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Movement and Activity Patterns of Non-Native Wels Catfish (*Silurus glanis* Linnaeus, 1758) at the Confluence of a Large River and Its Colder Tributary

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Abstract: The establishment and proliferation of non-native fish species can have a range of effects within the local ecosystem, including alteration of food webs, nutrient cycling, pathogen dynamics and predation, sometimes also resulting in changed behavior and distribution of native fish species. Knowledge about movements and activity patterns is important to understand the dynamics of non-native animals in their new environment. The Wels catfish (*Silurus glanis* Linnaeus, 1758) is considered an invasive species in many places in Western Europe, and regional control programs are in place. Here, using radiotelemetry, we study the movements and activity patterns of invasive Wels catfish at an invasion front within the Po River (Italy); namely, at the confluence between the main river, where the species is abundant, and a colder tributary, the Dora Baltea River, where it is absent. In addition, we also investigate potential spatiotemporal overlap between Wels catfish and native and endangered marble trout (*Salmo marmoratus* Cuvier, 1829) in the area. A total of nine Wels catfish and eight marble trout were tagged. The Wels catfish showed a very high degree of residency within the study area in the Po River, close to the mouth the colder tributary. Despite this, only one catfish entered the lower reaches of the tributary and did so only occasionally during August. No catfish moved further upstream in the tributary. It is likely that lower temperatures in combination with more challenging hydrodynamic conditions made the tributary unattractive to the catfish. The catfish were active during all times of the day but substantially more so during evenings and at nights. Some, but not all, tagged catfish moved to areas in the main stem upstream of the confluence with the tributary. A large proportion of the tagged marble trout made occasional or longer visits to the Po River, with several individuals becoming resident, but without apparent mortality, in the tagged catfish home range. The high residency of the Wels catfish suggests that removal efforts may do well to initially focus on areas close to the habitats of species under conservation concern.

Keywords: invasive species; Wels catfish; marble trout; invasion front; radio telemetry; daily activity; temperature

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1. Introduction

Introductions of non-native freshwater fish have a long history, and the rate has increased in the last decades as a consequence of the active stocking of non-native fish, as well as accidental releases from aquaculture, sportfishing or the ornamental fish hobby [1,2]. The establishment and proliferation of non-native fish species can have a range of effects within the local ecosystem, including alteration of food webs, nutrient cycling, pathogen dynamics and predation, sometimes also resulting in changed behavior and distribution of native fish species [1]. The introduction of non-native species is a primary cause of biodiversity change in temperate rivers [3], and, in Italy, almost half of the occurring fish species are now of non-native origin [2].

The Wels catfish (*Silurus glanis* Linnaeus, 1758) is the largest European freshwater fish, with confirmed sizes approaching 3 m [4,5]. It is an omnivorous predator with fast growth and high fecundity that inhabits lakes, large rivers and low-salinity coastal areas [5]. The native range of the Wels catfish spans from southern Sweden and Germany, via Eastern Europe to southern Turkey and northern Iran in the south, and through Russia to the Aral Sea of Kazakhstan and Uzbekistan in the east. It has been widely introduced, mainly for sportfishing and aquaculture, in Western Europe but also in North Africa and Brazil [5–7].

The Wels catfish is an opportunistic predator [5]. Juveniles feed on invertebrates, small fish and detritus, while the adults may also eat larger fish, small mammals, birds, plants, crustaceans, amphibians, and insects, exploiting the range of prey available [5,8,9]. It is a generalist feeder and able to adapt its behavior and specialize on available prey [10]. The Wels catfish has been observed to opportunistically feed on pigeons on shore [11], as well as on shad [12], roach [8], lamprey [13] and Atlantic salmon [14] during their respective spawning migrations, even exploiting crowding of migrating fish in fish passage facilities [14]. Consequently, Wels catfish can markedly affect lake ecosystems [8] and substantially decimate spawning fish populations [13,14].

Knowledge about movements and activity patterns is important to understand the dynamics of non-native animals in their new environment [15]. Wels catfish are typically active in the evening or at night [16–19] but this might differ with habitat [19], feeding opportunities [20] and season [17], with some fish being active also during the day. Wels catfish generally show strong site fidelity [16,17], with movements reportedly increasing in the summer [18,21] and with some individuals embarking on longer-distance movements [21]. The species shows preference for warm water and is experiencing a range expansion associated with climate change-related increases in temperatures [6].

