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Experimental and field evidence of behavioural habitat selection by juvenile Atlantic *Acipenser oxyrinchus oxyrinchus* and shortnose *Acipenser brevirostrum* sturgeons

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The present work reports behavioural responses by young-of-the-year (21–30 cm) Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus* and shortnose sturgeon *Acipenser brevirostrum* to nine binary combinations of dissolved oxygen saturation (40, 70 and 100%), temperature (12, 20 and 28° C) and salinity (1, 8 and 15). Both species showed no acclimation effects and similar discrimination and avoidance reactions to hypoxia (40% oxygen saturation), selecting higher dissolved oxygen choices in 71% of the tests. *Acipenser oxyrinchus oxyrinchus* and *A. brevirostrum* showed a similar preference for 20° C (>64% incidence), but differed in their responses to extreme temperature choices. *Acipenser brevirostrum* showed a significant avoidance behaviour to the 12° C but not to the 28° C choice. In contrast, *A. o. oxyrinchus* showed similar preference for 12 and 20° C, but avoided the 28° C choice in 71% of the tests where this temperature was included ($P < 0.01$). No significant preferences were observed among salinity choices, except between salinities 1 and 8, where *A. o. oxyrinchus* showed a significant preference for salinity 8. Behavioural responses matched expectations from bioenergetics in both species and were also consistent with the distribution of juvenile *A. o. oxyrinchus* capture locations in the Chesapeake Bay.

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INTRODUCTION

An implicit assumption commonly present in habitat suitability models is that fishes select physiologically optimal water quality conditions. Following this view, pioneering suitability models were developed by relating observed fish distribution and explanatory variables measured in the field (Terrel *et al.*, 1982). In more recent years, semi-mechanistic approaches based on laboratory responses and bioenergetics models have been used to predict habitat suitability for several species (Coutant, 1987; Brandt & Kirsch, 1993; Mason *et al.*, 1995; Braaten *et al.*, 1997). Thus, it has been possible to hindcast and forecast the effects of past and potentially new environmental changes upon habitat suitability in declining fish populations, for which

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distribution data might be scarce or non-existent (Niklitschek & Secor, 2005). This is the case for Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus* Mitchill and short-nose sturgeon *Acipenser brevirostrum* LeSueur populations inhabiting estuaries in the mid-Atlantic Bight of North America (Niklitschek & Secor, 2005; Woodland *et al.*, 2009).

Regardless of the approach used to generate habitat suitability models, a critical question in their application (*e.g.* for identifying and protecting essential fish habitat) is whether fish distribution and water quality relationships result from higher mortality rates in suboptimal areas, from active (behavioural) selection of optimal habitat or from a combination of both. Under the null hypothesis of no selection and random distribution, mean population production rates should be lowest due to increased mortality and reduced growth that occur in suboptimal areas. A similarly undesirable situation would occur if fishes actively selected and concentrated in optimal water quality habitats, ignoring density-dependent limiting factors, such as relative prey abundance. Under a third scenario, fish behaviour would be conditioned to balance water quality and foraging opportunities, leading to an energetically optimal population distribution (Wildhaber & Crowder, 1998).

Experimental evidence that fishes can discriminate and select physiologically optimal conditions exists for a range of species and systems. Laboratory and field studies show evidence for selection of temperature (Coutant, 1977; Jobling, 1981), salinity (Girsa *et al.*, 1980; Cardona, 2000; Edeline & Elie, 2004), dissolved oxygen (Khakimullin, 1987), temperature and salinity (Webster & Dill, 2006) and temperature and dissolved oxygen interactions (Schurmann & Steffensen, 1992). Optimal temperature and salinity levels have been interpreted as those at which growth (Jobling, 1981) or food conversion (Larsson, 2005) are maximized. While there is no equivalent concept of optimal dissolved oxygen conditions, for several species studied, individuals have been shown to select for dissolved oxygen levels that sustain a sufficient metabolic scope for growth and activity (Kramer, 1987; Borowsky, 1988; Burleson *et al.*, 2001).

Active selection of optimal physical and chemical habitat is, however, not always the case, and mismatches between behavioural selection and physiological expectations are not uncommon in the literature. Lack of behavioural response to non-lethal hypoxia can be observed when changes in physiology, activity or other compensatory mechanisms are present (Kramer, 1987). Selection of optimal water quality conditions can be subordinated to other environmental and biological factors, such as prey (Rahel & Nutzman, 1994; Bevelhimer, 1996; Krause *et al.*, 1998; Webster *et al.*, 2007) or refuge availability (Bevelhimer, 1996), season of the year (Mortensen *et al.*, 2007), reproductive stage (Wallman & Bennett, 2006), substratum (Peake, 1999) or density-dependent mechanisms (MacCall, 1989).

