Movement patterns and home range in
*Diplomystes camposensis* (Siluriformes: Diplomystidae),
an endemic and threatened species from Chile

Alejandra Oyanedel¹, Evelyn Habit¹, Mark C. Belk², Katherin Solis-Lufí³,
Nicole Colin¹,⁴,⁵, Jorge Gonzalez¹, Alfonso Jara¹ and Carlos. P. Muñoz-Ramírez⁴,⁵

We document movement patterns and home range of *Diplomystes camposensis*, an endemic and threatened freshwater catfish from Chile. We tracked the movements of seven individuals of different body size (13.5 to 19 cm SL) using portable radio telemetry equipment to investigate movement patterns in relation to day/night activity and habitat use in the San Pedro River (Valdivia Basin). Tracked movements and model-based analyses revealed that *D. camposensis* has a large home range and high mobility. The average home range was 0.068163 ± 0.033313 km², and the average area of higher activity was 0.005646 ± 0.011386 km². The mean linear home range was 387.4 m. The results also showed that movements were longer during the night, supporting nocturnal habits. Movements tended to be in an upstream direction for some individuals, although these differences were not significant when data was pooled. Large home range and movements suggest that the species may require large river areas to meet ecological demands, an aspect that could be severely affected by fragmentation. These results, along with previously published genetic data, suggest that the conservation of *D. camposensis* would be seriously threatened by hydromorphological alterations (*e.g.* lack of connectivity), such as those resulting from dam building.

Keywords: Endangered species, Fragmentation, Habitat use, Kernel, Radio telemetry.

En este trabajo documentamos patrones de movimiento y estimación de ámbito de hogar de *Diplomystes camposensis*, un siluriforme endémico y amenazado del Sur de Chile. Por medio de radio telemetría, se monitorearon 7 individuos con un rango de tamaño entre 13.5 y 19 cm de longitud estándar, para evaluar patrones de movimiento con respecto al uso de hábitat y tiempo de actividad (día/noche) en la zona del Río San Pedro, Cuenca del Río Valdivia. Los resultados muestran que *D. camposensis* tiene un ámbito de hogar grande y una alta movilidad. El ámbito de hogar fue de 0.068163 ± 0.033313 km² con un área promedio de mayor actividad de 0.005646 ± 0.011386 km². El ámbito de hogar lineal medio fue de 387.4 m. Los resultados también mostraron que la especie presenta una mayor actividad por la noche y una tendencia hacia un mayor flujo de movimiento en dirección aguas arriba, aunque esto último no fue significativo. Un ámbito de hogar grande y su alta movilidad sugieren que la especie podría requerir de amplias zonas del río para satisfacer sus demandas ecológicas. Al igual que estudios previos con datos genéticos, estos resultados sugieren que la especie *D. camposensis* se vería perjudicada por alteraciones en la hidromorfología del cauce (*e.g.* falta de conectividad) tales como aquellas que resulten de la construcción de represas.

Palabras clave: Especie amenazada, Fragmentación, Kernel, Radio telemetría, Uso de Hábitat.

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¹Departamento de Sistemas Acuáticos, Facultad de Ciencias Ambientales y Centro EULA-Chile, Universidad de Concepción, Barrio Universitario s/n, Concepción, Chile. (AO) alejandra.oyanedel@gmail.com, (EH) ehabit@gmail.com, (NC) colin.nicole@gmail.com, (JG) jorge.gonzalez@cequa.cl, (AJ) gaizcka@gmail.com
²Department of Biology, Brigham Young University, Provo, UT 84602, USA. (MCB) mark_belk@byu.edu.
³Doctorado en Ciencias de Recursos Naturales, Departamento de Ingeniería Química, Facultad de Ingeniería y Ciencias, Universidad de La Frontera, Temuco, Chile. (KS-L) k.solis01@ufronmail.cl
⁴Centro de Investigación en Biodiversidad y Ambientes Sustentables (CIBAS), Universidad Católica de la Santísima Concepción, Chile. (CPM-R) carmunoz@umich.edu, @https://orcid.org/0000-0003-1348-5476 (corresponding author).
⁵Facultad de Ciencias, Universidad Católica de la Santísima Concepción, Chile.
Introduction

The Chilean freshwater ichthyofauna includes a high number of endemic species (Dyer, 2000), many of which are threatened (Campos et al., 1998; Habit et al., 2006). An important group within the Chilean freshwater fish fauna is the catfish family Diplomystidae, endemic to the Austral sub region of South America (Arratia, 1983, 1987; Muñoz-Ramírez et al., 2010). Species in this small family (one genus and five species; Muñoz-Ramírez et al., 2014; Arratia, Quezada-Romegialli, 2017) are considered among the most primitive catfish (living or extinct), being placed by some authors as the sister group of all other catfish families (e.g. Arratia, 1987, 1992; Hardman, 2005; Lundberg, Baskin, 1969), or at least as one of the three main lineages (Sullivan et al., 2006). Unfortunately, species present in the Chilean province are considered endangered (Supreme Decree nº 51/2008, Ministry General Secretariat of the Presidency, Chile), and despite their importance for understanding catfish evolution, species are still poorly known in many aspects of their ecology (e.g. reproductive behaviour, population ecology).

