Trust Fund 2008 Work Program

Date of Report: December 31, 2008
Date of Next Status Report:
Date of Work program Approval:
Project Completion Date: June 30, 2011

I. PROJECT TITLE: Accelerating plans for the integrated control of the common carp

Project Manager: Peter W. Sorensen
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Location: Laboratory studies will be conducted at the St. Paul Campus of the University of Minnesota while field studies will be conducted in several dozen lakes located both in the Ramsey-Washington Metro Watershed District (RWMWD) (Partner) and west of the Twin Cities metropolitan area.

Total Trust Fund Project Budget:	**Trust Fund Appropriation:**	**$550,000**
	Minus Amount Spent:	**$ 0**
	Equal Balance:	**$550,000**

Legal Citation: ML 2008, Chap. 367, Sec. 2, Subd. 4(b)

Appropriation Language:
$550,000 is from the trust fund to the Board of Regents of the University of Minnesota to accelerate research on new approaches to control the invasive common carp. This appropriation is available until June 30, 2011, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. PROJECT SUMMARY AND RESULTS:

Our ongoing LCCMR-funded project has identified recruitment (herein defined as the process by which newly hatched fish survive to a year in age) as a key weakness in the life history of the common carp, the most damaging invasive fish in many Minnesota lakes. This project seeks to understand this weakness so that it might be eventually exploited to control carp. Of special interest is the possibility that winterkill (fish death caused by low oxygen levels attributable to heavy and prolonged snow/ice cover) in interconnected shallow lakes and wetlands appears to correlate with carp recruitment events, leading to the hypothesis that predatory gamefish (which are typically killed by such events, and unlike adult carp, are not highly mobile thus do not re-invade) might normally control carp recruitment. If true, then carp recruitment might be reduced in certain lakes by controlling winter oxygen levels in these lakes to prevent resident fish mortality (winterkills) and/or maintaining high densities of predatory fishes in carp nurseries (shallow marshes), and/or prevent movement of adult carp into winterkilled areas. This project tests the hypothesis that populations of predatory gamefish (ex. sunfish, crappies, walleye, etc.) normally control carp while attempting to develop new means to census and remove carp recruits, and lastly control their movement. It has six components. First, we conduct an in-lake experiment to test whether native gamefish at natural abundances can control the survival of carp eggs, larvae and fry. Second, we conduct a fish survey in shallow lakes (half of which we expect to winterkill) to test the hypothesis that the abundance of young-of-the-year carp (YOY) inversely correlates with game fish abundance and positively correlates with recent winterkill. The alternative hypothesis that food availability might also limit carp recruitment during many years is also examined. Third, we conduct an extensive study of the age-structure study of adult carp in several lakes to test the related hypothesis that winterkill events have historically triggered carp recruitment. Fourth, we test the hypothesis that food odors can be used to attract and trap young carp (less than two years in age) for census or removal. Fifth, we test the hypothesis that pheromones can be used to attract and trap young carp for census or removal. Lastly, we conduct a pilot study to determine whether acoustic field can be safely and effectively used to stop movement of young carp recruits between lakes and wetlands. Although relatively basic in nature, these studies will provide new, key information needed to develop an integrated control program for this, Minnesota's most damaging invasive fish species. If successful, the next step in this project will be to examine ways to manage predatory gamefish and/or watershed ecology (winterkill) to minimize carp abundance.

III. PROGRESS SUMMARY AS OF *(date)*: 250 word limit.

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1: To determine if predation by native gamefish on carp eggs, larvae and fry can potentially be used to control carp recruitment in lake enclosures.

Description: The goal of this experiment is to evaluate the possibility that predatory fish (gamefish in particular) can be managed to control recruitment processes of carp (survival of carp eggs and larvae to a year in age [at which point adult survival appears assured]). This hypothesis will be tested in experimental exclosures set up in a lake where densities of gamefish will be controlled, and the survival of carp eggs, larvae and fry during first 3 months of life measured. This experiment will be conducted in partnership with the Ramsey-Washington Metro Watershed District (RWMWD), which has agreed to cover the costs of the experimental exclosures and other materials, provide assistance with the experiments, and fund a postdoctoral associate for a year (total cost in excess of $350,000 including overhead). The LCCMR will fund the postdoctoral associate for two of the three years required to run this experiment. If we find evidence that gamefish can control carp recruitment then the next step will be to pursue ways to enhance their numbers through stocking and/or watershed management.

Summary Budget Information for Result 1:	**Trust Fund Budget:**	**$ 100,000**
	Amount Spent:	**$ 0**
	Balance:	**$ 100,000**

Deliverable
1. A report on the role of native gamefish in controlling carp recruitment based on experimental lake-enclosure data.

Completion Date: 6/31/2011 *(Note: the project will continue until December 31, 2011 with the support of RWMWD)*

Result Status as of *(12/31/2008):* Finalizing experimental design and signing a contract with the RWMWD

Result Status as of *(6/30/2009)***:** Postdoctoral researcher hired, initial surveys of study site in Lake Phalen system completed to determine vegetation, carp spawning activity and game fish abundance, test enclosure designed.

Result Status as of *(12/31/2009)***:** Preliminary field tests of enclosure design completed and analyzed.

Result Status as of *(6/30/2010)***:** First full-scale field experiment underway to test effects of gamefish on carp recruitment.

Result Status as of *(12/31/2010)***:** Analysis of year one experiment completed.

Final Report Summary: *(6/30/2011):* A report on the likely effectiveness of game fish on reducing carp recruitment based on a one full year of the study and the start of a second year. (Project continues for another 6 months with the sole support of the RWMWD to complete the second field study)

Result 2: To determine if the abundance of young-of-the-year (YOY) carp is inversely correlated with predator abundance in nursery areas following winterkills.

Description: This study further assesses the possibility whether gamefish can be used to control recruitment under 'real-life' conditions in lakes. Specifically, we seek to determine if the abundance of carp recruits is correlated with natural fluctuations in gamefish abundance caused by winterkills. Additionally, we explore the alternative hypotheses that planktonic food for larval carp, system productivity/ thermal regimes, aquatic plants (cover for young-of-the-year carp), and adult carp (source of young fish) might explain the abundance of young-of-the year carp. This study has two components: 1) a large-scale (dozens of lakes) correlative study which will be used to develop a regression model to predict the abundance of carp recruits based on the abundance of predators, competitors, productivity index, average temperature and variability, and abundance of adult carp, and 2) a more focused study which specifically investigates the relationship between the abundance of zooplankton and growth and survival of carp larvae. We will focus on lakes where predator density varies from year-to-year as a result of winterkills and where abundance of carp recruits has been previously documented. The Minnesota DNR is partnering with us on this result to identify and collect winterkill information on test lakes. If we find evidence in support of our hypothesis, the next step in the project will be to consider ways to reduce winterkill in ecologically responsible manner sin collaboration with the DNR.

Summary Budget Information for Result 2:	**Trust Fund Budget:**	**$148,200**
	Amount Spent:	**$ 0**
	Balance:	**$ 148,200**

Deliverables

1. A report which describes correlations between gamefish abundance and/or larval food supply on carp recruitment in Minnesota lakes and how this process might be influenced by winterkills.
2. A report describing a model for predicting the abundance of young-of-the-year carp based on predator density, food competitors, adult carp density, temperature, and lake productivity.

Completion Date: 6/31/2011

Result Status as of *(12/31/2008):* A pilot data on young-of-the-year carp versus gamefish abundance in 6 lakes with variable gamefish density

Result Status as of *(6/30/2009)***:** Analysis of winterkill conditions (oxygen, presence of dead fish in spring) which occurred during the winter of 2008/09, selection of up to 12 study lakes for sampling and analysis in the summer-fall of 2009

Result Status as of *(12/31/2009)***:** Analysis of correlations between predator abundance and other predictor variables and the abundance of carp recruits in the study lakes sampled to date. The correlation between plankton abundance and carp growth/ abundance will also be known in two of these lakes.

Result Status as of *(6/30/2010)***:** Analysis of winterkill conditions which occurred during the winter of 2009/10, selection of an additional group of ~12 new lakes for subsequent sampling and analysis during the summer-fall of 2010.

Result Status as of *(12/31/2010)***:** Preliminary analysis of the correlation between predator abundance (and remaining predictor variables) on young-of-the–year (YOY) carp based on the complete dataset across two years. Initial results of descriptive experiment evaluating possible effects of plankton abundance on carp larvae.

Final Report Summary: (6/30/2011): Final data analysis of the possible effects of predators, competitors, productivity index, vegetation density and adult carp abundance on the abundance of carp recruits completed. Manuscript submitted.

Result 3: Determine whether carp age structure correlates with winterkill events.

Description: The goal of this experiment is to conduct an independent test of our hypothesis that winterkill-driven declines in predatory fishes in interconnected shallow lake systems trigger carp recruitment. We expect that in interconnected lakes, carp populations will be dominated by a few age classes which correlate with winterkill events. While our extant analyses of carp ages in two lakes provide preliminary evidence for this hypothesis, sample size is too small to be definitive.

Here, we examine the age structures of three additional populations of carp, each from a separate watershed with known winterkill records.

Summary Budget Information for Result 3: **Trust Fund Budget: $ 111,500**
Amount Spent: $ 0
Balance: $ 111,500

Deliverables

1. A report which describes a correlation analysis between historical carp recruitment pulses and winterkill events in interconnected shallow lakes, including a logistic equation which predicts the probability of carp recruitment pulse during years with and without winterkills.

Completion Date: 6/31/2011

Result Status as of 12/31/2008: Three study lakes with abundant carp populations and known winterkill records identified for this study.

Result Status as of *(6/30/2009)***:** Otolith samples from 100 common carp from each of the study lakes will have been collected.

Result Status as of *(12/31/2009)***:** Analysis of age structure vs. winterkill record for carp population #1 completed.

Result Status as of *(6/30/2010)***:** Analysis of age structure vs. winterkill record for carp population #2 completed.

Result Status as of *(12/31/2010)***:** Analysis of age structure vs. winterkill record for carp population #3 completed.

