2005 Project Abstract
For the Period Ending June 30, 2009

PROJECT TITLE: Integrated and Pheromonal Control of Common Carp
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FUNDING SOURCE: Environmental Trust Fund
Legal Citation: ML 2005, First Special Session, Chp. 1, Art 2, Sec. 11, Subd. 5g
$275,000 the first year and $275,000 the second year are from the trust fund to the University of Minnesota for the second biennium to research new options for controlling common carp. This appropriation is available until June 30, 2009, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

ABSTRACT

The common carp (*Cyprinus carpio*) is an invasive fish that has dominated our shallow lake ecosystems for the past century and caused enormous damage to their water quality, plants, waterfowl and fisheries. The overarching goal of this project was to develop guidelines for an integrated control scheme for the carp based on its life history and reliance on pheromones (species-specific chemical signals). The possible use and identity of a female pheromonal attractant was studied in the laboratory while the reproductive habits of carp in the field were documented to determine how these traits might be targeted for control. Basic elements of carp biology were also examined to produce a statistical model that explored carp population dynamics and control strategies. Several key discoveries were made. First, behavior tests combined with chemical analysis confirmed the presence of a highly attractive, male-derived sex pheromone. This cue has polar and non-polar components with androstendione serving as a key component. While the presence of androsetendione causes the pheromone to attract sexually-active carp, the other components also serve as a strong species-specific signal that attracts all life stages and thus have potential for application. Detailed studies of carp spawning for two years demonstrated that while females prefer to spawn in fine-leafed, shallow vegetation in the spring and aggregate in the winter; removal schemes are possible. Lastly, a study of carp population dynamics discovered that while carp are mobile (they migrate into spawn each year), long-lived (over 50 years), fecund (females have up to 3 million eggs), but their young rarely survive. Further, larval survival only occurs in shallow, interconnected wetlands in years following severe winter-kills after which predatory native fish are not present: it appears that game-fish can control carp. This discovery was confirmed by modeling and demonstrates that carp control likely is feasible using an integrated scheme.

Project Results Use and Dissemination

The results of this project are being used by two large watershed districts (Riley Purgatory Creek, Ramsey Metro Washington) to study and start experimental projects to control carp. Both districts are contributing to the costs and are using techniques from this project. In addition, we are speaking with and advising at least half a dozen other groups on this topic across the state. The DNR is consulting with us. Late summer we disseminate our findings at the National Meeting of the American Fisheries

Society where we have organized an entire day-long symposium on carp control. Since the inception of the study, we have been giving 4-8 public talks a year on carp to various groups including watersheds. Our results have been covered by both the Star Tribune and Pioneer Press, The Chanhassen Villager, Outdoor News. Kare11 TV and the syndicated TV show ‘Minnesota Bound’ have done shows on us and we covered twice by NPR. Two peer reviewed publications are in press with four others in preparation.

LCCMR 2005 Work Program Final Report

Date of Report: June 30, 2009
LCCMR 2005 Work Program Final Report
Project Completion Date: June 30, 2009

I. PROJECT TITLE: Integrated and Pheromonal Control of Common Carp.

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

Legal Citation: ML 2003, [Chap. 128], Art 1, Sec.[14], Subd.5h.
$50,000 the first year and $50,000 the second year are from the trust fund to the University of Minnesota for research on new options for controlling carp. This appropriation is available until June 30, 2009, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program

II and III. FINAL PROJECT SUMMARY

The common carp (*Cyprinus carpio*) is an invasive fish that has severely damaged the water quality, aquatic plants, waterfowl and fisheries of the huge number of lakes it dominates across southern and central Minnesota. The overarching goal of this project was to develop guidelines for an integrated control scheme for the common carp based on its life history and reliance on pheromones (species-specific chemical signals). The possible use and identity of a female pheromonal attractant was studied in the laboratory while the reproductive habits of carp in the field were documented to determine how these traits might be targeted for control. Basic elements of carp biology were also examined to produce a statistical model that explored carp population dynamics and control strategies. Several key discoveries were made. First, behavior tests combined with chemical analysis confirmed the presence of a highly attractive, male-derived sex pheromone. This cue has both polar and non-polar components with androstendione serving as a key component. While the presence of androsetendione causes the pheromone to attract sexually-active carp, the other components also serve as a strong species-specific signal that attracts all life stages and thus have potential for application. Detailed studies of carp spawning for two years demonstrated that

while females prefer to spawn in fine-leafed, shallow vegetation in the spring and aggregate in the winter; adult removal schemes are possible. Lastly, and most importantly, a study of carp population dynamics discovered that while carp are highly mobile (they migrate to spawn each year), long-lived (over 50 years), fecund (females have up to 3 million eggs),their young rarely survive until summer. Further, larval survival only occurs in shallow, interconnected wetlands in years following severe winter-kills after which predatory native fish are not present: it appears that game-fish can control carp. This discovery was confirmed by statistical modeling and demonstrates that carp control likely is feasible using an integrated scheme.

IV. OUTLINE OF PROJECT RESULTS

Result 1: Identifying sensory attractants for female carp

This component of our study sought to determine whether and how female common carp, (hereafter 'carp') employ sensory signals to recognize and attract each other and if so, whether these cues might be useful to control this species. While studies focused on pheromones (chemical cues that pass between members of the same species), they also examined sounds made by spawning fish (i.e. other long-distance cues). We were specifically interested in female carp because given the large numbers of eggs they carry (1-3 million, see Result #3), their removal would be especially beneficial in a carp control program. A species-specific sexual attractant was isolated and identified which contained multiple components, a few of which were unique to males and only attracted sexually-active (ovulated) females. This cue has multiple components and functions as a mixture which includes androstenedione and has a species-specific non-reproductive component which attracts all life stages of carp. Key elements of this discovery are outlined below except for results of some pilot studies which used the closely related goldfish (*Carassius auratus*) and are not described for brevity but may be found in the June 30, 2007 LCCMR Work Program report. A manuscript is in preparation.

Our first set of experiments tested whether female carp use a pheromone and examined the behavioral preferences of sexually-mature, but sexually-inactive, female common carp (i.e. pre-spawning, non-ovulated females). A set of nearly a dozen experiments (highlights discovered that female carp are strongly attracted to the odor of both juveniles and mature males and they do not prefer one to the other ($P<0.05$; Fig. 1-1). This is an important finding because our previous LCCMR-funded research (Sisler and Sorensen, 2008) demonstrated that juvenile carp odor functions as a species-specific pheromone; inactive female apparently use the same pheromone. A common experimental protocol was used for all experiments which was based on Sisler and Sorensen (2008). Briefly, groups of five laboratory raised, sexually-mature carp (gonadosomatic index=13.3±2) were tested in a two-choice laboratory mazes into which pheromonal odors were added. Each trial had three periods: 1) a pre-test (no odor stimulus added to either side to establish baseline behavior); 2) a test period (well water control was added to one side and test odor to the other); and 3) a food odor test period which served as a 'positive' control. Test odors were injected into the side of the maze where the carp had spent the least amount of time during the previous test period. Fish (test) odor was prepared by allowing 12 carp (100g) to swim in 5 liters of aerated well water for an hour. The control stimulus lacked fish. Food odor control was prepared by placing 1g of flaked fish food into 100 ml of well water for 1 hour, then filtering it. Data were analyzed by examining changes in total time spent in the experimental sides of the maze during pre-test and test period (percent change in distribution) and these differences were then evaluated using analysis of variance.

