AQUATIC INVASIVE SPECIES

Zebra Mussels, Round Gobies, and Eurasian Ruffe: Predicting Ecological Impacts of the "Exotic Triad"

Final Report

Dr. Gary Lamberti (University of Notre Dame) and Dr. Martin Berg (Loyola University Chicago) will continue work on interactions between recently invading species (zebra mussels, round gobies, and Eurasian ruffe) and an important native sport fish, yellow perch. Recent declines in the Lake Michigan perch fishery have been attributed to zebra mussels (among other factors), but with little supportive evidence. The proposed work will determine whether the invasive species are contributing to poor perch recruitment by a variety of interactions, including competition for benthic invertebrate food. If invasive species x perch interactions prove critical, then management should target control of the invasive species. If one or more of the invasive species actually mitigates effects on yellow perch (e.g., the zebra mussel actually makes more food available to some invertebrates on which perch feed), then management efforts can be directed to other presumed causes of the perch declines. The researchers will meet with the Lake Michigan Yellow Perch Task Group and will periodically disseminate their findings through the list-serve operated by the Group.

Major Goals and Objectives

Our overall goal is to predict how a 'triad' of important exotic invaders in the Great Lakes – Eurasian ruffe, round gobies, and zebra mussels – will interact as their distributions converge in Lake Michigan and how native yellow perch will respond to the invasion. Our specific objectives are to determine: (1) whether ruffe and gobies display overlap in use of habitat and food and thus may compete for benthic resources, (2) whether zebra mussels will modify ruffe – goby interactions directly by serving as a major food resource for gobies or indirectly by increasing benthic heterogeneity and associated invertebrate production, and (3) how yellow perch will respond to coexistence with ruffe and gobies in the presence or absence of zebra mussels.

Summary of Progress

We are in the third (no-cost) year of active research for this project, which is a collaborative effort between the University of Notre Dame (UND) and Loyola University Chicago (LUC). We are using the Exotic Species Containment Facility at UND to conduct controlled experiments with invasive zebra mussels, round gobies, and Eurasian ruffe and native yellow perch. This facility has 12 experimental tanks, 12 fish-holding tanks, and numerous aquaria. We are also conducting experiments in southern Lake Michigan to examine the interactions of round gobies, zebra mussels, and yellow perch prior to invasion by Eurasian ruffe and performing field surveys of fish diets from sites throughout the Great Lakes. To date, we have completed the following: (1) conducted four laboratory experiments with ruffe and gobies to address objectives 1 and 2 above, (2) addressed objective 3 by conducting four laboratory experiments testing the habitat use and growth of perch in the presence and absence of gobies, ruffe, and zebra mussels (3) continued a major field experiment to examine interactions of round gobies with native fishes in Lake Michigan, and (4) analyzed field collections of perch, ruffe, and gobies from six areas in the Great Lakes to examine their gut contents as an indicator of dietary overlap and to validate laboratory food preference studies. In the past year, we have had one refereed paper appear in print, one paper accepted for publication, and a third paper in preparation. Finally, we made six presentations about our research at regional and national meetings or symposia, one of which one an award for the best student presentation in applied research at an international meeting.

Accomplishment/Benefits

This project is providing vital information relevant to the management of Eurasian ruffe, round gobies, and zebra mussels as they extend their range in the Great Lakes and beyond, and potentially threaten native fishes such as commercially important yellow perch. Our experiments have examined the interactions among round gobies, Eurasian ruffe, and yellow perch in environments that contain or do not contain zebra mussels, and resulting data can be used to target control strategies on invasive species if negative impacts are predicted. We are also developing a predictive model for the future dispersal of ruffe in the Great Lakes region and beyond (Kolar et al., in preparation), and hope to extend that model to other invasive fishes such as round gobies as well as potential invaders. We have communicated our findings with two talks and a poster at the Illinois-Indiana Sea Grant College Program Research Symposium in Chicago, a paper at the Annual Meeting of the North American Benthological Society held in LaCrosse, WI, a paper at the 11th International Conference on Aquatic Invasive Species in Alexandria, VA as part of the Biology and Ecology of New Freshwater Invaders Session, and a paper at the International Association of Great Lakes Research in Winnipeg, Manitoba as part of the Aquatic Exotics and Consequences of Invasion Session. We have published a major paper on Eurasian ruffe and yellow perch interactions in Transactions of the American Fisheries Society (Fullerton et al. 2000), had a paper on zebra mussels and ruffe accepted to the Journal of Great Lakes Research (Kolar et al., in press), and are preparing several other manuscripts for publication in journals such as Biological Invasions. We have also been quoted in regional newspapers (e.g., Chicago SunTimes) and interviewed by National Public Radio concerning the recent sighting of Eurasian ruffe in upper Lake Michigan.

