Patterns of Distribution of Bivalve Populations in a Mediterranean Temporary River

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Abstract: In the south of the Iberian Peninsula, many rivers are intermittent, a state most likely to be exacerbated by climate change, strongly affecting river biota. An additional challenge for native biota in this area is the arrival of new species, frequently aided by humans, and bivalves are particularly at risk. Here we assessed whether the native (Unio delphinus) and invasive (Corbicula fluminea) bivalves differed in habitat use. To address this question, we sampled populations of both species in six isolated permanent pools in the same river during summer in three consecutive years. U. delphinus occurred in all pools, while C. fluminea occurred only in the two most downstream pools. U. delphinus, but not C. fluminea, was found preferentially in patches under riparian vegetation cover. Both species were found in similar sediment types (coarse and fine gravel respectively). Although U. delphinus was present in all pools, recruitment was detected only in 2016, in one pool. We concluded that both species have the potential to compete for space, but a well-developed riparian vegetation cover may provide U. delphinus some advantage against C. fluminea.

Keywords: Unio delphinus; Corbicula fluminea; intermittent river; dry season; Guadiana basin; Mediterranean

1. Introduction

Bivalves have a pivotal importance in freshwater, filtering phytoplankton, bacteria and fine particulate organic matter from the water column and sediment [1]. With the exception of Invasive or exotic freshwater bivalves, bivalve biodiversity is declining rapidly at a global level [2], and most native bivalves are highly endangered [3–5]. This decline is caused mainly by habitat degradation and biological invasions [6].

Bivalve introductions were fostered by the globalization of economic trade routes, increased watershed connectivity and recreational transport [7] and most likely will continue to occur at a greater pace. In many systems the decline of native bivalves occurs concomitantly with the spread of the invasive Asian clam (Corbicula fluminea) or Zebra and Quagga mussels (Dreissena sp.) [8]. Invasive bivalves may often become dominant (by attaining high density and biomass rapidly [9,10]), and therefore alter the community structure and function of invaded systems [11–14].

The Oeiras (Guadiana basin, South Portugal; Mediterranean climate) is an intermittent river with superficial flow after winter rains but reduced to persistent isolated pools in the summer. These pools
are harsh environments for many species since they may attain high temperature and conductivity and low dissolved oxygen in the summer. According to the IPCC [15] global change predictions, an increase in the frequency and intensity of extreme events, such as droughts, is expected for this area. Under these conditions, biota in intermittent Mediterranean rivers may become extremely vulnerable since pools will be at increased risk of drying. Therefore, special conservation efforts may be needed for Mediterranean streams and rivers.

The Oeiras river has important populations of the unionids Unio delphinus, Unio tumidiformis and Anodonta anatina [16–18]. However, there are also large populations of the invasive Corbicula fluminea. Corbicula fluminea is a potential threat to U. delphinus in other Iberian rivers [9,11,19,20] since C. fluminea was negatively related to native mussel abundance at small spatial scales [21]. Moreover, another exotic bivalve, Dreissena polymorpha has been recorded in nearby rivers [22], and it is likely to reach South Portugal, further affecting native species and increasing the need to adopt urgent conservation measures for native bivalves.

To plan efficient conservation measures to protect native bivalves it is fundamental to obtain data on their current distribution, population structure and the appropriate conditions for these populations to thrive. Therefore, our objectives were: (i) to get insights on distribution of native (Unio delphinus) and invasive (Corbicula fluminea) in a 6 km stretch of the Oeiras river; (ii) to understand the microhabitat features influencing the distribution of these two species, and (iii) to estimate population parameters (densities, population structure). To fulfill these objectives, we sampled specimens and measured environmental conditions in six summer pools on three consecutive years from 2015 to 2017.