The Wels catfish was introduced in Italy for aquaculture in the early 20th century and has since spread throughout the country [5]. In the Po River, it is considered an invasive species, and regional control programs, including prohibited release and active removal, are in place (e.g., [22]). It is common in the main stem, with a progressive expansion upstream since 1989, while it has not yet been found in some colder tributaries [23,24]. Here, we study the movement and activity patterns of radiotagged invasive Wels catfish at an invasion front within the Po River, namely, the confluence between the main river, where the species is abundant, and a tributary, the Dora Baltea River, where it is absent [23,24]. In addition, we investigate potential overlap between Wels catfish and the endemic, endangered and highly valued marble trout (*Salmo marmoratus* Cuvier, 1829)—a potential prey [25].

2. Materials and Methods

2.1. Study Area

The study area is located at the confluence between the Po and the Dora Baltea Rivers in Piedmont, Italy The Po River is the largest Italian watercourse (watershed surface 74,000 km^2; mean annual flow 1540 m^3/s) and flows across northern Italy for 652 km from the Alps to the Adriatic Sea [26]. The upper part of its watershed, upstream of the confluence with the Dora Baltea River, has a drainage area of about 9050 km^2 and a mean annual discharge of about 160 m^3/s, with a nivo-pluvial hydrological regime and potamal characteristics typical of the rheophilic Cyprinids zone [24,27]. The Dora Baltea River is one of the most important tributaries of the Po River. It is 168 km long, with a watershed surface of 3891 km^2, and a mean annual discharge of 96 m^3/s (60% of the Po River discharge at the confluence). Its watershed includes the highest mountains of the Alpine range and is characterized by a much higher mean altitude a.s.l. (1871 m) compared to the Po River (1076 m). It is the only Italian river with a nivo-glacial regime, with a summer peak due to snowmelt, and its fast and cold waters and coarse substrates represent a suitable habitat for salmonid populations [24]. In particular, the lower stretch of the Dora Baltea River constitutes a spawning area for the endemic marble trout (*Salmo marmoratus*), whose declining populations are considered critically endangered, due to habitat alterations, fragmentation and hybridization with introduced brown trout (*Salmo trutta*) [25]. Instead,

in the Po River, the endemic cyprinid population is affected by a rapidly expanding presence of allochthonous species, such as Wels catfish (*Silurus glanis*), European barbel (*Barbus barbus*), and carp (*Cyprinus carpio*), which now constitute about 50% of the entire number of species present [24,27]. Water temperatures are consistently lower in the Dora Baltea compared to the Po River (Figure 1).

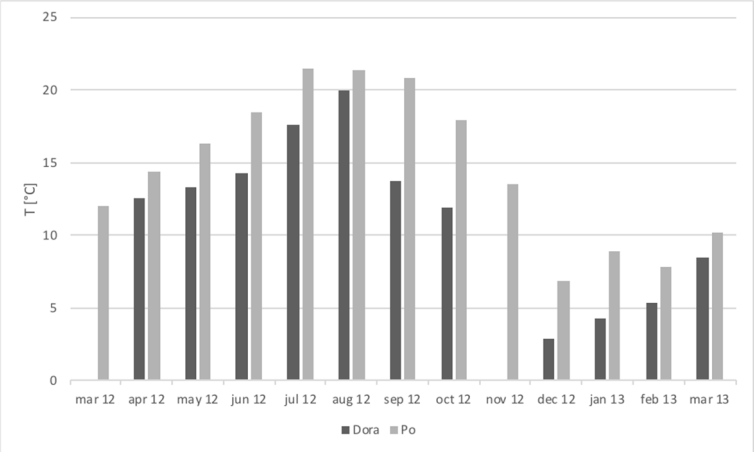

Figure 1. Monthly water temperatures of the Dora Baltea and Po Rivers from March 2012 to March 2013 (monthly average from [24] for April–July 2012, otherwise, point measurement data from ARPA Piemonte institutional monitoring network and [24]).