Many state and federal agencies are responsible for the management of fisheries and water resources within the Great Lakes. Nominally, these include the Biological Resources Division of the U.S.G.S., the U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, Great Lakes Fishery Commission, International Joint Commission, U.S. Army Corps of Engineers, and the departments of Natural Resources or Environmental Management for the various states bordering the Great Lakes. All of these agencies will be able to use our findings to better manage the 'exotic triad' in the Great Lakes and their associated watersheds. Recent concern about the yellow perch fishery in Lake Michigan highlights the importance of our research to help predict the impacts of exotic animals on native biota so that targeted control measures can be taken if needed. Conversely, if impacts are shown to be minimal, then measures can be directed to containment and prevention rather than control.

Keywords

Eurasian ruffe, round goby, zebra mussel, yellow perch, exotic species, Great Lakes, Lake Michigan, benthic macroinvertebrates, impacts, competition

Narrative Report

Ruffe and goby diets

Food preferences of ruffe (*Gymnocephalus cernuus*) and gobies (*Neogobius melanostomus*) were examined in a laboratory experiment. Twelve benthic invertebrate taxa were collected from local streams including Mill Creek (St. Joseph County, Michigan), Juday Creek (St. Joseph County, Indiana), and Christiana Creek (Cass County, Michigan). Insect orders included members of three trichopteran taxa, odonates, ephemeropterans, and coleopterans. Amphipods, crayfish, snails, Asiatic clams (*Corbicula* sp.) and zebra mussels (*Dreissena polymorpha*) were also collected. Chironomids and oligochaetes were not included in this study because of poor recovery from control tanks. Five individuals of each of the previous taxa were placed in 10-gallon aquaria. Each aquarium fell into one of the following treatments: one goby (n=5), one ruffe (n=5), one goby and one ruffe (n=5), or a fishless control (n=4). It appears that ruffe and gobies, both in isolation and together, prefer soft-bodied taxa such as hydropsychid caddisflies, amphipods, and mayflies, while many of the harder taxa were avoided. One exception to this trend is the preference of gobies for zebra mussels. Gobies consumed nearly all zebra mussels presented in the experimental tank, whereas ruffe generally

avoided mussels. It is interesting to note that gobies avoided *Corbicula* clams of a similar size. We also believe that the gobies and ruffe both consumed chironomids (Bauer, pers. obs.), but could not include this taxon in our analysis due to poor recovery from controls.

Perch, ruffe, and goby diets with and without zebra mussel habitat. We conducted experiments similar to the one described above, but added yellow perch to the treatments resulting in the following treatments: (1) control – no fish, (2) one yellow perch, (3) one goby, (4) one ruffe, (5) one perch + one goby, and (6) one perch + one goby + one ruffe (n=8). We added 7 individuals of each taxon (annelids, uncased caddisflies, mayflies, amphipods, snails, and zebra mussels). The number of individuals remaining at the end of the 18-h experiment (9L:9D) were recorded and presumed eaten. Preliminary results show that all soft-bodied taxa were eaten (particularly amphipods), but very few snails or zebra mussels were consumed. This could indicate that soft-bodied invertebrates are the preferred prey of all three fishes, and that gobies only switch to hard-bodied prey in the absence of preferred prey. The same taxa were added to tanks containing zebra mussel habitat (as in Kolar et al., in press) and then one perch, goby, or ruffe was added. This resulted in 4 treatments including a no-fish control. Recovery from the controls was fair for caddisflies and mayflies (~50%), but all other taxa had good (90-100%) recovery. Once again, hard-bodied taxa were not eaten whereas soft-bodied taxa were eaten. Particularly, all fish species preyed most heavily on amphipods. This indicates that amphipods remain an available food source to all fish species in areas with zebra mussel colonies.

