Environ Biol Fish
DOI 10.1007/s10641-009-9540-1

# Abundance and movement patterns of age-0 juvenile lake sturgeon in the Peshtigo River, Wisconsin

**David C. Caroffino · Trent M. Sutton · Mark S. Lindberg**

Received: 1 January 2009 / Accepted: 7 October 2009
© Springer Science + Business Media B.V. 2009

**Abstract** In Great Lakes tributaries, age-0 juvenile lake sturgeon *Acipenser fulvescens* use riverine nursery habitats during their first summer of life and migrate to adjacent lakes after a seasonal decline in water temperature. We used mark-recapture data collected during this river-residency phase to monitor patterns in juvenile abundance and movement in the Peshtigo River, Wisconsin, during 2006 and 2007. Jolly-Seber and multistate models were used to estimate abundance and describe the probability of movement between river sections. Juvenile abundance was higher in 2007 than in 2006; however, in both years, abundance at the end of the sampling season was lower than at the beginning. Downstream movements were observed more frequently than upstream movements, and the probability of a downstream movement was higher than the probability of an upstream movement. The lower abundance later in the sampling season and propensity for downstream movements suggests that some age-0 juvenile lake sturgeon may leave the natal river before a seasonal decline in water temperature.

**Keywords** Age-0 juvenile lake sturgeon · Abundance · Movement · Multistate model

D. C. Caroffino · T. M. Sutton
School of Fisheries and Ocean Sciences,
University of Alaska Fairbanks,
905 Koyokuk Drive, 245 O'Neill Building,
Fairbanks, AK 99775, USA

M. S. Lindberg
Department of Biology and Wildlife and,
Institute of Arctic Biology, University of Alaska Fairbanks,
Fairbanks, AK 99775, USA

*Present Address:*
D. C. Caroffino (✉)
Michigan Department of Natural Resources,
96 Grant St.,
Charlevoix, MI 49720, USA
e-mail: caroffinod@michigan.gov

## Introduction

Lake sturgeon *Acipenser fulvescens* were historically abundant throughout the Great Lakes; however, their current abundance is approximately 1% of historical levels (Hay-Chmielewski and Whelan 1997). Substantial declines occurred in the 1800s due to widespread overharvest and habitat degradation, and populations have persisted at low levels throughout the 1900s (Harkness and Dymond 1961; Auer 1999a). Although interest in rehabilitating this species has increased over the past few decades, critical knowledge gaps relating to juvenile lake sturgeon ecology, particularly movement patterns and recruitment, still exist. A better understanding of these attributes will aid restoration efforts by identifying the extent of critical habitats required by juveniles and allow more

Published online: 20 October 2009

accurate forecasting of adult populations (Auer 1999a; Secor et al. 2002).

Adult lake sturgeon migrate into tributaries of the Great Lakes for spawning, and their offspring use these rivers for nursery habitat. Larval lake sturgeon drift downriver from hatching to nursery areas between 16 and 22 mm in length, begin exogenous feeding, and take up residence on nursery habitat within the natal river (Kempinger 1988; Auer and Baker 2002; Benson et al. 2006). Once larvae reach 40–50 mm in total length and settle in nursery habitat they are considered age-0 juveniles. This life stage prefers shallow water depths (<1.5 m) and are typically found over soft sediments which allows them to forage for benthic macroinvertebrates (Kempinger 1996; Chiasson et al. 1997; Beamish et al. 1998; Benson et al. 2005a). The duration of this river-residency phase can vary, but once river water temperatures decline in late summer and fall, age-0 juvenile lake sturgeon in tributaries to the Great Lakes leave their natal river and migrate to the adjacent lake (Holtgren and Auer 2004; Benson et al. 2005a).

Age-0 juvenile lake sturgeon can be effectively sampled within river nursery areas and have been captured in a number of Great Lakes tributaries (e.g., Kempinger 1996; Holtgren and Auer 2004; Benson et al. 2005b). The resulting mark-recapture data can be used to determine age-0 juvenile abundance. However, only one study has sampled age-0 juveniles on a spatial and temporal scale sufficient enough to estimate abundance within natal river nursery habitats. Benson et al. (2006) estimated the abundance of the 2003 lake sturgeon year class within the Peshtigo River, Wisconsin, to be 261 age-0 juveniles (95% CI: 164–386 fish). This estimate was only for large (>150 mm) age-0 juveniles and was generated with a closed-population estimator. Through use of an open-population estimator and marking fish at smaller sizes, accurate estimates of abundance could be generated throughout the sampling season for a greater size range of age-0 juveniles. Conducting such estimates would allow for better forecasting of adult population abundance, and if conducted over sufficient years, may allow patterns in recruitment to be detected, promoting a better understanding of this population parameter.

Mark-recapture data can also be used to examine movement patterns of fish, and it serves as the basis for multistate models (Brownie et al. 1993). Multistate models are a generalization of the Cormack-Jolly-Seber models (Cormack 1964; Jolly 1965; Seber 1965) and, in addition to estimating survival and capture probabilities, also incorporate movement data (Brownie et al. 1993). These models allow the user to define specific states, then yield estimates of the probability that an individual within the given population will transition from one state to another. Biological hypotheses about the data can be tested by evaluating the fit of different models to the data. For example, to test the hypothesis that survival does not differ by river section, the support for a model with section-specific survival would be compared to that of a model without section-specific survival. By defining different sections of a river as states, the probability of movement within a river can be described.

While movement patterns of adult lake sturgeon have been described for a variety of systems (e.g., Fortin et al. 1993; Rusak and Mosindy 1997; McKinley et al. 1998; Auer 1999b; Knights et al. 2002), movement data on age-0 juveniles is less complete and has only been generated for large (>220 mm) fish using radio telemetry (Holtgren and Auer 2004; Benson et al. 2005a). Utilizing mark-recapture data would allow movement patterns of smaller (50 – 220 mm) age-0 juveniles to be described. The objectives of this study were to: 1) determine trends in abundance of age-0 juvenile lake sturgeon during river residency; and 2) describe the movement patterns of age-0 juvenile lake sturgeon. These results will provide information about the variation of lake sturgeon recruitment and provide a better understanding of the river-residency phase of juvenile lake sturgeon.

