely because they were not ready to smolt. Stocking steelhead prematurely extends their residency in tributaries, which may increase exposure to predation and suboptimal habitat conditions. Weber (1988) demonstrated that yearling brown trout stocked in Thunder Bay survived much better than those stocked as fall fingerlings and, among the yearlings, there was a tendency for the cohorts stocked at larger sizes to contribute more strongly to the creel. Johnson et al. (1987) found that 125 mm rainbow trout stocked in a river survived significantly better than those stocked at lengths of less than 100 mm. In

Michigan, Chinook salmon from Wolf Lake Hatchery are generally about 20 mm larger than those from Platte River Hatchery. Often Wolf Lake fish show signs of smolting at time of stocking while fish from Platte River Hatchery are usually stocked as parr. The effects of these differences in size and life stage on survival and homing are as yet unclear.

4) *Suitability of receiving waters*.–Manipulation of nutrient levels and predator abundance of the receiving waters can influence post-stocking performance (Smith 1968). Certain stocking sites in Lake Huron have been shown to be substantially more suitable for Chinook salmon survival than others (Rakoczy 1991) and stocking tributaries with steelhead smolts has ranged from successful to almost totally unproductive (Seelbach and Whelan 1989; Seelbach and Miller 1993; Seelbach et al. 1994). The specific causes of differing survival between these sites have not been identified, but could include temperature regime, water quality, prey availability, and predation.

5) *Emigration from the receiving waters.*–In the case of the Great Lakes, salmonids move between management units (Adlerstein et al. 2007), across state and national jurisdictions (Bence 2002), as well as between the Great Lakes, particularly between lakes Michigan and Huron (Michigan Department of Natural Resources, Charlevoix Fisheries Research Station, unpublished data). Emigration from the stocking site can affect return to creel (Johnson et al. 1987).

6) *Natural mortality*.–Natural mortality, including predation (Alexander 1977; Ottenbacher et al. 1994) and disease (Benjamin and Bence 2003) contribute to post-stocking losses (Latta 1963). Natural mortality is often a function of predation, including sea lamprey depredations (Johnson et al. 2004), and one or more of the above factors, such as suitability of the receiving waters or health of the fish at stocking. Latta (1963) found natural mortality of brook trout stocked in small lakes to be highest shortly after stocking and that mortality declined when number stocked was reduced. To the extent contributing factors can be controlled, natural mortality can be reduced and success of stocking programs enhanced. For example, Johnson and Rakoczy (2004) manipulated stocking dates for brown trout so that they corresponded with peak abundance of spawning alewives. The spawning concentrations of alewives were found to buffer the effect of predation on the stocked fish. With these changes, brown trout return to creel more than doubled. Similar improvements in stocking "windows" and management of predation promised sizable gains in stocking success for Chinook salmon.

Changes in the aquatic ecosystem can affect more than one of these factors. Christie et al. (1987) documented complex changes in eastern Lake Ontario fisheries caused by increasing avian and aquatic predators. Eck and Wells (1987) determined that major changes in fish populations occurred in Lake Michigan between the early 1970s and 1984, which altered composition of the prey available for stocked salmonids. Such ecosystem changes are most likely to affect predation (natural mortality) and prey composition (suitability of receiving waters), although Benjamin and Bence (2003) give evidence that ecosystem changes could also affect disease levels.

Thus, the issue of erratic or substandard survival of stocked fish is encompassed in a matrix of environmental conditions and management options, crossing species management programs and geographical and political boundaries.

In 1993, when this study was initiated, very little was known about performance of stocked Chinook salmon or reproduction rates or early life history of this species in Lake Huron. For that matter, the magnitude of natural reproduction of Chinook salmon in any of the Great lakes was poorly understood (Kocik and Jones 1999). No reproduction of Chinook salmon was detected in Michigan tributaries to Lake Huron during the late 1970s (Carl 1982). However, from 1985–87 wild Chinook salmon smolts were found in the Pottawatomi, Sydenham, Beaver, and Bighead rivers in southern Georgian Bay; and in the Saugeen and Sauble rivers, Ontario tributaries to the main basin of Lake Huron (Kerr and Perron 1986; Kerr 1987; Kerr et al. 1988). Also in 1987, mature Chinook salmon and their eggs and fry were observed on historically important lake trout spawning reefs in the North Channel, indicating that shoal spawning of Chinook salmon occurred in Lake Huron (Powell and Miller 1990). Elliot (1994) documented that age-0 Chinook salmon in Lake Michigan left river mouth areas to occupy the beach zone in early summer. Later in the summer they dispersed widely and occupied surface waters of shallow bays where they appeared to be feeding on insects in the surface film (Elliot 1993, 1994). During 1990–92, 27% to 66% of smolt production measured by Elliot (1994) in Lake Michigan was estimated to be from natural reproduction. Hesse (1994) determined that about 30% of Chinook salmon from the 1990–92 year classes harvested by recreational fishers in Lake Michigan were naturally produced.

Chinook salmon stocking rates in Lake Huron generally rose to a peak of 5 million in 1989, at which point fishery agencies became concerned that predator fish abundance could exceed the capacity of Lake Huron's prey base. By interagency agreement Chinook salmon stocking was capped at 1990 levels and remained near 4.5 million annually until 1999 when the agencies further reduced stocking by 20% (Woldt et al. 2005). The combination of rising stocking rates and the possibility that reproduction of Chinook salmon was also rising during the 1980s and early 1990s posed the concern that too little was known about sustainable limits to predator demand in Lake Huron (Kocik and Jones 1999). Both stocking success and production of wild-born Chinook salmon can be inconsistent (Elliot 1994), while production and stock size of Chinook salmon prey, particularly for the thermally-sensitive alewife, can also be variable (O'Gorman and Stewart 1999) and may be declining in Lake Huron (Bence et al., in press).

The principal objective of this study was to evaluate how attributes such as stocking location, characteristics of receiving waters, use of acclimation pens, and elements of the early life history of Chinook salmon, might explain variation in survival and recruitment to the fishery. Additionally, we assessed the relative contribution of natural reproduction to the 1991–95 Chinook salmon year classes in Michigan waters of Lake Huron to provide mangers with information for refining stocking strategies for Chinook salmon in Lake Huron.

Methods

Stocking and Marking

Experimentally stocked Chinook salmon were marked with site- and year-specific numbered coded-wire tags (CWT) injected into the snout. The adipose fin was removed so they could be identified externally as fish bearing CWTs (Table 1). After tagging, fin-clip quality and CWT retention rates were measured. Numbers of experimentally stocked Chinook salmon were then adjusted to reflect number of fish stocked with recognizable CWTs. CWT fish were stocked at Swan River (near Rogers City), Mill Creek (near Harrisville), Au Sable River (Oscoda), Pt. Austin, Harbor Beach, Au Gres, Port Sanilac, and Lexington (Figure 1) during the study period to evaluate relative performance of Chinook salmon stocked at each site. Paired comparisons of Lake Huron beach and Au Sable River stocking sites were conducted at Oscoda from 1995–97; for these test groups, length, weight, and other fish quality parameters as described by Goede and Barton (1990) were recorded from a sample of each test group on the day of stocking (Table 2).

Swan River was stocked with CWT Chinook salmon from Platte River Hatchery every year to index survival of fish stocked there over time and as a "benchmark" against which to compare other stockings. In 2001 and 2002, two CWT study groups were stocked in Swan River as part of another study, one group of which consisted of the usual Platte River Hatchery "benchmark" stocking (Table 1).

Acclimation Pens

Acclimation rearing facilities at Harbor Beach, Au Sable River at Oscoda, and Mill Creek in Harrisville (Figure 1) were used to compare the performance of the acclimated fish with conventionally-stocked CWT-marked fish. Acclimation consisted of holding fish in pens of mesh construction at Harbor Beach (1994–98) and Au Sable River (1991–92) or in off-channel raceways located adjacent to the stocking site at Van Etten Creek adjacent to the Au Sable River (1993–97) and Mill Creek for approximately 3 weeks or until smolting occurred. Fish were fed the same ration used by hatcheries while in acclimation facilities. At the end of the acclimation period, fish were released by opening the pens or raceways after dark. The goal of acclimation was to minimize stress at time of release and to provide an imprinting period. We also used pen-acclimated Chinook salmon to compare performance of Chinook salmon stocked at the river mouth with stockings about 9 miles upstream at the Whirlpool access site on the Au Sable River (Figure 2, Table 2).

Evaluating Contributions from Reproduction

From 1991–95 all stocked Chinook salmon were marked with oxytetracycline (OTC) by administering the antibiotic in feed. The feed mix was composed of 3.5% OTC in moist starter diet. The mix was fed at 2% of the Chinook salmon biomass for five consecutive days approximately one month prior to release (Hesse 1994). Guidelines called for fish to be at least 250 per kg in size before starting the OTC-mix feeding. Chinook salmon receiving CWTs were also OTC marked. During 1994 and 1995, samples of fish from each hatchery lot marked by feeding OTC-laced food were inspected for mark quality. Marks were categorized as “good”, “poor”, or “no mark”. No quality control data were recorded for OTC-marked fish stocked in 1991, 1992, or 1993. Ontario Ministry of Natural Resources cooperative hatcheries also stocked Chinook salmon, but they did not mark their fish during this study period. Therefore, we focused sampling effort on Chinook salmon early life stages under the assumption that the unmarked fish from Ontario would not reach Michigan waters within the first 6 months after stocking.

Early Life History

A 23-m beach seine was used to sample Chinook salmon parr and smolts during May and June, 1993–95. The seine was 1.6-m high and composed of two 12.7-mm mesh outer panels and a center panel of 9.5-mm mesh (stretch measure); each panel was 7.6-m long. Seining was conducted after dark. Unidentified fish and all age-0 Chinook salmon collected were placed on ice and returned to the lab for identification and measurement. We recorded length, fin clip, and presence of oxytetracycline mark for Chinook salmon and total number of other species incidentally caught. Chinook salmon with adipose fin clips were examined for presence of CWTs in the lab. In 1993, we did 159 seine hauls at 13 locations from Hammond Bay to Au Gres in north-central Lake Huron (Tables 3–5), of which 44 seine hauls were near the mouth of the Au Sable River in the Oscoda area (Figure 3). In 1994 and 1995, 44 and 23 seine hauls were made, respectively, at Oscoda (Figure 2; tables 5 and 6).

Predator relative abundance at stocking sites at time of stocking was indexed using graded-mesh gill nets in 1995–97. The gill nets were 76-m long and 1.8-m high, composed of 15-m panels of 38-mm to 114-mm stretch-measure multi-filament nylon twine mesh. These nets were set on beaches of Lake Huron within 3 miles of the Au Sable River mouth, within the harbor area of Harbor Beach and in Swan Bay off the mouth of the Swan River stocking site. In addition, predator fish were sampled near stocking sites using electrofishing in the Au Sable River and at Harbor Beach. Abundance was measured as catch per 1,000 m of gill-net effort or as catch per hour of electrofishing. For each predator, total length and diet (measured as count of prey items) were recorded.

Age-0 Chinook salmon summer and fall data were from three sources. In 1991 and 1992, we used gill nets that were 1.8-m high, 700-m-long, and composed of 38- and 51-mm stretch-mesh multifilament nylon. Although these nets were targeting yearling brown trout, they caught significant numbers of age-0 Chinook salmon. From 1993–96, we sampled age-0 Chinook salmon using gill nets that were 4.5-m high and made up of alternating panels of 38- and 51-mm stretch-measure mesh of multi-filament twine. A third source of age-0 Chinook salmon data was other surveys that employed 1.8-m high-graded mesh gill nets. Fishing of this gear was concentrated in Hammond, Thunder, and Tawas bays. Smaller amounts of this effort were deployed in southern Lake Huron near Harbor Beach and Pt. Austin, and northern Lake Huron near the Les Cheneaux Islands (Figure 1).

Vertebrae of age-0 Chinook salmon were examined for OTC marks in the lab. Fish with adipose fin clips were examined in the lab for presence of CWT. The stomach contents of a subsample of the catch were examined to identify and count prey items consumed. Recovered vertebrae were cleaned and examined using a dissecting microscope with UV light source to ascertain presence of OTC marks. For the period 1991–95, the light source was a Black Ray Longwave Ultraviolet Model B 100 AP lamp. OTC-positive age-0 fish displayed a florescent ring on the vertebra just inside the stocking check. Vertebrae from adult Chinook salmon were prepared, examined for OTC marks, and aged using the same equipment according to methods described by Hesse (1994).

Performance in the Recreational Fishery

CWT recoveries from angler harvest were used to measure performance of stocked Chinook salmon in the recreational fishery. Snouts from adipose-clipped / CWT Chinook salmon were collected by creel clerks and “head hunters”, who were assigned to examine recreational catch, record the incidence of marked fish, and collect heads or snouts from those with adipose clips. Other CWT returns were from anglers and Charter Boat Captains, who voluntarily turned in heads from Chinook salmon with adipose fin clips. Returns of CWT from the recreational fishery were adjusted for adipose clip detectability and CWT retention rates, based on quality control measurements taken prior to release of the fish. Results were expressed as number of CWT returned per 100,000 Chinook salmon released with detectable fin clips and retained tags. The CWT returns were not adjusted for differences in fishing power between the various segments of the recreational fishery or for differences in fishing effort over time and space. All Chinook salmon snouts collected from the recreational fishery were sent to the Charlevoix Fisheries Research Station for tag removal and reading. Snouts collected by surveys (seining, gill nets, and electrofishing) were sent to the Alpena Fisheries Station for extraction and reading. Differences in return rates in the recreational fishery were tested for significance using chi square statistics for numbers of tags returned. Expected ratios were based upon the number of recoverable tags released for each study pair. Chi-square probability ≤ 0.05 was considered to represent significant difference between study pairs.

Spawning-phase Returns

Spawning-phase Chinook salmon were sampled from the Au Sable River downstream of Van Etten Acclimation Facility (Figure 2) by electrofishing during September and October. We used the catch to monitor relative abundance of the CWT Chinook salmon in the spawning run; to determine the percentage of fish of the 1991–95 year classes that had OTC marks and therefore were of hatchery origin; and to monitor trends in biological parameters such as size at age, Fulton’s condition factor, and sea lamprey wounding rates. We also sampled spawning-phase Chinook salmon from the Swan River Weir in northwest Lake Huron. Swan River has little or no reproduction because it arises in a limestone quarry, has little spawning habitat, and has spring and summer water temperatures that are excessive for the needs of early-life-stage Chinook salmon. The percentage of unmarked fish collected from the Swan River Weir was therefore assumed to represent OTC mark retention in older fish. We inferred the proportion of wild-born fish in the Au Sable River samples by comparison with OTC marking rates in the Swan River Weir samples. From 1996–2004 we tried to sample at least 500 fish per year from the Au Sable River and 100 fish per year from the Swan River Weir. We recorded total length, weight, fin clip, sex, maturity, and number of lamprey wounds for each fish. Sea lamprey wounds were classified according to King (1980). Snouts from Chinook salmon with adipose fin clips were removed and CWT were extracted and processed in the lab. Samples of approximately six vertebrae were taken from immediately below the adipose fin for OTC detection and age determination using methods described by Hesse (1994). Samples were protected from ultraviolet light, packaged in ice for transport, and frozen until processed. Processing was done within a year of the collection dates.

During fall 1973–80, prior to this study, 1,440 Chinook salmon were gillnetted from the mouth of the Au Sable River in pre-spawning-phase condition. These fish were aged using scales. The data from these early collections were used to compare growth rates and condition factors (Fulton's K) between the two collection periods.

