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Diel and seasonal movements by adult Sacramento pikeminnow *(Ptychocheilus grandis)* in the Eel River, northwestern California

Harvey BC, Nakamoto RJ. Diel and seasonal movements by adult Sacramento pikeminnow *(Ptychocheilus grandis)* in the Eel River, northwestern California.
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Abstract - In late summer and fall, radio-tagged adult Sacramento pikeminnow *(Ptychocheilus grandis)* at three sites in the Eel River of northwestern California moved more at night than during the day. Fish moved up to 535 m at night and returned to their original positions the following morning. Adult Sacramento pikeminnow at all sites occupied only pools during the day, but at one site moved through high gradient riffles and occupied fast water habitats at night. Adult Sacramento pikeminnow at the upstream limit of their range in one Eel River tributary moved downstream up to 23 km during the winter and tended to return to their original position the following spring, where they remained through the summer. Fish radio tagged at downstream sites exhibited more variable behavior, moving 2-92 km over ≤393 days. Our observations suggest that the most appropriate scale of consideration for attempts to manage this species or estimate population size includes entire river drainages.

Key words: *Ptychocheilus grandis;* diel; movement; seasonality; radio telemetry; behavior; stream fish; river discharge

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Un resumen en espanol se incluye detras del texto principal de este articulo.

Introduction

The Sacramento pikeminnow *(Ptychocheilus grandis)*, a large piscivorous cyprinid, is native to the Sacramento-San Joaquin drainage and several smaller coastal drainages in California. In about 1979, the species was illegally introduced into the Eel River drainage of northwestern California, where it has become widespread (Brown & Moyle 1997). The life history and ecological interactions of the Sacramento pikeminnow in the Eel River are of considerable interest because the Eel River contains depleted populations of salmonid species that once provided the basis for large commercial fisheries. Coho salmon *(Oncorhynchus kisutch)* have recently been listed as threatened under the federal Endangered Species Act in the United States. Sacramento pikeminnow may compete with or prey on salmonids under some conditions (Brown & Moyle 1981).

The degree of movement by adult Sacramento pikeminnow will affect the extent of their interactions with other fishes and determine the appropriate scale for management of this species. For example, if long-distance movements are common, localized eradication efforts are unlikely to provide long-term consequences. While individual Colorado pikeminnow (*P. lucius*) are known to move tens to hundreds of kilometers annually (Tyus & McAda 1984, McAda & Kaeding 1991), there have been no attempts to closely monitor movements by Sacramento pikeminnow. Taft & Murphy (1950) noted that Sacramento pikeminnow appeared to make local migrations, upstream in spring and downstream in the fall. They also observed a specific adult pikeminnow in the same tributary pool over three successive years. However, these authors did not attempt to locate fish at night nor during periods of high turbidity in winter. In this study we documented both diel and seasonal movements of adult Sacramento pikeminnow in the Eel River using radio telemetry, in an attempt to measure behavior important to the basic understanding and management of this species.

Study area

The Eel River drainage encompasses about 9540 km^2 in the Coast Range of northwestern California, USA. In this study, we captured, tagged and released fish at sites 50.6 to 169.5 river km from the Pacific Ocean (Fig. 1). The downstream-most site was located on the mainstem Eel River, while the upriver sites were on the South Fork Eel River, a large tributary with a drainage area of 1785 km^2 that joins the mainstem Eel River at river km 66. Over the course of this study (25 August 1995-11 September 1996), discharge averaged 215 $m^3 \cdot s^{-1}$ at the downstream end of the study area and 24 $m^3 \cdot s^{-1}$ at the upstream end. The highest discharges during the study period were 2100 $m^3 \cdot s^{-1}$ downstream and 250 $m^3 \cdot s^{-1}$ upstream.

