10 April 2007

GEAR, PRODUCT, AND MARKET DEVELOPMENT FOR THE UNDERUTILIZED, YET BURGEONING POPULATIONS OF FRESHWATER COD (*LOTA LOTA*) IN THE GREAT LAKES

David Jude and Stephen Hensler
440 Church St.
School of Natural Resources and the Environment
University of Michigan
Ann Arbor, MI 48109-1115

Jill Bentgen
Mackinaw Straits Fish Company
St. Ignace, MI 49781

Date: 9 April 2007 (File: brfinal07v2.doc)
Report of Activities Covering the Period : 1 June 2003 to 31 December 2006

- **A** . Grant No. Reference: NOAA Award No. NA03NMF4270149
- **A.** Amount of Grant: Federal $120,284 Match $29,791 Total $150,075
- **B.** Project Title: **GEAR, PRODUCT, AND MARKET DEVELOPMENT FOR THE UNDERUTILIZED, YET BURGEONING POPULATIONS OF FRESHWATER COD (*LOTA LOTA*) IN THE GREAT LAKES**
- **C. Grantee: The University of Michigan**
- **D. Award Period: From 1 June 2003 (started later due to delays in awarding the grant) to 30 November 2004; extended to 31 December 2006**

Period covered by this report: Previous Work: Report provided of Activities Covering 1 August 2003 to 21 April 2004, which includes period 1 :1 June 03 - 30 Nov 03 and period 2: 1 December 03 - 31 May 03, one covering 21 April 2004 - 30 November 2004, one covering 1 October 2004 to 31 March 2005 and one covering from 1 April to 31 October 2006. Current work: This report summarizes activities from the beginning of the study 1 June 2003 to its end 31 December 2006.

- **E.** Summary of Progress to date:
  1. Work Accomplishments:
     a. What tasks were scheduled for this period?

The major tasks for this grant involve gear development/deployment/evaluation for burbot collection and product testing (transport-how best to deliver fish, processing, product development, and marketing). This report will summarize all of our work during this study.

b. What tasks were accomplished for this period- Preparation of the final report.

c. Explain differences if tasks not accomplished-some tasks were incomplete for various reasons and will be discussed in the report.

FINAL REPORT ON:

GEAR, PRODUCT, AND MARKET DEVELOPMENT FOR THE UNDERUTILIZED, YET BURGEONING POPULATIONS OF FRESHWATER COD (*Lota lota*) IN THE GREAT LAKES

David Jude and Stephen Hensler

440 Church St.
School of Natural Resources and the Environment
University of Michigan
Ann Arbor, MI 48109-1115

Jill Bentgen

Mackinaw Straits Fish Company
St. Ignace, MI 49781

TABLE OF CONTENTS

TABLE OF CONTENTS 3

INTRODUCTION 5

GEAR DEVELOPMENT 6

Introduction 6
Methods 7
Results 8
Description of Sampling Events 8
Length-weight Relationships 10
Burbot Catch Relationships 11
Discussion 12

BURBOT PRESERVATION, HANDLING, AND TRANSPORT 13

Introduction 13
Methods 13
Results 15
Change in Burbot Sizes, Livers, and Fillets with Season and Site 15

PROCESSING AND MARKETING OF BURBOT FILLETS 16

Introduction 16
Previous Sensory Testing/Background 16
Methods 17
Sensory testing 17
Taste-Test Protocol 17
One-On-One Interviews 18
Restaurant Use and Taste Tests for Burbot Fillets 18
Consumer Concept Test 19
Recipe Development 19
Results 19
Taste Tests 19
Chefs'/Restaurant Management Responses 20
Meat and Fish Market Personnel Responses 20
Culinary Personnel Responses 21
Restaurant Use and Taste Tests for Burbot Fillets 21
Questionnaire Responses 22
Recipe Development 26
Restaurant Use and Taste Tests for Burbot Fillets 26
Discussion 26

EXPLOITATION IMPACT 28

Introduction ... 28

ANCILLARY INFORMATION ... 28

Diet and Growth of Burbot ... 28
Use of Burbot Livers ... 29
Mercury and PCBs Concentrations in Burbot Liver and Fillets ... 29
Introduction ... 29
Methods ... 30
Results ... 30
SOLEC Conference Paper ... 31

SUMMARY AND CONCLUSIONS ... 31

Introduction ... 31
Gear Development ... 31
Burbot Transport from Source to Market ... 32
Burbot Carcass Disposal Problems ... 32
Taste Tests ... 32
Marketing ... 33
Questionnaire Responses to Burbot-Related Questions ... 33
Burbot Recipes ... 33
Markets for Burbot ... 34
Existing Restaurant That Serves Burbot ... 34
Over Exploitation ... 34
Recent Burbot Diets ... 35
Contaminants in Burbot ... 35

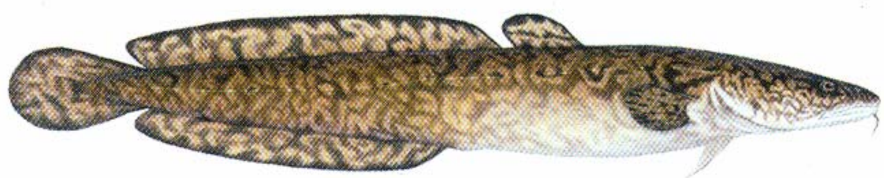
ACKNOWLEDGEMENTS ... 35

LITERATURE CITED ... 36

LIST OF FIGURES ... 37

APPENDIX 1. SUBMITTED PAPER ON BURBOT IN THE GREAT LAKES ... 50
APPENDIX 2. IMPACT OF ROUND GOBIES ON POTENTIAL COMMERCIAL UTILIZATION OF BURBOT IN THE GREAT LAKES ... 69
APPENDIX 3. CONCEPT STATEMENT GIVEN TO PEOPLE TO ASSESS THE POTENTIAL MARKET FOR BURBOT. IT WAS USED IN CONJUNCTION WITH THE QUESTIONNAIRE (APPENDIX 4) TO DETERMINE PEOPLE'S ATTITUDES ABOUT USE AND CONSUMPTION OF BURBOT FILLETS. ... 70
APPENDIX 4. QUESTIONAIRE USED TO POLL PEOPLE ABOUT THEIR ATTITUDES REGARDING CONSUMPTION OF FISH, ESPECIALLY BURBOT. ... 71
APPENDIX 5. BURBOT RECIPES ... 75

INTRODUCTION



The goal of this study was to explore the feasibility of establishing a new commercial fishery on the Great Lakes for a freshwater cod, the burbot *Lota lota* by developing a technique to preserve fillets for efficient transport from the source, manufacture effective fishery products from this fish, and test market them in selected fish markets and restaurants. Historically, burbot and lake trout *Salvelinus namaycush* were the two dominant top predators in the abyssal region of the Great Lakes, but over fishing and sea lamprey predation caused extinction in four of the lakes, and nearly caused extirpation in Lake Superior (Jude and Leach 1999). Despite intensive restoration efforts for 60 yr, lake trout have still not rebounded to even moderate population sizes in the four Great Lakes below Lake Superior, much less so to levels able to support commercial fishing again. Burbot abundance declined sharply due to sea lamprey predation as well, but burbot have since rebounded (Stapanian et al. 2006, Stapanian and Madenjian 2007, Stapanian et al. in press), while lake trout have only rebounded in Lake Superior. Without competition from lake trout and with the buffering against sea lamprey predation by these fish, burbot populations have achieved very high abundances, possibly the highest in history. Currently burbot are seldom utilized by humans, and they represent the only established large predator in the abyssal regions of the lakes, where one of their main prey, the deepwater sculpin flourish. They currently compose the highest percentage of forage fish in Lake Michigan according to recent USGS trawl surveys. Burbot are generally only considered by-catch for commercial fishers pursuing lake whitefish *Coregonus clupeaformis*, one of the last species being commercially fished in US waters of the Great Lakes.

Great Lakes commercial fisheries in US waters have steadily declined since the 1800s, and only bloater *Coregonus hoyi*, lake whitefish, yellow perch, and rough fish (e.g., common carp *Cyprinus carpio* and channel catfish *Ictalurus punctatus*) are sought by non-tribal fishers today. There has been a big shift in management philosophy toward recreational fisheries in the Great Lakes as fishery experts sought to stock salmonines to control the huge influx of alewives *Alosa pseudoharengus* that entered the lakes in the 1940s. The most recent closure was of the yellow perch commercial fishery on Lake Michigan in the 1990s. The high abundance of burbot presents an opportunity for the creation of a new commercial fishery for a fish common in all the Great Lakes. This would strengthen the U.S. fishing industry by providing another species for existing commercial fishers to pursue, and it may even allow some of the fishers who sought yellow perch or new individuals a chance to exploit the fishery. Further, the current situation presents an opportunity to begin a fishery which could be managed from the start, thus having much greater potential to be sustainable in the long term. We expect the project to determine whether these goals are attainable and potentially aid ongoing lake trout restoration efforts in the lower four Great Lakes by reducing the abundance of burbot, that in some cases are thought to compete with other top predators for forage fish prey and some eat lake trout eggs. In addition, the fishing community will benefit by having a new species to pursue and a more marketable use for current by-catch in the lake whitefish trap net and gill net fishery.

In this project we will explore the effectiveness of different gear for catching burbot, develop methods of efficient treatment of the fish or fillets, facilitate optimal transfer of a high quality fillet from source of collection to processor, and develop products and marketing schemes. While these studies have a Michigan-Wisconsin focus, the results will relate to the entire Great Lakes basin, which contain 20% of the worlds' supply of freshwater and burbot occur throughout these waters in varying densities.

Our specific goals for the study revolved around several major questions. First, what type of gear could we develop that would target burbot, yet reduce by-catch or is just using existing common gear (commercial fishers' gill nets and/or trap nets) the most efficient way to go about catching larger numbers for markets? When is the best time to harvest burbot to ensure maximum catches? Second, since burbot cannot be frozen and must be fresh for a good product, was there a method available that we could develop to treat the fillets to allow freezing or other processing so a useable product could be delivered to restaurants or other marketers for use as dinners or chowders? Third, what part of the fillets were best, are there seasonal or site differences in taste, how would various treatments of the fillet affect flavor, can the fillets be used for a standard restaurant meal, or in chowder, or for other products? What do the public, chefs, restaurant owners, and other marketers think about burbot fillets for use in their homes or business. These were the questions that drove this research. Some of these questions were answered fully, others partially, and some questions still remain.

GEAR DEVELOPMENT

Introduction

The main objective for this aspect of the study was to evaluate various gear types and how efficiently they captured burbot, usually in conjunction with and compared with fish caught during deployment of commercial gill nets and trap nets. A secondary goal was to determine the amount of by-catch associated with each type of gear used.

Burbot are ambush (Edsall et al. 1993, Boyer et al. 1989) or stalking predators (Hackney 1973), probably feed at night (K. Koyen, personal communication, commercial fisherman, Washington Island, WI) using their keen sense of smell and their lateral line, respond to light at night (fisherman increase catch rates by placing a light stick on their line) (Gallagher 2004), and seem to be attracted to holes, rocks, and other structure (Edsall et al. 1993, personal observations while SCUBA diving and observations with a remotely operated vehicle in southern Lake Michigan). They are a cold-water fish preferring 8-13 C water and they avoid water >13 C (Edsall et al. 1993, Hackney 1973). Slimy sculpin preferred temperatures of 4-6 C (Wells 1968) in August and were important food of burbot, as are yellow perch and bloaters, as well as the exotic species alewife and rainbow smelt (Fratt 1991). More recently a large part of the diet is being composed of another exotic species the round goby *Neogobius melanostomus* (Hensler and Jude in review – See Appendix 1).

Methods

We mobilized four gear types to exploit vulnerabilities in burbot behavior. Our experimental test gears included 1.) reinforced, cylindrical, wire catfish traps (38-mm square or bar mesh, 1.4 m long), 2.) square-mouthed, wooden catfish slat traps (mouth 0.3 m square, 1.4 m long), 3.) long or trot lines (30.5 m long, 25 long - shank hooks, 25 circle hooks, both size 11/0), and 4.) 91 m long x 1.2 m high trammel net with 305-mm-bar mesh, monofilament outer mesh and 6-mm-bar measure, inner mesh of monofilament. The reason we purchased a trammel net was that it appeared that burbot often were gill netted at the end of the nets, where they were "bagged" by overlapping material. A trammel net operates much like this in that it has outside large mesh which a fish swims through and then it tends to get "bagged" with the smaller mesh sizes in the middle. The two commercial fishers we sampled alongside, Ken Koyen at Washington Island, WI, and Bill Fowler at Leland, MI, both sampled using gill nets. Koyen's nets (152 m long, 114-mm bar mesh, 4.6 m deep) were set in gangs of three or four nets together. Fowler likewise used gill nets the same size as Koyen and set them in gangs of three. Additionally, Fowler used trap nets. His typical trap net was: pots were composed of 117-stretched measure-mesh of no. 15 thread, multifilament nylon. The pots were from 3.2 to 9.2 m high. Smaller pots were deployed usually in fall in shallow water (ca. 10 m). The hearts and tunnels (see Fig. 2 of Johnson et al. 2004) were constructed of the same twine size, but usually had somewhat larger mesh sizes. Leads were composed of nylon twine with mesh sizes ranging from 305 to 406 mm and were from 246 to 427 m long. These two net types are representative of the gear types used by commercial fishers in the Great Lakes, where burbot are present (Johnson et al. 2004).

We used various baits for the wire and wooden slat traps and the long lines, including cut up centrachids *Lepomis* spp., white suckers *Catostomus catostomus*, spottail shiners *Notropis hudsonius*, round gobies, common carp *Cyprinus carpio*, alewives, and various other fishes that we had seined for another project and kept frozen for this one. Light sticks were also used on one occasion in the slat traps. We kept track of bait position on the trot lines in case there was some type of preference shown. We baited the trot lines, put in a large chunk or chunks of fishes in a white mesh bag in the slat traps and mesh traps. They were deployed on several occasions (Table 1).

Side-by-side gear comparisons were conducted five times during the course of this study. Direct comparisons with commercial fishing gear occurred three times, and comparison only among our test gears occurred twice. Additional gear comparisons were attempted several times, but coordinating efforts with commercial fishers proved to be difficult at times.

We had intended to set our gear adjacent to commercial fisherman's trap nets, which we did on many occasions, but on other occasions, when we either did not obtain cooperation of a commercial fisherman, or the season was over, we deployed the gear independently of commercial fishing gear deployment. We were unable to set our gear next to commercial fishers gear for various reasons (e.g., ice on Green Bay, bad weather, an uncooperative commercial fisherman).

To assess catch efficiency among gear types, we calculated catch of burbot and other fishes per hour or per meter of each particular gear type. We used the length of net or long line or width of gear opening as the measure to compare different gears to account for the much larger sizes of nets being used by commercial fishers. These comparisons are qualitative in some cases, quantitative in others but do provide an overall comparison to guide decisions on gear usage.

An ANCOVA (alpha = 0.05) was used to determine if the mean weight at a given length was significantly different among sites for the length-weight relationships for burbot.

Results

Description of Sampling Events

Our first collections of burbot were in conjunction with the Michigan Department of Natural Resources in Alpena, MI in Lake Huron (Table 1- see Fig. 1 in Appendix 1 for map). They were doing fall assessment surveys, so we kept in touch with them. We used their facilities to process burbot from commercial fishers, who were hired to do the work. Fish were returned iced to the facility and we weighed, measured, filleted, did diet analyses, and liver/fillet weights on these fish. Our final sample size was 97 fish from this assessment. The largest burbot we sampled came from these collections (850 mm maximum size) and there appeared to be a larger proportion of longer fish than any we got in any other samples or ports. Biologists reported that catching this many burbot was unusual, as was the large size observed and interestingly enough in 2005 and 2006 they got so few in the nets that it was not worth it for us to come and process the fish.

Table 1. Date, location, Great Lake (LH=Lake Huron, LM=Lake Michigan), sample size, gear, project, and range in total length for burbot collected for gear comparisons and product testing in the Great Lakes. ST = wire and wooden slat or catfish traps, LL = trot or long line, GN = gill net, TR = trammel net, TN = trap net. See Fig. 1 in Appendix 1 for a map.

Date	Location		Gear Deployed	Project	Sample Size	Length Range (mm)	
10-11,17 Nov-04	LH:Thunder Bay	Alpena, MI	TN	MDNR/CF	97	515	850
14-Nov-04	LM:Muskegon River	Muskegon, MI	ST,LL,GN	This study	0		NA
2-Dec-04	LM:Green Bay	Wash. Isl., WI	GN	CF	10	525	729
5-Feb-05	LM:Big Bay de Noc	Fairport, MI	GN	MSU/CF	118	492	758
6-30 May-05	LM:Mid lake reefs	Mid LM	GN	WDNR	3	525	586
8-Jun-06	LM: NE shoreline	Leland, MI	GN	CF	22	540	804
13-15 Jun-06	LM:Green Bay	Wash. Isl., WI	GN, BP	CF	34	485	669
23-Jun-06	LM: NE shoreline	Leland, MI	TN	CF	3	559	728
23-25 Oct -06	LH:Drummond Isl.	Drum. Isl., MI	TR,LL,ST	This study	4	537	570
4-Dec-06	LM:Green Bay	Wash. Isl., WI	GN, LL,TR	CF	76	425	695
TOTALS					367		

The first deployment of our gear was at the mouth of the Muskegon River in Lake Michigan during 10-17 November 2004. The river is known to harbor both adult and juvenile burbot. We attempted to intercept the spawning migration that was undoubtedly underway at that time. We deployed two trotlines, two each of the slat traps and mesh traps, and a gill net in areas near the mouth of the river overnight. No fish were collected in the trotlines and only a rock bass was captured in one of the slat traps. The gill net collected no burbot, but did have a considerable by-catch of walleyes, rock bass, lake whitefish, round gobies, and round whitefish. Hence results were inconclusive. We did contact several commercial fishermen in Alpena, Saginaw, Muskegon, and Leland, MI during this period in order to set our gear next to their nets, but they either were not fishing as the season was over, they were not getting very many burbot, or we missed going out with them when they were getting fish.

During our work on this project, we became aware of a commercial fisherman, Ken Koyen in Washington Island, WI, which is located on the tip of the Dorr Peninsula, which separates Green Bay from the main body of Lake Michigan. He also is manager/owner of a restaurant in Washington Island which serves burbot three different ways. Since this is exactly one of the outcomes we had anticipated from the results of our study, we set up an appointment to visit him and sample from his catches on 2 December 2004. We ate burbot at his restaurant, which were excellent, obtained 10 burbot from his nets, which were set for lake whitefish and burbot, as he tries to obtain fresh burbot every day for his customers. These fish were 525-729 mm long and Ken agreed to assist us with more intensive fishing with our gear and his when we could arrange another visit.

On 5 February 2005 we also became aware of a research project, which required live lake whitefish for studies over all seasons. A commercial fisherman was hired to catch lake whitefish in Big Bay de Noc, MI in northern Lake Michigan at Fairport, MI. He purposely tried to avoid catching burbot in gill nets set through the ice. The area was composed of rocky reefs found near shore and was supporting a large population of spawning burbot at the time. It was also the spawning season for this fish. We collected 118 burbot in the gill nets set on this reef, the most of any of our collections. These fish were not spent, so had not spawned yet, but must have been close. Fish ranged from 492 to 758 mm.

On 6-30 May 2005, we received data from the WI Department of Natural Resources on burbot collected from East Reef, which is in southern Lake Michigan and about 50 m deep. These three burbot ranged from 525 to 588 mm long and all had eaten slimy sculpins.

We contacted a commercial fisherman in Leland, MI and helped pull their trap nets and gill nets, and set our gear alongside on 8 June 2006. We collected 22 burbot that ranged from 540 to 804 mm.

We returned to Washington Island, WI to work with Ken Koyen again on 13-15 June 2006. We were able to set our gear twice along his gill nets in the bay. We collected 34 burbot (485-669 mm) and also got our first burbot in a slat trap at this time.

On 23 June we obtained an additional three burbot from William Carlson, Leland, MI. They ranged in length from 559 to 728 mm.

On 23-26 October 2006 we sampled at Drummond Island (some parts are a lake trout sanctuary) in northern Lake Huron near the mouth of the St. Marys River, which connects Lake Superior with Lake Huron. We were unable to receive permission from a commercial fisherman in the area to set our gear next to his, so we set our gear independent of his. We deployed the gear over 3 days and were able to collect only three burbot, 537-570 mm.

Our last trip was to Washington Island, WI on 4 December 2006 when we obtained burbot collected the day before we arrived and then were able to set our gear next to his in some of the roughest weather we experienced during this study. We got 76 burbot that ranged from 425 to 695 mm long. Our total sample size for the study was 367 burbot and some by-catch that were returned to the water, with the exception of some exotic round gobies that were captured in gill nets and on the trot lines; they were euthanized.

Length-weight Relationships

The length-weight relationships showed that there was little difference among sites (Fig. 1). However, there were cases where some differences existed. First the Bridgman, MI samples from 1973 to 1977 collected in southern Lake Michigan (Jude, unpublished data, see map in Fig. 1, Appendix 1) had burbot that were much shorter than most of the other burbot collected from other sites. We attributed this to sampling near shore in 9 m of water in southern Lake Michigan, not prime habitat for burbot. The Lake

Huron burbot from Alpena, MI were the longest among all the sites we sampled. These burbot may have had accelerated growth due to eating large quantities of round gobies as their diet shifted from native species to round gobies.

