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NOTE

PASSING OF NORTHERN PIKE AND COMMON CARP THROUGH EXPERIMENTAL BARRIERS DESIGNED FOR USE IN WETLAND RESTORATION

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Abstract: Restoration plans for Metzger Marsh, a coastal wetland on the south shore of western Lake Erie, incorporated a fish-control system designed to restrict access to the wetland by large common carp (*Cyprinus carpio*). Ingress fish passageways in the structure contain slots into which experimental grates of varying size and shape can be placed to selectively allow entry and transfer of other large fish species while minimizing the number of common carp to be handled. We tested different sizes and shapes of grates in experimental tanks in the laboratory to determine the best design for testing in the field. We also tested northern pike (*Esox lucius*) because lack of access to wetland spawning habitat has greatly reduced their populations in western Lake Erie. Based on our results, vertical bar grates were chosen for installation because common carp were able to pass through circular grates smaller than body height by compressing their soft abdomens; they passed through rectangular grates on the diagonal. Vertical bar grates with 5-cm spacing that were installed across much of the control structure should limit access of common carp larger than 34 cm total length (TL) and northern pike larger than 70 cm. Vertical bar grates selected for initial field trials in the fish passageway had spacings of 5.8 and 6.6 cm, which increased access by common carp to 40 and 47 cm TL and by northern pike to 76 and 81 cm, respectively. The percentage of potential common carp biomass (fish seeking entry) that must be handled in lift baskets in the passageway increased from 0.9 to 4.8 to 15.4 with each increase in spacing between bars. Further increases in spacing would greatly increase the number of common carp that would have to be handled. The results of field testing should be useful in designing selective fish-control systems for other wetland restoration sites adjacent to large water bodies.

Key Words: coastal wetlands, common carp, fish-control system, grates, Great Lakes, northern pike, restoration

INTRODUCTION

Coastal marshes along the southern shore of western Lake Erie have long been important to fish, including game fish such as northern pike (*Esox lucius* L.), because they provide spawning, nursery, and feeding habitat (Herdendorf 1987). However, following European settlement of Ohio in the 1800s, those wetlands have been degraded and reduced in area due to human activities such as draining and filling, diking, increased nutrient loading, and introduction of exotic species, including common carp (*Cyprinus carpio* L.).

Northern pike were abundant in western Lake Erie in the early 1800s (Hartley and Herdendorf 1975). However, loss of accessible wetlands, increased turbidity, and decreased presence of aquatic plants have contributed to a large decrease in the northern pike population in western Lake Erie since 1900 (Trautman 1981). In the 1920s, most of the remaining coastal wetlands in western Lake Erie were diked to enhance managed production of aquatic vegetation and waterfowl. Hydrologic isolation of wetlands from the lake by diking further prevented recovery of northern pike populations, likely due to lack of access to required habitat (Johnson et al. 1997).

Common carp have been cited as creating management problems in diked wetlands (Robel 1961, King and Hunt 1967). They are able to enter these wetlands as fry that pass through pumps and gates when the wetlands are filled. Common carp increase in size and are unable to return to the lake. They then disrupt the diked wetlands through spawning, uprooting, and sediment-stirring activities (King and Hunt 1967, Herdendorf 1987).

Metzger Marsh, a 300-ha, lake-connected wetland located 48 km east of Toledo, Ohio, USA was heavily vegetated and protected from storm activity by a barrier beach prior to 1940. Storms during high lake-level periods in the late 1940s eroded portions of the barrier beach. Area of emergent marsh was greatly reduced following total loss of the barrier beach to erosion by wave action during a high lake-level period in 1973. By 1990, Metzger Marsh was an open water embayment with only scattered islands of *Typha* and *Phragmites* (Kowalski and Wilcox 1999). Loss of sediment supply due to extensive armoring of the Ohio shoreline of the lake made reestablishment of the barrier unlikely. In 1994, the Metzger Marsh Wetland Restoration Project was developed to provide improved habitat for wildlife. The initial plan was to construct a 2.4-km-long dike and manage water levels in an enclosed embayment that would lack characteristics of a lake-connected wetland. The plan was later revised to take an ecosystem approach that would provide broader habitat benefits; the dike therefore contains a water-control structure to restore hydrologic connection with Lake Erie following drawdown of water levels to allow reestablishment of vegetation from the seed bank. The physical setting of the restored wetland thus resembles a lake-connected wetland behind a protective barrier.

