

# Under-Ice Observations of Behavior of Selected Native and Exotic Fishes of the St. Lawrence River System

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Winter behavior of two native fishes (yellow perch, *Perca flavescens*, and killifish, *Fundulus heteroclitus*) and an exotic (goldfish, *Carassius auratus*) were studied in an outdoor experimental pond to quantify and link behavior to environmental conditions, and to identify interactions among the species that now co-occur in the wild. Killifish had high mortality and were not observed. However, contrary to our predictions, perch and goldfish had good overwinter survival and remained active in winter, and neither species spent most of their time in the warmest layer of the water column. Only two instances of aggression were seen: in both, goldfish charged perch. Both species were found principally in groups (schools); goldfish spent 18% of their time in multispecies groups.

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**Key words:** fishes, winter behavior, exotic species

## INTRODUCTION

Winter in temperate areas is a critical period for many animals [Dratnal and Davies, 1990; Marchand, 1987; Olsson, 1988; Ultsch, 1989; Whoriskey et al., 1990]. For fishes it is a time of reduced food availability and high mortality [Johnson and Evans, 1991]. Cold temperatures impair muscle contraction [Crawshaw, 1984], presumably restricting the activity of these poikilotherms. The ice and snow cover limit light penetration and block transfer of oxygen from the atmosphere to the water. Oxygen continues to be extracted from the water by biological and chemical processes, and this can result in low oxygen levels and periods of respiratory distress [Klinger et al., 1982]. Winter ponds typically show inverse thermal stratification with relatively warm (4°C) temperatures occurring near the bottom and temperatures decreasing to near 0°C beneath the ice surface [Wetzel, 1983]. These stresses are

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predictable, and temperate fishes have evolved life history strategies to cope with them [e.g., Fox and Keast, 1991; Hall and Ehlinger, 1989; Tonn and Magnuson, 1982]. Despite this, winterkills can occur when conditions become too severe [Magnuson and Karlen, 1970; Ultsch, 1989]. Flexible behavior is often an organism's first defense against unfavorable environmental conditions [Hocutt et al., 1982].

It is hard to observe fish behavior under an ice cover. Previous behavioral studies of fish in winter have relied on simulated conditions in the laboratory [Klinger et al., 1982; Petrosky and Magnuson, 1973], have been limited to qualitative observations [Magnuson and Karlen, 1970], or have sent divers into the habitat for brief periods [Cunjak, 1988; Emery et al., 1972]. This last approach may disturb the fish [Cunjak, 1988; Cunjak and Power, 1986].

The objectives of this study were to unobtrusively document and quantify winter behavior and observe group structure of three fishes of the St. Lawrence River system. We worked with two native species: the yellow perch (*Perca flavescens*), a winter-active, spring-spawning omnivore that is a dominant component of the fish fauna and sport fisheries of the St. Lawrence river system in Quebec [Ney, 1978; Scott and Crossman, 1973]; and the banded killifish (*Fundulus heteroclitus*), a common inshore planktivore/insectivore of which little is known [Scott and Crossman, 1973]. Goldfish (*Carassius auratus*), a spring and summer-spawning aquarium fish and a recent invader that is interacting with native aquatic species of the Montreal area [Richardson, 1991] were also studied. They are omnivorous, feeding on invertebrates, plants, and detritus. Popular magazines advocate goldfish release into swimming pools at the start of the winter to clean up the autumn fall of leaves [Anon., 1992], suggesting that they are winter active. They may compete with native species for food [e.g., Roy, 1992] but can be vulnerable to winterkills [Richardson, 1991].

We used a specially constructed outdoor pond with a central viewing chamber to observe the winter behavior of these species. The facility permitted observation under natural conditions and minimized the possibility of the escape of the exotics. We predicted that perch, killifish, and goldfish would have high overwinter mortality and would spend most of their time inactive, resting in shelter. Given the potential for winter food shortages, we also predicted that the larger yellow perch would aggressively dominate goldfish in order to maintain first access to food and shelter. Goldfish in the laboratory are known to shoal, in part because members of a shoal find food faster [Pitcher et al., 1982]. We also predicted that we would find goldfish primarily in shoals in the winter and that they would shoal with the killifish and thus opportunistically exploit the native species' food-finding ability. We predicted that all species would seek out the warmest (most comfortable) pond sections and would avoid oxygen-poor layers.