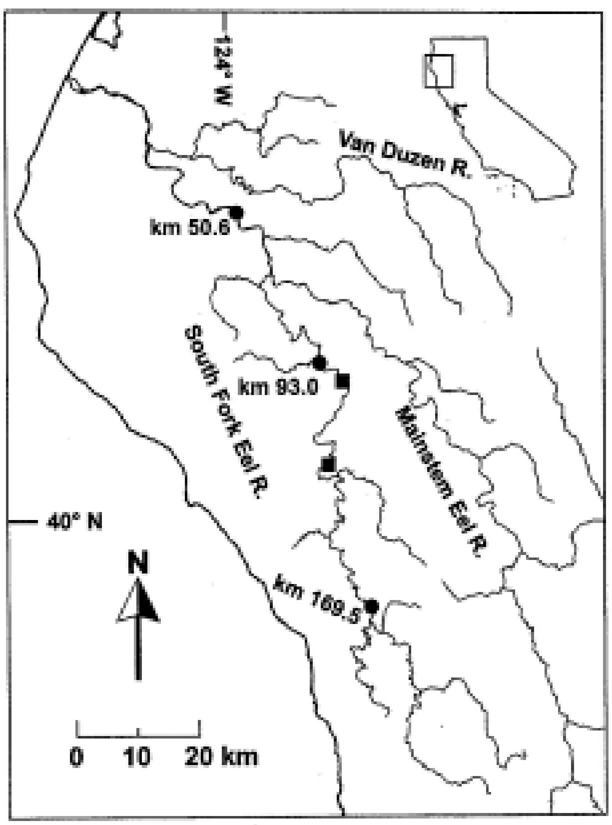

Fig. 1. The lower Eel River drainage including the South Fork Eel River. Circles (•) indicate sites where adult Sacramento pikeminnow were captured and released with radio transmitters in August and September, 1995. Squares (•) indicate additional sites where fish with transmitters were released from December 1995 to April 1996.

In the Eel River drainage, about 95% of annual precipitation falls from October to April. Late-summer discharges were about 2 $m^3 \cdot s^{-1}$ at the downstream end of the study reach and < 0.5 $m^3 \cdot s^{-1}$ at the upstream end. The one reservoir in the Eel River drainage at river km 250 on the mainstem has a negligible effect on discharge at the downstream-most study site. The South Fork Eel River is free-flowing. Pools commonly occupied by adult pikeminnow at the downstream-most site were up to 500 m long, 75 m wide and > 10 m deep and at the upstream site were about 100 m long, 10 m wide and 3-7 m deep.

Material and methods

We captured adult pikeminnow for radio tagging by several methods. Fish were captured at the upstream-most study site (river km 169.5, at Standish Hickey State Park) on 25 August 1995 using two seines approximately 45 m long and 3 m deep. This site was the upstream limit for Sacramento pikeminnow >300 mm standard length (SL) in the South Fork Eel River in 1995-1996. Because the size of the river and presence of woody debris prevented effective use of seines at downstream sites, we captured fish at these sites in September 1995 by boat electrofishing. We tagged 12 fish in August and September 1995 collected from three locations: river km 50.6 near Shively, river km 93.0 at Miranda, and river km 169.5. Later, we captured fish for radio tagging during high river discharge by both boat electrofishing and hook and line. Transmitters were implanted in 11 fish from 8 December 1995 to 2 April 1996 collected from five locations (river km 50.6-169.5), including the three sites where we tagged fish in September. Fish implanted with transmitters ranged 375 to 515 mm SL.

We implanted 9.6-g radio-transmitters (60 mm long, 12 mm diameter, with a 30-cm antenna) within the body cavities of adult pikeminnow. The weight of the transmitters never exceeded 2% of the weight of the fish. Before surgery, fish were anesthetized with 150 $mg \cdot l^{-1}$ MS-222. During surgery, the gills of the fish were irrigated for approximately 3 min with water containing MS-222, then with water only for the remainder of the surgery. Transmitters were implanted by first making two incisions in the body wall of the fish. The first was 20 mm long, located anterior to the pelvic fins and 20 mm dorsal to the ventral midline of the fish. The second was 8 mm long positioned along the midline posterior to the pelvic girdle. A metal rod with a loop on one end, inserted through the smaller midline opening and out the larger opening allowed the antennae to be pulled through the fish. The transmitter was then passed through the larger opening and positioned over the pelvic girdle. The larger opening was closed with three sutures and the smaller opening with two sutures, one anterior and one posterior to the antenna. The entire surgical procedure took approximately 5 min. We placed fish in a nylon mesh live car in the river following surgery All fish were released where they were captured after they regained the ability to maintain normal orientation and hold position in the current. All fish receiving transmitters recovered to this extent.

