Movement of Sacramento sucker (*Catostomus occidentalis*) and California roach (*Lavinia symmetricus*) in Strawberry Creek, a small urban Mediterranean-climate stream in Berkeley, CA

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ABSTRACT

The movements of aquatic organisms are poorly understood but have important ecological consequences. I studied fish movements of Sacramento sucker (*Catostomus occidentalis)* and California roach (*Lavinia symmetricus*) in Strawberry Creek, a small Mediterranean-climate stream on the University of California, Berkeley campus to quantify biweekly-scale movements, including distance and direction, over 9 months. I captured 101 sucker and 95 roach along a 1km stretch in July and September 2011 and January 2012, marked individuals with uniquely coded passive integrated transponder (PIT) tags, and released them to the area of initial capture. I resurveyed the stream biweekly to track the locations of individual fish using a portable antenna and quantify movement. Overall, suckers moved more than roach although most of the fishes did not move. Some physical barriers limited upstream movement although rain events aided upstream migration beyond the physical barriers. This study contributes information on the movements of two common stream fishes and highlights the influence of Mediterranean-climate regimes on fish movement patterns that have implications for future restoration efforts aimed at conserving fish populations in this urban stream.

KEY WORDS

seasonal movement, habitat restoration, natural and human disturbances, physical barriers, PIT tags

INTRODUCTION

Many Mediterranean-climate streams are altered by anthropogenic activities that can result in the decline of abundance of native fishes. Natural flows, on the contrary, are characterized by low water flows during the summer and high water flows during the winter and spring (Gasith and Resh 1999; Lytle and Poff 2004). Altering flow conditions may occur as a result of water diversion, dam construction, and heavy urbanization causing changes to the physical and biological characteristics of streams, including channel structure, sediment transport and species diversity (Bain et al. 1988, Ligon et al. 1995, Poff et al. 1997). Long periods of drought can cause a high mortality rate for native fishes (Gasith and Resh 1999) and when the habitat is ready to be colonized, native species compete against introduced species for the same space and food resources, leading to a decline in populations of native fishes (Lytle and Poff 2004). Evaluating fish responses to altered flows will provide adaptive management techniques to favor native species.

Quantifying movement within stream habitats is crucial to the understanding of ecological and demographical characteristics and requirements of aquatic species, especially in altered systems. For example, through the use of passive integrated transponder (PIT) tags that allow monitoring of tagged individuals without needing to capture fishes at each sampling event (Castro-Santos et al. 1996), longitudinal movement of fish in river systems have been tracked (Smithson and Johnston 1999), and life history characteristics had been understood (Riley et al. 2011). Movement of fishes can aid in evaluating restoration and management techniques that will sustain native populations and understand life history traits in an urban stream. However, the lack of published movement studies of nonsalmonids is pronounced (Ficke and Myrick 2011), and consideration should be given to endemic species that have declined in California from flow alterations (Marchetti and Moyle 2011). Therefore, examining trends in adaptations to the natural flow regime and quantifying fish movement can provide much-needed insight to management techniques that will protect native fishes from stream alteration.

After decades of habitat degradation due to urbanization in the Strawberry Creek watershed (University of California, Berkeley Campus), a restoration project was approved in 1987 to reestablish aquatic species, including the reintroduction of native fishes (Charbonneau and Resh 1992). Three native fish species have been successfully reintroduced, although it is unknown how well these populations will persist long-term. The stream has undergone unpredictable disturbances (e.g. chemical spills) that have resulted in mortality of organisms including fishes (Karlamangla 2011). Moreover, physical barriers could be limiting fish migration upstream, especially during spawning season when fishes tend to migrate (Moyle 2002). Although the stream is longitudinally connected throughout the year, it is unclear how much fish move seasonally and what effects urban disturbances and restoration structures have in fish movement within the system.

To understand the impact of the restored stream to the fish populations, I examined the movements of Sacramento sucker (*Catostomus occidentalis*) and California roach (*Lavinia symmetricus*) over the course of 9 months. I observed and monitored individual movement of the two common fishes and measured environmental variables to understand how physical barriers and human/natural disturbances affected native fish assemblages and movement patterns. I hypothesized that net distance movements would be driven by water flows and seasonality. Moreover, I also hypothesized that several physical barriers along the stream will limit upstream movement and disturbances will negatively impact fish assemblage.

METHODS

Study Site

Strawberry Creek is an urban stream in the University of California, Berkeley campus that underwent a major restoration project in the 1980s to reestablish the aquatic fauna and native riparian vegetation (Charbonneau and Resh 1992) (Fig.1). The creek is a third order stream and in the Berkeley campus two tributaries, the North and South Forks confluence at the Eucalyptus Grove (Charbonneau and Resh 1992). The stream is aboveground on campus then flows through an underground storm drain system under the city of Berkeley with the exception of the exposed day-lighted section in Strawberry Creek Park (Charbonneau and Resh 1992), finally flowing into the San Francisco Bay. Human disturbances caused by heavy urbanization have degraded the stream's natural conditions and it has affected the steelhead run that it was last seen in the early 1990s (Charbonneau and Resh 1992). Although the restoration project has significantly improved water quality, other urbanizations disturbances such as oil runoffs and construction may still be negatively impacting the native fishes that remain present. Sketches of the campus creek were drawn which included physical barriers and habitat surrounding the stream.