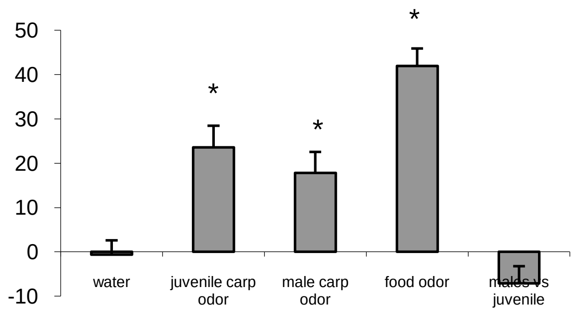

*Fig. 1-1. Attraction (percent change in distribution) of sexually mature but inactive female common carp to the pheromonal odor of juvenile and male carp (*P<0.05; N=11 groups of 5 fish for each). Both are equally attraction from the work of Sisler & Sorensen (2008) we know these odors to be species-specific and to function as a pheromone. Responses to food odor (tested as a positive control) are shown for comparison – responses to the pheromone (are) equally strong.*

A second set of experiments discovered that sexually-active female carp discern a slight different carp-specific pheromone released only by males. This is the first male-derived behavioral sex pheromone to be described in a teleost fish. For this set of experiments female carp were treated to make them sexually active/receptive by injecting them with prostaglandin F2α (PGF2α), a hormone which is associated with ovulation and sexual activity. We employed the same test protocols used before except that female carp odor was also tested as a control. These experiments discovered that sexually-active female carp are specifically and strongly attracted to the odor of male carp ($P<0.05$; Fig. 1-2). This result contrasts with the earlier result which found that inactive female did not distinguish between male, female and juvenile odors – males release a specific cue which only sexually receptive female carp response too. Subsequent tests confirmed that this male-derived pheromone is species-specific ($P<0.01$; data not shown) and described its composition (see below).

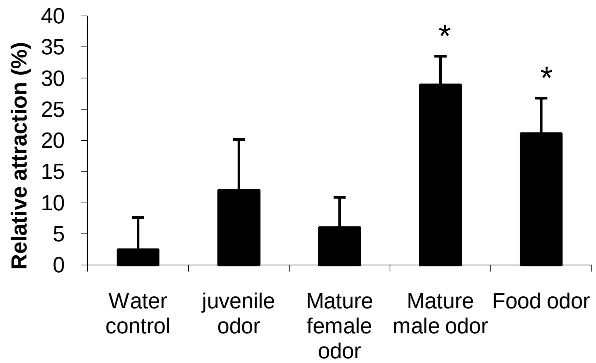

*Fig. 1-2. Attraction (percent) of sexually mature and active female common carp to the pheromonal odor of other carp. Note that only male odor is attractive (*P<0.05; N=11 groups of 5 fish for each).*

A third set of experiments examined the identity of this male-specific pheromone and described several components. PGF2α–injected (sexually-receptive) females were used once again in the two-choice maze. Initial experiments tested responses of these fish to non-polar and polar extracts of male carp odor which were produced using C18 fractionation; both the polar and nonpolar fractions were found to be attractive ($P<0.05$; data not shown) suggesting that this odor is multi-component. Hypothesizing that male sex pheromone might be a combination of known non-polar androgenic steroids (Sorensen *et al.*, 2005) and the components recognized by sexually-inactive females (Experiment #1), we tested the two stimuli on their own and then as a mixture. This experiment convincingly revealed that androstenedione (a nonpolar steroid known to be produced by carp) is a component of the male-derived pheromone; it is attractive on its own at near picomolar concentrations ($P<0.05$) and if mixed together with the odor of immature fish the two pheromones synergize each other to function as a highly attractive cue with activity to similar to that of whole male carp odor (Fig. 1-3). We conclude that sexually-active female carp recognize sexually mature conspecifics using a unique pheromonal odor comprised of androstenedione as well other unknown androgens within a matrix of species-identifying odorous compounds. These results are presently being prepared for two peer-review publications.

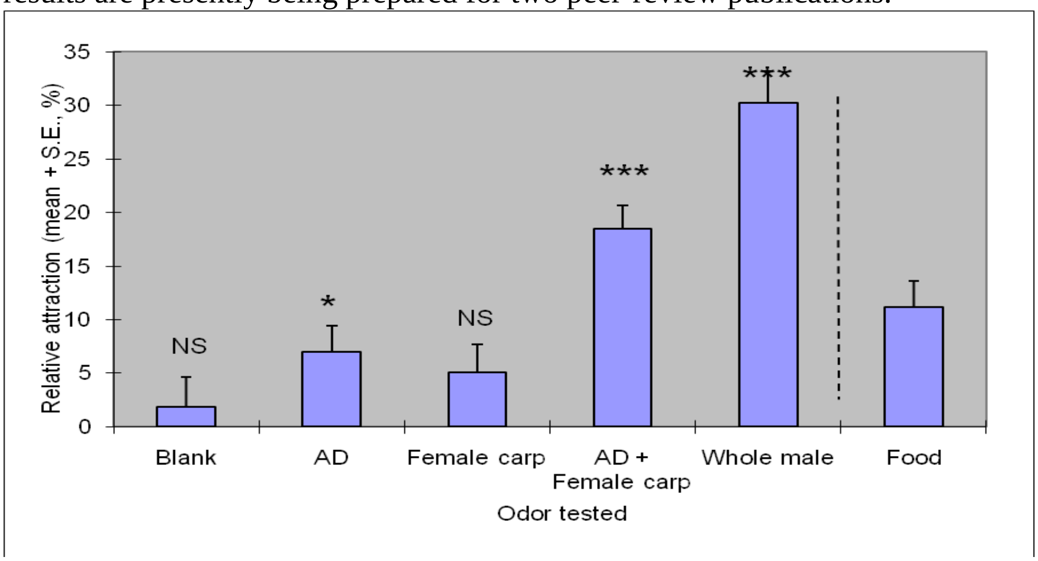

*Fig. 1-3. Attraction (percent) of sexually- active female carp to the odor of androstenedione (AD; a steroid released by males), mature females, a mixture of the aforementioned and the odor of males. Note the synergistic activity of AD and female odor (P<0.05; **P<0.01; ***P<0.001; N=11 groups of 5 for each).*