While the relative importance of physico-chemical, trophic or other habitat selection clues can change among species and ecosystems, the existence of sublethal thresholds at which behavioural responses to abiotic variables predominate can be expected. Thus, most tested fishes have shown behavioural avoidance of lethal temperature (Richardson *et al.*, 1994; Tsuchida, 1995; Mackenzie-Grieve & Post, 2006) and deleterious low dissolved oxygen levels (Stott & Cross, 1973; Matthews & Hill, 1979; Stott & Buckley, 1979; Ogilvie, 1982; Khakimullin, 1987; Breitburg, 1992, 1994; Weltzien *et al.*, 1999; Wannamaker & Rice, 2000; Burleson *et al.*, 2001; Hasler *et al.*, 2009). Integrating these escapement responses with habitat selection

behaviours is then needed to understand and predict fish distribution in nature, particularly across ecotones and degraded habitat conditions.

In the present work the hypothesis that juvenile acipenserids select physiological optimum water quality conditions as predicted by previous habitat suitability studies (Niklitschek & Secor, 2005; Woodland *et al.*, 2009) is tested. Thus, a series of choice experiments were conducted to assess the ability of juvenile *A. o. oxyrinchus* and *A. brevirostrum* to discriminate and select between different combinations of temperature, dissolved oxygen and salinity levels, which they would be expected to encounter in temperate North American estuaries. Results were then compared with predicted growth rates from multi-variable bioenergetics models (Niklitschek & Secor, 2009a; Woodland *et al.*, 2009) and observed distribution of juvenile *A. o. oxyrinchus* in the Chesapeake Bay.

MATERIALS AND METHODS

Experimental fishes were hatchery-produced *A. brevirostrum* ($n = 49$, 21–28 cm total length, L_T) and *A. o. oxyrinchus* ($n = 57$, 22–30 cm L_T). *Acipenser brevirostrum* individuals were Savannah River (32° 02' N; 80° 48' W) progeny, provided by the U.S. Fish and Wildlife Service (USFWS) Bear's Bluff Laboratory (South Carolina). *Acipenser o. oxyrinchus* were Hudson River (40° 42' N; 74° 02' W) progeny, provided by the USFWS Northeast Fishery Center (Lamar, PA). Experimental stocks were held in 2000 l circular tanks at salinity 8, 20° C and >80% oxygen saturation. Fish handling followed a vertebrate animal care protocol (S-CBL-99-01), approved by the University of Maryland Center for Environmental Science.

Fishes were divided and acclimated 10 days before experiments started in three temperature groups: 12, 20 and 28° C, two dissolved oxygen saturation groups: 50 and 100% and three salinity groups: 1, 8 and 15 (Table I). These nine binary combinations of salinity, temperature and oxygen saturation were then tested on each fish (Table II), following a random sequence of treatments. A minimum of 48 h resting period was given to each individual for recovery between subsequent tests.

Behaviour experiments were conducted in a choice chamber designed as two converging raceways (Fig. 1). Each raceway head was supplied with a constant water flow of 3.8 l min⁻¹ from two head tanks where temperature, dissolved oxygen and salinity were controlled to meet experiment specifications (Table II). The chamber maintained a strong gradient between raceways, which declined towards the holding cell. Water depth was kept between 5 and 8 cm. Although qualitative evaluations using commercial dye indicated a laminar flow for most treatments, three airlifts had to be set in sections of the chamber arm to avoid thermal

TABLE I. Acclimation groups used in behaviour experiments with *Acipenser oxyrinchus oxyrinchus* and *Acipenser brevirostrum* juveniles

Temperature (° C)	Salinity	Dissolved oxygen (%)	<i>Acipenser oxyrinchus oxyrinchus</i>	<i>Acipenser brevirostrum</i>
12	8	50	6	7
		100	11	11
20	1	100	6	7
		50	6	10
		100	8	11
28	15	100	6	6
		50	4	4
		100	6	4

TABLE II. Experimental conditions and choices provided to individual *Acipenser oxyrinchus oxyrinchus* and *Acipenser brevirostrum* in behavioural experiments

Controlled variable	Test variable	Choice 1	Choice 2
T = 20° C DO _{sat} > 95%	Salinity (Sal)	1	8
		8	15
		1	15
Sal = 8 DO _{sat} > 95%	Temperature (T)	12° C	20° C
		12° C	28° C
		20° C	28° C
Sal = 8 T = 20° C	Dissolved oxygen (DO _{sat})	40%	100%
		40%	70%
		70%	100%

stratification. Experimental conditions (choices) were randomly allocated between chamber raceways. A binomial test conducted on the pooled data set (including treatments as covariates) indicated no significant preference for any of the chamber raceways for both species.

During each experiment, individual fishes were transferred from their acclimation tank to the choice chamber and left to rest for ≥ 30 min in the holding cell. The fish was then released and allowed to swim freely along the choice chamber, and its relative position recorded every 1 min. After 30–45 min fishes tended to become sedentary. Experiments were terminated when the fish remained in a given section for > 5 min, the time at which the selected raceway and section were recorded. The fish was then removed and water quality measured along all chamber sections. If selection was not observed within 60 min, the experiment was recorded as failed.