## Methods

### Study site

This research was conducted in the lower Peshtigo River, a tributary of Green Bay, located in northeastern Wisconsin (N 45° 0.246' W 87° 41.335'; Fig. 1). Adult lake sturgeon spawn immediately below a dam (located 19 km upstream from Green Bay), and after hatching, larvae drift downriver and age-0 juveniles use the lower sections of the river as nursery habitat.

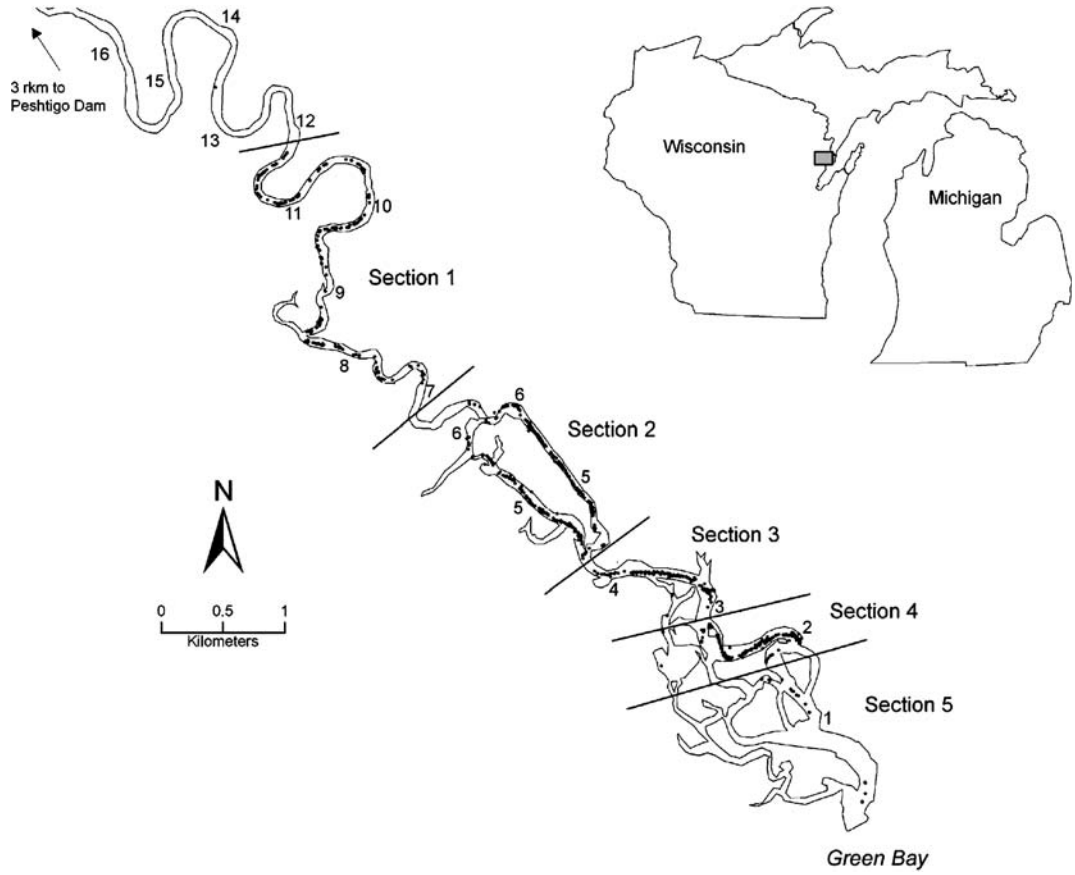


**Fig. 1** Map of the lower Peshtigo River, Wisconsin, showing the five river sections, capture locations of age-0 juveniles in 2007, and river distances from Green Bay

Based on river morphology and post-hoc fish capture locations, the nursery area was divided into five sections (Fig. 1). The upstream boundary of the sampled area was a rapid at river kilometer (rkm) 12 (distance from the mouth). Once larval or age-0 juvenile sturgeon drifted or moved downstream of this area, they likely could not move above it because of their poor swimming ability (Peake et al. 1997). Sampling above rkm 12 occurred on one occasion in 2006 and two occasions in 2007. No age-0 juveniles were captured above rkm 12 in 2006, and only one age-0 juvenile was captured above rkm 12 in 2007; therefore, the upper seven kilometers of river were not sampled in subsequent events. Each section was separated from those adjacent to it by a stretch of river at least 100 m in length that contained either poor habitat (woody debris, vegetation) or deep water (2 to 4 m). All deep waters (>2 m) within and between river sections were searched by SCUBA divers who neither captured nor observed age-0 juveniles in these areas.

## Field methods

For the remainder of the manuscript the term 'juvenile' refers to age-0 juvenile as all juvenile sturgeon captured on nursery habitat in the Peshtigo River were age 0. Juvenile lake sturgeon were captured during 10 sampling events each from 19 June through 9 August 2006 and from 13 June through 3 August 2007. Juvenile lake sturgeon between 50 and 100 mm were captured by daytime snorkeling. Three (2006) or four (2007) snorkelers were equally spaced across the river channel and passively floated downstream scanning waters up to 2 m in depth for juvenile sturgeon. When a juvenile sturgeon was located, the snorkeler floated past the fish, approached from downstream, and captured it

with a dip net. Once fish reached 100 mm in total length, their increased swimming ability allowed them to avoid capture. At this size, juveniles were large enough to be seen using a spotlighting technique (Benson et al. 2005a). Night sampling included scanning shallow waters (<2 m) with spotlights while wading or slowly motoring upstream. Once fixed in a spotlight beam, juveniles became stationary and could be approached from downstream and captured using larger dip nets.