2.2. Tagging Protocol

A total of nine Wels catfish were caught in the Po River and released downstream of the mouth of the Dora Baltea River between 2–14 March 2012. Overall, five fish were caught about 5 km and four fish 0.7 km downstream of the Po–Dora Rivers junction. All fish were released within the study area (Figure 2). A total of eight marble trout, including two marble trout–brown trout (*Salmo trutta)* hybrids, were caught, tagged and released in the Dora Baltea River between 1 March and 27 April 2012 (Figure 2). Overall, two trout were caught with a fishing rod, while all other fish were caught using electrofishing gear (model ELT60 II 1300 W). All fish were anaesthetized using benzocaine and surgically tagged with internal radio transmitters (Model F1835, 14 g, 17 × 44 × 15 mm, 55 bpm, Advanced Telemetry Systems, Isanti, MN, USA). Tags were placed in the body cavity through an incision made on the ventral side of fish and the incision was closed by two sutures. The transmitters weighed on average 0.33% (range = 0.14–1.07%) of the fish's body mass, considerably below the limits deemed to have important effects on fish behavior [28,29]. After tagging, the fish recuperated in tanks with river water before being transported to the release site and released the same day. Two stationary automatic receivers (model R4500S, Advanced Telemetry Systems, Isanti, MN, USA) were placed to detect fish in the approximately 2400 m long study area within the Po River, 800 m upstream and downstream of the confluence with the Dora Baltea, respectively. An additional stationary automatic receiver was placed along the Dora Baltea 1100 m upstream the confluence, to detect entry in to this river. All three receivers were equipped with two Yagi-antennas, directed in upstream and downstream directions (Figure 2). The network of automatic stationary receivers was run from March to the end of August 2012.

Opportunistic manual radio tracking was used to position tagged catfish in the river with higher spatial resolution than the network of automatic stationary receivers. Manual tracking was performed throughout the main study period (March–August 2012) and, less frequently, during the following autumn and winter (October 2012–March 2013).

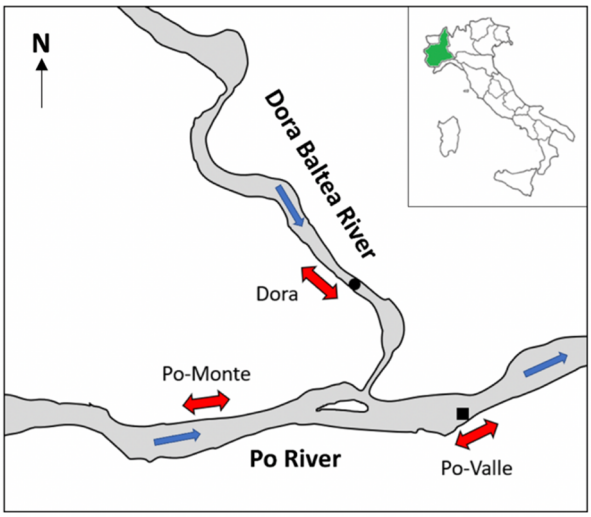

Figure 2. The study area. Double-directional red arrows represent automatic stationary receivers, unidirectional blue arrows represent the river flow direction, the black square the release site of the tagged Wels catfish in the Po River, and the black circle the release site of the tagged marble trout in the Dora Baltea River.

2.3. Data Interpretation

The raw radio data were filtered to remove noise based on NumPulses:NumMatches ratios <2. Detections on the Po River receivers defined presence in the study area. For the Wels catfish, movement up into the Dora Baltea was defined by passage of the Dora Baltea receiver, while presence in the lower part of the Dora Baltea was defined by detections (signal strength > 110) on the Dora Baltea receiver. The period and timing of entry into the lower Dora Baltea was quantified. The residence index in the Po River study area was calculated for each individual by dividing the number of days present by the number of days monitored [30,31]. Catfish defined to be in the Dora Baltea were not considered present in the Po River. To define an individual as present during one day, ten or more unique detections were required [32].

Manually tracked positions were used to calculate the mid-stream linear home range, including all positions tracked for the individual fish [33], as well as distance moved between tracking occasions. Due to the difference in tracking intervals, the distance moved between tracking occasions was divided by the time interval between them to obtain a comparable measure of rate of movement. Home ranges and mean rate of movement were calculated for each individual for the main study period and the following autumn and winter, separately. Individual home range was also calculated for all positions combined, showing yearly space occupancy. The home range and movement rate during the main study period and the following fall and winter were explicitly compared using the Wilcoxon signed-rank test.