Historically, Diplomystes species from Chile followed a North–South allopatric distribution from the Aconcagua River basin in the north to the Valdivia River basin in the south (Vila et al., 1996), but currently, the range of the genus has been reduced in its northern limit, being extirpated from two river basins, the Aconcagua and the Maipo systems (Arratia, 1987; Muñoz-Ramírez et al., 2010). Habitat fragmentation and the introduction of invasive species have been suggested as the main threats to the conservation of Diplomystes (e.g. Arratia 1983; Campos et al., 1998; Habit, 2005). However, because these species inhabit rithral zones (Arratia, 1983; Habit, 2005), mostly found in areas close to the Andes, other factors like dam building (Link, Habit, 2015) may become relevant threats for their conservation as these alterations can impact connectivity and affect natural hydrological dynamics (Campos et al., 1998; Habit, 2005).

Diplomystes camposensis (Arratia, 1987) is an endemic species with a distribution range restricted to some areas of the Valdivia River basin (which has a drainage area of 10,275 km²), inhabiting rithral parts of the Cruces, Enco, San Pedro, and Calle Calle rivers (Arratia, 1987; Campos et al., 1998; Habit et al., 2009; Colin et al., 2012; but see Muñoz-Ramírez et al., 2014). In addition, the species occupies a small portion of the basin, being documented only in rithral stretches of high-order rivers, and considered absent from lakes and low-order rivers (Habit et al., 2009). The scarce ecological information on the species indicates that small juveniles prefer shallow habitats and they move from riffles to pools with low flow velocity, in summer. Juveniles mainly use riffles (depth <1m), where the smaller sizes make a major use of shallow riffles (Garcia et al., 2012). Sexual maturity occurs when catfishes reach 120 mm of total length. Furthermore, populations present in the San Pedro River exhibit low genetic diversity and a high gene flow (Muñoz-Ramírez et al., 2016; Victoriano et al., 2012). Although the family has been assumed to have nocturnal feeding behavior (Link, Habit, 2015), no empirical evidence has been yet published supporting this claim supporting this claim. Species feed mainly on small to medium-sized invertebrates (Beltrán-Concha et al., 2012). D. camposensis is considered as endangered by the Chilean government due to habitat loss, water quality reduction and deleterious effects caused by alien species (Supreme Decree nº 51/2008, Ministry General Secretariat of the Presidency, Chile).

Materials and Methods

Study Area. This study was conducted in the San Pedro River, a tributary of the Valdivia River in Southern Chile (39°45’37”S, 72°34’48”W; see Fig. 1). This basin has a sequence of eight oligotrophic Andean lakes at its origin, beginning with the Lácar lake in Argentina and ending in the Ríñihue lake in Chile, whose outlet is the beginning of the San Pedro River. The San Pedro River has (see fig. 1 of S1 - Available only as online supplementary file accessed with the online version of the article at http://www.scielo.br/ni) a natural flow regime whose hydrological variation depends on the upstream lakes—although the construction of hydropower dams is being evaluated, which would create changes to the natural flow regime. The study area (Fig. 1) comprises 40 km of the San Pedro River, where we recognized three habitat zones (following Wilkes et al., 2016) characterized by different hydrogeomorphological traits, from the Ríñihue lake outlet (39°46’33”S, 72°27’21”W) to 500 m downstream of the confluence of the San Pedro with the Quinchilca River (39°51’10”S, 72°45’34”W).
Fish Capture, Radio Implantation and Telemetry. Adult specimens of *D. camposensis* were captured by electrofishing and, hook and line, using circle hooks with no barb to minimize injuries. Each individual was transported to the lab where they were weighed, measured, and then maintained individually in 500 L aquaria for 24 hours with filtered and UV-sterilized river water. For surgery, individuals were anesthetized with benzocaine 20% (1mL : 5000L), until minimum frequency in opercular movement was observed. Radio transmitters of 0.8 g and 2.8 g of weight (NTC-6-1 and NTC-4-2L, respectively, LOTEK, USA) were implanted in individuals with body mass ≥ 40 g. The first radio transmitter type was implanted in the individual RT 13, while the second type was used in all remaining individuals. Expected transmitter life was 46 and 186 days for the first and second type, respectively. From March 2006 to February 2007 we implanted radio transmitters in 7 individuals in the peritoneal cavity according to the procedure described in Solis-Lufí *et al.*, (2009). After surgery, fishes were maintained in recovery aquaria for 72 hours with similar conditions to the acclimatization period, applying an antibiotic bath during one hour per day with Sol-Flox® solution (0.15:1000). Each fish was released in the same location where it was captured during day time, corresponding to the initial point of tracking (designated as E0) (see tab. 1 and fig. 2 of S1 - Available only as online supplementary file accessed with the online version of the article at http://www.scielo.br/ni).