2. Materials and Methods

2.1. Environmental Conditions

We sampled six permanent pools in the Oeiras river: Ossada Montante (A), Monte Ossada (B), Monte Bentes (C), Pego do Inferno (D), Pego do Linho (E) and Pego dos Cágados (F) (Figure 1) in three consecutive summers (September) between 2015 and 2017. Each pool was mapped using satellite imagery and in loco measurements, and the extent of submerged area, the total length and width, the maximum depth, the micro habitat’s composition including sediment type (see below), were determined each year.

![Figure 1. Location of the six permanent pools in the Oeiras river, flowing north in this section. Ossada Montante (A), Monte Ossada (B), Monte Bentes (C), Pego do Inferno (D), Pego do Linho (E) and Pego dos Cágados (F).](image_url)
Concomitantly we characterized the pools in terms of riparian vegetation and possible human-impacted riparian features (e.g., presence of artificial structures and livestock access). We also measured turbidity and conductivity.

2.2. Qualitative Sampling

We firstly searched for bivalves with a batiscope (adapted from [12]) until the total pool area was explored or to a maximum of one hour of searching. Specimens were identified, measured, weighed and placed back at the same sampling location. For each pool, a capture-per unit of effort value (C.P.U.E.) was calculated, and results were expressed as the number of bivalves captured per person, per hour [23].

2.3. Quantitative Sampling

After the qualitative sampling, we established perpendicular transects starting at the tip of the submerged area, with a minimum distance of five meters, making sure that all micro-habitats were included. As pools length vary yearly with different submerged areas this procedure was repeated each year. In each transect, we established 0.25 m² quadrats with one quadrat randomly taken within the first meter of each margin (left and right) and two random quadrats in the middle of each transect to a maximum depth of 1.5 m [12,24,25]. The minimum distance between quadrats was three meters. Bivalves were identified, measured and weighed. We also recorded the water depth, distance to the margins, type of substrate and micro-habitat (see below) within the quadrat. Sediment grain size in each quadrat was classified according to American Society for Testing and Materials (ASTM) [26] as boulders (>300 mm), cobblers (75–300 mm), coarse gravel (19–75 mm), fine gravel (4.75–19 mm), sand (0.075–4.75 mm) and silt/clay (<0.075 mm).

Micro-habitats were defined by taking into consideration the sediment type, presence, type and extension of vegetation as well as whether quadrats were sampled under riparian vegetation shade. All native bivalves were left in their location while Corbicula fluminea specimens were removed from the pools. Yearly population estimates were obtained multiplying population density by pool size.

2.4. Data Analysis

When appropriate, environmental data was tested for normality (Kolmogorov–Smirnov normality test) and homogeneity of variances (Levene’s test) [27]. If normality and homogeneity of variances were not achieved, non-parametric tests were used.

Sediment data was expressed as percentages of cover at the sampling quadrats. A Multiple Correspondence Analysis (MCA) from FactoMineR package in R (Version 3.5.0, R. Core Team, 2018), was used to relate the presence/absence of bivalves and the environmental variables: sediment type, riparian gallery cover (presence or absence), distance to the nearest margin (m) and water depth (m).

We evaluated the correlation between the estimated densities and C.P.U.E. values and environmental variables using Spearman’s rank correlation (SPSS, version 22.0, IBM, Armonk, New York, NY, USA). For Corbicula fluminea the data used corresponded to the two most downstream pools. To assess habitat preferences in terms of sediment types we applied the Ivlev’s electivity index, Ei (Ivlev, 1961) adapted for habitat preferences (e.g., [28,29]), given by:

\[ E_i = \frac{r_i - P_i}{r_i + P_i} \]

where \( r_i \) is the proportion of individuals in a habitat with a specific sediment type (i), and \( P_i \) is the relative abundance of that habitat in the study area. Values of \( E_i = -1 \) indicate avoidance, \( E_i = 0 \) represents non-selective use of habitat type, and \( E_i = 1 \) indicates exclusive use of habitat type.