To map the use of river sections upstream of the confluence with the Dora Baltea, presence up and downstream of the confluence was quantified using both manual and automatic data. For automatic data, a conservative signal strength threshold of 130 was used to define presence in the vicinity of the up- or downstream receiver.

Often, signal strengths are used to position fish in spatial zones or along the river (e.g., [34–36]). Here, the extensive use of habitat sheltered from antenna reach (boulders, banks) obscured the relation between distance to antenna and special position [37]. Instead, recurring peaks in detection strength for fish present in the study area were interpreted as activity peaks, where the fish leave the banks and boulders to explore the water column. These activity peaks were defined as signal strengths above 15% the daily average for the individual fish when the daily average signal strength was 100 or higher. If the daily average signal strength was under 100, 8% above the average was used to define high activity periods, taking into account lower differences in signal strength for more distant

fish. An activity peak required three or more high power detections within a detection interval of 30 min. Timing and duration of these activity peaks were determined. To test for activity preference in relation to part of the day, the accumulated high activity duration during day, evening, night and morning was summarized for the whole study period for each individual. To account for the evenings and mornings being shorter than the nights and days, the same test was repeated but with activity duration normalized by the accumulated available time within the same time windows. Sunset and sunrise defined the time of day; evening was defined as 1 h before and 1 h after sunset, morning as 1 h before and 1 h after the sunrise, day as the period between morning and evening, and night as the period between evening and morning [38]. Differences in activity between the different times of day were tested using Friedman tests. Posthoc tests were performed using Conover's All-Pairs Comparisons Test with Bonferroni-corrected *p*-values [39].

The residence index for marble trout was calculated after the same principles as for Wels catfish. For trout, detections were manually inspected to infer presence in the Dora Baltea. As for catfish, trout defined to be in the Dora Baltea were not considered present in the Po River, even if they registered low power detections on the Po receivers.

Data on fish positions were converted to distances on a line using QGIS ver 3.16.3-Hannover (https://qgis.org/en/site/, accessed on 21 September 2022). Data analysis and statistical tests were performed in R ver. 4.0.3 [40] using ggplot2 (for plots and visual movement analysis; [41]), plotly (for visual movement analysis; [42]), dplyr (for data management; [43]), plyr (for data management; [44]) and sqldf (for data management; [45]). A *p*-value of 0.05 was used as the significance threshold.

3. Results

No tagged Wels catfish passed the Dora Baltea receiver to move up into the tributary. Only one catfish entered the Dora Baltea and only the lower parts of the tributary (downstream of the Dora Baltea receiver). This fish was repeatedly detected in the Dora Baltea during evenings and nights between 5–30 August.

The tagged catfish were successfully tracked manually six–nine times during the main study period (March–August) and an additional one–five times during the following autumn and winter. The fish were tracked manually on average every 17th day (interval range 6–42 days) during the main study period, and on average every 42nd day (interval range 21–79 days) after this period.

The catfish had a median mid-stream linear home range of 1023 m (range = 574–1858 m) during the main study period. During the autumn and winter, excluding the fish with just one position, the median home range was 389 m (range 80–1767 m), significantly smaller than during the spring and summer (Wilcoxon, $p = 0.04$). Combining all tracked positions, the home ranges varied between 864–1921 m (median 1605 m; Figure 3A). The movement rate was also higher in spring–summer (median = 23 m/day, IQR = 19–26 m/day) than in autumn–winter (median = 4 m/day, IQR = 0.7–11 m/day; Wilcoxon, $p < 0.001$; Figure 3B).

Overall, five Wels catfish were repeatedly tracked in the Po River upstream of the confluence with the Dora Baltea, having moved slightly upstream compared to the release site, while one additional fish was detected upstream by the automatic stationary receivers (Figure 4). The automatic receiver data revealed that three fish never visited the vicinity of the upstream receiver, three fish did so to never be detected downstream the confluence again, while one fish briefly visited the upstream area just to return downstream again. Two fish made repeated back and forth movements (4 and 11 return journeys), before settling down and upstream, respectively (IDs 753 and 713; Figure 4).