Results

Stocking

There was very little difference in size at stocking of Chinook salmon used for the paired comparisons at Oscoda. Mean total lengths of the stocking pairs were within 1 mm of each other in two of the three years. They were significantly different only in 1997, when they differed by 3 mm in total length (Table 2).

Early Life History and Associated Fishes

During 1993, 46 fish species were collected in 155 seine hauls (Table 3). The thirteen sites sampled represented six general areas of north-central Lake Huron: Hammond Bay, Thunder Bay, Black River (Alcona Co.), Oscoda, Tawas, and Au Gres (Figure 3). The most ubiquitous fish sampled, in terms of number of seine hauls where at least one specimen was encountered, were age-0 lake whitefish, spottail shiners, alewives, sand shiners, trout-perch, longnose dace, emerald shiners, rainbow smelt, and ninespine stickleback, in declining order. Numerically, more alewives were encountered than any other species owing to their patchy high abundance as spawning adults, particularly in Hammond, Thunder, and Tawas bays. Although age-0 lake whitefish were encountered at all areas from north Hammond Bay to Tawas, 90% of the catch was from sites in Thunder Bay. Most of the 119 age-1 brown trout taken were from Thunder Bay, where they had been stocked offshore by boat while we were seining, indicating many quickly returned to shore (Table 3).

In 1993, age-0 Chinook salmon were caught by beach seining in Hammond Bay near the Ocqueoc River (in Presque Isle County), near the Black River (Alcona County), in Oscoda near the Au Sable River, and in Tawas near the Tawas River; but 91% of the Chinook salmon catch was from Oscoda within 3 miles of the Au Sable River mouth (Table 4). The one Chinook salmon sampled at Hammond Bay near the Ocqueoc River, 30 km from the nearest stocking site, lacked a fin clip or OTC mark, and was evidently wild. Four unmarked Chinook salmon were sampled near the Black River (Alcona Co.), 46 km from the nearest Chinook salmon stocking site. In addition, four coho salmon smolts were sampled near the Black River (Alcona Co.); no coho salmon were stocked in Lake Huron during the study suggesting these fish were wild born, possibly in the Black River (Alcona Co.). Of the 253 Chinook salmon sampled near the Au Sable River mouth in 1993, 42% lacked fin clip, coded-wire tag, and/or oxytetracycline marks (Table 5). Of the 20 age-0 Chinook salmon sampled in Tawas Bay, 68% lacked hatchery marks. The average size and catch of unmarked

Chinook salmon rose sharply between 25 May and 1 June 1993. A large number of fish from Platte Hatchery that were not a part of this study were stocked in the Au Sable River between those dates. No estimate was made of OTC mark quality in 1993, thus we cannot estimate the contribution of poorly marked hatchery fish to the unmarked catch. It appears likely that the rise in unmarked Chinook salmon in our catch was partly due to these hatchery fish, which were exceptionally small that year, probably too small to be marked effectively with OTC.

In 1993 (Table 5), age-0 Chinook salmon of hatchery origin in the beach seine catch were larger than those lacking hatchery marks (analysis of variance, $p < 0.001$). The reported size at stocking of the hatchery fish that were not part of this study was 65 mm, considerably smaller than the CWT study groups, which measured 85 and 84 mm total length, beach and river stocking locations, respectively. There was no significant difference in length between the two study groups as measured over the period of our beach seining in spring 1993 (general linear model, $p = 0.43$).

In 1994 and 1995, Chinook salmon of hatchery origin caught in the Oscoda area were larger than those lacking marks (Tables 6 and 7) (t tests, $p < 0.001$). CWT test fish in 1994 were from Wolf Lake Hatchery, one lot of which was pen acclimated, the other stocked directly from the hatchery. Both study lots were larger than the other hatchery Chinook salmon that were not part of the study (t test, $p < 0.001$). In 1995, both study groups were pen acclimated and again were larger than conventionally stocked hatchery Chinook salmon (t test, $p < 0.001$). The non-study fish were from Platte Hatchery. An estimated 2.5% and 14% of OTC marks were classified as undetectable at Platte Hatchery in 1994 and 1995, respectively.

There was a tendency for the smaller wild and non-pen-acclimated Chinook salmon to persist in the seine catch into late June, even as water temperatures rose to nearly 20°C, while the larger, pen-acclimated Chinook salmon were captured only briefly after their release. The relatively high catch rates of pen-acclimated beach-stocked Chinook salmon in 1995 were probably due to their having been stocked at one of the seining sites. The catch rate of these fish declined to near zero within about a week of stocking, between 7 and 15 June (Table 7).

A total of 537 predator fish was sampled from the vicinity of stocking sites with gill nets and electrofishing gear in the springs of 1995–97. These predators' stomachs contained 209 identifiable age-0 Chinook salmon and 32 steelhead smolts. Other prey consumed included 428 alewives and 97 rainbow smelt (Table 8). The predators that most commonly contained stocked salmonids were walleyes, lake trout, and smallmouth bass. The highest consumption of salmonids, 1.1 per stomach, was in the Au Sable River. All the steelhead smolts observed in stomachs were eaten by walleyes sampled in the Au Sable River. The highest catch rate for walleyes in gill nets was at the mouth of the Au Sable River, but no stocked salmonids were in the stomachs of these fish, in spite of our stocking Chinook salmon on one netting site and evidence from beach seining that age-0 Chinook salmon were abundant. Alewives were abundant in seine catches and in walleye stomachs on the Oscoda beaches. Lake trout contained 0.22 and 0.39 age-0 Chinook salmon per stomach at Oscoda and Swan Bay, respectively. Lake trout catch rates were high at Swan Bay (CPE of 90), accounting for the large number of juvenile Chinook salmon observed in stomachs there. Rate of consumption of Chinook salmon was highest at Harbor Beach, where for the combined gill-net and electrofishing catch, each walleye contained an average of 2.1 juvenile Chinook salmon. In the Au Sable River, consumption of stocked salmonids was highest in 1995, when 34 age-0 Chinook salmon and 24 steelhead smolts were found in 36 walleyes and 1 smallmouth bass (1.57 salmonids per stomach). Conversely, we saw no salmonids in 45 predators sampled concurrently with gill nets set on the beach near the river mouth. The number of Chinook salmon per predator observed on Oscoda beaches rose from zero and 0.05 per stomach in 1995 and 1996 to 0.13 in 1997. Consumption of alewives declined from 1.40 and 1.21 per predator in 1995 and 1996 to 0.35 in 1997 (Table 9).

During summer of 1991, 85 age-0 Chinook salmon were taken using gill nets in Thunder Bay; 31% were wild judging by lack of fin clips or oxytetracycline marks (tables 10 and 11). In 1992, 162

Chinook salmon were sampled using gill nets, but only 12% were wild, based on fin clip and oxytetracycline composition. There were no assessments of OTC mark quality done in 1991–93. During the sampling, water temperatures were warmer in 1991 (16–20°C) than in 1992 (14–17°C). In both years, the fish were found at depths ranging from 8–16 m, usually on point bars and reefs extending into Thunder Bay.

From 1991–96, 1,542 age-0 Chinook salmon were netted (Table 10) from 24 statistical grids at a variety of nearshore locations from Mackinaw to Harbor Beach (Figure 4). Oxytetracycline mark composition varied considerably; all the fish examined in 1994 had the OTC mark and were therefore of hatchery origin, while in 1993 28.1% were lacking the mark, and were potentially wild-born (Table 11). As in 1991 and 1992, juvenile Chinook salmon were found in relatively shallow, warm water. Water temperatures averaged 18.2°C and capture site depth averaged 11 m. Catch rates were considerably higher in some grids than in others (Figure 4). Grids with highest catch rates were associated with Tawas, Thunder, and Hammond bays. The most productive netting sites appeared to be point bars, such as North Point of Thunder Bay and Tawas Point of Tawas Bay. The exceptionally high catch rate near Hammond Bay (Figure 4) is thought to be influenced by proximity of the netting to Lake Huron's largest Chinook salmon stocking site, Swan River.

From 1993–96, age-0 Chinook salmon targeted with small-mesh nets grew an average of 1.30 mm per day during the 3 July – 3 October sampling season, which was probably the period of peak daily growth in length. Mean growth of age-0 Chinook salmon during this sampling season, as measured by average daily length at capture, was described by the linear equation:

$$\text{Length (mm)} = -37.61 + (1.05 \cdot \text{day of year}).$$

Average total length increased regularly over the months of July through September (Table 12, Figure 5). We combined data across years and latitudes, which introduced annual and spatial variation including apparent negative growth during the 23–28 August period. Many of the observations for this period were during 1993 and 1995, when lengths were less than other years. Approximately 38% of variation in capture length was accounted for by month and grid of capture. While length increased regularly during the season, length varied without a distinct pattern across grids within months. For the combined months of August and September, length was weakly a function of grid ($R^2 = 0.17$) but, not surprisingly, was more strongly associated with month ($R^2 = 0.32$).

From 1993–96, stomachs of 1,133 age-0 Chinook salmon were examined for diet composition. Invertebrates composed the majority of the diet, particularly in June and July, when terrestrial and aquatic insects comprised 78%, and zooplankton 15%, of the diet (Table 13, Figure 6). Fish made up only 7% of the diet in June–July and 11% in August, but rose to 37% in September–October. Fish consumed late in the season were chiefly age-0 alewives. Rainbow smelt never made up more than 10% of the diet and contributed less in September and October than in July. The most common terrestrial invertebrates consumed were flying ants. Aquatic invertebrates were chiefly composed of spiny water fleas *Bythotrephes longimanus*, other unidentified zooplankton, and midges (Diptera). The rise in spiny water flea consumption corresponded with the usual pulse in their numbers in Lake Huron in late summer.

Including the targeted Chinook salmon catch, 28 species were captured in the small-mesh gill nets during 1993–96 (Table 14). Catches of age-0 Chinook salmon were most commonly associated with incidental catches of alewives. Yellow perch, round whitefish, lake whitefish, longnose suckers, white suckers, and rainbow smelt were other important contributors to the incidental catch. Among predator species, brown trout, adult Chinook salmon, lake trout, and walleyes were most common, but none were heavily represented in the samples, probably because of the small mesh size of the nets. None of the predator species caught from July through October had identifiable Chinook salmon remains in their stomachs. Eight lake herring were sampled; this species is uncommon in Lake Huron and all were sampled on the north shore, where a viable population of lake herring remains.

Performance in the Recreational Fishery

Acclimation pens.–For the Au Sable River, the acclimated Chinook salmon had significantly (chi square test, $p < 0.01$) higher overall return rates than conventionally stocked fish (2.4:1 ratio) to the recreational fishery for both the 1993 and 1994 cohorts. Acclimated fish had significantly higher return rates at ages 1, 2, and 3 (chi square test, $p < 0.013$), but the differences for age 4 were marginal and there were no CWT returns of any age-5 acclimated fish in either year (Table 15). For Harbor Beach, pen-acclimated fish stocked in 1996 and 1998 returned significantly better than the conventionally stocked groups (chi square probability ≤ 0.004, Table 16). In 1996, returns of pen-acclimated fish were significantly higher for ages 1, 3, and 4 ($p \leq 0.018$); there was not a significant difference in returns at age 2 ($p = 0.22$). In 1998, returns of Harbor Beach pen-acclimated fish were significantly higher for ages 1 and 2, but not for age 3 ($p \leq 0.36$). Returns of conventionally stocked fish were higher than pen-acclimated fish in 1995 ($p \leq 0.031$) and there was no significant difference between the two treatments released in 1997 ($p = 0.824$).

Coded-wire tagged fish were stocked conventionally and by using acclimation facilities at a number of locations in Lake Huron in other years, but not expressly for the purpose of comparing acclimation with conventional stocking methods. CWT returns rates for these stockings (Table 17) were not corrected for biases associated with the nature of the fisheries at the stocking sites, such as availability of fish cleaning stations, local drop-off points for Chinook salmon heads, and participation levels in the CWT recovery effort. The overall CWT return rate for Chinook salmon from acclimation pens during this period was 229.1 per 100,000 detectable marks, compared with 128.8 for conventionally released fish (Table 18). The return rates ranged as high as 450 for the Mill Creek (Harrisville) acclimation pen's 2001 cohort (Table 17). Returns are only partially complete at this time for age 0–2 fish of the 2002 cohort. These data suggest acclimated fish returned from the open-water fishery at an overall rate of approximately 1.5 times that of conventionally stocked Chinook salmon.

Survival indices by stocking site.–Pen-acclimated Chinook salmon smolts stocked in 1995 at 3-Mile Beach produced significantly higher CWT returns ($p < 0.001$) than pen-acclimated Chinook salmon stocked in the Au Sable River at the Whirlpool site, 9 miles upstream of Lake Huron (Figure 2; Table 19). The 3-Mile Beach 1995 stocking returned at nearly 1.5 times the rate of the fish stocked at Whirlpool and the returns were higher at all ages, significantly so for ages 1, 3, and 4 ($p \leq 0.037$). Returns of the 1996 cohorts stocked at 3-Mile Beach and Whirlpool were nearly identical at all ages (Table 19). The 1997 cohort stocked at Whirlpool (the river site) returned significantly better than the beach stocking ($p = 0.021$), but both of the 1997 test groups returned poorly. Return rates per 100,000 detectable tags, for both study groups combined, declined from an average of 311 for the 1995 cohorts to 213 for 1996 to only 44 for 1997. The 1997 returns totaled only 17% of the averaged return rates of the 1995 and 1996 cohorts.

Swan River had the highest return rates (number per 100,000 stocked) of coded-wire tags of the conventionally stocked sites evaluated. The average return rate from the 1999–2002 conventional stockings at Tawas, Au Gres, Port Sanilac, Lexington, and Port Austin, combined, was 54.3, while that of Swan River was 113.7. Return rates for Swan River varied with a declining trend from 1992–2003. Return rates recovered to former levels in 2001, but the 2002 cohort returned at the lowest level to date (Table 17). Return rate was the lowest at Lexington, with an average of 37.8. Return rates at Port Sanilac averaged 39.5, and return rates at Tawas, Port Austin, and Au Gres together averaged 69.5 (Table 17).

Survival indices across years.–Chinook salmon stocked between 1993 and 1996 had the highest return rates, which averaged 240 across all ports and release methods (Table 18). Mean CWT return rates declined to 69 for salmon stocked in 1997 and to 60 in 1998. Even the Van Etten Creek rearing pens experienced very low survival in 1997, a year of exceptionally low adult alewife abundance (Bence et al., in press). Return rates generally rose after the 1998 stockings, averaging 187 for the 2001 marked cohorts (Tables 17 and 18). A remarkably high return rate for the Mill Creek (Harrisville) acclimation pens contributed to the high 2001 CWT return rates. Excluding the Mill Creek (Harrisville) acclimated fish, return rates for Chinook salmon stocked in 2001 were still favorable, averaging 135. Return rates declined for the 2002 year class at all stocking sites in Lake Huron, including Mill Creek (Harrisville) acclimated fish.

Spawning-Phase Chinook Salmon Returns

The acclimated fish from both the 1993 and 1994 Au Sable River cohorts had significantly higher returns ($p < 0.0001$) in the fall electrofishing samples than conventionally stocked fish (Table 20). The ratio of acclimated to conventionally stocked fish was higher (7.6 to 1) for the 1994 cohorts, when the acclimated fish were transported from Van Etten to a Lake Huron beach 3 miles north of the river mouth. In 1993, the pen-acclimated fish were released directly into the Au Sable River from the Van Etten Creek acclimation site, which was located about 2 river miles above the Au Sable River mouth (Figure 2).