Final Report Summary: *(6/30/2011):* Final data analysis, and report on the relationship between historical winterkill occurrence and recruitment in three populations of common carp. Manuscript submitted.

Result 4: To determine if young-of-the-year (YOY) carp can be effectively trapped for census and/or removal using bait attractants.

Description: Integrated pest management (IPM) of carp will require that we have excellent tools to monitor the abundance and distribution of YOY carp so we can adjust recruitment suppression strategies effectively. Additionally, it would be extremely advantageous to have a technique capable of removing ‘outbreaks’ of YOY carp. This objective seeks to develop attractant based trapping as a means to assess the presence of YOY carp. Experience shows that attractants are needed because carp often hesitate to enter traps and do not seem to live in areas which can be sampled using electro-fishing. Pilot data suggests food might be a useful and if perfected, might be enhanced (synthesized) to remove recruits. Laboratory experiments first seek to explore/ develop the potential of food attractants under controlled conditions by examining preferred food items for YOY carp, daily feeding rhythms, and how to best use odor plumes in attraction. Then, field tests are planned to evaluate the true potential for a perfected stimulus. This project result will be the responsibility of a Ph.D. graduate student, Jacob Osborne, whose first two years of support are provided by the National Science Foundation. This project will be closely coordinated with Result #5 (pheromones). If successful, a partner to develop carp removal technologies will be sought.

Summary Budget Information for Result 4:	**Trust Fund Budget:**	**$ 79,000**
	Amount Spent:	**$ 0**
	Balance:	**$ 79,000**

Deliverables

1. A report which identifies food attractants for young carp and describes possible trapping system(s) which might employ these attractants to monitor YOY carp abundance in the field.

Completion Date: 6/31/2011

Result Status as of *(12/31/2008):* The food preference of young-of-year (YOY) common carp will be characterized.

Result Status as of *(6/30/2009)***:** The daily activity patterns of the YOY carp in the laboratory will be known, allowing us to suggest optimal times to use food attractants in the laboratory.

Result Status as of *(12/31/2009)***:** The potential of water flow to create attractive odor plumes will be known in the laboratory.

Result Status as of *(6/30/2010)***:** The possibility of using traps baited with food to will be known from initial field work.

Result Status as of *(12/31/2010)***:** If/ as appropriate (see result for result #5), the chemical characteristics of an optimal bait (or pheromone) will be known.

Final Report Summary: *(6/30/2011):* The potential for using food attractants to census, and perhaps remove, YOY carp in lakes will be known.

Result 5*:* To determine if young-of-the-year (YOY) carp can be effectively trapped for census and/or removal using pheromonal attractants.

Description: This project compliments that of result #4. Briefly, to suppress carp recruitment over the long term, we will need to be able to accurately and efficiently evaluate the presence of YOY carp in various lakes. While food-baited traps may be effective in many locations, they will not be useful if fish are not feeding or fish species have overlapping food habits with young carp (unknown at present). Our ongoing LCCMR funded research is demonstrating that juvenile common carp release a pheromone (a natural chemical signals that passes between members of the same species) which might have considerable potential for use in trapping. This work will continue until June 2010, after which the present project will continue to isolate and tests the potential of this cue. The Ph.D. student/ NSF Fellow responsible for Result #4 will also be responsible for this work and he will conduct these two closely-related projects hand-in-hand. Because this is basic research and extremely challenging (this is the first attempt to identify a juvenile pheromone aggregant in a fish), and we cannot sure when and if a breakthrough will occur, research will proceed in steps that offer flexibility and the potential to focus on food attractants (Result #4), should that option eventually prove the most promising.

Summary Budget Information for Result 5:	**Trust Fund Budget:**	**$ 84,300**
	Amount Spent:	**$ 0**
	Balance:	**$ 84,300**

Deliverables

1. A report on the potential use of an aggregation pheromone for sampling carp and the potential use of pheromonal traps to monitor YOY abundance in the field.

Completion Date: 6/31/2011

Result Status as of 12/31/2008: None for this project (continuation of work on pheromone chemistry under the auspices of our 2005-2009 LCCMR project)

Result Status as of *(6/30/2009)***:** The daily activity patterns of the YOY carp in the laboratory will be known, allowing us to suggest optimal times to use attractants in the laboratory (same Result for Result #4).

Result Status as of *(12/31/2009)***:** The ability of water flow to supplement pheromonal attractant in the laboratory will be known.

Result Status as of *(6/30/2010)***:** Preliminary assessment of the pheromones 9and food) to attract YOY carp in the laboratory and likely field, will be available. A tentative decision will be made as to whether food or pheromonal cues are the most promising.

Result Status as of *(12/31/2010)***:** The identity of the juvenile aggregation pheromone (or food attractant) will be known (see Result #4).

Final Report Summary: *(6/30/2011):* The potential for pheromones to control YOY carp will be established. Key information on chemical identity will be known. Manuscript submitted

Result 6: Developing barrier technologies to prevent spread of juvenile carp from their nurseries

Description: For a carp management program to be successful in the inter-connected lakes which typify Minnesota, it will have to both suppress (and likely remove) YOY carp and prevent re-infestation of carp from other water-bodies. In particular, safe and effective technologies are needed to stop the movement of YOY carp through creeks. Acoustic fields offer this opportunity for common carp and Asian carp species because both have an acute sense of hearing. A partnership with the Riley Purgatory Bluff Creek Watershed District (RPBCWD) which will provide part-time support for a Ph.D. fisheries student to share information gained on carp movement in their watershed offers an opportunity to start designing carp barriers. This result will support a part-time engineering graduate student at the University to work with this Ph.D. fisheries student to conduct laboratory studies for a year to assess the feasibility of using acoustic fields. If the results prove promising, we will seek more significant funding (perhaps from the LCCMR) to enhance this work in 2009 to continue this study.

Summary Budget Information for Result 6:	**Trust Fund Budget:**	**$ 27,000**
	Amount Spent:	**$ 0**
	Balance:	**$ 27,000**

Deliverables

1. A report which addresses how acoustic fields can be established and measured in a flowing laboratory flume, and then how they might be used to repel small groups of upstream-moving juvenile common carp.

Completion Date: *6/30/2009*

Result Status as of *(12/31/2008).* A design for creating and measuring acoustic fields in the laboratory will exist.

Final report Summary *(6/30/2009).* An analysis of the ability of an acoustic field to stop upstream swimming of small carp in the laboratory

V. TOTAL TRUST FUND PROJECT BUDGET:

Staff or Contract Services: **$409,800**
Equipment: **$4,800**
Development: $0
Restoration: $0
Acquisition, including easements: $0

Other: $135,400
- **Printing: $4,000**
- **Supplies: $68,900**
- **Travel: $31,500**
- **Services: $31,000**
  - **Equipment and vehicle repairs: $12,000**
  - **St. Anthony Falls: $4,000**
  - **Chemical analysis: $15,000**

TOTAL TRUST FUND PROJECT BUDGET: $550,000

Explanation of Capital Expenditures Greater Than $3,500:
Ageing analysis (Result #3) requires a low-speed diamond blade saw such as the Buehler Isomet low speed saw (http://www.buehler.com), to precisely section fish inner ear bones (otoliths). The cost estimate for the saw furnished by the local Buehler dealer is $4,800.

VI. OTHER FUNDS & PARTNERS:

A. Project Partners:

1. Ramsey-Washington Metro Watershed District: The RWMWD has pledged $323,000 to cover the costs of the experimental exclosures and other materials, and one year's salary for a postdoctoral research associate to conduct Result #1.

2. Minnesota Department of Natural Resources, Section of Fisheries will provide in-kind support for sampling lakes for Results #2 and 3.

3. Riley Purgatory Bluff Creek Watershed District (RPBCWD) will provide in-kind salary support for Result #6.

4. University of Minnesota St. Anthony Falls Laboratory will provide flumes for testing carp free of charge.

B. Other Funds Proposed to be spent during the Project Period:

Dr. Sorensen will be contributing part of his academic year salary time from the University of Minnesota to this project.

C. Past Spending:

2004-2004: Developing pheromones for use in carp control $100,000

2005-2009 (ongoing): Integrated and pheromonal control of carp ~$350,000 of $550,000 has been spent to date.

2005-2009 (on going). Minneosta Department of Natural Resources (Ecologcial Services). Deploying a population model for the common carp $60,000.

D. Time: July 1,2008 until June 30, 2011

We require three years of support for this project because of its complexity and difficulty. In particular, two full field seasons (2009, 2010) are needed to investigate processes that control carp recruitment (Results 2, 3) and to allow for surveying sifficient number of lakes and account for potential year-to-year variability in recruitment. Also, because Results 4 and 5 are complex and invlobe both laboratory and field component they require 3 years of funding.