Each sampling event included searching all waters from the mouth to the top of "Section 1" at rkm 12. Each event lasted two or three days, and between two and six days elapsed between sampling events. All captured sturgeon were measured for total length (to the nearest 1 mm), and fish observed for the first time were given a unique mark. Juveniles between 50 and 150 mm were marked with Visible Implant Elastomer (VIE; Northwest Marine Technology, Shaw Island, Washington), using a combination of four colors (orange, blue, red, and green) and four tagging locations (under the rostrum, anterior and posterior of the barbels on both sides of the body midline) to uniquely mark each fish. Once juveniles reached 150 mm in total length, a PIT tag (13.5 mm long; model TX1405L, Biomark Inc., Boise, Idaho) was implanted dorso-laterally behind the second scute of each individual. In 2006, all fish that received a PIT tag also received a VIE mark. Due to a larger year class in 2007, juveniles were given both marks only until VIE was no longer available. After marking, all fish were released at the site of capture. A handheld global positioning system (GPS; Garmin Ltd., Olathe, Kansas) was used to record the latitude and longitude of each capture and subsequent recapture location.

## Abundance

We used open population Jolly-Seber (JS) models (Jolly 1965; Seber 1965) in the POPAN option of program MARK (White and Burnham 1999) to obtain maximum-likelihood estimates of population size at the onset of the first sampling event and subsequent abundance during later events. In addition to abundance estimates, these models also provide estimates of survival and capture probabilities. The survival parameters represent apparent survival, allowing for both death and permanent emigration from the study site. We considered a small suite of models because our purpose for this analysis was abundance estimation rather than testing hypotheses about reasons for change in abundance. We considered combinations of models that allowed each of the parameters (abundance, survival, and capture) to remain constant or vary throughout the sampling season. Model selection was based on Akaike's information criterion ($AIC_c$; Hurvich and Tsai 1989). The selected model had the lowest $AIC_c$ value and highest Akaike weight, which represents the approximate probability that the specified model is best given the data and the other candidate models run (Burnham and Anderson 2002).

## Movement

The coordinates of each capture location were uploaded to ArcGIS 9.2 (ESRI, Inc., Redlands, California), and distances between the capture and recapture locations of each individual fish were measured to the nearest 10 m. Distances moved upstream were represented by positive values, while distances moved downstream were represented by negative values. The number of fish moving upstream and downstream during each sampling event was also recorded.

We estimated movement probability of age-0 juvenile lake sturgeon between sections of the river using multistate models (Brownie et al. 1993). Multistate models are similar to Cormack-Jolly-Seber models except estimated survival and capture probabilities are state-specific, which in our study was section of the river, and movement among states can be estimated (Brownie et al. 1993). Sufficient data was only collected from the 2007 lake sturgeon year class and multistate models were only fitted to that data set. Five states were defined, which corresponded to the five sections of the lower Peshtigo River, and we estimated the probability of movement between any pair of river sections. These models were fitted to the 2007 mark-recapture data using the multi-state option in program MARK (White and Burnham 1999). Goodness-of-fit testing for the most general model (Pradel et al. 2003) was conducted using the program U-CARE (Choquet et al. 2005).

The most general model was indicated by S(ts) p (ts) Ψ(ts), allowing the probabilities of survival (S), capture (p), and movement (Ψ) to vary both by time (t) and by river section (s). This general model failed to reach numerical convergence in MARK, likely due

to the number of movement parameters estimated (180, one for each possible movement between five river sections estimated during each of nine time intervals). The time specificity of each possible movement was removed (160 parameters) and the model S(ts) p(ts) Ψ (s) reached convergence and was used as a starting point for further constraints. Reduced models were chosen based on biological hypotheses (Table 1) and were named by removing sources of variation (t, s) to indicate the excluded effect. Model names that included (.) were those testing if the corresponding variable was constant over time and by section. Movement parameters were also modified to evaluate whether the probability of movement depended on the direction traveled (upstream versus downstream), the distance moved (one river section versus multiple river sections), and the river section from which the move was initiated. Mean water temperature and mean fish size were included as covariates in models that allowed movement to vary over time to determine if these factors explained variability in movement. The $AIC_c$ value and model weight were used to evaluate all candidate models and to determine which model best fit the data (Burnham and Anderson 2002). Estimated values of model parameters are followed by their standard errors.

## Results

Tag loss from age-0 juvenile lake sturgeon in the lower Peshtigo River was not observed in 2006 and was minimal in 2007. There was no evidence of VIE or PIT tag loss from any fish recaptured in 2006. In contrast, two of the recaptured fish in 2007 had likely expelled their PIT tag. A wound on each individual at the tagging site suggested a PIT tag loss, but because these two fish did not belong to the group of 13 fish that were double marked, tag loss could not be confirmed and unique identification could not be made. As a result, these fish were excluded from the study. There was no evidence of VIE tag loss during 2007.