Results were analysed using logistic regression through a generalized linear mixed models (GLMM) approach (Littel *et al.*, 1996). Thus, main effects of salinity, temperature, dissolved oxygen treatments and acclimation effects were tested, and correlation between repeated observations within individuals explicitly modelled. This GLMM is described by the expression: $\ln[p_i(1 - p_i)^{-1}] = X\beta + Zu + e$, Where p_i = probability of selecting choice i , X = fixed effects matrix (species, acclimation group, binomial test), β = fixed effects coefficients, Z = random effects matrix (individual fish), u = random effects coefficients $\sim N(0, G)$ and e = experimental errors vector $\sim \text{Binomial}(0, R)$.

Treatment effects were analysed using two types of inference. First, pair-wise comparisons were used to test the significance of preference or avoidance responses separately for each binary experiment. Here, response probabilities summed to unity, following a classic binomial distribution. In a second approach, overall selection coefficients were estimated, and then compared, for each of the three levels tested within each factor (oxygen saturation, temperature and salinity). Thus, each level was evaluated at a time by pooling all trials where that level was offered as a choice to the fish. Departure from the 0.5 proportion (null hypothesis of random distribution or no selection behaviour) was assessed by means of a χ^2 -test. Because only two of the three tested levels were included in each trial, selection coefficients did not sum to unity and cannot be interpreted as partial probabilities of a multinomial distribution. As in the pair-wise approach, acclimation conditions were added to the analytical model as a linear covariate, whenever they were significant.

Selection coefficients from the second approach were contrasted against predicted growth rates for 25 g fishes, given the oxygen saturation, temperature and salinity combination corresponding to each treatment. Predictions were made using published bioenergetics models derived from experiments conducted using the same experimental stocks of juvenile *A. o. oxyrinchus* and *A. brevirostrum* (Niklitschek & Secor, 2009a; Woodland *et al.*, 2009).

Selectivity patterns observed in laboratory experiments were also compared against apparent selectivity in the wild inferred from capture location of juvenile *A. o. oxyrinchus*, as recorded and available from a reward programme implemented by the USFWS (Secor *et al.*,

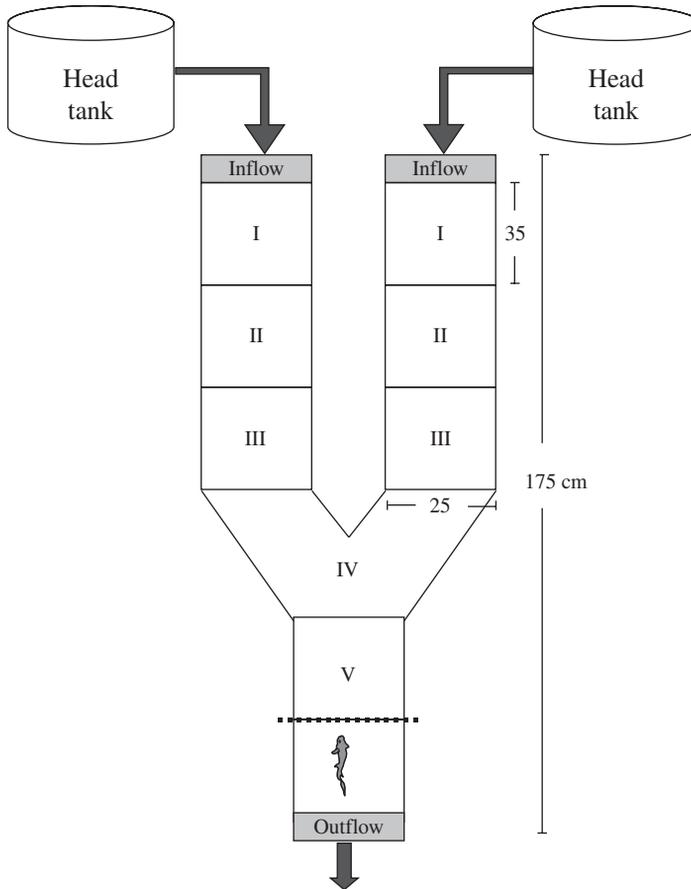


FIG. 1. Two-choice raceway built for habitat selection tests. Both head tanks had electronic temperature controllers. Inflow and outflow chambers had a plexi-glass division that caused a semi-laminar flow into the test chambers. The holding cell was separated from the experimental raceways by a removable screen.

2000; Welsh *et al.*, 2002). From a total of 1412 records, a sub-set of 619 captures was selected from 69 static pound-nets that had operated continuously in Maryland waters between 1997 and 1999. Pound-nets were chosen since they are passive non-towed gears, where catchability can be considered constant and relatively independent from fish and water quality distribution. The selected spatial and temporal sub-set allowed for a relatively high number of five to 20 records per month.