Returns during the spawning run of acclimated fish stocked on the beach were about twice those stocked in the river. The differences were statistically significant ($p < 0.001$) for the 1995 and 1996 cohorts, but not ($p = 0.75$) for 1997 due to small sample sizes.

About 20% of the 456 CWT Chinook salmon collected from Au Sable River were strays from eight other stocking sites, including three Lake Michigan sites (Table 20). We collected 78 strays that were stocked at Swan River Weir and 3 strays from each stocking site at Strawberry Creek (Wisconsin), Tawas River, and Harbor Beach. No stray fish were found among the 163 CWT fish sampled from Swan River Weir.

More Chinook salmon had OTC marks in the Au Sable River than at Swan River Weir for the four cohorts marked with OTC (Table 21). OTC marking was lowest in the 1992 cohort at both sites, but sample sizes were small. OTC marking rates were also low in 1993, which was expected because exceptionally cold spring weather that year caused the fish to grow slowly and to be marked at too small a size at the Platte River hatchery. Unfortunately, no data were collected by the hatcheries for OTC mark quality in 1992 and 1993. For the 1994 and 1995 cohorts, hatchery quality control samples suggested at least 85% of fish stocked in those years had detectable marks. We measured at least 92% OTC marking at both Swan and the Au Sable rivers among the 1994 and 1995 year classes, with a slightly higher incidence of OTC marks at the Au Sable River (Table 21).

Size and condition at age declined in 1998 and again after 2002, particularly for age-2 and age-3 Chinook salmon, at both the Au Sable River and Swan River Weir, but the declines were more pronounced for the Au Sable River fish (Table 22). After 1998, age-2 and age-3 Swan River Weir Chinook salmon were larger and in better condition than those in the Au Sable River. Age-1 Chinook salmon varied in size and condition with a slightly different pattern than older fish, but declined in condition to near or below 0.90 in 2003. The age composition of the catch changed over the study period, with a lower proportion of age-4 fish in recent years. Only seven age-4 Chinook salmon were sampled during 2002–04, comprising 0.4% of the sample. Age-4 Chinook salmon comprised 12.8% of samples collected from both locations during 1996–2001 (Table 22).

Size at age 3 and condition factors of spawning-phase salmon from the Au Sable River declined in stages from 1973 to 2004, becoming alarmingly low in 1998 and 2004. For the period 1973–86, lengths, weights, and condition factors at age 3 were significantly greater (t test, $p < 0.016$) than in any year after sampling was resumed in 1996 (Table 23, Figure 7). Within the later period, size parameters ($p < 0.001$) and condition ($p = 0.045$) were significantly less in 1998 and 2004 than other post-1995 years.

Several Chinook salmon with condition factors less than 0.75 sampled from the Au Sable River in fall 2004 were sent to Michigan State University, College of Veterinary Medicine for analysis. These fish were deemed by fish pathologists to be in, or approaching, moribund condition as a consequence of their emaciated state and presence of high titers of opportunistic bacterial pathogens (Mohamed Faisal, personal communication, 2005). Some of these fish are illustrated in Figure 8. From 1996–2002, an annual average of 3.3% of Chinook salmon older than age 1 had condition factors less than 0.75. The percentage in such critically low condition rose to 9.6 and 28.4, in 2003 and 2004, respectively.

Incidence of A-1, A-2, and A-3 sea lamprey wounds, which are considered representative of wounds inflicted in the past year, declined after 2001 to the lowest levels since fall escapement sampling began (Table 24). Wounding rates averaged 0.041 per fish > 700 mm from 1996–2003, but only 0.010 in 2004.

Discussion

Unmarked, age-0 Chinook salmon were already in the beach zone near the Au Sable River each year when seining began and prior to stocking dates; they continued to persist in the catch throughout the sampling period. The Au Sable River area yielded more unmarked, many undoubtedly wild-born, Chinook salmon to our seine catches than any other site. However, some of these unmarked fish were also of hatchery origin. We believe the non-study Chinook salmon stocked in 1993 did not take the OTC mark well because most of them were exceptionally small (65 mm) at Platte River Hatchery at the time of marking. Immediately after their stocking, the number of unmarked Chinook salmon in the seine catch rose and their mean lengths (67 mm) became similar to the fish stocked from Platte Hatchery. The catch of unmarked fish prior to May 27, 1993, however, provided unambiguous evidence of reproduction from the Au Sable River, because all stockings prior to May 27 were marked with the combination of CWTs, adipose fin clips, and OTC. Evidence of reproduction from the Au Sable River was much more pronounced in 1994, when 218 unmarked Chinook salmon were seined prior to the stocking date of non-study Chinook salmon. Wild Chinook salmon were also taken near the Ocqueoc, Black, and Tawas rivers (Figure 3). None were taken near the Au Gres River or its bypass channel, Whitney Drain, but suitable sites for seining were almost completely lacking near these two channel mouths. Chinook salmon probably reproduce in the Rifle River but there were no suitable seining sites near the Rifle River mouth. We did not seine the Upper Peninsula north shore of Lake Huron, thus we did not sample near the other likely reproduction site, the Carp River. The Chippewa-Ottawa Resource Authority (CORA) found evidence of reproduction near the Carp River during the late 1990s (Greg Wright, CORA, personal communication), which has recently been verified by findings of Lake Superior State University (LSSU unpublished data). LSSU has also measured significant levels of reproduction in the rapids of the St. Marys River in Sault Ste. Marie.

Hatchery Chinook salmon stocked in the Au Sable River appeared in the seine catch shortly after stocking. Like wild Chinook salmon, smaller Platte-River-Hatchery-stocked Chinook salmon persisted in the beach zone for some time after stocking. Most unmarked and smaller hatchery Chinook salmon retained parr marks and clearly had not reached the smolt stage. Larger CWT study fish contributed the least to the seine catch and then only immediately after stocking. The larger study fish, particularly those from the acclimation pens, were almost completely smolted at time of release and we believe the majority of these fish moved offshore shortly after stocking. Predator abundance was relatively high in the Au Sable River and the beach zone near the river mouth. Therefore, a shorter period of beach residence could confer a survival advantage for the larger, smolted Chinook salmon. The relatively long beach-residence time of smaller Chinook salmon could be at the cost of higher exposure to predation, possibly explaining the low numbers of unmarked Chinook salmon in spawning runs to the Au Sable River. In spite of the high numbers of wild juveniles sampled in beach seines, incidence of unmarked fish in the Au Sable River spawning run was below that of Swan River Weir, where we believe there is little or no reproduction. Thus, the reproduction we measured did not translate into a significant contribution of wild-born fish to the spawning run. Considering their small size in the beach zone, and the relatively high abundance of predators there, the most likely explanation for their failure to recruit is that most of the wild parr were consumed by predators. Exposure to predation in the beach zone would be particularly high at times when alternative prey, particularly alewives, are in low abundance.

The beach zone inhabited by Chinook salmon parr in Lake Huron was similar to that described for Chinook salmon parr in Lake Washington (Tabor and Piaskowski 2001; Sergeant and Beauchamp 2006; Tabor et al. 2006), where Chinook salmon parr occupied shallow, littoral regions of the lake with gentle slope and sand-silt substrate. As with Tabor et al. (2006) and Elliot (1994), catch rates were highest in proximity to mouths of Chinook salmon-producing streams (Au Sable and Tawas rivers) and stocking sites. Similar to Lake Washington (Tabor et al. 2006), the wild parr first appeared at relatively small sizes, as small as 40 mm. The high seine catch rate on sandy beaches is partly attributable to greater gear efficiency on sand bottoms, but is also consistent with habitats occupied by Chinook salmon parr in Lake Washington (Tabor and Piaskowski 2001; Tabor et al. 2006). Tabor et al. (2006) noted that Chinook salmon were observed on beach habitats with water depths less than 0.5 m and that depth occupied increased progressively with time to between 2 and 3 m by June. Tabor and Piaskowski (2001) and Tabor et al. (2006) found there to be weak affinity of Chinook salmon parr for overhead cover and woody debris. The Chinook salmon of Lake Washington are of nearly the same origin as those in Lake Huron. The Cedar River is the major spawning tributary for Chinook salmon reproduction in the Lake Washington watershed. The Green River (source of Lake Huron's Chinook salmon) and the Cedar River were both tributaries to the Dawamish River (a tributary to Puget Sound) before the Cedar was diverted to Lake Washington in 1912 (Tabor et al. 2006). Thus, the similarity in habitat selection between the Chinook salmon of our study and those of Lake Washington (Tabor et al. 2006) apparently reflects their common origin. In Lake Washington two emigration patterns were observed: post-fry migrants that entered the lake in late winter or early spring and remained in the lake until June; and pre-smolts that emigrated from tributaries in late spring (Tabor et al. 2006). We did not see the evidence of two emigration patterns, perhaps because rapid warming of the Au Sable River in May forced the pre-smolts to leave the river early or because our beach seining began too late in the spring to intercept both migrations.

Species diversity of the beach zone, as measured using the seine (46 species), was nearly twice that of the offshore areas sampled by gill nets (28 species). Seining was effective only on unobstructed sandy beaches. Had we been able to sample other shoreline habitat types, additional nearshore species would have been recorded. Since 1992, the beach zone has been colonized by several invasive species including zebra mussels *Dreissena polymorpha*, quagga mussels *Dreissena bugensis*, and round goby *Neogobius melanostomus*. Low lake levels have tempted beach owners to groom their shorelines to improve them for swimming. This combination of invasive species, low lake levels, and habitat alterations may have changed the nearshore ecosystem considerably. A follow up to our survey would contribute to an understanding of the effects of these recent changes on the integrity of the nearshore ecosystem.

An unanticipated finding was the heavy seine catches of post-larval lake whitefish in the Thunder Bay area. This area has hosted one of Michigan's most prolific whitefish commercial fisheries since the mid 1800s (Van Oosten et al. 1946) and is thought to be one of Lake Huron's most important spawning sites for lake whitefish (Ebener 2006). Our seine catches suggest that, although juvenile whitefish were sampled in a variety of locations, Thunder Bay is indeed the most prolific reproduction area of the sites we sampled.

The stomachs of the 537 predator fish sampled at the stocking sites contained an average of 0.45 identifiable stocked salmonids each. Age-0 Chinook salmon and yearling steelhead smolts were more frequently seen in walleye stomachs (0.67 per stomach) than other predator species. The total number of juvenile Chinook salmon and steelhead trout consumed cannot be estimated without predator population estimates and measurements of daily consumption. The predation data suggest, however, that where alewives were abundant there was less consumption of stocked salmonids. For example, salmonids were more important to the diets of walleyes collected from the Au Sable River, where alewives were absent, than for walleyes from the lake, where alewives were abundant. Predation rates on recently stocked salmonids were much higher in years of especially low alewife abundance. Adult alewife abundance and biomass in Lake Huron's main basin declined from 1995–97 (Bence et al., in press) while numbers of age-0 Chinook salmon in stomachs of predators gill netted in the beach zone during May rose from zero in 1995 to 0.13 per predator in 1997. Thus, high alewife abundance in the beach-zone appeared to shield Chinook salmon parr and smolts in 1995, but the alewife shield was much diminished in 1997. As with Tabor et al. (2006), we saw little evidence that Chinook salmon parr sought shelter from woody debris. Age-0 Puget Sound strain Chinook salmon parr prefer homogenous shorelines with fine substrates (Tabor and Piaskowski 2001; Tabor et al. 2006), and apparently predation risk has little effect on habitat preferences (Sergeant and Beauchamp 2006). Chinook salmon may be more willing to risk predation exposure than other salmonids; this behavior may represent a tradeoff of higher predation risk for faster growth, which could confer improved survival prospects at later life stages (Abrahams and Healey 1993; Biro et al. 2005, as reviewed by Sergeant and Beauchamp 2006). The abundance of adult alewives appeared to be one of the factors that shield Chinook salmon from predation in predator-heavy beach zones in our study area. However, alewives nearly disappeared from Lake Huron by 2003 (Bence et al., in press), thus predation on year classes stocked since 2002 may have been much higher than levels observed during this study.

Temperature conditions may influence nearshore abundance of predators. Lake trout were scarce in the beach zone in 1995, when only one was sampled. They were common in 1996 and 1997, probably as a consequence of cooler than normal water temperatures in the beach zone through early June. A potential method for reducing exposure of stocked Chinook salmon to lake trout predation would be to stock after beach temperatures warmed to above approximately 18°C, when lake trout would be less likely to be near shore.

We observed that some predators switched to stocked salmonids after stocking events but most walleyes and lake trout continued to eat exclusively alewives and smelt. The relatively few fish that switched to predominantly salmonid prey accounted for most of the salmonid consumption measured. For example, in 1997 7.5% of 66 predators with food in their stomachs had eaten at least one Chinook salmon. A single walleye sampled that year at Harbor Beach contained 23 age-0 Chinook salmon. In 1996 a walleye contained 14 age-0 Chinook salmon and a lake trout contained 9 Chinook salmon. Thus, much of the predation we observed was accounted for by a relatively few individual predators.

Our small-mesh gillnetting data suggest that reproduction from Michigan's tributaries of Lake Huron contributes little to Lake Huron's Chinook salmon population. Hatchery-mark composition of the small-mesh gill-net catch in July–October, 1991–95 (Table 11), indicates Chinook salmon reproduction may have contributed significantly in 1991. However, there were no measures of OTC mark quality in 1991–93. We believe mark quality was low in 1993 and that most of the unmarked gill net catch was of hatchery origin. Platte Hatchery Chinook salmon, in particular, were marked at sizes below the 250 per kg threshold called for by the OTC marking protocol. As with their effect on the seine catch composition, hatchery fish with undetectable OTC marks probably contributed substantially to the unmarked Chinook salmon catch in small-mesh gill nets in 1993 (Table 11). The incidence of Chinook salmon without detectable marks in the small-mesh gillnet catch was near or below the mark failure rate measured by the hatcheries in 1994 and 1995. Thus, there was not significant reproduction on the Michigan side of Lake Huron in 1994 and 1995. Access of potamodromous fish species to most Michigan tributaries of Lake Huron is blocked by dams. Reproduction sites are probably limited to a few relatively small tributaries, such as the lower Au Sable River below Foote Dam (Figure 2); the Carp, Ocqueoc, Black (Alcona Co.), Au Gres, and

Rifle rivers; the Tawas River watershed; and perhaps a few others. Over 95% of the returning adults to the Au Sable River spawning run had OTC marks (Table 21) and thus were of hatchery origin. Although many Ontario tributaries to Lake Huron are not blocked by dams and are known to sustain natural reproduction (Kerr and Perron 1986; Kerr 1987; Kerr et al. 1988), it seems unlikely that recruits from Ontario would be found on the Michigan side of the lake as young-of-year. Thus, our age-0 mark compositions from small-mesh gillnetting probably reflect recruitment from the Michigan side, where the incidence of wild-born fish appears to be much lower than in Ontario waters.

Small-mesh gillnetting revealed that by mid-summer age-0 Chinook salmon were distributed in the nearshore zone in relatively warm, shallow water, similar to the distribution reported by Elliot (1994) on the east shore of Lake Michigan. Their association with points, such as Tawas Point and North Point of Thunder Bay, may be explained by their diets, which included terrestrial insects and emerging and adult forms of aquatic insects prior to September. Insects and other surface debris appeared to be concentrated by currents rounding these points. Growth of 1.3 mm per day was measured. This rapid growth probably reflects the influence of warm temperatures (about 18°C) on Chinook salmon metabolic rates combined with availability of adequate food supplies.