**Table 1** Hypotheses and candidate models used to estimate probabilities of survival (S), capture (p), and movement (Ψ) of age-0 juvenile lake sturgeon in the Peshtigo River, Wisconsin, during 2007, including $AIC_c$ values, model weights, and number of parameters (NP) estimated for each model

| Hypothesis Tested | Model Name | AICc | AICc Weight | NP |
|---|---|---|---|---|
| General model — failed to converge | S(ts) p(ts) Ψ (ts) | | | 270 |
| General baseline model, no difference in movement over time | S(ts) p(ts) Ψ (s) | 2617.138 | 0.00 | 110 |
| No difference in survival between sites | S(t) p(ts) Ψ (s) | 2536.872 | 0.00 | 74 |
| No difference in survival over time | S(s) p(ts) Ψ (s) | 2536.117 | 0.00 | 70 |
| No difference in survival between sites or over time | S(.)p(ts) Ψ (s) | 2527.725 | 0.00 | 66 |
| No difference in capture probability over time | S(.)p(s) Ψ (s) | 2545.651 | 0.00 | 26 |
| No difference in capture probability between sites | S(.)p(t) Ψ (s) | 2565.857 | 0.00 | 30 |
| No difference in capture probability between sites or over time | S(.)p(.) Ψ (s) | 2593.475 | 0.00 | 22 |
| No difference in probability of movement between river sections | S(.) p(ts) Ψ (t) | 2530.918 | 0.00 | 55 |
| Probability of movement varies only by direction traveled | S(.) p(ts) Ψ (D) [d] | 2520.268 | 0.04 | 48 |
| Probability of movement varies only by distance traveled (short versus long) | S(.) p(ts) Ψ (C) [c] | 2519.832 | 0.05 | 48 |
| Probability of movement varies by direction and distance | S(.) p(ts) Ψ (A)[a] | 2515.046 | 0.50 | 49 |
| Probability of movement varies by direction, distance, and starting river section | S(.) p(ts) Ψ (B) [b] | 2515.424 | 0.42 | 55 |

[a] A: Ψ modeled as 3 parameters, 1) movement of one section upstream from any section, 2) movement of one section downstream from any section, and 3) movement of two or more sections in any direction from any section

[b] B: Ψ modeled as 9 parameters, 1–8) movement of one section upstream and one section downstream from each of the five sections, and 9) movement of more than one section in any direction from any section

[c] C: Ψ modeled as 2 parameters, 1) movement of one section in any direction from any section and 2) movement of more than one section in any direction from any section

[d] D: Ψ modeled as 2 parameters, 1) upstream movement of any distance from any section and 2) downstream movement of any distance from any section

## Abundance

The best supported JS model during 2006 estimated time-varying abundance, but capture probability and survival did not differ by time. During 2006, 50 lake sturgeon were marked with 27 subsequent recaptures, including six fish that were recaptured twice and three fish that were recaptures three times. The total length of fish that were captured ranged from 53 to 215 mm. Population abundance declined from an initial estimate of 108 (95% CI: 80–162) juveniles to 28 (95% CI: 10–45) fish by the 4 August sampling event (Fig. 2). Capture probability for each sampling event and daily survival throughout the sampling season were estimated to be 0.18 (0.04) and 0.95 (0.02), respectively.

The 2007 year class was larger than 2006 and although survival did not vary between the time periods, capture probability and abundance did. During the sampling season, 649 different juvenile lake sturgeon were marked with 384 subsequent recaptures, including 65 fish that were recaptured twice, 18 fish that were recaptured three times, and six fish that were recaptured four times. Fish size ranged from 50 to 210 mm in total length. The JS model that had the lowest $AIC_c$ value and highest model weight (0.60) included a single parameter for survival (0.94, 0.006), but capture probability differed by sampling event (ranged from 0.07, 0.016 to 0.32, 0.034). The abundance estimates yielded by this model began with an initial population size of 1260 (95% CI: 1127–1431) juveniles, which had declined to 454 (95% CI: 384–522) fish on the 31 July sampling event (Fig. 2).

## Movement

Downstream movements were observed more frequently than upstream movements in 2006. Of the 27 lake sturgeon recaptured, 16 were recaptured downstream and nine upstream, with two fish being recaptured within 10 m of their last capture location. The mean distance moved by recaptured juveniles was 130 m downstream, and the median distance moved was 20 m downstream. The longest observed downstream movement was 2240 m, and the longest observed upstream movement was 370 m (Fig. 3). Only one juvenile was captured in river "Section 1", and that individual was never

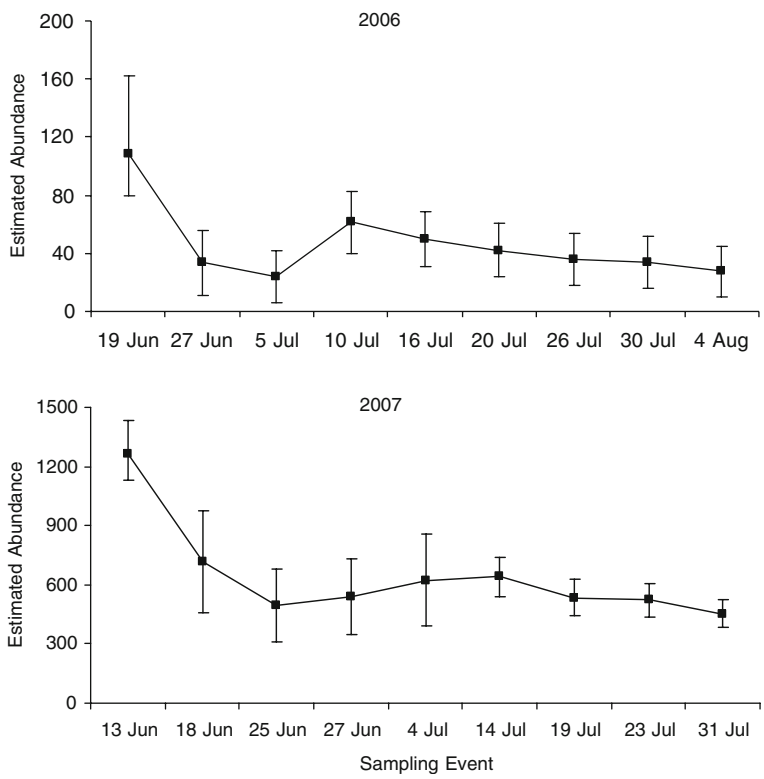


**Fig. 2** The estimated age-0 juvenile abundance during 2006 and 2007 sampling events; error bars represent 95% confidence intervals