To evaluate these predictions, we (1) recorded the overwinter survival and growth of three replicate "communities" composed of the three species; (2) recorded the behavior and compared the activity budgets of the fishes; (3) compared the fishes' occurrences in single or multispecies groups; and (4) monitored environmental conditions in the pond throughout the study period, to correlate them with fish behavior.

The pond was divided into four sections. Three of them provided replicates for our work, whereas the fourth was a focus for a trial exhibit that displayed the fishes under study and interpreted the research work to the public.

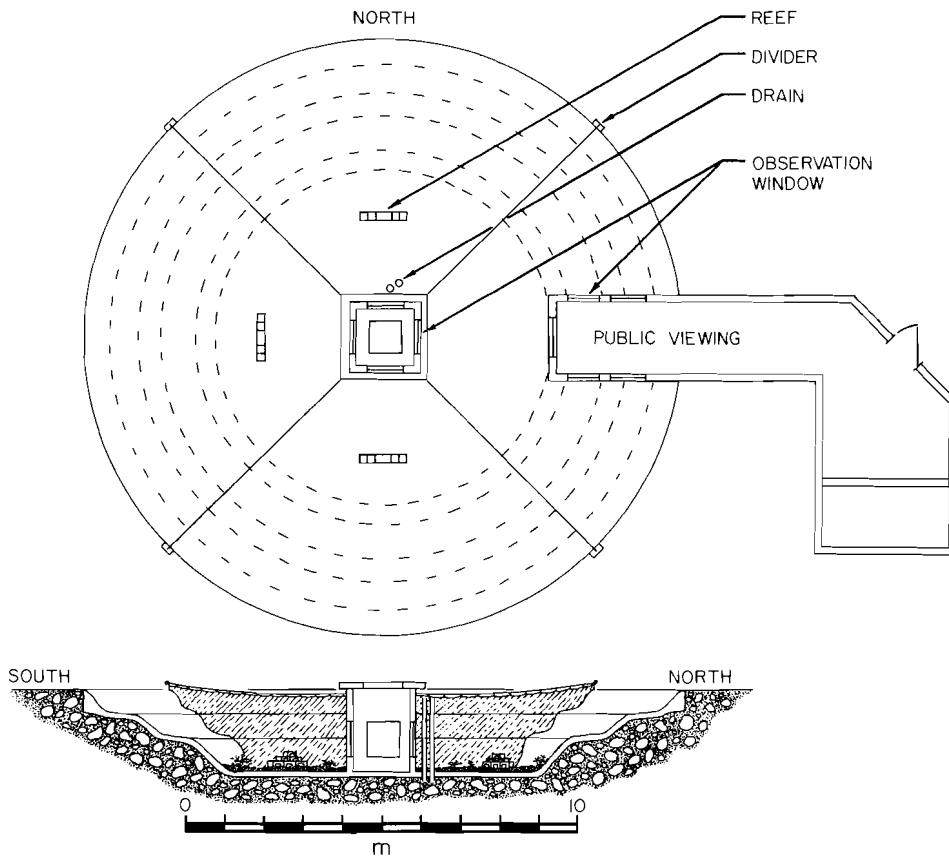


Fig. 1. The study pond. Replicate communities were placed in the three sections having artificial reefs.

## METHODS

The study was performed from December 6, 1990 to April 7, 1991, in an experimental facility located at the St. Lawrence Valley Natural History Society Ecomuseum, in Ste. Anne-de-Bellevue, Quebec. The pond (Fig. 1) was 15 m in diameter and had a maximum depth of 2 m. A layer of Ste. Rosalie clay, the typical sediment of ponds and rivers in the area, overlaid the substrate. The sides sloped upward and were terraced at depths of 0.66 and 1.3 m. A 2 × 2-m observation chamber with glass windows (0.88 × 0.88 m) on each face permitted the underwater observations. Water inflow was limited to runoff from the land immediately surrounding the pond. A standpipe drain kept water levels from rising over the pond lip.

The pond was partitioned into four equal sections with a 7-mm mesh nylon seine netting. Replicate experiments were run in three sections. The fourth section was accessible to the public through an underground corridor (Fig. 1). No attempt was made to collect data on fish behavior from this section because it could be disturbed by the movements of people and by occasional tapping on the windows. Instead we displayed the fishes under study, and the observer at work was also visible through the windows. Information on the goals of the experiment in progress and the species

under study were posted along the walls in the access corridor and also explained to visitors by our guides. The end result was that the experiment and the scientist both became part of the exhibit, and the exhibit could change when the experiments changed.