Burbot Catch Relationships

We set our special gear next to commercial fishing gear and sometimes alone, but only collected six burbot in three different gear types (Table 2). It was obvious that baiting traps and hooks increased chances of catching fish, since five of the six fish were collected in baited traps and on baited long lines in June and October-December 2006 at Washington Island, WI and Drummond Island, MI. The trammel net also collected some burbot, but also collected a considerable amount of by-catch. The slat traps and trammel nets were easy to deploy, while the long lines were tedious to bait, difficult to set (we had problems with sea gulls trying to eat the bait), easily became tangled, and dangerous for people handling 100 hooks in rough weather.

Table 2. Date, location, gear type, and lengths of burbot collected during this study using specialized gear targeted for burbot.

Date	Location	Gear Type	Lengths (mm)
14-Jun-06	Washington Island	Slat Trap	602
5-Dec-06	Washington Island	Trammel Net	695
5-Dec-06	Washington Island	Long Line	425,545,440
23-25 Oct-06	Drummond Island	Long Line	513

The highest commercial catch (no. of burbot) we obtained was in gill nets set at Fairport, MI in Big Bay de Noc in northern Lake Michigan during winter, the spawning season of burbot (Fig. 2). This catch was substantially higher than all the other catches. The next highest number of burbot caught was also in gill nets set at Leland, MI and Washington Island, WI.

By-catch was represented by a large number of species, including lake trout, walleye, rock bass, round gobies, alewife, lake whitefish (the target species for commercial fishers), lake herring, coho salmon, and brown trout. Their appearance in the nets were highest at Leland, MI in gill nets (mostly lake whitefish) compared with other catches elsewhere, especially catches in gill nets at Fairport and Muskegon (Fig. 3).

When catch was quantified by catch/hr, burbot catches in the Fairport gill nets again were substantially higher than other catches (Fig. 4). Trap nets and the long lines at Leland and gill nets and the trammel net at Washington Island yielded high mean catches as well. The mean by-catch (catch/hr) was highest in gill nets at Leland (again mostly the target species lake whitefish), followed by Muskegon (Fig. 5). Modest catches were also recorded in gill nets at Washington Island and Fairport. By-catch was also high in the trammel net set at Drummond Island.

In an effort to further clarify catch statistics, we calculated the catch-per-m of net (see Methods). Here, the baited wire traps, because they were so small, had the highest catch/m, followed by gill nets again at Fairport (Fig. 6). Burbot were also caught on the long lines at Washington Island, making its catch/m small but noticeable compared with the long gill nets and trap nets CPUE with which it was compared. The by-catch using similar catch information showed that the slat traps in Washington Island had the highest catches (Fig. 7), followed by gill nets at Muskegon and Leland. The reason for the high by-catch at Washington Island was that the slat trap collected a large number of round gobies, which inflated the CPUE.

Discussion

To summarize, despite all the effort expended with our gear, we caught only six burbot in three different gear types: one in a slat trap, one in trammel nets, and four on long lines. Of the six fish, five were collected in gear baited with fish, which strongly suggests baiting will increase catch. The trammel net, although it caught only one burbot, had a high incidence of by-catch, while surprisingly the trot lines seldom caught other species (e.g., round gobies in Washington Island). Sometimes we collected comparable numbers of burbot when compared with the gill nets and trap nets set by commercial fisherman; most times we did not. Often, large numbers of burbot were collected in trap nets and gill nets, especially the gill nets set under the ice at Fairport, MI. Obviously, burbot are vulnerable during the spawning season, when they congregate on reefs and should probably be targeted then to maximize catch and storage for use later in the year. If the project leads to more harvesting of burbot it could lead to higher collections of burbot. Currently, burbot are not regulated and are considered by-catch by the MI DNR.

By-catch was a concern by other researchers/biologists with whom we talked, especially for the trot lines. However, we did not see any by-catch of lake trout or other species, besides round gobies, on the trot lines. We did see many hooks that were bare, many that were bent or broken, and sometimes the line had snapped connecting the hook to the main line. We suspect round gobies and burbot were the bait stealers, as we caught many large specimens on the long line, and that other large species, such as lake sturgeon, may have broken hooks and snapped lines. The catch-per-unit effort for both the slat traps/wire mesh pots and the trot line is difficult to compare among gear, but it does suggest that these specialized gear can catch burbot and with further development by commercial fisherman, could be used to target mostly burbot. However, the most efficient way would probably be to utilize the burbot collected in the commercial gill nets and trap nets, since they would be set anyway. Lastly, it does establish that burbot can be caught with bait. This implies that burbot do use their sense of smell or taste to find prey and that during times when they are concentrated, for example during spawning, these gear should be considerably more effective. Light sticks have been used by sport fisherman and we tried them in some sets, but no burbot were collected. More work should also be done with this as an attractant.

BURBOT PRESERVATION, HANDLING, AND TRANSPORT

Introduction

Our second and third goals were to determine if there were differences in season and site in the taste of fillets collected and to determine what type of treatment of fish fillets or fish on or just off the boat would provide the best product for consumption or future testing and development. We were aware from prior studies (Krivchenia and Fennema 1988) and anecdotal information that burbot that were frozen developed hardened texture and poor taste; hence we attempted to try other methods to get the burbot fillets to market in an acceptable manner. We set up treatments of fillets at each site, such that some were treated with sodium tripolyphosphate (TPP), an established enzyme inhibitor (Krivchenia and Fennema 1988), some were untreated controls, some were vacuum packed, and some were both vacuum packed and treated with TPP. Krivchenia and Fennema (1988) treated burbot fillets with sodium tripolyphosphate and other chemicals; some were injected and then frozen. Samples treated with TPP had better textural properties than controls. Injecting fish was no different than dipping fish, and in some cases injected fillets were worse. They found that burbot are a low fat (muscle lipids <1%) fish, but becomes "dry" after prolonged periods of frozen storage. Burbot under go changes in the flesh after being frozen with no treatments. They produce dimethyl amine an enzymatic breakdown product of trimethylaminic oxide, which causes the textural changes in the flesh (toughens extensively). TPP significantly reduced free drip and cooking loss in burbot. Sensory analyses showed that interior portions of burbot were of comparable eating quality to commercially obtained cod, haddock, and pollock. Additional studies of Lindsay et al. (1981) showed similar results: they found that 35% of a burbot is usable fillets. Surface browning and excessive drip and cooking losses occurred as a result of freezing or refrigerated storage. Such losses were inhibited by dipping fillets in TPP. Fish sticks made with burbot were tested using taste panels and found to be similar to commercially obtained cod, haddock, and pollack products. Fillets were stable during freezing. Lake Michigan fillets in 1980 contained <1 ppm of PCBs.

We also conducted a consumer concept test to assess consumer interest in burbot. A concept statement and questionnaire was developed to determine intent-to-purchase, likely preparation methods, product positioning, and retail prices.

Methods

All burbot used for this study were placed on ice in the field (both aboard commercial fishing vessels and during our individual sampling bouts) and kept on ice until we were able to process them up to 2 days later. Percentage of total body weight of burbot fillets and livers was calculated to assess the expected fillet output and how much the liver contributes to their total weight. Burbot use their livers as an excess energy store. Thus, the relative proportion of body weight composed by the liver allows for a rough estimate of condition factor. An ANCOVA (alpha =0.05) was used to statistically compare percentages of total body weight (%) and weight (g) of burbot fillets and livers among sites with length as the covariate.

Early in the study (2004-2005), burbot fillets were preserved using different methods to test for differences among preservation, transportation, and storage methods. During these years, fillets from each fish were preserved in one of four ways: (1) placed in a Ziploc bag and frozen, (2) vacuum-sealed and frozen, (3) dipped in a 2-5% solution of sodium tripolyphosphate, placed in a Ziploc bag and frozen, or (4) dipped in a 2-5% solution of sodium tripolyphosphate, vacuum-sealed, and frozen. All fillets were transported to the Mackinaw Straits Fish Company in St. Ignace, MI, for tests of flesh quality, and product and market development.

Our preliminary results suggested some of our other planned treatments (boiling, bringing them back alive) were not necessary and unrealistic. Fillets were then taken to St. Ignace, MI where they were subsequently taste tested to determine which fillets were best. Tests were done on the fillets by Jill Bentgen and her employees. A sample of fish was cut, microwaved for a set amount of time, and various parameters of taste were assessed for each sample (texture, taste, color, odor). These measurements were compared with marine cod purchased from local stores. In addition, whenever we collected a sufficient number of burbot fillets in the field, they were labeled with a number and sent to Jill Bentgen for blind taste tests to determine the influence of site, season, fillet type (front or back), length of time the fish were filleted prior to processing, etc.

More detailed methods for how fish were handled are noted below:

1. Measure total length (mm) of fish and inform the recorder
2. Make an incision behind the head all the way around the fish
3. Use a catfish pliers to grab the skin and pull it all the way off
4. Determine sex and gonad condition of the fish and identify its stomach contents
5. Fillet the fish
6. Cut each fillet lengthwise to yield a top and bottom portion of each fillet
7. Place one fillet piece from each fish into the following four treatments:

Fillet treatments for each fish			
On Ice	STP + Ice	Vacuum	STP + Vacuum
Top	Bottom	Bottom	Top

For the data collection process the following protocol was followed;

1. Prepare a ~5% solution of sodium tripolyphosphate (STP) for soaking fillets (this is best done before heading out into the field)
2. Note the site fish were collected from and the type of gear in which they were captured
3. Note the collection, process, and transport dates for fillets from each fish
4. Note the type and how many other fishes (by-catch) were collected in the same gear burbot were collected
5. Assign a fish number to each fish and keep track of fillets to ensure they are not confounded (fish numbers should be assigned ahead of time based on numbers from the last batch of burbot collected)
6. Record the length and weight of each fish as well as the weight of the fillets and liver each fish yields
7. Record sex, gonad condition, and stomach contents for each fish

8. Keep track of fillets so that proper portions are placed in the proper treatments
9. For a sample requiring STP treatment, submerge the fillet in the solution and soak it for 3 min before either putting it on ice or vacuum sealing it

Results

Change in Burbot Sizes, Livers, and Fillets with Season and Site

The mean length of burbot at the four sites for which we evaluated data showed that burbot were substantially shorter at Washington Island during spring, summer, and fall than they were at other sites and seasons (Fig. 8); however, an ANCOVA revealed no differences in mean weight at a given mean length when all data were pooled over sites (n = 357, sites: Fairport, Alpena, Leland, Wash. Island, df = 3, F = 27.08, p = 5.0). Burbot from Fairport were on the whole shorter, were gravid, and 77 (65%) were females and 41 were males. Burbot were similar in length at Washington Island during all three seasons (around 560 mm), with mean lengths comparable and sometimes less than the mean length at Fairport. Highest mean lengths were seen at Alpena, followed closely by fish from Leland. The largest specimen we collected was from a trapnet catch from Alpena, MI in November 2004 (850 mm); the smallest came from Washington Island (425 mm).

Mean weights of burbot were lowest for all three seasons at Washington Island than at any other sites studied (Fig. 9). Mean weights were highest during spring at Leland, followed by fish from Alpena in fall, and Fairport in winter. Mean weights of fillets from burbot were significantly different (ANCOVA: n = 132, sites: Fairport, Alpena, Wash. Isl., df = 2, F = 10.71, p < 0.0001) among sites with Alpena having the highest mean weight (507 g), followed by Fairport (468 g), and Washington Island (379 g) (Table 3). Fillet weight however did not vary substantially between seasons, fall vs. winter. The percentage of the total weight composed of fillet did not vary among sites (ANCOVA: n = 132, sites: Fairport, Alpena, Wash. Isl., df = 2, F = 2.62, p = 0.07**)** with Fairport having the highest percentage (25.2), followed by Washington Island (22.9) and then Alpena (21.4) (Fig. 10). There were seasonal differences with winter having a higher percentage fillet than fall.

Weight of liver varied from 134 to 146 g, with no significant differences among sites (ANCOVA: n = 109, sites: Fairport, Alpena, Wash. Isl., df = 2, F = 6.62, p < 0.05), although Washington Island had the highest mean weight (Table 4). Liver weights over seasons fall and winter varied little. Mean weight that the liver composed of total burbot weight however, did vary significantly among sites (ANCOVA: n = 109, sites: Fairport, Alpena, Wash. Isl., df = 2, F = 10.79, p < 0.0001), with Washington Island having the highest percentage (8.6), followed by Fairport (7.8), and Alpena (5.6) (Fig. 11). Mean percent liver values were substantially higher in winter than fall (Fig. 11).

Table 3. Mean weights (g) and percentage of the total burbot weight for fillets and liver taken from fish collected at Alpena and Fairport, MI and Washington Island, WI during 2004-2006. Sample size and SE also given. ANCOVA results are reported as: NS=not significant; *=significant at $p<0.05$, **=significant at $p<0.01$, ***=significant at $p<0.001$.

Type	Site	Sample Size	Mean (wt or %)	SE
Liver	Alpena	49	134	9
(wt – g)*	Fairport	50	145	6
	Wash. Island	10	146	21
Fillet	Alpena	72	507	18
(wt – g)***	Fairport	50	468	14
	Wash. Island	10	379	28
Liver	Alpena	48	5.6	0.3
(%)***	Fairport	50	7.8	0.2
	Wash. Island	10	8.6	1.0
Fillet	Alpena	48	21.4	0.4
(%)NS	Fairport	50	25.2	0.4
	Wash. Island	10	22.9	0.6

PROCESSING AND MARKETING OF BURBOT FILLETS

Introduction

This portion of the study focused on feasibility of processing fresh burbot into acceptable products for the food service and retail markets. The majority of work was done at the Mackinac Straits Fish Company, located in St. Ignace, MI. Mackinac Straits Fish Company is a freshwater fish processor that processes approximately 1 million pounds (453,592 kg) of locally caught fish annually. It was established in 1978. The company's retail manager has 26 years with the company. Three of its five fresh fish processors also are commercial fishermen. In addition to fresh fish, the company also has a line of smoked, packaged items. It markets to large distributors, specialty food stores, regional grocery store chains, and retail fish markets. The company also has a retail outlet at its St. Ignace location.

Previous Sensory Testing/Background

Two previous studies of burbot reported sensory evaluations. Krivchena and Fennema (1988) reported results of various treatments of cryoprotectants on frozen burbot fillets. Two descriptive sensory analyses of poached burbot were conducted at 12 weeks of frozen storage. Their panelists found that the samples dipped in STP (sodium tripolyphosphate) were significantly moister, contained fewer off-flavors and had better overall quality (overall preference) than the control samples.

In a separate study, Lindsay et al (1981) conducted sensory evaluation on a variety of burbot preparations with comparisons to commercially popular cod and pollack items. Sensory evaluation of the products consisted of descriptive sensory analysis panels. Panelists evaluated products using semi-structured quantitative descriptive analysis (QDA) scales that included flesh color, saltiness, fishy flavor intensity, tenderness, moistness, and overall preference. Tripolyphosphate (TTP) dipping of burbot fillets inhibited drip losses from frozen fillets, retarded browning in refrigerated and frozen fillets, and retarded moisture loss during cooking of frozen breaded products. With proper handling and processing, it should be possible to substantially increase the commercial utilization of burbot in highly consumer-acceptable forms. This study also reported wide variation among samples. They found that whole burbot fillets were irregular in shape and compositionally quite variable, and the various fillet sections yielded products with quite different characteristics and quality.

Methods

Sensory testing

Based on these previous studies, it was determined to conduct all sensory testing using only anterior burbot fillets, the hedonic scale and attributes described in the study by Lindsay et al. (1981) and side-by-side comparisons. Instead of developing a QDA panel that was beyond the scope of this research, it was decided to use expert panelists consisting of the eight most experienced employees of the Mackinac Straits Fish Company. These panelists work with a variety of freshwater fish on a daily basis, eat fresh fish multiple times per week, and on average have many years of experience in the industry. As frequent fish consumers, they have the capability of noticing subtle differences between samples that would not be discernible to most people that routinely eat fresh fish.

Product samples were boneless, skinless anterior burbot fillets from a variety of sources: 1) from Jude from his field samples as already filleted and packaged products, 2) from freshly caught burbot delivered by Jude and processed at the Mackinac Straits Fish CO, and 3) from freshly caught burbot as an incidental catch by local commercial fishermen. Treated samples were dipped in a 5 % solution of TPP for about 3 min. Samples were frozen at –15 F for later use.

Taste-Test Protocol

1. Frozen test fillets were removed from frozen storage and placed in refrigerated storage 24 hr prior to testing.
2. A 57-g (2 ounce) sample was cut from each of the thawed treated samples and the untreated sample. The samples were washed with cool, potable water, and dried with a paper towel.
3. Each sample was placed on its own individual small paper plate and loosely covered with clear plastic wrap.

4. Both samples, treated and untreated, were placed in a microwave oven (GE Brand, Model # JES933 WN 001) and cooked on high heat (power level 10) for 30 seconds.
5. Samples were removed from the oven and the plastic wrap removed.
6. Samples were allowed to cool slightly (about 2 min) and then taste tested side by side.
7. Prior to testing the first sample, panelists took a drink of water to clear the palate. The palate was also cleared when sampling between treated and untreated samples.
8. A simple ballot was completed at the time of product sampling.

One-On-One Interviews

Individual interviews were conducted among a variety of culinary professionals consisting of chefs, restaurant personnel, cooking school teachers, meat and fish market personnel, and food writers. These background interviews were used to form the basis for concept questionnaires among consumers. It was thought these individuals would be most open to a new fish species and have an informed opinion concerning positioning and marketing to retail consumers and the food service industry. Panelists were recruited from past personal relationships as customers and professional colleagues.

Restaurant Use and Taste Tests for Burbot Fillets

A number of restaurants were recruited to use burbot fillets in their facility either as a replacement of usual fish or as a menu special. Forty establishments were initially recruited. However, test product was placed with only 15 restaurants based on the experience level of the kitchen staff. Kitchen personnel in most of the restaurants had little training beyond on-the-job training in their current jobs.

Approximately 1.36 kg (3 pounds) of product (packaged as fillets from individual fish, coded to correspond to different conditions) were provided to each test facility with instructions to use the product in their normal operation and then complete a questionnaire. This test method proved problematic. The kitchen staff that received instructions were not the same staff that used the product. The questionnaire developed to gather very specific information was too open ended. In the end, on-site interviews with selected kitchen staff were conducted to obtain feedback.

Twelve of the 15 restaurants deep-fried the burbot fillets in place of their usual product. Eight of the 12 restaurants used pollack as their usual product and four used frozen ocean cod. One restaurant featured burbot as part of their “All You Can Eat Fish” Friday Special. The burbot fillets were seasoned and baked and set out on a self-serve buffet table. Two of the restaurants “lost” the test product; they were not sure how the fish was used or who might have prepared it.

Consumer Concept Test

Questionnaire – The concept test consisted of a Concept Statement on burbot life history and suitability for consumption (see Appendix 3) followed by a 3-page questionnaire (see Appendix 4). Each panelist was instructed to read the concept statement, then answer questions specific to the statement about burbot and general questions concerning purchase, preparation, and consumption of fish.

Panel Recruitment- Panelists were recruited using local churches in the Traverse City, MI area. For each returned questionnaire, the participating church received $5.00. Qualification for panel participation was that the person consumes fish occasionally. This requirement eliminated anyone that might be allergic to fish or intensely disliked fish for whatever reason. The concept and questionnaire was mailed to each panelist along with a pre-addressed and stamped envelope. After reading the concept statement and completing the questionnaire, the panelist returned the questionnaire using the envelope enclosed. Of 200 panelists receiving the concept, 124 were returned.

Recipe Development

Based on concept test results, eight recipes featuring burbot fillets were developed (Appendix 4). The majority of recipes incorporated the preferred preparation methods of baking, broiling, and grilling.

Based on previous recipe development projects, the following criteria were used to initially evaluate potential recipes.

- No lengthy or complicated preparation techniques
- Ingredients available in the local area
- Preparation time minimal for the quality of the finished product
- Does not require expensive or exotic ingredients
- Generally makes four servings
- Does not require special equipment

Recipes were collected from personal files and a library of cookbooks and culinary magazines collected over the past 25 years. Approximately 25 recipes were selected for preparation, further refinement, and final selection.

Results

Taste Tests

Expert panel results of side-by-side testing of burbot fillets that were treated and untreated confirmed results of previous studies (Lindsay et al. 1981, Krivchena and

Fennema (1988); samples dipped in a dilute solution (5%) of TPP provided superior taste attributes versus a comparable untreated sample. In spite of wide variability in the size of the fillet and collection method, there was a clear preference for the treated sample. Specific results are below.

Sample Condition	Base Size	Characteristic Flavor – Positive (1)	Fishy/off flavor Negative (1)	Texture Tenderness (2)	Moistness (3)	Overall Preference (4)
Untreated	12	3.66	4.08	3.89	4.17	4.27
Treated	12	3.76	4.04	4.21	4.37	3.55

(1) Scale: 1 = none; 7 = pronounced
(2) Scale: 1 = tough, chewy; 7 = flaky, tender
(3) Scale: 1 = very dry; 7 = very moist
(4) Scale: 1 = dislike extremely; 7 = like extremely

Chefs'/Restaurant Management Responses

Among chefs and restaurant owners, the idea of using burbot fillets was perceived primarily as a direct replacement for cod or pollack that they were already using. Input centered more on what impact using burbot would have on their operations. The majority of these panelists perceived ocean cod as a bland tasting, inexpensive fish. The most common restaurant preparation was deep fried cod or pollock. Typical comments/questions were:

How much will it cost me versus the cod I am already buying?
How is it packaged? Is it frozen or fresh?
Where would I buy it? Can I get it from my usual fish supplier (usually a large food service distributor)?