A final set of experiments focused on the species-identifying portion of the pheromone. We focused on this portion of the entire pheromone as it seemed most likely to be immediately useful in carp control because it attracts a variety of life stages (results Experiments # and #3). Several experiments were conducted. Juveniles and their odor (holding water) were used because they are relatively straightforward to produce and test, and show the same responses as sexually-inactive, mature female carp. Initial experiments dried juvenile holding water down and showed it to be stable and active a month (data not shown). Other experiments found it to be active when diluted over 10-fold (P<0.05) and that it is multi-component with both nonpolar and polar components (P<0.05; data not shown – see the March 31, 2008 LCCMR Work Program report). Analysis of the nonpolar component demonstrated the presence of three bile acids (cyprinol sulfate; taurocholic acid and taurochenodeoxycholic acid) but behavioral tests showed that they could not explain activity (P>0.10; data not shown). The nonpolar C18 fraction was fractioned by HPLC and activity found in two fractions (Fig 1-4), demonstrating that while it is multi-component but it is stable, can be purified and identified. Chemical analysis of the promising, polar fraction continues as part of our new 2007 LCCMR project.

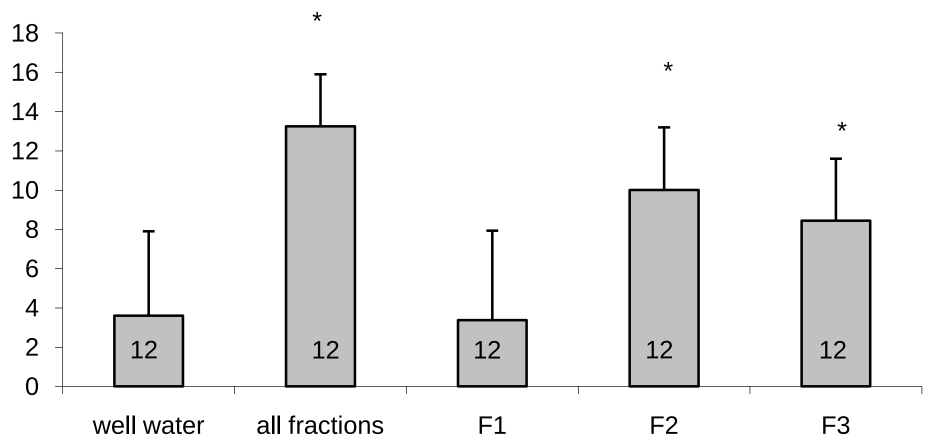

*Fig. 1-4. Attraction (percent) of e common carp to three nonpolar fractions (F1 ,F2, F3, and a mixture of the three) of the species-specific pheromone (*P<0.05; N=shown in bars).*

In conclusion, we have discovered that mature female carp recognize and are strongly attracted to a potent male-derived pheromone, one component of which is especially and uniquely attractive to sexually-active females. One component of this cue was identified as androstenedione, while the others have been purified, characterized and judged suitable for further work, development and application. The species-specific portion of the pheromone appears specially promising and is being examined by a new 2007 LCCMR project. Three manuscripts are being prepared for peer-review.

RESULT 2: Defining carp spawning habitat preferences and nursery habitat in the field

This component of our study examined where/ when wild common carp spawn and whether/ how they produce young (recruits) to determine if this component of their biology might be amenable to control. The inspiration for this project came from an Australian study which found that carp in two Tasmanian lakes (Lakes Sorrell and Crescent) only used a few aquatic plant beds to spawn and that their reproductive success could be controlled by blocking and removing reproductive carp as they entered these areas. For our study we focused on a seemingly typical set of lakes in Chanhassen and Eden Prairie (lakes Susan, Rice Marsh and Riley) and tracked spawning adult carp and their young for three years. Two discoveries were made. First, we found that female carp do prefer to spawn in particular types of habitat but that unfortunately this preference is probably not strong enough to serve as means to control. Second, and more optimistically, we discovered that carp nursery habitat (regions where carp young survive after hatching) is extremely limited and almost certainly can be controlled. Additional, coincidental work discovered that carp aggregate strongly in the winter and can be effectively removed by commercial seining. These conclusions were strongly supported by analyses of carp population age structure conducted as part of Result #3 (see section below).   A description of key details is found below.

Lakes Susan, Rice Lake Marsh, and Riley (Eden Prairie/ Chanhassen, MN) were selected for this study because this chain of lakes was deemed representative of many throughout the state, appeared to contain many carp and a range of habitats, and accessible by boat. Low-frequency radio-tags (F1850, Advanced Telemetry Systems MN) were selected for this study because they are lightweight (24 g), have a good detection range (100-400m), and a two-year battery life. Forty-nine mature carp (20 females and 29 males) were subsequently captured by boat electro-fishing in 2006 and surgically implanted with these radio-tags. Another 24 carp were added to this pool at a later date. Starting in March of both 2006 and 2007, radio-tagged carp were located each week by surveying the entire chain of lakes using a small boat equipped with a portable Yagi antenna and a GPS unit. Once spawning started (May-June), we located fish on a daily basis and mapped the locations of spawning sites along with key habitat variables (temperature, depth, vegetation species, density and depth). Later, to characterize nursery habitat, we surveyed both our main study lakes and three other lakes (Echo, Dutch, and Dog [Carver County]) for juveniles using trapping netting and boat electro-fishing surveys. Additionally, we confirmed that carp eggs were viable by bringing them into the laboratory to document the numbers that hatched and survived to the larval stage in aquaria supplied with *Artemia* naupli, a food item for larval carp.

Radio-telemetry demonstrated that a third-to-half of the adult male and female carp from lakes Susan and Riley aggressively moved into Rice Marsh Lake each April, immediately prior to spawning (Fig. 2.1). This movement was followed by intense spawning activity for several weeks (with synchronized peaks), after which these carp returned to their 'home' lakes (Figs. 2-1, 2-2). Carp were also observed spawning in lakes Susan and Riley so while they seem to prefer shallow marshy lakes, it is not a strong preference. Spawning sites were identified based on fish behavior (splashing in the aquatic plants where they deposit their sticky eggs) and the presence of eggs. Over 600 spawning sites were identified and characterized in all three systems in 2006 and 2007. Analysis of these spawning sites demonstrated that fine-leaf plants (ex. coontail [*Ceratophyllum demersum*] and Eurasian milfoil [*Myriophyllum spicatum*]) are preferred when present (lakes Riley and Rice Marsh Lake); however, when absent (Lake Susan), carp readily spawn on other surface material including broad-leaf species, white water lily (*Nymphaea odorata*) in particular (Table 2.1). Analyses of depth and location found that carp prefer floating patches of vegetation along the shoreline and can be patchy, suggesting locale aggregation behaviors play a role as well (Table 2.1; Fig. 2.1). In conclusion, while carp possess preferences for specific types of habitat, these preferences appear too weak and potential spawning habitat too abundant for spawning sabotage to be a viable option for controlling carp in Minnesota lakes.