A reef of six cinder blocks (Fig. 1) was placed 1.6 m in front of each viewing window, providing shelter. The pond was filled and left to stand for 6 months before we introduced the fish, permitting colonization by phytoplankton, zooplankton, and insect populations. We did not quantify these populations.

The yellow perch and killifish were seined from Lac St. Louis (an enlargement of the St. Lawrence River near Montreal), and goldfish were purchased from local pet stores. We believe local feral goldfish populations result from pet releases. Prior to stocking, all the fish were held in a temperature control room whose photoperiod and temperatures ( $\pm 1^\circ\text{C}$ ) were continually adjusted to match outside conditions. Goldfish were acclimated by reducing the temperature  $1^\circ\text{C}/\text{day}$  until the pond's temperature was reached. They and the wild fish were then held at this temperature for 2 weeks and released to the pond in early December.

Prior to stocking, all fish were measured (total length, T.L.); then goldfish and yellow perch were fin clipped, which permitted the identification of individuals during behavior observations. The killifish, being small and numerous, were not individually marked. Three large perch ( $18.5 \pm 2.2$  cm T.L.), four small perch ( $11.7 \pm 1.2$  cm T.L.), seven goldfish ( $10.8 \pm 0.9$  cm T.L.), and 60 killifish ( $4.6 \pm 0.8$  cm T.L.), were placed into each of the three replicate sections.

Sightings of fish could be patchy due to variable water clarity and a few "blind zones" which could not be observed from the observation chamber windows. Trial observations showed behavior bouts were of long duration and that individual instantaneous samples gave good approximations of true time budgets [Pöysä, 1991]. Therefore, we adopted a scan sampling method to follow behavior of as many individuals as possible [Altmann, 1974]. We recorded the behavior of all visible individual fish in each chamber at one minute intervals during each 30-min observation period. Two 30-min observations were made per chamber each week, once in the morning and once in the afternoon. Morning and afternoon samples were done on different days. Individuals were seen in 1–30 scans during the observation periods. We recorded:

*Reef use:* Any activity (e.g., swimming to/from, feeding, and resting upon), within 0.5 m of the reef.

*Water column position:* Fish recorded as being either at the surface (the zone from the ice surface to a depth of 0.6 m), the bottom (the area from the substrate to a height of 0.6 m), or in the mid-water column (the area between the surface and bottom zones).

*Hovering:* remaining in the same place in the water column.

*Swimming:* active displacement by beats of the caudal fin.

*Feeding:* Seizing of food items from the pond bottom, the reef substrate, or the water column.

*Shoaling:* two or more fish within 50 cm of each other moving in tandem and engaged in the same behavior (number and species of fish in the shoal also recorded).

*Aggression:* bites, chases, lunges, and displays by one fish toward another.

Following the behavior observations, snow and ice thickness over each section were recorded. A 16 cm diameter hole was drilled with an ice auger to measure water temperature and oxygen concentration (YSI model 57 oxygen meter, which also has a thermistor) at the surface (10 cm below the ice/water interface), and in the mid-water (1m depth) and bottom (10 cm from the substrate) zones. Water samples were obtained at a depth of 1m, and filtered, the filter was placed in chilled ethanol for 24 hr, and the extract was read in a spectrophotometer to determine chlorophyll-a content, following Marshall and Peters [1989]. This provided an estimate of primary production in the pond in winter.

Immediately after the spring ice melt, the pond was drained and all remaining fish recovered. They were counted, remeasured, and weighed. Specific growth rates (SGR) were calculated as  $SGR = \ln(\text{final length}) - \ln(\text{initial length})/t$ , where length was measured in mm and  $t$  is the time in days. Condition factors (K), a measure of fish body condition, were computed as  $K = (W * 100)/L^3$ , where  $W$  is body mass in g and  $L$  is fish length in cm. Values  $>1$  generally indicate fish are healthy.