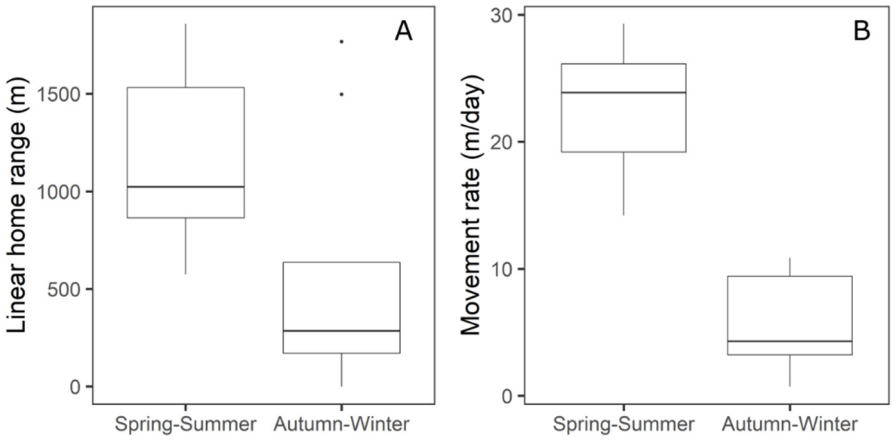

Figure 3. (**A**) Linear home range of tagged Wels catfish during spring–summer and autumn–winter (n = 9). (**B**) Average individual rate of movement during spring–summer and autumn–winter (n = 9).

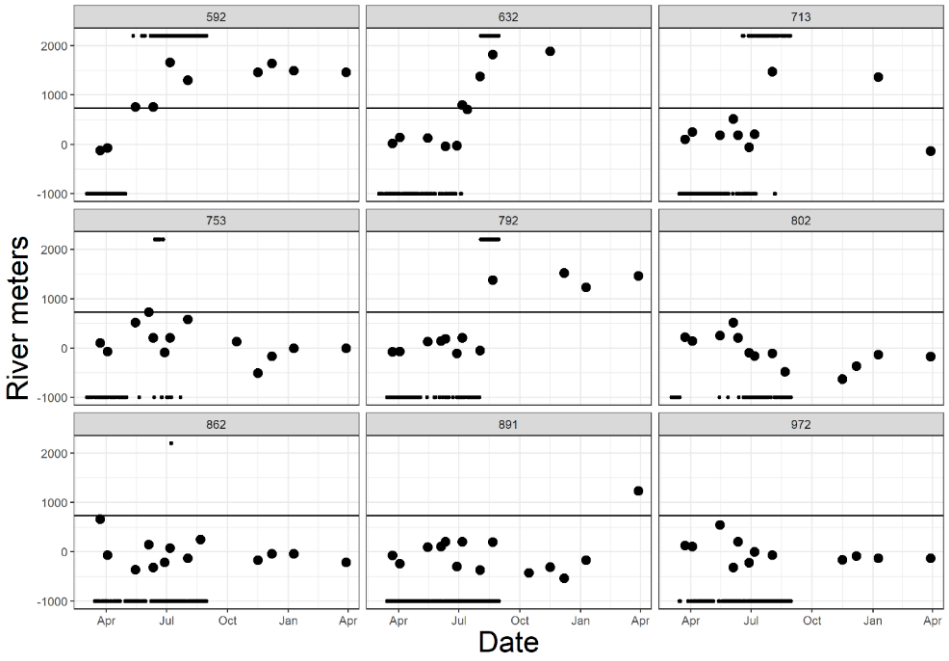

Figure 4. Fish detected over the study period (March 2012–March 2013). River meters from the release site on the *Y*-axis and time on the *X*-axis. Large dots represent manually tracked positions, whereas the smaller dots at the top and bottom of each plot represent detections in the vicinity of the upstream and downstream receivers (unrelated to the river meter axis). The black line constitutes the longitudinal position of the Dora Baltea River confluence. Fish IDs as plot subtitles.

Activity peaks were detected for all tagged catfish during all times of the day, but clear differences between different parts of the day were found (Friedman tests, $p < 0.001$). Conover's all-pairs comparisons posthoc tests of Friedman-type ranked data showed higher activity both in absolute terms ($p < 0.001$) and relative to the time available ($p = 0.05$) at night compared to the day, while the difference between night and morning was only statistically significant in absolute terms ($p < 0.001$) and not when weighted against available time ($p = 0.16$). The Wels catfish were more active in the evening compared to morning in both absolute ($p = 0.05$) and relative terms ($p < 0.009$), or, when weighted against available time, they were also more likely to be active in the evening than during the day ($p = 0.002$). No differences between morning and day were seen ($p > 0.35$) (Figure 5).