Tracking was conducted with portable equipment (Lotek® Receiver SRX 400A), during day (6:01 - 20:30 hours) and night hours (20:31 - 6:00 hours), until the radio transmitters failed (maximum lifespan of transmitters was 172 days). Tracking periods were not the same for all individuals (see Tab.1) which depended on when fishes were released into the river. Tracking effort differed among individuals due to differences in fish detectability. Tracking frequency of each individual was performed every 2 days, but not all individuals were detected all the time, so localization events were variable (Tab.1). When we detected the first radio signal from a fish, we located every 30 minutes until the fish did not show movement during 5 consecutive periods. This typically occurred when fishes moved to a refuge habitat from where signal was not obtained by the receiver antenna. During tracking, we walked along the riverside and we registered locations (UTM coordinates) at 3 m of precision by GPS (Garmin eTrex H), distance to riverside, date, and hour for each individual record. To get accurate positions of each fish, we measured intensity of the signal using triangulation according to Springer (1979). The specific river stretches where individuals were captured, released, and tracked are represented in Fig. 1.

Data Analysis. Coordinates of detection points of each specimen were saved as a thematic layer and located on aerial pictures and on cartography of the San Pedro River hydrological network (Official Chilean Maps IGM, scale 1:50.000), from where we measured the length of all stretches traveled by each fish in ArcView 3.2. Movements were analyzed using Animal Movement V2.0, an ArcView application (Hooge *et al.*, 2001). To analyze movement patterns we used records from individuals with multiple recaptures. Seven individuals were detected multiple times and included in the majority of analyses, except individual R 52, that was excluded for night-day comparison analyses due to the lack of night measurements (Tab. 1).
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From these data, four movement indicators were measured for each individual with the purpose of knowing the magnitude of displacement within a given period (Tab.1). First, total movement was estimated as the sum of the absolute distances of all movement segments for a given fish. Second, average movement distance was estimated as the average distance (m) of all segments recorded for a given fish between consecutive detection points (including zero values). Third, cumulative directional movement was estimated as the sum of all movement segments, with upstream movements designated as positive and downstream movements designated as negative (see Khan et al., 2004). This is an aspect that should be evaluated to generate mitigation measurements of impacts due to a hydroelectric plant (e.g. for management plans aiming at the maintenance of gene flow). Fourth, average distance from E0 (the release site) was estimated as the average of the linear distances (m) between each detection point and E0. Since the fish were caught feeding at night (ostensibly due to prey presence in mouth), we calculate how far they traveled from E0 (catch and release site) to investigate whether there is any tendency to return to feeding sites (E0). Shorter E0 distances, which indicate that detection points were close to the release point, could indicate that there is fidelity of feeding sites.

Considering the common, although unsupported claim that *D. camposensis* is more active during the night than during the day (see Link, Habit, 2015), differences between diurnal and nocturnal movements were tested using the Friedman’s test (non-parametric, repeated measures) in R (R Development Core Team 2017). For this test we used the average movement distance using Day and Night categories as treatments and each fish specimen as the blocks (except for specimen 52 due to insufficient data). Multiple values for each specimen were averaged for each combination of treatments and blocks.

Fixed kernel home range was estimated for each individual using the Animal Movement Extension (Hooge, Eichenlaub, 1997) in ArcView 3.2 software. Kernel home range is an estimation of isopleths that contain a fixed percentage of the utilization density which is an indicator of time spent by animals in a specific area (Hooge et al., 2001; Hemson et al., 2005). Estimations of home range size at 95, 70 and 50 percent density were calculated to determine total area used by the fish (95%) and to identify where successively higher zones of activity (70% and 50%) were located in the river (Worton, 1989). Kernel method works through a grid of probability density to assign a value to each of the observed points which is the average of all the values that intersect at a point (Seaman, Powell, 1996; Worton, 1989). The grid width is known as smoothing parameter or bandwidth (h) and it is one of the critical factors for the method of Kernel (Silverman, 1986). Very small values of this parameter reveal details of the structure of the data resulting in home ranges as disconnected islands. Conversely, high values have the effect of overestimating the home range size (Silverman, 1986). In this case, the smoothing parameter was calculated by Animal Movement using the ad-hoc method based in Silverman (1986). Additionally, we calculated the linear home range for each individual which corresponds to the length of the river stretch used by fish. To estimate the linear home range, we measured the distance between the two farthest points where the fish were recorded during the radio tracking periods (Khan et al., 2004).