We quantified diel patterns of movement by the 12 fish tagged in August and September 1995 in September and October 1995. We also obtained one set of observations on fish at the upstream site in November 1995. During 24-h observation periods, we attempted to track each fish for at least 5 min on four or more occasions. These efforts always yielded at least two observations of individual fish during the day and two at night separated by $\geq$ 4 h. We varied the timing of observations during three or four different 24-h periods to obtain data for each fish from throughout the day. Longitudinal position was determined by running a tape measure along the shoreline parallel to the thalweg or by matching the position of the fish to distinctive features of the habitat in areas which had been mapped previously. We estimated the longitudinal positions of transmitters placed in the river by another person within 1 m at the upstream-most site and within 3 m at the downstream-most site, where the river was wider. The location of fish in the dimension perpendicular to the direction of flow was usually not determined because movement of fish often only allowed us time to establish their longitudinal positions. We chose not to conduct statistical analyses of diel patterns in movement because all adult pikeminnow occupied pools and ranged <20 m in longitudinal position during the day.

We made observations on the seasonal movements of fish using a variety of methods. During high river discharge in winter, we tracked fish by boat, raft, and helicopter. Searches for radio-tagged fish included major tributaries of the lower Eel Drainage, the entire South Fork Eel River, and the mainstem Eel River from the estuary upstream to 70 km above the confluence with the South Fork Eel. After the battery life of the transmitters was exceeded (approximately 200 days), we obtained additional location data and condition information for three radio-tagged fish by spear-fishing. Spear-fishers also made qualitative observations of the behavior of radio-tagged fish. Large variation in movement by fish from particular sites precluded meaningful statistical comparisons based on longitudinal position.

Results

Diel patterns

At the upstream site in September 1995, the five radio-tagged adult pikeminnow were always confined to one of two large pools during the day, but at night commonly moved through high-gradient riffles to occupy small pools or runs up to 535 m away from their daytime locations (Fig. 2). During the night of 21-22 September 1995, we found all five fish outside the pool they occupied during the day. On three other nights, we located three of the five fish outside the pool occupied during the day. All five fish at the upstream site were found outside the pool they occupied during the day on at least two of the four nights of observation in September. Because fish never occupied one fast water location all night and on some occasions more than 4 h elapsed between observations of individual fish, we probably often failed to detect nighttime movements out of the large pools. In some cases, individual fish moved in one night both upstream and downstream of the pool they occupied during the day. Movements out of the large, deep pools fish occupied during the day occurred as early as sunset. Conversely, fish returned to these pools following nighttime forays as late as sunrise. In contrast to observations in September, on 2-3 November 1995 at the upstream site we found the five radio-tagged fish in a single pool during all day and night observations. Summertime observations by divers revealed that during the day large pikeminnow formed schools, often associated with schools of adult Sacramento suckers *(Catostomus occidentalis).*

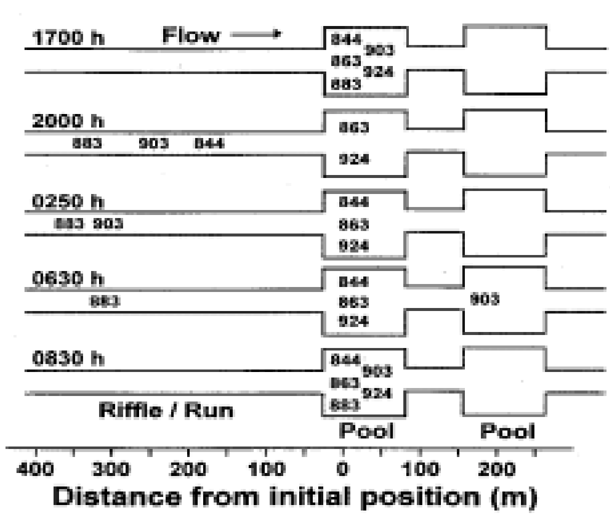

Fig. 2. Schematic diagram of the distribution of five adult Sacramento pikeminnow in the South Fork Eel River, California at river km 169.5 on 27-28 September 1995. Individual fish are represented by three digit numbers that partly reflect transmitter frequency.