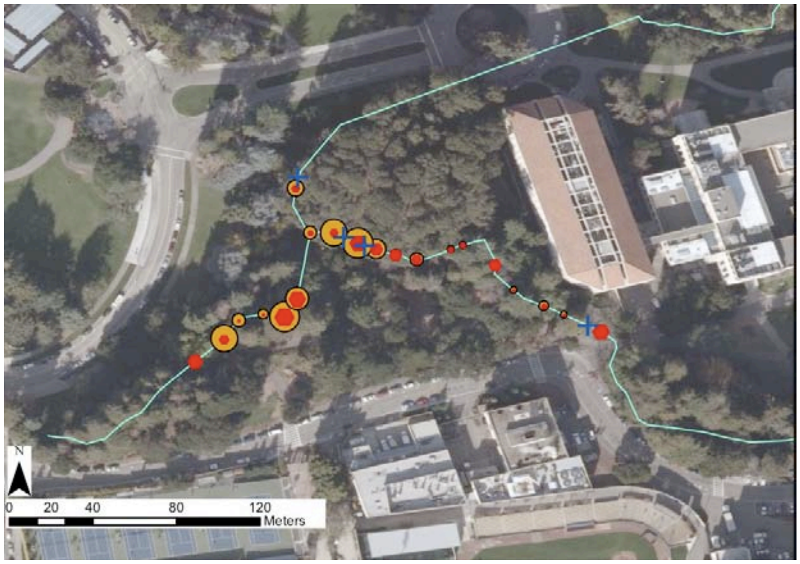

Fig.1. Strawberry Creek study site. The size of the circles corresponds with the abundance of sucker (yellow) and roach (red) in the South and North Forks and below the confluence. Four check dams (blue x marks) are also noted.

Study Species

I investigated the in-stream movement of the two common native stream fishes in Strawberry Creek among species and seasons. Sacramento sucker (*Catostomus occidentalis*, Fig.2a) is native to the San Joaquin River system; it is widely distributed in streams and reservoirs in central and northern California and found in an abundance of other native fishes (Moyle 1976; Villa 1985). Sucker abundance is positively correlated to water temperature, percent open canopy, and deeper pools in San Francisco Tributaries (Leidy 2007). California roach (*Lavinia symmetricus*, Fig. 2b) is endemic to the state and can withstand extremely low levels of dissolved oxygen (Moyle 1976). Roach are found in shallow pools, sand-gravel substrate size and warm water temperatures (Leidy 2007). Threespined stickleback (*Gasterosteus aculeatus*, Fig. 2c) is the third fish specie found in the creek. The specie is well distributed and endemic to California because it can tolerate elevated levels of salinity and is therefore found in brackish-, fresh-, and saltwater (Moyle 1976). Sticklebacks are associated with riparian cover, cold temperatures and in shallow pools with small substrate size (Leidy 2007).

Fig. 2. Study fishes. I studied both a) Sacramento sucker and b) California roach species at Strawberry Creek. c) Threespined stickleback was also found in the creek although not studied.

Fish marking and tracking

During July 2011, we (Stephanie Carlson, Kristina Cervantes-Yoshida, Jason Hwan, Hua Trong, Daisy Gonzalez, Esther Essoudry, Kaua Fraiola, Emma Kohlsmith, and David Enrique Garcia) captured Sacramento sucker, California roach, and threespined stickleback starting at the most downstream pool below the confluence of the North and South Forks of Strawberry Creek, and moved upstream to sample all open pools from the below confluence area and the South and North Forks. We captured fishes using a combination of the backpack electrofisher (Smith Root, Incorporated, Vancouver, Washington, USA; Fig. 3a) and seine nets. In September 2011, we sampled arbitrary reaches from the below the confluence area, North Fork, and South Fork for a UC Berkeley class using three-passes electrofishing. The last fish sampling event occurred in January 2012 following a diesel spill accident, where we used a combination of the backpack electrofisher and seine nets to sample all the open areas from the campus creek.

We focused our movement study on sucker and roach but not on the threespined stickleback because they do not reach at least 60 mm fork length and 2 grams in mass for tagging purposes. Using carbon dioxide, I sedated the fishes and measured fork length and weight. Fishes exceeding the desired minimum tagging requirement were implanted with uniquely coded passive integrated transponder (PIT) tags (Biomark, Idaho) by making a small incision in the stomach area. We released each individual to the pool where it was captured. Using a portable antenna (Biomark, Idaho, Fig. 3b), we then resurveyed the stream bi-weekly to detect each individual's location. As a result of a diesel spill that occurred in December 10, 2011, tracking of fishes was suspended for 50 days in that month and in January 2012.