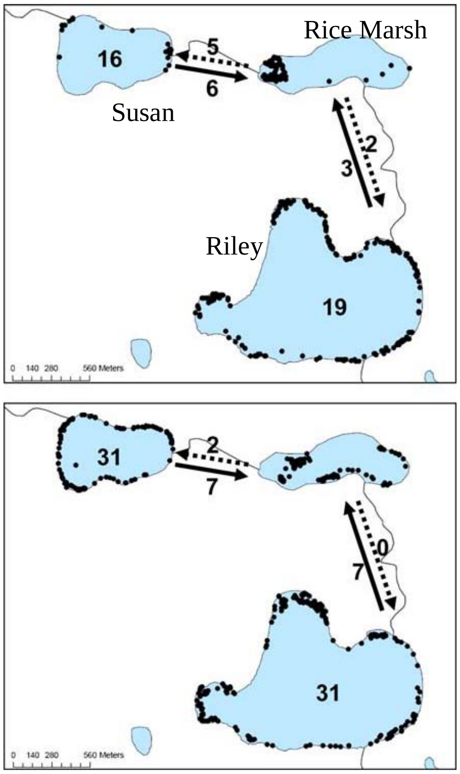

***Fig. 2-1** Maps showing the movement of radiotagged adult carp from lakes Susan and Riley into Rice Marsh Lake in 2006 (top panel) and 2007 (bottom panel). The numbers in each lake show how many radiotagged adult carp inhabited lakes Susan and Riley before the spawning season, while the numbers next to the solid arrows show how many of these carp moved to Rice Marsh Lake shortly before spawning(solid arrows) and then returned (dashed arrows). Black dots indicate carp spawning sites.*

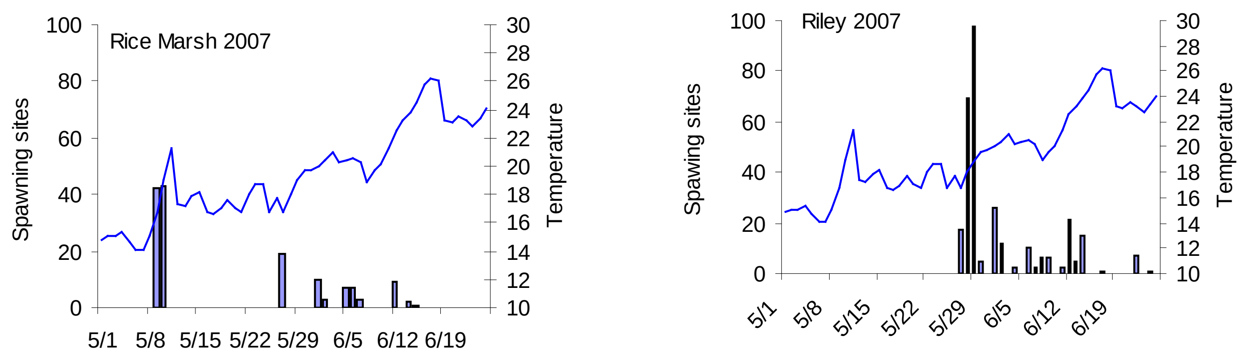

***Fig. 2-2.** Number of carp spawning sites (columns) observed in Rice Marsh Lake and Lake Riley May -June 2007. The blue line indicates water temperature.*

Table 2-1. Characteristics of spawning micro-habitats used by the common carp in lakes Susan, Rice Marsh, and Riley 2006 - 2007. Approximate availability of each habitat type is described in an ordinal fashion: + low availability; ++ moderate availability; +++ high availability n=637

	Susan	Rice Marsh	Riley
Fine-leaf	14% (+)	100% (+++)	66% (+++)
Broad-leaf	21% (+++)	0% (+)	0% (+)
Algae on shore	65% (+++)	0% (++)	34% (+++)
Average water depth (m)	0.31	1.25	0.86
Average vegetation depth (m)*	0.02	0.02	0.01

Average vegetation density	55.5	98.5	81.1

* zero = vegetation extends to the surface

In contrast to the situation for spawning habitat selection, analyses of carp nursery habitat provided strong evidence that it is limiting and represents a weakness in the carp's biology that could be controlled. In particular while laboratory tests of carp eggs showed that large numbers of egg were viable and hatched into larvae (49%), repeated, intensive lake surveys found that almost none actually survived through the summer in the wild. Several hundred hours of sampling effort using several types of gear yielded only six year-old carp in Lake Riley where fecundity estimates suggested that least two billion viable eggs are released each year. Aging analyses of adult carp caught in lakes Susan and Riley (see below) also found strong evidence that almost none of the carp eggs spawned in these lakes survive most years although they occasionally do in adjoining Rice Marsh lake following winter-kill (low levels of oxygen caused by heavy ice and snow). Apparently, most carp eggs/ larvae suffer nearly complete mortality in most locations. Ongoing data collection now suggests that predatory game-fish can explain this phenomenon because they normally are abundant and consume young carp but suffer heavy mortality with winterkill after which they are much slower/less able to recover than the highly mobile adult carp (results described above). Further support comes from recent surveys (2007 LCCMR project, data not shown here) of shallow, interconnected lakes after winter-kill which find few game-fish and many young carp. We conclude that shallow, inter-connected, winterkill lakes are prime (and often limiting) carp nursery habitat. This is a very significant finding because carp production/survival might be controlled in shallow lakes by adding aerators, barriers and/or stocking with game-fish. Of course, these strategies need to be considered and implemented carefully as they all have potential to alter the ecosystem. A report to the DNR summarizes these ideas and a manuscript for peer journals is in preparation Our ongoing 20007 LCCMR project is pursuing this hypothesis. Some of these results were recently published in the journal *Biological Invasions* (Bajer and Sorensen, 2009).

RESULT 3: *Defining carp population dynamics and establishing a model for integrated management of this species.*

Working under the premise that an understanding of why there are so many carp is needed to guide programs seeking to control this species, we examined carp population dynamics and modeled it. In the course of collecting the first quantitative North American data on carp biology, this study provided new evidence that carp abundance is driven (and can be controlled) by the presence of nursery habitats in shallow, winter-kill lakes. A, novel statistical model which was developed with the assistance of Australian scientists and DNR financial support lent further support to the winterkill hypothesis and offers a promising option for integrated management of the common carp. A paper has been published (Bajer and Sorensen, 2009).