To address managers' concerns about common carp activity, the water-control structure includes a fish-control system. The structure is divided into five 2-m-wide channels that can be closed individually. Vertical bar grates with 5-cm-wide spacing were placed across three of the channels to restrict entry of large common carp into the wetland. The spacing between bars was based on similar work at Cootes Paradise marsh in western Lake Ontario (V. Cairns, Fisheries and Oceans Canada, Burlington, Ontario, pers. comm.). The remaining two channels were designed to serve as ingress and egress fish passageways; they contain slots into which experimental grates of varying design can be placed. These grates will allow movement of larger fish into the passageways, where they can be retrieved in a lift basket operated by an electric winch. After identification, enumeration, and measurement, large native fish such as northern pike, muskellunge (*Esox masquinongy* Mitchill), channel catfish (*Ictalurus punctatus* Rafinesque), and largemouth bass (*Micropterus salmoides* L.) will be released into the wetland (ingress) or into the lake (egress). Common carp captured at the ingress passageway will be released into the lake or harvested.

To maximize effectiveness of the fish passageways, the size and shape of openings in the experimental grates should maximize passage of native fish into the lift baskets while minimizing the number of common carp to be handled. The objective of this study was to test passage of common carp and northern pike through various grates in an experimental tank for the purpose of selecting the best size and shape grate opening to install in the fish-control system at Metzger Marsh and for potential use elsewhere. Northern pike were selected for testing because of concern about the decrease in their populations related to wetland access.

METHODS

Fish Used in Study

Five northern pike and 15 common carp were electrofished from Lake St. Clair and the Huron River in southeastern Michigan, USA in fall 1997 and spring 1998. Twelve small common carp (TL < 39 cm) were also purchased in July 1998 because we were unable to capture small fish from the lake or river. Each northern pike was held in a separate fiberglass tank (750 L) to avoid aggressive interactions among fish. As is often the case (e.g., Ogle et al. 1996), sample size for northern pike had to be kept small because this species is difficult to maintain in a laboratory setting. Common carp were held in two large fiberglass tanks (1000 L). Water was passed through all tanks at temperatures of 12 ± 1°C and continously aerated. The difference in water temperature between holding and experimental tanks was less than 1°C. Fish were placed in the experimental tank at least 24 hr prior to testing. Morphometric data were also collected from 23 northern pike (43.5–94.3 cm TL) at the Wolf Lake Fish Hatchery in Van Buren County, Michigan in March 1999. These fish were not available for testing.

Study Facility

Tests were conducted in a circular raceway (2.1-m outer diameter, 1.3-m inner diameter, 0.8-m height). Four types of removable grates were constructed from 1.2-cm-thick, fiberglass-resin-coated plywood (Figure 1). Pipes (21-mm-dia PVC) were fastened to plywood with tie cables to form vertical bar and rectangular barriers (Figure 1a,b). Opening sizes of these grates could be changed by adjusting the tie cables and pipes. The initial slit width between vertical bars was 5 cm, and rectangle size was 5 × 9 cm. Circular openings (Figure 1c) were 10.3 cm in diameter, which was about the same size as diagonals of the initial rectangular openings. Preference grates with two columns of circular (dia = 10.3 cm) and rectangular (5 × 9 cm) openings were constructed to determine preference of fish for passage (Figure 1d). Vertical bars were not used in preference grates because space on the grates