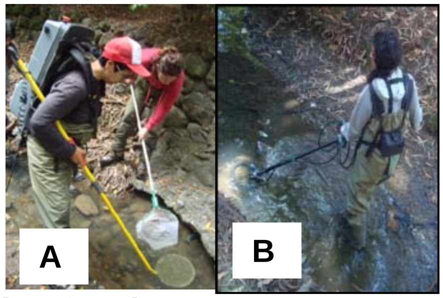

Fig. 3. Capturing and tracking fishes. a) Student assistants, Daisy Gonzalez and Kristina Cervantes-Yoshida, electrofishing in the South Fork of Strawberry Creek and b) tracking location of fishes in the below confluence area of the creek (Berkeley, California) during late July 2011.

Recapture Rates

For each tracking event, recapture rates were calculated for each specie by diving the total number of fish detected during a tracking event by the total number of individuals known to be alive, which included individuals found during the tracking day and individuals that were missed that day but were found in the future (Carlson personal communication). Following the diesel spill, recapture rates were not calculated because of the high concentration of diesel in the creek. Recapture rates were resumed following a three-day long storm that occurred in January 19-21, 2012, which diluted the diesel concentration in the stream.

Analysis of fish movement

I calculated directional (both upstream and downstream) movement for each specie and compared the differences within and between the two species. I calculated directionality by 1) counting the number of individuals that moved either upstream or downstream for each tracking day and 2) by quantifying displacement for mobile and nonmobile fishes between each sequential tracking. I also counted the upstream and downstream movement of fishes at a specific check dam. The designed followed by Turchin (1998) created a two-tailed recapture distribution by indicating upstream and downstream displacement by assigning positive and negative values, respectively. The relation between size and movement distance for each specie was determined using linear regression analysis of initial length and distance moved following the first rain event of the fall and the diesel spill.

RESULTS

Distribution of fishes

I tagged a total of 101 sucker and 96 roach from the three sampling events (total number tagged for sucker and roach, respectively, July 76-54, September 11-14, and January 14-27) in the study site. The fishes were concentrated in the lower reaches of the two forks and in the main channel stream (Fig. 1). In the North Fork, about 10 meters upstream of the confluence, a meter in high check dam was observed followed downstream by a deep pool containing all of the fish species found in the stream. Upstream of the check dam, only threespined sticklebacks were captured. The South Fork consisted mainly of roach (Fig. 1) and tagged fishes were concentrated in the downstream 200 meters of the fork with 3 adult suckers (112-226mm) found upstream in isolated deep pools. Suckers were larger in length (mean length 83.2 mm) compared to roach (mean length 68.3 mm) (Table 1).

Table 1: Mean, range and standard deviation of fork length (mm) for sucker and roach.

	Total tagged	Mean length (mm)	Range (mm)	Standard deviation (mm)
sucker	101	83.5	57 – 226	25.2
roach	95	68.3	56 - 98	9.8

Recapture rates

I recaptured most of the tagged sucker and roach in the pools they were initially found during the summer and fall seasons. Recapture rates were relatively constant for sucker (80%-90%) and roach (70%-83%) during the summer and fall seasons (Fig. 4). Following the diesel spill in mid-December 2011, recapture rates for sucker decreased 25% and for roach stayed constant at 50%. Four roach lacked tags when captured during the sampling events, indicating a tag loss less than <1%.