Habitat preference

Artificial lake environments (1 m2 surface area) with equal areas of cobble, macrophytes, and sand were used to determine whether ruffe and gobies use similar habitats. Low (3 individuals) and high (6 individuals) densities of ruffe and gobies were held alone and in combination to determine the effects of fish species and density on habitat use (n=4 per treatment). We also determined whether the habitat use of perch would be altered in the presence of gobies and ruffe by observing perch habitat use alone (3, 6, or 18 perch), in combination with gobies (3 perch + 3 gobies, 6+6), and with both gobies and ruffe (2 perch + 2 gobies + 2 ruffe, 3+3+3, 6+6+6; n=6). These treatments were chosen to represent the past (perch alone), present (perch + gobies), and future (perch + gobies + ruffe) scenarios which may be found in the nearshore habitats of Lake Michigan under both invasion (total number of fish increase with addition of exotic species) and replacement scenarios (number of total fish stays the same, but the relative number of perch declines). Habitat use by all fish, separated by species, was assessed visually and recorded every 15 minutes in light and dark during each 8-hour trial. Our first experiment indicated that neither fish species, density, nor their interaction significantly affected habitat use by gobies and ruffe (MANOVA Wilks' lambda > 0.05). Overall, gobies and ruffe used cobble and plants more than sand at all times, but sand use increased during the dark. Preliminary analysis indicates that perch habitat use was not affected by the presence of round gobies or by both gobies and ruffe. Perch used the plants heavily at all times with increased use of other habitats during the dark, while gobies and ruffe continued use of both plants and cobble during the day with increased sand use in the dark.

Ruffe-goby competition for limited food resources

In the artificial lake environments, growth of each species alone (2 ruffe or 2 gobies, Alone treatment) was compared to the growth of the two species together (1 ruffe plus 1 goby, Replacement treatment or 2 ruffe plus 2 gobies, Invasion treatment). Thus, each 1 m2 artificial lake environment contained one of the three treatments listed above (n=3 per treatment; average temperature, 15 C). The fish were fed a limiting ration of 6% of their body weight per day of an aquatic annelid, Tubifex species (or 3% for 2 ruffe and 2 gobies combined to simulate an invasion scenario) during the dark when both species are active. Round gobies grew significantly more than ruffe (daily growth; species effect p = 0.0061). The treatment effects were nearly significant (p = 0.0501). While the interaction of species and treatment was statistically nonsignificant (p = 0.120), Eurasian ruffe growth was decreased in the presence of round gobies at a ration of 3% of their

body weight (Treatment 3). This result may be biologically meaningful. When ruffe invade in an area where round gobies are present and benthic invertebrates are limiting (simulated by treatment 3), ruffe may not have high enough growth rates to establish self-sustaining populations.