The relationship between body mass and home range size was determined through simple correlation. Because of the low sample size (n = 7 fish) a resampling procedure was used to get a robust estimate of the significance of the correlation. Values of home range size were randomly shuffled (without replacement) and the correlation was calculated between the shuffled values of home range size and body mass via Pearson’s r. This procedure was repeated 10,000 times to generate a random distribution against which the observed correlation value was compared. The correlation was considered significant if at least 95% of the randomized r values were lower than the non-randomized (observed) value of r. Because the number of tracking days (Tab. 1) may be correlated with estimates of home range size, we used the residuals from the regression between home range size and number of days tracked to re-evaluate the relation between home range size and body mass.

Testing fish mobility. We tested how mobile *D. camposensis* was by modelling its movement under different scenarios using the fishmove R-package. This package predicts movement parameters of leptoikurtic fish dispersal based on a meta-analysis of heterogeneous fish movement in rivers (Radinger, Wolter, 2014). We obtained the predictions under three different scenarios, mobile population (1% site fidelity), intermediate population (50% fidelity), and sessile population (99% fidelity) using the body sizes (L) reported in Tab. 1, the aspect ratio of the caudal fin (SO) set to 1.2, a time period (T) set to 28 days (the maximum number of days an individual was tracked in this study) and a stream order of 4 (estimated in this study; see supplementary material for further methodological details and fig. 2 of S1 - Available only as online supplementary file accessed with the online version of the article at http://www.scielo.br/ni). To test

| Code | SL (cm) | Weight (g) | Number of Recaptures | Radio tracking Period |
|------|---------|------------|-----------------------|----------------------|
| 13   | 19.9    | 142.9      | 80                    | 28 september-20 november 2006 |
| 14   | 17.3    | 118.7      | 42                    | 3 october-20 november 2006    |
| 52   | 18.5    | 91.7       | 9                     | 13 february-22 february 2007 |
| 61   | 15.0    | 75.0       | 29                    | 5 december-27 december 2006 |
| 62   | 13.5    | 44.7       | 84                    | 27 december 2006-25 january 2007 |
| 63   | 17.5    | 90.5       | 22                    | 11 february-19 february 2007 |
| 67   | 16.0    | 78.0       | 50                    | 14 november-12 december 2006 |
whether movements in *D. camposensis* were consistent with a mobile, intermediate, or sessile species, we sampled from the distributions obtained to estimate the probability of finding the values equal to or more than the mean linear home range (387.4 m) under the three scenarios. A scenario is rejected if the p-value is significant (p < 0.05).

**Results**

*Diplomystes camposensis* individuals moved upstream, downstream, and across the river (transversal), during both day and night (Fig. 2). Tracking period was different for each fish ranging from 8 to 52 days. We found that the major distance traveled by fish was 2,840 m and 2,284 m in RT 13 and RT 14, respectively (Fig. 2). Comparing distance versus tracking time we observed that total movement varied from 383.5 m traveled in 28 days to 1,462 m traveled in 9 days, for RT 61 and RT 52, respectively (Tab. 1). Distances were not correlated neither with tracking period (number of days) (p= 0.06) nor recaptures (p= 0.61).

Results for second indicator, average movement distance calculated for each fish varied between 4.6 ± 1.3 m (average ± SE) traveled in 28 days and 163 ± 62 m traveled in 9 days, in individuals RT 62 and RT 52, respectively. Average movement distance across all individuals was different between day and night time (see Fig. 3c). The average distance recorded during the day was 18.6 ± 6.7 m, while the average distance travelled at night was 33.3 ± 12.9 m. This difference was statistically significant under the Friedman test (Friedman chi-squared = 6; p = 0.014).

Cumulative directional movement (CDM) averaged for seven individuals showed an overall tendency for movement in the downstream direction (-174.4 ± 29.6 m), with no significant differences between movements registered at night and day time (Friedman chi-squared = 0.67, p = 0.41) (see Fig. 3b). Distances for RT 14 and RT 67 tended to be upstream during both night and day, with greater movements during day (negative value far from zero) than during the night (negative value near zero). In contrast, RT 62 traveled downstream during night and upstream during day time.

