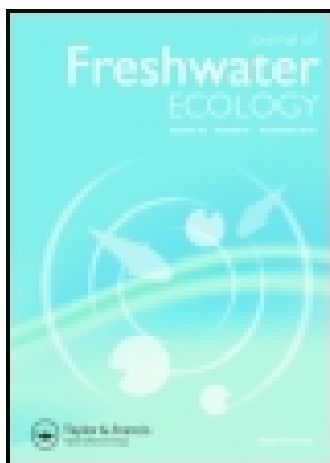


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### Large-scale dispersal patterns and habitat use of plains topminnow *Fundulus sciadicus*: implications for species conservation

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## Large-scale dispersal patterns and habitat use of plains topminnow *Fundulus sciadicus*: implications for species conservation

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Movement behaviors attributed to spawning, dispersal, or altered habitat availability are essential to the ecology of many lotic fishes and, although considerable research has described movements of sport fish, little is known about the movement patterns of nongame species. Streams and rivers, wherein plains topminnow *Fundulus sciadicus* are prevalent, occur in a nonequilibrium state in which habitat patches are sporadically created and lost due to hydrologic variability. This results in regular extirpation and need for recolonization of many plains fishes, including plains topminnow. Species persistence, therefore, is dependent on tolerances to fluctuating habitat conditions and life-history traits that allow dispersal over large areas. To better understand the regional distribution of plains topminnow, we monitored large-scale dispersal patterns and habitat use of two introduced populations in Nebraska. In 2011 and 2012, plains topminnow were marked using visible implanted elastomer (VIE) marks and released at the center of two 3000-m study reaches. Populations were sampled monthly from April to November in 2011 and April through September in 2012 to describe movement patterns and habitat use. Plains topminnow were highly mobile, consistently associated with select habitat features, and the estimated individual home range exceeded standard sampling reach distances by nearly four times. The movement of plains topminnow occurred at greater rates and to distances further than known for similar species. These large-scale movements likely help maintain connectivity among populations within stream drainages and facilitate recolonization of regularly extirpated habitat patches. In this context, species movement may be critical to the maintenance and potential recovery of populations of this and other rare lotic fishes.

**Keywords:** *Fundulus sciadicus*; habitat use; dispersal; reintroduction; movement

### Introduction

Movement behaviors attributed to spawning, dispersal, and responses to fluctuating habitat availability are common among lotic fishes (Peterson & Bayley 1993; Dingle 1996; Schmetterling & Adams 2004). Although there has been considerable research evaluating movement patterns of sport fish species (Rodríguez 2002; Schmetterling & Adams 2004; VanArnum et al. 2004), details concerning the movement potential of nongame species remain mostly unknown (Smithson & Johnston 1999; Hudy & Shiflet 2009; Hodges & Magoulick 2011). Understanding movement and spatially explicit patterns of habitat use

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is central to developing concepts of large-scale lotic ecology (Fausch et al. 2002; Scheurer et al. 2003).

Stream fish populations have been considered homogenous with individuals moving freely throughout a system (Gowan et al. 1994; Fausch & Young 1995) or as relatively discrete populations with restricted movement (Gerking 1959; Heggeness et al. 1991; Larson et al. 2002). The recognition of complex dispersal patterns in stream fishes and frequent long-distance movement (e.g., Fausch & Young 1995; Gowan & Fausch 1996; Hudy & Shiflet 2009) is contrary to the notion that stream fishes are completely sedentary (Fausch et al. 2002). Movement behaviors likely are necessary responses to changing resource abundance, distribution, and quality that cease when suitable habitat patches are encountered (Dingle 1996; Fausch et al. 2002). However, the scale at which these movement behaviors transpire has varied greatly among taxonomic groups and is commonly contingent upon distances to important habitats or mobility of the species (Skalski & Gilliam 2000; Kahler et al. 2001; Rodríguez 2002; Hudy & Shiflet 2009). Therefore, dispersal events are important to the regulation of population structure, connection of spatially divided populations, colonization of newly accessible habitat patches, and recolonization of areas where populations have been extirpated (Schlosser & Angermeier 1995; Taylor 1997; Lonzarich et al. 1998; Hughes 1999; Johnston 2000).