The Chesapeake Bay Program water quality interpolation tool (Bahner, 2001) was used to calculate water quality at each pound-net location on a monthly basis. Water quality conditions at each site were then classified into one of the nine choices of temperature, salinity and oxygen saturation used in laboratory experiments (Table II), using a tolerance criterion of $\pm 15\%$ respect of nominal values. Acipenserid catch data were then re-coded as presence or absence values by pound-net, month and year, which allowed capture incidence rates per water quality category to be estimated and compared. In this comparison, a logistic regression analysis, implemented through a GLMM analogous to that used for laboratory results, was used. This permitted adjustment of data for correlation between multiple captures within pound-nets (subjects) and months within years (random factors). Finally, the odds ratios between capture incidence at each category and at reference levels: salinity = 8, 20° C and

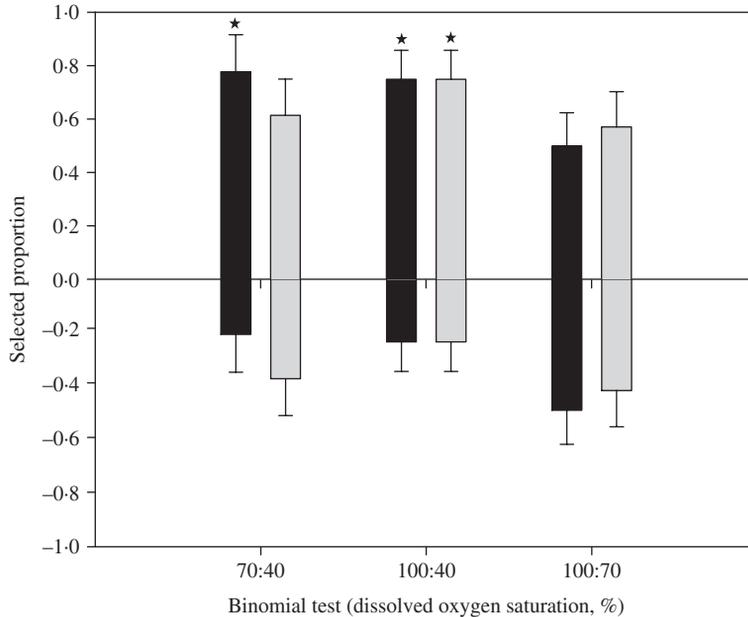


FIG. 2. Proportional incidence (\pm s.e.) of juvenile *Acipenser oxyrinchus oxyrinchus* (■) and *Acipenser brevirostrum* (□) selecting the highest (positive numbers) or the lowest (negative numbers) provided choice of dissolved oxygen saturation. Binary choices indicated in x -axis. ★ indicates a significant difference between choices ($P < 0.05$).

100% oxygen saturation were calculated and compared against odds ratios constructed from laboratory observations at corresponding water quality categories. The correlation between these field and laboratory odds ratios was evaluated using the non-parametric Spearman's test.

RESULTS

Behavioural responses to dissolved oxygen were not significantly different between *A. o. oxyrinchus* and *A. brevirostrum* (Fig. 2). Furthermore, no significant effects of dissolved oxygen acclimation history were detected for any of the species or binary tests. A clear avoidance to the lowest tested oxygen level (40% oxygen saturation) was evident in both species (Fig. 2), particularly under the 100:40% binomial trials, where 75% of the fish ($P < 0.01$) selected the 100% oxygen saturation raceway. In the 70:40% oxygen saturation experiments, 78% of *A. o. oxyrinchus* and 62% of *A. brevirostrum* subjects also selected the highest oxygen saturation choice. This preference for the highest oxygen saturation level in the 70:40% experiment was not significant when *A. brevirostrum* was analysed as a separate group. No significant differences between choices were observed in the 70:100% oxygen saturation test, with *c.* 50% incidence of either choice in both species (Fig. 2).

No significant effects from acclimation temperature upon binary behaviour responses were detected in either *A. o. oxyrinchus* ($P > 0.05$) or *A. brevirostrum* ($P > 0.05$). While the F -test failed to show significant differences in behavioural responses to temperature between species ($P > 0.05$), specific responses to some