VII. DISSEMINATION:

1. Publications in peer-reviewed literature
2. Presentations at scientific meetings
3. Collaborations with local watershed districts and lake associations
4. Web site

VIII. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than ________. A final work program report and associated products will be submitted between June 30 and August 1, 2009 or 2010 as requested by the LCCMR

IX. RESEARCH PROJECTS:

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Attachment A: Budget Detail for 2008 Projects - Summary and budget page for the University of Minnesota

Project Title: ***Accelerating plans for the integrated control of the common carp***

Project Manager Name: ***Peter W. Sorensen***

Trust Fund Appropriation: $ *550,000*

2008 Trust Fund Budget	**Result 1 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 2 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 3 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 4 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 5 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**Result 6 Budget:**	**Amount Spent** *(date)*	**Balance** *(date)*	**TOTAL BUDGET**	**TOTAL BALANCE**
	To determine if predation by native gamefish on carp eggs, larvae and fry can potentially be used to control carp recruitment in lake enclosures.			*To determine if the abundance of young-of-the-year (YOY) carp is inversely correlated with predator abundance in nursery areas following winterkills.*			*To determine whether carp age structure correlates with winterkill events*			*To determine if young-of-the-year (YOY) carp can be effectively trapped for census and/or removal using bait attractants.*			*To determine if young-of-the-year (YOY) carp can be effectively trapped for census and/or removal using pheromonal attractants.*			*Developing barrier technologies to prevent spread of juvenile carp from their nurseries*				
BUDGET ITEM																				
PERSONNEL: wages and benefits (TOTAL)	100,000	0	100,000	115,200	0	115,200	89,400	0	89,400	43,100	0	43,100	43,100	0	43,100	19,000	0	19,000	409,800	409,800
Academic salaries and fringe : Pincipal Investigator and Project Manager (10%) Co-project manager (50% time; Objectives 2,3) Postdoctoral Associate (100% time, Objective 1)	100,000	0	0	69,100	0	69,100	46,700	0	46,700	14,100	0	14,100	14,100	0	14,100	3,500	0	3,500	247,500	247,500
Graduate students salary and fringe : PhD student (Objective 4,5, 1 year) MS student (Objective 6, 25% time, 1 year)	0	0	0	0	0	0	0	0	0	17,700	0	17,700	17,700	0	17,700	15,500	0	15,500	50,900	50,900
Undergraduate student salary and fringe	0	0	0	10,300	0	10,300	6,900	0	6,900	11,300	0	11,300	11,300	0	11,300	0	0	0	39,800	39,800
Civil service salary and fringe : Field technician (50% time)	0	0	0	35,800	0	35,800	35,800	0	0	0	0	0	0	0	0	0	0	0	71,600	71,600
Equipment *(saw for Csectioning carpiotoliths; i.e.aging)*	0		0	0	0	0	4,800	0	4,800		0	0		0	0		0	0	4,800	4,800
Printing *(copies, publication costs)*	0	0	0	1,000	0	1,000	1,000	0	1,000	1,000	0	1,000	1,000	0	1,000	0	0	0	4,000	4,000
Supplies (TOTAL);	0	0	0	10,600	0	10,600	10,700	0	10,700	22,100	0	22,100	22,000	0	22,000	3,500	0	3,500	68,900	68,900
General operating supplies	0	0	0	600	0	600	2,700	0	2,700	3,100	0	3,100	3,000	0	3,000	500	0	500	9,900	9,900
Laboratory and field supplies	0	0	0	10,000	0	10,000	8,000	0	8,000	19,000	0	19,000	19,000	0	19,000	3,000	0	3,000	59,000	59,000
Travel expenses in Minnesota (TOTAL)	0	0	0	15,000	0	15,000	3,000	0	3,000	3,500	0	3,500	3,500	0	3,500	500	0	500	25,500	25,500
Fuel for dedicated field vehicle (~15,000 miles/yr)	0	0	0	14,000	0	14,000	2,000	0	2,000	2,000	0	2,000	2,000	0	2,000	0	0	0	20,000	20,000
Vehicle rental for peak field season	0	0	0	0	0	0	0	0	0	500	0	500	500	0	500	500	0	500	1,500	1,500
travel to local meetings	0	0	0	1,000	0	1,000	1,000	0	1,000	1,000	0	1,000	1,000	0	1,000	0	0	0	4,000	4,000
Travel outside Minnesota *(professional acientific meetings)*	0		0	0	0	0	0	0	0	3,000	0	3,000	3,000	0	3,000	0	0	0	6,000	6,000
Other: Equipment and field vehicle maintenance and repairs	0	0	0	6,400	0	6,400	2,600	0	2,600	1,800	0	1,800	1,200	0	1,200	0	0	0	12,000	12,000
Other: Lab/ medical Services *St. Anthony Fall Laboratory, Chemcial anlyses of attractants*	0	0	0	0	0	0	0	0	0	4,500	0	4,500	10,500	0	10,500	4,000	0	4,000	19,000	19,000
COLUMN TOTAL	**$100,000**	**$0**	**$100,000**	**$148,200**	**$0**	**$148,200**	**$111,500**	**$0**	**$111,500**	**$79,000**	**$0**	**$79,000**	**$84,300**	**$0**	**$84,300**	**$27,000**	**$0**	**$27,000**	**$550,000**	**$550,000**

** The principle investigator is a professor with 9 months of regular pay from the University of MN ; the 10% time is over and above that pay level and is for summer research*

*** Supplies to include:*

General operating supplies to include: Result 1: and 2: small boat gasoline and oil for boats raingear, small sampling nets, baits; Res 4 and 5: Fish traps and baits; Res 6: nets, carp , sound projection systems

Labaoratory and field supplies to include: Result 2: plankton and other fish nets, oxygen meter, small boat; Result 3: saw blades, resins, molds, microscope slides; Results 4 and 5: carp for lab work, aquarium supplies, fish food lab solvernts, glass ware, baits and related chemicals, electrodes, pheromones; Result 6: air bubblers, video cameras, carp for tests, fish food, etc

*** Professional meeting(s): Data on carp will be presented and exchanged with national and international experts at scientific meetings which will include: Annual meetng of the American Fisheries Society, International Chemical Ecology Sooiety; Midewest Fish and Wildlife Conference*

Research Addendum for Peer Review

PROJECT MANAGER: Peter W. Sorensen

PROJECT TITLE: Accelerating Plans for Integrated Control of the Common Carp

PROJECT NUMBER:

I. ABSTRACT

Our ongoing LCCMR-funded project has identified recruitment (herein defined as the process by which newly hatched fish survive to a year in age) as a surprising weakness in the population dynamics of common carp in Minnesota lakes. Aging studies of adults suggest that recruitment may only occur in lakes connected with marshy regions, and then only when these regions experience winterkill. Many lakes in Minnesota fit these criteria. The most logical explanation for this phenomenon is that winterkill reduces the number of predatory fish in the shallow, marshy regions into which carp migrate to spawn. If this hypothesis is true, carp recruitment might be controlled by managing predatory game-fish populations either through stocking programs or indirectly by controlling winter oxygen levels. Of course, carp recruitment might also be controlled using targeted trapping or rotenone if survivorship of young carp is detected early enough. Here we test these ideas. First, we conduct a fish survey in 24 shallow lakes to examine the hypothesis that the abundance of young-of-the-year carp (YOY) inversely correlates with game fish abundance and positively correlates with recent winterkill in these lake systems. The alternative hypothesis that food availability might also limit carp recruitment many years is also examined. Second, we conduct an extensive age-structure study to test the hypothesis that winterkill events have historically triggered carp recruitment. Third, we test the hypothesis that food odors can be used to attract and trap YOY carp for census or removal. Fourth, we test the hypothesis that pheromones can be used to attract and trap YOY carp for census or removal. Together with ongoing research focused on adult carp removal funded by a local watershed district, this project represents a strong positive step towards developing sustainable common carp control in our region.

II. BACKGROUND AND HYPOTHESES

II.1 Preface

This proposal is the second step in a plan to develop an integrated pest management program for common carp (*Cyprinus carpio*) in Minnesota. It builds on an existing

LCCMR-funded project (Integrated and Pheromonal Control of Carps) which, although it has approximately a year remaining, has discovered that recruitment (survival of newly hatched fish until a year old), is a weak link in carp biology that can be exploited for control. Additionally, the Sorensen laboratory has been fortunate enough to receive a pledge of almost a million dollars to conduct an experimental (3year) integrated control program for carp in 3 metropolitan lakes (Lakes Susan, Riley, and Rice Marsh). While this program will also examine/control recruitment processes, the three lakes it focuses on do not often experience recruitment so opportunities are limited. Accordingly, it is timely to accelerate/ promote research in carp recruitment. The work outlined in this proposal will examine the issue of carp recruitment across a broad region of the state. This version of the proposal reflects a 20 percent cut of the initially proposed budget (final recommended budget of $450,000 vs. $564,000 requested) through elimination of one objective (an experimental test of the role of game-fish in carp control) and modification of the other objectives. Pheromone studies will be continuing under the auspices of our ongoing LCCMR project (only briefly reviewed in the methods section herein).

II.2. Introduction to the common carp and the damage it causes

The common carp, *Cyprinus carpio* (herein,'carp'), was intentionally introduced to North America from Europe in the 1870's by the U.S. Fisheries Commission and quickly established itself as one our most damaging invasive fish, especially in shallow inland waterways (Smiley, 1886; Cole, 1905). The damage caused by carp is related to both its abundance and the fact that, unlike any native fish, adult carp dig deeply into bottom sediments for food (Nikolsky, 1963). In doing so, carp disturb large quantities of sediment, uproot aquatic plants, and release nutrients (both directly and indirectly though excretion), thereby causing turbid, eutrophic conditions (Lamarra 1975; Parkos et al., 2003; Robertson et al., 1997). Consequently, shallow lakes with abundant carp populations usually 'flip' from a state of clear water with abundant native vegetation to a state of turbid water with (often toxic) algal blooms (Moss, 1990; Lougheed et al., 1998). Once waterways are eutrophic, carp usually become the dominant fish species in these systems, perpetuating eutrophic conditions indefinitely. We estimate that the ecological integrity of hundreds of thousands of acres of shallow waterways across the region have been severely compromised in this manner by the common carp.

The impacts of carp on aquatic systems are particularly severe in shallow and productive systems which do not stratify where carp have constant access to foraging habitats and waters can mix from top to bottom (Zambrano et al., 2001). Almost certainly carp are able to maintain their dominate status because of their tolerance of degraded conditions, extreme fecundity (a female can produce over a million eggs), habits of moving throughout watersheds, and large adult size, making them immune to common predators (Koehn et al., 2000). Although the common carp's tolerance of eutrophic conditions has led some to suggest that their presence reflects, rather than causes, environmental deterioration, the truth is very likely a combination of the two. Most resource managers readily acknowledge that restoration of pristine shallow-water habitat is impossible without removing this species (Cahoon 1953; Meijer et al. 1999). No organized sustainable strategy exists for carp control at this time although occasionally expensive efforts using whole-lake poisoning with rotenone and barrier construction (which can cost millions of dollars) are attempted. These efforts often lead to temporary improvements in water quality (ex. Lake Christina, MN [Ray Norrgard, Wetland Wildlife, Minnesota DNR]; DesPlains River Wetland, Illinois [www.wetlands-nitiative.org], Swan Lake, Iowa [Hanson and Butler, 1990; Hill, 1998]), but the effects are often very short-lived because carp eventually get back into these systems or kills are incomplete. Although there have been no estimates of the economic impact of carp infestation on Minnesota and the Midwest, we imagine it would be in the tens of millions of dollars annually, similar to numbers calculated for Australia (McLeod, 2004). Clearly, a strategy is needed to control this species.