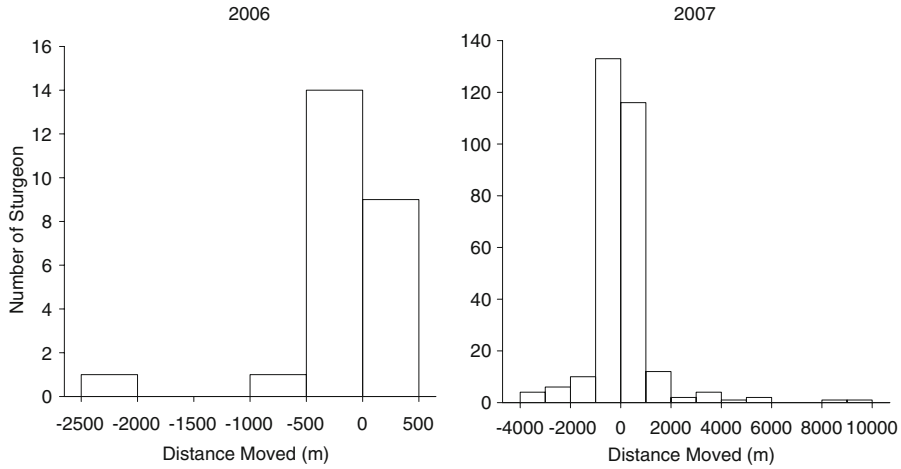


**Fig. 3** Distances moved by age-0 juvenile lake sturgeon in 2006 and 2007. Negative values represent downstream movements, while positive values represent upstream movements

recaptured. Due to lack of sufficient data, multistate modeling was not conducted for this year class.

Spatial coordinates of capture locations were only recorded for 312 of the 384 total lake sturgeon recaptured in 2007; therefore, distances moved could only be calculated for this subset of fish. More fish moved downstream than upstream (153 compared to 139; Fig. 3), while 18 fish were recaptured within 10 m of their last capture location. Two juveniles were marked on one side of the split in river "Section 2" and recaptured on the other side, requiring both a downstream and upstream movement. The mean distance moved by recaptured juveniles was 90 m upstream, and the median distance moved was 0 m. The longest observed downstream movement was 3590 m and the longest observed upstream movement was 9190 m. The number of age-0 juveniles moving upstream and downstream was similar during each of the sampling events (Fig. 4).

The most general multistate model (S(ts) p(ts) Ψ(ts)) adequately described the data set ($\chi^2$=68.21, *df*=84, *P*=0.894). In the best supported models, survival was constant between river sections and over time; however, capture probabilities varied by both river section and sampling event (Table 1). Models that allowed movement to vary only by river section or time were not well supported ($\Delta AIC_c$ >15.87), and including mean water temperature and mean age-0 juvenile size as covariates for movement did not improve model fit ($\Delta AIC_c$=34.53; weight <0.01).

Once the number of movement parameters was reduced by direction and distance traveled, two models were clearly better supported than all the rest. The weight of the best fit model (referred to as model A) was 0.50, and the weight of the second best model (referred to as model B) was 0.42, with a $\Delta AIC_c$ of 0.379. This indicated nearly equal support for these two models, which were approximately eight times better supported by the data than the next best model (weight=0.05; Table 1).

There was no difference in the structure of the parameters estimating survival and capture probability between models A and B. The probability of daily survival in between sampling events was constant by site and through time and was estimated to be 0.953 (0.006) in model A. Combined, there were 27 days between the sampling events, so the overall probability of surviving and remaining in the study area for the duration of this research was $0.953^{27}$=0.273. Capture probability differed both by sampling event and river section. The 45 parameters for capture probability varied from 0 (instances when no fish were captured) to 0.469 (0.066), and generally decreased from upstream to downstream sections (Table 2).

Models A and B only differed by the number and type of movement parameters. In model A, three movement parameters were estimated: 1) the probability of moving upstream one river section from any location; 2) the probability of moving downstream one river section from any location; and 3) the probability of moving two or more sections in any direction. The probability of moving one section downstream (0.064, 0.016) was greater than the probability of moving one section upstream (0.028, 0.008), and the probability of making any other movement (0.015, 0.004) was lower than both of these movement probabilities. Model B had

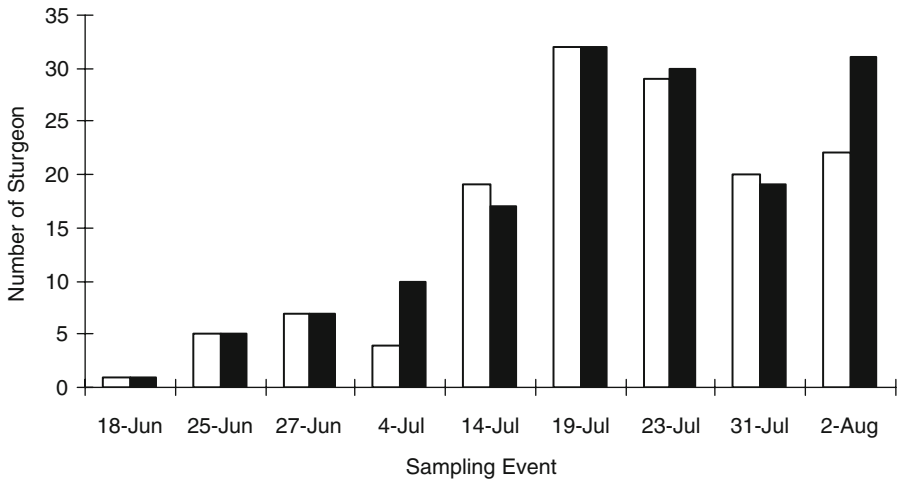


**Fig. 4** Number of recaptured sturgeon observed moving upstream (white bars) and downstream (black bars) during each sampling event in 2007

nine movement parameters: 1) the probability of moving two or more sections in any direction (0.013, 0.004); and 2–9) the probability of moving one section upstream or one section downstream from each location. For any given section, there was a higher probability that a juvenile lake sturgeon would move downstream rather than upstream (Table 2). Neither of these models reflected a directional difference in the probability of moving more than one section.