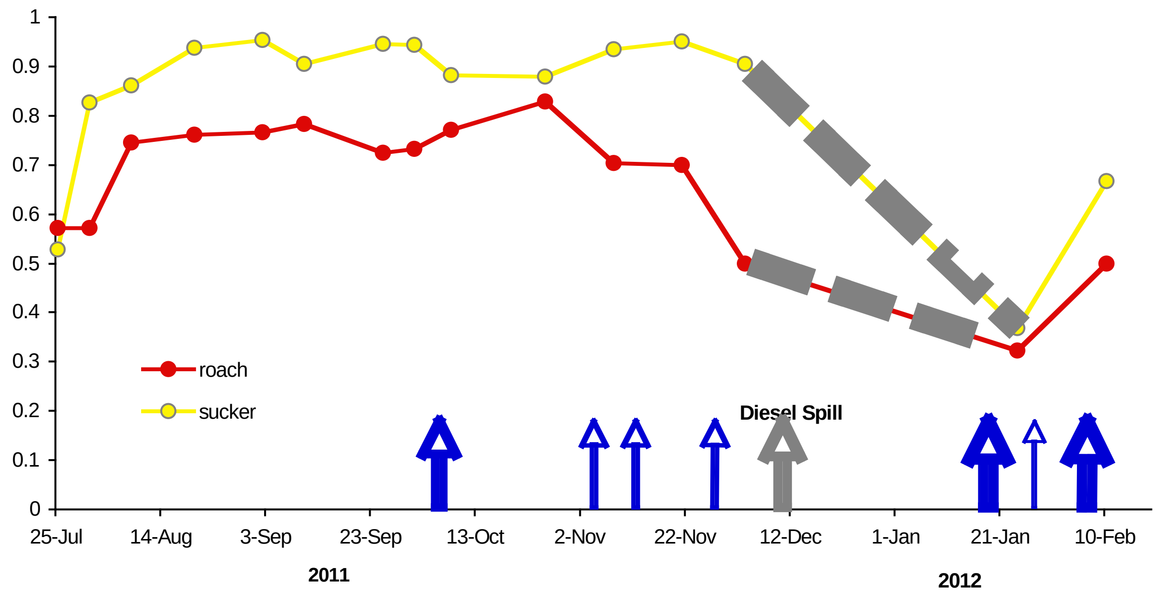

Figure 4. Recaptures rates from each tracking event and the occurred predicted and unpredicted disturbances. Recaptured rates for sucker (yellow) and roach (red) for each week that fishes were tracked. The thicknesses of the blue arrows indicate the intensity of the rain event. The gray arrow indicates the date when the diesel spill occurred in campus. As a result, no tracing was conducted for more than a month because of potential health issues for humans.

Seasonal movement

I found the net movement of individual fishes over the course of sampling events varied within species and tracking event. A qualitative comparison of the two species revealed that sucker tend to move more than roach regardless of conditions during the summer, but that roach move more than sucker after the first fall rain event during the eighth tracking day (Fig. 5). Following the diesel spill, the percent of recapture roach moving downstream increased compared to the previous weeks and the percent of recapture sucker generally decreased from previous weeks.

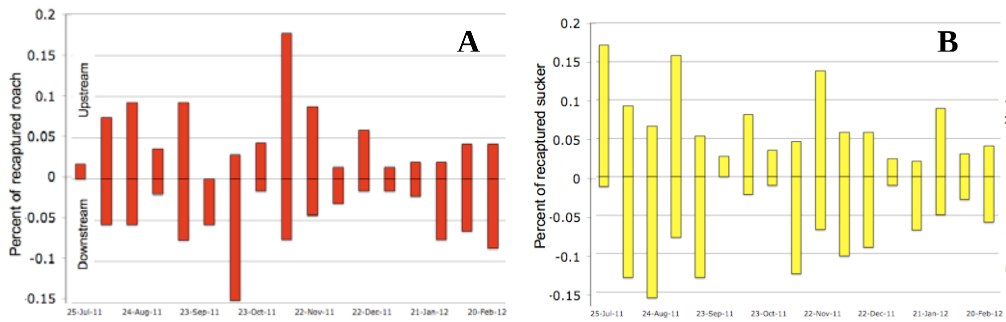

Fig. 5. Percent of recaptured a) roach and b) sucker in relation to upstream or downstream movement for each tracking day.

Roach and sucker displayed high site affinity prior to the diesel spill and did not exhibit trends in directional movement in the urban stream during the 9 months of study (Fig.6). Site affinity was less than 15% of recaptured roach after November 21, 2011 tracking day and less than 20% of recaptured sucker following the diesel spill accident. During the summer and early fall, site affinity was greater than 40% of recaptured fishes and gradually decreased afterwards. Sucker moved the most distance in both directions (120m) in most of the tracking events. Following the fall first rain event, the sizes of the fishes were not correlated with the distance moved (roach , r^2 = 0.213, p-value = 0.097, n = 14; sucker, r^2 = 0.139, p-value = 0.19, n = 14) (Fig. 7) and results were much lower after the diesel spill (roach low sampled size n = 2; sucker, r^2 = 0.152, p-value = 0.39, n = 7).

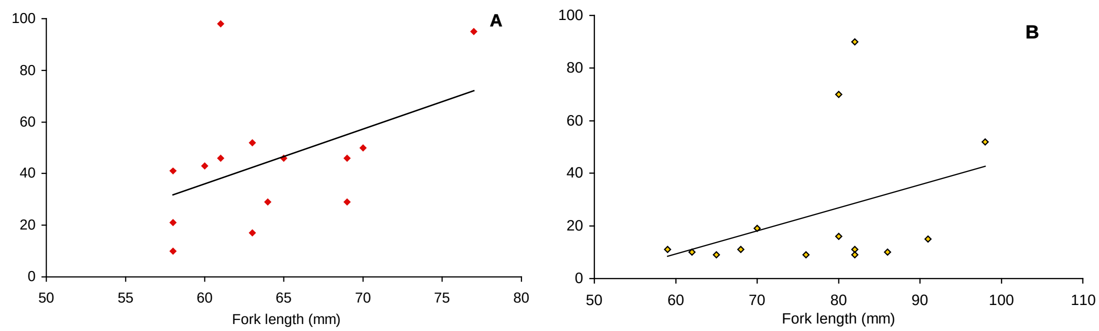

Fig. 7. Relationship between net displacement and fork length (mm) for a) roach (red , r^2 = 0.213, p-value = 0.097, n = 14) and b) suckers (yellow, r^2 = 0.139, p-value = 0.19, n = 14).