Integrated pest management (IPM) appears to represent a realistic solution to the carp problem. The IPM approach is based on the premise that pest species can be controlled in economically and ecologically sustainable manners using specific combinations of targeted techniques that exploit weaknesses in their life histories over the long term (Roberts and Tilzey, 1996; Christie and Goddard, 2003; Sorensen and Stacey, 2004). IPM typically does not seek eradication but rather cost-effective control to sustainable (tolerable) levels of the unwanted species based on scientific principals. IPM has worked well for many invasive insect and plants, and is now being employed for an invasive fish, the sea lamprey, with considerable success (Christie and Goddard, 2003). Herein, we hypothesize that IPM is a viable strategy for controlling the common carp and seek to develop tools to initiate such a program. Successful IPM requires an understanding of the processes that drive the abundance of the pest species and tools to monitor and control it. Therefore, this proposal focuses on controlling and monitoring recruitment.

II.3. Recent advances in carp research by our ongoing LCCMR project

Our ongoing LCCMR-funded work, which seems to represent the largest active and focused study of carp biology in North America, has 3 components: 1) Isolating/

identifying possible sensory (pheromonal) attractants that might be used in trapping; 2) Defining carp spawning habitat preferences and nursery habitat to see if they might be targeted; and 3) Elucidating population dynamics to simulate and evaluate control options. A brief synopsis of key results on carp ecology that serve as a basis for this study follows.

To elucidate the population dynamics of carp we have been studying carp population in 6 lakes. In addition, to performing large-scale mark-recapture studies to get detailed information on carp numbers, we have examined age structure of randomly selected portion of the population using otoliths. This work has been conduced in collaboration with Paul Brown (Primary Industries Victoria, Australia) who has considerable experience aging carp. Briefly, these ongoing studies show that Minnesota carp populations are especially large in shallow lakes that have connections with other shallow water systems. Interestingly, these carp populations are typically dominated by few year classes, many of which are very old. Specifically, we find carp up to 20 years in age (ranging up to 53) distributed amongst only a handful of year classes (Fig.1). Further, when we have been able to find climatological data for these lakes, we have found that year class strength correlates with winterkill events (Fig. 1). For example, of the seven recruitment events that occurred during the last 20 years in Lake Susan (located 20 mile west of Minneapolis), four occurred immediately after either this lake or its adjacent marsh suffered from winterkills (Fig. 2). The extraordinarily strong year class of 1991 (Fig. 2; 15 year olds) was born immediately after Lake Susan suffered from the last of four consecutive winterkills. Although these data are admittedly sparse (they were a chance discovery and were not a specific focus of our ongoing LCCMR project), they are extremely important because they suggest that natural processes in lakes typically control carp abundance. This notion runs counter to established dogma about carp and warrants confirmation. Specifically, we hypothesize that carp recruitment is normally controlled by predatory fishes in the shallow marshes that carps enter for spawning but that abundance of predators is suppressed during winterkill years, thereby triggering recruitment events. Anecdotal support for this important hypothesis comes from our ongoing studies of carp spawning habits (below).

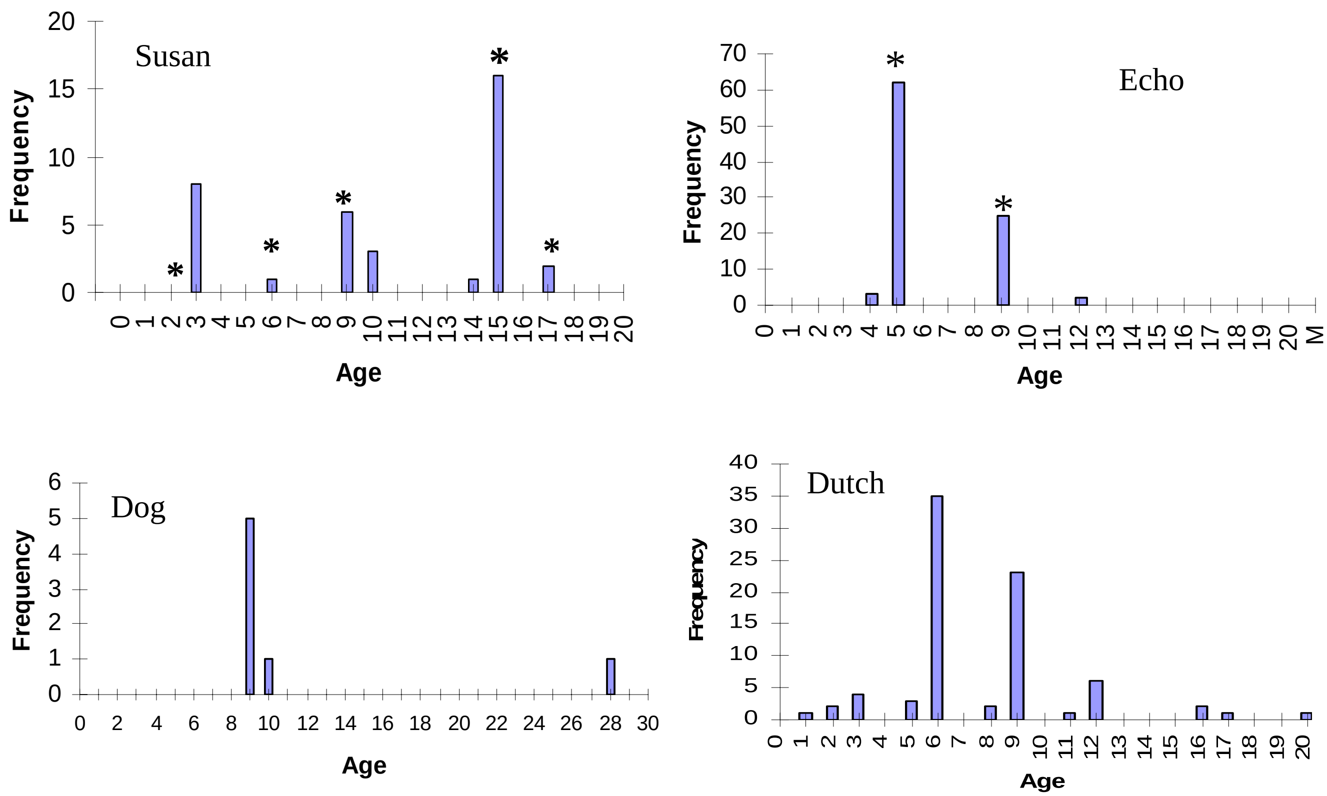


Fig. 1. Age structures of carp populations in lakes Susan, Echo, Dog, and Dutch documented in 2006 using otolith aging. Winterkill histories (records of fish mortality in anoxic waters) could only be verified for Lakes Susan and Echo; asterisks indicate winterkill events in these lakes or interconnected marshes. The last winterkill in Lake. Susan occurred 15 years go, since then only the adjacent Rice Marsh Lake winterkilled

so we speculate that most of the fish probably came from the latter system. Gaps in age structures indicate recruitment failures.

Reproductive activity (release of fertilized gametes) *per se* does not seem to explain the timing of recruitment success of carp while the distribution of spawning activity emphasizes the importance of marsh systems that are know to winterkill. Briefly, we have been continuously tracking radio-tagged carp in three lakes for the last two years, paying special attention to when and where they spawn. We find that that while female carp exploit a vast range of spawning habitats, they aggressively move up shallow waterways to spawn in marshy areas where they may spawn for many weeks. Further, we have found that while over 1 billion fertile eggs are deposited along the shores, the majority are fertile (confirmed by lab testing). However, few seem to survive past the first month. In particular, extensive post-spawning sampling efforts for young-of-the-year (YOY) using electro-fishing, and trap-net surveys have yielded on 6 fish in 2 years (Table 1). Control studies in marshy areas outside of our study regions suggest the cause is not gear failure. We now need to understand what is happening to the many billions of carp eggs/larvae/fry in our study regions and why on some occasions (but none we have personally witnessed) they survive. Largely based on the winterkill data described above, we believe that predation by game fish is the explanation. The extended spawning period of the carp and our ability to hatch them argues against critical food shortages for larvae or disease. Our hypothesis is supported by the fact that all study lakes had/ have abundant populations of predatory fishes easily capable of foraging on the extremely small and vulnerable carp eggs and larvae. This hypothesis is also supported by the earlier observation that survival of YOY carp occurs only after winterkills when we know populations of predatory fishes are greatly reduced. We know of no study that has attempted to document the effects of predation on carp recruitment..

Table 1. A summary of average yearly carp reproductive output and spawning success in Lakes Susan, Rice Lake Marsh and Riley during 2006 and 2007; numbers represent averages per year. Abundance of females in Lake Susan was estimated via mark-and-recapture, while the numbers of females in the other lakes are approximated from catch rates. Total number of fertilized eggs is estimated as # females * fecundity*fertilization rate; average female fecundity (stage III eggs) is estimated from total length (Fecundity = 0.0028 * length – 0.9; $P<0.01$; $r^2=0.73$). Fertilization rate = 50% from laboratory experiments.