Meat and Fish Market Personnel Responses

Local fish and meat markets that carry fresh fish were more interested in burbot as an additional, new fish offering. They thought it was important that it was a local fish that had a distinctive character that would set it apart from other fish. One local grocery chain felt it was important that it came from a well known, local processor with a reputation of providing consistently high quality. A high-end fish market, selling fresh cod at $15.59/pound, said they would try anything once. These panelists were long time local residents, had some previous knowledge of burbot as a recreational catch, and its reputation of "tasting like lobster". However none had ever seen a burbot or eaten the fish.

This group also felt it was important to provide point of purchase information about the fish to help educate their customers and that their staff was trained to answer questions about the fish. There was clear preference for fresh, never-frozen fillets among fish market personnel. Grocery store personnel involved with the meat/fish department did not have a strong preference for fresh versus frozen product.

Culinary Personnel Responses

This diverse group of people consisted of food scientists, cooking-school instructors, cook-book authors, and food-marketing managers. This group was geographically dispersed throughout the United States. This group felt strongly that any new fish product needed to be distinctive versus other choices. Input from this group focused more on the fish's special qualities. This group was also more aware of environmental issues. Comments included:

Is this species going to be over fished like Atlantic cod?
I would want to know that there are no toxic substances.
Why would I want to buy this fish? What makes it special?
Is this fish farmed or is it wild? I heard farmed fish and shrimp cause lots of environmental problems.

Restaurant Use and Taste Tests for Burbot Fillets

All of the 13 restaurants completing the assessment wanted a larger package size. Individually packaged fillets were tedious to work with. These establishments were accustomed to working with packages containing 5 pounds or more. They removed all of the fillets from individual packages and combined them into one pan, treating all of the fillets as one lot of product. The 12 restaurants that deep-fried the product reported that it fried normally, that they saw no difference between the burbot fillets and the product they usually used. (I suspect some of the personnel did not know they were using a test product.) None of the 12 restaurants had any complaints that they could recall. While there were no strong testimonials for the burbot fillets, these 12 restaurants were open to purchasing the fish as long as it was priced comparably to their usual product, estimated to be about $3.00/pound.

Twelve of the 15 restaurants deep-fried the burbot fillets in place of their usual product. Eight of the 12 restaurants used pollack as their usual product and four used frozen ocean cod. One restaurant featured burbot as part of their "All You Can Eat Fish" Friday Special. The burbot fillets were seasoned and baked and set out on a self-serve buffet table. Two of the restaurants "lost" the test product; they were not sure how the fish was used, who might have prepared it, or what consumers thought of it.

The one restaurant that featured burbot on the "All You Can Eat Buffet" was more enthusiastic. This restaurant reported that his clientele consumed all of the burbot he was given to test. He positioned it as a local fish and used the name burbot. However, when asked about the product quality relative to frozen ocean cod that would normally be used, he rated it no better than ocean cod and was only willing to pay a price comparable to ocean cod. Nevertheless, this restaurant wanted to purchase burbot on an ongoing basis for the "All You Can Eat" Friday Fish Special because use of local fish was important to his clientele.

Questionnaire Responses

Most of the panelists ate fish frequently (Table 5). This level of fish consumption is not unusual for a northern Michigan community with fresh, local fish readily available.

Table 5. Responses of 124 out of 200 people asked to respond to various questions regarding the use, cost, and consumption of burbot.

How often do you Consume fish per week?	Percentage responding
At least once per week	62%
About once every 2 weeks	10%
About once or twice per month	25%
Less than once per month	3%

There is definite interest in purchasing burbot based on the concept provided indicating these consumers were open to new fish varieties (Table 6). Although it is difficult to translate intent-to-purchase to sales volume, these results indicate that there is little concern about buying burbot at least to try.

Table 6. Responses of 124 out of 200 people asked to respond to various questions regarding the use, cost, and consumption of burbot.

How often do you intend to purchase burbot?	Percentage saying yes
Definitely will buy	37%
Probably will buy	41%
Might or might not buy	19%
Definitely will not buy	3%

Of those indicating likely purchase of burbot (base 108), 64% anticipated eating more fish while 36% anticipated eating the same amount of fish.

The three most likely ways consumers anticipated preparing burbot were baking, broiling and grilling (Table 7). There was slightly more interest for the combined frying preparations versus boiling preparations.

Table 7. Responses of 124 out of 200 people asked to answer various questions regarding the use, cost, and consumption of burbot fillets. This question asked what methods of preparation were considered to be best.

What is your preferred method of fish preparation?		Percentage of group that preferred one particular method	
Bake	70%	Poach/boil	13%
Broil	50%	Simmer in Soup/Chowder	25%
Grill	70%		38%
Microwave	10%	Sauté	22%
Marinade/raw	0%	Deep Fry	5%
		Pan Fry	25%
			52%

There is no single type of outlet that is preferred for purchasing fish (Table 8). Fish purchases split about equally between large national chains, local full-line grocery stores, and specialty fish and meat markets. This suggests it is possible to reach the majority of fish consumers without the complexity and large volume associated with dealing with a large, national chain.

Table 8. Responses of 124 out of 200 people asked to respond to various questions regarding the use, cost, and consumption of burbot fillets. This question asked where you would most likely purchase your fish products.

Where would you most likely purchase your fish products?	Percentage of panelist response
At a large national or regional supermarket	38%
At a local or regional grocery store	27%
At a specialty meat of fish market	35%

Analysis of recent fish and seafood purchases show canned, non-perishable fish is the single most common purchase at 32.1% (Table 9). This is likely due to the purchase of canned tuna. However, when all fresh-fish purchases were combined and all frozen purchases combined, data showed that fresh-fish purchases at 39.4% were the most common form purchased and frozen-fish purchases were less common at 15.8%. This bias toward fresh fish may make marketing of frozen burbot fillets more difficult, and may require incentives for purchase. This might include in-store sampling or signature entrees on the menus of restaurants known for their fish.

Table 9. Responses of 124 out of 200 people asked to respond to various questions regarding the use, cost, and consumption of burbot fillets. This question asked what type of purchases would you make.

Type of fish product		Percentage of the panelists that chose each product	
Fresh, local fish	17.2%	Frozen, farm raised salmon	2.7%
Fresh, farm raised salmon	13.5%	Frozen ocean fish such as tilapia	13.1%
Fresh ocean fish (like tilapia	8.7%		15.8%
	39.4%		
Fresh or frozen seafood	12.5%	Non-perishable, canned	32.1%

Baking, broiling and grilling were the three most popular methods of fish preparation either at-home or dining out (Table 10). However, deep frying was much more popular when dining out and almost never used at-home.

Table 10. Responses of 124 out of 200 people asked to respond to various questions regarding the use, cost, and consumption of burbot fillets. This question asked what methods of fish preparation were most often used to cook fish at home and requested or served at a restaurant. Panelists were asked to rank only the top three choices for each category.

What method of fish preparation do you use to cook fish at home? Or request at a restaurant?	Percentages of panelists and how they ranked choices	
Choices	In-Home Preparation	Dining Out Preparation
Grill	54%	41%
Bake	68%	38%
Deep Fry	3%	32%
Poach	11%	5%
Broil	43%	70%
Pan Fry	30%	19%
Sauté	22%	22%
In a soup	16%	19%
Other	3% (Shrimp cocktail)	16% (Cold salad)

When purchasing fish at stores, two thirds of consumers would like recipe cards and preparation suggestions (Table 11). In general, consumers would like point-of-purchase information about the fish they are eating, its taste qualities and its nutritional profile. This suggests that both brochures and recipe cards would be useful. Because of the high desire for recipes and preparation suggestions, any informational brochure should include at least one recipe.

Table 11. Responses of 124 out of 200 people asked to respond to various questions regarding the use, cost, and consumption of burbot fillets. This question asked what information should be provided with a fish product.

What information should be provided with a fish product to enhance value?	Percentage of panelists who picked Various options for enhancing value
Suggestions for preparation/recipe cards	68%
Description of taste qualities	60%
Nutritional information	50%
Place of origin; local vs. domestic vs. imported	47%
How raised; Farmed vs. wild harvest	45%
Sustainability; fish viability, environmental impact	15%
General information about the fish and its habitat	12%

When ordering fish in a restaurant, consumers were most interested in the fish's taste qualities and the background of the particular fish being ordered. However, nutritional information continued to be important.

Table 12. Responses of 124 out of 200 people asked to respond to various questions regarding the use, cost, and consumption of burbot fillets. This question asked what information should be made available to purchasers.

What information should be made available to purchasers of fish products?	Percentage of panelist responding to question
Description of taste qualities	76%
How raised; Farmed vs. wild harvest	59%
Place of origin; local vs. domestic vs. imported	57%
Nutritional information	41%
Special/Uniqueness; seasonal, rare	27%
Sustainability, fish viability, environmental impact	15%
General information about the fish and its habitat	10%

About half of the panelists reported spending between $5.00 and $7.00 per pound with about one third of the panelists reported spending between $3.00 and $5.00 per pound for fish, either fresh or frozen. A retail price of about $5.00/pound would be perceived as a reasonable price relative to other fish purchases.

Recipe Development

Individual recipe cards were designed and printed. The 4" x 6" cards have the recipes printed on one side. The other side is blank to allow an individual establishment the ability to print business information on the blank side or use as a post card to send to potential customers. Eight recipes were developed including simple dishes that could be grilled, broiled, or baked (Appendix 6).

Restaurant Use and Taste Tests for Burbot Fillets

Twelve of the 15 restaurants deep-fried the burbot fillets in place of their usual product. Eight of the 12 restaurants used pollack as their usual product and four used frozen ocean cod. One restaurant featured burbot as part of their "All You Can Eat Fish" Friday Special. The burbot fillets were seasoned and baked and set out on a self-serve buffet table. Two of the restaurants "lost" the test product; they were not sure how the fish was used, who might have prepared it, or what consumers thought of it.

Discussion

Commercial fishers we discussed this project with complained about the large amount of waste generated when dealing with burbot carcasses. The percent of the fish that is fillet ranged from 21.3 to 25.9 %, with a good additional proportion being liver (5.6-8.6%). If the liver could be utilized, this would be an additional good use of the product. Previous researchers (Lindsay et al. 1981) showed that 35% of a burbot is composed of usable fillets, leaving 65% of the fish as waste.

Burbot are susceptible to being captured in large numbers when they congregate on spawning sites in mid winter, usually rocky reefs and rivers in the Great Lakes. This strongly suggests that one would have to target these large concentrations of fish to make collection of burbot productive. However, we have seen large catches of burbot in NE Lake Michigan during summer in gill nets set by commercial fisherman. Collection of large numbers of fish mandates that some type of preservation and processing of the product will need to be done at the time of maximum harvest potential and make it available for large periods of time after collection. Hence TPP treatment and vacuum packing is one way to treat burbot to establish a viable way of handling large numbers of fish fillets that can be used later for dinners or fish chowder.

Results of taste tests on flesh quality showed: 1.) there did not appear to be a difference in taste among site or season, 2.) often the burbot were as good as the control marine cod product, and 3.) the front part of the burbot fillet (there are two major types of fillets one gets, a nice piece adjacent to the head and a smaller, more dark tail piece) was far more desirable for handling and producing a nice product, but the taste was similar between the two types of fillet (they were kept separate in early tests), and 4.) It was immediately obvious that the vacuum-packed, TPP treatment was superior to all other treatments, so for the last collection of specimens, all fish were vacuumed packed and treated with TPP, then frozen for future analyses. Some of these fish were provided to local chefs and restaurants and some were shipped to a Chicago fish company, which requested burbot for a specific application.

While it is technically feasible to process fresh burbot into an acceptable tasting product, marketability will be limited 1) by inability to capture the "lobster taste" associated with absolutely fresh burbot that are caught and eaten the same day, and 2) by its frozen-only form, which was required to deliver commercially available quantities with acceptable taste quality.

There appears to be no major negatives associated with the concept of using burbot fillets that would prohibit market introduction. However, inability to deliver a product with distinctive and exceptional taste would limit its potential within the food-service segment as a lower-priced replacement for undifferentiated ocean whitefish. As a retail product it would provide an additional local, freshwater fish variety with a unique texture attribute that allows the meat to maintain its form when used in a variety of preparations, such as grilled kabobs, stir-frys, and soups and chowders.

Discussions among company employees indicated little enthusiasm for commercializing burbot. There were two reasons. First, there was concern about consistently receiving high quality burbot from fishers and the need to process it immediately to capture its positive eating qualities. Even with careful handling, the employees did not think the eating quality of burbot was comparable to other commercial species of freshwater fish. Second, yield of useable fillets was low and would generate considerable waste creating a disposal problem. Subsequent discussions with local commercial fishers revealed that the prized "lobster-like" taste associated with burbot was elusive. It was only detectable in fish caught and eaten the same day. With very careful handling, the "lobster-like" flavor may be present 1 day after being caught, but no longer.

Employees concluded the only feasible processing method for commercial production of burbot should consist of the following steps:

1. Same day processing of freshly caught fish into boneless, skinless fillets
2. Treatment of fillets by dipping in a 5% solution of TPP
3. Separate vacuum packaging of anterior and posterior fillets
4. Freezing of the packaged fillets within 24 hr of initial receipt of the fish.

Anterior fillets proved best for dinners and fish frys. The irregular form and darker color of the posterior fillets makes this portion of the fish suitable only as an ingredient in a formulated finished product, possibly a chowder or fish cake.

Lastly, it should also be noted, that our contact with Ken Koyen, a Green Bay commercial fisherman was very productive for several reasons. He is currently doing what we proposed for this study. He tries to collect fresh burbot every day for his restaurant on Washington Island, WI. He uses gill nets and is very knowledgeable about where to go and obtain fish; he also collects lake whitefish. Burbot is served at his restaurant, and we sampled some of the fish he served on several different days. He served them deep-fried, broiled, and boiled. The broiled and deep fried ones were the best in our opinion, but the other form was also very good. He reported that he has had people fly in from Chicago when they knew he had fish available; other people at the restaurant also raved about his burbot. Thus, we believe that productive use of burbot has been proven, the product is excellent, it can be served in restaurants, the TPP-vacuum-packed treated fish gets around the problem of supply, since fish can be frozen and used later with little loss of quality, and knowledgeable commercial fisherman know where and when to harvest them.

EXPLOITATION IMPACT

Introduction

At our Washington Island, WI, site, Ken Koyen, restaurant owner and commercial fisherman, specifically targeted burbot to catch fish for his restaurant every day, which provided us the opportunity to get a glimpse of what might occur if commercial fishers began targeting burbot on a larger scale. Assessing the impact of commercial fishing on burbot was beyond the scope of this project. However, we examined the length of burbot among sites to see if commercial gillnet fishing altered the size of burbot at Washington Island, as we would suspect this sort of fishery would remove the fattest individuals at a given length from the local population. Interestingly enough, fish from Washington Island were generally lower in weight and shorter than those from our other sites, where burbot were caught but not targeted.

ANCILLARY INFORMATION

Diet and Growth of Burbot

One of the startling results of this study concerns some of the basic information we gathered. Besides burbot length, weight, and weight of liver and fillet (collected to provide information on fillet yield per fish), we also collected diet information. Fish were dissected, stomach contents removed, and individual fish eaten were identified, weighed on a portable digital scale (to nearest 0.1 g), and total length measured or estimated if there were enough remains. Invertebrates, when present were also weighed. Diet information was synthesized and analyzed by size, season, and site. We also examined growth differences among sites using length-weight regression equations and covariance analyses.

The data on diet and growth of burbot was compiled into a paper that was submitted to the Proceedings of the American Fisheries Society's Second International Burbot Symposium (see Appendix 1). Here we recount some of the information used in that paper. The length-weight relationship was calculated to determine if there were differences among sites (Fig. 1). As can be seen, the Alpena, MI Lake Huron fish were much larger than the Washington Island, WI, or the Fairport, MI fish. The Washington Island population is subjected to a fishery by Ken Koyen and the smaller size might reflect the selective removal of larger individuals or it may be that those burbot grow slower. However, it was obvious, at all three sites that diets of burbot and hence the fish communities they now inhabit, have changed dramatically. The historical diets of burbot relied exclusively on native species (Beeton 1956, Bonde and Maloney 1960, McCrimmon and Devitt 1954, Bohr and Liston 1981, Muth 1973); however, diets of the fish we sampled in the 2004-2005 era shifted dramatically to non-indigenous round gobies, first discovered in the Great Lakes in 1990 (Jude et al. 1992). Round gobies were found in the diets of burbot from all three populations studied. Interestingly, the Alpena, MI population was the one that showed the largest individual burbot (see Fig. 1) and DNR biologists noted that was something they had not seen prior to this year (2004). The diets of those burbot were also composed of the highest percentage composition of round gobies of the three populations studied. We found up to 46 round gobies in some stomachs, so fish there were availing themselves of the apparently abundant supply of this exotic fish species. This has consequences ecologically for the Great Lakes, as Janssen and Jude (2001) have found that anywhere round gobies dominate, that sculpin populations were reduced or extirpated. We believe this has or is in the process of happening at the sites we have studied and probably any other reefs where round gobies now dominate.

Secondly, round gobies eat large quantities of zebra mussels (French and Jude 2001), which can bioaccumulate toxic substances because of their filtering of the water column of algae and associated detritus. This can lead to increased uptake of toxic substances because of the new ecosystem pathway established by the zebra mussel-round goby interaction. Certainly more work needs to be done in this area to elucidate effects and we either have or expect to submit proposals to EPA and have just recently received notice that a preproposal was asked to be updated to a full proposal by the Great Lakes Fishery Commission to pursue this line of study. The title of the proposal is: The Role and Impact of Round Gobies on Native Fish Communities on Coldwater, Great Lakes Reef Food Webs due in June 2007.

Use of Burbot Livers

Burbot livers were used for cod liver oil substitutes (e.g., lantern fuel) during world war II and there still may be a market for their use both as an oil product and for omego-3 fatty acid contributions for pharmaceutical and dietary supplements. We contacted a company in Ann Arbor, MI called Cayman, Inc., which works with biological products derived from many different sources. We proposed the idea to investigate the use of the liver of freshwater cod for various products, including omega-3 fatty acids, and as cod liver oil. We have not received a response.

Mercury and PCBs Concentrations in Burbot Liver and Fillets

Introduction

Development of any market for a fish product invariably brings up the question of toxic substances. The two most important ones in the Great Lakes have been PCBs and to a much lesser extent, mercury. PCBs generally are associated with fatty fishes, such as salmon and common carp, while high mercury levels, since they are associated with flesh, and not fat, generally accumulate in less fatty fish, especially if the water body they reside in has a large watershed and gets a considerable amount of atmospheric input from sources upwind. As we have noted elsewhere, burbot are not fatty fish and probably most PCBs bioaccumulated will end up in the liver. However, this is not true for the flesh, which is a terminal depot for mercury. In an effort to determine if there might be problems with burbot fillets we examined the literature and have data on mercury for some burbot fillets. These data on mercury came from another study to which we were fortuitously asked to provide specimens.

Methods

We have initiated another research effort with Joel Blum, Department of Geology, University of Michigan to investigate mercury uptake and depuration in burbot livers and fillets. Fish are oven-dried, ground up, and mercury is measured on state of the art spectrophotometers. Analyses continue and results presented here are preliminary. We will continue to work with Joel and supply him with additional samples of livers and fillets from burbot we collected.

Results

This change in burbot diets and shift to exotic species may compromise the use of burbot to be used commercially if these changes result in toxic substance buildup in top predators, such as the burbot. Paakkonen et al. (2005) fed PCBs to burbot and found that: 1.) 65-81% of the PCBs were retained with highest doses found in the liver, and 2.) levels of PCBs in burbot collected in 2005 were no different from levels observed in the 1970s, despite banning PCBs. Lindsay et al. (1981) showed Lake Michigan fillets in 1980 contained <1 ppm of PCBs.

The preliminary mercury data (Fig. 12) showed that of the 12 samples that were analyzed, that most fillets were well below 0.5 mg/kg wet-wt (PPM), which in Michigan is the level of mercury in fish fillets that would trigger some restrictions to eating them. The upper limit for no consumption is 1 mg/kg and no burbot were close to that level.