Population structure (sum of all pools) were compared using a G-log likelihood ratio (SPSS, version 22.0) to test for differences among years (using the post hoc z test). Six size classes were considered for Ut. delphinus: <30 mm, [30–40] mm, [40–50] mm, [50–60] mm, [60–70] mm and ≥70 mm. Juveniles were grouped in the first size class according to Smith [30]. Corbicula fluminea were also grouped in five size classes: <10 mm, [10–20] mm, [20–30] mm, [30–40] mm and ≥50 mm.
Table 1. Environmental conditions and population parameters in six pools (A to F) in the Oeiras river in 2015–2017.

| Environmental Parameters | Pools | Pools | Pools | Pools | Pools | Pools |
|--------------------------|-------|-------|-------|-------|-------|-------|
|                          | A     | B     | C     | D     | E     | F     |
| Maximum depth range (cm) | 72–80 | 75–90 | 90–160| 200   | 130–160| 20–20 |
| Maximum width range (m)  | 17–30 | 7–10  | 21–26 | 23–24 | 16–23 | 12–16 |
| Maximum length range (m) | 84–102| 28–32 | 226–268| 100–113| 159–236| 37–88 |
| Total area (m$^2$)       | 3015  | 2411  | 16910 | 4065  | 489393| 6400  |
| Exotic vegetation        | No    | No    | Yes   | Yes   | Yes   | Yes   |
| Riparian gallery vegetation cover | Continuous gallery composed of initial succession vegetation, reeds, presence of few trees—Fraxinus angustifolia or shrubs—Nerium oleander. | Gallery almost continuous composed mainly of shrubs—Flueggea tinctoria and N. oleander.128(409,128),(884,161) | Gallery almost continuous in the left bank with F. angustifolia and Salix spp. and the exotic (Giant cane, Arundo donax). Discontinuous gallery of F. angustifolia and N. oleander in the right bank. | Almost continuous gallery of F. angustifolia and N. oleander in right bank, but very thin transversely. Left bank with sparse vegetation with few individuals of F. angustifolia and N. oleander. Presence of Eucalyptus globulus. | Sparse gallery in both banks, N. oleander in the right rocky bank, F. angustifolia Salix spp. and E. globulus in the left bank. | Continuous gallery composed by initial succession vegetation, reeds, presence of few trees of F. angustifolia Salix spp. and E. globulus. |
| Cattle presence          | Yes   | Yes   | Yes   | Yes   | Yes   | Yes   |
| Sampling year            | 2015  | 2016  | 2017  | 2015  | 2016  | 2017  |
| Submerged area (m$^2$)   | 991   | 1172  | 1232  | 136   | 240   | 177   |


3. Results

3.1. Sites Description

The six pools differed in their physical conditions. Some locations had a well sustained riparian vegetation cover, mainly with ash and willow trees (Fraxinus angustifolia and Salix atrocinerea) and stable margins (e.g., pool C; Table 1), while others had discontinuous riparian corridors, unstable banks, some non-native tree species, modified river channels or cattle presence. Water conductivity (>600 µS cm⁻¹), and turbidity (5.69–57.9 NTU's) were high. Conductivity was high in all pools as sampling occurred in late summer with low water availability and varied between years due to shifts in water volume and depth. Turbidity varied because intrinsic pool characteristics were also different. Some pools are shallower, some pools have more fish fauna, some pools might experience increased anthropogenic pressure, all are variables that might influence turbidity differently.

3.2. Bivalve Abundance and Distribution

Four bivalve species occurred in the Oeiras river. The native U. delphinus and the invasive C. fluminea were the most abundant, while Anodonta anatina and Unio tumidiformis were scarcer. Unio delphinus catch per unit effort (C.P.U.E.) ranged from zero (pools B and E in 2017) to 50.5 per researcher h⁻¹ (pool A in 2017; Table 2). Unio delphinus densities attained up to 6.0 individuals per m² (pool D in 2017) while maximum densities of C. fluminea were estimated in 12.7 individuals per m² (pool E; Table 2, Figure 2). For C. fluminea C.P.U.E. and estimated densities were related (Spearman’s rank correlation: n = 6; rs = −0.829; p = 0.042) unlike for U. delphinus (n = 18; rs = −0.273; p = 0.274).