The Great Plains contain a variety of diverse and dynamic aquatic systems with high variation in physical and chemical properties (Poff & Ward 1989; Rinne & Stefferud 1999; Dodds et al. 2004; Franssen et al. 2006). Lotic systems of the region oscillate between precipitous states; consequently, habitat patches are sporadically created and lost (Fausch et al. 2002; Scheurer et al. 2003; Dodds et al. 2004; Franssen et al. 2006). Plains fishes are typically tolerant of wide fluctuations in habitat conditions at a local scale (Smale & Rabeni 1995) and have life-history traits that result in dispersal (Matthews & Marsh-Matthews 2003; Scheurer et al. 2003; Dodds et al. 2004; Gido et al. 2010).

Plains topminnow, *Fundulus sciadicus*, populations have declined in both distribution and local abundance throughout their native range (Rahel & Thel 2004; Pasbrig et al. 2012). Declining water quality and quantity, habitat degradation, population fragmentation, and the introduction of nonnative fishes have resulted in declines of other Great Plains stream fishes (Haslouer et al. 2005), and likely influence the persistence of this species (Rahel & Thel 2004; Pasbrig et al. 2012). Plains topminnow is a habitat specialist that occurs in widely distributed, isolated, and dynamic habitat patches characterized by shallow, stagnant water that are especially vulnerable to desiccation by means of prevalent agricultural activities that divert water from the channel or lower the water table (Rahel & Thel 2004; Fischer & Paukert 2008; Pasbrig et al. 2012). The isolated nature of plains topminnow populations suggests that stream connectivity may be important to their long-term persistence (Cross & Collins 1995; Pflieger 1997; Rahel & Thel 2004; Pasbrig et al. 2012).

Movement behaviors permit the occupancy of irregularly distributed and sporadically available habitat patches important to lotic fish occurrence. In recent years, the understanding of movement patterns and habitat use of sport fish species has greatly increased; however, little is currently known about the movement behaviors of many nongame fishes. To further understand the regional population dynamics of plains topminnow and the influence of dispersal on large-scale conservation activities, the movement patterns and spatially explicit habitat use of two introduced populations were monitored in Nebraska over a two-year period.

## Methods

### Study area

Two low-order prairie streams in which plains topminnow were thought to have been locally extirpated were selected for reintroduction to evaluate movement patterns and habitat use as part of an effort to recover the species in Nebraska. Historic occurrences were identified using the Nebraska Game and Parks Fish Inventory Database and were recently confirmed in a range-wide survey to describe the species status (Pasbrig et al. 2012). Both streams are located in the 39,103 km<sup>2</sup> Loup River Basin in central Nebraska. Human settlement in the area is sparse with land use dominated by pasture and to a lesser degree groundwater-irrigated crop cultivation. Plains topminnow were historically common throughout the Loup River Basin; however, following substantial declines the species currently occurs sporadically in relatively close proximity to the selected reintroduction locations (Pasbrig et al. 2012).

Sweet Creek is a low-gradient, meandering stream with a broad, well-developed floodplain that flows through a sand-dominated alluvial valley in the 257-km<sup>2</sup> Sweet Creek subwatershed (Figure 1). Sweet Creek is located near the confluence of the South Loup River near Ravenna, NE. In the 3000-m stream reach selected for study, the available macrohabitat included isolated perennial pools, limited backwater, and scour pools, and many reaches with minimal surface flow (e.g., glides) embedded within larger intermittent segments that expand and contract seasonally. The average gradient throughout Sweet Creek is <0.01% (elevation of 602–605 m), and at base flow the wetted width (mean  $\pm$  standard error, SE) was  $5.84 \pm 0.20$  m during 2011 and 2012. Sand was the dominant substrate found in association with abundant slow-moving glides, but finer