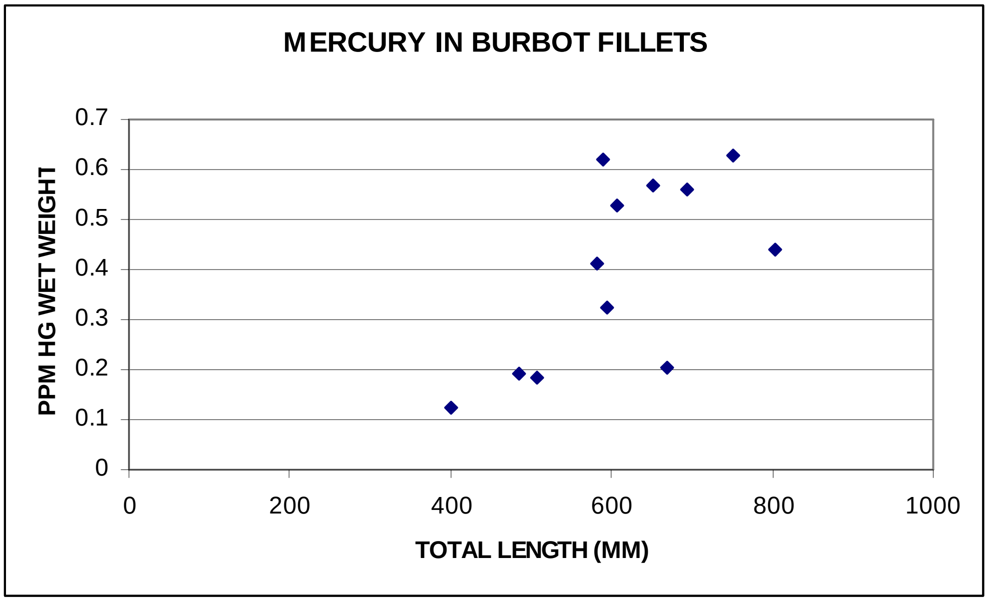


Figure 12. Preliminary data on total mercury concentrations of burbot collected from Leland and Charlevoix, MI and Washington Island, WI. Fish were collected during June 2006 from commercial fishers during our study. Data were provided by J. Blum, Department of Geology, University of Michigan and are preliminary.

SOLEC Conference Paper

Lastly, we were invited to present a paper on our work to the SOLEC (State of the Lakes Ecosystem Conference - a conference on Great Lakes research sponsored by EPA) and it was given on 1-4 November 2006. The abstract is presented as Appendix 2.

SUMMARY AND CONCLUSIONS

Introduction

We made progress on all three fronts for this study, including gear development, how to best treat fish collected in the field that would facilitate the best transportation to a processing facility, and we taste-tested fillets, developed recipes for marketable food products, involved chefs who used them in their restaurants, and pursued other product and marketing developments. We also explored avenues for product development outside the food industry.

Gear Development

We researched burbot behavior and determined that they are active predators that can travel long distances, use their lateral line and barbel to detect prey, and can migrate into the water column to capture prey items in the pelagic zone. Our intent was to exploit these behaviors to target burbot using non-traditional gear that would limit by-catch. We used four gear types: square slat or catfish traps made of wood, other cylindrical traps covered with large-mesh, nylon netting, baited with fish; trammel nets; and long or trot lines baited with fish. We fished these gear alone and in conjunction with cooperative commercial fishermen, who were enthusiastic about our research. We collected six burbot: one in the trammel net, one in a baited slat/catfish trap, and four on the long lines. We concluded from this work that burbot were attracted to bait; that commercial fisherman could probably set enough of the slat traps to target mostly burbot; that the long lines were not very effective, needed more testing, had surprisingly little by-catch, and were potentially dangerous to handle and tangled often; and the trammel nets, although they collected one burbot, had too much by-catch to recommend them. Our work also suggested that burbot are often part of the by-catch in gill nets and commercial trap nets, so could be utilized, and often are, as a food product. The catch in the winter at Fairport demonstrated the high catch rates that are attainable during the spawning season and strongly suggests that if large numbers are to be harvested, targeting the spawners would yield high catches. Overharvest might also result, so careful planning would be required.

Burbot Transport from Source to Market

Burbot cannot be frozen raw without first being dipped in a sodium tripolyphosphate solution, as considerable degradation of the fish and fillets can result. Hence we worked on determining what methods might be utilized to ensure a high quality product is delivered to markets. We devised a research strategy to test various ways of treating burbot fillets to ascertain which methods would provide the best product. This included filleting the fish, processing the fillets using various treatments, and then taste testing each one to determine which one provided the best product. We found from previous work that enzymes were responsible for hardening the flesh and making it unacceptable for consumption, and further, that TPP (tripolyphosphate) could deactivate these enzyme systems. Hence our recommended treatment of fillets included: Same day processing of freshly caught fish into boneless, skinless fillets; TPP treatment + vacuum packing; freezing of the packaged fillets within 24 hr of initial receipt of the fish.

Burbot Carcass Disposal Problems

Commercial fishers we discussed this project with complained about the large amount of waste generated when dealing with burbot carcasses. The percent of the fish that is fillet ranged from 21.3 to 25.9 %, with a good additional proportion being liver (5.6-8.6%). If the liver could be utilized, this would be an additional good use of the product. Previous researchers (Lindsay et al. 1981) showed that 35% of a burbot is usable fillets.

Taste Tests

Expert panel results of taste tests with side-by-side testing of burbot fillets (various treatments) found that samples dipped in a dilute solution (5% TPP) and vacuum packed provided superior taste attributes versus a comparable untreated sample. In spite of wide variability in the size of the fillet and collection method, there was a clear preference for the treated sample.

While it is technically feasible to process fresh burbot into an acceptable tasting product, marketability will be limited 1) by inability to capture the "lobster taste" associated with absolutely fresh burbot, caught, and eaten the same day, and 2) by its frozen-only form, required to deliver commercially available quantities with acceptable taste quality.

Marketing

Questionnaire Responses to Burbot-Related Questions

Among chefs and restaurant owners, the idea of using burbot fillets was perceived primarily as a direct replacement for cod or pollack that they were already using. The majority of these panelists perceived ocean cod as a bland tasting, inexpensive fish. Local fish and meat markets that carry fresh fish were more interested in burbot as an additional, new fish offering. They thought it was important that it was a local fish that had a distinctive character that would set it apart from other fish. One local grocery chain felt it was important that it came from a well known, local processor with a reputation of providing consistently high quality.

The one restaurant that featured burbot on the "All You Can Eat Buffet" was more enthusiastic. This restaurant reported that his clientele consumed all of the burbot he was given to test. He positioned it as a local fish and used the name burbot. However, when asked about the product quality relative to frozen ocean cod that would normally be used, he rated it no better than ocean cod and was only willing to pay a price comparable to ocean cod. Nevertheless, this restaurant wanted to purchase burbot on an ongoing basis for the "All You Can Eat" Friday Fish Special because use of local fish was important to his clientele.

There was no single type of outlet that was preferred for purchasing fish. This suggests it is possible to reach the majority of fish consumers without the complexity and large volume associated with dealing with a large, national chain.

Fresh fish were the most common way that fish products were purchased (39.4%). There was a bias against frozen fish, which may make marketing of frozen burbot fillets more difficult. When purchasing fish at stores two thirds of consumers would like recipe cards and preparation suggestions. In general, consumers would like point-of-purchase information about the fish they are eating, its taste qualities, and its nutritional profile. This suggests that both brochures and recipe cards, along with the fish product, would be useful.

Burbot Recipes

Based on concept test results, eight recipes featuring burbot fillets were developed. The majority of recipes incorporated the preferred preparation methods of baking, broiling, and grilling, and simplicity in preparation.

Markets for Burbot

There appears to be no major negative aspects associated with the concept of marketing burbot that would prohibit introduction to the public. However, inability to deliver a product with distinctive and exceptional taste, would limit its potential within the food service segment as a lower-priced replacement for undifferentiated ocean fishes. As a retail product it would provide an additional local, freshwater fish variety with a unique texture attribute that allows the meat to maintain its form when used in a variety of preparations, such as in grilled kabobs, in stir-fry, and in soups and chowders.

Discussions among company employees indicated little enthusiasm for commercializing burbot. First, there was concern about consistently receiving high quality burbot from fishermen and the need to process it immediately to capture its positive eating qualities. Second, yield of useable fillets was low and would generate considerable waste, creating a disposal problem. Subsequent discussions with local commercial fishermen revealed that the prized "lobster-like" taste associated with burbot was elusive. It was only detectable in fish caught and eaten the same day. With very careful handling, the "lobster-like" flavor may be present 1 day after being caught, but no longer.

Consequently, all use testing of burbot was done with treated, vacuum-packed, frozen fillets. All testing was done with anterior fillets. The irregular form and darker color of the posterior fillets makes this portion of the fish suitable only as an ingredient in a formulated finished product, possibly a chowder or fish cake.

Existing Restaurant That Serves Burbot

Ken Koyen, Washington Island, WI is currently doing one of the activities we recommended from our work: he collects fresh burbot and serves them at his restaurant every day during the year that he can get out and fish. He serves them deep-fried, broiled, and boiled. The deep-fried and broiled ones were the best in our opinion, but the other form was also very good. It is a popular item on the menu and is well known, even as far away as Chicago as the place to come for burbot dinners. We believe similar enterprises could be developed using treated burbot for dinners as well. Other products have also been tested, such as cod chowder, which turned out to be very good because the texture of burbot lends itself to firmness in the product, which is better for chowder than other fish that flake and disintegrate.

Over Exploitation

Burbot are vulnerable during their spawning time in winter as they aggregate on the reefs of the Great Lakes and migrate up rivers as well. This will be an obvious place to collect them, which will be good as it concentrates the fish making capture easy, but could also lead to over fishing, if the project leads to higher collections of burbot. Currently, burbot are not regulated and are considered by-catch by the MI DNR and possible competitors for prey with other salmonines.

We examined the length of burbot among sites to see if commercial gill net fishing altered the burbot at Washington Island, as we would suspect this sort of fishery would remove the heaviest individuals at a given length from the local population. Interestingly enough, fish from Washington Island were generally lower in weight and shorter than those from our other sites, where burbot were caught but not targeted.

Recent Burbot Diets

Burbot diets have changed substantially from native fish and invertebrate species to a diet that includes large proportions of the non-indigenous round goby (77% in Lake Huron near Alpena, MI; 53% in Lake Michigan near Fairport, MI). Establishment of round gobies in the open waters of the Great Lakes is likely to change cold-water food webs, including replacement of sculpins (*Cottus* spp.) at depths up to 70 m, where round gobies have been found. Round gobies have the potential to accumulate more toxic substances than native forage fishes through consumption of zebra (*Dreissena polymorpha*) and quagga (*D. bugensis*) mussels.

Contaminants in Burbot

If burbot retain high concentrations of toxic substances from eating native species or if the recent change in burbot diets and shift to the exotic round goby, which eats the exotic filter-feeding dreissenids, lead to toxic substance bioaccumulation in burbot, it could compromise the commercial use of burbot products. Paakkonen et al. (2005) fed PCBs to burbot and found that: 1.) 65-81% of the PCBs were retained with highest doses found in the liver, and 2.) levels of PCBs in burbot collected in 2005 were no different from levels observed in the 1970s, despite banning PCBs. Lindsay et al. (1981) showed Lake Michigan fillets in 1980 contained <1 ppm of PCBs.

The preliminary mercury data we obtained showed that of the 12 samples that were analyzed, that most fillets were well below 0.5 mg/kg wet-wt (ppm), which in Michigan is the level of mercury in fish fillets that recommends some restrictions for consumption. The upper limit for no consumption is 1 mg/kg and no burbot were close to that level.

ACKNOWLEDGEMENTS

We thank the National Marine Fisheries Service, whose support through Saltonstall-Kennedy Program funds enabled sample collections for this study. We thank Joyce Lacerda, NMFS, who congenially guided us through the process of dealing with all the requirements of the grant and Kathy Majors, SNRE, who handled all the financial report requirements and budget details for the grant. We also are grateful for the sampling assistance provided by: Jim Johnson and Randy Claramunt, Michigan Department of Natural Resources in Alpena and Charlevoix, MI; Mark Ebener, Inter-Tribal fisheries and Assessment Program, Chippewa Ottawa Resource Authority, Sault Ste. Marie, MI; commercial fishermen Ken Koyen, Washington Island, WI, William Fowler, Leland, MI, and Bill Peterson, Fairport, MI. William Carlson, Leland, MI and Paul Jensen, Muskegon, MI provided advice and specimens. Sample analysis space was graciously provided by Paul Jensen in Muskegon; Michigan DNR, Alpena, MI; the Mackinac Straits Fish Company, St. Ignace, MI; and Ken Koyen, Washington Island, WI.

Arthur Cooper, Institute for Fisheries Research, MDNR, graciously provided the map we used in the report. The burbot picture was provided by Michigan Sea Grant.

LITERATURE CITED

Beeton, A. Food habits of burbot (*Lota lota lacustris*) in the White River, a Michigan trout stream. Copeia 1956 (1):58-60.

Bohr, J. and C. Liston. 1981. Relative abundance and feeding relationships of sculpin (*Cottus* spp.), johnny darter (*Etheostoma nigrum*) and trout-perch (*Percopsis omiscomaycus*) in the Ludington pumped storage reservoir on Lake Michigan. Michigan Academician 111-123.

Bonde, T. and J. Maloney. 1960. Food habits of burbot. Trans. Amer. Fish. Soc. 89:374-376.

Edsall, T., G. Kennedy, and W. Horns. 1993. Distribution, abundance, and resting microhabitat of burbot on Julian's Reef, southwestern Lake Michigan. Trans. Amer. Fish. Soc. 122:560-574.

French, J.R. III and D. Jude. 2001. Diets and diet overlap of nonindigeneous gobies and small benthic native fishes co-inhabiting the St. Clair River, Michigan. J. Great Lakes Res. 27:300-311.

Gallagher, Linda. 2004. Luring lawyers. Michigan Out-of-doors, February 2004: 26-27.

Janssen, J. and D. J. Jude. 2001. Recruitment failure of mottled sculpin *Cottus bairdi* in southern Lake Michigan induced by the newly introduced round goby *Neogobius melanostomus*. J. Great Lakes Res. 27:319-328.

Johnson, J., M. Ebener, K. Ebhardt, and R. Bergstedt. 2004. Comparison of catch and lake trout by catch in commercial trap nets and gill nets targeting lake whitefish in northern Lake Huron. Michigan Department of Natural Resources, Fisheries Research Report 2071, Ann Arbor, MI.

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

Jude, D. J. and J. Leach. 1999. Fish Management in the Great Lakes (revised), Chapter 23, pp. 623-664. In: Fisheries Management in North America, (Eds.) C. Kohler and W. Hubert, American Fisheries Society, Bethesda, Maryland.

Krivchenia, M. and O. Fennema. 1988. Effect of cryoprotectants on frozen burbot fillets and a comparison with whitefish fillets. J. Food Science 53(4):1004-1008.

Lindsay, R., D. Stuiber, B. Stewart, and V. Carlson. 1981. Evaluation of burbot (*Lota lota*) acceptability for processing. Can. Inst. Food Sci. Technol. J. 14:196-202.

McCrimmon, H. and O. Devitt. 1954. Winter studies on the burbot, *Lota lota lacustris*, of Lake Simcoe, Ontario. Can. Fish. Cult. 16:35-41.

Muth, K. 1973. Population dynamics and life history of burbot, *Lota lota* (Linnaes), in Lake of the Woods. PhD thesis, University of Minnesota.

Stapanian, M, C. Madenjian, C. Bronte, M. Ebener, B. Lantry, and J. Stockwell. In press. Status of burbot populations in the Great Lakes. J. Great Lakes Res.

Stapanian, M. and C. Madenjian. 2007. Evidence that lake trout served as a buffer against sea lamprey predation on burbot in Lake Erie. N. Amer. J. Fish. Mangt. 27:238-245.

Stapanian, M, C. Madenjian, and L. Witzel. 2006. Evidence that sea lamprey control ed to recovery of the burbot population in Lake Erie. Trans. Amer. Fish. Soc. 135:1033-1043.

LIST OF FIGURES

Figure 1. Length-weight regressions for three populations of burbot sampled in the Great Lakes. Fish came from NW Lake Huron (Alpena, MI), N Lake Michigan (Fairport, MI), and Green Bay (Washington Island, WI). Lengths and weights were log transformed.

Figure 2. Mean number of burbot collected in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

Figure 3. Mean number of fishes other than burbot (by-catch) collected in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

Figure 4. Mean number of burbot collected per hour in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

Figure 5. Mean number of fishes other than burbot (by-catch) collected per hour in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

Figure 6. Mean number of burbot collected per meter in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear.

Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

Figure 7. Mean number of fishes other than burbot (by-catch) collected per meter in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

Figure 8. Mean length (mm) of burbot by season in Lake Huron at Alpena, MI, and in Lake Michigan at Fairport and Leland, MI, and Washington Island (Wash. Is.), WI during 2004-2006. Error bars represent ± 2 standard deviations of the mean.

Figure 9. Mean weight (g) of burbot by season in Lake Huron at Alpena, MI, and in Lake Michigan at Fairport and Leland, MI, and Washington Island (Wash. Is.), WI during 2004-2006. Error bars represent ± 2 standard deviations of the mean.

Figure 10. Mean percentage that fillets compose of total body weight (g) of burbot collected in lakes Huron and Michigan at Alpena and Fairport, MI, and Washington Island, WI, (Wash. Is.) during fall and winter 2004 through 2006. Error bars represent ± 2 standard deviations of the mean.

Figure 11. Mean percentage that livers compose of total body weight (g) of burbot collected in lakes Huron and Michigan at Alpena and Fairport, MI, and Washington Island, WI, (Wash. Is.) during fall and winter 2004 through 2006. Error bars represent ± 2 standard deviations of the mean.

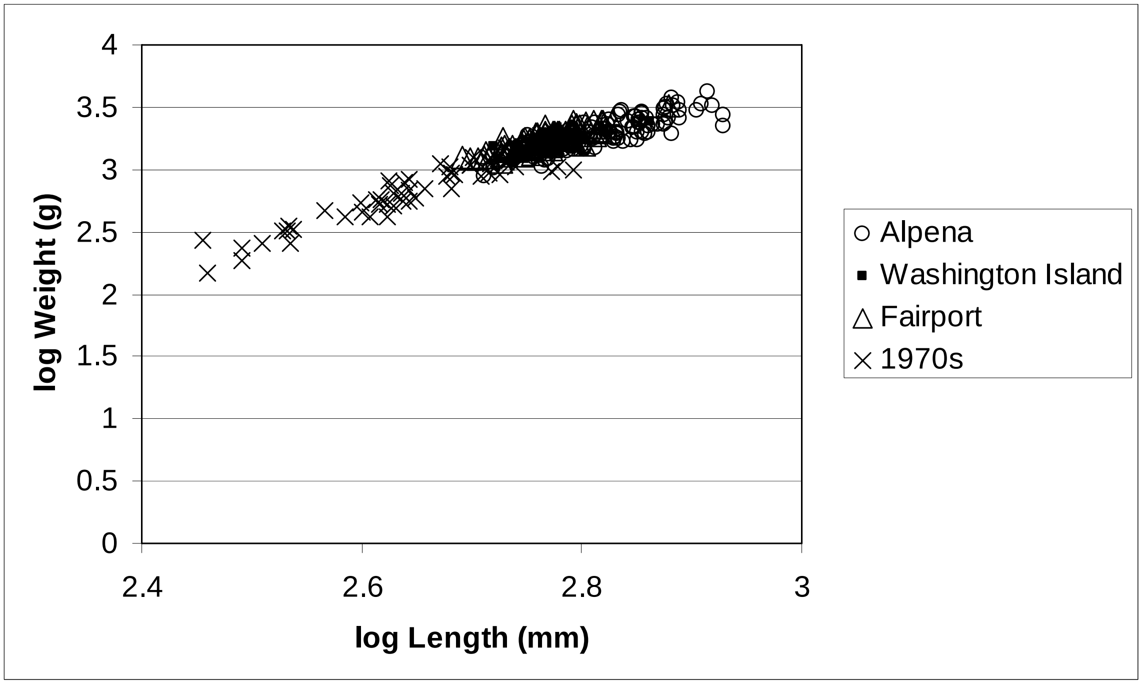


Figure 1. Length-weight regressions for three populations of burbot sampled in the Great Lakes. Fish came from NW Lake Huron (Alpena, MI), N Lake Michigan (Fairport, MI), and Green Bay (Washington Island, WI). Lengths and weights were log transformed.