As with juveniles in the beach zone during spring, age-0 Chinook salmon in summer and fall were closely associated with aggregations of alewives, the chief prey of such predators as walleyes and lake trout. From July through August, diets of age-0 Chinook salmon were composed of about equal proportions of zooplankton, terrestrial insects, and aquatic invertebrates. By far the most common zooplankton species consumed during late summer was the spiny water flea *Bythotrephes longimanus*. Fish contributed less than 10% (by number) to the diet until September, then fish (chiefly age-0 alewives) rose to more than a third of the diet (Figure 6). We did not measure the biomass of prey consumed, but undoubtedly fish were the dominant component of the diet in September by virtue of the relatively large size of individual alewives by that time of year. However, prey-fish availability did not appear to be important to growth of age-0 Chinook salmon because, at least until September, invertebrates were the principal component of the predators' diets. High alewife abundance probably contributed to high survival of age-0 Chinook salmon during summer, not by providing prey, but by offering alternative prey to predators that otherwise would eat young Chinook salmon. An abundance of age-0 alewives probably also contributed to high Chinook salmon survival in late summer and fall by providing appropriately sized prey as age-0 Chinook salmon made the transition to eating fish.

Juvenile Chinook salmon were similar in size and appearance to adult alewives and may present an alewife-like search image for predators. Thus, predation on Chinook salmon could be heightened at times by their association with alewives, particularly if alewife abundance is relatively low. However, we found no Chinook salmon in the stomachs of predators caught in the small-mesh gill nets after June. More likely, adult alewives buffered predation on Chinook salmon by virtue of their far greater numbers during this study. Johnson and Rakoczy (2004) demonstrated that post-stocking survival of yearling brown trout was higher when adult alewife numbers were high, presumably owing to the abundance of alternative prey presented by the alewives.

Performance in the Recreational Fishery

Acclimation pens.–The acclimation pen at the mouth of Van Etten Creek, (lower Au Sable River, Figure 2) during 1993 and 1994 produced return rates 2.4 times those of matched stockings of conventionally released fish. At Van Etten, conditions during the rearing periods were satisfactory; there were no instances of excessive rearing temperatures or observations of unusual stress or mortalities. The better rearing conditions probably contributed to higher return rates from fish acclimated at Van Etten than from the fish acclimated at Harbor Beach.

In all years of the Harbor Beach study, there were periods when acclimation pen temperatures rose above 18°C and we believe the acclimated fish were exposed to inappropriate levels of thermal stress. In 1995 the fish in the acclimation pens were visibly stressed for several days before release and there was noticeable (but not measured) mortality. We therefore extended the Harbor Beach evaluation to a fourth year. In spite of the evidence of thermal stress, both the penned and conventionally stocked fish of the 1995 cohort experienced relatively high return rates, with conventionally-stocked fish returning at slightly higher rates than acclimated fish. Comparing all four years of Harbor Beach acclimation study data, acclimated Chinook salmon returned at 1.2 times the rate of conventionally stocked Chinook salmon. The return ratio rises to 1.5 if the first year of study is excluded (Table 16).

Survival indices by stocking site.–Clearly, the stockings near Oscoda and Harrisville experienced years of exceptionally high survival, probably owing to the benefits of acclimation facilities there. However, we did not attempt to standardize the CWT returns for fishing effort, fishing power of various types of recreational fishing (charter vs. private trips), or response rates of different segments of the fishery. "Head hunter" effort was uniformly deployed at all ports except for Au Gres, but these seasonal workers were employed principally during June through August. The CWT returns were probably sensitive to fishing pressure associated with the return of mature fish in September and October. For example, an average of 61% of CWT returns for fish released at Harrisville from 2000–02 were from the September–October period, when "head hunters" were not available, and most were thus voluntarily returned through drop off stations. Harrisville, Oscoda, Port Austin, and Rogers City had public or private fish cleaning stations or services and CWT head drop-off stations, which should have contributed to enhancing voluntary CWT return rates. Lower CWT returns from Lexington, Port Sanilac, Harbor Beach, Au Gres, and Tawas may in part be due to the lack of fish cleaning services in these ports.

Both quality control and seine samples showed that the paired test groups stocked at Oscoda were virtually the same size at stocking. Thus, size at stocking was effectively controlled as a variable affecting subsequent differences in performance between paired stockings.

At Oscoda, the equivocal differences between returns of acclimated smolts trucked to the traditional stocking site at Whirlpool on the Au Sable River and those stocked at 3-Mile Beach suggests that predation on out-migrating smolts in the Au Sable River was not an exceptional source of mortality for acclimated fish. The fish trucked to 3-Mile Beach survived better than the river-stocked fish in 1995, when alewives were abundant. The river-stocked fish survived better in 1997, though neither group returned well. Alewife abundance was exceptionally low in 1997 (Bence et al., in press). Predation effects are probably a function of amount of time that the stocked fish are exposed to predator-rich habitats such as tributaries and beach zones and the availability of alternative prey, such as alewives. Acclimated fish were stocked as smolts and appeared to exit the Au Sable River quickly after stocking, as evidenced by their appearance in our beach seining samples the night after stocking. Also, pen-acclimated fish appeared in beach seine catches only briefly, suggesting they moved offshore of the beach zone more quickly than conventionally-stocked or wild parr. Thus, pen-acclimated fish, regardless of where stocked, appeared to move more quickly than other juvenile Chinook salmon to the less predator-rich open waters of Lake Huron. This rapid rate of out-migration may be the single most important attribute contributing to the higher return rates for pen-acclimated fish. When alewives are scarce, however, as in 1997, there may be no refuge from predation, which could reduce benefits of acclimation.

Returns of CWT Chinook salmon stocked at Swan River tended to be higher than those from other conventionally-stocked sites on Lake Huron, but return rates declined over time. Both Platte River Hatchery and Wolf Lake Hatchery lots stocked at Swan River in 2001 returned well to the creel. However, the 2001 cohort produced one of the weakest runs of mature salmon to the Swan River Weir since records began (Michigan DNR, Fisheries Division, unpublished data). The failure of the otherwise successful 2001 cohort to return well to the weir may have been caused by a combination of straying to other streams and failure to survive to the point of maturity. As of December 2004, the 2002 cohort stocked at Swan River produced the lowest returns to the recreational fishery at both ages 1 and 2 of the time series for Swan River stockings, as well as the lowest weir returns on record. Predator gill-net catch rates were similar in Swan Bay, the Au Sable River mouth, and Harbor Beach, but unlike the other sites, the predator composition was almost entirely lake trout in Swan Bay. Lake trout are unlikely to be in the beach zone when water temperatures warm above about 18°C. Thus, stocking Swan River at a slightly later date, when beach temperatures approach 18°C, could reduce exposure of the parr to predation during the period immediately following stocking.

CWT returns from Chinook salmon stocked in Swan River were consistently higher than for CWT returns of conventionally stocked Chinook salmon at Port Sanilac, Lexington, and Harbor Beach. Chinook salmon were stocked directly into harbors at the latter three stocking sites because no tributaries were available. It is possible that stocking into tributary habitats is more favorable to post-stocking survival than stocking into harbor environments.

Survival indices across years.–After 4 years of relatively high returns, return rates of the 1997 and 1998 cohorts declined sharply at all ports. The decline was probably in response to lack of alewives. USGS trawl-based alewife biomass estimates declined sharply from 1996–97, apparently in response to a combination of rising consumption of alewives by predators (Dobiesz 2003), food web change (Bence and Mohr in press), and relatively harsh winters in those years (Bence et al., in press). Our small-mesh gillnetting revealed that most age-0 Chinook salmon were distributed in water depths of 6–20 m and were associated with alewives during late summer. Thus, the lack of alewives in 1997 and 1998 probably caused predation to increase on juvenile Chinook salmon. Alewife abundance recovered briefly from 1998–2001 (Bence et al., in press). Correspondingly, return rates for the 1999–2001 CWT Chinook salmon also recovered. Alewives declined again from 2001–03 and were almost absent from trawl assessment in 2004 and 2005 (Bence et al., in press). It appears that Chinook salmon post-stocking survival is positively correlated with alewife abundance and that prospects for survival are diminished for Chinook salmon year classes that correspond with years of alewife scarcity.

Spawning-phase Returns to Au Sable River

Return ratios (test to control) of pen-acclimated Chinook salmon of the 1993 and 1994 year classes to the Au Sable River spawning run averaged 6.4 to 1, considerably higher than the return ratios of the same cohorts in the recreational fishery, which averaged 2.5 to 1. The higher return of pen-acclimated fish to the Au Sable River spawning run relative to their recreational returns suggests that imprinting was considerably enhanced by pen-acclimation. Thus, the acclimated Chinook salmon appeared to have benefited from both enhanced post-stocking survival and reduced straying (enhanced imprinting). Consequently, pen acclimated fish dominated the fall electrofishing catches of the 1993 and 1994 year classes.

Straying rates of stocked fish can be considerable, as indicated by the 78 CWT Chinook salmon stocked at Swan River Weir and sampled in the Au Sable River. More CWT Chinook salmon stocked at Swan River in 1994 were caught by electrofishing in the Au Sable River (54) than CWT Chinook salmon stocked conventionally the same year in the Au Sable River (11) (Table 20). The converse was not observed; no CWT Chinook salmon from other stocking sites were sampled from Swan River Weir. The low rate of straying of CWT salmon into the Swan River supports our assumption that almost all fish sampled at Swan River Weir were stocked there. There is almost no spawning habitat in the Swan River and, based on straying rates of CWT fish, it appears very unlikely significant numbers of wild fish would stray into the Swan. Therefore, mature Chinook salmon returning to

Swan River Weir are almost exclusively from Swan River stockings and constitute a source of quality control for oxytetracycline mark-retention rates in adult fish.

Surprisingly, there was no evidence that wild-born Chinook salmon contributed significantly to the Au Sable River spawning run. Wild Chinook salmon parr were abundantly evident in seine catches near the mouth of the Au Sable River in 1993–95. Yet, the percentage of OTC-marked Chinook salmon was higher in the Au Sable River than at the Swan River Weir for every one of the OTC-marked cohorts (Table 21). The higher OTC marking rates in the Au Sable than in the Swan was probably caused by the higher number of CWT fish stocked in the Au Sable; the combination of CWT, adipose fin clip, and OTC mark is far less likely to escape detection than the OTC mark alone. Assuming there is little reproduction in the Swan River, there must also be almost none surviving to spawning-phase in the Au Sable River. Evidently, very few of the wild Chinook salmon produced in the Au Sable River survive and recruit to the Chinook salmon population. In both the Au Sable and Swan River spawning runs, a high percentage of the 1992 cohort was unmarked when sampled in 1996. The relatively low marking rate of the 1992 cohort is probably due to a combination of an initially low marking rate (as measured in age-0 Chinook salmon with small-mesh gillnets, Table 11) and mark deterioration as the fish grew older.

Both test groups of the 1995–97 year classes were pen acclimated, but the test groups trucked to 3-Mile Beach produced higher fall electrofishing catches (Table 20) than those released at the Au Sable River Whirlpool access site, significantly so for the 1995 and 1996 year classes. Thus, there was no measurable enhancement of imprinting conferred upon the Whirlpool test group by the opportunity to migrate out from the Au Sable River.

The inconsistent differences between years (1995–97) in returns from the fishery and from the spawning assessment (Tables 19 and 20) suggest that beach stocking does not always confer a survival advantage to pen-acclimated fish. The greater contribution of beach-stocked fish of the 1995 year class to both the recreational and fall electrofishing catches may be related to the higher abundance of alewives in 1995 (Bence et al., in press), which may have sheltered the beach-stocked Chinook salmon from predation.

Size and condition of spawning-phase Chinook salmon in the Au Sable River declined in stages from 1976 through 2004 (Table 23). Condition factors were stable, averaging 1.2, from 1976 until sampling was interrupted in 1982. After sampling resumed in 1996 and until 2001 condition factors were lower and more variable, averaging 0.95. Condition factors declined again after 2001 to what can only be described as critical levels, reaching 0.83 in 2004. Twenty-five percent of Chinook salmon sampled in 2004 had condition factors below 0.75. Chinook salmon with condition factors less than 0.75 composed 10% or more of the monthly recreational harvest from Lake Huron in 2004 (Michigan Department of Natural Resources, Charlevoix Fisheries Research Station, unpublished data). Considering the poor health of some of these under nourished fish (Figure 8), we conclude that Chinook salmon with condition factors less than 0.75 are likely to succumb to malnutrition or opportunistic pathogens associated with malnutrition. Thus, the generally declining CWT return rates since 1997 (Table 18) are probably the result of reduced recruitment caused by elevated predation on age-0 Chinook salmon and increased natural mortality of older Chinook salmon induced by malnutrition.

Sea lamprey wounding rates in the Swan and Au Sable spawning runs declined sharply after 2001. The decline is partially attributable to increased effectiveness of sea lamprey control (Morse et al. 2003; Mullett et al. 2003; Schleen et al. 2003). However, the decline in wounding rates is also approximately proportional to declines in average size of spawning-phase Chinook salmon. Their smaller body sizes in 1998 and 2004 may have made the Chinook salmon less attractive targets for sea lampreys in those years. In either case, it appears very unlikely sea lamprey depredation contributed to recent changes in CWT return rates.

Management Implications

Pen acclimation clearly enhanced the post-stocking performance of the test groups stocked at the Au Sable River in 1993 and 1994, and probably contributed to the exceptional performance of Chinook salmon stocked at Mill Creek, near Harrisville. Acclimated fish migrated out of the Au Sable River more quickly, spent less time in the beach zone, and probably were exposed less to predators compared to conventionally stocked fish. Exposure of Chinook salmon smolts and parr to predation appears to be a function of their time of residence in the river and beach zone and abundance of alewives as a buffer against predation. Appropriately-designed pen acclimation facilities can be valuable for enhancing post-stocking survival, at least when alewife abundance is high. Furthermore, pen acclimation appears to enhance imprinting and, thus, return to the stocking site of spawning-phase Chinook salmon, enhancing fall return fisheries for stocked Chinook salmon.

Conversely, wild Chinook salmon at the mouth of the Au Sable River had the longest beach-zone residence and were the smallest of the Chinook salmon in our beach seine samples. Although abundant in the beach zone as young of year, wild fish were scarce in the spawning population of the Au Sable River, suggesting survival of the wild parr to maturity was minimal. This finding is consistent with our observations that smaller Chinook salmon, in general, spend more time in the beach zone, where they are exposed to relatively high densities of predators. It is also consistent with the behavior of juvenile Chinook salmon in their native range (Green/Cedar/Duwamish River strain, Lake Washington) where a significant portion of out-migrating parr resided for extended periods on beaches of Lake Washington (Tabor et al. 2006). Au Sable River water temperatures reach near lethal levels by late May in most years. Thus, early warming of the Au Sable River may have forced Chinook salmon parr to emigrate from the river prematurely, explaining their small size in beach-seine samples. More likely, out-migration of Chinook salmon at these small sizes is typical of Puget Sound/Duwamish Watershed Chinook salmon. This pattern of early out-migration, with attendant high predation risks, may explain the failure of wild-born Chinook salmon from the Au Sable River to subsequently appear in spawning escapement sampling. Survival of wild Chinook salmon appears unlikely in such predator-rich environments as the Au Sable River, which enters Lake Huron only about 16 miles north of Saginaw Bay, a major walleye fishery. Chinook salmon reproduction is likely to be more successful in tributaries with fewer predators.