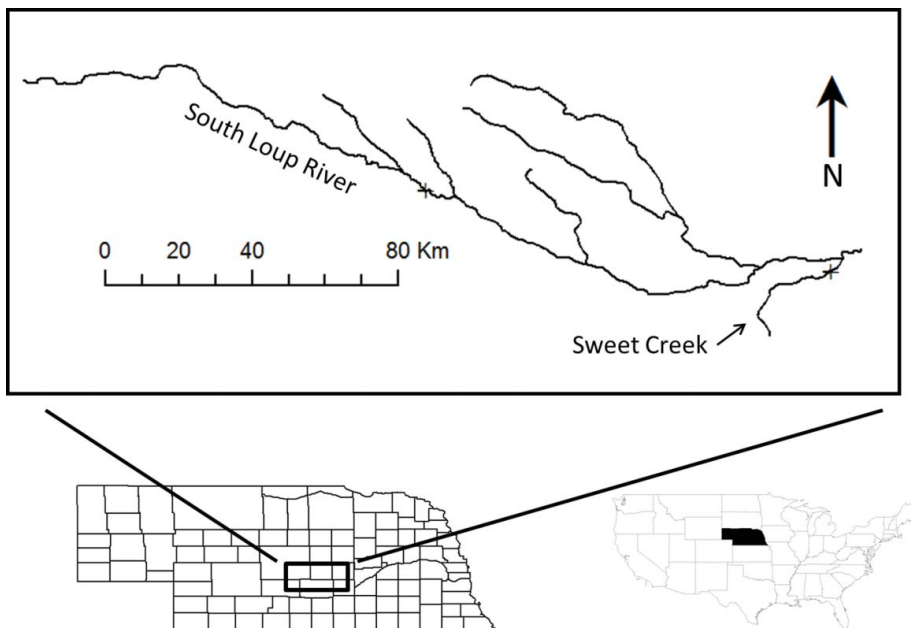


Figure 1. Prairie streams in the Loup River Basin, NE, which were sampled during 2011 and 2012 to describe movement behaviors and habitat use of introduced plains topminnow. The 3000-m sampling reaches (X) were sampled monthly to describe movement behaviors after reintroduction.

substrates were present in the isolated backwater areas. The most abundant resident fish species included sand shiner, *Notropis stramineus*, bigmouth shiner, *Notropis dorsalis*, and brassy minnow, *Hybognathus hankinsoni*. Largemouth bass, *Micropterus salmoides*, green sunfish, *Lepomis cyanellus*, bluegill, *Lepomis macrochirus*, fathead minnow, *Pimephales promelas*, red shiner, *Cyprinella lutrensis*, common carp, *Cyprinus carpio*, black bullhead, *Ameiurus melas*, and plains killifish, *Fundulus kansae*, were also present.

The South Loup River is a relatively low-gradient stream with highly entrenched banks and many meanders that flows through a sand-dominated alluvial valley in the 4099-km<sup>2</sup> South Loup River subwatershed near Oconto, NE (Figure 1). In the 3000-m stream segment selected for study, the most abundant macrohabitats consisted of perennial runs and low-velocity marginal areas with abundant overhanging vegetation. Isolated backwater habitats and scour pools were rare along the sampling reach but were consistently available. The South Loup River has an average gradient of approximately 0.01% (elevation of 725–729 m), and at base flow the wetted width was  $25.9 \pm 3.99$  m during the two-year sampling period. Sand was the dominate substrate found in association with runs, with finer substrates available in areas with little flow. The most abundant resident fish were red shiner and sand shiner. However, fathead minnow, bigmouth shiner, brassy minnow, flathead chub, *Platygobio gracilis*, channel catfish, *Ictalurus punctatus*, green sunfish, bluegill, largemouth bass, river carpsucker, *Carpoides carpio*, shorthead redhorse, *Moxostoma macrolepidotum*, white sucker, *Catostomus commersonii*, and common carp were also present.

### **Plains topminnow introductions**

Plains topminnow were released at the center of the 3000-m sampling reach which limited upstream and downstream detection of dispersal to a maximum of 1500 m. Introductory population sizes were determined based upon the total area of habitat considered suitable for plains topminnow colonization, using velocity tolerances and introduction rates of western mosquitofish, *Gambusia affinis*, and Gila topminnow, *Poeciliopsis occidentalis* (Duryea et al. 1996; Ward et al. 2003). Water velocity was measured during base-flow conditions at five points along equally spaced transects throughout each sampling reach, and was interpolated to describe the total area available to plains topminnow. Areas with velocities less than 0.365 m/s were considered suitable for plains topminnow. A total of 1000 individuals per suitable hectare were released in March of 2011 and 2012 at each site. At Sweet Creek, a total of 662 adult (age 1+) individuals (total length, TL  $\pm$  SE:  $47.3 \pm 0.53$ ) were released in both 2011 and 2012. At the South Loup River, 770 adult (age 1+) individuals (TL  $\pm$  SE:  $47.3 \pm 0.53$ ) were introduced each year. All plains topminnow were obtained from an extensive aquaculture pond constructed to house a species-specific refuge population near Wilcox, NE (Schumann et al. 2012).