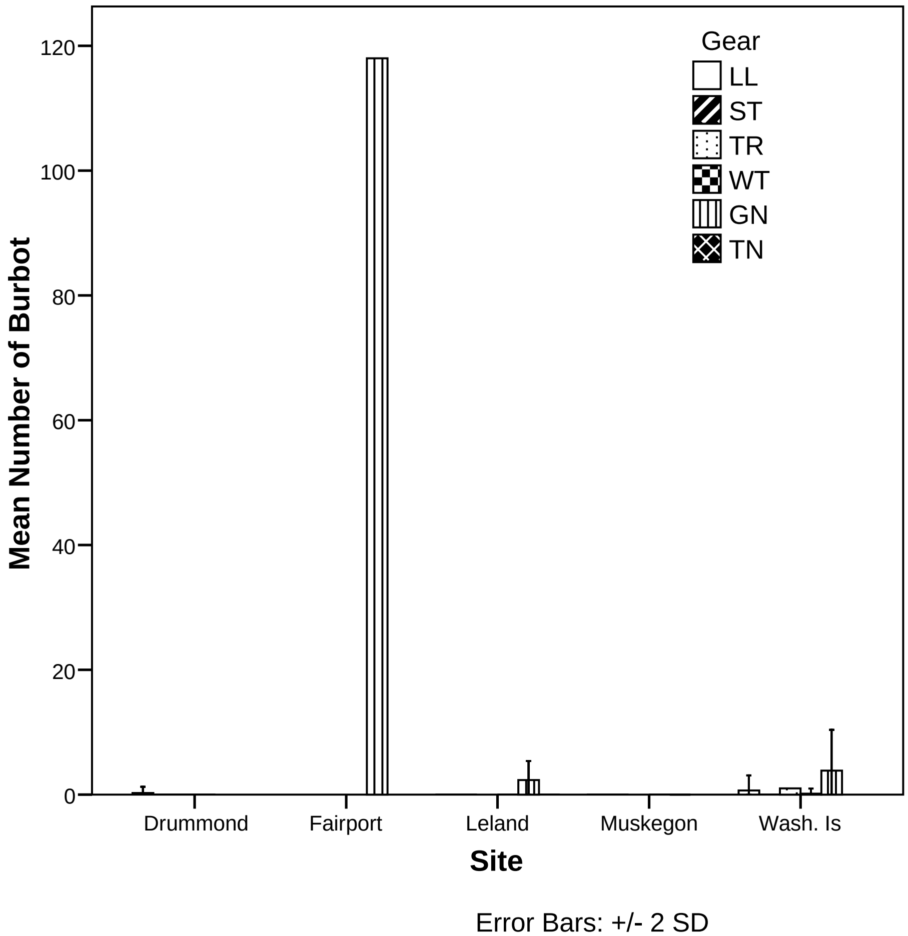


Figure 2. Mean number of burbot collected in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

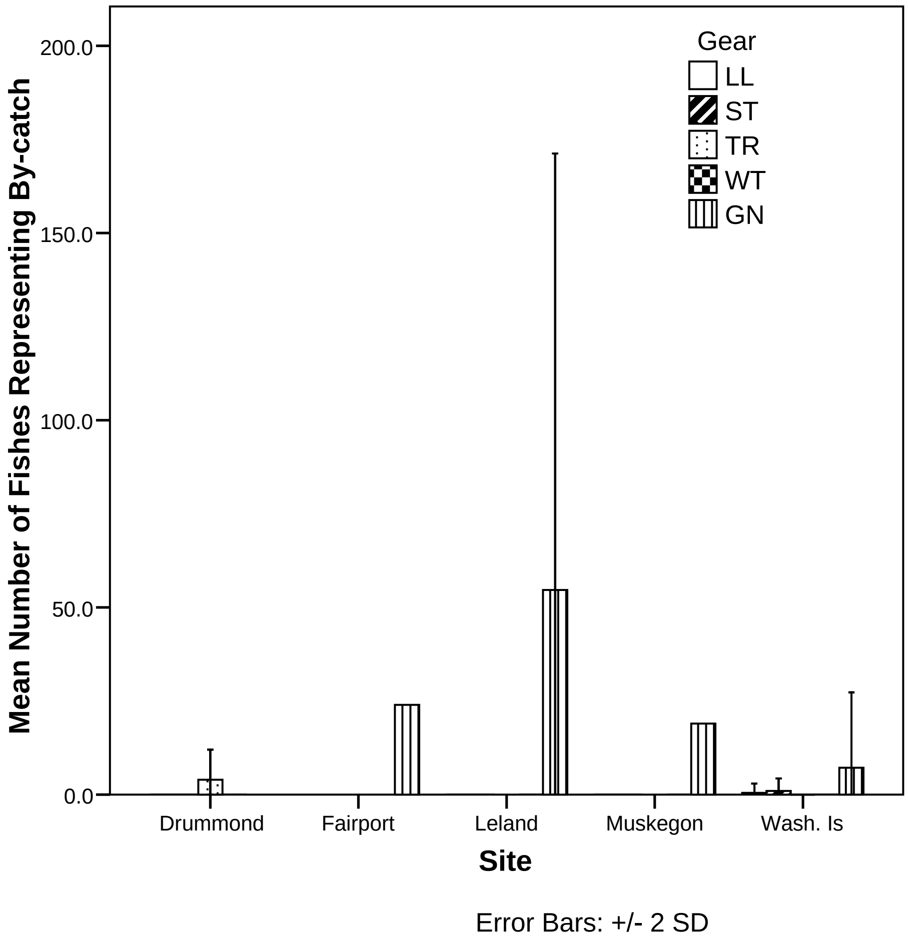


Figure 3. Mean number of fishes other than burbot (by-catch) collected in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

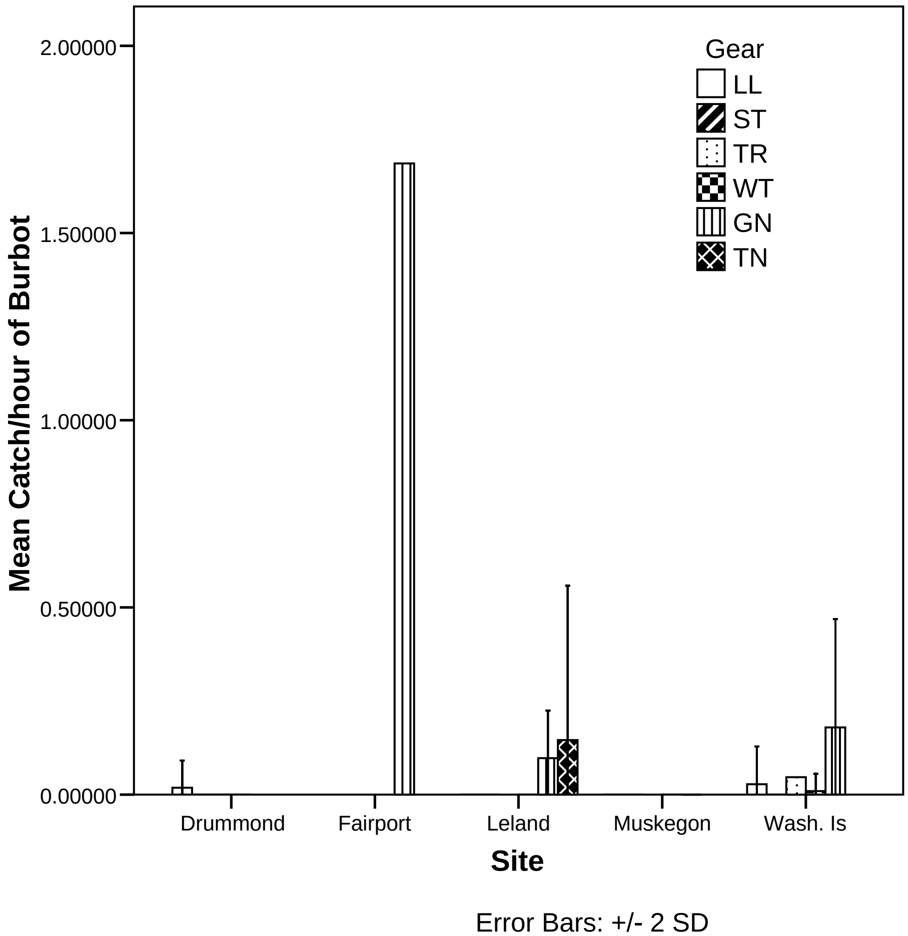


Figure 4. Mean number of burbot collected per hour in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

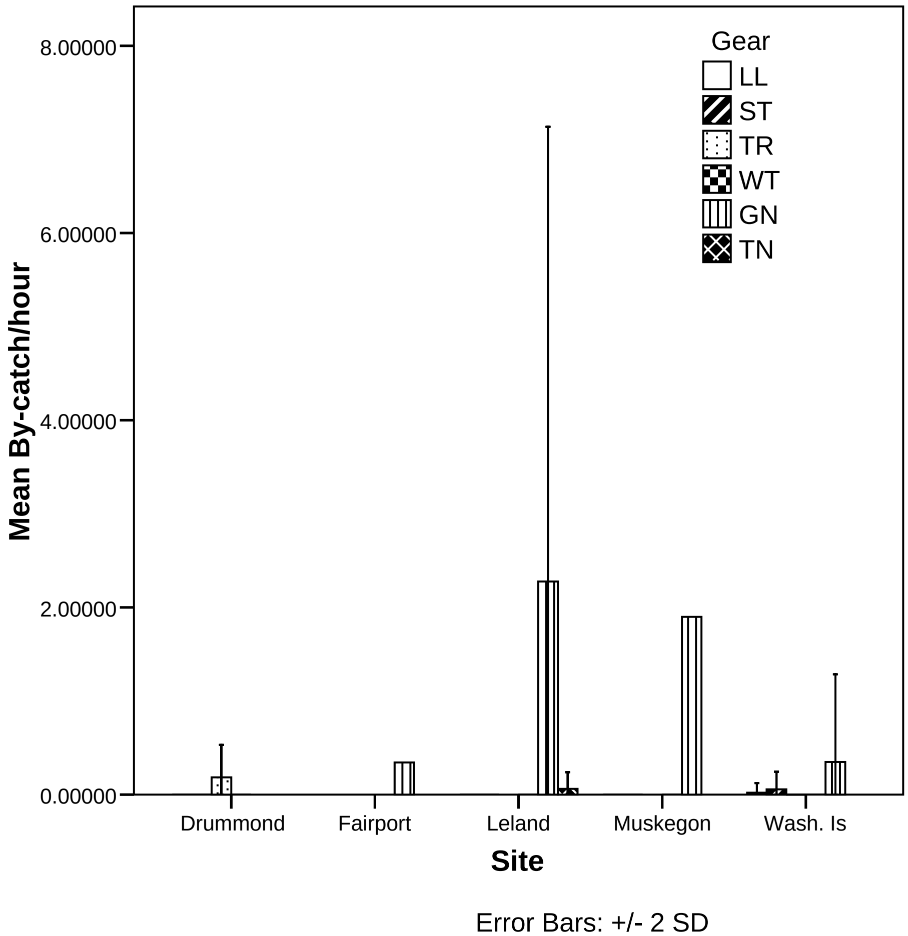


Figure 5. Mean number of fishes other than burbot (by-catch) collected per hour in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

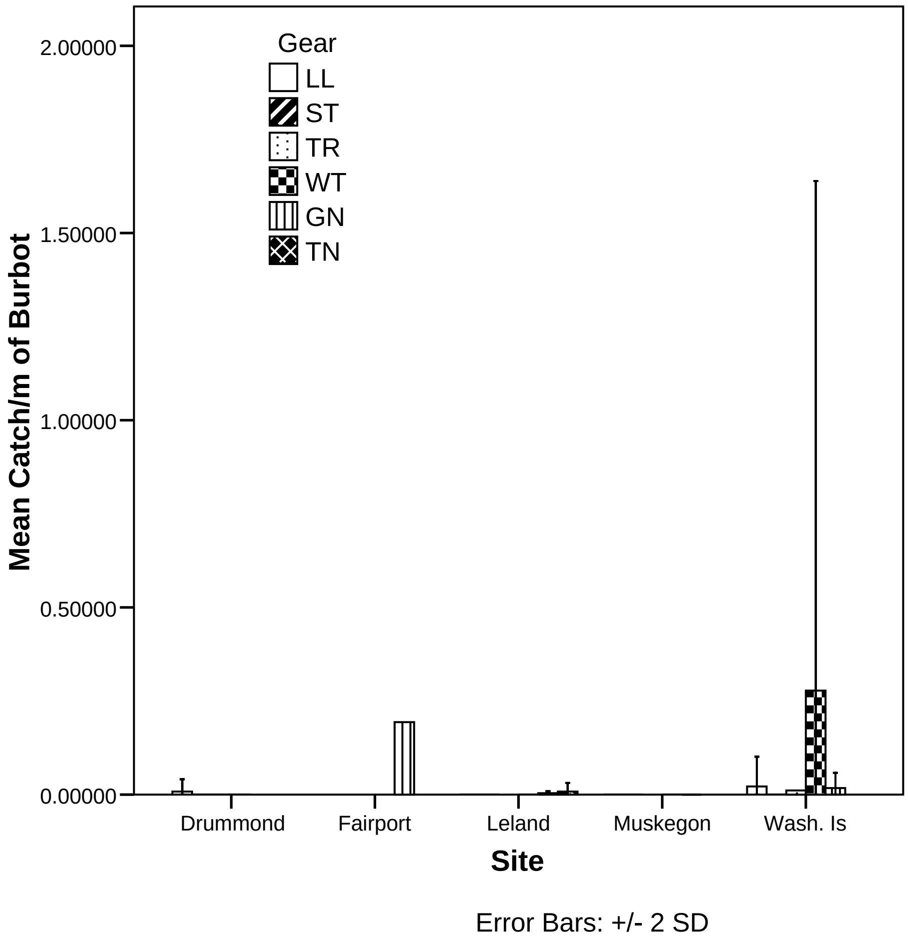


Figure 6. Mean number of burbot collected per meter in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

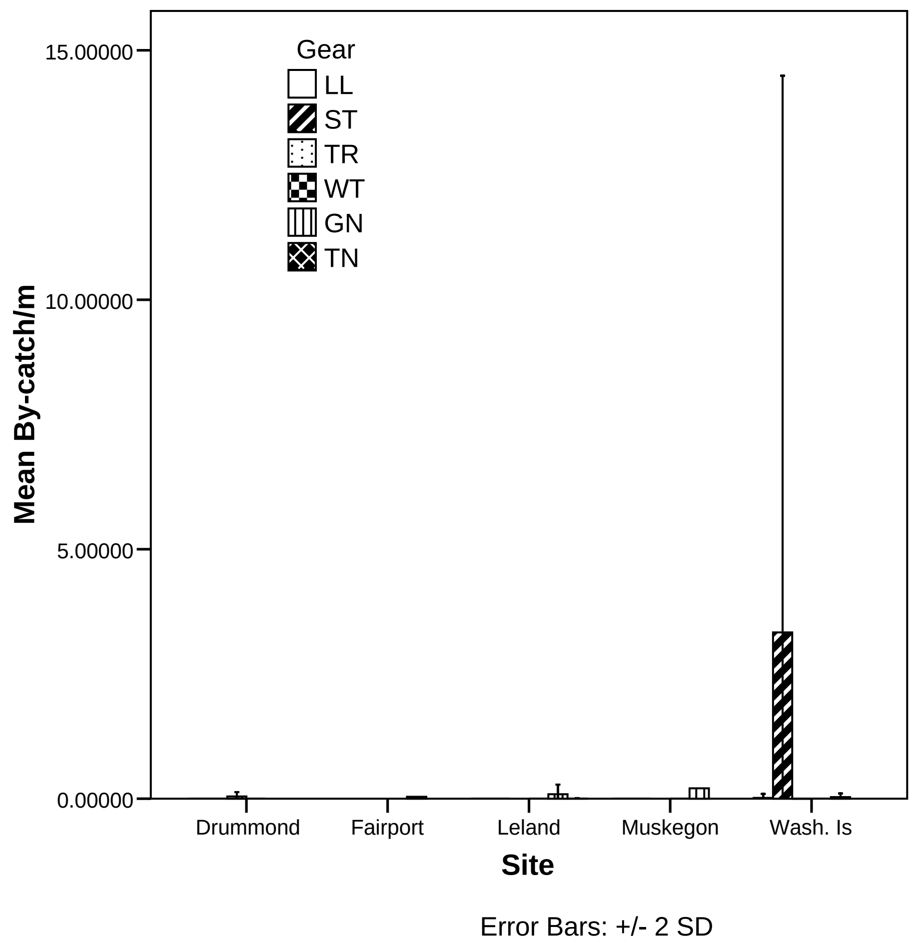


Figure 7. Mean number of fishes other than burbot (by-catch) collected per meter in lakes Huron and Michigan at Drummond Island (Drummond), Fairport, Leland, and Muskegon, MI, and Washington Island, WI, (Wash. Is.) during 2004 through 2006 in six different types of fishing gear. Error bars represent two standard deviations of the mean (only positive values displayed). Bars without standard deviation lines indicate infinite error bar results. Gears used were long lines (LL), slat traps (ST), trammel nets (TR), wire traps (WT), gill nets (GN), and trap nets (TN).

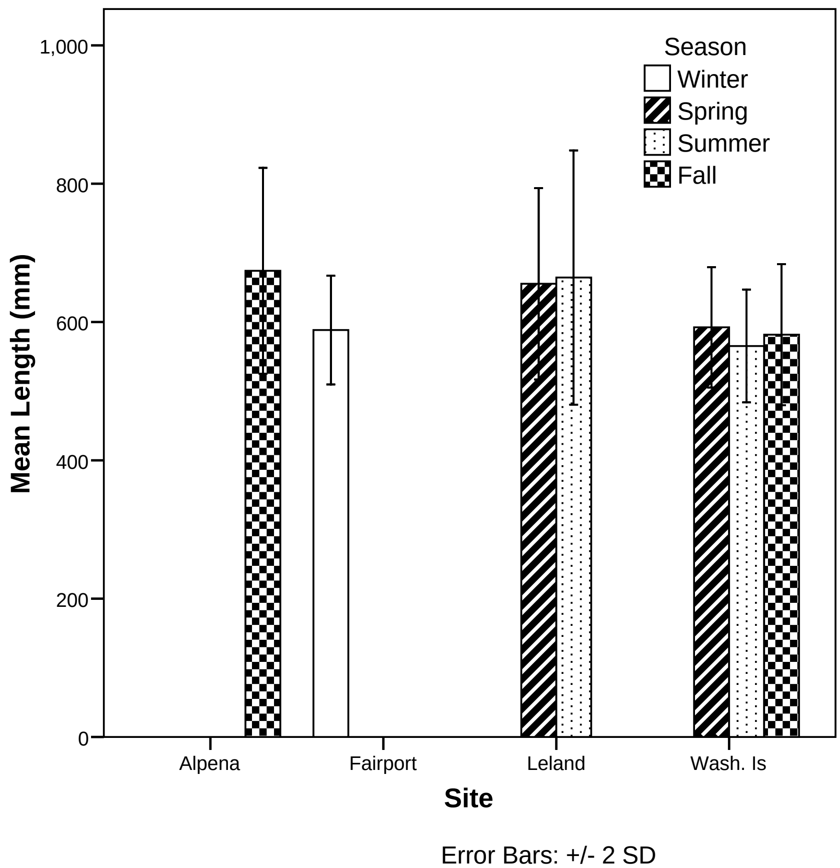


Figure 8. Mean length (mm) of burbot by season in Lake Huron at Alpena, MI, and in Lake Michigan at Fairport and Leland, MI, and Washington Island (Wash. Is.), WI during 2004-2006. Error bars represent ± 2 standard deviations of the mean.

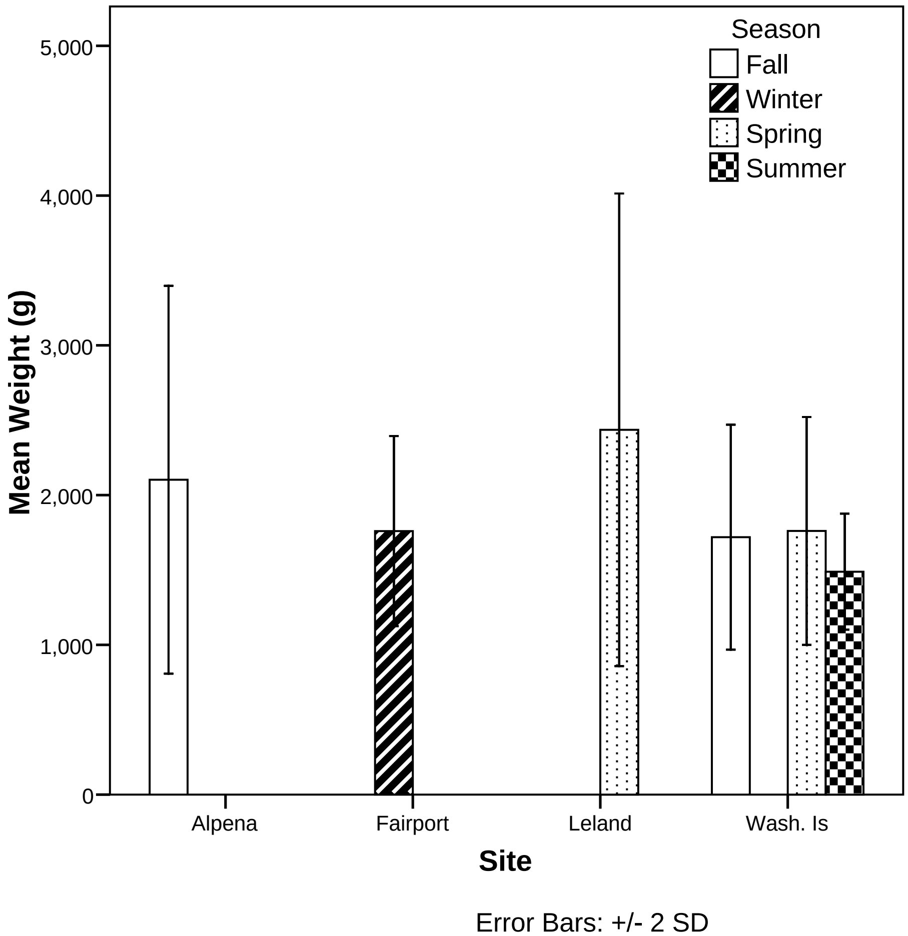


Figure 9. Mean weight (g) of burbot by season in Lake Huron at Alpena, MI, and in Lake Michigan at Fairport and Leland, MI, and Washington Island (Wash. Is.), WI during 2004-2006. Error bars represent ± 2 standard deviations of the mean.