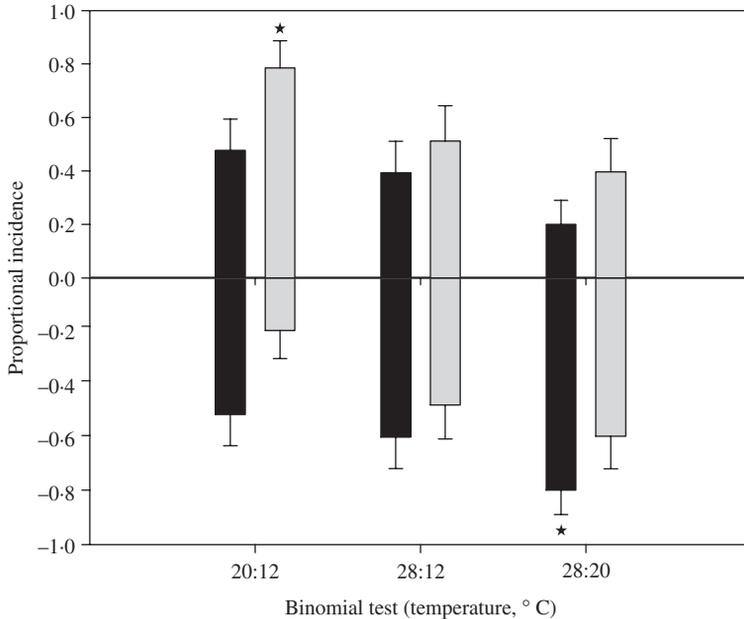


FIG. 3. Proportional incidence (\pm S.E.) of juvenile *Acipenser oxyrinchus oxyrinchus* (■) and *Acipenser brevirostrum* (□) selecting the highest (positive numbers) or the lowest (negative numbers) provided choice of water temperature. Binary choices indicated in x-axis. ★ indicates a significant difference between choices ($P < 0.05$).

binary choices differed between species. Both species showed an overall preference for 20° C, but failed to express a common selection pattern between the two extreme tested temperatures, 12 and 28° C (Fig. 3). As a general pattern, *A. o. oxyrinchus* tended to choose the lowest temperature choices more often (65%) than *A. brevirostrum* (44%). This contrast was particularly clear in the 28:20° C comparisons (Fig. 3), where only *A. o. oxyrinchus* showed a strong and significant ($P < 0.01$) avoidance to the 28° C choice (80% incidence). The opposite occurred in the 20:12° C trials, where 76% ($P < 0.01$) of *A. brevirostrum* avoided the lowest temperature choice (Fig. 3).

Acclimation salinity showed to have a significant effect upon *A. brevirostrum* behavioural responses ($P < 0.01$), but not upon those of *A. o. oxyrinchus* ($P > 0.05$). Pair-wise analyses for each treatment indicated these acclimation effects upon *A. brevirostrum* were only significant for the 15:8 salinity test ($P < 0.01$). After correcting for acclimation, overall salinity preferences were different between species ($P < 0.05$). *Acipenser o. oxyrinchus* tended to select higher salinity choices more often (69%) than *A. brevirostrum* (27%), particularly in the 8:1 and 15:8 salinity tests (Fig. 4). Pair-wise analyses showed, however, that only the *A. brevirostrum* response to the 8:1 salinity test was significant ($P < 0.05$).

Overall selectivity coefficients indicated both species selected oxygen saturation levels $>70\%$, while selection of preferred temperature and salinity ranges differed. Thus, while *A. o. oxyrinchus* juveniles exhibited similar selectivity coefficients for 12:20° C and salinities 8:15, *A. brevirostrum* juveniles showed a narrower pattern

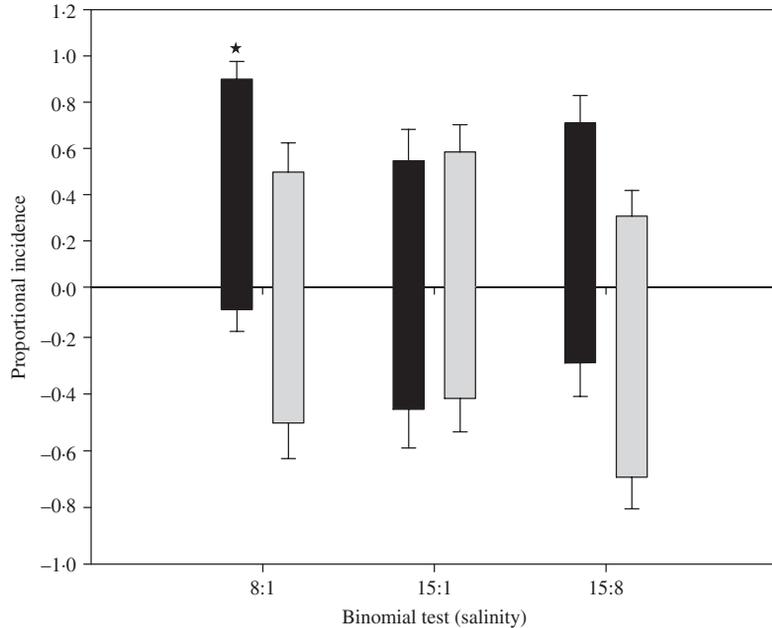


FIG. 4. Proportional incidence (\pm S.E.) of juvenile *Acipenser oxyrinchus oxyrinchus* (■) and *Acipenser brevirostrum* (□) selecting the highest (positive numbers) or the lowest (negative numbers) provided choice of salinity. Binary choices indicated in *x*-axis. ★ indicates a significant difference between choices ($P < 0.05$).

centred at 20° C and salinity 8 (Fig. 5). A significant correlation was found between these selectivity coefficients and growth rates predicted by bioenergetics models in both species. Thus, laboratory choices that showed the highest selectivity coefficients tended to match those predicted to provide the highest growth rates (Fig. 5), exhibiting Spearman's coefficients of 0.85 ($P < 0.01$) and 0.75 ($P < 0.05$) in *A. o. oxyrinchus* and *A. brevirostrum*, respectively.