Plains topminnow were marked with red visible implanted elastomer (VIE) in 2011 and blue VIE marks in 2012. All VIE marks were injected under the integument on either side of the fish, either immediately below or slightly anterior to the dorsal fin. Experimental evaluation of long-term VIE mark retention and marking mortality of plains topminnow found zero-marking mortality and 100% retention (Schumann et al. 2013).

### **Plains topminnow sampling**

Starting one month after introduction, sampling was conducted in an upstream direction using single-pass backpack electrofishing for the entire 3000-m study reach. Study

reaches were sampled monthly from April to November in 2011 and between April and September in 2012. All captured plains topminnow were checked for a VIE mark and measured to the nearest 1 mm TL. Global positioning system coordinates were recorded for all plains topminnow captured to determine the distance moved. The macrohabitat type where individuals were captured was described and the substrate composition was visually estimated using a modified Wentworth classification for dominant type as silt/muck (<0.06 mm), sand (0.06–2 mm), fine gravel (2–16 mm), coarse gravel (16–64 mm), cobble (64–250 mm), and boulder (>250 mm) categories. The captured individuals were released approximately 50 m downstream of the capture location to avoid incidental recapture.

### Data analysis

Marked fish were classified as sedentary or mobile in either the upstream or downstream direction. Individuals that did not move beyond the central reach (i.e., <150 m) were classified as sedentary and assigned a value of zero distance moved. Distance traveled by mobile individuals was measured relative to the center of the reintroduction reach with a maximum of 1500 m moved. The percent of recaptured individuals that were mobile was expressed as the ratio of recaptures that were mobile to those that were sedentary (Roberts & Angermeier 2007). Home range size was estimated as the median linear distance moved by recaptured individuals at each site (Valley et al. 2010). We evaluated movement patterns of plains topminnow by comparing the differences among the three movement groups (sedentary, upstream, and downstream) at each site and during each year using a Mann–Whitney *U*-test. To compare temporal movement patterns, we fit a linear regression model to movement distance for each recapture period. Habitat use was described as the proportion of captured individuals in association with each substrate and macrohabitat available at each site.

## Results

### Sweet Creek

Of the 1324 released plains topminnow, 40 marked individuals were recaptured which represented 7.3% of the 547 individuals captured during the monthly sampling (Figures 2 and 3). No plains topminnow that were marked in 2011 were encountered in 2012 sampling efforts; however, the number of recaptured individuals was greater in 2012 ( $n = 24$ ) than 2011 ( $n = 16$ ) (Figure 2). Across years, three individuals were recaptured within the central release reach (Figure 2). These individuals had zero movement whereas a significantly greater number of individuals ( $n = 37$ ) were mobile (Mann–Whitney *U*-test:  $U = 143.5$ ;  $p = 0.02$ ). The average movement rate of plains topminnow was calculated as 93.3% (standard deviation,  $SD = 11.18$ ) which increased through time ( $F_{1,12} = 5.09$ ,  $r^2 = 0.30$ ,  $p = 0.04$ ) as marked individuals moved away from the release point and with decreased discharge (Figure 3). Plains topminnow were captured throughout the 3000-m study reach at Sweet Creek; however, a majority (Mann–Whitney *U*-test:  $U = 141.5$ ;  $p = 0.03$ ) of individuals were recaptured downstream of the release point (Figure 2). The greatest movement distance observed was 1300 m with individuals moving this distance in both the upstream and downstream directions (Figure 2). The median movement distance or the estimated home-range size was 655 m and was greater than four times the standard sampling reach for a stream of this size (i.e., 150 m).