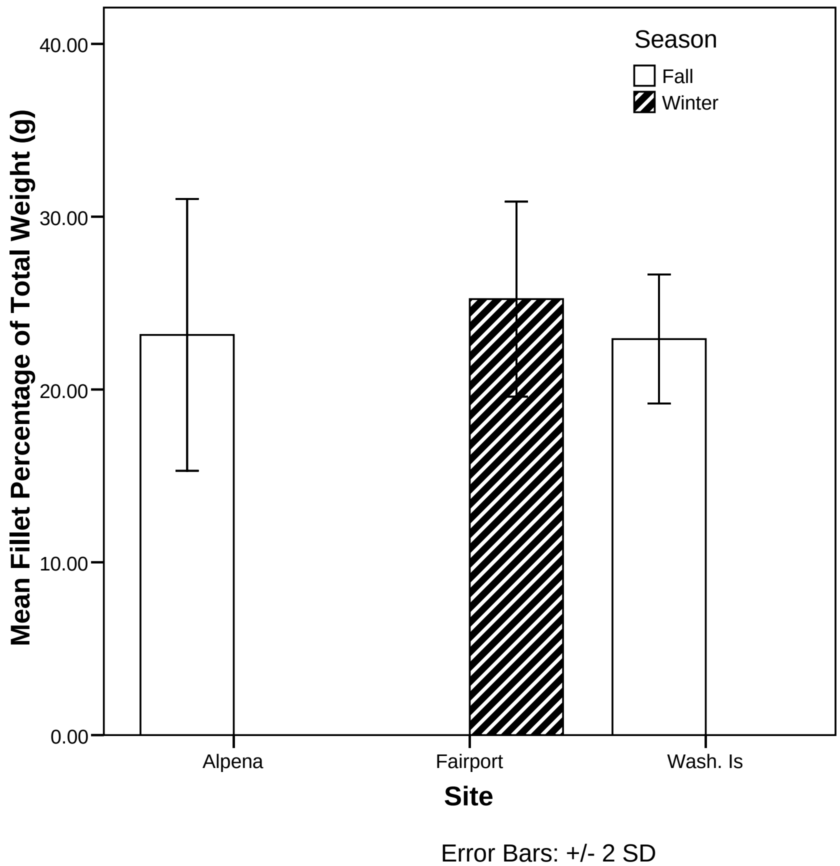


Figure 10. Mean percentage that fillets compose of total body weight (g) of burbot collected in lakes Huron and Michigan at Alpena and Fairport, MI, and Washington Island, WI, (Wash. Is.) during fall and winter 2004 through 2006. Error bars represent ± 2 standard deviations of the mean.

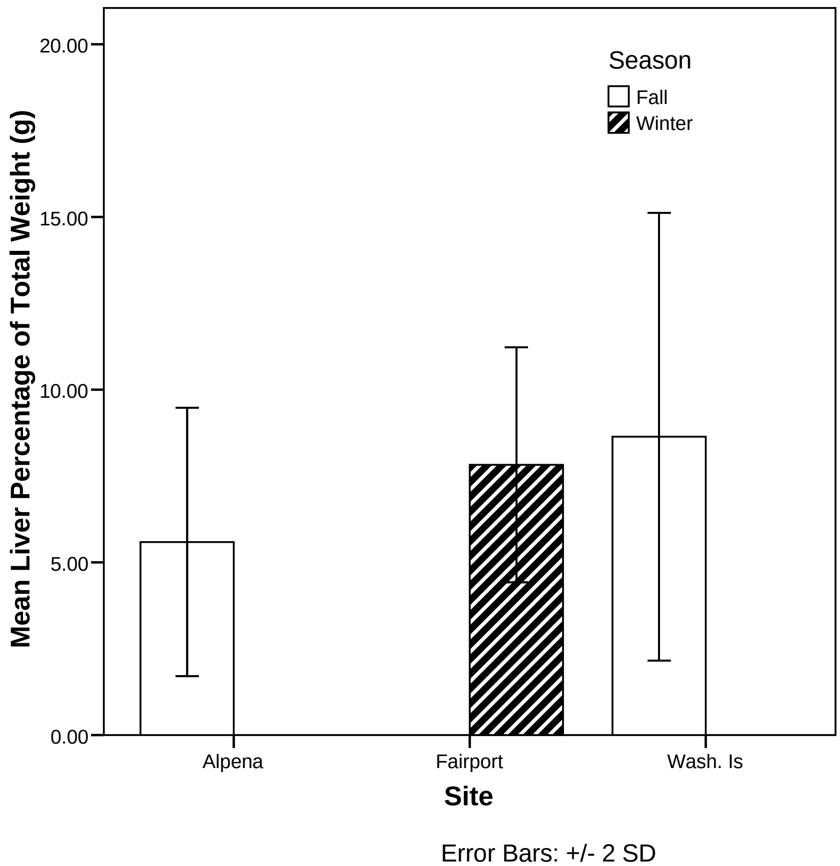


Figure 11. Mean percentage that livers compose of total body weight (g) of burbot collected in lakes Huron and Michigan at Alpena and Fairport, MI, and Washington Island, WI, (Wash. Is.) during fall and winter 2004 through 2006. Error bars represent ± 2 standard deviations of the mean.

APPENDIX 1. SUBMITTED PAPER ON BURBOT IN THE GREAT LAKES
Version: 18 Feb 2007

Submitted and reviews are back: accepted with revisions to be done: to

Proceedings of the American Fisheries Society's Second International Burbot Symposium

Impact of Invasive Round Gobies on Burbot Growth and Diets in Lakes Michigan and Huron

STEPHEN R. HENSLER* AND DAVID J. JUDE

University of Michigan, School of Natural Resources and Environment

440 Church St.

Ann Arbor, Michigan 48109, USA

JI X. HE

Michigan Department of Natural Resources, Alpena Fisheries Research Station

160 East Fletcher Street

Alpena, MI 49707, USA

*Corresponding author: shensler@umich.edu

Abstract-- Burbot *Lota lota* is a native species of cod found in the cold-water regions of all five Great Lakes. Burbot age-at-length data for three statistical districts in Lake Huron showed that fish reached ages of 18 yr old and grew faster in southern Lake Huron than in north-central and northern Lake Huron. Burbot growth and diet data were recorded for fish collected from three sites in Lake Michigan and one in northern Lake Huron to determine changes in growth and diet with the recent invasion of non-indigenous round gobies *Neogobius melanostomus*. We compared burbot growth from these locations with historical data from other available datasets and found no significant changes in burbot growth among sites. Burbot from Lake Huron were on average longer than those collected elsewhere. Burbot diets have changed substantially from native fish and invertebrate species to a diet that includes large proportions of the non-indigenous round goby (77% in Lake Huron near Alpena, MI; 53% in Lake Michigan near Fairport, MI). Establishment of round gobies in the open waters of the Great Lakes is likely to change cold-water food webs, including replacement of sculpins (*Cottus* spp.) at depths up to 70 m, where round gobies have been found. In areas where round gobies become abundant, commercial utility of burbot and potentially other top predators in cold-water environs of the Great Lakes may be compromised, as round gobies have the potential to accumulate more toxic substances than native forage fishes through consumption of zebra (*Dreissena polymorpha*) and quagga (*D. bugensis*) mussels.

Burbot (*Lota lota*), with a circumpolar distribution, are important top predators in the cold water regions of the Great Lakes. Historically, they co-evolved with lake trout (*Salvelinus namaycush*) as the two most important top predators in these cold water regions (Ward et al. 2000). Lake trout were extirpated in all the Great Lakes except Lake Superior and burbot populations were greatly depressed in Lake Michigan and other Great Lakes during the 1950s (Wells and McLain 1973), following colonization by the invasive sea lamprey (*Petromyzon marinus*) (Lavis et al. 2003). Burbot are particularly susceptible to sea lamprey predation (Swink 2003) and their larvae are also preyed on by alewives (Eshenroder and Burnham-Curtis 1999), which delayed their recovery in Lake Michigan till the 1980s (Madenjian et al. 2002). Burbot were likely able to survive and rebound from sea lamprey predation in the Great Lakes due to their high fecundity (up to 1 million eggs/female – Bailey 1972), early age at maturity (Swink and Fredricks 2000), and spawning in tributaries (Mansfield et al. 1983) and on reefs in lakes.

The burbot is a cold water, benthic, omnivorous fish species. Its main food items are other fish and invertebrates, with the proportion of fish in the diet increasing with size in burbot (Guthruf et al. 1990; Rudstam et al. 1995). Burbot are poor swimmers, but voracious feeders, adapted to stalking (Hackney 1973) and hunting from ambush (Boyer et al. 1989), taking advantage of the absence of light (Scott and Crossman 1973; Jones et al. 1974). On soft substrates, they inhabit trenches they excavate when possible (Edsall et al. 1993; Boyer et al. 1989). Because of their occasional feeding on emerald shiners *Notropis atherinoides*, they are assumed to be able to rise into the water column and migrate long distances, including to shallow water, in search of food (Clemens 1951; McCrimmon and Devitt 1954). Historically, native cottids and coregonines were eaten in Lake Michigan (Van Oosten and Deason 1938); in other areas yellow perch *Perca flavescens* were eaten in Mille Lacs Lake, MN (Bonde and Maloney 1960) and Heming Lake, Manitoba (Lawler 1963), while yellow perch *Perca flavescens*, lake herring *Coregonus artedii*, and emerald shiners were eaten in river mouths of Lake Simcoe, Ontario (McCrimmon and Devitt 1954). In Lake Michigan, diets of burbot shifted in the late 1980s to more exotic species, as Fratt et al. (1997) found alewife *Alosa pseudoharengus* and rainbow smelt *Osmerus mordax* to compose 56% of the diet. However, diet of burbot from Green Bay waters greater than 40 m deep changed little from what was found in the 1930s and was similar to that found in Lake Superior fish in the 1960s (Bailey 1972).

It is important to understand diet information for this important top predator, since it occupies rocky areas, which are prime feeding and spawning sites for lake trout *Salvelinus namaycush* and lake whitefish *Coregonus clupeaformis*, with implications for predation on their eggs, newly hatched fry, and stocked yearlings; they also might compete with lake trout for food (Edsall et al. 1993; Jones et al. 1995). Janssen et al. (2006a) have recently documented natural reproduction of lake trout on Lake Michigan's mid-lake reef complex, where burbot were often abundant; however, few lake trout apparently have survived to adulthood. Slimy sculpin *Cottus cognatus* and burbot predation may be part of the reasons for low lake trout survival.

A second concern for burbot is potential changes in food webs induced by the non-indigenous round goby *Neogobius melanostomus*, which entered the Great Lakes in 1990 (Jude et al. 1992) and has since spread to all the Great Lakes and has recently been introduced into the Mississippi River watershed. The round goby eats zebra *Dreissena* *polymorpha* and quagga *D. bugensis* mussels (French and Jude 2001) and has been responsible for the extirpation of mottled sculpin *C. baridii* (Janssen and Jude 2001) and greenside darter *Etheostoma blennoides* (Jude 2001) in areas of overlap. Round gobies have become abundant and flourished in the near shore zone, harbors, and river mouths, which are replete with rocks and debris that provide spawning substrate for round gobies (Wickett and Corkum 1998) and habitat for their dreissenid prey. Two recent ecosystem level changes, the introduction of quagga mussels, which have replaced zebra mussels and extended their range over much of the deep water abyss and reefs of Lake Michigan (and other Great Lakes), and movement of round gobies to deeper water in Lakes Michigan (Jude, unpublished data), Huron (Schaeffer et al. 2005), and Lake Ontario (Walsh et al. in press), have changed energy flow to top predators and caused shifts of fishes to deeper waters (O'Gorman et al. 2000). Many predators, such as lake trout, brown trout *Salmo trutta*, yellow perch, smallmouth bass *Micropterus dolumieu*, rock bass *Ambloplites rupestris*, and walleyes *Sander vitreus* have been documented eating round gobies (Jude 2001), and Schaeffer et al. (2005) and Jude (unpublished data) also found them in lake whitefish stomachs. Adult dreissenids filter about l L of water per day, removing phytoplankton and detritus from the water column (Vanderploeg et al. 2002), sometimes resulting in accumulation of toxic substances by round gobies (Kwon et al. 2006; Jude, unpublished data), which can then be bioaccumulated in food chains.

In this paper we present diet and growth information to document the massive shift in burbot diets from native species to round gobies, which is occurring on many rocky reefs and elsewhere in the Great Lakes. These changes may negatively affect burbot and other native species and change bioaccumulation pathways in cold water food webs in the Great Lakes.

Methods

Adult burbot utilized for diet analysis during this study were collected from a variety of sources, including Michigan Department of Natural Resources (MDNR) surveys and commercial fisherman in Michigan and Wisconsin (Table 1). Trap nets were large Great Lakes commercial trap nets set at various depths between 20 and 39 m according to the interest of the project or fisherman. Most were deployed near rocky reefs. At Alpena, MI, surveys were conducted in northern Lake Huron reefs by the MDNR on 18 November 2004. Commercial gill nets (several gangs of 300 m long, 50-mm-bar, multifilament, nylon mesh) were deployed near Washington Island, WI, in Lake Michigan by Ken Koyen, a commercial fisherman. Similar gill nets were set through the ice in Big Bay de Noc, Lake Michigan near Fairport, MI, in conjunction with Bill Peterson, a commercial fisherman, the MDNR, and Michigan State University during February 2005. Commercial fishermen also collected burbot for us using trap nets and gill nets in northern Lake Michigan off Leland, MI.

After field collections were made, burbot were kept on ice until total length (mm) and weight (g) could be measured and diets determined by dissection. Diet items were first weighed in mass (nearest 0.1 g), then individual items were weighed, identified to the lowest possible taxonomic unit, and for fish, total length was measured to the nearest mm or estimated from remains when possible. For burbot collected and immediately iced at Alpena, diets were analyzed no later than 2 days after nets were pulled. Burbot collected off Washington Island, WI, were analyzed in the field immediately after they were collected, while burbot collected off Fairport, MI, were examined the day they were collected after being transported on ice to the Mackinac Straits Fish Company, St. Ignace, MI.

We also used length and weight data from burbot collected during 1973-1977 studies at the Cook Nuclear Power Plant, which is located in southeastern Lake Michigan (Jude et al. 1986; Tesar et al. 1986). Burbot from the 1970s were collected in gill nets and trawls deployed monthly in water 6-9 m deep from April through November.

Length and weight data were log-transformed and length-weight regression equations calculated using data from all sites. A linear, fixed-effects model (Lai and Helser 1994) was used to test for significant weight-length differences among burbot from the four recent study sites and burbot collected near the Cook Nuclear Power Plant during the 1970s.

The MDNR collected burbot using gill nets as part of routine sampling in Michigan waters of Lake Huron, in statistical districts MH-1, MH-2, and MH-3+, which are located along the western side of Lake Huron (Smith et al. 1961). Burbot were measured to the nearest mm and otoliths removed from the head for the samples from 1996-2006. These otoliths were prepared using the crack-and-burn method, and aged using a binocular microscope. Sample sizes from the three areas were 144, 194, and 229 fish, respectively.

Results

Age-at-length data from burbot collected from western Lake Huron were available from 1996 to 2006. Fish generally grew about 40 mm/yr to about 6 yr old, after which growth slowed down substantially (Fig. 1). The oldest burbot was 18 years old. Asymptotic length (SD) showed a gradient from north to south of 577 (10), 619 (14), and 750 (29) mm for northern (MH1), north-central (MH2), and southern (MH3+) Lake Huron, respectively. The longest fish were in the south, smallest in the north, and the difference was significant. Thus, burbot reached much larger size at age 7 and older in north-central (MH1) and southern (MH3+) Lake Huron than in northern (MH1) Lake Huron (Fig.1). Lengths at young ages, however, were smaller in southern Lake Huron than the other two areas. Growth coefficient K with standard deviations were 0.271 (0.041), 0.284 (0.065), and 0.143 (0.024) for northern, north-central, and southern Lake Huron, respectively; the among-area difference was significant.

While burbot diets changed substantially from native species to sometimes large numbers of round gobies in some areas (Table 2), overall length-weight relationships of burbot have not significantly changed among our study sites (Table 3). However, the weight-at-length data for small and medium-sized (500 and 600 mm) burbot at Washington Island were significantly lighter than those found at other sites.

Burbot diets in some areas have changed dramatically since the benthic round gobies have become established in the Great Lakes (first found in 1990 – Jude et al. 1992). Where alewives, rainbow smelt, sculpins, and sometimes bloaters *Coregonus hoyi* once composed a substantial portion of burbot diets, they are now being replaced with round gobies in areas where round gobies are present (Table 2). The only small (less than 500 mm total length) (n = 9) burbot collected during 2004 – 2006 were caught in Lake Michigan off Fairport, MI in Big Bay de Noc, and at Washington Island, WI, and consumed 100% and 85% round gobies, respectively. Dominance of round gobies in the diets of medium-sized burbot (500 to 599 mm total length) varied by location. No round gobies were present in diets of burbot of any size from Leland, MI, where medium-size burbot ate alewives (89%), *Cottus* spp. (8%), and rainbow smelt (4%). At the other three sites, round gobies composed 32-84% of the diet of medium-sized burbot, with the Lake Huron Alpena site having the highest percentage. Medium-size burbot from the Washington Island Green Bay site had the most diverse diet with alewives, rainbow smelt, *Cottus* spp., and other fish making up from 5 to 35% of the remaining diet. Invertebrates and miscellaneous food items composed 3% of medium-size burbot diets at Washington Island. Large burbot (> 599 mm) ate round gobies in high percentages (38-77) at all recent sites except Leland, MI, where no round gobies were consumed. At Leland, large burbot ate *Cottus* spp. (25%), unidentified fish (25%), alewife (21%), miscellaneous food (11%), rainbow smelt (8%), bloater (5%), and other fish (4%). The average percent composition of round gobies in the burbot diet at the three sites where round gobies were present was: 93% for small burbot, 58% for medium burbot, and 58% for large burbot.

Average amount of food eaten per fish for small burbot at Fairport, MI (30 g/fish, n = 2) and Washington Island, WI (35 g/fish –n = 7) was higher than the average amounts of food eaten by small burbot in Green Bay, WI (Fratt : 3.9-26.4 g/fish) prior to the round goby introduction (see Locations A1-A3- Table 2). For medium-size burbot however, the average amount of food eaten at one of our four sites (Lake Huron: Alpena, MI) was 51.8 g/fish, which was at least twice as high as the rate eaten at any of the other seven sites for which data were calculated. Round gobies composed 84% of the fish eaten by these burbot. This trend of high consumption of round gobies by burbot was even stronger for large burbot, which had a rate of consumption of 55.6 g/fish at the Alpena, MI, Lake Huron site. Even so, a higher rate was recorded for large burbot diets prior to round goby colonization, when over 60 g/fish were eaten by fish from Green Bay at station A 5. Rates of consumption at our other three study sites were far below (less than 10 g/fish) those noted and at the other sites prior to round goby appearance.

Discussion

There was a significant difference in length-at-age of burbot which was related to a north-south gradient in Lake Huron. Burbot from southern Lake Huron grew slower than those farther north, but once they reached ages around 6, they grew significantly faster than burbot from the north. These differences could be related to thermal characteristics or prey availability changes in burbot ontogeny. Burbot length-weight relationships did not indicate that burbot consuming round gobies are heavier at a particular length than those not consuming round gobies. However, burbot collected in areas where round gobies were present tended to be longer than those in areas without round gobies. The largest burbot we collected came from near Alpena, MI, in Lake Huron, where diet of large burbot was composed of the highest percentage of round gobies (77%). We found up to 46 round gobies in some of these fish. The ones collected in southeastern Lake Michigan near the Cook Nuclear Power Plant in the 1970s were the smallest in maximum length. Reasons for this could be a combination of gear bias or a function of the fish being collected near shore (9 m) in the 1970s, away from prime rocky habitat for burbot, where they may grow larger.

Round gobies appear to be distributed in water about 70 m or less in lakes Huron, Ontario, and Michigan (Schaeffer et al. 2005; Walsh et al. in press; and Jude, unpublished data), hence we expect that burbot residing deeper than 70 m will not find any round gobies to eat. On the other hand, near shore rocky reefs are expected to be colonized by round gobies, providing burbot and other top predators with a new, abundant prey fish. Evidence for this was that wherever round gobies composed a large percentage of the diet, no *Cottus* spp. were found in burbot stomachs. In addition, WI DNR found no round gobies in burbot stomachs they examined from gill netting on the offshore (50 m), mid-lake reefs in southern Lake Michigan (personal communication, P. McKee, WI DNR, Sturgeon Bay, WI).

We found no trout or salmon juveniles in any stomachs we examined (some lake whitefish were eaten at Alpena and Fairport, MI), hence it appears that they do not prey on salmonines directly. This was similar to what Fratt et al. (1997) concluded from their Green Bay, WI burbot studies. While overall competition for food between burbot and salmonines (see Jude et al. 1987 for salmonine diets) in the Great Lakes may be reduced due to habitat differences (benthic vs. pelagic), there is still substantial diet overlap, which may create an important bottleneck during specific ontogeny's of certain salmonines. For example, juvenile lake trout eat a considerable amount of sculpins (Madenjian et al. 1998) and Jude et al. (1987) found that brown trout juveniles relied heavily on sculpins in the spring in Lake Michigan.

Burbot also were found to eat lake whitefish eggs at Alpena, MI in Lake Huron and deepwater sculpin eggs at Leland, MI in Lake Michigan. They also eat lake trout eggs in the fall (Claramunt et al. 2005) as do slimy sculpins, one of their prey (Janssen et al. 2006a). Therefore predation by burbot on slimy sculpins and the current switch to the new invasive round goby, which also is known to eat lake trout eggs (Chotkowski and Marsden 1999), could favor lake trout survival, if enough round gobies are removed.