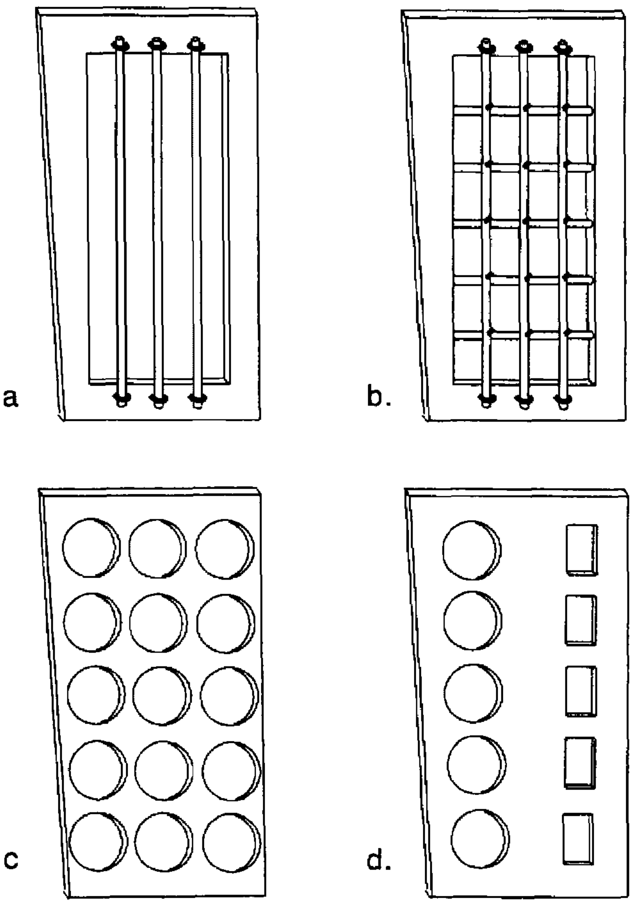

Figure 1. Types of barriers used to test northern pike and common carp movement in experimental tanks. a) vertical bar, b) rectangular, c) circular, and d) preference.

was limited. Square openings were not tested because fish could swim through on a diagonal (Webb et al. 1996).

The tank bottom was covered with white garden gravel. The top was covered with plastic screen to prevent fish from jumping from the tank. Flood lights were installed about 1 m above one side of the tank to stimulate northern pike to move to the dark side of the tank, which was shaded by a cardboard cover placed on the screen. A submersed water pump was placed in the raceway to maintain water movement and to stimulate movement of common carp from one side of the tank to the other.

Testing Procedures

After putting a northern pike or common carp into the raceway with vertical bar grates, videocameras were turned on and lights or pumps turned on gradually. Lights did not stimulate northern pike to swim to the dark side of the tank; water movement did not stimulate common carp movement. Therefore, a plastic pipe with 12-cm plastic disk attached was placed in the raceway behind the fish and moved toward them at a slow pace (about 10 cm/sec) to induce them to move to the barriers (Webb et al. 1996). Each passage by a fish through an opening or failure to pass through once was one trial. After a successful passage, the vertical bar grate was replaced by circular, rectangular, and then circular/rectangular preference grates. If a fish resisted passing through more grates, it was returned to the holding tank to await further testing with different opening sizes.

Because we had limited numbers of fish and not all incremental sizes of fish were represented, slit widths of the vertical bar grates were adjusted to determine the relationship between fish size and slit width that would allow passage. Slit widths were reduced by 0.5 cm after testing passage of fish through the initial width (5.0 cm). Each fish was retested with reduced slit widths at intervals of 0.5 cm until it failed to pass through the grate. Slit widths of vertical bar grates were increased at intervals of 0.5 cm for fish that failed to pass through the grate with slit widths of 5.0 cm. The narrowest passable slit width was recorded for each fish. For the rectangular grate, opening sizes were reduced by 1 cm for both width and height for successive tests. We found that soft abdominal bodies enabled some common carp to pass through the circular openings despite the fact that their body heights exceeded 10.3 cm. We then discontinued testing with the circular grates because they did not seem a likely choice for excluding common carp.

Fish were anesthetized with MS-222 after all testing was completed. Total and standard lengths, widths of body and head, and depths of body and head were measured to the nearest 1 mm with calipers.