In relation to the average distance from E0 (or release site) and considering the average across individuals, results showed that distance from E0 was 573 ± 51.4 m during day and 283 ± 43.1 m at night time (Fig. 3a). Results did not show significant differences between day and night (Friedman chi-squared = 0.4, p=0.41).

Average area of the 95% probability home range was 0.068 ± 0.033 km$^2$, and major utilization density areas were 0.019 ± 0.010 km$^2$ for 70% probability kernel home range and 0.011 ± 0.005 km$^2$ for 50% probability kernel home range. Furthermore, linear home range was 0.387 ± 0.104 km.

![Fig. 2](image-url)  
Fig. 2. River sections showing movement patterns (black lines) for each of the seven individuals of *Diplomystes camposensis* studied. a) RT 13, b) RT 14, c) RT 52, d) RT 61, e) RT 62, f) RT 63, g) RT 67. Note that scales are different in each case. Please refer to Fig. 1 for reference to the location of these areas within the main study area (San Pedro River).
Fig. 3. Three measures of movement of Diplomystes camposensis. The x-axis shows six individuals and the combined data during day (D) and night time (N). The y-axis shows values of a) distance from E0 (m); b) Cumulative directional movement (m), and c) Average movement (m), differentiating between displacements upstream (positive) or downstream (negative) in direction. Black squares show mean value and whiskers show standard error. Individual R 52 not included here due to the lack of night measurements.
Body mass was significantly correlated with home range size. Home range was larger for fishes with greater mass (Fig. 4; $R^2_{(95\%)}=0.74$, $p<0.05$; $R^2_{(70\%)}=0.81$, $p<0.01$; $R^2_{(50\%)}=0.79$, $p<0.01$), and the pattern remained significant after accounting for number of days tracked, although with lower fit ($R^2_{(95\%)}=0.41$, $p=0.06$; $R^2_{(70\%)}=0.51$, $p<0.05$; $R^2_{(50\%)}=0.48$, $p<0.05$). We found no significant relationship between body mass and lineal home range.

![Graph showing relationship between body mass and home range size.](image)

**Fig. 4.** Relationship between body mass (g) and Kernel home range (m²). Black circles, gray squares, and white pentagons correspond to Kernel estimation with 95%, 75%, and 50% density, respectively.

**Fish movement modelling results.** The use of a modelling approach to evaluate fish movement produced a range of predictions for the breath of movement of *D. camposensis*, assuming the three mobility scenarios tested (low, intermediate, and high mobility; see fig. 2 of S1 - Available only as online supplementary file accessed with the online version of the article at http://www.scielo.br/ni). When comparing these predictions against the observed linear home range of the species (387.4 m), we found that both the models of low mobility and intermediate mobility were statistically rejected ($p=0.001$ and $p=0.034$, respectively), whereas the model of high mobility was not ($p=0.088$). In other words, the probability of sampling a home range value equal to or larger than the observed was extremely low under the low and intermediate mobility scenarios. Therefore, the scenario of high mobility for *D. camposensis* was strongly supported.

**Discussion**

Diplomystidae is one of the most threatened taxa of the freshwater fish fauna of Chile (Arratia, 1983; Habit *et al*., 2009; Muñoz-Ramírez *et al*., 2010). Historically, species in the genus Diplomystes were assumed to have low movement capacity, as were most native Chilean fish species, because of their relatively small body size (Link, Habit, 2015; but see Buria *et al*., 2007). Paradoxically, little information has been published about Chilean freshwater fish movements (Piedra *et al*., 2012) hence, those claims had not yet found support in empirical data. Our data and analyses show that adults of *D. camposensis* exhibit substantial movement. Movements of Diplomystes camposensis were smaller than those of large-bodied Siluriformes found in the large tropical South American rivers (i.e. 400 to 600 km; Bonetto *et al*., 1981; Paiva, Bastos, 1982), although these are migratory fish for which larger movement are expected. In contrast, movement patterns of *D. camposensis* were larger than those predicted based on its body size, caudal fin shape and habitat (stream order) (Radinger, Wolter, 2014). Previous work has shown indirect evidence of high mobility for *D. camposensis*. For example, patterns of genetic diversity and lack of genetic structure have suggested high levels of gene flow (Victoriano *et al*., 2012), while low rates of recapture found by Piedra *et al*. (2012) in capture-recapture studies could also suggest high mobility. Our telemetry data is the first direct empirical evidence of the high mobility of the species and it is consistent with the previous indirect evidence. It is unlikely that Chilean Diplomystes are migratory fish because all the data available suggest they inhabit a very specific type of habitat (large order rivers, boulder substrate, and well oxygenated, middle to fast flowing water) with little or no records in other habitats (Habit *et al*., 2009; García *et al*., 2012).