There has been a major ecosystem shift in many of the Great Lakes as invasive species have modified energy flow and changed bioaccumulation paths (Vanderploeg et al. 2002; Madenjian et al. 2002). Introduction of zebra and quagga mussels, a major diet item for round gobies > 50 mm, have made it easier for round gobies to expand their populations from their initial dumping sites at ports and harbors from freighters (Hensler and Jude in press) to adjacent Great Lakes deep water sites, including critical rocky reefs, which act as important nursery, feeding, and spawning sites (Janssen et al. 2006b). Once round gobies colonize these sites, we expect mottled and slimy sculpins to be extirpated (Janssen and Jude 2001) and diets of top predators to begin to include round gobies (Jude 2001). Our data support that this scenario has already occurred at three of our four sites where we collected burbot diet information, as no or very few *Cottus* spp. were eaten at sites where the most prominent diet item was round gobies. In some cases, availability of round gobies has enhanced survival of some juvenile fishes (Steinhart et al. 2004), while in others they caused local extirpation of native species (Jude 2001). We are beginning to see this for burbot, as diets now include large percentages of round gobies. Burbot historically ate native species such as slimy and mottled sculpins in northern Lake Michigan (Bohr and Liston 1981), sculpins, yellow perch, bloaters, and deepwater sculpin *Myoxocephalus thompsoni* in Green Bay (Rudstam et al. 1995; Fratt et al. 1997), and cottids and coregonines in Lake Michigan (Van Oosten and Deason 1938). In Lake Erie they ate mainly yellow perch, but also walleye, white bass *Morone chrysops*, freshwater drum *Aplodonotus grunniens*, trout-perch *Percopsis omiscomaycus*, log perch *Percina caprodes,* and sculpins (Clemens 1951). Lake Superior burbot ate bloater, ninespine stickleback, and slimy and spoonhead sculpin *Cottus ricei* (Bailey 1972).

This switch to round gobies could have implications for toxic substance uptake. We have found that large round gobies, because of their great consumption of zebra and quagga mussels, actually contain lower concentrations of PCBs than smaller round gobies which tend to eat more benthos and fish eggs, which accumulate higher concentrations of PCBs that are passed on to top predators (Kwon et al. 2006, Jude, unpublished data). Jude studies showed that in highly contaminated Areas of Concern, such as the River Raisin, a tributary to Lake Erie, round gobies can accumulate up to 5 mg/kg of PCBs. We would expect considerably less uptake in less contaminated sites, such as where we obtained our burbot samples, but never-the-less, it certainly suggests that round gobies will accumulate and pass on more toxic substances than when burbot ate more native species.

This change in burbot diets may also compromise their ability to be used commercially (Krivchenia and Fennema 1988; Lindsay et al. 1981). Paakkonen et al. (2005) fed PCBs to burbot and found that: 1.) 65-81% of the PCBs were retained with highest doses found in the liver, and 2.) levels of PCBs in burbot collected in 2005 were no different from levels observed in the 1970s, despite banning PCBs. While fillets are probably going to be considered "safe," liver oils may become more highly contaminated, particularly with PCBs, as a result of the high proportion of round gobies in diets from the early 2000s. The liver is a major source of revenue in oceanic cod fisheries, and this may make commercial fishing for burbot a less lucrative venture for commercial fishers in the Great Lakes.

Several recent papers have documented changes in burbot populations in the Great Lakes (Stapanian et al. 2006, Schram et al. 2006, Stapanian and Madenjian in press), showing recent population upsurges due to sea lamprey control and the reduction of alewife predation on burbot larvae. Burbot compete with other top predators for similar fish prey and may be a linchpin for successful lake trout reproduction, by reducing lake trout egg predators, such as slimy sculpin and round gobies. Because of these changes in their population levels and their recent switch to the invasive round gobies with its implications for toxic substance bioaccumulation, it is important to monitor their population abundances so managers can implement changes that might favor other competing species, such as lake trout.

Acknowledgements

We thank the National Marine Fisheries Service, whose support through Saltonstall-Kennedy Program funds enabled sample collection for this analysis. We also are grateful for the sampling assistance provided by: Jim Johnson and Randy Claramunt, Michigan Department of Natural Resources in Alpena and Charlevoix, MI; Mark Ebener, Inter-Tribal fisheries and Assessment Program, Chippewa Ottawa Resource Authority, Sault Ste. Marie, MI; commercial fishermen Ken Koyen, Washington Island, WI, William Fowler, Leland, MI, and Bill Peterson, Fairport, MI. William Carlson, Leland, MI and Paul Jensen, Muskegon, MI provided advice and specimens. Sample analysis space was graciously provided by Paul Jensen in Muskegon; Michigan DNR, Alpena, MI; the Mackinac Straits Fish Company, St. Ignace, MI; and Ken Koyen,

Washington Island, WI. Patrick McKee, Wisconsin DNR is thanked for providing diet data on some burbot from the mid-lake reefs in Lake Michigan.

References

Bailey, M. M. 1972. Age, growth, reproduction, and food of the burbot, *Lota lota* (Linnaeus), in southwestern Lake Superior. Transactions of the American Fisheries Society 101:667-674.

Bohr, J., and C. Liston. 1981. Relative abundance and feeding relationships of sculpin (*Cottus* spp.), johnny darter (*Etheostoma nigrum*) and trout-perch (*Percopsis omiscomaycus*) in the Ludington pumped storage reservoir on Lake Michigan. Michigan Academician 13:111-123.

Bonde, T., and J. Maloney. 1960. Food habits of burbot. Transactions of the American Fisheries Society 89:374-376.

Boyer, L., R. Cooper, D. Long, and T. Askew. 1989. Burbot (*Lota lota*) biogenic sedimentary structures in Lake Superior. Journal of Great Lakes Research 15:174-185.

Chotkowski, M. A., and J. E. Marsden. 1999. Round goby and mottled sculpin predation on lake trout eggs: field predictions from laboratory experiments. Journal of Great Lakes Research 25:26-35.

Claramunt, R. M., J. L. Jonas, J. D. Fitzsimons, and J. E. Marsden. 2005. Influences of spawning habitat characteristics and interstitial predators on lake trout egg deposition and mortality. Transactions of the American Fisheries Society 134:1048-1057.

Clemens, H. P. 1951. The food of the burbot, *Lota lota maculosa* (LeSueur), in Lake Erie. Transactions of the American Fisheries Society 80:56-66.

Edsall, T., G. Kennedy, and W. Horns. 1993. Distribution, abundance, and resting microhabitat of burbot on Julian's Reef, southwestern Lake Michigan. Transactions of the American Fisheries Society 122:560-574.

Eshenroder, R. L., and M. K. Burnham-Curtis. 1999. Species succession and sustainability of the Great Lakes fish community. Pages 145-184 *in* W. W. Taylor and C. P. Ferreri, editors. Great Lakes fisheries and policy management: a binational perspective. Michigan State University Press, East Lansing, Michigan.

Fratt, T. W., D. W. Coble, F. Copes, and R. E. Bruesewitz. 1997. Diet of burbot in Green Bay and western Lake Michigan with comparison to other waters. Journal of Great Lakes Research 23:1-10.

French, J.R., III, and D. Jude. 2001. Diets and diet overlap of nonindigenous gobies and small benthic native fishes co-inhabiting the St. Clair River, Michigan. Journal of Great Lakes Research 27:300-311.

Guthruf, J., S. Gerster, and P.-A. Tschumi. 1990. The diet of burbot (*Lota lota*) in Lake Biel, Switzerland. Archiv fur Hydrobiologie 199:103-114.

Hackney, P. 1973. Ecology of the burbot *Lota lota* with special reference to its role in the Lake Openogo fish community. Ph.D thesis, University of Toronto, Toronto, Ontario.

Hensler, S. R. and D. Jude. In press. Diel vertical migration of round goby larvae in the Great Lakes. Journal of Great Lakes Research 33.

Janssen, J., and D. J. Jude. 2001. Recruitment failure of mottled sculpin *Cottus bairdi* in southern Lake Michigan induced by the newly introduced round goby *Neogobius melanostomus*. Journal of Great Lakes Research 27:319-328.

Janssen, J., D. Jude, T. Edsall, M. Paddock, N. Wattrus, M. Toneys, and P. McKee. 2006a. Evidence of lake trout reproduction at Lake Michigan's Mid-lake Reef Complex: hypotheses regarding the indigenous fish and implications for restoration. Journal of Great Lakes Research 32:749-763.

Janssen, J., Berg, M., and Lozano, S. 2006b. Submerged terra incognita: the abundant but unknown rocky zones. pp. 439-477. In: The State of Lake Michigan, Ed.: M. Munawar and T. Edsall, Ecovision World Monograph Series, S. P. B. Academic Publishing, The Netherlands. In: The State of Lake Michigan, M. Munawar and T. Edsall

Jones, D., J. Kiceniuk, and O. Bamford. 1974. Evaluation of the swimming performance of several fish species from the Mackenzie River. Journal of the Fisheries Research Board of Canada 31:1641-1647.

Jones, M. L. K., G. W. Eck, D. O. Evans, M. C. Fabrizio, M. H. Hoff, P. Hudson, J. Janssen, D. Jude, R. O'Gorman, and J. F. Savino. 1995. Limitations to lake trout *(Salvelinus namaycush)* rehabilitation in the Great Lakes imposed by biotic interactions occurring at early life stages. Journal of Great Lakes Research 21 (Supplement 1):505-517.

Jude, D. J. 2001. Round and Tubenose Gobies: 10 Years with the Latest Great Lakes Phantom Menace. Dreissena 11:1-14.

Jude, D. J., F. J. Tesar, S. DeBoe, and T. Miller. 1987. Forage fish selection by Lake Michigan salmonines, 1973-1982. Transactions of the American Fisheries Society 116:677-691.

Jude, D. J., R. H. Reider, and G. R. Smith. 1992. Establishment of Gobiidae in the Great Lakes basin. Canadian Journal of Fisheries and Aquatic Sciences 49:416-421.

Jude, D., D. Bimber, N. Thurber, F. Tesar, L. Noguchi, P. Mansfield, H. Tin, and P. Rago. 1986. Impact of the D. C. Cook Plant on fish. In: Southeastern Lake Michigan: the impact of the D. C. Cook Nuclear Plant. Edited by R. Rossmann, Publication Number 22, Great Lakes Res. Division, University of Michigan, Ann Arbor, MI.

Krivchenia, M., and O. Fennema. 1988. Effect of cryoprotectants on frozen burbot fillets and a comparison with whitefish fillets. Journal of Food Science 53:1004-1008.

Kwon, Tae-Dong, S. Fisher, G. Kim, H. Hwan, and Jang-Eok Kim. 2006. Trophic transfer and biotransformation of polychlorinated biphenyls in zebra mussel, round goby, and smallmouth bass in Lake Erie, USA. 2006. Environmental Toxicology and Chemistry 25(4):1068-1078.

Lai, H., and T. Helser 1994. Linear mixed-effects models for weight-length relationships. Fisheries Research 70:377-387.

Lavis, D. S., M. P. Henson, D. A. Johnson, E. M. Koon, and D. J. Ollila. 2003. A case history of sea lamprey control on Lake Michigan: 1979 to 1999. Journal of Great Lakes Research 29 (Supplement 1):584-598.

Lawler, G. 1963. The biology and taxonomy of the burbot, *Lota lota*, in Heming Lake, Manitoba. Journal of the Fisheries Research Board of Canada 20:417-433.

Lindsay, R., D. Stuiber, B. Stewart, and V. Carlson. 1981. Evaluation of burbot (*Lota lota*) acceptability for processing. Canadian Institute of Food Science and Technology Journal 14:196-202.

Madenjian, C. P., G. L. Fahnenstiel, T. H. Johengen, T. F. Nalepa, H. A. Vanderploeg, G. W. Fleischer, P. J. Schneeberger, D. M. Benjamin, E. B. Smith, J. R. Bence, E. S. Rutherford, D. S. Lavis, D. M. Robertson, D. J. Jude, and M. P. Ebener. 2002. Dynamics of the Lake Michigan food web, 1970-2000. Canadian Journal of Fisheries and Aquatic Sciences 59:736-753.

Madenjian, C. P., T. J. DeSorcie, and R. M. Stedman. 1998. Ontogenic and spatial patterns in diet and growth of lake trout in Lake Michigan. Transactions of the American Fisheries Society 127:236-252.

Mansfield, P., D. Jude, D. Michaud, D. Brazo, and J. Gulvas. 1983. Distribution and abundance of larval burbot, *Lota lota*, and deepwater sculpin, *Myoxocephalus thompsoni*, in Lake Michigan. Transactions of the American Fisheries Society 112:162-172.

McCrimmon, H., and O. Devitt. 1954. Winter studies on the burbot, *Lota lota lacustris*, of Lake Simcoe, Ontario. Canadian Fish Culturist 16:35-41.

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

Paakkonen, J.-P., A. L. Rantalainen, A. Karels, A. Nikkilak, and J. Karjalainen. 2005. Bioaccumulation of PCBs in burbot (*Lota lota*) after delivery in natural food. Archives of Environmental Contamination and Toxicology 49:223-231.

Rudstam, L. G., P. E. Peppard, T. W. Fratt, R. E. Bruesewitz, D. W. Coble, F. A. Copes, and J. F. Kitchell. 1995. Prey consumption by the burbot (*Lota lota*) population in Green Bay, Lake Michigan, based on a bioenergetics model. Canadian Journal of Fisheries and Aquatic Sciences 52:1074-1082.

Schaeffer, J. S., A. Bowen, M. Thomas, J. R. P. French, III, and G. L. Curtis. 2005. Invasion history, proliferation, and offshore diet of the round goby *Neogobius melanostomus* in western Lake Huron, USA. Journal of Great Lakes Research 31:414-425.

Schram, S. T., T. B. Johnson, M. J. Seider. 2006. Burbot consumption and relative abundance in the Apostle Islands region of Lake Superior. Journal of Great Lakes Research 32: 798-805.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184.

Smith, S. H., H. J. Buettner, and R. Hile. 1961. Fishery statistical districts of the Great Lakes. Technical Report 2, Great Lakes Fishery Commission, Ann Arbor.

Stapanian, M. A., and C. P. Madenjian. In press. Growth and mortality of burbot in Lake Erie, 1995-2003. North American Journal of Fisheries Management

Stapanian, M. A., C. P. Madenjian, and L. D. Witzel. 2006. Evidence that sea lamprey control led to recovery of the burbot population in Lake Erie. Transactions of the American Fisheries Society 135:1033-1043.

Steinhart, G. B., E. A. Marschall, and R. A. Stein. 2004. High growth rate of young-of-the-year smallmouth bass in Lake Erie: a result of the round goby invasion? Journal of Great Lakes Research 30:381-389.

Swink, W. 2003. Host selection and lethality of attacks by sea lampreys (*Petromyzon marinus*) in laboratory studies. Journal of Great Lakes Research 29(Supplement 1):307-319.

Swink, W. D., and K. T. Fredericks. 2000. Mortality of burbot from sea lamprey attack, and initial analyses of burbot blood. Pages 147-154 i*n* V.L. Paragamian and D. Willis, editors. Burbot biology, ecology and management. American Fisheries Society, Fisheries Management Section Publication 1, Spokane, Washington.

Tesar, F., D. Jude, H. Tin, and P. Mansfield. 1986. Ecology of fish in near shore southeastern Lake Michigan, 1973-1982. In: The impact of the D. C. Cook Nuclear Plant on southeastern Lake Michigan. Edited by R. Rossmann. Publication Number 22, Great Lakes Research Division, University of Michigan, Ann Arbor, MI.

Van Oosten, J., and H. Deason. 1938. The food of lake trout (*Cristivomer namaycush namaycush*) and of the lawyer (*Lota maculous*) of Lake Michigan. Transactions of the American Fisheries Society 67:155-177.

Vanderploeg, H. A., T. F. Nalepa, D. J. Jude, Edward L. Mills, Kristen T. Holeck, J. R. Liebig, I. A. Grigorovich, and H. Ojaveer. 2002. Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 59:1209-1228.

Walsh, M., D. Dittman, and R. O'Gorman. In press. Occurrence and food habits of round goby in the profundal zone of southwestern Lake Ontario. J. Great Lakes Res. 33:

Ward, C., R. L. Eshenroder, and J. R. Bence. 2000. Relative abundance of lake trout and burbot in the main basin of Lake Michigan in the early 1930s. Transactions of the American Fisheries Society 129:282-295.

Wells, L., and A. L. McLain. 1973. Lake Michigan - man's effects on native fish stocks and other biota. Great Lakes Fishery Commission Technical Report 20, Ann Arbor, Michigan.

Wickett, R. G., and L. D. Corkum. 1998. Nest defense by the non-indigenous fish, the round goby, *Neogobius melanostomus* (Gobiidae), on a shipwreck in western Lake Erie. Canadian Field-Naturalist 112:653-656.

Table 1. Date, location, and type of gear used to collect burbot for diet analyses from several sites on Lake Michigan (LM) and Lake Huron (LH) during 2004-2006. TN=trap net, GN = gill net, MDNR and WDNR = Michigan and Wisconsin Departments of Natural Resources, CF = commercial fisherman, MSU= Michigan State University.

Date	Location	City	Gear Deployed	Project
23-Jun-04	LM: eastern shoreline	Leland, MI	GN, TN	CF
18-Nov-04	LH:Thunder Bay	Alpena, MI	TN	MDNR/CF
3-Dec-04	LM:Green Bay	Washington Island, WI	GN, TN	CF
3-Feb-05	LM:Big Bay de Noc, MI	Fairport, MI	GN, TN	MSU/CF
8-Jun-06	LM: eastern shoreline	Leland, MI	GN, TN	CF
15-Jun-06	LM:Green Bay	Washington Island, WI	GN, TN	CF
6-Dec-06	LM:Green Bay	Washington Island, WI	GN, TN	CF

Table 2. Percent composition and, in parentheses, mean prey consumption per fish (g) of burbot diets from lakes Michigan and Huron at depths of 20-39 m during 1986-88 (Fratt et al. 1997) before round gobies were introduced to the Great Lakes, and during 2004-06 (this study). Sites A 2-5 were selected from Fratt et al. (1997) as being comparable to locations where burbot were recently collected. Burbot prey codes are RG = round goby, AL = alewife, RS = rainbow smelt, BL = bloater, CT = *Cottus* spp., DS = deepwater sculpin, YP = yellow perch, OF = other fish, IV = invertebrates (not including crayfish), UF = unidentified fish, and MC = miscellaneous. Study locations include Leland, Fairport, and Alpena, MI, and Washington Island, WI (W. Isl.).

Site	A 2	A 3	A 4	A 5	Leland	W. Isl.	Fairport	Alpena
400-499 mm								
Food (g)	272	1,080	8	158		35	60	
N	17	128	2	6	0	7	2	0
RG						85 (30.0)	100 (30.0)	
AL	30 (4.8)	25 (2.1)		36 (9.5)				
RS	1 (0.2)	9 (0.8)		8 (2.1)				
BL		1 (0.1)		25 (6.6)				
CT	2 (0.3)	10 (0.8)	38 (1.5)	4 (1.1)				
DS		5 (0.4)		9 (2.4)				
YP								
OF						15 (5.0)		
IV	1 (0.2)	2 (0.2)	3 (0.1)					
UF	15 (2.4)	17 (1.4)	38 (1.5)	10 (2.6)				
MC	51 (8.2)	31 (2.6)	21 (0.8)	8 (2.1)				
500-599 mm								
Food (g)	5,847	2,455	1	623	79	750	622	505
N	296	212	1	25	5	69	76	9
RG						32 (3.5)	58 (2.8)	84 (42.8)
AL	37 (7.3)	7 (0.8)			89 (14.1)	35 (3.8)		
RS	19 (3.8)	10 (1.2)		14 (3.5)	4 (0.6)	5 (0.5)	2 (0.2)	
BL	1 (0.2)	12 (1.4)		36 (9.0)				

CT	3 (0.6)	13 (1.5)		3 (0.7)	8 (1.3)	2 (0.2)		
DS	1 (0.2)	2 (0.2)						
YP	2 (0.4)			2 (0.5)				
OF						17 (1.9)	31 (2.5)	
IV	2 (0.4)			3 (0.7)		1 (0.1)		7 (3.9)
UF	6 (1.2)	28 (3.2)		13 (3.2)		5 (0.5)	7 (0.6)	9 (5.1)
MC	29 (5.7)	28 (3.2)	100 (1.0)	29 (7.2)		2 (0.2)		
Longer than 599 mm								
Food (g)	3,555	997	161	598	173	476	299	2,224
N	142	53	1	9	20	45	40	40
RG						58 (6.2)	38 (2.8)	77 (42.8)
AL	29 (7.3)	17 (3.2)	92 (148.1)	3 (2.0)	21 (1.8)	8 (0.8)		
RS	33 (8.3)	4 (0.8)			8 (0.7)		2 (0.1)	
BL	3 (0.8)	18 (3.4)	4 (6.4)		5 (0.4)			
CT	4 (1.0)	8 (1.5)			25 (2.2)	2 (0.1)		
DS		6 (1.1)		25 (16.6)				
YP				34 (22.6)				
OF		2 (1.4)			4 (0.3)	24 (2.5)	40 (3.0)	4 (2.2)
IV							4 (0.3)	10 (5.6)
UF	6 (1.2)	30 (5.6)		2 (1.3)	25 (2.2)	8 (0.8)	16 (1.2)	6 (3.3)
MC	25 (5.7)	15 (2.8)	4 (6.4)	36 (23.9)	11 (1.0)	2 (0.2)		3 (1.7)

Table 3. Mean weight at given lengths derived from length-weight regression equations calculated for burbot collected from various locations in the Great Lakes. Other = Lake Michigan: Leland, Fairport, and Lake Huron: Alpena, MI; all = other sites plus Washington Island, WI in Green Bay. *= significant at the 0.05 level.