The predators we sampled in the Lake Huron nearshore zone were feeding principally on adult alewives and were probably habituated to eating alewives. To these predators, age-0 Chinook salmon probably closely matched their search image of alewives in size, distribution, and appearance during summer and early fall. When alewives become scarce, predators might take more juvenile Chinook salmon incidental to their feeding on alewives or even switch their attention to the juvenile Chinook salmon. Thus, alewife and predator abundance are probably important determinants of age-0 Chinook salmon survival, both during their occupation of the beach zone and during their later residence in nearshore waters. The high quality of the Chinook salmon fishery during the early and mid-1990s, therefore, was in large part the product of an abundance of adult alewives. We did not study years when alewives were absent, but our data suggest that the future of Lake Huron's Chinook salmon fishery is highly uncertain given the current near absence of adult alewives.

We noted relatively high rates of straying into the Au Sable River of Chinook salmon stocked at Swan River. Return rates to the Swan River Weir would likely benefit from the enhanced imprinting provided by an acclimation facility. Pen acclimation at Swan River could also be used to better manage stocking times, such that releases occurred only after beach temperatures warmed above those suitable for lake trout, the leading predator in Swan Bay. Maintaining good return rates to Swan River Weir is important not only to the local fall fishery but to the Michigan Department of Natural Resources' Chinook salmon hatchery production program, which is partially dependant upon eggs taken at Swan River Weir. Since 2003, however, alewives have become especially scarce. It is unclear whether acclimation pens would be cost effective under conditions of such low alewife abundance.

Our ability to assess levels of reproduction was hampered by lack of quality control data for the OTC mark from the hatcheries in 1991–93. It appears Swan Weir, and perhaps other such stocking sites where there is little habitat for reproduction, can be used to measure mark quality and mark retention.

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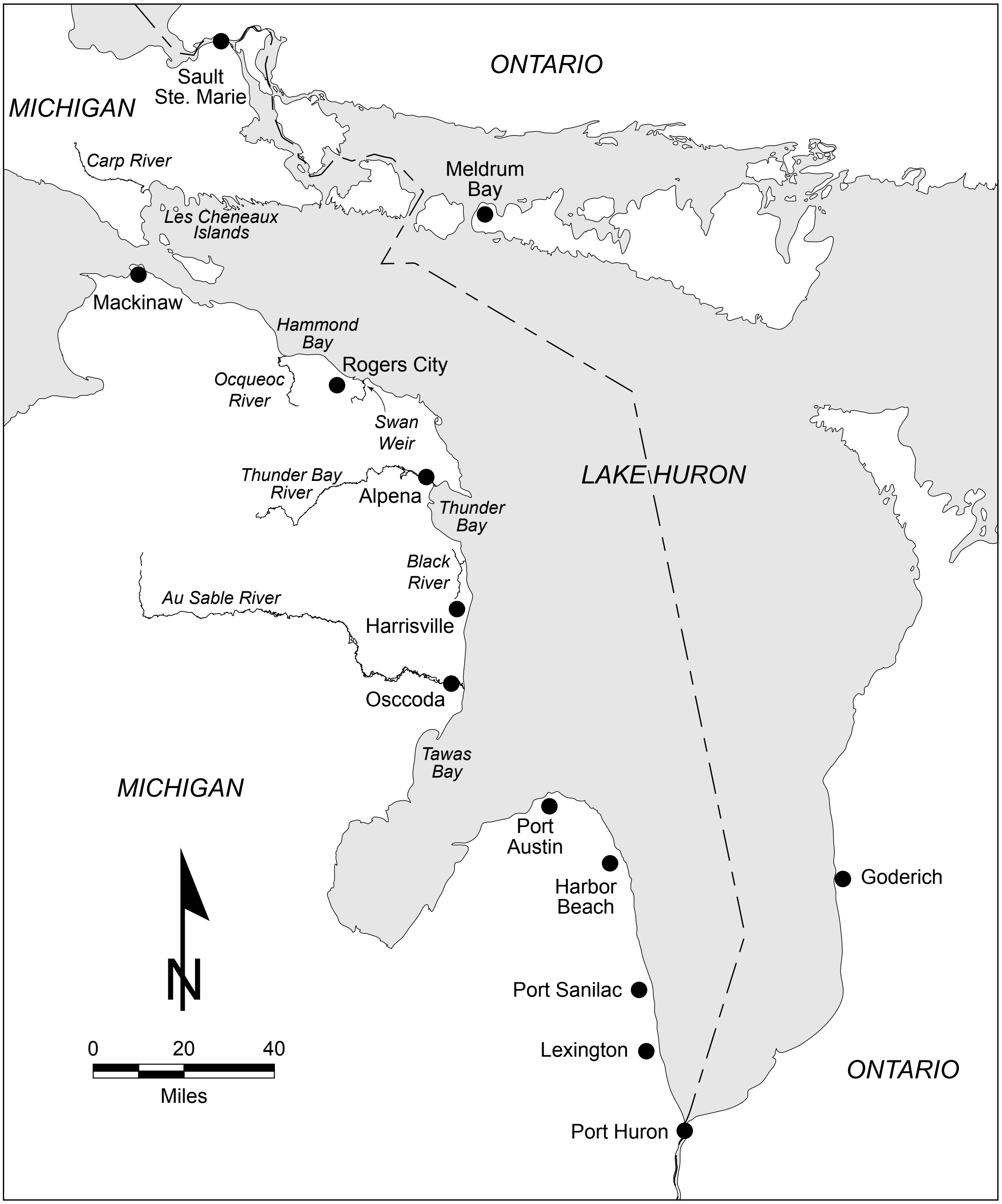

Figure 1.–Lake Huron study area.

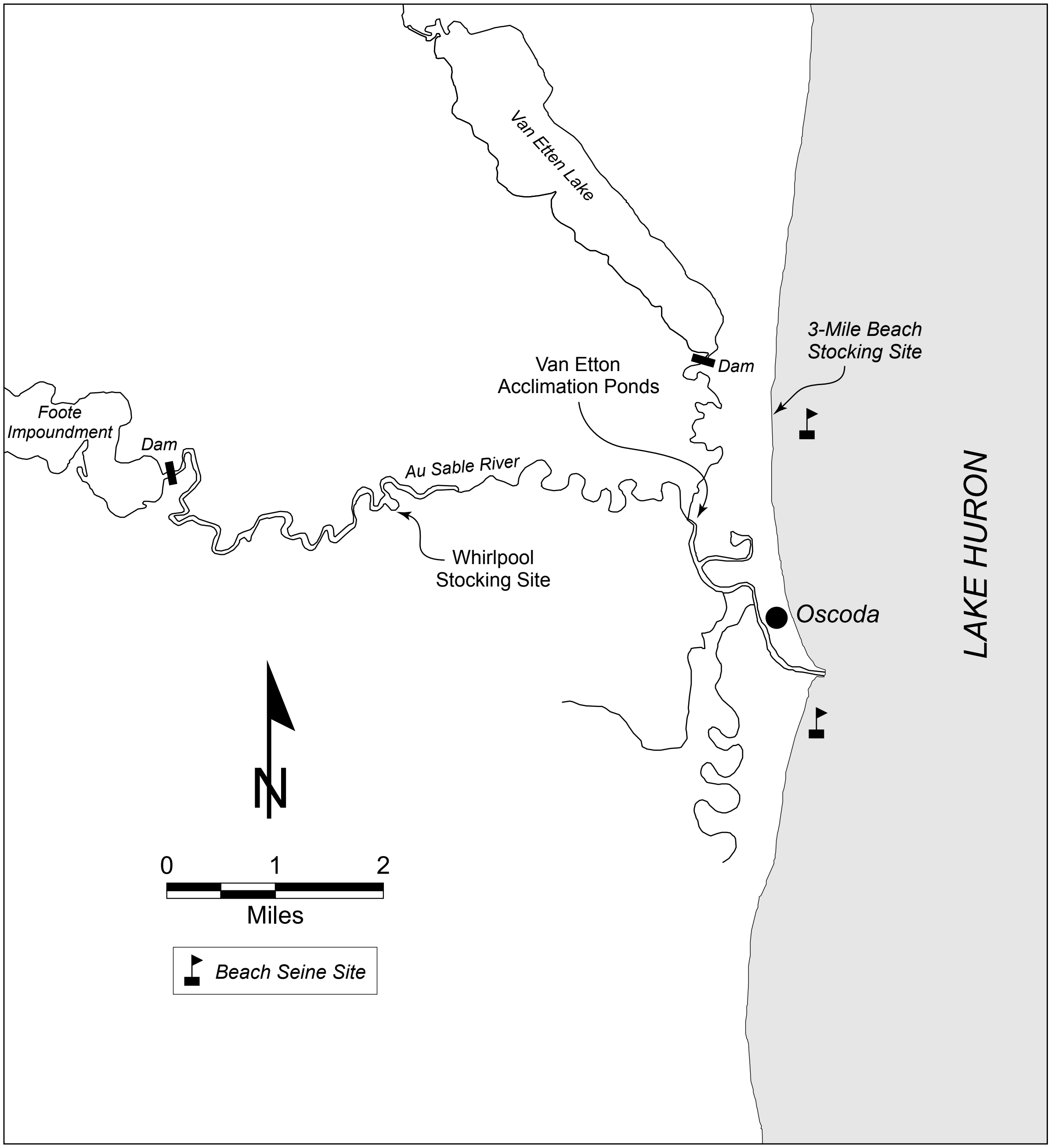

Figure 2.–Au Sable River study area including beach seine sites and locations of acclimation facility and Whirlpool and 3-Mile Beach stocking sites.

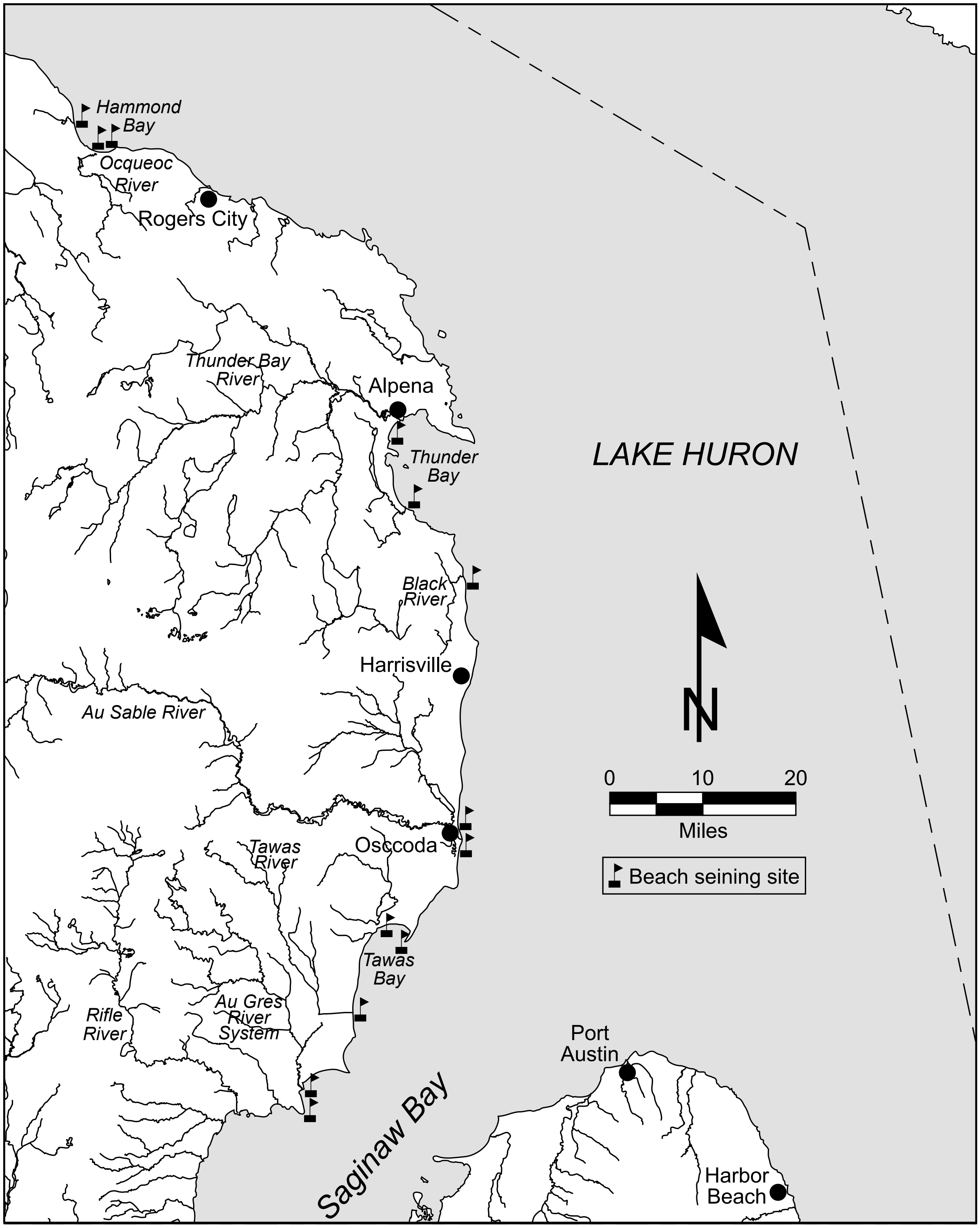

Figure 3.–Beach seining locations, 1993–95, and nearby tributary systems.

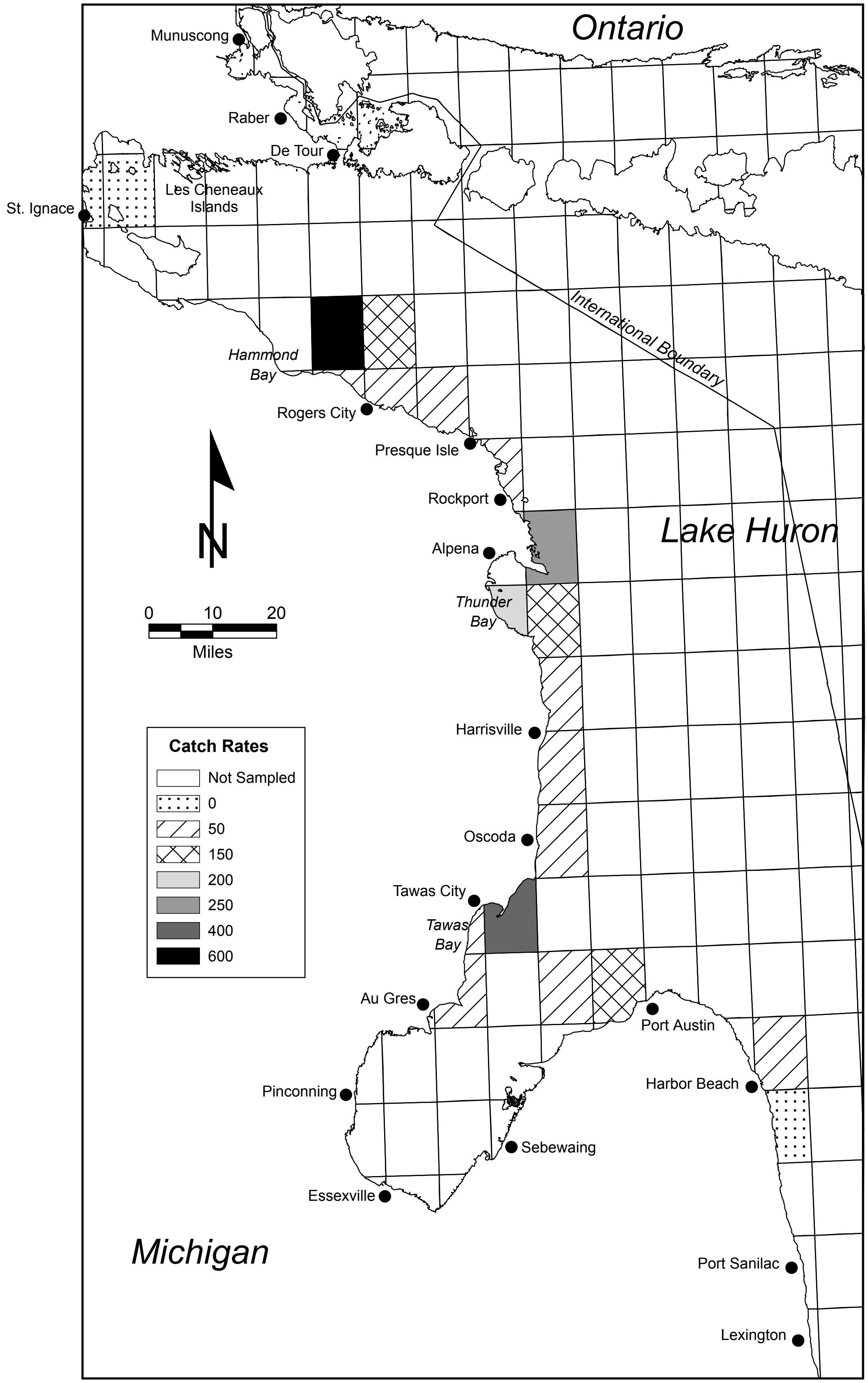

Figure 4.–Catch rates of age-0 Chinook salmon in small-mesh gill nets, by grid, Lake Huron.