Lake	Spawning sites	Spawning days	# Females	Total fertilized eggs	Number of YOY carp in surveys
Susan	110	12	2,050 ± 400	0.8 bln	0
Rice Marsh	117	10	~1,500	0.6 bln	0
Riley	297	19	~5,000	2.0 bln	0

II. 4. Processes that might drive recruitment of carp in Minnesota lakes

In retrospect, our finding that recruitment in common carp is sporadic and likely influenced by predation should not have been surprising; many examples exist of predator-driven recruitment suppression in shallow lakes (Broenmark at al., 1995; Tonn et al., 1992; Post et al. 1998; Santucci and Wahl, 2003; O'Gorman et al., 2004). Of special significance to our studies of common carp is an elegant study of a very close relative of the common carp, the crucian carp (*Carassius carassius*), in Scandinavian winterkill lakes (Tonn et al., 1992). This particular study demonstrated that yellow perch introduced into lakes with YOY crucian carp consumed over 90% of all crucian carp during the summer while relegating the remaining fishes to shallow, weedy regions where they suffered great reductions in growth rates. Effects of predatory game fish may be strong and both direct and indirect (for instance predators may drive YOY into vegetation where they starve).

Although predation pressure is the most compelling explanation for recruitment failure after winterkill, a few other factors might also help explain this observation. For example, although undocumented, limited food reserves,, perhaps triggered by greater survival of other species eggs, may also affect survival of YOY carp. Indeed, pond aquaculture studies demonstrate that survival of carp larvae is strongly dependent on diet quality and quantity, with adequate survival and growth rates occurring at high densities of small zooplankton, mainly rotifers and small cladocerans (*Bosmina* sp.) (Sarig 1966; Dabrowski and Poczynski, 1988). In addition to causing mortality directly, food shortage can also profoundly affect growth rates of carp larvae (Schäperclaus 1961) making them more vulnerable to predation. Of course, cold or variable temperatures during larval development (mid May-June) may slow down growth of larvae and fry and increase mortality (Tomcko and Pierce, 2005; Post et al., 1998; O'Gorman et al., 2004; Beard et al., 2003). Conversely, higher water levels in spring after extensive ic melting may enhance carp survival by opening new habitats and reducing crowding (King 2005). All of these variables are correlated and potentially distracting. Nevertheless, the fact remains that in shallow Minnesota lakes that experience winterkill, winterkill seems to correlate strongly with peak recruitment events when the abundance of resident predatory game fish most likely drops dramatically while adult carp retain access – predation on eggs, larval, and/or YOY carp appears most likely to be the driving force that controls recruitment. Accordingly, our primary goal is to investigate the possible effects of predatory gamefish on carp recruitment, while being mindful of several alternative/

modulatory factors through a broad correlative study which includes a small-scale study of the survival and growth of carp larvae.

II. 5 Our hypothesis to explain the abundance of common carp in Minnesota lakes.

We hypothesize that common carp have come to dominate local lakes as a consequence of several attributes of their biology, some of which are controllable. Carp appear to combine key attributes of both 'K' and 'r' selections in their reproductive biology. As our research shows, adult carp are long-lived, resilient and immune to predation. However, they also mature early (3-4), are extremely fecund (over 1million eggs/female), have relatively indiscriminant spawning habits, and are able to exploit very shallow connected systems to spawn. Once in these systems they appear to release eggs in huge numbers as discrete synchronized events (likely triggered by pheromones; Sorensen and Stacey, 2004). The extreme mobility of adult carp and plasticity in selecting spawning substrate, of which shallow inland regions that are heavily vegetated appear to be favored (Swee and McCrimmon, 1966), allows them to exploit wide range of systems. A final key element in carp success is their broad diet (Crivelli, 1981) and fast growth rates of YOYs (10-20 cm by the end of the year; P.G. Bajer; unpublished data), which grow beyond the size that predatory fish can consume within a few months. It appears that YOY carp that survive past the first year of life, they typically persist in lakes for decades, spawning each year in very opportunistic manner.

Early survival of YOY appears to be the foremost weakness in carp life history strategy. Although never studied in the field, lab studies from China describe YOY carp as poor swimmers that have little ability to hide or defend themselves from predators

(Jhingran and Pullin, 1988). Interconnected shallow-water systems such as those found across the Midwest which offer occasional refuge from predation either because of predator mortality (winterkill) or the opening of new areas (flooding) might thus comprise ideal habitat for YOY carp. Likewise, we expect lake systems that have extremely stable game fish populations (deep water systems) or offer no refuges for YOY carp (isolated lakes with no connections) to be poor habitat for YOY carp. The hydrographic conditions of most Minnesota lake-systems nevertheless provide perfect match for carp as the vast majority are interconnected systems of both deeper lakes that do not winterkill where carp can survive for decades, as well as shallower lakes and marshes that do winterkill and comprise optimal nursery. The excellent news for carp control is that winterkill (and game fish abundance) can be controlled in many of these shallower systems using combinations of aeration (to enhance game fish overwinter survival), game fish stocking programs, and/or recruit removal programs. Barrier systems may also be useful if deployed wisely.

Based on our hypothesis, any IPM plan seeking to control carp in a sustainable manner needs to understand carp recruitment, be able to monitor it, and suppress it as and when it occurs. Although compelling, the unpublished data we describe above are as yet too poorly developed to instigate large-scale programs to suppress carp recruitment by reducing winterkill and stabilizing water levels while barricading potential adjoining wetlands that could serve as carp spawning/ nursery habitats. This is especially true because carp nursery habitat requirements have never been studied. The present study will examine these critical issues and develop means to monitor the abundance of YOY carp. Other ongoing work is presently examining adult carp removal and barrier systems to systematically block their access to nursery habitats.

II. 6. A note on predictive models

Development of statistical models capable of predicting recruitment strength has been at the core of marine and freshwater fisheries science for decades. Typically, fish managers are trying to understand what conditions regulate recruitment, and how they can be manipulated to enhance recruitment. Our approach would be different: we want to determine what conditions are best at suppressing carp recruitment and how they may be manipulated (practically). Recent studies recognize that multiple regression models that include both main variables, as well as secondary variables that modify the main effects, are best at predicting recruitment strength in lakes (Maceina, 2003; Bunnell et al., 2006; O'Gorman et al. 2004). Accordingly, we propose to develop multiple regression models for predicting the abundance of YOY carp in response to larger-scale variables that include the abundance of predators (main factor) as well as a few secondary factors including 'competitors' (YOY of other species that might consume larval carp food and may also be suppressed during winterkills years) , temperature (it influences growth), water level (high water levels may provide refuges for young carp), plant density (cover for young fish), and productivity (Total P – a predicator of plankton abundance).

II. 6. Hypotheses to be tested by this project

To address the role of predators in carp recruitment and ways to monitor and control it, we test four hypotheses:

H1: The abundance of YOY carp in interconnected shallow lakes in Minnesota is primarily regulated by predator abundance in the late spring and early summer when YOY carp are most vulnerable, the two of which are inversely correlated and influenced by winterkill. Other correlated factors include larval food abundance (possibly as influenced by competing larvae and young of other species), temperature, and aquatic plants (cover).

H2: Carp age structures will correlate with historical winterkill events in systems that also have connected deeper-water refuges for adult carp.

H3: Feeding stimuli can be used to attract and trap YOY carp for population census or perhaps removal.

H4: Pheromones can be used to attract and trap YOY carp for population census or perhaps, removal.

III. METHODS

Hypothesis 1: The abundance of young-of-the-year carp will be much higher following winterkills due to reduced predation in shallow nursery areas.

We will address this hypothesis by conducting an extensive sampling study for YOY carp and predatory fish, combined with a focused study on larval survival and abundance. Modeling approaches will be used for both. We focus on YOY (vs. larvae) because we are best able to sample them across a wide range of habitats. This combination will provide direct and independent tests of the predatory hypothesis while allowing us to address and a few important alternative hypothesis (possible food limitation). Given our limited budget and time, we feel that this approach (vs. direct tests of predator control) is very reasonable, because important basic information on carp recruitment is sure to result and this information will allow for well-defined direct tests of predator stocking if/ appropriate (these tests were removed because of budget cuts).

Correlative study of YOY carp, predatory fishes, and other environmental variables.

First, we examine the relationships between YOY carp (operationally defined as carp less than a year old and large enough to be sampled using electrofishing) and a variety of environmental variables across a large variety of lakes. We know that electrofishing will allow us to effectively sample a wide range of lakes and habitats quickly, giving us great analytical power. Specifically, we will survey the fish fauna found in 24 hallow lakes to document the relative abundance of YOY carp while measuring our main predictor variable (adult predatory game fish) as well as several secondary ones (food abundance [plankton density and the larval fishes that may also eat it as well as water productivity that might predict it]), temperature, aquatic plants (cover), adult carp (source of young fish), productivity. These data will then be employed to model YOY abundance (see below). Study lakes will be selected in consultation with DNR personnel whom we will ask to identify a group of shallow lakes which we believe could/do produce YOY carp with some frequency (every 3-5 years) and which we can also sample efficiently (size <

350ha, depth < 3m, moderate plant density, boat access). We will then select a subset of 24 lakes which, based on lake morphology or historical records, we deem to be highly likely (or not) to experience winterkills and/or have variable game fish populations. Initial discussions with DNR managers in Hutchinson have already identified Byron, Silver, Little Wolf, Mallard Pass, and Swan Lakes as possible candidates for this work. Because recruitment appears to be infrequent, we expect many lakes will naturally serve as positive controls for the study but we will adjust lake selection if need be. Two full field seasons will be conducted.