Our study shows that *D. camposensis* is active during day and night, although it was clearly more active during the night. These results support previous suggestions that the species was nocturnal and it is in agreement with empirical data from other catfish that show nocturnal (Casatti, Castro, 1998; Yu, Peters, 2003; Hahn *et al*., 2007) or crepuscular (Paxton, 1997) behavior. Other indexes (cumulative distance and distance travelled from the release site) did not show significant differences between day and night, which could be due to a lack of statistical power. Both the number of marked individuals and the number of tracking days should be increased to statistically confirm other tendencies such as the general trend showing these catfish move upstream, and remain moving closer to the riparian zone (E0) at night. Nocturnal behavior may be associated with feeding activity (Hossain *et al*., 1999) because several benthic invertebrates avoid predation by hiding in the river substrate during day time, and feed only during dusk or night time (Townsend, 2003). The main prey of *D. camposensis* is the decapod *Aegla rostrata* (Habit *et al*., 2009; Beltrán-Concha *et al*., 2012), whose availability increases during crepuscular-nocturnal time when they feed on macroinvertebrates in the drift (Figueroa *et al*., 2000; Moya *et al*., 2002). In addition, nocturnal behaviour in *D. camposensis* may represent a defensive mechanism against visually orientated predators such as salmonids (Metcalfe, Arnold, 1997) or birds. At night, Diplomystes may have moved upstream and into shallow riparian areas to feed, but remained far from...
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**Comments on conservation implications.** The movements described here are of considerable magnitude for a species of the size of *D. camposensis* (Radinger, Wolter, 2014; Minns, 1995). This supports previous reports of high gene flow levels inferred in the population of the San Pedro River based on mitochondrial DNA analyses (Habit et al., 2009; Victoriano et al., 2012), and these movements appear to be involved in ecologically important activities of the species. Accordingly, construction of a hydropower station might generate significant negative impacts on this species, as it has been demonstrated previously for other catfish species from South America (e.g. Barthem et al., 1991; Hahn et al., 2007; Makrakis et al., 2007). Fragmentation of an already small population with low genetic diversity (Habit et al., 2009; Victoriano et al., 2012) and relatively large home range (relative to the size of the Valdivia basin) could carry a number of conservation problems. First, small populations are more exposed to inbreeding and genetic drift which accelerates the loss of genetic diversity and may cause inbreeding depression (Newman, Pilson, 1997; Keller, 1998; Saccheri et al., 1998). Second, the interruption of movement between areas of the river may prevent both the rescue of populations that may go locally extinct (Hanski, 1991) and the movement of genes that might be beneficial in scenarios of environmental change (Tallmon et al., 2004). The total absence of diplomystids in smaller river systems such as all the coastal basins and low-order rivers (*i.e.* diplomystids have only been documented in Andean, high-order basins) (Muñoz-Ramírez et al., 2010), may well be indirect evidence of the need for larger areas to allow population persistence. Therefore, considering that the species may require maintaining a high magnitude of movement and it is already in a vulnerable condition (Habit et al., 2006), maintenance of movement patterns and connectivity in *Diplomystes camposensis* appears to be essential for its conservation. A potential mitigation measure for the impact of dams on habitat fragmentation could be the construction of fishways interconnecting the isolated areas. Diplomystids have been collected previously in irrigation canals (Habit, 1994), and genetic evidence has suggested diplomystids from central Chile are using irrigation canals to migrate between, otherwise, isolated basins (Muñoz-Ramírez et al., 2015), indicating diplomystids may successfully use artificial passages to overcome the need of movements between river areas. Studies will be needed to understand whether this potential solution could work for *D. camposensis* and whether it could generally work for other fish species in the basin.

Further studies will be needed to evaluate other potential aspects of the species biology including its dependence on riparian habitats, so other mitigation practices can be properly evaluated and proposed.

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**References**

Arratia G. Preferencias de hábitat de peces siluriformes de aguas continentales de Chile (Fam. Diplomystidae y Trichomycteridae). Stud Neotrop Fauna E. 1983; 18(4):217-37.

Arratia G. Description of the primitive family Diplomystidae (Siluriformes, Teleostei, Pisces): Morphology, taxonomy, and phylogenetic implications. Adenauerallée: Zoologisches Forschungsinstitut und Museum Alexander Koenig; 1987. Bonn Zool Monogr; 24:1-120.