Table 2. Densities (individuals per m²) and catch per unit of effort (C.P.U.E., number of bivalves collected per researcher per hour) of U. delphinus and C. fluminea in six pool sites in the Oeiras river in three years.

| Site | Species         | 2015     | 2016     | 2017     |
|------|----------------|----------|----------|----------|
|      |                | Individuals per m² | C.P.U.E. | Individuals per m² | C.P.U.E. | Individuals per m² | C.P.U.E. |
| A    | U. delphinus   | 1.67     | 3.0      | 2.17     | 5.2      | 4.17     | 50.5      |
|      | C. fluminea    | 0        | 0        | 0        | 0        | 0        | 0         |
| B    | U. delphinus   | 3.20     | 2.5      | 0.80     | 7.5      | 0.73     | 0         |
|      | C. fluminea    | 0        | 0        | 0        | 0        | 0        | 0         |
| C    | U. delphinus   | 0.86     | 18.7     | 1.94     | 4.0      | 1.38     | 5.7       |
|      | C. fluminea    | 0        | 0        | 0        | 0        | 0        | 0         |
| D    | U. delphinus   | 2.67     | 6.3      | 2.32     | 15.0     | 6.00     | 0.9       |
|      | C. fluminea    | 0        | 0        | 0        | 0        | 0        | 0         |
| E    | U. delphinus   | 2.27     | 42.3     | 2.40     | 36.0     | 1.57     | 0         |
|      | C. fluminea    | 0        | 0        | 0        | 0        | 0        | 0         |
| F    | U. delphinus   | 12.00    | 2.0      | 6.29     | 20.0     | 11.38    | 10.7      |
|      | C. fluminea    | 0        | 0        | 0        | 0        | 0        | 0         |

C. fluminea and U. delphinus density was not correlated (n = 170; rs = 0.110; p = 0.154). In general U. delphinus density tended to increase from 2015 to 2017 in most pools (except B and E), while C. fluminea density increased only in pool E within the same period.

At patch scale, the presence of bivalves was explained by the distance to the margins and depth (more individuals in the shallow margins) and fine gravel (C. fluminea) or coarse gravel substrates (U. delphinus) (Multiple correspondence analysis; Table 3 and Figure 3). These results were partially consistent with Spearman’s rank correlation: Densities of U. delphinus were correlated with the presence of fine gravel (rs = 0.126, p < 0.01) coarse gravel (rs = 0.160, p < 0.001) and riparian vegetation cover (rs = 0.153, p < 0.01). Densities of C. fluminea were positively correlated with fine gravel (n = 170;
\[ r_s = 0.260; p < 0.001 \]

sand \((n = 170; r_s = 0.170; p = 0.027)\) and silt/clay \((n = 170; r_s = 0.210; p < 0.01)\) and negatively correlated with depth \((n = 170; r_s = -0.207; p = 0.007)\) and rock presence \((n = 170; r_s = -0.302; p < 0.001)\). Although significant, all these correlations were low.

**Figure 2.** Estimated population size \((n)\) of *U. delphinus* (top) and *C. fluminea* (below) in six pool sites (A–F) along the Oeiras river.