Lakes Susan (Chanhassen), Echo (Hutchinson), and Dutch (Hutchinson) were selected in 2006 to study carp demographics based on the variety of seemingly representative lake habitats in southern and central Minnesota they contain (Fig. 3-1). Specifically, these lakes are moderately productive, range up to several ha in surface area, vary in depth from 10 to 40 feet, and are dominated by plants and littoral zone (i.e. type 2 and 4 lakes as outlined by Valley et al., 2004 DNR Special publication 160). Carp were sampled at least five times in each of them during the summer and fall of 2006 using both 1000-foot seine nets and by boat electro-fishing the entire shoreline. All captured carp were counted, measured (total length), injected with numbered tags (model TBA-1; Hallprint Australia), fin-clipped (to monitor tag loss), and released except for a few hundred individuals which were kept for aging (see below). Population size was then estimated using Schnabel's equations for multiple mark-and-recapture censuses from the numbers of marked and unmarked carp in each census (Van Den Avyle and Hayward, 1999). The density of carp in both lakes Susan and Echo ranged between 300-400 kg/ha, approximately four times the value which our other studies (Bajer et al., 2009) suggest to represent a non-damaging threshold for ecological damage (Table 3-1). These are the first quantitative estimates of carp abundance in North American lakes.

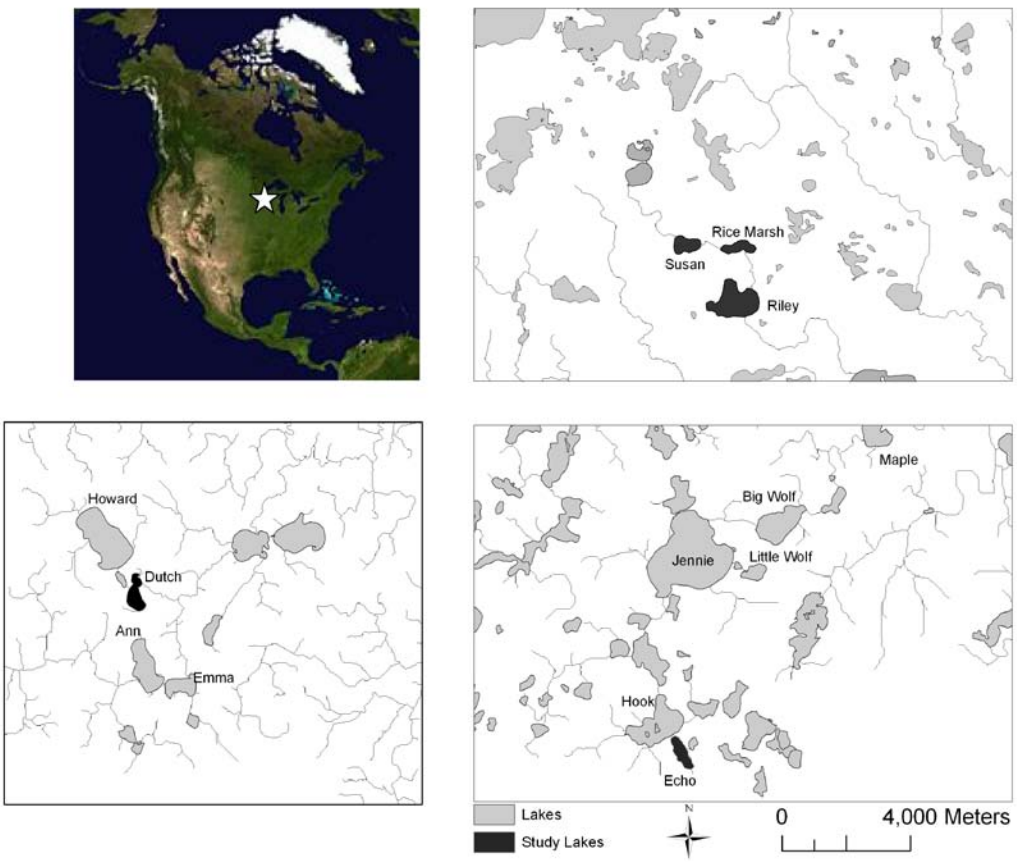

Fig. 3-1 *The three systems which we studied. The top right panel shows the Riley Creek chain of lakes where we studied lakes Susan, Rice Marsh and Riley. The bottom left panel shows the upper portion of the Big Swan Lake Watershed where we studied Lake Echo. The bottom left panel shows Howard Lake Watershed where we studied carp in Dutch Lake. Panel in the upper left shows the location of the study area (star).*

Table 3-1. Carp population estimates (*N*) and their 90% confidence intervals (*CI*) in lakes Susan and Echo using multiple-census mark and recapture; EF stands for electro-fishing. The table is extracted from Bajer and Sorensen (2009).

	Total captured	Recaptured	Marked in the population

Date	Gear	(C_i)	Unmarked	(R_i)	(M_i)
		Lake Susan			
9/7/06	seine	50	50	0	0
9/21/06	seine	43	43	0	50
10/3/06	EF	27	27	0	93
10/10/06	EF	39	37	2	120
10/16/06	EF	33	30	3	157
10/23-30/06	EF	32	29	3	187
11/13/06	seine	137	130	7	216
4/23/07	seine	488	449	39	346

$$\sum_{i=1}^{8} C_i \cdot M_i = 218{,}946\,;\ \sum_{i=1}^{8} R_i = 54\,;\ N = \frac{218{,}946}{54} = 4{,}054\,;\ 90\%\ \text{CI} = 3{,}312 – 5{,}223$$

Date	Gear	(C_i)	Unmarked	(R_i)	(M_i)
		Lake Echo			
8/18-21/06	seine	320	278	0	0
8/28-31/06	EF	106	96	10	278
9/20/06	seine	301	268	18	374
9/26/06	EF	92	84	8	642
10/9-26/06	EF	121	38	15	726

$$\sum_{i=1}^{5} C_i \cdot M_i = 288{,}952\,;\ \sum_{i=1}^{5} R_i = 51\,;\ N = \frac{288{,}952}{51} = 5{,}666\,;\ 90\%\ \text{CI} = 4{,}605 - 7{,}361$$

Aging analyses of carp conducted using otoliths from several hundred carp demonstrated several striking phenomenon. First, we found that carp are very long-lived in Minnesota (they routinely live up to 20 years but can survive to 53). Second, by blocking Lake Echo and studying its fish across several years we determined that adult carp have very low mortality rates (7-25% annually). Third, by analyzing the age structures of entire lake populations, we discovered that in contrast to adults, young-of-the year carp suffer close to 100% mortality in most years at most locations. Thus, most shallow lakes in Minnesota contain only a few age classes of carp. Further, by examining these data in great detail, we found that young carp only survive in years and locations where winter oxygen levels dip to values that cause winterkill (fish death) in adjoining wetlands. For example, in Lake Echo nearly 95% of its carp was comprised of only two age classes (1997 and 2001), both of which were born (hatched) following winters when oxygen levels in its watershed dipped below 2 mg/L (Fig. 3-2). Accordingly, we once again come to the conclusion that superabundance of carp in Minnesota lakes is driven by the presence of wetland nursery habitat which is itself characterized by heavily vegetated, shallow regions that are both prone to winterkill and inter-connected so spawning adult carp can use them in early spring. Apparently, such regions, frequently lack predatory game-fish which eat (control) young carp. If true, a solution for carp may be at hand because at least some of these regions can be controlled using winter aeration or by stocking game-fish. Tests of this important hypothesis were carried out with a statistical simulation (see below) and are presently underway in the field as part of a new 2007 LCCMR project.