Arratia G, Quezada-Romegliali C. Understanding morphological variability in a taxonomic context in Chilean diplomystids (Teleostei: Siluriformes), including the description of a new species. PeerJ. 2017; 5: e2991. Available from: https://doi.org/10.7717/peerj.2991.

Arratia G. Development and variation of the suspensorium of primitive catfishes (Teleostei: Ostariophysi) and their phylogenetic relationships. Adenauerallée: Zoologisches Forschungsinstitut und Museum Alexander Koenig; 1992. Bonn Zool Monogr; 32:1-156.

Barquete V, Bugoni L, Vooren CM. Diet of Neotropic cormorant (*Phalacrocorax brasilianus*) in an estuarine environment. Mar Biol. 2008; 153(3):431-43.

Barthem RB, de Brito Ribeiro MCL, Petrere Jr M. Life strategies of some long-distance migratory catfish in relation to hydroelectric dams in the Amazon Basin. Biol Conserv. 1991; 55(3):339-45.

Beltrán-Concha M, Muñoz-Ramírez C, Ibarra J, Habit E. Análisis de la dieta de *Diplomystes* (Siluriformes: Diplomystidae) de Chile. Gayana (Concepción). 2012; 76(2):102-11.

Bonetto AA, Canon Veron M, Roldan D. Nuevos aportes al conocimiento de las migraciones de peces en el Paraná. Ecosur. 1981; 8:29-40.

Bunt CM, Katopodis C, McKinley RS. Attraction and passage efficiency of white suckers and smallmouth bass by two Denil fishways. N Am J Fish Manag. 1999; 19(3):793-803.

Bunt CM, Castro-Santos T, Haro A. Performance of fish passage structures at upstream barriers to migration. River Res Appl. 2012; 28(4):457-78.

Buria L, Walde SJ, Battini M, Macchi PJ, Alonso M, Ruzzante DE, Cussac VE. Movement of a South American perch *Percichthys trucha* in a mountain Patagonian lake during spawning and prespawning periods. J Fish Biol. 2007; 70(1):215-30.

Campos H, Dazarola G, Dyer B, Fuentes L, Gavilán J, Huaquín L et al. Categorías de conservación de peces nativos de aguas continentales de Chile. Bol Mus Nac Hist Nat. 1998; 47:101-22.

Casatti L, Castro RM. A fish community of the São Francisco river headwaters riffles, southeastern Brazil. Ichthyol Explor Freshw. 1998; 9(3):229-42.
Colin N, Piedra P, Habit E. Variaciones espaciales y temporales de las comunidades ribereñas de peces en un sistema fluvial no intervenido: Río San Pedro, Cuenca del Río Valdivia (Chile). Gayana. 2012; 76(Suppl.1):24-35.

Cooke SJ. Biotelemetry and biologging in endangered species research and animal conservation: Relevance to regional, national and IUCN Red List threat assessments. Endanger Species Res. 2008; 4(1-2):165-85.

Dyer BS. Systematic review and biogeography of the freshwater fishes of Chile. Estud Oceanol. 2000; 19:77-98.

Figueroa R, Araya E, Valdivinos C. Deriva de macroinvertebrados bentónicos en un sector de rítrón: Río Rucúe, Chile Centro-Sur. Bol Soc Biol Concepc. 2000; 71:23-32.

García A, González J, Habit E. Caracterización del hábitat de peces nativos en el río San Pedro (cuenca del río Valdivia, Chile). Gayana. 2012; 76(Suppl.1):360-44.

Habit E. Ichtofauna en canales de riego de la cuenca del río Itata durante la época de otoño-invierno. Comun Mus Hist Nat Concepción. 1994; 8:7-12.

Habit E. Aspectos de la biología y hábitat de un pez endémico de Chile en peligro de extinción. Interciencia. 2005; 30(1):8-11.

Habit E, Dyer B, Vila I. Current state of knowledge of freshwater fishes of Chile. Gayana. 2006; 70(1):100-13.

Habit E, Jara A, Colin N, Oyanedel A, Victoriano P, González J, Solis-Luñí K. Threatened fishes of the world: Diplomystes camposensis Arratia, 1987 (Diplomystidae). Environ Biol Fish. 2009; 84(4):393-94.

Hahn L, English K, Carosfeld J, Da Silva LGM, Latini JD, Agostinho AA et al. Preliminary study on the application of radio-telemetry techniques to evaluate movements of fish in the Lateral canal at Itaipu Dam, Brazil. Neotrop Ichthyol. 2007; 5(2):103-08.