Specific sampling protocols will proceed as follows. Each February, we will travel to 12 of our 24 study lakes to evaluate winterkill conditions by drilling through the ice and checking oxygen levels. In our experience, lakes that winterkill have typically ~ 1 mg/l oxygen by February. Six lakes deemed likely to winterkill will then be selected as well as six controls. We will return to each lake monthly to monitor conditions until ice out when temperature loggers will be set so that we may correlate fish growth rates, which may determine susceptibility to predation. All 12 lakes will then be surveyed in July-August (when YOY should be large enough to sample) using an electrofishing boat to determine the abundances of YOY carp, predatory game fish (sunfish, pike, bass, walleye, etc), possible competitors (i.e. YOY of other species) and adult carp. A fall survey will also be conducted – by conducting a summer and fall survey we should be able to identify windows of vulnerability in YOY carp. In both cases, will collect fish from a range of habitats to be sure that if carp are present we sample them. Monitoring changes in numbers and sizes of YOY carp over time will allow us to assess the role of predators in suppressing YOY abundance. For example, in systems dominated by small predators (bluegills) that are more capable of foraging on carp eggs and larvae, we might expect to measure low numbers of early YOYs (July) which will then remain stable throughout the rest of the year. In systems where larger predators (ex. crappie, bass, pike, walleye) dominate that forage primarily on carp fry, we expect to see higher numbers of early YOYs that will then gradually decline throughout the season. Optimal control of carp YOY is expected in systems where both small and large predators are abundant. All fish collected during electrofishing surveys will be measured to the nearest mm. This cycle will be repeated for two years, using new experimental lakes (if/as appropriate). While conducting fish surveys, we will visually estimate plant density in several randomly selected littoral sites, and water turbidity (Secchi depth). Water levels will be monitored more continuously in a small group of lakes to represent general hydrological conditions for a given year (see below). System productivity will be approximated from total P concentrations collected during spring or fall overturn (O'Gorman et al., 2004).

Multiple regression models will be developed to assess the effects of relative abundance of predators, competitors (YOY of other species that may share the same planktonic diet as carp larvae and early fry or eat them; age will be judged from fish length), and adult carp, as well as the temperature (mean and standard deviation), aquatic plant cover, and productivity on relative abundance of YOY carp. First, we will examine temporal relationships to determine if there is evidence of specific windows in time when young carp suffer unusual mortality. Then, and as appropriate, a stock-recruitment relationship will be developed, to which additional effects will be added to explain the YOY abundance (Bunnell et al., 2006; O'Gorman et al., 2004). Models containing different subsets of predictor variables will be ranked using Akaike Information Criterion (AIC) (Burnham and Anderson, 2002; Bajer et al., 2007). Best candidate models will then be independently tested (cross-validation; based on a subset of data) to determine model accuracy. Separate analyses will be conducted for early and late samples of YOYs.

A Descriptive correlative study of larval carp

It is possible that the factors which drive carp recruitment exert their influence specifically on larval carp (here defined as recently hatched planktonic carp that cannot be sampled using electrofishing). If true, we will know this because effects on YOY abundance and size will be already evident at the time of our first YOY sampling. To give us the ability/ flexibility to address this question, we will conduct a smaller study each year to examine larval carp. This study, which will be the first of its kind, could be enhanced or otherwise modified as needed. Because studies of this kind involve detailed observations of spawning sites, followed by frequent sampling of larval fish and plankton abundance, we can only examine a small number of lakes. Each year, four lakes will be selected, two that experienced winterkill and two control lakes that did not. In mid May, when water temperatures increase to 18-20ºC and carp are likely to initiate spawning (P.G. Bajer unpublished data), a shoreline survey will be conduced every 2d for the next three weeks in each lake to document intensity and location of carp spawning sites (carp spawning is typically easy to observe). Documenting spawning sites will likely be critical to determine the spatial distribution of carp larvae, and then sample them effectively. Once spawning activity occurs, samples of carp larvae will be collected every 4 days in two major aggregations of carp spawning activity in each lake using plankton nets. Samples of zooplankton communities in these habitats will also be collected. All samples will preserved and then examined if deemed necessary (i.e. whether YOY studies suggest larval survival is important to examine). Two samples of predatory fishes will be collected with electrofishing near each carp site at the time of peak larval abundance to evaluate their stomach contents and assess presence of carp larvae in their diet. If/ when we examine larval fish samples, larval fish and plankton will be identified to species and gut contents will be analyzed for food preferences and diet overlap. Density and size of carp larvae will be analyzed in both lake types (winterkill or not) against the existing plankton communities to understand effects of food limitation on early survival of carp larvae.. If larval survival is key to recruitment, we expect to see both a slower decline of carp larvae over time in winterkill lakes and larger fish with fuller intestines in these systems. If predation (vs food supply) is the specific mechanism controlling larval carp, we expect the decline in larval abundance should be especially striking in winterkill and non-winterkill lakes.

Hypothesis 2: Carp age class abundance will correlate with historical winterkill events

A powerful and independent test of our hypothesis that winterkill events can trigger carp recruitment events would be to confirm this phenomenon in age structures of carp populations. While our extant analyses of carp ages in Lakes Susan and Echo provide preliminary evidence for our hypothesis, we do not regard them as definitive on their own. Nor can we rely on field work conducted to test the first hypothesis. Here, we propose to examine the age structures of three additional populations of carp, each from a separate small watershed (system of 3-7 interconnected lakes relatively segregated from other carp populations) that is known to periodically experience partial winterkill – that is some lakes in the watershed winterkill but not all, thus the 'winterkill record' is maintained in the age structure of the surviving population of carp. Many watersheds in central Minnesota fit this description and we will select those with excellent winterkill records after consulting with DNR personnel. Lakes with recent aeration would be favored as they provide more direct evidence to test the winterkill hypothesis.

Approximately 100 carp will be randomly sampled from each of the three populations using an electro-fishing boat. All fish will be aged using their otoliths (Brown et al., 2004) to develop an age structure for each population. We have been aging carp for two years in this manner in collaboration with established experts (Paul Brown, Dept. Primary Industries, Victoria, Australia). Because re-creating past recruitment strength may be difficult in systems that experience winterkill where some unknown numbers of carp die, we will simply code year classes that are detected in the population as '1', and the missing year classes as '0'. To statistically evaluate the effect of winterkill on carp recruitment (and thus indirectly test the 'predatory fish' hypothesis) we will construct a logistic equation that is suited for handling zero-one data. The logistic equation will simply predict the probability of a successful carp recruitment event ('1's') during years with and without winterkills. Additional climatic variables that we believe may be of secondary importance in determining carp recruitment will be also evaluated, including spring temperature and its variability and water level/precipitation. The best logistic equation for predicting the occurrence of carp recruitment will be determined using AIC criteria. The best candidate model will be evaluated for predictive accuracy via cross-validation techniques.

Carp populations are ideal for retrospective analyses where historical recruitment events are being correlated against climatic data because carp populations maintain a record of recruitment events that extends for decades owing to their longevity. Thus, evaluating past recruitment history from only three independent populations will generate approximately 60 data points. The downside to this analysis is that: 1) the predation hypothesis cannot be directly evaluated because historical data on game fish abundance is incomplete (thus winterkill is used as a surrogate), and 2) the strength of recruitment cannot be predicted in a linear fashion (only probability of occurrence can be predicted). Nevertheless, together with ongoing analyses of carp age structure we believe our test will be sufficiently rigorous to warrant publication in peer-reviewed literature.

Hypothesis 3: YOY carp can be effectively trapped for census and/or removal using bait attractants.

An integrated pest management (IPM) approach to controlling common carp by suppressing recruitment processes can only work if we understand these processes well and have multiple tools to deal with them. No tool is likely to be perfect at controlling recruitment and several may have to be deployed in varying manners at various times to suppress recruit abundance and distribution; accurate numbers of recruit abundance will be a requirement of such schemes. Thus, the success of IPM will rely heavily upon our having a tool to rapidly and accurately access the distribution and abundance of young carp, ideally at very young stages before they are in the open lake and sensitive to sampling by electrofishing. An analogous situation is found in sea lamprey control where more manpower and funds are currently spent assessing the distribution of larval sea lamprey than actually poisoning them. This objective and its closely related objective (hypothesis #4) aim to develop attractant based trapping as means to assess the presence of recruits in the field. Experience shows that attractants are needed because carp are relatively intelligent fish that do not enter traps by chance, and we do not want to capture other species. A trapping technique might, if it proves to be especially effective, eventually be employed to remove recruits.

Although some work has been conducted on sampling young carp in Australian rivers using plankton nets (Dean Gilligan, personal communication, department of Primary Industries, South Australia), we are not aware of any studies in Northern Hemisphere lakes – we are in virgin territory. The issue is complicated by that fact that YOY are very likely found in shallow, weedy regions (Gilligan, Australia; Julien Cucherousset, France, personal communication) where electroshocking surveys will not work. Trapping appears to be the only reasonable option to census the abundance of YOY carp but this will require attractants. Although the Sorensen laboratory presently focuses on pheromonal attractants (because of their specificity; see section below), it is not yet clear when we will have these cues ready to deploy, so we will examine food stimuli as well. Pilot studies in the lab suggest that YOY carp are strongly and consistently attracted to crude food odors which can be relatively inexpensive to prepare.

Further, we have found in baiting experiments in which we simply added corn to specific areas of a lake that corn appears to have special promise (Fig 1.). This concept warrants closer study to understand its potency, specificity, the role of learning, and the best formulation – especially if we are to use traps that require carp to enter a trap that might normally not enter. At least initially we will not attempt to synthesize a food attractant because where studied (there have been no studies in carp), they have been found to be comprised of complex mixtures of amino acids, polyamines and nucleotides which can be difficult and expensive to mimic. Nevertheless, if successful and time permits we will examine this question in the final year. Our study will proceed in several steps as outlined below.