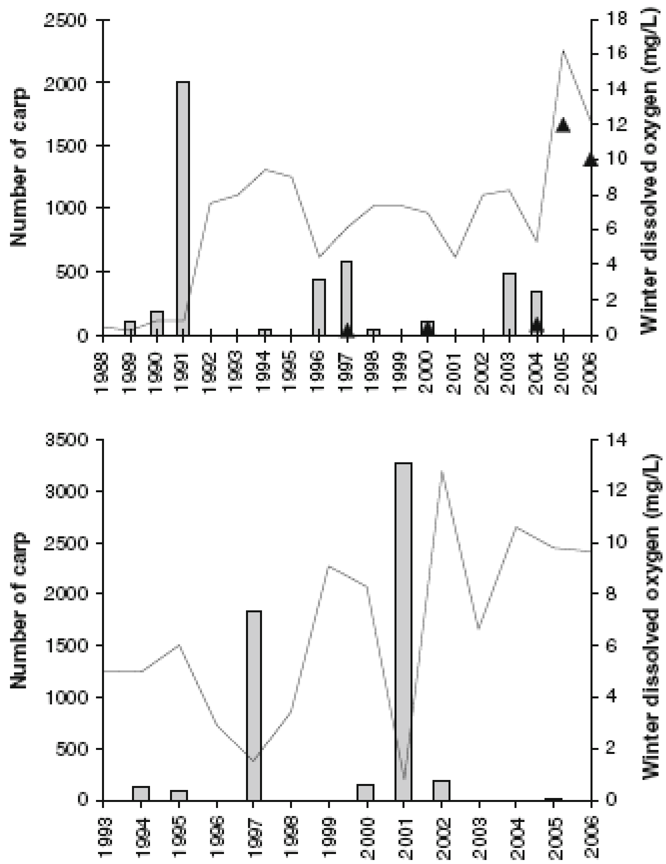

Fig. 3-2 *Top panel: The age structure (numbers of carp in each age class listed by year hatched) of carp in Lake Susan along with the annual dissolved oxygen winter-minima (line). Triangles show years when winter-minima of dissolved oxygen were also measured in the adjoining Rice Marsh Lake which winter-kills. Bottom panel: The age structure of carp in Lake Echo (columns) and the winter-minima of dissolved oxygen for lakes in the watershed (from Bajer and Sorensen, 2009).*

Important, new information was also generated on carp maturity, fecundity and growth rates by aging several hundred maturing individuals from several lakes and examining the histological condition of their gonads. We found that female carp in Minnesota mature at approximately three years of age and at a size of just over 340mm (i.e. relatively young and small in size) (Fig. 3-3). Males mature at an average age of two and females can carry over two million eggs. Clearly, adult fecundity is not an attribute that can be easily controlled and manipulated in this species.

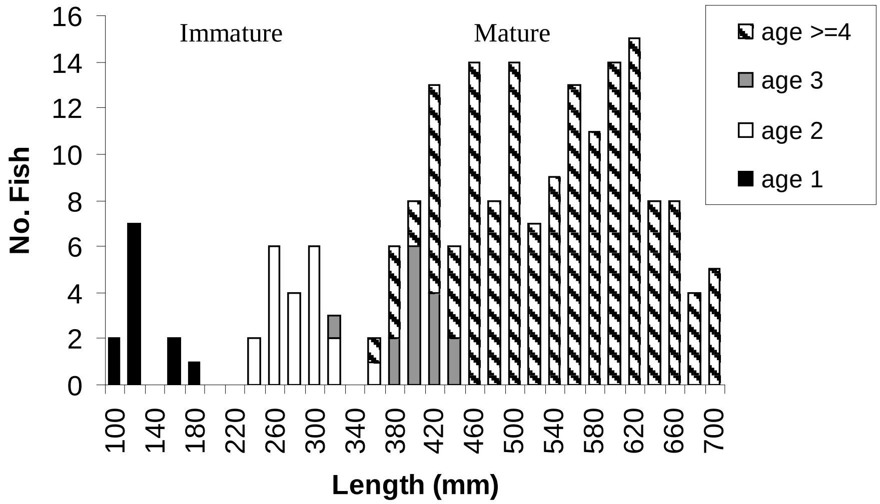

Fig. 3.3. *Length, age, and maturity of female common carp in Minnesota lakes. All females greater than 340mm in length were mature.*

Lastly, using estimates of carp abundance, mortality, and recruitment strength and its association with winter-kill, we developed a statistical model to simulate and test the abundance and biomass of common carp in Minnesota ('CarpSimMN'). This model was able to simulate the abundance and biomass of carp inhabiting in an isolated lake and developed a function which successfully predicted (i.e. could explain) the effects of recruitment events and biomass. The model also tested for factors which might drive carp population abundance in isolated lakes without nurseries (ex. Dog Lake) and interconnected lakes which have nurseries (ex. lakes Susan, Rile and Rice Marsh). CarpSimMN accurately predicted ('explained') carp biomass in all situations although some improvement is needed in its emigration/immigration function. Specifically, this model showed that carp biomass should be low (40 kg/ha) in the absence of recruitment pulses associated with winterkills, but might be expected to rise to ~ 300-500 kg/ha within a few years in lakes which receive annual recruitment pulses from interconnected marshes that winter-kill (Fig. 3.3). These densities are similar to those that we have measured in the field. The model also predicted that control strategies that simultaneously control winter-kill (such as might be achieved by aeration) and remove adult carp (such as by commercial seining) should reduce carp biomass by half 9to below damaging levels) within a few years. These results are very encouraging and this useful model has been made available to the DNR.