When results indicated that the vertical bar grate was the best design for installation at Metzger Marsh, linear regression models were developed to determine the relation of fish body size to minimum slit width of the grate that allowed fish passage. A logistic regression model was also developed to estimate the proportion of common carp biomass that would be handled in the fish passageways at varying slit widths.

RESULTS AND DISCUSSION

Northern Pike

Five northern pike (TL = 49.4–58.0 cm) were tested in the experimental tank (Table 1). Fish #1 successfully passed through all three grate types and went through the circular opening of the preference grate. Fish #3 and #4 passed through the 5-cm vertical bars, 10.3-cm-dia circular grates, 5- × 9-cm rectangular grates, and through only the circular openings of the

Table 1. Measurements (cm) of northern pike (NP) and common carp (CC) and minimum slit widths of vertical bar barriers negotiated by these species.

Species	Total Length	Standard Length	Body Width	Body Depth	Head Width	Head Depth	Minimum Slit Width
NP #1	58.0	51.0	5.3	7.2	4.3	6.4	3.5
NP #2	52.7	47.2	5.0	6.6	4.2	5.6	3.5
NP #3	51.7	46.5	5.6	6.9	4.5	6.1	3.5
NP #4	50.0	43.3	4.9	6.4	4.0	5.6	3.0
NP #5	49.4	43.0	5.0	6.1	4.1	5.1	3.0
CC #1	49.8	41.2	7.0	11.7	7.1	8.2	7.0
CC #2	47.2	39.2	7.9	12.0	7.5	7.3	7.5
CC #3	47.0	38.5	7.1	11.3	6.7	7.7	6.5
CC #4	46.7	38.0	6.4	10.7	7.0	7.3	5.5
CC #5	45.0	37.0	6.9	11.1	6.9	6.6	6.5
CC #6	44.9	37.0	7.0	10.8	6.9	7.3	5.5
CC #7	44.1	35.5	6.3	9.8	6.1	6.8	6.0
CC #8	43.9	35.8	6.5	10.6	6.3	7.5	5.5
CC #9	43.9	35.7	6.4	10.3	6.6	7.2	6.0
CC #10	43.8	36.5	6.9	10.2	7.1	7.4	7.0
CC #11	43.8	35.4	7.1	10.8	7.0	7.2	6.5
CC #12	43.5	35.7	7.6	11.1	6.8	7.6	5.5
CC #13	43.4	35.2	6.8	10.6	6.6	7.2	6.5
CC #14	41.6	33.4	6.4	10.1	6.4	7.3	6.0
CC #15	39.5	32.2	7.3	10.5	6.5	7.0	6.5
CC #16	31.4	25.8	4.3	7.8	4.5	5.6	5.0
CC #17	30.1	25.9	4.3	7.1	4.3	5.2	4.0
CC #18	30.0	25.0	4.1	7.4	4.1	4.7	4.0
CC #19	29.6	23.9	4.7	7.4	4.5	4.6	5.0
CC #20	29.2	24.3	4.0	7.2	4.1	5.0	4.0
CC #21	28.9	23.7	4.1	7.0	4.3	5.0	4.5
CC #22	28.4	24.0	4.0	6.9	3.8	4.4	4.0
CC #23	28.0	23.4	3.8	7.0	4.1	4.6	4.5
CC #24	28.0	23.2	3.9	6.8	4.0	4.8	4.0
CC #25	27.5	22.8	3.6	6.8	3.8	4.7	4.0
CC #26	27.3	24.1	4.0	6.3	3.9	5.0	4.0
CC #27	26.0	21.0	4.1	6.1	3.7	4.0	3.5

preference grate. Fish #2 and #5 passed through the 5-cm vertical bars, but both refused to move after passing through the rectangular grates, so they were not tested on the preference grates.

Slit widths of vertical grates were reduced three times after successful passage by all northern pike. The narrowest slit width that all northern pike could pass through was 3.5 cm. The two smallest fish successfully passed through 3.0-cm wide slits (Table 1).

In testing of reduced rectangle sizes, all northern pike went through the 4- × 8-cm opening twice. Fish #4 managed to squeeze through the 3- × 6-cm opening once but resisted the second attempt. All other northern pike failed to pass through this smaller rectangle, even though fish #5 successfully passed through vertical bars of the same width. Reduction of the rectangular grate size was then discontinued.