**Table 2.** Densities (individuals per m\(^2\)) and catch per unit of effort (C.P.U.E., number of bivalves collected per researcher per hour) of *U. delphinus* and *C. fluminea* in six pool sites in the Oeiras river in three years.

| Site | Species      | 2015 Individuals | C.P.U.E. | 2016 Individuals | C.P.U.E. | 2017 Individuals | C.P.U.E. |
|------|--------------|------------------|---------|------------------|---------|------------------|---------|
| A    | *U. delphinus* | 1.67             | 3.0     | 2.17             | 5.2     | 4.17             | 50.5    |
|      | *C. fluminea* | 0                | 0       | 0                | 0       | 0                | 0       |
| B    | *U. delphinus* | 3.20             | 2.5     | 0.80             | 7.5     | 0.73             | 0       |
|      | *C. fluminea* | 0                | 0       | 0                | 0       | 0                | 0       |
| C    | *U. delphinus* | 0.86             | 18.7    | 1.94             | 4.0     | 1.38             | 5.7     |
|      | *C. fluminea* | 0                | 0       | 0                | 0       | 0                | 0       |
| D    | *U. delphinus* | 2.67             | 6.3     | 2.32             | 15.0    | 6.00             | 0.9     |
|      | *C. fluminea* | 0                | 0       | 0                | 0       | 0                | 0       |
| E    | *U. delphinus* | 2.27             | 42.3    | 2.40             | 36.0    | 1.57             | 0       |
|      | *C. fluminea* | 9.93             | 51.3    | 9.73             | 11.0    | 12.71            | 0       |
| F    | *U. delphinus* | 0                | 20.0    | 0                | 0       | 4.3              |        |
|      | *C. fluminea* | 12.00            | 2.0     | 6.29             | 20.0    | 11.38            | 10.7    |

**Table 3.** Statistical parameters from multiple correspondence analysis on factors explaining the distribution of *U. delphinus* and *C. fluminea* in six pools.

| Statistical Parameters | Dimension 1 | Dimension 2 |
|------------------------|-------------|-------------|
| Eigenvalues            | 0.2         | 0.21        |
| % of variance          | 2.01        | 1.90        |
| Cumulative % of variance| 2.01       | 3.91        |

| Variable               | Dimension 1 | Dimension 2 |
|------------------------|-------------|-------------|
| Distance to near margin (m) | 0.54 | 0.54 | \(1.83 \times 10^{-46}\) |
| *C. fluminea*          | 0.17        | 0.09        | \(2.31 \times 10^{-12}\) |
| Silt/Clay              | -           | 0.42        | \(7.94 \times 10^{-83}\) |
| Riparian gallery cover | -           | 0.16        | \(5.86 \times 10^{-22}\) |
| Water column depth (m) | 0.65        | 0.56        | \(3.32 \times 10^{-36}\) |
| Coarse Gravel          | 0.09        | 0.17        | \(2.12 \times 10^{-33}\) |
| Fine Gravel            | 0.18        | 0.05        | \(1.00 \times 10^{-36}\) |
| Boulders               | 0.55        | 0.02        | \(6.65 \times 10^{-34}\) |
| Sand                   | -           | 0.08        | \(3.73 \times 10^{-11}\) |
| Cobble                 | 0.15        | 0.15        | \(1.76 \times 10^{-20}\) |
| *U. delphinus*         | 0.07        | 0.05        | \(1.00 \times 10^{-36}\) |
which was found preferentially in fine ($E < 0.22$) and sand ($E < 0.34$) and avoided sandy substrates ($E > 0$). Results are similar for *C. fluminea*, which was found preferentially in fine ($E = 0.53$) and coarse gravel ($E = 0.49$), avoiding boulders ($E = -0.22$) and sand ($E = -0.16$; an opposite result from Spearman rank correlations).

The previous findings were also mostly consistent with the Ivlev’s electivity index results regarding the native Unionidae (Figure 4; Table A1 of Appendix). *Unio delphinus* preferred coarse ($E = 0.47$) and fine gravel ($E = 0.34$) and avoided sandy substrates ($E = -0.28$). Results are similar for *C. fluminea*, which was found preferentially in fine ($E = 0.53$) and coarse gravel ($E = 0.49$), avoiding boulders ($E = -0.22$) and sand ($E = -0.16$; an opposite result from Spearman rank correlations).