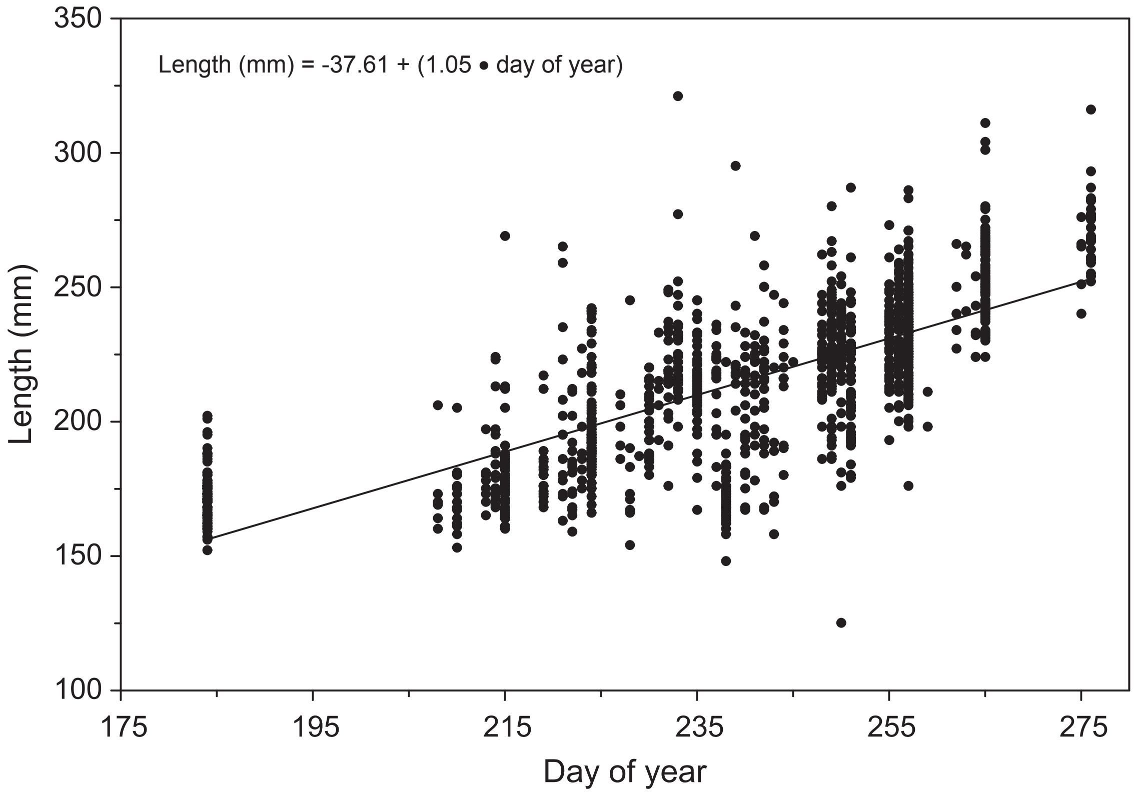

Figure 5.–Total length of Chinook salmon as a function of day of year sampled for years 1993–96.

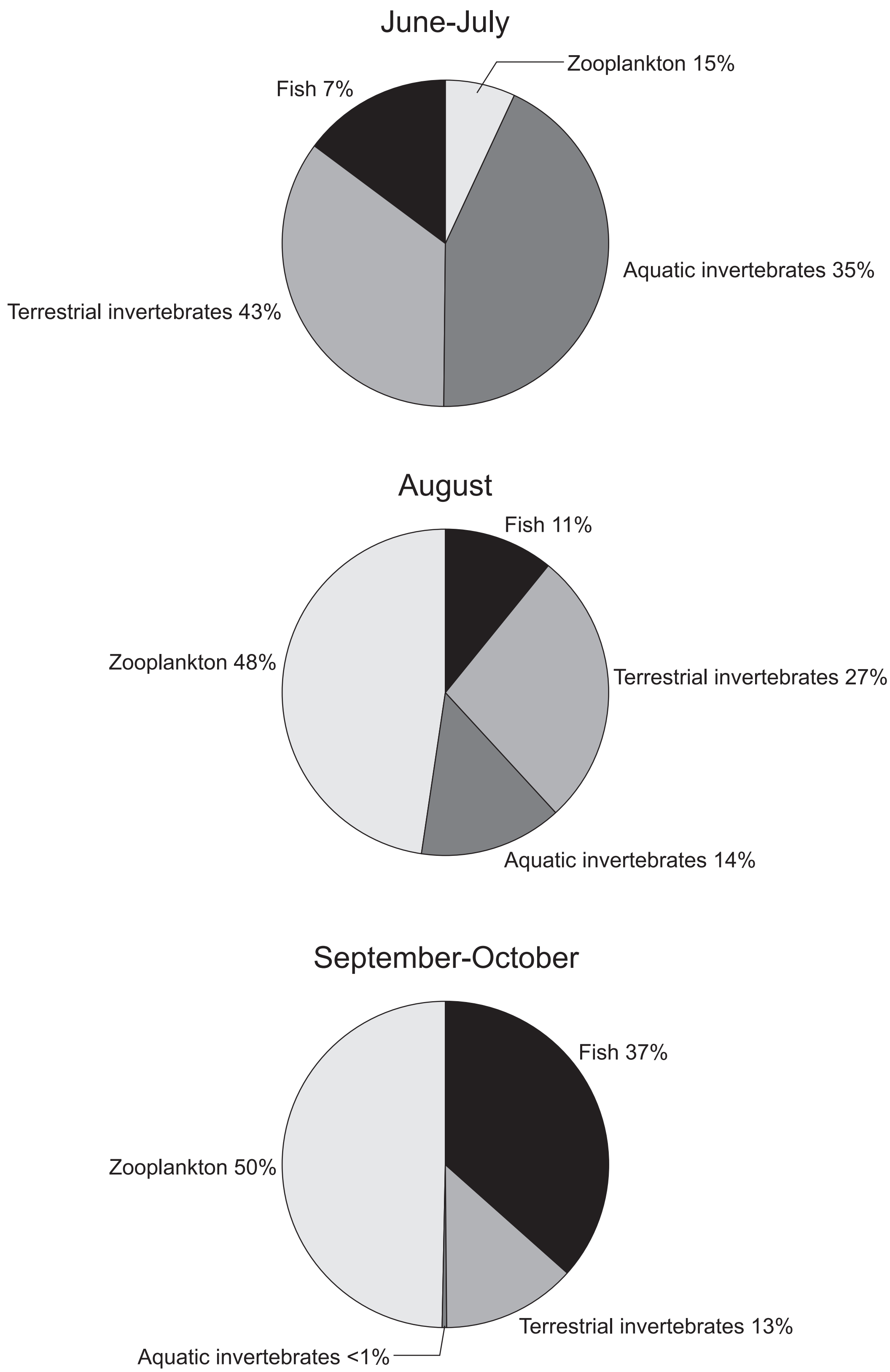

Figure 6.–Monthly diet composition (% of identifiable food items) of age-0 Chinook salmon, Lake Huron, 1991–96.

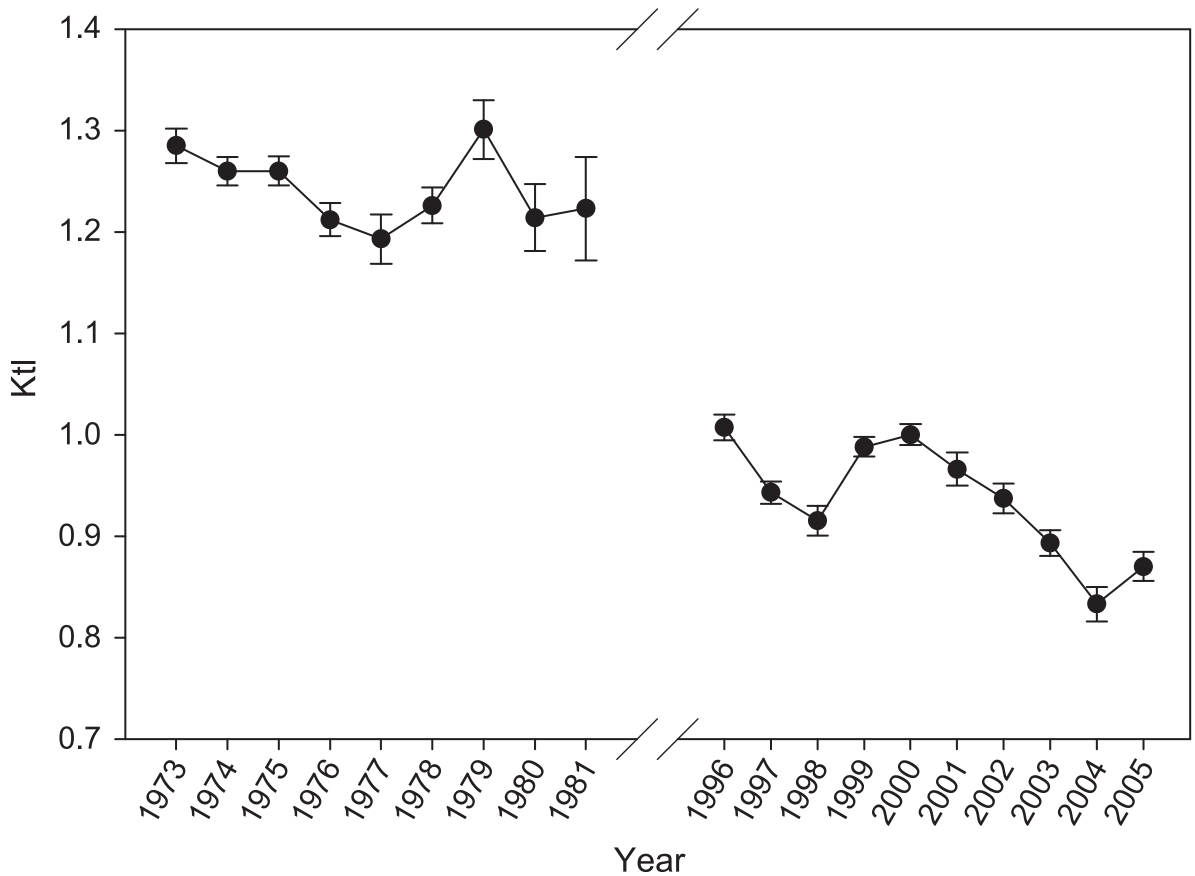

Figure 7.–Fulton's Condition Factors (Ktl) of Chinook salmon sampled from the Au Sable River, 1973–2005, with 95% confidence limits. No data were available from 1982–95.

Figure 8.–Photos of Chinook salmon with condition factors averaging 0.63, Au Sable River and Harrisville, fall 2004.

Table 1.–Number of Chinook salmon spring fingerlings stocked with recoverable coded-wire tags, by stocking site and study group, Lake Huron.

Stocking site	Year											
Study group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Swan River												
Index (Platte Hatchery)	202,742	186,813	188,803	185,557	92,021	86,034	90,587	86,048	93,969	87,510	84,703	95,666
Wolf Lake Hatchery	–	–	–	–	–	–	–	–	–	–	102,749	84,027
Oscoda/Au Sable River												
Pen [a]	107,542	47,627	93,139	92,594	–	–	–	–	–	–	–	–
Direct, river	105,220	96,287	97,641	85,648	–	–	–	–	–	–	–	–
Pen, beach	–	–	–	–	84,574	83,257	80,105	–	–	–	–	–
Pen, river	–	–	–	–	84,574	90,404	86,947	–	–	–	–	–
Harbor Beach												
Pen	–	–	–	–	90,139	93,863	92,680	78,673	–	–	–	–
Direct	–	–	87,742	90,983	95,734	87,663	98,084	81,749	–	–	–	–
Port Sanilac	–	–	–	–	–	–	–	–	–	66,664	68,446	77,696
Lexington	–	–	–	–	–	–	–	–	–	67,580	67,408	78,022
Port Austin	–	–	–	–	–	–	–	84,354	91,093	84,021	–	–
Tawas River	–	–	–	–	–	–	–	59,153	60,631	54,732	–	–
Au Gres River	–	–	–	–	–	–	–	–	–	49,150	49,658	55,413
Mill Creek, Harrisville	–	–	–	–	–	–	–	–	–	80,715	78,398	91,304

[a] A net pen in Au Sable River near river mouth was used in 1991 and 1992; Van Etten acclimation off-channel raceways 2 miles upstream of the river mouth used in 1993–97.

Table 2.–Mean total length, weight, and condition factor (Ktl) for study lots of pen acclimated Chinook salmon stocked at Oscoda, Lake Huron, 1995–97 (standard error in parentheses).

Year	Stocking location	Sample size	Length (mm)		Weight (g)		Ktl [a]	
1995	Beach	160	85	(0.55)	5.7	(0.11)	0.91	(0.005)
	River	160	84	(0.63)	5.6	(0.13)	0.91	(0.009)
1996	Beach	60	95	(0.76)	7.3	(0.16)	0.85	(0.009)
	River	60	94	(0.98)	7.3	(0.21)	0.85	(0.009)
1997	Beach	60	80	(0.67) [b]	5.7	(0.17) [b]	1.06	(0.020)
	River	60	77	(0.64) [b]	4.8	(0.14) [b]	1.02	(0.009)

[a] Fulton's K (weight/length^3*10^5)
[b] Significant difference between treatment pairs (t-test probability <0.05)

Table 3.–Summary of nighttime beach seine catch, north-central Lake Huron, May–June 1993.