The probability of *A. o. oxyrinchus* captures in the Chesapeake Bay was found to be higher at pound-nets exhibiting water quality conditions classified into the 20° C, 100% oxygen saturation and salinity 8 categories, with mean (monthly) incidence rates of 47, 17 and 45%, respectively (Table III). These selectivity patterns tended to be consistent and showed a significant correlation (Spearman's index = 0.91, $P < 0.001$) with selectivity patterns (odds ratios) observed in laboratory experiments (Fig. 6). The largest disagreements between field and laboratory odds ratios corresponded to 12° C and salinity 1 categories, where field incidence rates were much lower than laboratory ones (Fig. 6).

DISCUSSION

Behavioural experiments showed that both juvenile *A. o. oxyrinchus* and *A. brevirostrum* were able to discriminate and select among water quality conditions that significantly affect their growth and metabolism. Hence, both fishes

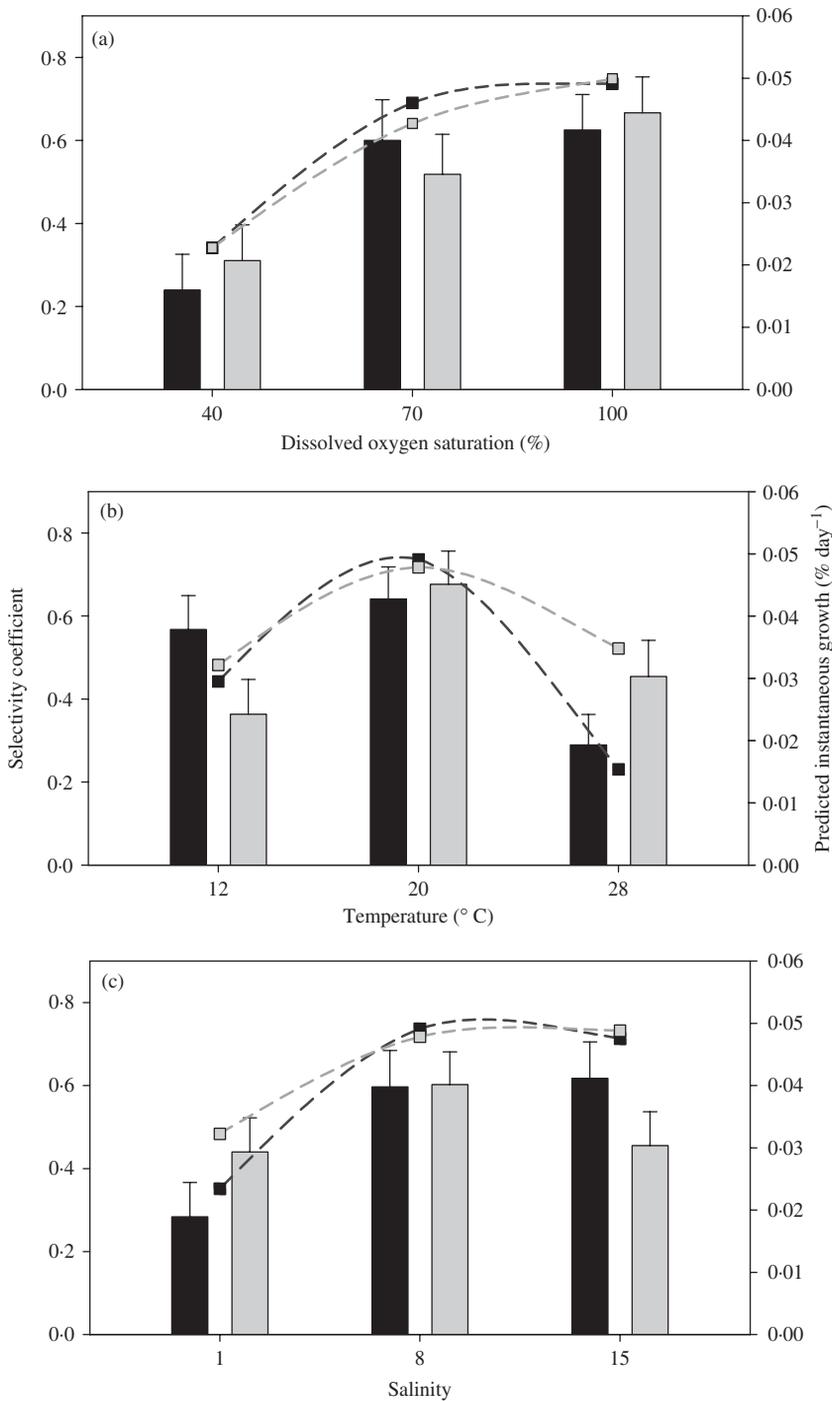


FIG. 5. Mean + s.e. selectivity coefficients (■, □) and predicted maximum growth rates (-■-, -□-) at levels of (a) dissolved oxygen (b) temperature, and (c) salinity tested in behavioural experiments for juvenile *Acipenser oxyrinchus oxyrinchus* (■, ■) and *Acipenser brevirostrum* (□, □).