Physical Barriers

Over 30 physical barriers, mostly check dams that vary in height (19-150 cm), were mapped in the stream. However, I was mostly concerned in the check dams found in the area were most of the fishes were concentrated. A total of 5 check dams were present varying from 19-100 cm in height (Fig. 8). The highest check dam found in the North Fork was followed downstream by a deep pool containing all of the tagged fishes for that fork (Fig. 8). No upstream movement was observed. The lowest in height check dam at the confluence had the most upstream and downstream movement (Table 2). The lower most check dam in the South Fork (92cm) only downstream movement was observed mainly from sucker individuals (Table 2). The upstream movement from check dam 4 only occurred following rain days and only roach moved upstream.

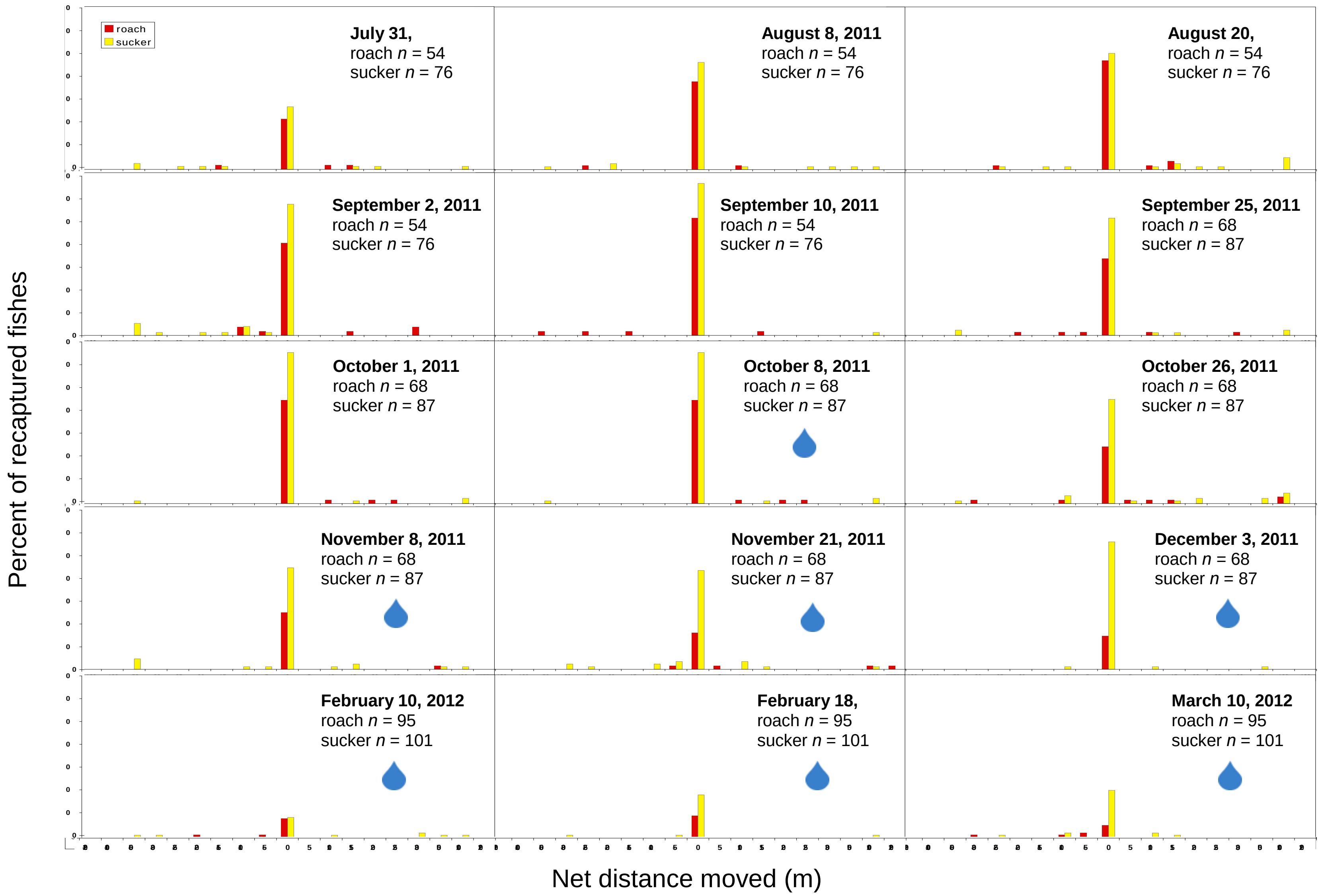

Fig. 6. Relative frequency distribution of the net distance moved (m) by roach (red) and sucker (yellow) for each tracking event. The blue raindrop indicate that rain occurred a day or two before the tracking event. Upstream and downstream movements are arbitrarily coded as positive and negative, respectively.