## STATISTICAL ANALYSES

Temperature, snow cover, ice cover, oxygen, chlorophyll-a, and fish behavior patterns did not differ significantly among the three replicates (Kruskal-Wallis ANOVAs,  $P > 0.10$ ), so observations were pooled for the analyses. Nonparametric statistics were used because of a lack of normality and homogeneity of variance in the data and our failure to find a suitable transformation. For these reasons, we report median values and ranges. Specific statistical tests used are given with the results. Significant differences ( $P < 0.05$ ) detected by Kruskal-Wallis ANOVAs were followed by a multiple comparison test [Conover, 1980]. Mann-Whitney U-tests were used for two sample comparisons, and Kendall's  $\tau$  for correlations. Where behavior of small and large perch were similar (Mann-Whitney U-test,  $P > 0.05$ ), data were pooled for comparison with the goldfish.

## RESULTS

### Environmental Conditions

Pond ice thickness grew steadily throughout the winter, achieving its maximum in late February (Fig. 2). By contrast, snow cover was variable and peaked in early January. An inverse thermal stratification occurred, with warmest temperatures found at the pond bottom and coolest temperatures just below the ice surface (Fig. 2). Pond oxygen concentrations gradually decreased to a minimum of 4.3 mg/L by late February (Fig. 2). Two chlorophyll-a concentration peaks were observed: one in mid-January, and another at the beginning of March. There were no significant correlations between fish behavior and depth of snow cover, depth of ice cover, depth of snow and ice cover, date from the start of the study, temperature, chlorophyll-a concentration or oxygen levels (Kendall's  $\tau$   $P > 0.10$ ). This indicates that environmental trends did not strongly influence behavior. Hence, data from all sessions on all dates were pooled for individual fish in order to calculate time budgets for the winter period. Subsequent behavior analyses treated individual time budgets as replicates.

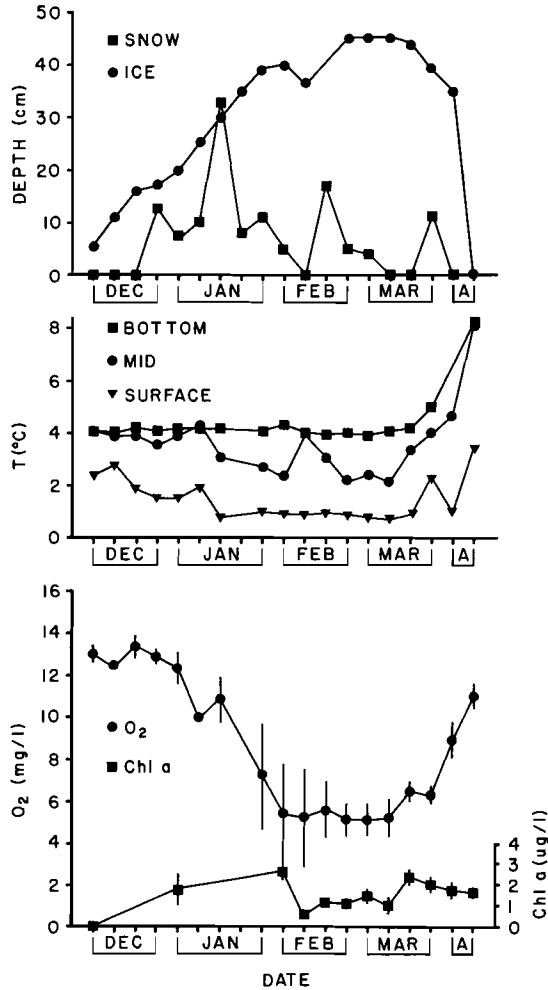


Fig. 2. Snow and ice cover, water temperatures measured at the surface, middle, and bottom of the water column, and oxygen and chlorophyll-a (Chl a) concentrations in the pond in winter.

### SURVIVAL AND GROWTH

High overwinter survival rates were observed for large perch (67%, 6 of 9 fish stocked in the three pond sections were recovered), small perch (75%, 9 of 12 fish recovered), and goldfish (81%, 17 of 21 fish recovered). By contrast, only 2% (3 of 180 fish recovered) of the killifish successfully overwintered.

Individual growth (in length) observed over the study period for all species was negligible. Median values were 0.001 mm/day, 0.002 mm/day, and 0.001 mm/day for large yellow perch, small yellow perch, and goldfish, respectively. However, final condition factors for surviving fish were good, with median values of 1.23 (range 1.12–1.49), 0.96 (range 0.83–1.04), and 1.23 (range 0.87–1.16) for large perch, small perch, and goldfish, respectively.