The dominant size classes of *U. delphinus* were [40–45] mm in 2017, [60–65] mm in 2016 and [55–60] mm in 2015, and for *C. fluminea* [20–25] mm both in 2015 and 2017 and [30–35] mm in 2016. However, for both species, population structure was different among years (G-log likelihood ratio: $G = 198$, $p < 0.01$, d.f. = 10, $n = 762$ for *U. delphinus* and $G = 201$, $p < 0.01$, d.f. = 10, $n = 750$ for *C. fluminea*; Table 4, Figure 5). In 2016 and 2017 there was an increase of *U. delphinus* smaller size classes (especially in the classes >30 mm and [30–40] mm (in 2017) (Figure 5). A similar pattern was observed for *C. fluminea* in 2017 (size classes >10 mm and [10–20] mm).
Table 4. Results from the post hoc $z$ test after the G likelihood ratio was performed comparing size structure for both bivalve species. Same letters from $a$, $b$ and $c$ denote a subset of Year categories whose column proportions do not differ significantly from each other at the 0.05 level.

| Species | Size Class | Year | 2015 | 2016 | 2017 |
|---------|------------|------|------|------|------|
| U. delphinus | >30 mm | a | b | b | |
| | 30–40 mm | a | a | b | |
| | 40–50 mm | a | b | c | |
| | 50–60 mm | a | a | b | |
| | 60–70 mm | a | a | b | |
| | <70 mm | a | b | b | |
| C. fluminea | >10 mm | a | b | b | |
| | 10–20 mm | a | a | b | |
| | 20–30 mm | a | b | a | |
| | 30–40 mm | a | a | b | |
| | 40–50 mm | a | a | b | |
| | <50 mm | a | a | b | |

Figure 5. Size frequency distributions (according to the different size classes) of U. delphinus and C. fluminea from 2015 to 2017 (pooled data from six pools).
4. Discussion

The native *U. delphinus* and the introduced *C. fluminea*, when co-occurring, they roughly coexist in the same substrate types, preferring coarse and fine gravel, respectively. Nevertheless, *U. delphinus* was more abundant in locations under riparian tree cover, unlike *C. fluminea*. The importance of vegetation for *U. delphinus* is unclear, but it may be related to protection against high temperatures caused by direct sunlight. Other authors reported *U. delphinus* burrowing in banks between tree roots in hydraulically more stable locations [16]. Related species, such as *U. tumidiformis*, *U. mancus*, and *U. ravoisieri* seem to have the same preference for river locations shaded by riparian vegetation [31,32].

Densities of *U. delphinus* were higher than the reported for the northern Portuguese rivers Tua and Sabor (0.015–0.121 ind/m²; [33]), although sampling techniques differed, and those rivers were permanent. In the Oeiras river, while *U. delphinus* occurred in all the sampled pools, *C. fluminea* was only present in the two most downstream pools. It is possible that *C. fluminea* had fewer capabilities to expand upstream due to the river intermittency despite studies suggesting *C. fluminea* can move upstream up to 2.4 km per year [34]. In our study site the closest pool is approximately 4 km upstream (with the section in between pools being dry most of the year). Native bivalves are very adapted to summer conditions, unlike *C. fluminea*, which is known to be sensitive to summer environmental stress, suffering mass mortality events [35] making upstream dispersal more difficult. Some studies also suggest that the success of *C. fluminea* invasion decreases with increasing abundance of adult native mussels, probably due to lack of space for the invaders, physical displacement by actively burrowing mussels and locally reduced food and oxygen resources [21]. *C. fluminea* is a hermaphroditic species. Larvae are incubated until being released as juveniles into the water column, settle and bury [9]. Before settling they can be dragged through currents or move attached to other organisms [9]. Unlike native mussels this invasive species does not need a fish host to successfully reproduce, which is an enormous competitive advantage. On the contrary, glochidium larvae of freshwater Unionidae need to find suitable fish hosts to attach themselves to and metamorphose into free-living juveniles [17].