During three 24-h observation periods in October 1995, the seven radio-tagged fish in the mainstem and lower South Fork Eel River also utilized longer reaches of stream at night. In general, fish occupied the central portions of pools during the day and at night moved into both upstream riffle-pool transition areas and pool tails, while also spending time in deep areas. At River KM 50.6 we observed fish over about 250 m of the thalweg during the day versus 450 m at night. At river km 93.0, fish used 200 m of stream during the day but were found throughout a 490 m reach at night. Habitat occupied during the day was always > 1.25 m deep, while habitat occupied at night included water depths of 0.30 m. In contrast to fish at the upstream study site on the South Fork Eel River in September, fish at the lower sites did not cross riffles during our 24-h observations in October. However, in October we found three of the seven radio-tagged fish at the lower sites outside the pools where they were captured. We were able to make only one set of 24-h observations on two of these fish; both fish continuously occupied a single pool.

Seasonal patterns

During low water in summer and fall 1995, four of the five fish tagged in August at river km 169.5 used only the deep pool where they were captured or an adjacent large pool during the day. One fish moved about 7 km downstream within 2 days of receiving a transmitter but returned to the original site within 2 weeks. We assume this behavior was a response to the capture and implantation procedures. After the onset of high flows in winter, the five fish from the upstream limit of adult pikeminnow were found various distances downstream (Fig. 3A) of their capture site. Over the course of the winter, fish from this site moved downstream 2-23 km, then tended to move upstream in spring. The two fish in this group recaptured more than a year after tagging (September 1996, 375 and 380 days after tags were implanted) were collected in the same pool where they were first captured. Two of the other fish in this group were last detected in spring 1996 at positions upstream of positions they held in winter. The fifth fish in the group was captured by electrofishing in February 1996 within 2 km of the pool where the group was initially captured and tagged.

One fish captured by hook and line and implanted with a transmitter on 6 December 1995 at river km 102.5 on the South Fork Eel River exhibited a pattern of movement similar to fish from the most upstream site. This fish moved downstream about 27 km during high discharge in December, but eventually moved upstream in March. In this case, the upstream movement covered 92 km and brought the fish to the upstream limit of large pikeminnow at river km 169.5.

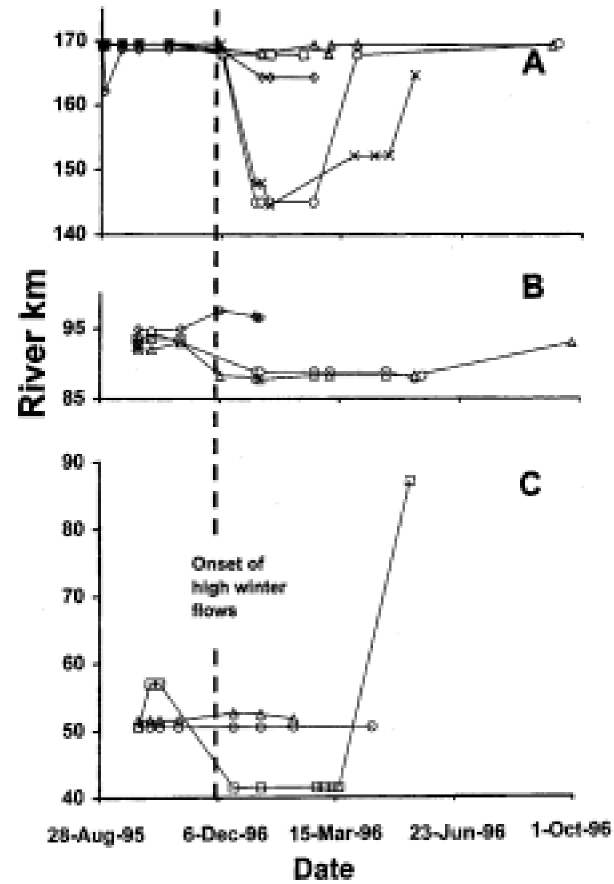

Fig. 3. Movements by adult Sacramento pikeminnow implanted with radio transmitters in the Eel River, California. The three panels reflect the three sites where fish received transmitters in August and September, 1995: **A**) Standish Hickey State Park, river km 169.5; **B**) Miranda, river km 93.0; **C**) Shively, river km 50.6. In each panel, different symbols represent individual fish. Data after 23 June 1996 are based on recapture of fish by spear-fishing.