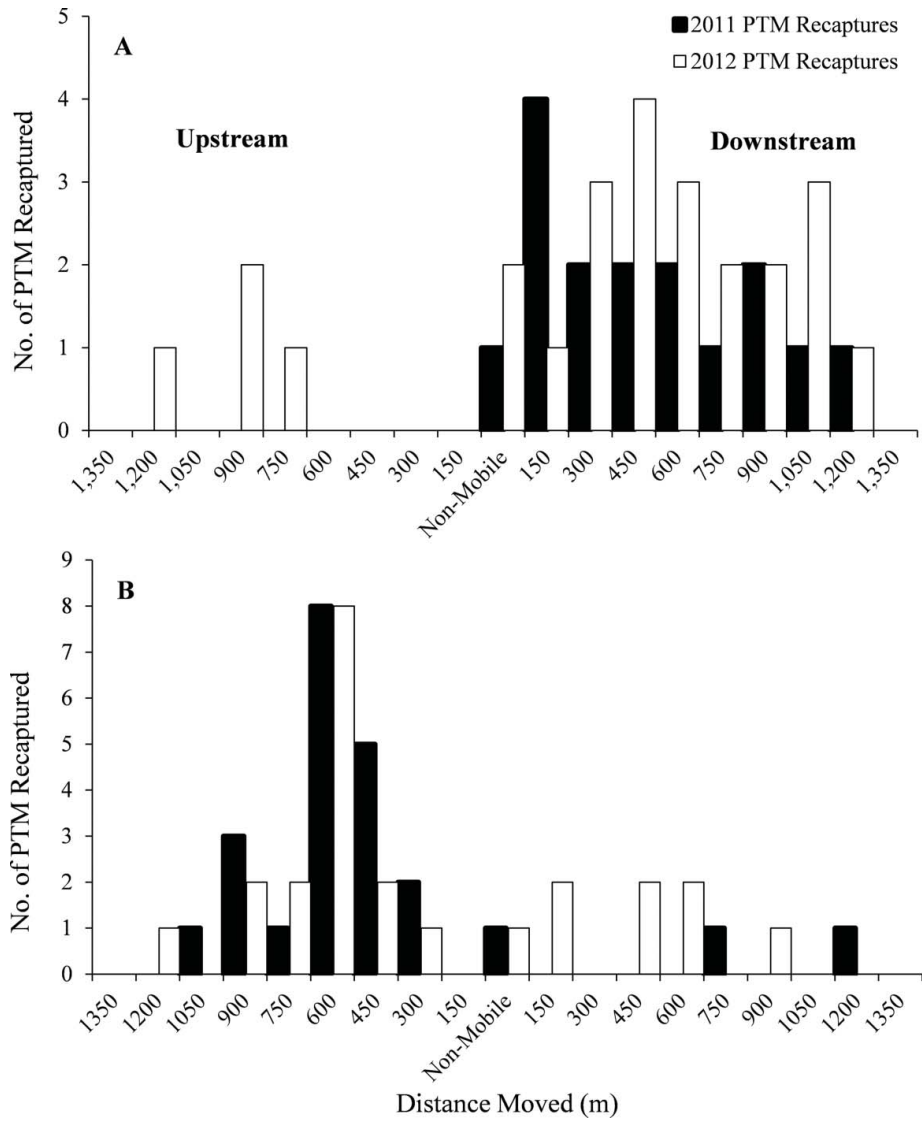


Figure 2. Distribution of distances moved by released plains topminnow at Sweet Creek (A) and the South Loup River (B) in Nebraska, throughout a 3000-m sampling reach during April to November in 2011 (black) and April to September in 2012 (white).

No plains topminnow individuals were captured at the reintroduction site (i.e., 40 times mean wetted width) during preliminary assessments of the fish community. However, after the release of marked individuals unmarked, adult (>25 mm TL) plains topminnow were encountered throughout the 3000-m sampling reach (Figure 3). Unmarked juvenile and adult plains topminnow captured during the monthly sampling efforts were potentially wild individuals that were present prior to introductions or developed offspring from the hatchery stocked individuals. Regardless of origin, both marked and unmarked plains topminnow moved similarly throughout Sweet Creek, and were consistently captured in association with the same habitat features. Recaptured and unmarked