Ruffe-goby competition for limited food resources in the presence of zebra mussels. This short-term competition experiment (1 week in duration) had fish treatments similar to the previous experiment, but was performed in 40-L aquaria at 16 °C (n = 8). Due to the small size of the experimental arena, fish treatments were 2 gobies alone or 2 ruffe alone fed 6% ration (Alone treatment), 1 ruffe plus 1 goby fed 6% ration (replacement treatment), and 1 ruffe plus 1 goby fed 3% ration (Invasion treatment). In this experiment, we simulated increased fish density by decreasing the ration by half. The fish treatments were either held in aquaria with or without zebra mussels. Zebra mussels (50 g blotted wet weight per tank; approximate density of 1000 mussels/m2 was within the lower range of densities recorded from North American lakes colonized with zebra mussels; Nalepa et al. 1995) were colonized on bricks for 1 week prior to the addition of fish treatments to the tanks. This experiment showed that growth was measurable in a 1-week period in both ruffe and gobies. The two species had similar growth rates, but significant differences were seen among the different fish treatments. Fish growth rates in the Alone treatment was similar to growth rates in the Replacement treatment (Tukey's $p = 0.232$) whereas the Invasion treatment had significantly lower growth rates than the Alone or Invasion treatments (Tukey's $p<0.001$ and $p=0.005$, respectively). Interestingly, adding zebra mussels to the tank did not significantly affect fish growth ($p = 0.558$). We expected that gobies would have higher growth rates than ruffe due to the consumption of zebra mussels, but gobies did not have higher growth rates than ruffe nor did they consume zebra mussels. While gobies are known to eat zebra mussels in the Great Lakes, this experiment further strengthens our conclusion that soft-bodied invertebrate prey are preferred when available.

Competition for limited food resources among perch, gobies, and ruffe

Perch growth was measured when alone, with gobies, or with gobies and ruffe in the presence and absence of zebra mussel habitat in 1-m2 artificial lake environments. These treatments were chosen to reflect past (6 yellow perch), present (3 yellow perch and 3 gobies) and future (2 perch, 2 gobies, and 2 ruffe) scenarios of benthic fish co-occurrence in Lake Michigan. We also used this design to determine the effect that zebra mussel habitat (1760 mussels m-2) has on fish growth. Artificial lake environments were covered with sand and were overlain with 16 concrete hemispheres (with or without attached zebra mussel shells) and three bunches of plants. Fish were fed a daily ration of 4.5% of their body weight per day for six weeks and growth was measured weekly. Preliminary results show that average daily growth rates of perch were not affected by the presence of neither gobies and ruffe, nor zebra mussel when resources were held constant (replacement scenario). To test the effects of increasing fish density and the resulting decrease in available food resources (invasion scenario), we conducted additional replicates of this experiment with both increased densities of perch, and perch in combination with ruffe and gobies in the presence of zebra mussel habitat. We also conducted extensive behavioral observations during this experiment and recorded aggression and activity levels. The results from this experiment still have to be analyzed, but we witnessed decreased growth of all species, as one might expect from increasing fish densities associated with an invasion.

Live zebra mussel effects on benthic fishes

Yellow perch growth was examined in the presence and absence of the 'Exotic Triad' over a 2-week period. The fish treatments were (1) 3 perch without mussels, (2) 3 perch with mussels, (3) 1 perch + 2 gobies with mussels, and (4) 1 perch + 1 goby + 1 ruffe with mussels. We chose these treatments to once again reflect conditions in Lake Michigan during the 1980's (Treatment 1), 1990's (Treatment 2), early 2000's (Treatment 3), and mid-2000's (Treatment 4). The fish treatments were added to 40-L aquaria and fed either a high (6%) or low (3%) daily ration of aquatic annelids to simulate both replacement and invasion scenarios. In addition to recording the weekly growth rates of the fish, we also sacrificed a subsample of the fish at the end of the

experiment for molecular analysis of short-term growth rates (see Fullerton et al. 2000). These results still have to be statistically analyzed, but we again witnessed decreased grow of all species, as one might expect from increasing fish densities associated with an invasion (3% ration). Zebra mussels did not significantly affect perch growth rates, but gobies did eat some zebra mussels during this experiment that may have increased their growth rate or decreased their consumption of soft-bodied invertebrates.