## Discussion

Wide fluctuations in recruitment are not uncommon in species with reproductive strategies similar to that of the lake sturgeon (Winemiller and Rose 1992). Estimates of juvenile abundance and recruitment should be made over multiple years so that the extent of variation in year-class strength can be described. The absolute abundance of age-0 juvenile lake sturgeon in the Peshtigo River was more than ten-fold greater in 2007 than it was in 2006. A dewatering event at the Peshtigo dam soon after lake sturgeon had deposited eggs reduced the size of the 2006 year class (D. Caroffino, unpublished data). The abundance of the 2003 year class of lake sturgeon in the Peshtigo River was estimated using mark-recapture data from PIT tagged age-0 juveniles (Benson et al. 2006). Comparing this estimate to those made from similar sized fish during 2006 and 2007 suggested that the 2003 year class was likely intermediate in strength (261 juveniles; 95% CI: 164–386 fish) between the poor year class of 2006 (36 juveniles; 95% CI: 18–34 fish) and the strong year class of 2007 (535 juveniles; 95% CI: 442–628 fish). Continued sampling of future year classes to establish a long-term data set in this and other sturgeon rivers will only increase the understanding of the variability that can be expected in annual lake sturgeon recruitment.

The capture probability for juvenile lake sturgeon was not constant during this study. Differing sampling methods and conditions contributed to changing

**Table 2** Parameter estimates for second best multistate model, including the probability of juvenile sturgeon moving upstream or downstream one river section and mean capture probability (p) in each section. Probability of survival was constant (0.953, SE=0.06)

| Section | Upstream probability (SE) | Downstream probability (SE) | Mean p (SE) |
|---|---|---|---|
| 1 | – | 0.023 (0.014) | 0.33 (0.058) |
| 2 | 0.021 (0.008) | 0.073 (0.028) | 0.23 (0.035) |
| 3 | 0.023 (0.015) | 0.173 (0.063) | 0.08 (0.015) |
| 4 | 0.047 (0.028) | 0.062 (0.045) | 0.14 (0.030) |
| 5 | 0.099 (0.101) | – | 0.07 (0.027) |

capture probabilities over time. Snorkeling was most effective during sunny days with low flow conditions as the river was clearer and a greater number of deep areas could be effectively searched. Calm, clear nights were essential for successful capture during spotlighting. Surface disturbances caused by rain or wind reduced visibility, sometimes to the extent that sampling could not be performed. Although each river section was subjected to the same amount of effort, capture probability also varied between the five river sections, likely caused by river morphology. Lower capture probabilities were observed in wider, deeper areas of the Peshtigo River.

Although the absolute abundance of age-0 juvenile lake sturgeon differed greatly between 2006 and 2007, the pattern of the abundance estimates between the 2 years was similar. The number of sturgeon present on the nursery grounds declined rapidly from the initial estimate and then increased before slowly declining again. The increase, observed in both years, corresponded to the switch of sampling methods from snorkeling to spotlighting, which occurred in the fourth sampling event (10–11 July) in 2006 and the fifth sampling event (5–6 July) in 2007. This increase may represent an influx of juveniles moving downriver into the sampling area. Because no fish were captured during snorkeling surveys above the rapids at rkm 12 in 2006, it was assumed that most larvae drifted into the sampled area. Due to the small year class in 2006, if a group of juveniles was present and not detected upstream of "Section 1", their downstream movement into the sampled area could have caused the observed increase in juvenile abundance. Only one juvenile was captured above rkm 12 in 2007, and because of the overall size of the year class, the impact of a small group of fish moving into the sample area would not have been as large. The increase in abundance observed in 2007 was within the bounds of the confidence intervals from previous sampling events.

The drift behavior of larvae may have caused abundances to decline from their initial level. Larvae moved downriver up to 40 d after spawning in the Sturgeon River, Michigan (Auer and Baker 2002). Sampling in the Peshtigo River began 30 and 37 d after spawning in 2006 and 2007, respectively. Although marked fish all exceeded 50 mm on the first sampling event, they resembled larvae, lacking the distinctive mottled coloration, scutes, and well-developed fins that characterize age-0 juveniles (Peterson et al. 2006). Some individuals marked on the initial sampling event may have continued to move downstream and left the river, preventing their recapture and causing the initial drop in abundance. Recaptures were infrequent during the early sampling events, preventing evaluation of the movement of fish of this size. Small lake sturgeon may also be susceptible to higher rates of predation until their protective scutes develop; however, analysis of stomach contents from 746 potential sturgeon predators revealed that only one lake sturgeon (<50 mm) was consumed (Caroffino 2009). If predation contributed to the decline of age-0 juveniles, it would be expected to have a high impact while juveniles are small and a diminishing effect as age-0 juveniles attain a larger size (Gadomski and Parsley 2005b).

Once juveniles exceeded 100 mm in total length, the estimates of abundance were lower during subsequent sampling events. Although there was overlap in some of the confidence intervals for the latter abundance estimates, we also observed fewer fish in the river later in the season. This decline may represent natural mortality from starvation or predation. Despite the extensive visual surveys conducted throughout 2006 and 2007, no dead sturgeon were observed. All fish that were captured were in good condition and demonstrated rapid growth rates (up to 3.8 mm per day), similar to those observed in the 2003 year class (Benson et al. 2006). In addition, stomach contents from 376 potential piscine predators were examined for the presence of juvenile lake sturgeon larger than 50 mm during the 2 years of this study, and there was no evidence of juvenile consumption (Caroffino 2009). Although the impact of avian predators present along the lower Peshtigo River was not evaluated, the following species were observed during this research: belted kingfisher *Megaceryle alcyon*, great blue heron *Ardea herodias*, snowy egret *Egretta thula*, black-crowned night heron *Nycticorax nycticorax*, osprey *Pandion haliaetus*, and bald eagle *Haliaeetus leucocephalus*. The nocturnal behavior of age-0 juvenile lake sturgeon (Chiasson et al. 1997; Holtgren and Auer 2004; Benson et al. 2005b) may reduce predation risk from both avian and fish predators. Gadomski and Parsley (2005a) found that predation of juvenile white sturgeon *Acipenser transmontanous* was reduced in low-light conditions. It is unlikely that natural mortality alone

caused the reduction in abundance of age-0 juvenile lake sturgeon that was observed.