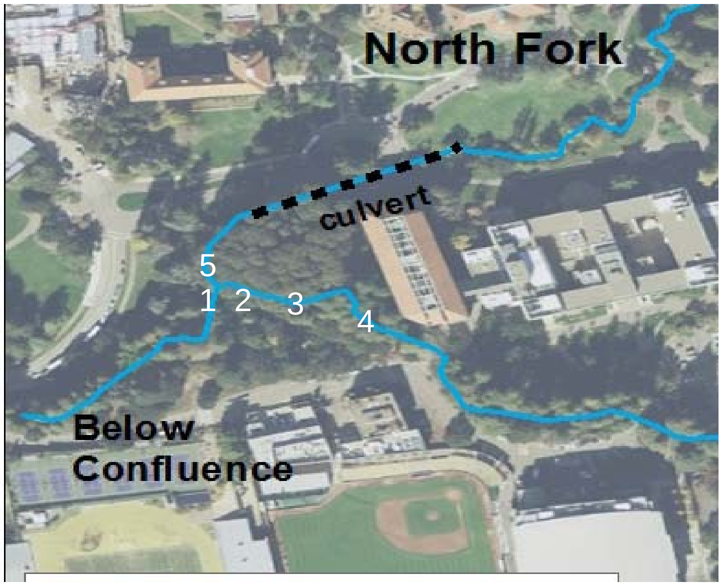

Fig. 8. Check dam location in Strawberry Creek, corresponding to the number in Table 2. Check dam 5 (1 meter height) only contained tagged fishes downstream and no movement was observed upstream.

Table 2. Total movement upstream and downstream of check dams (m) found in the lower reaches and main channel for roach and sucker.

Dam	Height (cm)	Direction	Total roach	Total sucker
1	19	Upstream	8	12
		Downstream	7	15
2	92	Upstream	0	0
		Downstream	2	6
3	20	Upstream	2	2
		Downstream	5	1
4	23	Upstream	3	0
		Downstream	2	0

DISCUSSION

In order to minimize negative impacts to Mediterranean stream fishes it is critical to understand movement patterns of stream fishes in urban landscapes. The results show that these two common stream fishes experience little net movement within seasons although net movement decreased with seasonal precipitation. A small net movement difference occurred between the two species with suckers moving more than roach. However, both species recapture rates decreased following a combination of storm events and a diesel spill. This study provides new insight into the life history of both species in an urban creek and suggests that the physical barriers constructed for restoration purposes might be limiting migration of fishes.

Distribution of fishes

Habitat characteristics potentially influenced the distribution of fishes in Strawberry Creek. For example, the area below the confluence contained the highest abundance of both stream fishes compared to the forks. This area followed a sequence of reaches (pool and riffle) with distant habitat complexity including extended undercut bank, large woody debris that provide deep pools and distant gradient types. In the North Fork, both species were captured in a deep pool less than 10 meters upstream of the confluence upstream of a meter long check dam. In the South Fork, the fishes were concentrated in the lower 200 meters before the confluence with an abundance of roach increasing upstream. Gorman and Karr (1978) observed that the stream size was positive correlated to fish diversity which accounts for the high abundance of both species in the below confluence area. However, other factors might account for the distributional differences among the forks.

Physical barriers limited upstream movement during low flows although increases in water flow might aid upstream movement of fishes passed physical barriers. Over 30 physical barriers, mostly check dams that vary in height (19-100 cm), were mapped in the creek. As part of the restoration project, check dams were constructed to provide pool habitat for the fishes and erosion from rain although it was anticipated that culverts and check dams would pose a physical barriers to migrations to recolonize upstream reaches (Charbonneau and Resh 1992). Three adult suckers and one adult roach were found in distinct deep pools in the South Fork indicating that suitable habitat is available but the barriers might be limiting dispersal to the upstream reaches. Even long concrete riffles can be an obstacle for upstream movement during storm events (Hans and Maranzana 2006) and the forks contained a couple of long stretches of concrete riffles. From the 5 check dams in the area where the fishes were concentrated, a total of 3 upstream migration occurred following a rain event and no upstream movement was seen in the highest check dam (92cm) suggesting that a maximum height threshold for the fishes to migrate upstream pass check dams exist (Fickle and Myrick 2011).

Habitat use and seasonal movement

Sacramento suckers were found in deep pools with undercut banks or large woody debris coverage as found by Jeffres et al. (2006) in the Mokelumne River, California. Although I expected less movement in the summer and fall seasons, suckers exhibited the most movement during these seasons. This behavior is not typical for native California fishes although most movement studies have been conducted in native salmonids (Villa 1985). Displacements and recapture rates decreased following the diesel spill suggesting that sucker was affected by the disturbance. Understanding fish response and how they adapt to disturbances is essential to determine the habitat that will act as refugia.