Species	Number seine hauls encountered	Total number caught
Alewife *Alosa pseudoharengus* (adult)	110	5,787
Alewife (juvenile)	46	307
Banded killifish *Fundulus diaphanous menona*	1	1
Black crappie *Pomoxis nigromaculatus*	1	1
Blacknose dace *Rhinichthys obtusus*	2	4
Bluegill *Lepomis macrochirus*	2	2
Brassy minnow *Hybognathus hankinsoni*	24	91
Brook stickleback *Culaea inconstans*	26	91
Brown bullhead *Ameiurus nebulosus*	2	2
Brown trout *Salmo trutta* (adult)	5	5
Brown trout (age-1)	23	119
Central stoneroller *Campostoma anomalum pullum*	1	1
Chinook salmon *Oncorhynchus tshawytscha* (age-0)	34	277
Coho salmon *Oncorhynchus kisutch* (age-1)	1	4
Common carp *Cyprinus carpio*	34	82
Common shiner *Luxilus cornutus*	15	410
Emerald shiner *Notropis atherinoides*	67	494
Freshwater drum *Aplodinotus grunniens*	4	4
Golden shiner *Notemigonus crysoleucas*	1	1
Hornyhead chub *Nocomis biguttatus*	6	10
Johnny darter *Etheostoma nigrum*	12	26
Lake chub *Couesius plumbeus*	7	17
Lake trout S*alvelinus namaycush* (adults)	2	5
Lake whitefish *Coregonus clupeaformis* (juveniles)	159	2,075
Longnose dace *Rhinichthys cataractae*	74	957
Longnose gar *Lepisosteus osseus*	2	2
Longnose sucker *Catostomus catostomus*	7	13
Mimic shiner *Notropis volucellus*	2	3
Ninespine stickleback *Pungitius pungitius*	39	86
Northern logperch *Percina caprodes*	2	2
Northern pike *Esox lucius*	2	2
Rainbow smelt *Osmerus mordax*	42	264
Rainbow trout *Oncorhynchus mykiss* (adults)	2	2
Rainbow trout (smolts)	9	14
River chub *Nocomis micropogon*	1	7
Rock bass *Ambloplites rupestris*	5	8
Round whitefish *Prosopium cylindraceum* (adult)	1	1
Sand shiner *Notropis stramineus*	93	1,908
Sculpin *Cottus sp.*	24	91
Sea lamprey *Petromyzon marinus*	5	6
Smallmouth bass *Micropterus dolomieu*	4	4
Spotfin shiner *Cyprinella spiloptera*	10	358
Spottail shiner *Notropis hudsonius*	125	3,929
Threespine stickleback *Gasterosteus aculeatus*	1	1
Trout perch *Percopsis omiscomaycus*	90	964
Walleye *Sander vitreus* (age-0)	1	2
Walleye (age-1)	4	5
White bass *Morone chrysops*	1	1
Yellow perch *Perca flavescens*	14	76

Table 4.–Catch of Chinook salmon in beach seines, by location, in Lake Huron, 1993.

Location	Effort	Catch	CPE	Unmarked	% unmarked
Hammond Bay (Ocqueoc River)	34	1	0.03	1	100
Thunder Bay (Thunder Bay River)	29	0	0	0	–
Thunder Bay (Devils River)	18	0	0	0	–
Alcona Beach (Black River, Alcona County)	16	4	0.25	4	100
Oscoda (Au Sable River)	25	253	10.12	108	42
Tawas Bay (Tawas River)	27	20	0.74	13	68
Au Gres (Au Gres River and Whitney Drain)	10	0	0	0	–

Table 5.–Nighttime beach seining catch of Chinook salmon, by study group, with mean lengths (mm), May–July 1993, Oscoda, Lake Huron.

				Potentially wild (no CWT, OTC negative)			Hatchery [a] (OTC positive)		Penned [b]		Control (truck stocked) [c]		Adipose clip (CWT not detected)	
Date	Number of tows	Water temp °C	Total catch	Number	%	Mean length	Number	Mean length	Number	Mean length	Number	Mean length	Number	Mean length
21 May	2	12.2	85	5	6	50	0	–	40	89	29	91	11	84
25 May	3	11.1	27	4	15	38	0	–	12	90	5	87	6	92
1 Jun	2	11.7	50	31	62	67	6	70	7	96	2	89	4	95
7 Jun	2	14.4	28	15	54	58	4	77	3	105	2	105	4	102
10 Jun	3	14.4	11	5	45	62	3	84	1	107	1	105	1	103
14 Jun	2	14.4	31	24	77	69	6	76	1	104	0		0	–
22 Jun	4	17.0	16	16	100	68	0	–	0	–	0	–	0	–
28 Jun	2	15.6	19	13	68	76	6	90	0	–	0	–	0	–
1 Jul	3	18.3	6	5	83	88	1	103	0	–	0	–	0	–
6 Jul	2	17.8	5	4	80	73	1	90	0	–	0	–	0	–

[a] 356,143 fingerlings stocked May 27 at mean length of 64 mm (These fish were not stocked as part of the study.)
[b] 102,754 fingerlings stocked May 19 at 91 mm
[c] 102,097 fingerlings stocked May 19 at 95 mm

Table 6.–Nighttime beach seining catch of Chinook salmon, by study group, with mean lengths (mm), May and June 1994, Oscoda, Lake Huron.

					Potentially wild (no CWT, OTC negative)			Hatchery [a] (OTC positive)		Control (truck stocked) [b]		Penned (beach stocked) [c]		Adipose clip (CWT not detected)	
Date	Number of tows	Water temp °C	Total catch	Examined for marks	Number	%	Mean length	Number	Mean length	Number	Mean length	Number	Mean length	Number	Mean length
16 May	2	11.1	8	8	8	100	41	0	–	0	–	0	–	0	–
17 May	1	12.2	1	1	1	100	35	0	–	0	–	0	–	0	–
18 May	3	12.8	44	44	44	100	43	0	–	0	–	0	–	0	–
19 May	3	12.8	9	9	9	100	45	0	–	0	–	0	–	0	–
20 May	2	15.0	60	60	58	97	43	0	–	1	96	0	–	1	93
23 May	3	13.3	50	49	43	86	47	0	–	1	88	5	86	1	118
26 May	3	11.7	30	30	30	100	51	0	–	0	–	0	–	0	–
31 May	3	14.4	31	31	25	81	56	1	–	1	90	4	101	0	–
02 Jun	5	15.0	121	66	17	26	63	41	72	4	102	4	105	2	96
07 Jun	3	12.2	157	157	121	77	62	30	71	2	106	3	116	0	–
09 Jun	2	NA	931	215	66	31	67	141	74	2	103	5	110	1	100
15 Jun	1	18.3	33	33	13	39	71	20	78	0	–	0	–	0	–
23 Jun	3	NA	35	35	27	77	66	8	79	0	–	0	–	0	–
29 Jun	3	19.4	17	16	12	71	77	4	93	0	–	0	–	0	–

[a] 393,454 fingerlings stocked June 2 at mean length of 78 mm (These fish were not stocked as part of the study.)
[b] 100,130 fingerlings stocked May 19 at mean length of 98 mm
[c] 101,306 fingerlings stocked May 20 at mean length of 104 mm

Table 7.–Nighttime beach seining catch of Chinook salmon, by study group, with mean lengths (mm), May and June 1995, Oscoda, Lake Huron.

				Potentially wild (no CWT, OTC negative)			Hatchery[a] (OTC positive)		Penned, stocked in river by truck[b]		Penned, stocked on beach by truck[c]		Adipose clip, (CWT not detected)	
Date	Number of tows	Water temp °C	Total catch	Number	%	Mean length	Number	Mean length	Number	Mean length	Number	Mean length	Number	Mean length
25 May	5	13.9	113	19	17	51	5	79	5	87	73	80	11	82
31 May	5	15.6	120	24	20	56	24	69	5	83	58	83	9	85
07 Jun	3	12.2	296	49	17	66	141	74	14	94	72	97	20	92
15 Jun	5	17.2	197	50	25	70	142	74	0	–	5	106	0	–
21 Jun	5	17.8	117	28	24	76	84	83	0	–	5	108	0	–

[a] 423,285 fingerlings stocked May 31 and June 7 at mean length of 78 mm (These fish were not stocked as part of the study.)
[b] 99,033 fingerlings stocked May 24 at mean length of 87 mm
[c] 106,772 fingerlings stocked May 24 at mean length of 84 mm

Table 8.–Predator catch in graded-mesh gill nets and number of prey in stomachs, three Chinook salmon stocking sites, Lake Huron, 1995–97.

Location, effort, and species	Length range (mm)	Predator count	CPE [a]	Number void	Invertebrates	Age-0 Chinook salmon	Age-1 steelhead	Alewife	Smelt	Trout-perch	Unidentified fish
Oscoda											
Beach zone											
(30 76-m gill-net nights)											
Rainbow trout	167–725	10	4.37	3	13	0	0	0	0	0	0
Brown trout	412–633	13	5.68	2	0	3	0	20	0	9	0
Lake trout	470–679	34	14.86	1	20	8	0	37	23	10	4
Walleye	243–732	138	60.33	63	0	0	0	128	2	0	2
Chinook salmon	252–354	5	2.19	4	0	0	0	0	6	0	1
Au Sable River											
(455 min electrofishing)											
Rainbow trout	212–837	18	2.37	18	0	0	0	0	0	0	0
Walleye	339–721	82	10.81	22	0	60	32	63	0	0	52
Smallmouth bass	269–420	5	0.66	2	0	10	0	0	0	0	3
Rock bass	182–248	9	1.19	4	17	0	0	0	0	0	0
Atlantic salmon	560	1	0.13	1	0	0	0	0	0	0	0
Brown trout	436	1	0.13	0	0	0	0	0	0	0	0
Harbor Beach											
(11 76-m gill-net nights)											
Walleye	314–749	34	40.54	11	0	45	0	39	0	0	17
Northern pike	435–884	25	29.81	2	0	1	0	33	0	0	2
Chinook salmon	264–522	12	14.31	5	0	0	0	0	10	0	2
Brown trout	500	1	1.19	0	0	0	0	0	0	0	3
Smallmouth bass	334–422	17	20.27	5	5	0	0	0	0	0	5
Channel catfish	585–614	4	4.77	0	0	0	0	9	0	0	8
Burbot	523	1	1.19	0	0	0	0	1	0	0	1
Freshwater drum	362–380	3	3.58	3		0	0	0	0	0	0
Yellow perch	253	1	1.19	0	0	0	0	0	0	0	1
Rock bass	225	1	1.19	1	0	0	0	0	0	0	0

Table 8.–Continued..

Location, effort, and species	Length range (mm)	Predator count	CPE [a]	Number void	Invertebrates	Age-0 Chinook salmon	Age-1 steelhead	Alewife	Smelt	Trout-perch	Unidentified fish
Harbor Beach–continued.											
(electrofishing 88 min)											
Walleye	323–685	5	1.07	0	0	37	0	0	0	0	0
Northern pike	435–730	3	0.64	0	0	6	0	0	0	0	2
Smallmouth bass	262–422	21	4.50	7	9	7	0	4	0	1	17
Chinook salmon	320	1	0.21	0	0	0	0	0	1	0	0
Rock bass	260	1	0.21	1	0	0	0	0	0	0	0
Freshwater drum	350–433	4	0.86	1	50	0	0	0	0	0	2
Swan Bay											
Rogers City											
(12 76-m gill-net nights)											
Burbot	498–616	5	5.46	0	1	0	0	4	0	0	10
Lake trout	403–688	82	89.62	9	0	32	0	90	55	0	50
Totals											
Rainbow trout		28		21	13	0	0	0	0	0	0
Brown trout		15		2	0	3	0	20	0	9	3
Lake trout		116		10	20	40	0	127	78	10	54
Chinook salmon		18		9	0	0	0	0	17	0	3
Atlantic salmon		1		1	0	0	0	0	0	0	0
Walleye		259		96	0	142	32	230	2	0	71
Northern pike		28		2	0	7	0	33	0	0	4
Channel catfish		4		0	0	0	0	9	0	0	8
Burbot		6		0	1	0	0	5	0	0	11
Smallmouth bass		43		14	14	17	0	4	0	1	25
Rock bass		11		6	17	0	0	0	0	0	0
Freshwater drum		7		4	50	0	0	0	0	0	2
Yellow perch		1		0	0	0	0	0	0	0	1
All species		537		165	115	209	32	428	97	20	182

[a] CPE = catch per 1,000 m in gill nets and catch per hr electrofishing

Table 9.–Chinook salmon and alewife consumption by predators, and predator and alewife catch rates, in gill nets set on the beach at Oscoda, Lake Huron, May 1995–97.

Year	Catch of predator fish [a]	Number net nights	Predator CPE	Chinook salmon consumed per predator	Alewife total catch	Alewife catch rate	Alewife consumed per predator
1995	48	8	6.0	0.00	756	94.5	1.40
1996	87	10	8.7	0.05	2,761	276.0	1.21
1997	55	12	4.6	0.13	81	6.8	0.35

[a] Predator fish were walleyes, lake trout, and brown trout.

Table 10.–Summary of small-mesh gill-net effort and catch, by gill-net height and year, Lake Huron, 1991–96.

Year	Gill net height (m)	Effort (m)	Number grids sampled	Chinook salmon catch	Chinook salmon CPE
1991	1.9	2,682	1	85	31.69
1992	1.9	8,046	5	151	18.77
1993	1.9	6,934	12	25	3.61
	4.5	44,925	23	137	3.05
1994	1.9	610	2	0	0.00
	4.5	16,580	13	341	20.57
1995	1.9	610	1	0	0.00
	4.5	14,142	9	554	39.17
1996	1.9	1,448	3	8	5.52
	4.5	8,351	9	230	27.54
Totals	1.9	20,330		269	13.23
	4.5	83,998		1,262	15.02

Table 11.–Incidence of either fin clips or OTC marks among age-0 Chinook salmon examined for marks in small-mesh gill-net catch, Lake Huron, 1991–95.

Year	Number examined	Number with OTC or fin clip	% of catch unmarked	Mark quality (all Michigan hatcheries)	Comments
1991	85	59	30.6	NA	All effort in MH-2
1992	162	143	11.7	NA	All effort in MH-3
1993	153	110	28.1	Poor [a]	Begin using 4.6 m deep nets, MH-1 through MH-3
1994	347	347	0.0	2.5% not detectable	MH-1 through MH-4
1995	537	523	2.6	14% not detectable	MH-1 through MH-4
1996					End marking with OTC

[a] Platte River Hatchery's fish were too small to effectively mark but no marking quality data were collected from any of the hatcheries that year.

Table 12.–Trends in mean length of age-0 Chinook salmon taken in small-mesh gill nets, by sampling period, Lake Huron, 1991–96.

Period	Mean length	N	Standard deviation	Increment	Mean Julian day	Mean daily increment
3 Jul	172	77	10		184	
27 Jul–3 Aug	178	98	16	6	214	0.20
7–9 Aug	192	30	26	14	220	2.33
10–12 Aug	195	104	19	3	224	0.75
15–20 Aug	212	102	23	17	231	2.43
23–28 Aug	202	152	24	-10	237	-1.67
29–31 Aug	212	53	23	10	242	2.00
1–5 Sep	220	45	16	8	247	1.60
6–8 Sep	225	174	20	5	250	1.67
12–15 Sep	232	308	15	7	256	1.17
16–22 Sep	251	104	17	19	265	2.11
2–3 Oct	270	33	14	19	276	1.73
Mean daily increment across sampling season:						1.30

Table 13.–Number of prey items consumed and percent composition of diet, from age-0 Chinook salmon sampled in Lake Huron June–October 1993–96.