Two of four fish tagged in September at the middle site (river km 93.0) crossed shallow riffles during low water conditions in the fall and occupied deep pools within 2 km of the pool where they were captured. With the commencement of high discharge, we found radio-tagged fish 4-5 km both up- and downstream of the pool where this group was first captured (Fig. 3B). For much of the winter and spring, the two fish at this site which we were able to locate for > 130 days occupied a reach 4.7 km downstream from the pool where they were first captured. While that site was simple run habitat in summer 1995, bank erosion during winter caused several old-growth redwood trees *(Sequoia sempervirens)* to fall into the channel. The fish apparently utilized relatively slow water among these trees during several of our observations at this site during high water and a high density of pikeminnow, including radio-tagged fish, occupied the pool at this site during low water in spring and summer 1996. The fish from river km 93.0 which we observed for the longest time was recaptured by spear-fishing after 393 days from the pool where it was first tagged. Two additional fish implanted with transmitters at this site in April 1996 remained in the pool where they were captured for at least 45 days before their signals were lost.

One of three fish tagged in September at the lowest site (river km 50.6) left the pool where it was captured during low water conditions, moving 6.4 km upstream and occupying another large pool. After moving about 9 km below the original capture site with the onset of high discharge, this fish moved upstream 46 km in March. The other two fish tagged in September at this site remained in the pools where they were captured (Fig. 3C). Three additional fish tagged at this location in February 1996 exhibited a similar pattern: two remained in the large pool where they were captured while the third moved 42 km upstream in March.

General

The behavior of fish appeared to be unaffected by the transmitters implanted during low-water conditions. Fish implanted with transmitters behaved similarly to those without transmitters and the two groups could only be distinguished by snorkelers after close inspection for the external antenna. The condition of the radio-tagged fish we recaptured after up to 380 days appeared normal, several contained prey, and the wounds from surgery were healed. The three radio-tagged fish which we recaptured about 1 year after tagging had grown 30-40 mm in length, similar to the growth rates predicted for large Sacramento pikeminnow (Taft & Murphy 1950, Brown 1990, Brown & Moyle 1997).

We made observations on the 12 fish tagged during low water in August and September 1995 for an average of 218 days, while fish tagged in winter were detected for an average of 55 days. Three fish implanted with transmitters in winter were not detected after they were released.

Discussion

Adult Sacramento pikeminnow moved long distances at night compared to daytime during summer or fall low flows in the Eel River. At night near the upstream extent of their range in the Eel Drainage, the fish commonly occupied riffles and runs adjacent to the pools they occupied during the day. Considering that pikeminnow commonly feed at night (Brown 1990, Petersen & Gadomski 1994), and that prey fishes were more abundant in fast water at our upstream-most site (B.C. Harvey & R.J. Nakamoto, personal observations), the nighttime movements we observed were probably associated with feeding.

Nighttime movement into fast water by adult pikeminnow appears to offer several advantages. Prey capture success may be highest for these fish at low light levels (Petersen & Gadomski 1994). Thus, they appear to occupy areas of relatively high prey density specifically when capture success is highest. Also, the fish probably expend less energy by moving between pools and riffles rather than continually occupying fast water.

The diel pattern of movement by adult Sacramento pikeminnow may also be influenced by risk of predation. Presumably, the relatively shallow habitats fish moved through and occupied at night would be more dangerous for adult pikeminnow during the day due to predation by birds and mammals. Also, occupation of deep pools and formation of schools probably both serve to reduce predation risk during the day. The possible negative effect of schooling on prey availability is mitigated by dispersal at night.

The high level of nocturnal activity by Sacramento pikeminnow we observed differs from movement by Colorado pikeminnow in rivers where high turbidity probably reduces the risk of predation. Colorado pikeminnow in the Green, White and Yampa rivers of Utah and Colorado moved at similar rates throughout the day during pre-spawning and spawning periods and were most active in daylight morning hours after spawning (Tyus & McAda 1984).

In contrast to the fish we observed upstream, adult pikeminnow at our downstream sites did not occupy riffles and runs at night. This difference may be linked to prey and habitat availability. The large pools downstream contained emergent vegetation and large woody debris which provided habitat for juvenile pikeminnow and California roach *(Lavinia symmetricus)*, both potential prey for adult pikeminnow. In contrast, riffles downstream were shallow with uniform gravel substrate and a low density of potential prey.