California roach were found in shallow pools with medium cover as suggested by Moyle (2002) and evenly distributed throughout the study reaches. During the summer and fall seasons movement was sedentary although high displacement occurred during the first rain event in the fall. However, recapture rates decreased significantly following rain days suggesting that roach are moving out of study area or might be hiding well in their home range. During early March, I observed breeding activity for females, which has been observed in other San Francisco tributaries for this timing in the year (Leidy 2007). Understanding how fish life history traits are altered by urban disturbances will provide knowledge to protect the specie.

Movement of fishes and responses to disturbances

Many native stream fishes use spring water flows as cue to start the breeding season and migrate upstream (Moyle 2002). These natural disturbances favor fish migration and persistence (Lytle and Poff 2004). Following the first rain event of the fall caused an increase of movement for both species suggesting that increases in water flow are important for species to move out of home range to a breeding area. Moreover, fishes utilized rain events to move upstream of check dams which is important for successful breeding of both species.

A barrier to migration exposes fishes to several habitat limitations during chemical spills, breeding success, and survival of eggs/fry (Herron et al. 2004). The ability of fishes to leap over physical barriers depend of the swimming performance of the specie, which is determine by body length, physiological condition, and water quality factors (temperature) (Kemp et al. 2008).

Moreover, it is also determine by the water flow. Several studies have examined the critical velocity (U_{crit}) to obtain measurements in swimming capability of *Catostomus* and *Lavinia* species (Fickle and Myrick 2011, Myrick and Cech 1999). Management tools should be developed that will favor swimming performances during storms and removing or mitigating dams.

Unpredictable disturbances caused higher mortality rates than predictable disturbances that favor migrations of fishes. During the study, two unpredictable disturbances occurred. The first was caused by a van that lost control and crashed into a fire services pipe delivering clean water to the North Fork and main channel for 45 minutes (Tim Pine personal communication). The second disturbance occurred December 10, 2011 when a diesel generator function failed at Stanley Hall and approximately 2,000 gallons of diesel were lost; 1,200 gallons were estimated to have reached the stream affecting the North Fork and below the confluence (Karlamangla 2011). Following these disturbances, recapture probabilities were low and mortality rates high, although little net movement occurred. Because of high variability in stream flows, unstable habitats could result (Bain et al. 1988) and human disturbances (e.g. pollution) can increase instability to the fish communities (Vila-Gispert et. al. 2001).

Limitations

Critics of mark-recapture studies have argued that mark-recapture results could be biased due to the restriction of sampling in the study area. It is expected that recapture probabilities would decrease with time but if an individual is absent it is difficult to assume whether it is the result of mortality or whether the fish migrated out of the study area. Therefore, although I tagged a high proportion of the total fishes found in the stream, but only a small proportion was used for analysis including confirmed mortalities because of the uncertainty that could increase biases. To address these biases, others have formulated mathematical models that can address these limitations. Rodriguez (2002) created models for homogenous and heterogeneous groups, but I did not integrate these methods into my results because of time limitations.

A multi-year study will provide more understanding to yearly seasonal patterns. I planned to collect at least 12 months of data but due to two unexpected events (waiting for animal care permit and no access to the affected area during the diesel spill due to health issues) the project reduced the sampling period to 9 months. As a result of limited time, I could not examine more habitat characteristics (e.g. canopy cover, stream velocity) or compare movement patterns to other urban streams in the area such as Cordonices Creek.

Future Directions

It is essential to understand movement patterns of these two common stream fishes for better restoration and improvement efforts to highly altered streams. Moreover, a longer than a year study should be implemented to first, assess human disturbances immediately after it occurs and second, to examine movement trends over time to understand seasonal and yearly differences. Furthermore, PIT tagging techniques could be also use to examine growth rates and compare these within the two forks in the stream to study more profoundly the differences in distribution between the forks. In addition, other common stream fishes should be examined including the threespined stickleback, steelhead, hitch and prickly sculpin because of their abundance in urban streams (Carlson personal communication). The use of mathematical models to understand movements' trends and life history characteristics should be used to reduce biases that could result (Rodriguez 2002; Gowan et al. 1994).

Conclusion

These two common stream fishes are highly abundant in many urban streams in the San Francisco Bay tributaries and can withstand many human disturbances including diesel spills. Moreover, this study has provided insight to the behavioral characteristics of fish, which contribute to conservation and restoration techniques that can be implemented to minimize negative affects to native fish populations (Marchetti and Moyle 2001). Following a natural flow regime will favor native fish populations and it is crucial that this regime be adopted in urban, Mediterranean streams (Marchetti and Moyle 2001). Documentations of game fishes are found in the literature but little consideration has been given to nongame fishes as an indication of the stream health (Villa 1985). Consequently, quantifying movement of Sacramento suckers and California roach in a restored urban stream provides more understanding to the behavioral movement of the native fishes in an effort to restore native fish populations in Mediterranean-climate regions.