Regression analyses on northern pike were limited by the small sample size, but they showed head width to be most correlated with ability to pass through the vertical grates. The relation between head width of northern pike (HW in cm) and minimum slit width (SW in cm) of vertical bar grates that they could pass through was $SW = 1.1(HW) - 1.5$ ($r^2 = 0.65$, $p = 0.099$). At a 10% confidence interval, this suggests that the 5-cm slit width may allow northern pike with head width of 5.9 cm to pass. However, since fish measurements do not commonly include head width, we converted head-width data to approximate total length using the regression $TL = 50(\ln HW) - 19$ ($r^2 = 0.87$, $p < 0.001$) derived from morphometric data from the 28 northern pike measured. Thus, the 5-cm vertical grate would likely allow northern pike with total length of 70 cm to pass.

Common Carp

All 15 common carp collected from the Huron River (TL = 39.5–49.8 cm) failed to pass through the 5-cm vertical bar grates, but one of them (#7; TL = 44.1 cm, body width = 6.3 cm, body depth = 9.8 cm) managed to squeeze through the 5- × 9-cm rectangular grate on a diagonal. Two common carp passed through the 10.3-cm-dia circular barrier despite their body depths of 11.1 and 11.3 cm exceeding the diameter of the openings (body width was not restrictive). Their soft abdominal area allowed compression of body height. As a result, we discontinued testing common carp with the circular grates and did not test them with the preference grates. We did not test common carp with the reduced 4- × 8-cm rectangular grates because they passed through larger rectangles on a diagonal and were likely too big to squeeze through this opening size.

The vertical bar grate with slit width of 5.0 cm excluded common carp down to at least 39.5 cm TL and allowed 12 smaller hatchery fish (TL = 26.0–31.4 cm) to pass through (Table 1). The smallest common carp (TL = 26.0 cm) successfully went through the narrowest slit width of 3.5 cm. Head width of common carp was positively correlated with minimum slit width of vertical bar grates (SW = 0.78(HW) + 0.98, $r^2 = 0.87$, $p < 0.001$, N = 27). However, total length of common carp was equally correlated with minimum slit width (SW = 0.13TL + 0.56, $r^2 = 0.81$, $p < 0.001$, N = 27). Therefore, we chose to use the total length regression directly to estimate common carp exclusion at varying slit widths because it required no conversion. This regression suggests that the 5-cm slit width will exclude common carp larger than 34 cm TL.

Selection of Grate Size for Installation

Rectangular grates were eliminated from consideration for installation in the fish-control structure at Metzger Marsh because common carp passed through them on a diagonal. Circular grates were also excluded because they relied on a vertical restriction to exclude common carp, which were capable of compressing vertically. With vertical bar grates thus selected, a decision was necessary on the optimum slit width that would reduce the number of common carp to be handled in the fish passageway and make management reasonable. This determination required knowledge of the size distribution of the common carp population in the Metzger Marsh region of western Lake Erie; those data have not been collected by natural resource agencies nor researchers in the region (D. Davies, Ohio Division of Wildlife, Sandusky, Ohio and D. Johnson, Ohio State University, Columbus, Ohio, pers. comm). However, studies of common carp populations in western Lake Ontario were conducted during pre-restoration activities at the Cootes Paradise marsh near Hamilton, Ontario, Canada (Randall et al. 1993). Similarities between wetland sites suggest that these size-distribution data might be useful in estimating the potential for common carp exclusion at Metzger Marsh. Biomass-distribution data across 5-cm fork length classes from 30 to 95 cm were provided by Victor Cairns, Fisheries and Oceans Canada, Burlington, Ontario (Figure 2). The passage of common carp through a vertical slit is a binary response (either the fish passed through the slit or it did not) and can be related to the size of the fish and the slit using a logistic regression model:

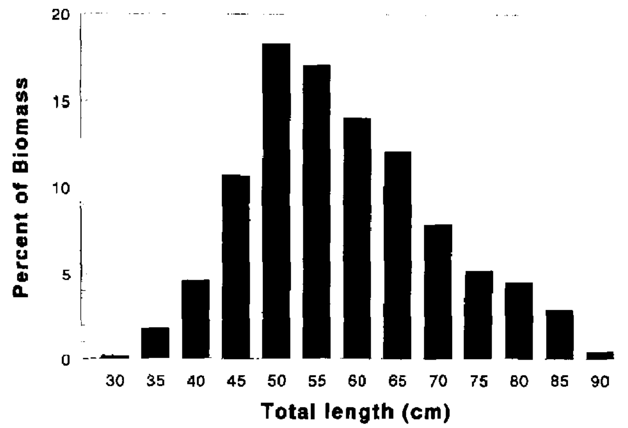

Figure 2. Distribution of common carp biomass by length group in Cootes Paradise Marsh, Lake Ontario. These fish were measured in cm fork length (FL) then converted to total length using a regression model, TL = 1.11FL − 0.56 ($r^2 > 0.99$, $p < 0.001$).

$$\log [P/(1 - P] = \beta_0 + \beta_1 \, TL + \beta_2 \, SW$$

where P is the probability of passage of common carp, TL is the total length of common carp, SW is the width of the vertical slit, and the βs are parameters to be estimated (Agresti 1990). The logistic regression model, fit to our data on 297 common carp and solved for P, was $P = 1/(e^{1 + 0.048TL - 0.38SW} + 1)$. Size-distribution data for common carp were then combined with the predicted probabilities of passage to estimate the proportion of common carp biomass (from population of fish seeking entry to the wetland) that would pass through the ingress grates at various slit widths (Table 2). Common carp biomass to be handled in the fish-control system increased from 0.9 to 4.8 to 15.4 percent with increases in slit widths from 5.0 to 5.8 to 6.6 cm and increased substantially at greater slit widths (Table 2).

Our study demonstrated that northern pike with TL from 49.4 to 58 cm could pass readily through vertical bar grates with 5-cm-wide slits. Because they are able to compress their width, northern pike up to 70 cm TL likely could pass through the grates that guard much of the water-control structure at Metzger Marsh. How-

Table 2. Maximum total length (cm) of northern pike and common carp that would pass through given slit widths and predicted percentage of biomass of common carp seeking entry into the wetland that would pass through vertical bar gates at Metzger Marsh.

Slit Width (cm) of Vertical Bar Grates	Maximum Total Length		Percentage of Common Carp Biomass
	Northern Pike*	Common Carp	
5.0	70	34	0.9
5.4	73	37	2.3
5.8	74	40	4.8
6.2	78	43	8.9
6.6	81	47	15.4
7.0	83	50	24.5
7.4	86	53	35.2
7.8	88	56	46.0

* Estimated total length based on head width.

ever, northern pike >70 cm likely need a wider space (>5.0 cm) between bars in the experimental grates to allow them to enter the fish passageways and be transferred into the wetland. Our study suggests that vertical bar grates with a 5.8-cm slit width would potentially allow northern pike up to 76 cm TL (converted from head width) to enter the fish passageways while continuing to restrict common carp entry to less than 5% of total biomass of the fish seeking entry (Table 2).

Grates were installed in the Metzger Marsh fish-control system for initial field testing in 1999. Since larger northern pike and other large fish may be seeking entry into the wetland also, field trials also began in 1999 using 6.6-cm vertical bar grates, which could allow access of northern pike up to 81 cm TL. Total common carp biomass to be handled would likely increase to about 15% of the fish seeking entry to the wetland. Depending on initial results, larger grate sizes may be tested in 2000. Final determination of grate size for routine use will depend on trade-offs between actual increases in access by larger native fishes and the practicality of handling greater numbers of common carp. The practical results of field trials, coupled with the results of these laboratory tank experiments, will also be useful in decision-making at other sites in Lake Erie, other lakes, and large rivers where management concerns dictate allowing fish access to diked wetlands while restricting common carp access.

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