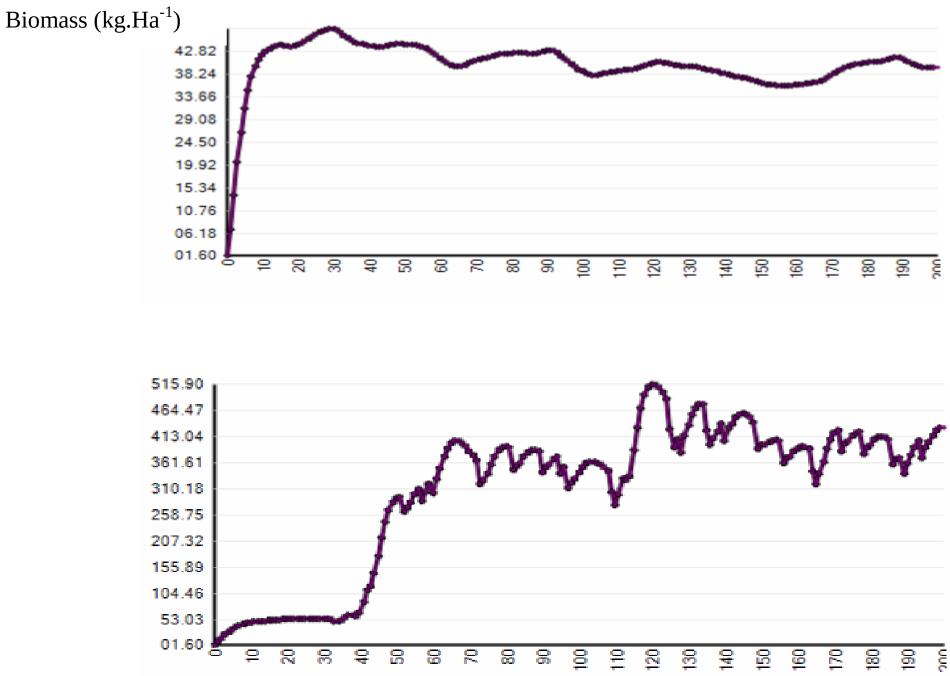

Figure 3.4*. Statistical simulation of the biomass of carp in a lake that does not winterkill (top panel) and in a lake which is connected to a marsh that does (bottom panel). Note that the scale of the Y-axis of the bottom figure is much smaller.*

In conclusion, our studies of carp population dynamics shed new light on why Minnesota has so many carp and how integrated pest management strategies might control this damaging species. Specifically, we find that interconnected lakes located in the central regions of Minnesota which winter-kill function as essential but limiting nursery habitat for this species which otherwise has explosive reproductive potential. We also find some evidence that managing/promoting predatory native game-fish in these potential nurseries might be used (in various ways) to control the carp. In particular, pheromonally-assisted trapping, perhaps combined with other techniques such winter seining, could supplement control of nursery habitat as directed by a refined version of CarpSimMN. Notably, our studies have necessarily been restricted to south-central regions of the state but do include shallow as well as deeper lakes. A new LCCMR project (2007) is examining recruitment control in additional sets of lakes. Ultimately, these lessons will benefit our understanding and ability to control this and other damaging invasive fishes such as the Asian carps.

V. TOTAL LCCMR PROJECT BUDGET

- See Attachment A.-

All Results: Personnel: $446,305 (includes benefits)
All Results: Equipment: $0
All Results: Development: $0
All Results: Acquisition: $0
All Results: Other:

Computer for modeling: $1,349
Supplies: $62,289
Xerox: $154
Equipment repair: $1,110
Cell phone for project field work: $75
Laboratory services (analyses): $3,817
Computer for HPLC analysis: $1,250
Software for BRAM (HPLC): $507
Software for HPLC: $7,463
Subcontract to commercial fisher to census fish: $15,550

Travel:
In Minnesota: $8,293
Out of State: $1,838

TOTAL LCCMR PROJECT BUDGET: $550,000

Explanation of Capital Expenditures Greater Than $3,500

The computer control for the Sorensen laboratory's high performance liquid chromatograph (HPLC) is no longer working properly and because it is 15 years old cannot be fixed. It is needed for pheromone isolation and identification (Result #1). A new software package ($7,463) and computer to run the HPLC ($1,250) are now needed for pheromone identification..

VI. OTHER FUNDS & PARTNERS

A. Project Partners:

1. Minnesota Department of Natural Resources.

Fisheries and Wildlife, Mr. Paul Wingate ($0 received)

Ecological Services, Mr. Jay Rendall ($0 received)

2. Department of Primary Industries, Victoria, Australia

Mr. Paul Brown (0$ received).

B. Other Funds being Spent during the Project Period:

1. Minnesota Department of Natural Resources.

Fisheries and Wildlife, Mr. Paul Wingate (extensive in-kind assistance including boats, equipment, personnel with field work associated with Results 2 and 3, estimated value $100,000).

Ecological Services, Mr. Jay Rendall ($60,000 grant to support Paul Brown for CarpSim)

2. Department of Primary Industries, Victoria, Australia

Mr. Paul Brown (in-kind matching salary and support from the Department of Primary Industries, 2 weeks a year for 4 years, estimated value is $20,000).

C. Required Match (if applicable): *-none-*

D. Past Spending:

$100,000

E. Time:

We require four years of support for this project because of its inherent complexity and difficulty. Especially complicating is the fact that the field work can only be conducted for a few (1-2 months) each year because carps spawn on a seasonal (and erratic) basis and we need at least two years of data from several sites before any statistical modelling can commence. Laboratory work is also complicated by the fact that carp take a year to mature in the laboratory and behavioral and biochemical analyses are slow and tedious. This project is original research.

VII. DISSEMINATION

1. *Publication in peer-reviewed literature*

Sisler, S.P. and Sorensen, P.W. 2008. Common carp and goldfish discern conspecific identity using chemical cues. *Behaviour.* 145: 1409-1429.

Bajer, P.B., Sullivan, G. and Sorensen, P.W. 2009. Effects of a rapidly increasing population of carp on vegetative cover and waterfowl in a recently restored Midwestern lake. *Hydrobiologia.* 632: 235-245

Bajer, P.B. and Sorensen, P.W. 2009. Recruitment and abundance of an invasive fish, the common carp, is driven by its propensity to invade and reproduce in basins that experience winter-time hypoxia. *Biological Invasions* DOI 10.1007/s10530-009-9528-y.

2. *Presentations at scientific meetings (local, national, international)*

Sorensen, P.W., Bajer, P.B., Lavesque, H., and Hennon, M. 2006. Pheromonal and IntegratedControl of the Common Carp, First International meeting on Asian carps, Illinois

Sorensen, P.W. 2007. Pheromones in the common carp, University of Canberra, Australia

Sorensen. P.W. 2007. Carp control, Riley Purgatory Bluff Creek Watershed District

Sorensen, P.W. 2007. Controlling carp, Lake Susan Association.

Sorensen, P.W., Bajer, P., Levesque, H., and Lim, H. 2007. Common carp: Control of this invasive species demands the support of the Aquatic Nuisance Species Task Force. Aquatic Nuisance Species Task Force, Washington D.C.