**TABLE 1. Median values for percentage of time spent by fishes in different strata of the water column\***

Depth	Large perch	Small perch	Goldfish	<i>P</i>
Surface	0.6	0	0	NS
Mid-column	78.4 <sup>a</sup>	54.0 <sup>a</sup>	93.8 <sup>b</sup>	<0.05
Bottom	20.0 <sup>a</sup>	46.1 <sup>b</sup>	0 <sup>c</sup>	<0.05

\*Medians in a row marked with different letters differ significantly; Kruskal–Wallis ANOVA, followed by a multiple comparison test.

## BEHAVIOR

The killifish were never seen from our central chamber, hence the absence of quantitative behavior data for them. Before the first snowfall, we glimpsed their shoals just below the ice surface. They stayed in the shallowest water near the shoreline around the perimeter of the pond. This anecdotal evidence suggests that the species remains in shallow water in winter and follows the ice downward as it develops. Diatoms and zooplankton are reported to be abundant near the ice–water interface in lakes [Wetzel, 1983]. Remaining results concern the behavior of the perch and goldfish.

## WATER COLUMN PREFERENCE

Both perch and goldfish apparently avoided the cold zone beneath the ice surface, spending less than 1% of their time there, and instead concentrated their activity in the midwater zone (Table 1). Goldfish spent significantly more time in the mid-water column than both the small and large perch (Kruskal–Wallis ANOVA  $P < 0.05$ , followed by a multiple comparison test). Small perch also tended to use the midwater zone less than the large perch (Table 1, multiple comparison test,  $P < 0.10$ ).

Small perch were found significantly more frequently near the bottom than the large perch, and both size classes used this area significantly more than goldfish (Kruskal–Wallis ANOVA, followed by a multiple comparison test,  $P < 0.01$ , Table 1).

## REEF USE

Both species spent less than 19% of their time associated with the reef. Large perch (18.3% of time, range 0–59.5%) and goldfish (4.3% of time, range 0–55.0) had similar patterns of reef use; both groups were significantly more reef oriented than the small perch (0% of time, range 0) (Kruskal–Wallis ANOVA  $P < 0.01$  followed by a multiple comparison test).

## ACTIVITY

Swimming was the largest component of the time budgets of large perch, small perch, and goldfish. Small and large perch did not differ significantly in the time they spent swimming or hovering (Mann Whitney U-test,  $P > 0.05$ ), so the data were pooled for comparison with the goldfish. Goldfish swam significantly more

**TABLE 2. Median percentage of time spent in different activities by species\***

Activity	Perch		Goldfish	<i>P</i>
	Large	Small		
Feeding	2.2 <sup>a</sup> (0–9.9%)	14.7 <sup>b</sup> (5.1–47.4%)	8.0 <sup>b</sup> (2.6–83.2%)	<0.05
Resting	15 <sup>a</sup> (0–59.5%)	0 <sup>b</sup> (0%)	0 <sup>b</sup> (0%)	<0.05
Hovering		40 <sup>a</sup> (9.9–65.5%)	5.9 <sup>b</sup> (0–53.8%)	<0.05
Swimming		45.6 <sup>a</sup> (15.8–75.4%)	76.5 <sup>b</sup> (22.8–92.6%)	<0.05

\*Ranges are given in parentheses. Data on hovering and swimming by small and large perch did not differ significantly and were pooled for comparison with goldfish.

Medians in a row marked with different letters differ significantly (Kruskal-Wallis ANOVA, followed by a multiple comparison test).

(Wilcoxon–Mann–Whitney U-test  $P < 0.05$ , Table 2) and hovered significantly less (Wilcoxon–Mann–Whitney U-test  $P < 0.01$ ) than the perch. Both species fed infrequently (less than 15% of the time budget). Goldfish and small perch spent similar amounts of time feeding, and both fed more than the large perch (Table 2). Resting was observed only for large perch, and occupied 15% of their time. Aggressive interactions were observed on only two occasions, when goldfish charged small perch. No courtship activity was evident for either species, despite the fact both are early spring spawners.