	Number				Percent composition			
Prey item	Jun–Jul	Aug	Sep–Oct	All months	Jun–Jul	Aug	Sep–Oct	All months
Zooplankton								
Unidentified plankton	10	120	280	410	3.15	10.42	25.11	15.87
Spiny water flea	37	429	274	740	11.67	37.24	24.57	28.64
Aquatic invertebrates								
Midges	107	160	5	272	33.75	13.89	0.45	10.53
Mayflies	4	2	0	6	1.26	0.17	0.00	0.23
Snails	0	1	0	1	0.00	0.09	0.00	0.04
Terrestrial invertebrates								
Unidentified terrestrial insects	15	78	2	95	4.73	6.77	0.18	3.68
Ants	115	233	145	493	36.28	20.23	13.00	19.08
Unidentified invertebrates	7	4	1	12	2.21	0.35	0.09	0.46
Fish								
Alewife	5	14	402	421	1.58	1.22	36.05	16.29
Smelt	17	107	6	130	5.36	9.29	0.54	5.03
Ninespine stickleback	0	3	0	3	0.00	0.26	0.00	0.12
Trout perch	0	1	0	1	0.00	0.09	0.00	0.04
Total zooplankton	47	549	554	1,150	14.83	47.66	49.69	44.50
Total aquatic invertebrates	111	163	5	279	35.02	14.15	0.45	10.80
Total terrestrial invertebrates	137	315	148	600	43.22	27.34	13.27	23.22
Total fish	22	125	408	555	6.94	10.85	36.59	21.48
Number stomachs observed	106	394	633	1,133				

Table 14.–Summary of catch in small-mesh gill nets fished for age-0 Chinook salmon in Lake Huron, July–October, 1993–96.

Species	Number
Chinook salmon *Oncorhynchus tshawytscha* (age-0)	1,295
Chinook salmon (age-1 and older)	16
Alewife *Alosa pseudoharengus*	5,516
Brown bullhead A*meiurus nebulosus*	1
Brown trout *Salmo trutta* (yearlings)	43
Brown trout (adult)	31
Burbot *Lota lota*	12
Channel catfish *Ictalurus punctatus*	5
Common carp *Cyprinus carpio*	2
Freshwater drum *Aplodinotus grunniens*	7
Gizzard shad *Dorosoma cepedianum*	38
Lake chub *Couesius plumbeus*	16
Lake herring *Coregonus artedi*	8
Lake trout *Salvelinus namaycush*	23
Lake whitefish *Coregonus clupeaformis*	493
Longnose sucker *Catostomus catostomus*	534
Northern pike *Esox lucius*	6
Rainbow smelt *Osmerus mordax*	578
Rainbow trout *Oncorhynchus mykiss*	3
Rock bass *Ambloplites rupestris*	3
Round whitefish *Prosopium cylindraceum*	1,723
Smallmouth bass *Micropterus dolomieu*	4
Spottail shiner *Notropis hudsonius*	1
Stonecat *Noturus flavus*	6
Trout perch *Percopsis omiscomaycus*	3
Walleye *Sander vitreus*	20
White bass *Morone chrysops*	26
White perch *Morone americana*	46
White sucker *Catostomus commersonii*	303
Yellow perch *Perca flavescens*	1,241

Table 15.–Returns per 100,000 Chinook salmon stocked with recognizable CWT in the Au Sable River, from conventional releases (direct river) and acclimation pens.

Year class	Ages	Direct river	Pen acclimated	Chi-square probability
1993	0	0.00	0.00	
	1	30.72	63.35	0.006
	2	63.50	125.62	0.000
	3	54.28	93.41	0.013
	4	6.14	16.10	0.070
	5	2.05	0.00	–
	Total	156.70	298.48	0.000
1994	0	0.00	1.08	–
	1	24.52	73.44	0.000
	2	30.36	98.28	0.000
	3	56.04	157.68	0.000
	4	1.17	6.48	0.072
	5	0.00	0.00	
	Total	112.09	336.95	0.000

Table 16.–Recreational fishery returns per 100,000 Chinook salmon stocked with recognizable CWT at Harbor Beach, Lake Huron, from conventional releases (direct plant) and acclimation pens.

Year class	Ages	Direct plant	Pen acclimated	Chi-square probability
1995	0	0.00	1.11	–
	1	33.43	32.17	0.701
	2	94.01	106.50	0.660
	3	111.77	75.44	0.011
	4	44.92	18.86	0.002
		1.04	0.00	–
	Total	285.17	234.08	0.031
1996	0	0.00	0.00	–
	1	19.39	38.35	0.018
	2	86.70	104.41	0.222
	3	83.27	145.96	0.000
	4	9.13	23.44	0.018
	5	0.00	0.00	–
	Total	198.49	312.16	0.000
1997	0	0.00	0.00	–
	1	8.16	7.55	0.959
	2	28.55	32.37	0.382
	3	26.51	22.66	0.856
	4	2.04	0.00	–
	5	0.00	0.00	–
	Total	65.25	62.58	0.824
1998	0	0.00	0.00	–
	1	7.34	19.07	0.036
	2	9.79	22.88	0.035
	3	12.23	17.80	0.340
	4	0.00	0.00	–
	5	0.00	0.00	–
	Total	29.36	59.74	0.004

Table 17.–Summary of CWT returns to date[a] from the Lake Huron recreational fishery per 100,000 Chinook salmon stocked with recognizable marks, by stocking site, 1993–2002 cohorts.

	Plant year									
Stocking site	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Swan River										
Platte Hatchery	217.2	299.1	111.9	245.3	130.3	89.5	124.5	89.1	207.8	33.4
Wolf Lake Hatchery	–	–	–	–	–	–	–	–	280.3	3.6
Au Sable										
(Van Etten) net pen										
River plant	298.5	337.0	253.0	212.4	56.4	–	–	–	–	–
3-Mile Beach	–	–	368.9	213.8	32.5	–	–	–	–	–
Direct plant	156.7	112.1	–	–	–	–	–	–	–	–
Harbor Beach										
Acclimation pen	–	–	234.1	312.2	62.6	59.7	–	–	–	–
Direct plant	–	–	285.2	198.5	65.3	29.4	–	–	–	–
Tawas River	–	–	–	–	–	–	56.1	49.3	–	–
Port Austin	–	–	–	–	–	–	130.6	66.7	–	–
Mill Creek										
Harrisville acclimation	–	–	–	–	–	–	–	291.1	450.3	43.8
Au Gres River	–	–	–	–	–	–	–	63.1	90.6	18.0
Port Sanilac	–	–	–	–	–	–	–	43.5	57.0	18.0
Lexington	–	–	–	–	–	–	–	62.1	38.2	12.8

[a] Including tags returned and processed through December 2005.

Table 18.–Mean return rates to date[a] from all Lake Huron sites stocked with CWT Chinook salmon[b].

Plant year	Acclimation pens	Conventional	All ports
1993	298.5	186.9	224.1
1994	337.0	206.6	249.4
1995	285.3	198.5	250.6
1996	246.1	221.9	236.4
1997	50.5	97.8	69.4
1998	59.7	59.4	59.5
1999	–	103.7	103.7
2000	291.1	62.3	95.0
2001	450.3	134.8	187.4
2002	43.8	17.2	21.6
Means	229.1	128.8	149.7

[a] Including tags returned and processed through December 2005.
[b] 1991 and 1992 not included because acclimation pens designs were inadequate and did not represent results of the current configuration.

Table 19.–Returns from the recreational fishery per 100,000 Chinook salmon stocked with recognizable CWT, acclimated at the Van Etten Raceways, and released in the Au Sable River at either Whirlpool Access Site on the Au Sable River or at 3-Mile Beach on Lake Huron.

Year class	Ages	Whirlpool Au Sable River	3-Mile Beach Lake Huron	Chi-square probability
1995	0	0.00	0.00	–
	1	52.03	80.40	0.023
	2	87.50	115.87	0.067
	3	98.14	140.71	0.011
	4	15.37	30.74	0.037
	5	0.00	1.18	–
	Total	253.03	368.91	0.000
1996	0	0.00	0.00	–
	1	42.03	42.04	0.993
	2	81.85	96.09	0.327
	3	79.64	66.06	0.290
	4	8.85	9.61	0.873
	5	0.00	0.00	–
	Total	212.38	213.80	0.967
1997	0	0.00	0.00	–
	1	9.20	2.50	0.076
	2	25.30	9.99	0.019
	3	21.85	19.97	0.787
	4	0.00	0.00	–
	5	0.00	0.00	–
	Total	56.36	32.46	0.021

Table 20.–Electrofishing catch of CWT mature Chinook salmon in Au Sable River, fall 1996–2004. Total sample = 1,420 fish; number with coded-wire tags = 460; 76% of sample was not tagged (lacked fin clip or coded-wire tag).

Study group	Number stocked with recoverable CWTs	Number sampled	Number sampled per 100,000 identifiable marks	Percent of sample, test pairs	Ratio test:control	Chi-square probability
Au Sable study groups						
1993 Van Etten Pen	93,139	54	58.0	83.7	5.1	<0.0001
1993 conventional (control)	97,641	11	11.3	16.3		
1994 Pen, 3-Mile Park	92,594	82	88.6	88.4	7.6	<0.0001
1994 conventional (control)	85,648	10	11.7	11.6		
1995 Pen, beach	84,574	85	100.5	72.0	2.6	<0.0001
1995 Pen, upstream (control)	84,574	33	39.0	28.0		
1996 Pen, beach	83,375	54	64.8	68.6	2.2	<0.0001
1996 pen, upstream (control)	91,250	27	29.6	31.4		
1997 Pen, beach	80,105	5	6.2	57.6	1.4	0.75
1997 Pen, upstream (control)	86,947	4	4.6	42.4		
Other coded-wire tags						
1993 Swan River	188,803	11	5.8			
1994 Swan River	185,557	52	28.0			
1995 Swan River	92,021	3	3.3			
1996 Swan River	86,034	4	4.6			
1997 Swan River	90,587	2	2.2			
1999 Swan River	93,969	2	2.1			
2001 Swan River	102,749	3	2.9			
2002 Swan River	95,473	1	1.0			
1995 Harbor Beach conventional	95,734	1	1.0			
1997 Harbor Beach conventional	89,084	1	1.1			
1998 Harbor Beach net pen	79,796	1	1.3			
1994 Strawberry Creek, Wisconsin		1				
1997 Strawberry Creek, Wisconsin		1				
2000 Strawberry Creek, Wisconsin		1				
1993 Grand River, Lake Michigan	92,384	1	1.1			
1999 Port Austin	91,093	1	1.1			
1999 Tawas River	19,648	3	15.3			
2000 Au Gres River	49,150	1	2.0			
2001 Medusa Imprint Pond, Lake Michigan	94,462	1	1.1			

Table 21.–Incidence of marks (CWT, fin clip, and/or OTC) on spawning-phase Chinook salmon sampled from two stocking sites, monitored from 1996–99, Lake Huron.

	Au Sable electrofishing		Swan River Weir	
Year class	% Marked	Sample size	% Marked	Sample size
1992	51.9	27	30.8	13
1993	90.5	241	82.9	41
1994	94.5	397	93.9	146
1995	95.7	766	92.7	109

Table 22.–Mean lengths (mm), mean weights (gm), and condition factors by age group and year for spawning-phase Chinook salmon, Au Sable River and Swan River Weir, September–October 1996–2004.

Age	Sample	Swan River Weir				Au Sable River			
group	year	Length	Weight	Condition (Ktl [a])	Sample size	Length	Weight	Condition (Ktl [a])	Sample size
1	1996	569	1,773	0.95	10	543	1,727	1.05	126
	1997	507	1,372	1.05	6	528	1,580	1.08	34
	1998	509	1,470	1.13	7	561	1,970	1.06	11
	1999	629	2,468	0.98	46	608	2,464	1.07	40
	2000	593	2,250	1.06	58	572	2,003	1.09	186
	2001	591	2,120	1.01	68	594	2,160	1.02	40
	2002	563	1,812	0.98	44	535	1,564	1.00	76
	2003	561	1,510	0.85	2	589	2,065	0.98	31
	2004	563	1,634	0.91	12	586	1,727	0.86	6
2	1996	776	4,414	0.93	52	766	4,590	1.00	124
	1997	840	4,040	0.74	3	724	3,730	0.97	190
	1998	691	3,150	0.95	61	710	3,300	0.92	95
	1999	789	5,025	0.99	52	771	4,627	0.99	56
	2000	824	5,705	1.00	37	786	4,799	0.97	96
	2001	820	5,592	1.00	86	775	4,538	0.96	55
	2002	806	4,893	0.92	143	763	4,161	0.91	110
	2003	784	4,585	0.93	98	743	3,732	0.88	178
	2004	734	3,567	0.86	10	708	3,032	0.83	51
3	1996	852	5,769	0.92	25	857	6,246	0.98	149
	1997	822	4,973	0.89	40	827	5,260	0.92	239
	1998	846	5,610	0.90	86	783	4,490	0.92	310
	1999	864	6,365	0.97	91	847	6,092	0.99	278
	2000	915	7,577	0.98	89	875	6,545	0.97	114
	2001	917	7,399	0.95	37	839	5,567	0.93	41
	2002	891	6,823	0.95	61	855	5,798	0.91	66
	2003	914	7,137	0.92	43	869	6,037	0.89	69
	2004	838	5,456	0.91	121	770	3,978	0.83	157
4	1996	967	8,886	0.97	13	911	7,513	0.98	27
	1997	860	5,706	0.88	16	858	5,830	0.91	92
	1998	866	5,860	0.88	56	825	4,840	0.85	33
	1999	864	6,257	0.96	10	863	6,233	0.96	136
	2000	921	7,182	0.91	16	899	6,862	0.94	38
	2001	865	6,051	0.91	9	917	6,775	0.87	2
	2002	–	–	–	0	815	4,960	0.92	1
	2003	915	6,465	0.84	4	750	3,080	0.73	1
	2004	905	7,380	1.00	1	–	–	–	0

[a] Ktl = $(\text{Weight}/\text{Length}^3)\ X10^5$

Table 23.–Summary of mean lengths, weights, and condition factors of age-3 spawning-phase Chinook salmon, Au Sable River, 1973–2004. No data collected from 1982–95.

	Length (mm)		Weight (g)		Condition	
Year	mean	SD	mean	SD	(Ktl [a]) mean	SD
1973	886	54	8,685	1,540	1.24	0.09
1974	909	53	9,276	1,554	1.23	0.11
1975	952	50	10,719	1,265	1.25	0.14
1976	904	48	8,850	1,382	1.19	0.09
1977	888	51	8,298	1,421	1.18	0.08
1978	887	50	8,424	1,442	1.20	0.10
1979	899	34	8,785	1,401	1.20	0.10
1980	882	52	7,946	1,386	1.15	0.10
1981	897	47	8,425	835	1.17	0.11
1996	857	63	6,246	1,529	0.99	0.11
1997	827	60	5,265	1,320	0.92	0.13
1998	783	72	4,492	1,304	0.92	0.17
1999	847	61	6,092	1,449	0.99	0.12
2000	875	63	6,545	1,537	0.96	0.12
2001	840	60	5,567	1,336	0.93	0.10
2002	855	61	5,798	1,516	0.91	0.10
2003	869	75	6,037	1,958	0.89	0.12
2004	770	69	3,978	1,522	0.83	0.13

[a] Ktl = (Weight/Length^3) X10^5

Table 24.–Number of A1–A3 (fresh) wounds per 100 spawning-phase Chinook salmon ≥700 mm total length, Au Sable River and Swan River Weir, combined fall collections.

Year	Wound rate	Sample size
1996	8.0	375
1997	3.4	523
1998	2.4	544
1999	5.5	605
2000	3.2	381
2001	5.3	225
2002	1.9	362
2003	2.7	330
2004	1.0	296

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