Sorensen, P.W., and Bajer, P.B. 2007. Common carp, an enigmatic invasive fish. University of St. Thomas, MN

Bajer, P. Sorensen, P.W., Brown, P. 2007. Carp population dynamics, Annual meeting of the American Fisheries Society, San Francisco

Levesque, H.L. 2007. Carp pheromones. Annual Midwest Fish and Wildlife Meeting, Madison, WI

Lim, H. 2007. Carp sex pheromones. Annual Midwest fish and Wildlife Meeting, Madison, WI

Bajer, P.B. 2007. Carp population dynamic modeling, Annual Midwest fish and Wildlife Meeting, Madison, WI

Sorensen, P.W. and Bajer, P.B. 2008. Progress controlling carp. Riley Purgatory Bluff Creek Watershed District

Sorensen, P.W., and Bajer, P.B. 2008. Common carp . Ramsey Washington Metro Watershed District

Sorensen, P.W., and Bajer, P.B. 2008. What to do about carp? Carver County Watershed District

Sorensen, P.W., Lim, H.K. and Levesque, H.L. 2008. Carp pheromones and their application. Minnesota Chapter of the American Fisheries Society

Sorensen, P.W. 2009. Integrated control of the common carp. Mississippi River Basin Aquatic Invasive Task Force.

Sorensen, P.W. and Bajer, P.B. Carp and their control. Saulk Center, MN

Sorensen, P.W. 2009. Recent progress controlling carp in Riley Creek. Riley Purgatory Bluff Creek Watershed District

3. *Meetings with DNR*

Sorensen, P.W. 2007. *How to control common carp.* 1 hour meeting, St. Cloud

Sorensen, P.W.2008. *Carp biology and control,* 2 hour meeting, St. Paul

Sorensen, P.W. 2009. *CarpMN model*, 1 hr seminar, St. Paul

4. *Media*
National Public Radio May 2006

Outdoor News, June 2006

Minneapolis Star Tribune, July 2006

Minneapolis Star Tribune, July 2007

Minnesota Bound TV Show, 2009

Minneapolis *Star Tribune*, July 2009

5. *Web Site:*
http://fwcb.cfans.umn.edu/sorensen/

IX. RESEARCH PROJECTS

Research Addendum as Attachment B.

Attachment A: Budget Detail for 2005 Projects Update 10/15/09

Proposal Title: Integrated and pheromonal control of carp

Project Manager Name: Sorensen.

2005 LCMR Proposal Budget	**04116479**					**04116480**					**04116481**				
Amended Result 1 Budget**		**Revised budget as of 4/20/09**	**Expenses thru** *6/30/09*	**Balance 6/30/09**	**Amended Result 2 Budget****		**Revised Budget as of 4/20/09**	**Expenses thru** *6/30/09*	**Balance 6/30/09**	**Amended Result 3 Budget**:**		**Revised budget as of 4-20-2009**	**Expenses thru** *6/30/09*	**Balance 6/30/09**	
	Pheromone Identification				*Spawning Microhabitat Identification*					*Population Modeling (CarpsIm)*					
BUDGET ITEM															**TOTAL ammended BUDGET ITEM**
PERSONNEL: Staff Expenses, wages Ph.D. student (0) Undergrad assistant (15,000) Postdoctoral fellow (131,000) Project manager (0) Principal investigator (28,599)	**Total Personnel** 174,500	**189,628**	185,418	4,210	**Personnel** Ph.D. student (0) Undergrad assistant (10,500) Postdoctoral fellow (43,500) Project manager (0) Principal Investigator (5,400)	**Total Personnel** 59,400	**72,436**	72,144	292	**Personnel** Ph.D. student (0) Undergrad assistant (10,500) Postdoctoral fellow (87,000) Project manager (0) Principal Investigator (10,800)	**Total Personnel** 108,300	**117,788**	117,689	99	**379,852**
PERSONNEL: Staff benefits Ph.D. student (0) Undergrad assistant (0) Postdoctoral fellow (26,800) Project manager (0) Principal investigator (10,100)	**Total Staff Benefits** 36,900	**28,512**	30,261	-1,749	**Staff benefits** PhD student (0) Undergrad student (0) Postdoctoral fellow (9,000) Project manager (0) Principal investigator (2,000)	**Total Staff Benefits** 11,000	**15,426**	15,194	232	**Staff benefits** PhD student (0) Undergrad student (0) Postdoctoral fellow (17,400) Project manager (0) Principal investigator (3,900)	**Total Staff Benefits** 21,300	**22,515**	22,504	11	**66,453**
Office equipment & computers Computer for Carpsim modelling	**0**		**0**		**0**		**0**	**0**	0	1,500		1,349	1,349	0	**1,349**
Supplies: **Laboratory supplies** *(fish, fish food, aquaria, odors, pumps, aquaria, C18 columns, solvents, VCR tapes, lab notebooks, etc) (31,000)* **Field supplies** *(radiotags, lab radio receivers, GPS unit, notebooks, nets, raingear, etc) (0)*	**Total Supplies** 31,000	**34,674**	37,040	-2,366	**Supplies** **Lab:** 1,500 . . **Field:** 27,500	**Total supplies** 29,000	**23,482**	23,984	-502	**Supplies** **Lab and field:** 5,700 . **General:** 2,500	**Total Supplies** 8,200	**4,133**	4,995	-862	**62,289**
Travel expenses in Minnesota*** **(***Fisheries meetings with DNR, travel and accomodations at field sites)*	3,000	3,000	601	2,399	**Travel in Minnesota** 7,100		**1,118**	1,140	-22	**Travel in Minnesota** 10,500		4,175	3,423	752	**8,293**
Travel expenses outside Minnesota *** Attendance at national meetings (on invasive fishes and their control) International travel for Mr. P. Brown *(1 visit at of project to train DNR)*	4,000	1,838	4,237	-2,399	**Travel expenses outside MN** 2,000		0	0	0	**Travel expenses outside MN** 0		0	0	0	**1,838**
Other:					**Other**	**Total Other** $2,500			.	**Other**					
Publication of findings ($1,500)		0	0	0	Publication - $750				0	Publication of findings ($750)				0	**0**
Photocopying ($500)		120	135	-15	Photocopying - $250		**19**	19	0	Photocopying ($250)		15	15	0	**154**
Equipment repairs (3,000)		591	591	0	Equipment repairs - $1,000		**519**	519	0	Cell phone specific to project ($500)		75	75	0	**1,185**
Laboratory services *(Mass spec, nmr analyses)* ($8,000)		3,817	4,122	-305											**3,817**
HPLC COMPUTER ($1,250)		1,250	1,238	12					0						**1,250**
HPLC software (BRam) ($500)		507	507	0					0						**507**
HPLC Software (Trilution) ($7,250)		7,463	7,250	213					0						**7,463**
					Outboard motor ($2,500)		0	0	0	**Other:** Contract commercial carp fisher (14,300)	**Total Other:** 14,300	**15,550**	15,550	0	**15,550**
	271,400	**271,400**	**271,400**	**0**		**113,000**	**113,000**	**113,000**	**0**		**165,600**	**165,600**	**165,600**	**0**	**550,000**