Modeling suggested that survival of age-0 juvenile lake sturgeon was constant by site and through time. This parameter does not exclusively estimate the probability of survival, but the probability of surviving and remaining in the sampled area. Due to the observed initial drop in population abundance, we speculated that survival may have differed during the first or second time period; however, modeling survival as two parameters, one for the initial drop and one for the remainder of the time period was not better supported than models with a single survival parameter ($\Delta AIC_c$=3.70). The best fit models estimated daily survival between the sampling periods to be 0.953. The remaining 0.047 represents mortality and/or emigration. In a laboratory environment, mortality of age-0 juvenile lake sturgeon was negligible, ranging from 0 to 0.6% over 5 weeks (Fajfer et al. 1999). Although consumption of lake sturgeon by predators or evidence of other mortality was not observed in the Peshtigo River, it may occur. However, it is also likely that juveniles may leave the river and migrate to Green Bay throughout the summer months.

Despite capture probabilities that generally decreased in lower sections, downstream movements were detected more often than upstream movements. Multistate models that separated movements by direction, either upstream or downstream, were better supported than those that did not. In all cases, if a juvenile sturgeon had the opportunity to move upstream or downstream to an adjacent section, the probability of moving downstream exceeded the probability of moving upstream, reflecting an apparent trend toward downstream movement. Research utilizing radio telemetry to monitor the movements of age-0 juvenile lake sturgeon has suggested that they leave the natal river after a decline in water temperatures during late summer and early fall (Holtgren and Auer 2004; Benson et al. 2005b). However, monitoring age-0 juvenile movements with this method has only occurred near the end of the growing season and after juveniles have exceeded 220 mm in total length. While the majority of age-0 juveniles may remain in the natal river until fall, the evidence presented here suggests that there may be a tendency for downstream movement throughout the summer that results in some age-0 juveniles leaving the natal river before a decline in water temperature occurs.

It is unclear why some age-0 juvenile lake sturgeon leave the Peshtigo River during the summer months. Although food availability has not been compared between the Peshtigo River and Green Bay, the growth rates of juveniles suggest that it is not limiting. There is also substantial habitat available for juvenile lake sturgeon in the lower Peshtigo River (Benson et al. 2005b). Because of the small size and connectivity of this system uniform thermal conditions are common, and lethal levels were not observed (Fajfer et al. 1999). If conditions were not suitable for age-0 juvenile lake sturgeon we would have expected to observe a larger-scale emigration from the river. The likely reason that some age-0 juveniles emigrate from the Peshtigo River may be related to the reduced length of the available river. The historic spawning grounds in this and many tributaries to the Great Lakes were located well upstream of present-day barrier dams (Daugherty et al. 2009). Larvae had to drift for longer periods of time and greater distances to reach nursery habitat, and that same movement in a short-run stream could result in emigration. Likewise, age-0 juveniles could historically move greater distances downriver without leaving the nursery habitat, but such movements in restricted habitats in a shortened stream would result in emigration.

If properly designed, annual monitoring of age-0 juvenile lake sturgeon populations can continue to fill gaps in knowledge concerning this life stage. Multiple years of complete river sampling will determine the extent of critical nursery habitat for each sturgeon population, as the amount used by juvenile lake sturgeon will vary widely with changing year-class strength, as observed in the Peshtigo River during 2006 and 2007. Large reaches of habitat should be protected, so that in years of favorable reproductive conditions, sufficient habitat is available to facilitate high survival of juveniles. This research was not designed to capture juvenile lake sturgeon in Green Bay; however, such captures could be incorporated as an additional state in multistate models, allowing the probability of river emigration to be estimated throughout the summer months. Without estimates of emigration rates, downstream movement that results in emigration from the natal river could produce misleading estimates of age-0 abundance generated by closed-population estimators. Capturing and marking juveniles after summer emigration may allow the contribution of this group to future adult

populations to be determined. Presently, the survival rate of larval and juvenile lake sturgeon once they enter the adjoining lake is unknown. It is unclear if annual survival and is maximized by spending extended periods in the natal river or if an early exit is advantageous. Continued research that incorporates the patterns of abundance and movement observed during our study to address these questions about the dynamics of age-0 juvenile lake sturgeon populations will increase the effectiveness of annual monitoring programs and contribute the overall goal of basin-wide restoration.

**Acknowledgments** We would like to thank J. Lorenz, N. Barton, S. Tyszko, R. Turner, R. Elliott, and M. Donofrio for their assistance with field collections and project logistics. A. Rosenberger and J. Margraf provided constructive comments on a draft of this manuscript. Support for this project was provided by the Great Lakes Fishery Trust, Purdue University, and University of Alaska Fairbanks.