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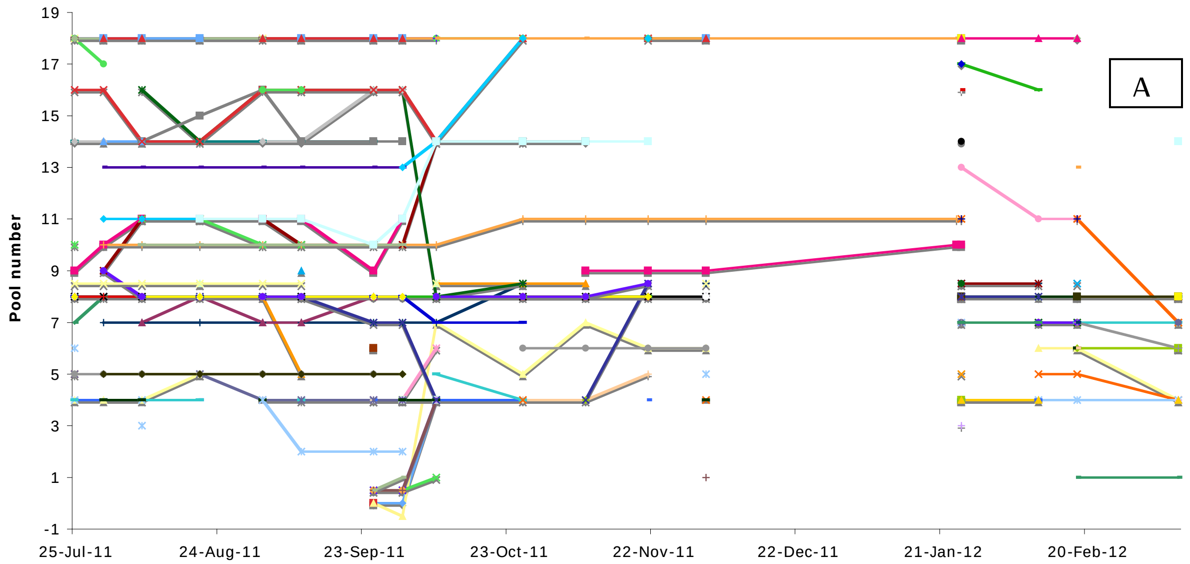
APPRENDIX A: Bi-weekly movement



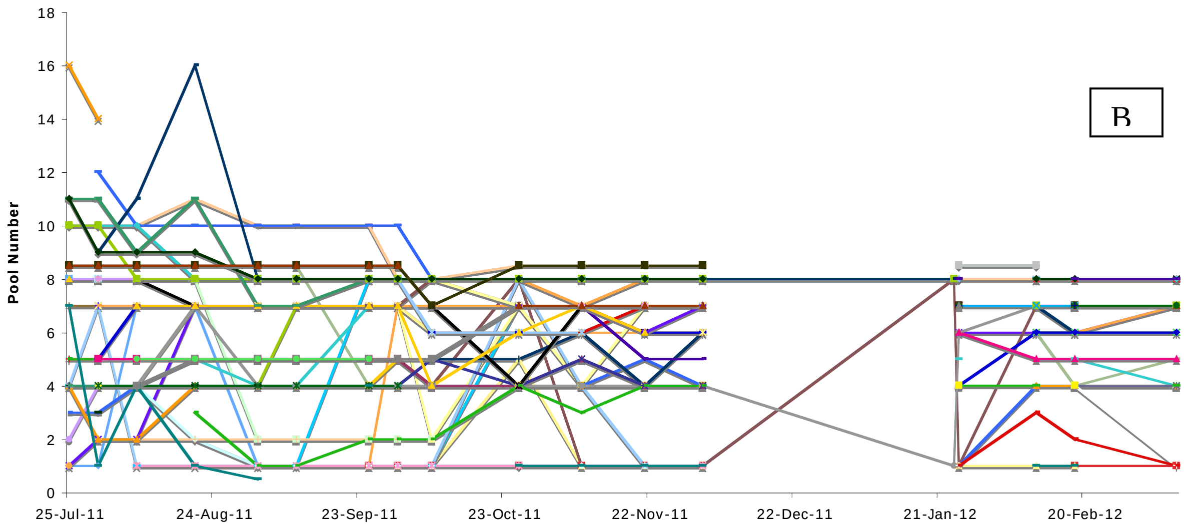


Fig. A1. Movements of individual (A) Sacramento sucker and (B) California roach across the 9 months of study. The y-axis indicates the individuals location (pool number) across time (on the x-axis). Each line corresponds to one individual. If the line is horizontal, that suggests that the fish did not move. Any non-horizontal segments indicate movement between pools.