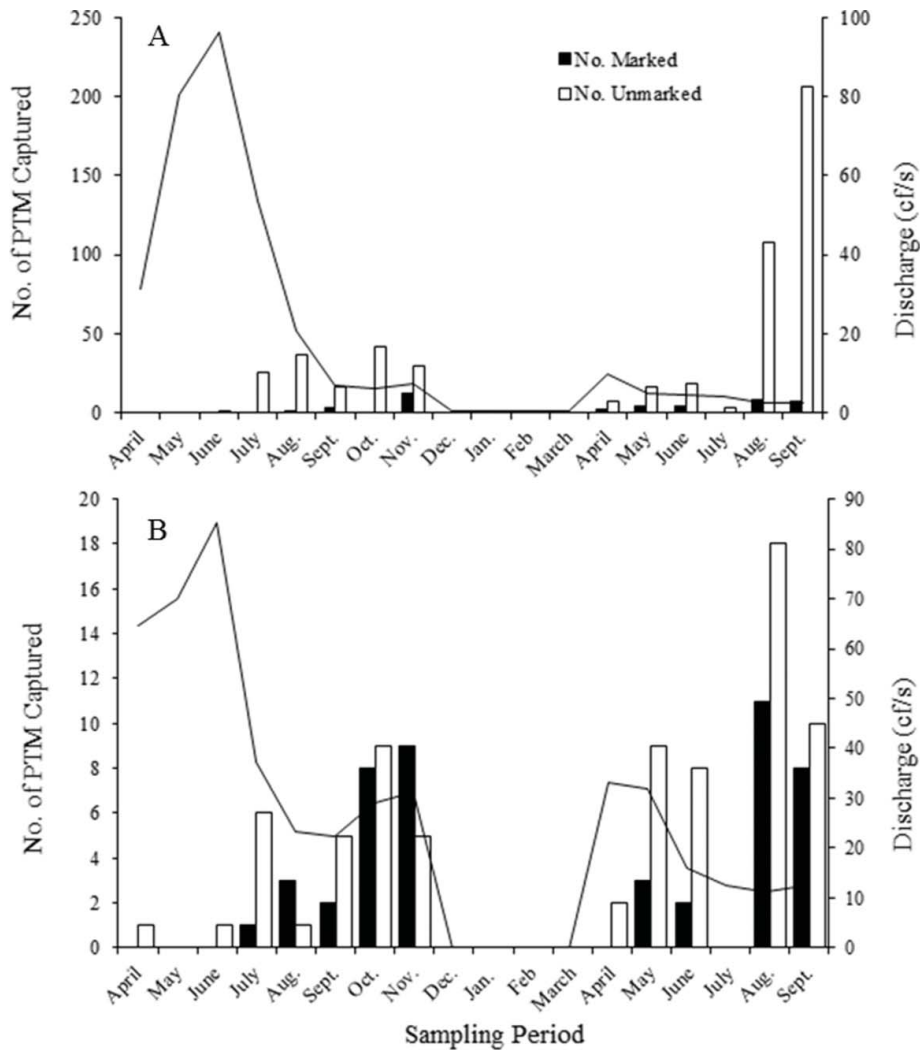


Figure 3. Mean monthly discharge (solid line) at Sweet Creek (A) and the South Loup River (B), in Nebraska, and total number of both marked (dark) and unmarked (white) plains topminnow captured during 2011 and 2012.

plains topminnow were concentrated along the inner margin of a stream bend downstream of the release site ( $n = 469$ ) and relatively few individuals ( $n = 78$ ) were captured in the artificially channelized upstream reach (Figure 2). A majority of marked and unmarked plains topminnow individuals were consistently captured along the unstable, stagnant stream margins ( $n = 404$ ), while fewer individuals were encountered in glides ( $n = 87$ ) and backwater habitats ( $n = 56$ ). Nearly all plains topminnow were captured in association with sand substrates (92%), with few captured over fine substrates.