Mean Total Length (mm)	Mean Wt (g) at length	Location
500	1,200-1,204	Other
	*1,127	Washington Island, WI
600	1,791-1,829	Other
	*1,754	Washington Island, WI
700	2,490-2,605	All
800	3,312-3,539	All

Figure 1. Map of lakes Michigan and Huron showing the statistical districts in Lake Huron, sampling locations for burbot, and the mid-lake reef, East Reef.

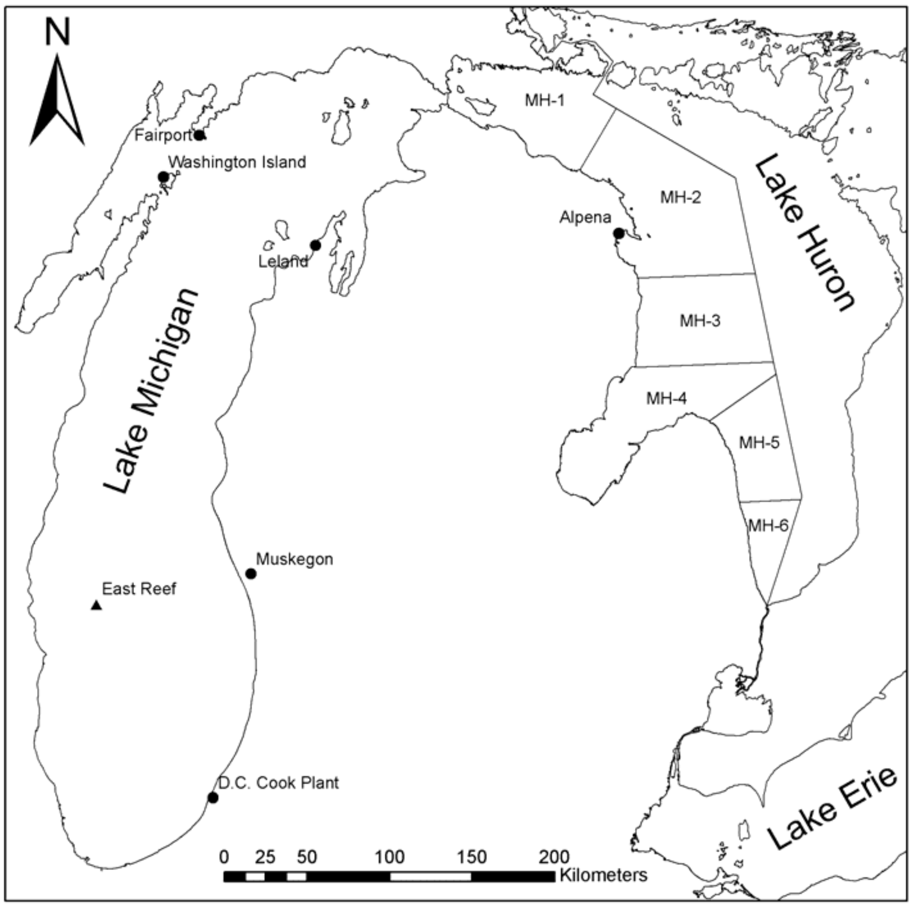
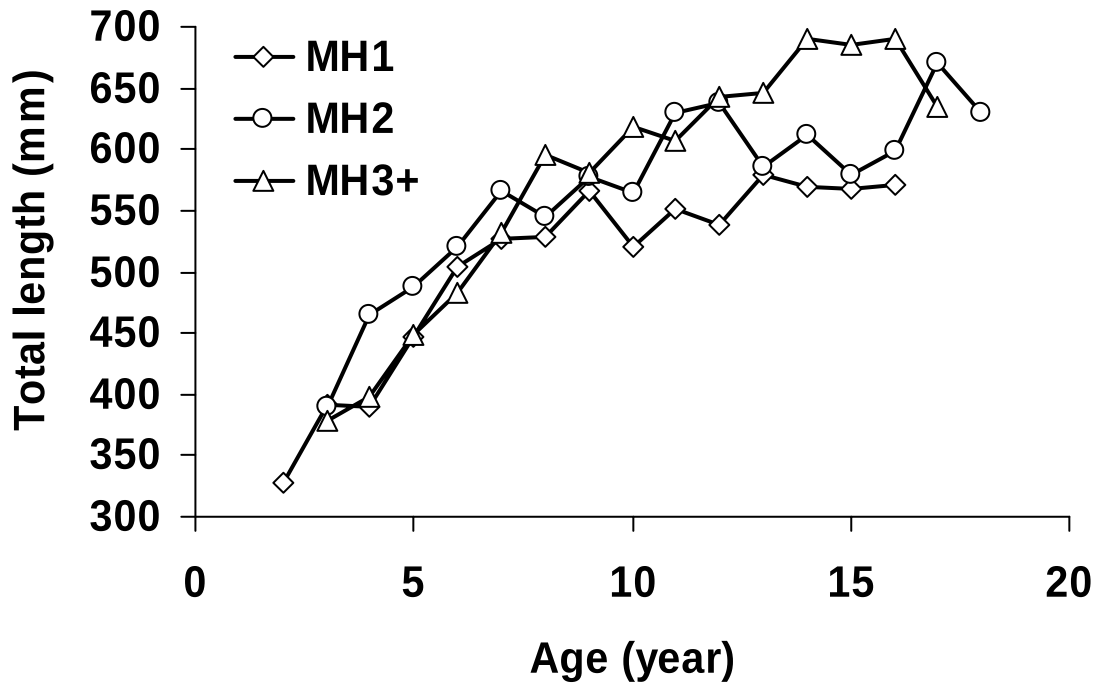


Figure 2. Trends in growth (length at age) of burbot from northern (MH1), north-central (MH2), and southern (MH3-5) Lake Huron. See Smith et al. (1961) for details of the statistical districts. Fish samples were from 1996 to 2006. Age was based on reading otoliths. Sample sizes were 144, 194, and 229 for the three areas, respectively.



APPENDIX 2. IMPACT OF ROUND GOBIES ON POTENTIAL COMMERCIAL UTILIZATION OF BURBOT IN THE GREAT LAKES

STEPHEN R. HENSLER AND DAVID J. JUDE

University of Michigan, School of Natural Resources and Environment

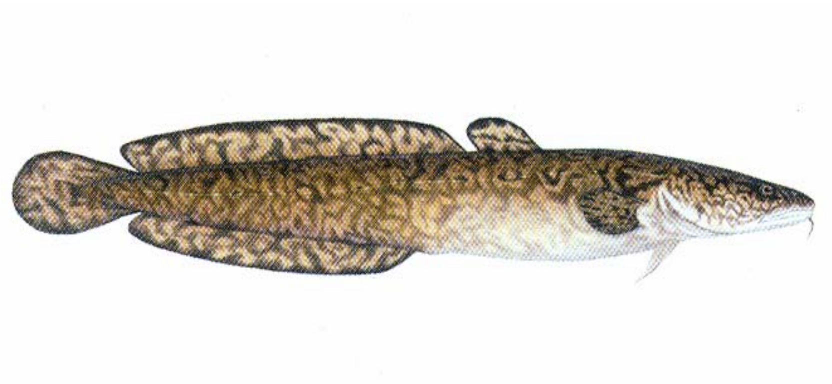
440 Church St.

Ann Arbor, Michigan 48109, USA

Invited to give an oral paper on our work to the SOLEC Conference (State of the Lakes Ecosystem Conference - a conference on Great Lakes research sponsored by EPA), which was given on 1-4 November 2006 in Green Bay, WI.

Abstract: Burbot, *Lota lota*, are a native species of cod found in the cold-water regions of all five Great Lakes and are currently being studied as a new target fish for commercial fishing. During exploratory sampling, burbot growth and diet data were recorded for fish collected in northern Lake Huron near Alpena, MI, and northern Lake Michigan near Fairport, MI, to help determine commercial potential. We compared burbot growth from these locations with historical data from other available datasets and found no significant change in burbot growth. However, burbot diets have changed substantially and now include large proportions of round gobies (77% near Alpena, 53% near Fairport). Establishment of round gobies in the open waters of the Great Lakes is likely to change cold-water food webs. Commercial utility of top predators in cold-water environs of the Great Lakes may be compromised as round gobies displace sculpins in fish diets, thus changing bioaccumulation patterns of toxic substances.

APPENDIX 3. CONCEPT STATEMENT GIVEN TO PEOPLE TO ASSESS THE POTENTIAL MARKET FOR BURBOT. IT WAS USED IN CONJUNCTION WITH THE QUESTIONNAIRE (APPENDIX 4) TO DETERMINE PEOPLE'S ATTITUDES ABOUT USE AND CONSUMPTION OF BURBOT FILLETS.



The burbot is a freshwater fish related to the saltwater cods. It is found in all of the Great Lakes and many of the rivers and inland lakes of the North. It is not present in waters that typically exceed 69 F during summer months. It is a nocturnal fish and prefers to be near the bottom in areas of low-light intensity. It also inhabits areas with aquatic vegetation, rock piles, submerged logs, and other underwater structures. It typically weighs between 1 and 3 pounds but they may weigh over 12 pounds. The primary diet is small forage fish and aquatic insects. They are plentiful in the Great Lakes with no catch limits or concerns about over fishing; however, they have been depressed by sea lamprey predation and consumption of their larval forms by the exotic alewife.

Local fishermen have long known about the excellent eating qualities of burbot. Freshly caught fish when poached and served with drawn butter, has a mild yet slightly sweet and delicate flavor similar to lobster and has earned the title of "poor man's lobster". Its tender, but meaty, texture makes burbot a versatile fish that may be prepared a variety of ways. It can be grilled, broiled, baked, sautéed, fried, and poached. It is excellent in soups, chowders, and stews because it does not readily flake apart. Burbot is naturally a low fat, high protein fish. An 85-g (3 oz) cooked portion of skinless burbot has:

97 calories
21 grams of protein
<1 gram of fat
0 grams of carbohydrates

To preserve its delicate taste, most burbot are processed, vacuum packed, and frozen the same day they are caught. It is rarely found fresh, even in local fish markets. Frozen boneless, skinless burbot fillets will be available in the frozen foods section of local grocery stores and fish markets later this year. It will be priced comparable to saltwater cod at about $5.00/LB.

APPENDIX 4. QUESTIONAIRE USED TO POLL PEOPLE ABOUT THEIR ATTITUDES REGARDING CONSUMPTION OF FISH, ESPECIALLY BURBOT.

Burbot Questionnaire

***Based on everything you have read concerning Burbot*, how likely are you to buy this fish to try it? Check the phrase that best describes your intent to purchase.**

Definitely will buy
Probably will buy
Might or might not buy
Definitely will not buy
Probably will not buy

What in particular do you *like* about Burbot based on what you read?

Is there anything in particular you *dislike* about Burbot based on what you read?

***Thinking only of Burbot,* which statement below best describes your potential consumption of this fish? Check the phrase that best describes your potential consumption. Skip this question if you answered the above question as probably or definitely will not buy.**

I will eat more fish. Burbot will not replace fish I normally purchase and consume.

I will not eat more fish. Burbot will replace fish I normally purchase and consume.
Please list the fish Burbot is most likely to replace.

***Thinking only of Burbot,* select the three (3) preparation methods you are most likely to try.**

Bake
Broil
Sauté
Deep Fry
Microwave
Raw
Grill
Pan Fry
Poach/Boil
Simmer in Soup/Stew/Chowder
Marinade in lime juice/consume

The following questions refer to your experience with purchasing, preparing and consuming fish.

How often, on average, do you eat fish including canned fish, seafood and smoked fish?

At least once per week **About once or twice per month**
About once every 2 weeks **Less than once per month**

Where are you *most* likely to eat fish? Check the phrase that best describes where you eat fish.

I never prepare fish at home. I only eat it in a restaurant or when dining out.
I often prepare fish at home but I am just as likely to eat fish when dining out.
I always purchase and prepare fish and seafood to eat at home. I never select fish when dining out.

Where are you *most* likely to purchase fish? Check the phrase that best describes where you purchase fish. Skip this question if you never purchase fish for at-home consumption.

At a large national or regional supermarket such as Meijers or Sam's Club.
At a local or regional grocery store that may have multiple locations.
At a specialty meat market or fish market.

Thinking of your most recent purchases of fish, indicate approximately how many of your last 10 purchases were the following. Example: If you estimate 4 of your last 10 purchases were canned tuna, place a "4" beside the phrase shelf stable packaged fish

Fresh, local fish **Fresh, farm raised salmon**
Frozen, farm raised salmon **Fresh ocean fish such as tilapia**
Frozen ocean fish such as tilapia **Fresh or frozen seafood such as shrimp**
Non perishable, shelf stable packaged fish such as canned tuna

Thinking only of your consumption of fish,
What is your primary reason for eating fish?

What is the primary reason preventing you from eating fish more often?

Thinking of your current preparation and consumption of fish, *select the three (3) preparation methods you are most likely to prepare/consume*. Select three (3) methods for
in-home preparation and dining out preparation.

AT-HOME PREPARATION

- **Grill**
- **Bake**
- **Deep Fry**
- **Poach/Boil**
- **Broil**
- **Microwave**
- **Pan Fry**
- **Sauté**
- **Simmer in Soup/Stew/Chowder**
- **Other;**

DINING OUT PREPARATION

- **Broiled**
- **Deep Fried**
- **In a Soup/Chowder/Stew**
- **Sautéed**
- **Baked**
- **In a cold salad**
- **Pan Fried**
- **Grilled**
- **Poached**
- **Other;**

When purchasing fish in a store what types of information would you like to have available at the time of purchase? *Select three (3) types of information you consider most important.*

- **Description of taste qualities**
- **Place of origin; local vs. domestic vs. imported**
- **Nutritional information**
- **Suggestions for preparation and recipe cards**
- **How Raised; Farmed vs. Wild Harvest**
- **General information about the fish and its habitat**
- **Photograph or picture of a fish in its habitat**
- **Sustainability; fish viability, environmental impact of production method**
- **Other;**

When ordering fish in a restaurant what types of information would you like to have available on the menu or tabletop card*? Select three (3) types of information you consider most important.*

- **Description of taste qualities**
- **Nutritional information**
- **How Raised; Farmed vs. Wild Harvest**
- **Place of origin; local vs. domestic vs. imported**

Special/Uniqueness; seasonal, rare
General information about the fish and its habitat
Sustainability; fish viability, environmental impact of production method
Other;

On average, what price do you normally pay for fish, either fresh or frozen when purchasing for at-home consumption?

Less than $3.00/LB
$3.00 to $5.00/LB
$5.00 to $7.00/LB
$7.00 to $10.00/LB
Greater than $10.00/LB

Is there anything else you would like to share concerning your preparation and consumption of fish?

Thank you for completing this questionnaire. Please place both pages of this questionnaire in the stamped envelope provided and mail at your earliest convenience.

APPENDIX 5. BURBOT RECIPES.

Recipe No. 1
Baked Burbot in Fennel Cream Sauce — Serves 4

4 (about 1 1/2 LB) boneless, skinless Burbot fillets

1 TBS olive oil
1 fennel bulb, trimmed and sliced thinly
1/2 cup thinly sliced onion
2 cloves of garlic finely minced
1/2 LB white mushroom, sliced
1 tsp fresh thyme
1 TBS freshly grated orange zest
2 cups Half & Half

Place burbot fillets in greased, shallow oven proof dish. Season with salt and pepper. In a large skillet add olive oil and sauté the fennel, onions, garlic and mushrooms until onion and fennel begin to soften. Add cream, thyme and orange zest and simmer for 5 minutes or until starting to thicken. Pour sauce over fish and bake in 350 F oven for 30 minutes. May be served over pasta or rice.

Recipe No. 2
Broiled Burbot Fillets in Mustard Glaze — Serves 4

4-4 oz skinless, boneless Burbot fillets
1/2 cup mayonnaise
2 tsp Dijon mustard
1 tsp lemon juice
1/4 tsp cayenne pepper
1 TBS minced fresh parsley

Arrange fillets on a greased or foil lined baking sheet. In a small bowl, combine remaining ingredients except parsley. Spread the mixture evenly over the surface of the fillets. Broil for about 7 minutes until topping is golden and fish flakes with a fork. Sprinkle with parsley and serve.

Recipe No. 3
Burbot Fillets in Pecan Crust — Serves 4

1 1/2 cup pecans, coarsely chopped
1 1/2 cup bread crumbs
1/2 tsp salt
1/4 ground black pepper

1 cup flour
2 eggs slightly beaten
2 TBS milk
4-6 oz boneless, skinless burbot fillets
4 TBS oil
4 TBS butter
Combine pecans, bread crumbs, salt and pepper. Place on a plate. Pour flour on another plate. In a bowl, whisk eggs and milk together.

Dry burbot fillets. Dredge in flour, dip in egg mixture, and coat with pecan and bread crumb mixture.

In a large skillet, melt 2 TBS butter with 2 TBS oil. Add 2 fillets and sauté over medium heat until golden brown on both sides – about 6 to 8 minutes. Transfer to a platter and repeat with the other 2 fillets. Serve with a fruit salsa or tartar sauce.

Recipe No. 4

Burbot with Lemon and Capers Serves 2

2-6 oz skinless, boneless Burbot fillets
2 TBS flour
1 TBS olive oil

1 TBS butter
1/4 cup chicken broth
2 TBS fresh lemon juice
2 TBS each chopped ripe olive and capers
Black pepper to taste
2 TBS parsley
Lemon wedges

Rinse, then dry Burbot fillets. Coat the fillets in flour. In a large skillet sauté the fillets in olive oil over medium high heat about 4 minutes per side.

Transfer fillets to a serving plate and keep warm.

Add the chicken broth, butter, lemon juice, olives, capers and pepper to the skillet and bring to boil. Remove the pan from heat and add parsley. Taste the sauce and adjust seasonings to taste. Pour sauce over fillets. Serve with lemon wedges.

Recipe No. 5

Early Spring Burbot Chowder

1 cup Yukon Yellow potatoes, peeled and cut into 1/2 inch dice.
1 parsnip, peeled and diced
3 cups chicken stock
1 strip of bacon diced
1 small onion, diced
1 rib of celery, diced
1-2 tsp mild curry powder
2 TBS butter
1/4 cup flour
1 cup of Half & Half
1 cup canned creamed corn
10-12 oz Burbot fillets, chunked
2 TBS parsley, chopped
Salt and pepper to taste

Serves 6

Cook potatoes and parsnips in chicken broth until tender, about 10 minutes. Separate broth from vegetables and save both for later use. In a separate pot, cook the bacon until beginning to brown. Add butter, onion and celery and sauté until onions are soft.
Add flour and combine with onions and bacon to make a roux. Cook for 5 minutes, stirring constantly. Gradually add the hot broth, stirring until thickened and smooth.
Add Half & Half and corn and simmer about 10 minutes
Add potatoes and parsnips and stir gently
Add Burbot and parsley and simmer until done (about 4 minutes). Season with salt and pepper

Recipe No. 6

Gingered Burbot Kabobs　　　　　　Serve 4

1 TBS sesame oil
2 TBS soy sauce
2 TBS olive or peanut oil
1 TBS fresh ginger, grated
1 TBS fresh garlic, minced

1 LB Burbot Loin fillets, cut into 1 inch cubes
1/2 small red onion, cut into 1 inch cubes
1 1/2 medium sweet peppers of various colors, red, yellow, green

1/4 cup minced fresh cilantro leaves

Mix together the first five ingredients in a medium glass bowl. Add next three ingredients and marinade 15 minutes. Tread fish and vegetable pieces on skewers. Grill over high heat until fish is cooked thoroughly, about 4 to 5 minutes per side. Place on platter and sprinkle with fresh cilantro and serve.

Recipe No. 7

Poached Burbot Fillets Serves 4

4 – 4 oz boneless, skinless Burbot fillets, rinsed and patted dry
1 green pepper, seeded and cut into 1/2 inch dice
1 medium red onion, peeled and cut into 1/2 inch dice
2 cloves garlic, peeled and minced finely
3/4 cup semi dry white wine
salt and pepper

Place each fillet in the middle of piece of aluminum foil, crimping the ends and sides to form a packet. Season the fillets with salt and pepper. Top the fillets with green pepper, onion and garlic, dividing evenly among the 4 fillets. Pour wine over each fillet dividing evenly between the 4 fillets. Crimp the sides of the pouch shut forming a closed packet. Grill on medium high heat for 10 minutes. Remove from grill. Let stand about 3 minutes before opening. Serve immediately.

Recipe No. 8

Simply Grilled Burbot Fillets Serves 2

2 – 6 oz Burbot fillets, rinsed and patted dry
1 TBS olive oil
2 TBS lemon juice
1/4 tsp garlic salt
paprika
Brush fillets with a mixture of olive oil, lemon juice, and garlic salt. Sprinkle fillets with paprika to cover. Grill on high heat approximately 4 minutes per side. Serve with tartar sauce or lemon wedges.