Ongoing studies

From the completed studies, it appears that there is potential for perch and the 'exotic triad' to co-occur in nearshore benthic areas, particularly in macrophyte beds. However, our studies suggest that perch will not alter their preference for macrophytes in the presence of gobies and/or ruffe. Thus, the most important interactions among these species may be competition for food resources. If total fish densities increase in the upper Great Lakes due to the invasion of ruffe and gobies into additional nearshore habitats, our results indicate that the growth of perch, goby, and ruffe growth will decline if food resource levels remain constant. However, in the presence of zebra mussels, gobies may have a competitive advantage over ruffe and perch by switching their diet from preferred soft-bodied invertebrates to zebra mussels, which are more abundant. It is still unclear what effects, if any, zebra mussels will have on benthic fish growth, but increasing habitat complexity (at least at low to moderate levels of mussel colonization) does not seem to decrease foraging efficiency enough to affect fish growth rates. This is a significant finding, as it does not support the hypothesis that increased habitat heterogeneity due to zebra mussel colonization of substrates could have a negative impact of foraging efficiency, and thus lead to declines in fish growth. Our ongoing work, including data analysis, the processing of gut contents from fish collected from Lakes Superior, Huron, and Michigan, and analysis of fish tissue samples for RNA as an indicator of short-term growth rates, will help us to further address these potentially important interactions.

Lay Summary

Exotic species now dominate the food webs of the Great Lakes, including Lake Michigan. Recently, a number of particularly successful invaders have reached the Great Lakes via transoceanic transport from Europe and Asia, including an ‘exotic triad’ of Eurasian ruffe, round gobies, and zebra mussels. Mussels and gobies now are extremely abundant in Lake Michigan, and ruffe have recently been collected in upper Lake Michigan are thus poised to invade southern Lake Michigan in the near future. A major issue in the management of native yellow perch, an important commercial and sport fish in Lake Michigan, is how this fishery will respond to this influx of exotic organisms. Our IISG project has assessed the potential impacts of the ‘exotic triad’ on yellow perch and benthic invertebrates in Lake Michigan. We have found that ruffe will compete with yellow perch for food and habitat, and that the growth of both species declines during coexistence. However, we have also found that yellow perch have a greater ability to withstand periodic hypoxia (i.e., low oxygen levels) at summer water temperatures than do ruffe. Our experiments with ruffe and gobies show that both species prefer to eat soft-bodied invertebrate taxa, but gobies also eat zebra mussels. Gobies and ruffe also prefer similar habitats, such as macrophytes and cobble in clear-water systems. When both species are placed together and food resources are limiting, gobies continue to show positive growth while ruffe growth is negligible. Thus, our research suggests that where food resources are limiting in the Great Lakes, gobies will have a competitive advantage over ruffe, which could impede the invasion of ruffe into areas where gobies are firmly established. Our research on the added impacts of gobies, ruffe, and zebra mussels on yellow perch growth and behavior suggest that all fish are similarly affected by the decrease in food availability associated with increasing fish densities and that yellow perch growth rates do not decline disproportional

International Implications

Invasions of new areas by exotic species such as fish are an international problem that respects no national boundaries. For example, Canadian provincial and federal agencies, such as the Ministries of Natural Resources, are involved in addressing and managing the ruffe, goby, and zebra mussel invasions of the Great Lakes. The U.S.-Canadian Joint Commission addresses regulatory issues involving shared lakes and

resources. Furthermore, ruffe, gobies, and zebra mussels have invaded most of continental Europe, Scandinavia, and the British Isles from their origin in the Baltic Sea area, with various ecological and economic impacts. Thus, invasions by the 'exotic triad' are a global problem and research on them has substantial global relevance and application.

Media Coverage

Our research was cited in a newspaper article in the South Bend Tribune entitled "Exotic species upsetting lakes" The PI Gary Lamberti was recently cited in a story in the Chicago Sun Times and was interviewed for National Public Radio concerning the recent collection of Eurasian ruffe near Escanaba in upper Lake Michigan.

Partnerships

This project is a collaboration between researchers at the University of Notre Dame and Loyola University Chicago. We are also cooperating with researchers at other agencies and institutions to collect fish from several of the Great Lakes for dietary analysis. These collaborators include the Biological Resources Division of the USGS (Ashland, WI), the USFWS-Ashland Fisheries Resources Office and Alpena Fisheries Office, the Wisconsin Department of Natural Resources, the Natural Resources Research Institute at the University of Minnesota – Duluth, the Illinois Natural History Survey, and Ball State University.