## GROUPING PREFERENCES

The median value of time spent alone was similar for both goldfish and perch [Kruskal–Wallis ANOVA,  $P > 0.05$ ; large perch 33.9% (range 13.3–59.4%), small perch 23.7% (5.3–47.6%), and goldfish 23.5% (0–62.5%)]; however, both species spent significantly more time (Mann–Whitney U-test,  $P < 0.05$ ) shoaling than alone. Large perch, small perch, and goldfish spent similar amounts of time in conspecific shoals (59.4%, range 33.3–84.6; 72.6%, 47.6–78.9; and 52.8%, 32.5–94.1 of time budgets, respectively, Kruskal–Wallis ANOVA  $P > 0.05$ ). However, goldfish were observed in mixed species shoals significantly (Kruskal–Wallis ANOVA,  $P < 0.05$ ) more often (18.2% of time, range 2.8–35.3%) than the large (4.4% of time, range 0–20.6%) and small perch (2.3% of time, range 0–15.8%). Median size of perch shoals was three individuals (usually one large and two small perch), whereas goldfish and mixed species shoals were composed of three and four (one large perch, one small perch and two goldfish) fish, respectively.

## DISCUSSION

Contrary to our predictions, overwinter survival for perch and goldfish were good. By contrast, the killifish did very poorly. Large perch can be piscivores [Craig, 1987], and the killifish may have been eaten during the winter. However, we never

observed predation. Killifish have a short life span [about 2 years, Scott and Crossman, 1973], and it is also possible that they died of natural causes. We did not find any dead fish in the pond when we drained it. Goldfish and perch may have done well because environmental conditions remained favorable. Oxygen concentration decreased but did not fall below a value of 4.3 mg/L. Neither species is stressed at these levels [Petrosky and Magnuson, 1973; van den Thillart et al., 1983]. By contrast, a feral goldfish population died out in a local pond that became anoxic [Richardson, 1991]. Although little growth occurred, body condition was good at the end of the study, suggesting that the fish obtained sufficient food to meet energetic demands, and did not exhaust winter food reserves as has been observed at some field sites [e.g., Newsome and Leduc, 1975].

The chlorophyll-a data suggest that primary productivity was high despite the snow and ice cover and short daylengths. Our peak winter values of chlorophyll-a were similar to summer levels of Quebec lakes (0.3–27 mg/L) [Rasmussen, 1988]. Feeding goldfish take up and spit out mouthfuls of sediments into the water to isolate invertebrate prey [Richardson and Whoriskey, 1992]. This process may release nutrients which promote algae growth. Goldfish introduced into these ponds could foster winter blooms and high algal respiration rates which could contribute to the oxygen depletion and stress native fish [e.g., Petrosky and Magnuson, 1973].

Contrary to our predictions, the fish remained active in winter. However, we had a subjective impression that swimming speeds of both species were reduced compared to those of warmer times, although we had no way to measure this. Except for the large perch, there was relatively little resting and/or hiding in the reef. By contrast, Johnson and Evans [1991] found that young perch sought cover and remained quiet in simulated winter conditions in laboratory tanks. We do not know why large fish would seek refuge more than small ones. Generally, fishes of all sizes are attracted to the safety offered by any sort of cover, especially reefs [Johnson and Stein, 1979].

Instead of searching out the deep, warm layer, as we predicted, the fish preferred the mid-water column with the intermediate temperature. This may be, at least in part, an energy conservation strategy. Johnson and Evans [1991] found perch starved at 2.5°C, depleted energy reserves more slowly, and lived longer than those held at 4°C. Food availability declines in winter, and fishes surviving off stored energy reserves could reduce energetic demands by seeking out colder temperatures.

Goldfish and perch were most frequently seen in multispecies schools. Hasler [1945] inferred from gill net captures that perch schooled in nature in winter. By contrast, Petrosky and Magnuson [1973] simulated winter conditions and found that perch spent little time in groups, although grouping increased as oxygen concentration decreased. Our results support Hasler's [1945] contention. Only goldfish spent large periods of time (a median value of 18%) shoaling with heterospecifics. Casual observations indicated that in the first week after we introduced the goldfish to the chambers they schooled with perch at all times. Perch were never observed behaving aggressively to goldfish, and it is unclear why the two species eventually segregated into primarily monospecific schools. Perhaps the goldfish initially grouped with the native species until they became familiar with the habitat, at which point they reverted to associating principally with conspecifics. An ability to learn from native species could facilitate an exotic's invasion.

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