### ***South Loup River***

Of the 1540 released plains topminnow, 47 marked individuals were recaptured which represented 62.7% of the 74 individuals captured during the monthly sampling (Figures 2

and 3). The number of plains topminnow recaptured in 2011 ( $n = 23$ ) was similar to the number captured in 2012 ( $n = 24$ ) and no individuals released in 2011 were encountered in 2012 (Figure 2). Across years, only two individuals exhibited no movement and were recaptured at the reintroduction site (Figure 2), while a significantly greater number of individuals ( $n = 45$ ) were considered mobile (Mann–Whitney  $U$ -test:  $U = 154.0$ ;  $p = 0.004$ ). At the South Loup River, plains topminnow movement rate was 97.8% (SD = 4.18), and the rate of movement and total capture were stable through time ( $F_{1,12} = 2.02$ ,  $r^2 = 0.14$ ,  $p = 0.18$ ) despite the decreasing discharge (Figure 3). No significant difference between the number of fish that moved upstream ( $n = 36$ ) and downstream ( $n = 9$ ) was found, despite a greater number of individuals captured upstream (Mann–Whitney  $U$ -test:  $U = 72.5$ ;  $p = 0.22$ ; Figure 2). The greatest observed distance moved was 1255 m in the upstream direction, while the furthest downstream movement was 1200 m (Figure 2). The estimated home range of recaptured plains topminnow was 635 m (Figure 2), which were more than twice the previously designated sampling reach (i.e., 300 m).

No plains topminnow were captured at the reintroduction site during the preliminary assessments of the fish community. However, after the release of marked individuals in 2011 and during the 3000-m sampling conducted in summer 2011, adult (>25 mm TL) unmarked individuals were captured (Figure 3). Unmarked plains topminnow had the potential to be wild individuals that were present prior to introductions or offspring of stocked individuals. Irrespective of source, both marked and unmarked plains topminnow were found in similar habitats in the South Loup River and were consistently captured in association with similar habitat features (Figure 2). A majority of both unmarked and marked plains topminnow ( $n = 74$ ) were captured upstream of the introduction location and those individuals were frequently captured in association with a large bend (80.5%). Location and extent of habitat patches were relatively consistent throughout the study and individuals were captured most often in a single, large backwater area ( $n = 44$ ) but were also prevalent along the stream margin ( $n = 30$ ). Most individuals were captured in association with fine (silt/muck) substrates (75%), with fewer individuals captured in association with sand substrates (25%).

## Discussion

The demonstration of explicit dispersal patterns and frequent large-scale movements of plains topminnow challenges the assumption that the resident stream fishes exhibit restricted movement (Gerking 1959; Hill & Grossman 1987; Heggeness et al. 1991; Gowan et al. 1994; Fausch & Young 1995). This evidence of large-scale movement behaviors is in agreement with several contemporary studies of lotic fish movement in which similar patterns were found (Gowan & Fausch 1996). Although individual plains topminnow recaptured at both sites exhibited both sedentary and mobile behaviors, the movement rate and the distance traveled greatly exceeded values reported by previous studies of small lotic fishes (Schlosser 1998; Smithson & Johnston 1999; Larson et al. 2002; Rodríguez 2002). Additionally, our estimates of movement are likely conservative as most marked fish were not recaptured and many may have moved beyond the established 3000-m sampling reach. Plains topminnow were encountered in association with specific habitat types available at each site regardless of proximity to the release location. The occurrence of marked and unmarked individuals at specific habitat patches was similar; however, the presence of individuals from each cohort was sporadic through time suggesting regular movement behaviors occurring within these systems. These observations

supplement a developing landscape paradigm for stream assemblages in which large-scale movement patterns are common in response to resource demands and habitat availability (Fausch & Young 1995; Gowan & Fausch 1996; Fausch et al. 2002). We acknowledge the possibility that our introduction of hatchery-reared plains topminnow influenced the rates and distances we observed; however, the research has shown that hatchery-reared fish can acclimate and behave similarly to wild individuals and use the entire study area (Jordan et al. 2006).