TABLE III. Incidence rate of *Acipenser oxyrinchus oxyrinchus* captures at 48 pound-nets categorized into nine selected water quality conditions ($\pm 10\%$). Each variable tested separately

Variable	Nominal value	Mean \pm S.E. incidence rate	Odds ratio
Temperature ($^{\circ}$ C)	12	0.140 \pm 0.130	0.15
	20	0.467 \pm 0.053	1.00
	28	0.195 \pm 0.044	0.27
Dissolved oxygen (%)	40	0.000 \pm 0.003	0.00
	70	0.182 \pm 0.082	0.76
	100	0.223 \pm 0.037	1.00
Salinity	1	0.000 \pm 0.001	0.00
	8	0.454 \pm 0.067	1.00
	15	0.275 \pm 0.062	0.45

tended to select conditions that would maximize growth as predicted by bioenergetics models. This match between behaviour and bioenergetics is consistent with observations regarding temperature preferendum in several other fishes (Girsa *et al.*, 1980; Jobling, 1981; Coutant, 1987; Schurmann & Steffensen, 1992; Edeline & Elie,

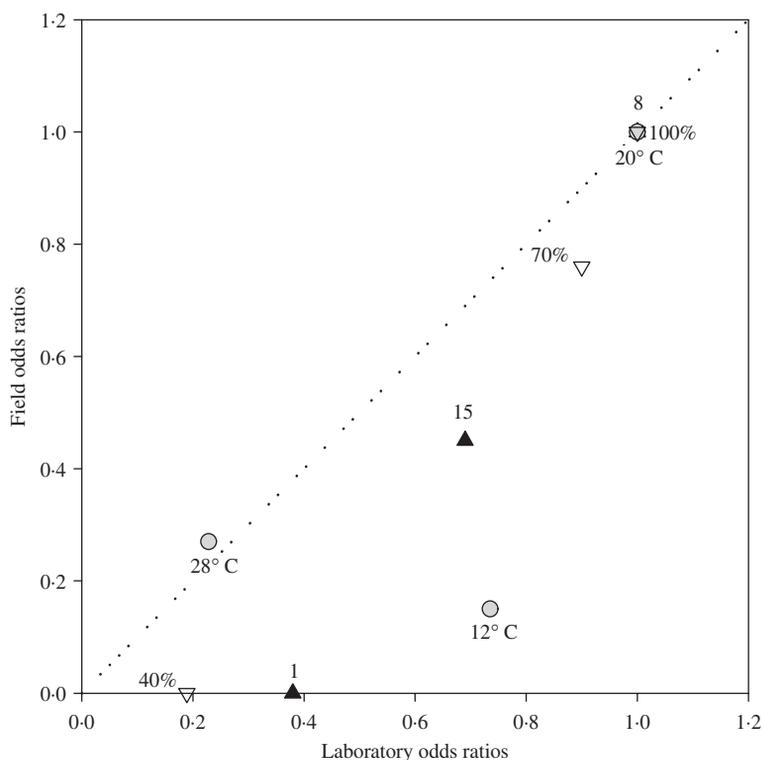


FIG. 6. Apparent selectivity of *Acipenser oxyrinchus oxyrinchus* in laboratory experiments and field observations, expressed as odds ratios relative to dissolved oxygen (∇), temperature (\circ) and salinity (\blacktriangle) reference levels of 8, 20° C and 100%, respectively.

2004; Webster & Dill, 2006) and support the possibility to expand the relevance of bioenergetics models to other environmental variables (*i.e.* dissolved oxygen and salinity).

Although similar responses to oxygen choices were observed in both species, a trend to prefer higher temperatures and lower salinities was observed in *A. brevirostrum*. Because experimental fishes were obtained from wild brood stock each located several hundred kilometres and *c.* 7.5 latitudinal degrees apart, confounding species and strain effects are likely to bias species comparisons. Nonetheless, the behavioural differences observed in the present work matched field observations for sympatric populations of these two *Acipenser* species (Dadswell, 1979; Dovel & Berggren, 1983; Dadswell *et al.*, 1984; Dovel *et al.*, 1992) that indicate a more freshwater-oriented life cycle in *A. brevirostrum*, which shows a delayed and facultative migration to sea water, whereas *A. o. oxyrinchus* uses marine waters intensively after its first 3–5 years of life. Thus, the higher preference for, and stronger acclimation response to, higher salinities observed in the present work for *A. o. oxyrinchus* yearlings are consistent with the progressive displacement to brackish waters reported after the first year of life in wild populations of this species (Dovel *et al.*, 1992; Bain, 1997). It also matches the very quick and directional adaptation to increasing salinity observed in hatchery-produced *A. o. oxyrinchus* yearlings released into the Chesapeake Bay (Secor *et al.*, 2000).