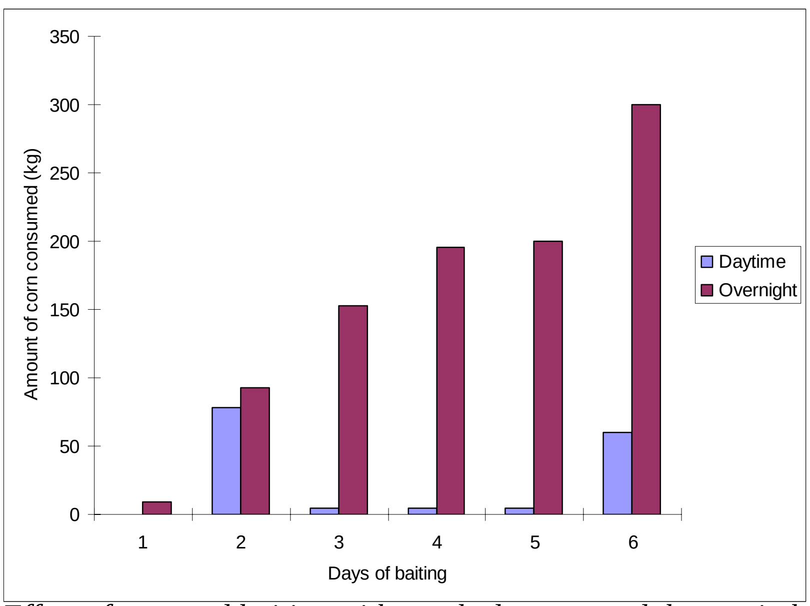


Fig. 2. Effect of repeated baiting with cracked corn on adult carp in late summer in specific section of lake without traps. Increased consumption of corn shows that it was a strong night-time attractant. However, these data also show that fish had to be 'trained' to come to this location (i.e. they go better with time after being given free access to consume) and do not separate the effects of odor attractant from food consumption itself

– its unclear how well an odor (or bait) placed in a trap might be. Further, YOY have not been tested.

i. Determining food items preferred by carp so they might be developed as bait attractants.

In conjunction with carp sampling efforts (Hypothesis #1), a sample of YOY carp will be captured using appropriate sampling gear, sacrificed and their gut contents checked to determine their natural food preferences. Meanwhile, YOY carp will be obtained from local lakes or a commercial fish farm (Osage Catfisheries, MI) and maintained in large (800 L) tanks as groups of 5. Each day fish will be fed a mixture of food items (trout pellets, soaked corn, as well as representative food items from the field) to assess what they prefer to eat by monitoring the rates at which each is consumed. Data would be analyzed by analysis of variance (ANOVA). Later this experiment will be repeated using native fishes (sunfish, perch) to determine if we can identify food items that carp consume and other fish do not. Although corn seems to have promise as carp-selective bait, we want to explore all options before starting a lengthy study to optimize how it (or another bait) might be used. Once we have identified food items that are strongly and specifically preferred by carp, we will test their odors as described below.

ii. Determining the relationship between time of day and food search.

To be optimally efficient, trapping activity needs to be focused on the time(s) when carp are likely to be foraging for food and/or shoaling. This is especially important because escape rates can be high from traps and confounded as traps start to take on the odor of the fish they capture with time or attract predators. Accordingly, we will determine the daily patterns of activity patterns (shoaling and foraging) of groups of 5 YOY carp and then see how might enhance this activity using odorous attractants. Fish will be held in large tanks under a natural photoperiod with infrared light being using and fed small quantities of food at random intervals to establish baseline activity. Food search (time spent picking up items form the bottom) and shoaling behavior (time fish spend within 5 cm of each other) will be noted at the same time. Later, we will test the intensity of foraging rates and how they might be exploited by adding food odors at times of low and high activity and observing how quickly they are located. This experiment will then be repeated using the odor of food alone (food placed in 10 L of well water for 1 h) and then juvenile pheromone (see below).

iii. Determining the effects of water flow on the ability of carp to locate bait.

Odor sources can be difficult for fish to track in the aquatic environment because of their diffuse nature. We will test the possibility that bait odors introduced into test tanks within a flow are easier for fish to locate if introduced into flowing waters using a submersible pumps. Odor would be introduced through a cage-like structure at optimal times of the day and fish rewarded with bait as soon as they enter this structure. Well water alone will be tested as a control. The time it takes for carp to locate the source, and time they spend in its vicinity will be monitored and analyzed using repeated measures ANOVA. This experiment will be conducted using both food and juvenile pheromone (see below) odor, increasing efficiency and allowing for direct comparisons of the potency of the two attractant types.

iv. Testing whether experience with a food can increase baiting efficiency.

Like all animals, fish will change their responses to specific food items and odors with experience (ex. Atema et al., 1980). For instance, if fish are routinely rewarded with food when they find a specific type of odor (as we did on our Lake Susan experiment) , they may be much more likely to be attracted to it, and even enter locations/traps that they otherwise might not. Here we will test this possibility by pairing odor introduction with food reward in large tanks. Non-food odors including identified pheromones would be tested as stimuli, particularly if previous experiments indicate that carp bait items are likely to attract other fish species. Pilot experiments in the laboratory suggest carp will learn to make these associations within 3-4 trials.

v. Developing trapping techniques in the field.

Experimental ponds (less than a hectare) that routinely winterkill that either lack carp or have reasonably well known populations will be chosen for these experiments. If necessary, ponds be stocked with YOY carp and traps designed on the basis of laboratory experiments will be placed into them in habitat that we would predict (from Hypothesis #1) carp will favor. These traps will be fished for three days (or nights) and the number of carp in the ponds increased before the traps will be deployed again. This cycle will be repeated several times to generate estimates of trapping efficiency. Trap designs will be modified if/as necessary. In a final experiment, traps will be employed in the experimental lakes studied for Hypothesis #1. Results will be analyzed using ANOVA.

vi. Chemical identification

We will attempt to identify either the odor of most attractive food item discerned by YOY carp, or the pheromone in the last piece of this project, depending upon which cue has greatest apparent promise in the lab and field. It is very important to know chemical identity for a few reasons. First, if we understand identity, we will be able to administer the attractant more efficiently and perhaps at lower cost (synthesis may be possible). Second, it is highly likely that regulatory agencies will request specific information on attractant identity if it is used on a large scale the US EPA classifies any chemical that controls a nuisance species as a 'pesticide'). For the food attractant, effort would focus on amino acids and small peptides by analyzing their presence and or employing bio-assay guided fractionation scheme and laboratory behavioral and EOG assays (Sorensen and Hoye, 2007).

Hypothesis 4: YOY carp can be effectively trapped for census and/ or removal using pheromonal cues.

Pheromone traps would be ideal for censusing carp populations because of their potential specificity. Although we now know that YOY release a multi-component species-specific attractant (Sisler et al., in preparation) (Fig. 3; Fig. 4a), we have been unable to develop a means to concentrate it and identify it as yet – elements of the pheromone are non-polar (extractable by C18) and polar (not easily extracted but capable of being concentrated using roto-evaporation) (Fig. 4b) (Leveseque and Sorensen, unpublished data). It is presently not possible to estimate when a break-though in identification might occur (a juvenile aggregant has yet to be identified in any fish) and our ongoing LCCMR study which has about 1.5 years left to pursue this question. Accordingly, we propose a modest scheme to continue to elucidate the potential of juvenile carp pheromone first using a crude odors and later, if/when available, synthesized pheromone. If a breakthrough occurs in the meantime we will focus on the pheromone instead of the food cue. We must be flexible in our approach. Initial pheromone experiments will focus on assessing activity and will occur concurrently with food experiments (Hypothesis #3) and culminate with a decision about whether to proceed with pheromone and/or food cue identification.

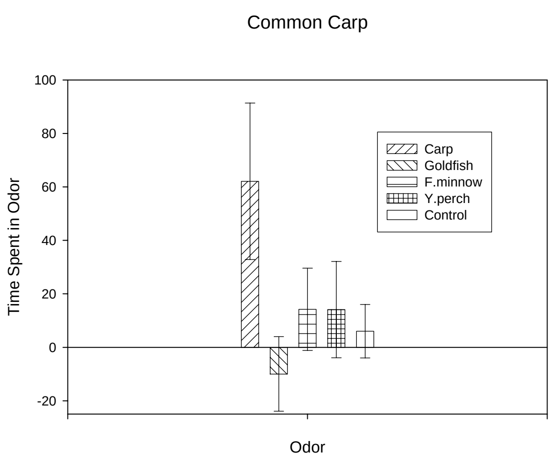
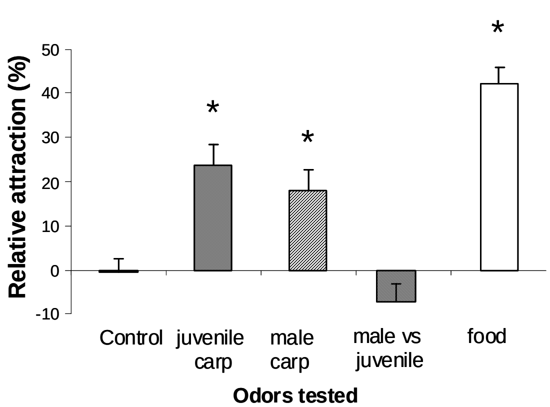


Fig. 3. Attraction of juvenile carp to fish body odors in a circular test maze (Maniak et al., 2000) showing that conspecific odor only attracts other carp.



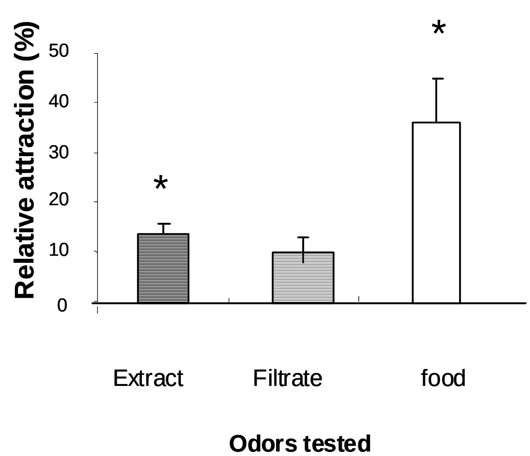


Fig.4. Left-side (a): Attraction of YOY carp to conspecific odors in circular test maze (Maniak et al., 2000) showing that conspecific odor is nearly as potent as food and not influenced by maturational state. Right-side (b): Attraction of YOY carp to C18 extract of conspecific odor and then the filtrate. Note, that both fractions are active. Studies presently focus on a critical mixture of L-amino acids and carp-specific bile acids.

i. Determining the relationship between time of day and conspecific attraction.

This experiment will be conducted concurrently with food odor attraction study (i.e. same fish, same tanks, see above). The only difference is that instead of using food odor we will introduce water from a large group of YOY carp (20 fish in 5 liters of well water, or identified cues if available) into one section of the tank and examine changes in carp shoaling and distribution. Scores will be compared using a paired Wilcoxin test and ultimately with food odor tests.

ii. Determining the effects of water flow on the ability of carp to locate conspecifics.