Both Brown & Moyle (1991) and Brown & Brasher (1995) found that small fishes (<120 mm SL) in the Eel River responded to large Sacramento pikeminnow (>200 mm SL) by avoiding relatively deep, slow-water habitats. Because of nighttime movements by the predator, this behavior apparently does not eliminate the risk of predation from Sacramento pikeminnow. In the limited areas in the Eel River drainage where their distributions overlap during summer, large Sacramento pikeminnow consume juvenile steelhead *(Oncorhynchus mykiss)* even though the two are rarely found within the same habitat units (e.g., pools and riffles) during the day (R.J. Nakamoto & B.C. Harvey, unpublished data). While microhabitat data for native California fishes have been collected primarily during the day (e.g., Moyle & Baltz 1985, Brown & Moyle 1991), our observations indicate additional investigation of diel changes in use of microhabitat by these species might elucidate important ecological interactions.

Our observations also suggest that physical conditions during winter influence the upstream limit of large Sacramento pikeminnow. While all of the fish at the upstream limit in the South Fork of the Eel River moved downstream during winter, fish tagged at downstream sites moved in both directions or remained in the pools they occupied in summer. Both gradient and channel confinement are greater at the upstream site, suggesting that a shortage of habitat with low water velocity necessitated downstream movements by adult pikeminnow. If high discharge during winter commonly controls the upstream limit of adult pikeminnow, reservoirs throughout the species' range may serve to extend their distribution upstream by providing refuge from harsh physical conditions.

While several benefits of the short-term, reach-scale movements by adult pikeminnow are apparent, the mechanisms driving the long upstream movements we observed are not clear. Sampling of larval fish drift throughout the lower mainstem Eel River and South Fork Eel River indicates that the species spawns successfully at many locations throughout that part of the drainage, including several tributaries (B.C. Harvey & R.J. Nakamoto, unpublished data). However, the majority of our observations of springtime upstream movements might be explained by fish returning annually to particular spawning locations. One possible benefit for individual fish of living near the upstream limit of adult pikeminnow is that prey moving downstream at that site, such as out-migrating juvenile chinook salmon *(Oncorhynchus tshawytscha)* and steelhead, may be encountering piscivorous fish for the first time, resulting in relatively high capture success for pikeminnow in those areas.

The long-distance movements by adult Sacramento pikeminnow in the Eel River have several ramifications for fisheries and habitat managers. Any local reductions in the abundance of pikeminnow would probably be obscured within one or two years by movements of individuals coupled with the species' high fecundity (Moyle 1976). Also, the distribution of adult Sacramento pikeminnow in the Eel Drainage will probably change rapidly in response to habitat changes such as reduction in barriers to upstream movement or increased frequency of deep pools providing physically complex habitat in warmer sections of the drainage. Our observations suggest that management or study of the population biology of this species should incorporate entire river drainages. That individual adult Sacramento pikeminnow commonly utilize large proportions of the Eel River drainage on an annual basis also supports the suggestion of Moyle & Yoshiyama (1994) that conservation of native California fishes be approached at the scale of entire watersheds.

Resumen

1. En tres localidades que, practicamente, delineaban la distribuci6n longitudinal de *Ptychocheilus grandis* en el rio Eel (NO de California, USA), los adultos marcados con radio-transmisores se movieron mas por la noche en verano y otofio. Los peces se desplazaron 535 m durante la noche y regresaron a sus posiciones originales a la mafiana siguiente. En todas las localidades, los adultos ocuparon las pozas durante el dia, aunque en una de ellas se movieron a zonas de rapidos donde pasaron la noche.
2. Durante los periodos de alto nivel de agua en primavera a invierno, los adultos localizados en el limite aguas arriba de su distribuci6n en un afluente del rio Eel, se desplazaron unos 23 km aguas abajo durante el invierno y tendieron a volver a su posicion original la primavera siguiente, donde permanecieron todo el verano. Por el contrario, los peces marcados aguas abajo exhibieron un comportamiento mas variable en invierno y en primavera, moviendose entre 2y92 km en $\leq$393 dias. Tambien, varios individuos migraron 46-92 km aguas arriba en primavera.
3. Nuestras obervaciones sugieren que los cambios de habitat documentados previamiante para las especies-presa como respuesta a la presencia de adultos de *P. grandis* no elimina el riesgo de predaci6n y que, ademas, la escala de conocimiento mas apropiada para la gesti6n de estas poblaciones o para estimar el tamamo poblacional de la especie, debe ser toda la cuenca.

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