The more freshwater-oriented life cycle of juvenile *A. brevirostrum* suggests that this species should have a higher tolerance to a greater range in temperatures, inherent to rivers in winter and summer. This expectation is supported by the higher tolerance of juvenile *A. brevirostrum* to high temperature (28° C) observed in present laboratory experiments and by field distributional data. The latter shows, however, some latitudinal gradient. While northern populations tend to avoid waters >22° C (Dadswell *et al.*, 1984), fish from southern populations have been found in water temperatures up to 34° C, although rarely beyond 30° C (Dadswell *et al.*, 1984; Kynard, 1997; Collins *et al.*, 2002). The lowest temperature choice provided in present experiments (12° C) was close to the lowest temperature at which wild counterparts of these *A. brevirostrum* have been found in their natal system, the Savannah River (Collins *et al.*, 2002).

The present work shows that yearling *A. o. oxyrinchus* and *A. brevirostrum* were able to discriminate and select between discrete choices, several units apart in water quality levels. Nonetheless, the minimum level of discrimination among water quality levels remains an unknown but relevant issue given the continuous nature of water quality conditions in the wild. Although the present work did not focus on establishing behavioural sensitivity thresholds, water quality conditions in the choice chamber tended to mix from the head tanks to the holding chamber and it seems reasonable to suppose that as experimental fishes acclimated to the choice chamber, they discriminated between smaller differences in water quality than those represented by each binomial experiment.

Habitat selection might be expected to increase in response to water quality levels as conditions become increasingly stressful. Experimental fishes preferred 70 over 40% oxygen saturation, but failed to show a significant preference for 100 over 70% oxygen saturation. Wannamaker & Rice (2000) showed a similar trend in behavioural responses to hypoxia among seven estuarine species: although all tested species discriminated between 1 and 2 mg l⁻¹ (12 *v.* 24% oxygen saturation),

several fishes failed to discriminate between 4 and 6 mg l⁻¹ (49 v. 73% oxygen saturation). Contrasting these results to those presented here gives additional support to the idea that acipenserids may be particularly sensitive to hypoxia, showing avoidance and physiological reactions to oxygen saturation levels <70% (Klyashtorin, 1976; Secor & Niklitschek, 2002; Campbell & Goodman, 2004; Niklitschek & Secor, 2009b).

Despite constraints due to the need to simplify choice experiments, a high agreement (91% correlation in odds ratios) was found between observed laboratory responses and habitat preferences inferred from juvenile *A. o. oxyrinchus* capture locations in the wild. This is noteworthy considering the variety of biotic and abiotic factors, which were statistically unaccounted for in the pound-net capture data, and the large size range corresponding to captured fish (40–92 cm), which exceeded the size range of experimental fish (21–30 cm). This size difference might explain, however, departures found between laboratory and field odds ratios. Larger fish are expected to exhibit lower preference for low-salinity waters, which also can be associated with cooler waters during summer months, when most captures were recorded.

The choice experiments presented in this work isolated three key water quality variables in a rather simple arrangement of binomial choices, where interactions between main variables remain to be investigated. Hence this study provides only a partial view of behavioural habitat selection clues used by juvenile *A. o. oxyrinchus* and *A. brevirostrum*. In the wild the actual behaviour of juvenile acipenserids will correspond to an integrative response to a multidimensional array of stimuli, including biological ones, such as prey abundance, as well as other abiotic factors relevant to habitat selection, including bottom substratum, depth and flow (Hall *et al.*, 1991; Moser & Ross, 1995; Haley, 1999; Peake, 1999; Kynard *et al.*, 2000). Habitat preferences and sensitivity are also expected to change with age and size. Although an ontogenetic increase in salinity tolerance has been suggested for both species (Dadswell *et al.*, 1984; Smith, 1985; Niklitschek & Secor, 2009a), a reduced sensitivity by acipenserid larvae to hypoxia was found in Siberian sturgeon *Acipenser baerii* Brandt, where larvae and early juveniles failed to show avoidance reactions to hypoxia until they reached 1.8 g (Khakimullin, 1987).

The present work provides additional support to the hypothesis that juvenile *A. o. oxyrinchus* actively select for habitats where growth and potential production (growth minus mortality) are maximized (Niklitschek & Secor, 2005). New results contribute to the available information on juvenile distribution in the wild, which matches distribution patterns expected from both behavioural (this paper) and physiological (Niklitschek & Secor, 2009a, b) responses measured under laboratory conditions. Thus, although observed distribution may also result from higher mortality rates in suboptimal areas, active water quality selection appears to be a strong force driving spatial distribution of juvenile *A. o. oxyrinchus* and, probably, juvenile *A. brevirostrum* in highly structured water masses, such as the Chesapeake Bay estuarine system. This active selection behaviour would induce high seasonal concentration of individuals at limited suitable and optimal habitats, which may reduce exposure to lethal and sublethal waters, but increases trophic demand and vulnerability to predation, fishing or other deleterious factors in suitable patches. These findings emphasize the need to identify and protect seasonal habitats that might still remain for juvenile acipenserids in North American estuaries.

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