Just as carp might find food more efficiently (resulting in stronger attraction) if a flow-induced concentration gradient were present, so might flow positively effect pheromonal attraction. Here we would test that possibility using the same procedure as described for food odor for Hypothesis #3 (see above) while those tests were be conducted. Food, control, and, pheromone odors would be tested following a randomized schedule.

iii. Developing pheromonal trapping techniques in the field.

Concurrent with food attraction studies, experiments will be conducted in small experimental ponds using stocked YOY carp in exactly the same manner as for the bait experiment described above for food odor (see above).

iv. Chemical identification

If appropriate (the pheromone is particularly attractive and we appear to be close to having a pheromone identified at the end of our ongoing LCCMR project, we will attempt to identify the full compliment of components in carp odor. The precise methodology would be determined by the status of the project at that time. We will consider going to the National Science Foundation for supplemental funding if deemed appropriate.

V. TIMETABLES

Hypothesis 1. Modeling abundance of YOY carp

DATE	*MILESTONE*
December 2008	Consultations with DNR personnel to select 25 study lakes; preliminary lake surveys and collecting data from 6 lakes.
July 2009	Winter DO measured in all study lakes to document winterkill; temp loggers installed; total P samples collected; descriptive study of carp larval abundance and plankton dynamics completed in 2 lakes .

December 2009	First full field season completed; data from lakes 1-12 collected
July 2010	Initial data analysis, lakes for the second season selected; descriptive study of carp larval abundance and plankton dynamics completed in 2 more lakes if promising results from year one are achieved, and feasible.
December 2010	Second field season completed; data from lakes 13-24 collected.
July 2011	Final data analysis, predictive equation developed, manuscript submitted

Hypothesis 2. Correlations between age structures and winterkills

DATE	*MILESTONE*
December 2008	Three study lakes selected upon consultation with DNR; winterkill records documented for the study lakes
July 2009	Otolith samples collected from populations 1-3
December 2009	Otolith samples for population 1 aged
July 2010	Otolith samples for population 2 aged
December 2010	Otolith samples for population 3 aged
July 2011	Final data analysis, predictive equation developed, manuscript submitted.

Hypothesis 3. Food odor attractants

DATE	*MILESTONE*
December 2008	Food items preferred by YOY carp identified
August 2009	Lab experiments on daily activity/ odor completed*
December 2009	Lab experiment on flow enhancement of odor completed*
August 2010	Field attraction with crude odors*
December 2011	Possible work on the chemistry*
June 2011	Manuscript submitted

Hypothesis 4. Pheromonal attractants

DATE	*MILESTONE*
December 2008	*Ongoing work on pheromone chemistry (extant LCCMR)*
August 2009	Lab experiments on daily activity and odor completed*
December 2009	Lab experiments on flow enhancement of odor completed*
August 2010	Field attraction with crude odors*
December 2011	Possible work on chemistry*
June 2011	Manuscript submitted

* These experiments associated with Hypotheses 3 and 4 will be conducted simultaneously.

VI. DELIVERABLES

1. We will know if game fish populations have the potential to control carp recruitment.

2. We will have a model for predicting the abundance of YOY carp based on predator density, food competition from young fish of other species, adult carp density, temperature and lake productivity,

3. We will know if juvenile food supply might influence carp recruitment processes.

4. We will know if winterkill triggers carp recruitment in interconnected shallow lakes.

5. We will have developed a logistic equation to evaluate the probability of YOY carp survival during years with and without winterkills.

6. We will have identified a food attractant for young carp.

7. We will know the potential of an aggregation pheromone for sampling carp

8. We will have a trapping system(s) which uses either food and/or pheromonal attractants to monitor YOY abundance in the field.

VII. TENTATIVE BUDGET

	Thousands (K) of $
Salaries:	
Half-time Research Associate (Bajer; 25K+30K+31K)	86
One month summer salary P.I. (Sorensen; 8K+9K+10K)	27
Half-time field technician (17+18+19)	54
Full-time PhD student for behavior (18+20+21)	59
Summer undergraduate assistant (4+6+6)	16
TOTAL:	**242**
Fringe benefits for above:	
Half-time Research Associate (Bajer; 8.25+9.9+10.23)	28.38
One month summer salary P.I. (Sorensen; 2.6+3.0+3.3)	8.91
Half-time field technician (5.6+5.9+6.3)	17.8
Full-time PhD student (15+15+16)	46
Summer undergraduate assistant (0.28+0.42+0.42)	1.12
TOTAL:	**102.23**
Equipment:	
Bone saw for otolith analysis	**4.3**
Supplies*:*	
Field (5+13+10)	28
Lab (10.47+12+7)	29.47
	57.47
Repairs to equipment (2+2+2)	**6**
Services:	
Lab analysis of odors (LC-MS) (3+5+7):	**15**
Travel:	
Local (travel to field sites; 7+8+8)	**23**
TOTAL:	**450**

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IX. RESUMES

SORENSEN, PETER W.
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INTERESTS:
Peter is interested in the physiological basis of fish behavior and its ramifications for fish health and invasive fish control. Pheromones, chemical signals that pass between member so the same species, are of special interest.

PROFESSIONAL PREPARATION:
Bates College (Maine), Biology, B.A. 1976
University of Rhode Island, Biological Oceanography, Ph.D., 1984
University of Alberta, Zoology/Medical Science, Postdoctoral Fellowship, 1984-1988.

APPOINTMENTS:
Professor, Department of Fisheries, Wildlife & Conservation Biology, U. of Minnesota, 1997 –
Associate Professor, Department of Fisheries & Wildlife, U. of Minnesota, 1993 - 1997.
Assistant Professor, Department of Fisheries & Wildlife, U. of Minnesota, 1988- 1993.
Lecturer, Providence College, Rhode Island, 1982.

PUBLICATIONS:
101 peer-reviewed publications
12 book chapters
25+ non-peer reviewed publications

Most relevant publications on invasive fishes:

1. Sorensen, P.W. and Hoye, T.E. (in press). A critical review of the discovery and application of a migratory pheromone in an invasive fish, the sea lamprey, *Petromyzon marinus* L. Journal of Fish Biology 71 (supplement D) 110-114.
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3. Sorensen, P.W., Murphy, C.A., Loomis K., Maniak P., and P. Thomas. 2004. Evidence that 4-pregnen-17,20β,21-triol-3-one functions as a maturation inducing hormone and pheromone precursor in the percid fish, *Gymnocephalus cernuus*. General and Comparative Endocrinology 139: 1-11.
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5. Vrieze, L.A., and P.W. Sorensen. 2001. Laboratory assessment of the role of a larval

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11. Sorensen, P.W., T.A. Christensen, and N.E. Stacey. 1998. Discrimination of pheromonal cues in fish: emerging parallels with insects. Current Opinion in Neurobiology 8(4): 458-467.

GRADUATE STUDENTS:
17 total, 11 graduated, 14 postdocs

TEACHING:
Fish Physiology and Behavior (2 credits spring)
Marine Biology (3 credits, spring)

RECENT SYNERGISTIC ACTIVITIES:
Member of National Aquatic Nuisance Species Task Force for Asian Carp (2004); Gave talk to National Caucus of Environmental Legislators, Washington. D.C., Program Committee (2004); AChems Program Committee (2004-2007); Organizer, Fish Biology Symposium, Minnesota Chapter American Fisheries Society (2004, 2005, 2007); Member of Great Lakes Fisheries Commission Task Force for Sea Lamprey Control through Reproductive Suppression (2003-2005); National Science Foundation, Grant Review Panel on Animal Movement and Sensation (Fall 2003); Member, National Committee on Uses of Fishes in Research, American Fisheries Society (1998-2003); Co-editor of**:** Advances in Chemical Signals in Vertebrates, Plenum Press, NY; Featured in several national and international newspaper and television stories (2003-2005)

COLLABORATORS (does not include my own students in last 4 years):
Ankley, G. EPA Duluth
Baker, C., N.I.W.A. New Zealand
Canario, A.P., U. of Algarve, Portugal
Hobson, K. Canadian Wildlife
Hoye, T.A. U. of MN
Kobayashi, M U. of Tokyo
Mensinger, A, U of MN
Sato, K. U. of Tokyo
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Date of birth: August 11, 1973

INTERESTS: Przemek is interested in fish population dynamics and bioenergetics. Of special interest are mechanisms that determine recruitment strength and overall abundance of fish populations. Since 2006 he has been studying common carp populations in Minnesota lakes and is becoming an expert on carp ecology and control.

EDUCATION

1997	M.S. in Applied Ecology, University of Lodz, Poland
2005	Ph.D. in Fisheries and Wildlife Sciences, University of Missouri-Columbia

EMPLOYMENT

1997-1998	Research Assistant, Department of Applied Ecology, University of Lodz, Poland.
March-July 1998	Visiting Scholar, Ohio State University, Columbus, OH.
2000- 2005	Graduate Research/Teaching Assistant, University of Missouri – Columbia.
May-Dec 2005	Senior Research Laboratory Technician, USGS, Environmental Research Center, Columbia, MO.
2006 - present	Research Associate, University of Minnesota, St. Paul.

PUBLICATIONS

Bajer, P. G., J. J. Millspaugh, and R. S., Hayward. 2007. Application of discrete choice models to predict white crappie temperature selection in two Missouri impoundments. Transactions of the American Fisheries Society 136.

Bajer, P. G., and M. L. Wildhaber. 2007. Population viability analysis of Lower Missouri River shovelnose sturgeon with initial application to the pallid sturgeon. Journal of Applied Ichthyology 23:457-464.

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PRESENTATIONS (12 presentations on national meetings, including two as an invited speaker)

INVITED WORKSHOPS

Hayward R. S, and P. G. Bajer – Theory and application of fish bioenergetics models. American Fisheries Society, Centrarchids Technical Committee. July 19-20, 2005. Prairie du Chien, WI.