Our results were consistent with previous studies reporting *C. fluminea* preference for sediments with large organic matter content (lower grain sized sediments) such as sand mixed with silt and clay [10]. Organic material in sediments may be important for *C. fluminea* as this species is known for high filtration and growth/turnover rates, exacerbated during summer conditions [10,36]. Nonetheless in our pools sand was very uncommon, only detected in 2016. Therefore, the Ivlev’s index avoidance and the association observed in Spearman’s rank correlation have to be interpreted very carefully. Karatayev and co-workers [37], found a correlation between *C. fluminea* occurrence and of other three unionids. The same study reported that both were mostly found in coarse detritus (as *U. delphinus* in our study) and clay substrates (*C. fluminea*), similar to this study, due to the higher organic matter content and at the same depth.

*Corbicula fluminea* presence can exacerbate the pressure on *U. delphinus* by competing for food [21,38] and reducing available habitats for juvenile unionids. Suspension and deposit feeding negatively impact unionid recruitment, and the ingestion of unionids sperm, glochidia and juveniles may contribute to population declines [9,20]. Also, the introduction of new parasites and diseases [39], and increased ammonia toxicity as a result of massive *C. fluminea* die-offs, especially in the summer, may also increase native bivalves’ mortality [40].

Changes in environmental conditions due to global warming may enable the colonization by new fish, which may not be suitable hosts for some native bivalve’s glochidia [41]. Additionally, invasive invertebrate species may predate or compete with *U. delphinus* [1,9,42–45]. Several invasive predatory species are already abundant in this river, such as the Pumpkinseed sunfish (*Lepomis gibbosus*), the Chameleon cichlid (*Australoheros facetus*) and the red swamp crayfish (*Procambarus clarkii*), which may partially explain the low number of juveniles detected during this three-year survey.

Finally, as a consequence of global warming, and water deviation for irrigation and livestock, a reduction in water availability is expected in pools in the coming years [14] further increasing the pressure on *U. delphinus*. 
5. Conclusions

In conclusion, the knowledge about *U. delphinus* preference for locations under riparian vegetation, with coarse and fine gravel, may aid conservation efforts. In this context, improvement of riparian vegetation should lead to better-quality habitat, potentially decreasing suitability for invasive species such as *C. fluminea*. Mitigation or protection measures should start by protecting or increasing riparian areas, enabling protection from high summer temperatures, and maintaining areas with coarse and fine gravel. Since our results suggest that native and invasive species prefer similar sediment types and may compete for space, extreme caution should be taken not to allow *C. fluminea* expansion upstream.

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**Conflicts of Interest:** The authors declare no conflict of interest.

### Appendix A

**Table A1.** Percentage of occurrence of *U. delphinus* and *C. fluminea* in sediment types and percentage of occurrence of each sediment type (yearly).

| Year | Species   | Sediment Type | Boulders | Cobblers | Coarse Gravel | Fine Gravel | Sand | Silt/Clay | % of occurrence |
|------|-----------|---------------|----------|----------|---------------|-------------|------|-----------|----------------|
| 2015 | *U. delphinus* | 8            | 15       | 42       | 25            | 1           | 8    |           | 29             |
|      | *C. fluminea*  | 4            | 16       | 41       | 8             | 0           | 31   |           | 14             |
| 2016 | *U. delphinus* | 29           | 16       | 24       | 10            | 4           | 18   |           | 13             |
|      | *C. fluminea*  | 13           | 22       | 30       | 22            | 8           | 5    |           | 10             |
| 2017 | *U. delphinus* | 23           | 11       | 11       | 43            | 0           | 12   |           | 14             |
|      | *C. fluminea*  | 19           | 13       | 10       | 44            | 0           | 13   |           | 10             |

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