Direct comparisons to previous movement studies are difficult due to differing monitoring methods, timing, duration of studies, and limited knowledge of movement patterns of nongame fishes. However, movement was quantified for two species in Fundulidae: blackspotted topminnow, *Fundulus olivaceus* (Smithson & Johnston 1999) and banded killifish, *Fundulus diaphanous* (Valley et al. 2010). Adult blackspotted topminnow regularly moved among study pools in a dynamic lotic system at rates that exceeded other taxa evaluated (i.e., creek chub, *Semotilus atromaculatus*, green sunfish, and longear sunfish, *Lepomis megalotis*), similar to our results for plains topminnow. The observation of large-scale movement behaviors for both species emphasizes the importance of movement to the life history of this family of fishes (Smithson & Johnston 1999). Banded killifish also exhibited similar movement patterns to plains topminnow and generally moved greater distances than blackchin shiner, *Notropis heterodon*, and blacknose shiner, *Notropis heterolepis*, in a lentic system (Valley et al. 2010). Despite traveling greater distances (maximum distance: 1813 m) than plains topminnow, banded killifish exhibited a more limited linear home range likely as a result of uniform habitat distribution in the lentic system relative to the longitudinal habitat mosaic common to lotic environments (Valley et al. 2010). Such consistency accentuates the importance of movement behaviors for these short-lived, opportunistic taxa (Dingle 1996).

Our investigation revealed multidimensional movement patterns in response to the available habitat complexes at two distinct lotic systems in which experimental populations of marked plains topminnow were introduced. At Sweet Creek, where the extent and location of habitat patches varied considerably, plains topminnow moved more frequently. In contrast, at the South Loup River site, habitats were relatively stable through time and the locations of capture were more consistent. Despite the differences between sites, the movement was regularly responsive to the availability of specific morphological stream features that are the results of lower water velocities. These results support past suggestions of the contributions that habitat heterogeneity has in structuring lotic fish movement patterns and longitudinal distribution (Labbe & Fausch 2000; Johnston 2000; Scheurer et al. 2003; Schmetterling & Adams 2004). Thus, plains topminnow movement behaviors are unlikely random, but rather facultative responses to environmental conditions that cease when suitable habitat patches are encountered (Dingle 1996; Johnston 2000; Kahler et al. 2001; Fausch et al. 2002; Schmetterling & Adams 2004).

Our recapture rates of plains topminnow were low throughout the study duration, potentially affected by sampling inefficiently, mortality of marked individuals, and the probable absence of individuals that migrated from the study area (Fausch et al. 2002). The marking process employed in the current study is known to result in limited mortality and has high retention and recognition (Schumann et al. 2013). Because we were able to sample a large segment of each system repeatedly, it is unlikely that sampling failed to detect a large number of individuals within the sampling reach. Instead, many individuals potentially moved beyond our sampling reaches. The failure to recapture individuals marked in 2011 in the subsequent year's sampling may be due to the high annual mortality previously reported for the species (Rahel & Thel 2004).

The observation of large-scale movement behaviors of plains topminnow identifies the importance of spatial dynamics in fish distribution. Traditional sampling methodologies may be inadequate for defining species' presence or absence at typical spatial scales (i.e., 100–300 m) that may not reflect the life history of all taxa (Fausch & Young 1995; Fausch et al. 2002). Recent surveys of plains topminnow throughout its native range described a substantial number of local extirpations (Pasbrig et al. 2012). However, attempts to identify range-wide distributions of this species may have underrepresented the spatial extent and number of extant populations, given our results of regular, large-scale movements. Sampling of historically occupied localities resulted in numerous discrete populations in close proximity that likely interact. These conclusions for plains topminnow demonstrate the importance of large-scale spatial patterns of lotic species distribution and conservation efforts.

Species movement behaviors appear to be important for the maintenance and potential recovery of populations of threatened and endangered fish species. Plains topminnow demonstrated consistent patterns of movement and clear associations with select habitat features throughout the riverscape. Large-scale movements maintain connectivity among populations within stream drainage areas (Li et al. 2009), reduce the potential for local extinctions, allow recolonization of habitats following extirpation, and have implications for population genetics (Jackson et al. 2001; Larson et al. 2002; Rahel & Thel 2004).

This study of movement behaviors and occupancy of critical habitat patches at multiple scales highlights the importance of embracing the continuous and heterogeneous nature of linear aquatic habitats to understand fish spatial dynamics (Labbe & Fausch 2000; Fausch et al. 2002; Scheurer et al. 2003; Dodds et al. 2004). Plains topminnow are highly mobile components of stream ecosystems and their occurrence is regulated by hydrologic variability and habitat features that occur disparately throughout these streams. The heterogeneous nature of plains topminnow occurrence exemplifies the difficulties associated with measurements and predictions of species distributions and further reveals the need to understand the spatial and temporal organization of important habitat patches.

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