Publications

Fullerton, A.H., G.A. Lamberti, D.M. Lodge, and F.W. Goetz. 2000. Potential for resource competition between Eurasian ruffe and yellow perch: growth and RNA responses in laboratory experiments. Trans. Am. Fish. Soc. 129: 1387-1395.

Kolar, C.S., A.H. Fullerton, K.M. Martin, and G.A. Lamberti. In press. Effect of zebra mussel shells on amphipod behavior and foraging rates of Eurasian ruffe and yellow perch. J. Great Lakes Res.

Bauer, C. R., and G. A. Lamberti. In preparation. The 'Exotic Triad': Interactions among benthic invasive species, Eurasian ruffe, round gobies, and zebra mussels, in the Great Lakes. Biological Invasions.

Presentations

Lamberti, G.A. Zebra mussels, round gobies, and Eurasian ruffe: Should we be afraid of this 'exotic triad'? Illinois-Indiana Sea Grant College Program Research Symposium, Chicago. April 12, 2001.

Bauer, C.R., G.A. Lamberti, and M.B. Berg. Zebra mussels, round gobies, and Eurasian ruffe: Predicting ecological impacts of the 'exotic triad' to improve control. Illinois-Indiana Sea Grant College Program Research Symposium, Chicago. April 12, 2001.

Berg, M.B. The little fish that could: round gobies and their impacts in the Great Lakes. Illinois-Indiana Sea Grant College Program Research Symposium Chicago. April 12, 2001.

Bauer, C.R., G.A. Lamberti, and M.B. Berg. Potential interactions between Eurasian ruffe and round gobies in the Great Lakes: prey and habitat preferences. Annual Meeting of the North American Benthological Society, LaCrosse, WI. June 7, 2001. (NOTE: this presentation won the "Best Student Paper in Applied Research" at this conference)

Bauer, C.R., G.A. Lamberti, and M.B. Berg. Zebra mussels, round gobies, and Eurasian ruffe: Predicting ecological impacts of the 'exotic triad' to improve control. State of Lake Michigan Research Symposium, Muskegon, MI. November 6, 2001.

Bauer, C.R., G.A. Lamberti, and M.B. Berg. Potential interactions between Eurasian ruffe and round gobies in the Great Lakes: prey and habitat preferences. 11th International Conference on Aquatic Invasive Species, Alexandria, VA. February 26, 2002.

Bauer, C. R., G. A. Lamberti, and M. B. Berg. Eurasian ruffe, round gobies, and zebra mussels: Will the 'exotic triad' spell trouble for Great Lakes yellow perch? Annual Meeting of the International Association of Great Lakes Research, Winnipeg, Manitoba, Canada. June 3, 2002.

Undergraduates/Graduates

A total of 11 graduate and undergraduate students were supported in part or in whole by this project since 2001.

Students Supported at the University of Notre Dame:
Graduate students: Candice R. Bauer – Ph.D. candidate, Cynthia S. Kolar - Ph.D. candidate, Michelle Evans-White – Ph.D. student
Undergraduate students: Anthony Cak, Lindsay Goodwin, D. Barry Hester.
Alison Hodrick, Michael McDunough

Students Supported at Loyola University Chicago:
Graduate students: Holly Arrigoni - M.S. student, Kirby Wolfe - M.S. student
Undergraduate student: Grace Kilbane - current M.S. student at Ohio State University

Related Projects

Influence of marine nutrients from salmon on stream ecosystems. USDA – CREES National Research Initiative Competitive Grants Program, 1999-2002.
Consequences of round goby invasion for littoral zone communities: Effects on sculpins and benthic invertebrates. Illinois-Indiana Sea Grant College Program, 2000-2002.

Ecological forecasting and risk analysis of nonindigenous species: strategic optimization using a bio-economic approach. National Science Foundation, 2002-2007.

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Research Information

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