Hanski I. Single-species metapopulation dynamics: concepts, models and observations. Biol J Linn Soc Lond. 1991; 42(1-2):17-38.

Hardman M. The phylogenetic relationships among non-diplomystid catfishes as inferred from mitochondrial cytochrome b sequences; the search for the icatuid sister taxon (Otophysi: Siluriformes). Mol Phylogenet Evol. 2005; 37(3):700-20.

Hemson G, Johnson P, South A, Kenward R, Ripley R, Macdonald D. Are kernels the mustard? Data from global positioning system (GPS) collars suggests problems for kernel home-range analyses with least-squares cross-validation. J Anim Ecol. 2005; 74(3):455-63.

Hooge PN, Eichenlaub B. Animal movement analysis extension to Arcview ver. 1.1. Anchorage: U.S. Geological Survey; 1997.

Hooge P, Eichenlaub W, Solomon E. Using GIS to Analyze Animal Movements in the Marine Environment, Spatial Processes and Management of Marine Populations. Anchorage: Alaska Sea Grant College Program; 2001.

Hossain MAR, Batty RS, Haylor GS, Beveridge MCM. Diel rhythms of feeding activity in African catfish, Clarias gariepinus (Burchell 1822). Aquac Res. 1999; 30:901-05.

Keller LF. Inbreeding and its fitness effects in an insular population of song sparrows (Melospiza melodia). Evolution. 1998; 52(1):240-50.
Movements and home range in *D. camposensis*

Radinger J, Wolter C. Patterns and predictors of fish dispersal in rivers. Fish Fish (Oxf). 2014; 15(3):456-73.

Saccheri I, Kuussaari M, Kankare M, Vikman P, Fortelius W, Hanski I. Inbreeding and extinction in a butterfly metapopulation. Nature. 1998; 392:491-94.

Seaman DE, Powell RA. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology. 1996; 77(7):2075-85.

Silverman BW. Density estimation for statistics and data analysis. London: Chapman & Hall; 1986.

Springer JT. Some Sources of Bias and Sampling Error in Radio Triangulation. J Wild Manage. 1979; 43(4):926-35.

Solis-Luﬁ K, Jara A, Colin N, González J, Oyanedel A, Habit E. Implante quirúrgico de radiotransmisores en *Diplomystes camposensis* (Siluriformes, Diplomystidae). Arch Med Vet. 2009; 41:269-74.

Sullivan JP, Lundberg JG, Hardman M. A phylogenetic analysis of the major groups of catﬁshes (Teleostei: Siluriformes) using rag1 and rag2 nuclear gene sequences. Mol Phylogenet Evol. 2006; 41(3):636-62.

Supreme Decree nº51/2008. Ministry General Secretariat of the Presidency, Chile. Tercer proceso de clasiﬁcación de especies según su estado de conservación. 2008. Gobierno de Chile.

Tallmon DA, Luikart G, Waples RS. The alluring simplicity and complex reality of genetic rescue. Trends Ecol Evol. 2004; 19(9):489-96.

Townsend CR. Individual, population, community, and ecosystem consequences of a ﬁsh invader in New Zealand streams. Conserv Biol. 2003; 17(1):38-47.

Travade F, Bomassi P, Bach JM, Brugel C, Stein-bach P, Luquet JF et al. Use of radiotracking in France for recent studies concerning the E.D.F. Fishways Program. Hydroécol Appl. 1989; 1:33-51.

Vitorianop PF, Vera I, Olmos V, Dib M, Insunza B, Muñoz-Ramírez C et al. Patrones idiosincráticos de diversidad genética de peces nativos del Río San Pedro (Cuenca del Río Valdivia), un sistema de la región glaciateda del sur de Chile. Gayana. 2012; 76(Suppl.1):71-85.

Vila I, Contreras M, Fuentes L. Reproducción de *Diplomystes nahuelbutaensis* Arratia 1987 (Pises: Diplomystidae). Gayana. 1996; 4(2):129-37.

Wilkes MA, Maddock I, Link O, Habit E. A community-level, mesoscale analysis of ﬁsh assemblage structure in shoreline habitats of a large river using multivariate regression trees. River Res Appl. 2016; 32(4):652-65.

Winter J. Advances in underwater biotelemetry. In: Murphy BR, Willis DW, editors. Fisheries Techniques. Maryland: American Fisheries Society; 1996. p.555-590.

Worton BJ. Kernel Methods for Estimating the Utilization Distribution in Home-Range Studies. Ecology. 1989; 70(1):164-68.

Yu SL, Peters E. Diel and seasonal abundance of ﬁshes in Platte River, Nebraska, USA. Fish Sci. 2003; 69(1):154-60.