## References

Auer NA (1999a) Lake sturgeon: a unique and imperiled species in the Great Lakes. In: Taylor W, Ferreri CP (eds) Great Lakes fisheries policy and management: a binational perspective. Michigan State University Press, East Lansing, pp 515–536

Auer NA (1999b) Population characteristics and movements of lake sturgeon in the Sturgeon River and Lake Superior. J Gt Lakes Res 25:282–293

Auer NA, Baker EA (2002) Duration and drift of larval lake sturgeon in the Sturgeon River, Michigan. J Appl Ichthyol 18:557–565

Beamish FWH, Noakes DLG, Rossiter A (1998) Feeding ecology of juvenile lake sturgeon, *Acipenser fulvescens*, in northern Ontario. Can Field-Naturalist 112:459–468

Benson AC, Sutton TM, Elliott RF, Meronek TG (2005a) Evaluation of sampling techniques for age-0 lake sturgeon in a lake Michigan tributary. N Am J Fish Manage 25:1378–1385

Benson AC, Sutton TM, Elliott RF, Meronek TG (2005b) Seasonal movement patterns and habitat preferences of age-0 lake sturgeon in the lower Peshtigo River, Wisconsin. Trans Am Fish Soc 134:1400–1409

Benson AC, Sutton TM, Elliott RF, Meronek TG (2006) Biological attributes of age-0 lake sturgeon in the lower Peshtigo River, Wisconsin. J Appl Ichthyol 22:103–108

Brownie C, Hines JE, Nichols JD, Pollock KH, Hestbeck JB (1993) Capture-recapture studies for multiple strata including non-Markovian transitions. Biom 49:1173–1187

Burnham KP, Anderson DR (2002) Model selection and multimodel inference. Springer, New York

Caroffino DC (2009) Early life history dynamics of lake sturgeon. University of Alaska Fairbanks, Dissertation

Chiasson WB, Noakes DLG, Beamish FWH (1997) Habitat, benthic prey, and distribution of juvenile lake sturgeon (*Acipenser fulvescens*) in northern Ontario rivers. Can J Fish Aquat Sci 54:2866–2871

Choquet R, Reboulet AM, Lebreton JD, Gimenez O, Pradel R (2005) U-CARE 22 User's Manual CEFE, Montpellier, France (http://ftp.cefe.cnrs.fr/biom/Soft-CR/)

Cormack RM (1964) Estimates of survival from the sighting of marked animals. Biom 51:429–438

Daugherty DJ, Sutton TM, Elliott RF (2009) Suitability modeling of lake sturgeon habitat in five northern Lake Michigan tributaries: implications for population rehabilitation. Rest. Ecol. 17:245–257

Fajfer S, Meyers L, Willman G, Carpenter T, Hansen M (1999) Growth of juvenile lake sturgeon reared in tanks at three densities. N Am J Aquac 61:331–335

Fortin R, Mongeau J, Desjardins G, Dumont P (1993) Movements and biological statistics of lake sturgeon (*Acipenser fulvescens*) populations from the St Lawrence and Ottawa River system, Quebec. Can J Zool 71:638–650

Gadomski DM, Parsley MJ (2005a) Effects of turbidity, light level, and cover on predation of white sturgeon larvae by prickly sculpins. Trans Am Fish Soc 134:369–374

Gadomski DM, Parsley MJ (2005b) Laboratory studies on the vulnerability of young white sturgeon to predation. N Am J Fish Manage 25:667–674

Harkness WJK, Dymond JR (1961) The lake sturgeon: the history of its fishery and problems of conservation. Ont Dept of Lands and Forests, Ottawa

Hay-Chmielewski EM, Whelan GE (1997) Lake sturgeon rehabilitation strategy. Michigan Dept of Nat Res, Special Rep Number 18, Lansing

Holtgren JM, Auer NA (2004) Movement and habitat of juvenile lake sturgeon (*Acipenser fulvescens*) in the Sturgeon River/Portage Lake system, Michigan. J Freshw Ecol 19:419–432

Hurvich CM, Tsai CL (1989) Regression and time-series model selection in small samples. Biom 76:297–307

Jolly GM (1965) Explicit estimates from capture-recapture data with both death and immigration in a stochastic model. Biom 52:225–247

Kempinger JJ (1988) Spawning and early life history of lake sturgeon in the Lake Winnebago system, Wisconsin. Am Fish Soc Symp 5:110–122

Kempinger JJ (1996) Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. N Am J Fish Manage 116:102–114

Knights BC, Vallazza JM, Zigler SJ, Dewey MR (2002) Habitat and movement of lake sturgeon in the upper Mississippi River system, USA. Trans Am Fish Soc 131:507–522

McKinley S, Der Kraak GV, Power G (1998) Seasonal migrations and reproductive patterns in the lake sturgeon, *Acipenser fulvescens*, in the vicinity of hydroelectric stations in northern Ontario. Environ Biol Fish 51:245–256

Peake S, Beamish FWH, McKinley RS, Scruton DA, Katopodis C (1997) Relating swimming performance of lake sturgeon, *Acipenser fulvescens*, to fishway design. Can J Fish Aquat Sci 54:1361–1366

Peterson DL, Vecsei P, Jennings CA (2006) Ecology and biology of the lake sturgeon: a synthesis of current

knowledge of a threatened North American *Acipenseridae*. Rev Fish Biol Fish 16:386–404

Pradel R, Winterbert CMA, Gimenez O (2003) A proposal for a goodness-of-fit test to the Arnason-Schwarz multisite capture-recapture model. Biom 59:43–53

Rusak JA, Mosindy T (1997) Seasonal movements of lake sturgeon in Lake of the Woods and the Rainy River, Ontario. Can J Zool 74:383–395

Seber GAF (1965) A note on the multiple recapture census. Biom 52:249–259

Secor DH, Anders PJ, Van Winkle W, Dixon D (2002) Can we study sturgeons to extinction? What we do and don't know about the conservation of North American sturgeons. Am Fish Soc Symp 28:3–10

White GC, Burnham KP (1999) Program MARK: survival estimation from populations of marked animals. Bird Study 46(suppl):120–139

Winemiller KO, Rose KA (1992) Patterns of life-history diversification in North American fishes: implications for population regulation. Can J Fish Aquat Sci 49:2196–2218