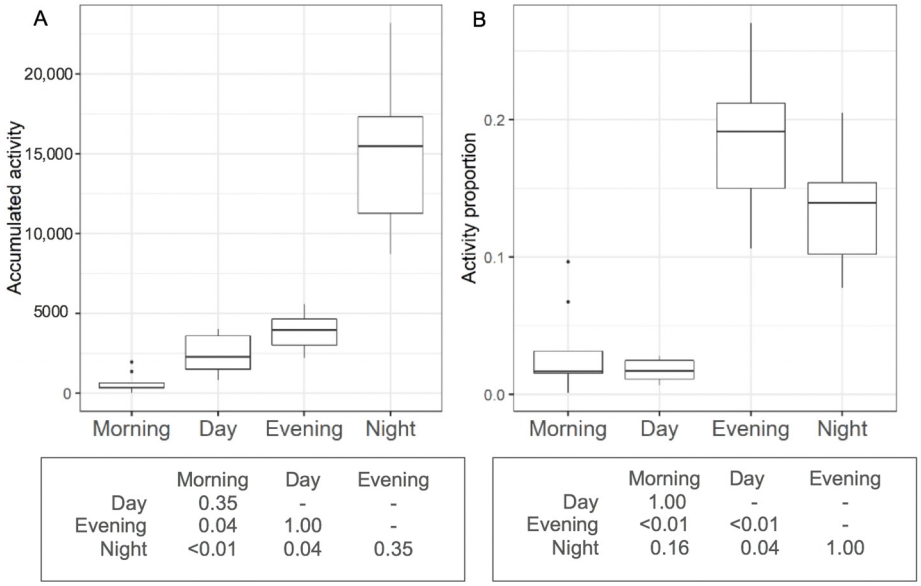

Figure 5. (**A**) Accumulated durations of high-activity events averaged over the individual catfish during the main study period (March–August). (**B**) The accumulated duration of high-activity events averaged over each individual and weighted against available time in the respective time period during the main study period (March–August). Tables of Bonferroni-corrected *p*-values from Conover's all-pairs comparisons posthoc tests of Friedman-type ranked data are found below the respective table.

From the eight marble trout caught, tagged and released in the Dora Baltea, two never left the tributary, two visited the Po River on two occasions each, while four left to the Po, never to return again. Three of the latter were detected within the study area until the end of the study, while one trout left it in a downstream direction nine days after release. The median time from release to the first visit to the Po River was 10 days (range 0.4–56 days). For the marble trout, the residence index in the study area ranged from 0 to 95%, with a median of 6%, but with three fish with values above 50%.

4. Discussion

In this first radiotelemetry study on Wels catfish in Italy, the tagged and tracked Wels catfish showed a very high degree of residency within the study area in the Po River, close to the mouth of the Dora Baltea, a colder tributary. Despite this, only one catfish entered the lower reaches of the tributary and did so only occasionally during August. No Wels catfish moved further upstream in the tributary to approach the stationary receiver placed about 1 km from the confluence. The catfish were active during all times of the day but substantially more so during evenings and nights. A large proportion of the tagged marble trout, on the other hand, made occasional or longer visits to the Po River, with several individuals becoming resident, but without apparent mortality, in the Wels catfish home range.

While the Wels catfish is abundant and invasive in the Po River, it has not yet been regularly found in the colder tributary, Dora Baltea [23,24]. This presents the confluence between the two rivers as an invasion front, offering the opportunity to study the dynamics limiting and promoting range expansion [46]. All tagged fish were present close to the tributary mouth almost continuously during the main study period, covering the warmest summer months of the year. Despite this, only one catfish visited the lower parts of the tributary and no tagged catfish moved further upstream in the tributary. The lower temperatures in the tributary may constitute a limiting factor for the catfish expansion. The Wels catfish is relatively tolerant to lower temperatures [5] and has been described to increase predation rates already at 15 °C [9]. Summer temperatures in the Dora River (July and August) exceed this threshold, as do Po River temperatures associated with Wels

catfish activity during other parts of the year in this study. (Figure 1). Nevertheless, being a glacial-fed river, the Dora Baltea consistently maintains lower temperatures than the Po River (on average, −3.6 °C along the study period), suggesting that the lack of Wels catfish movements into the tributary could be a matter of preference rather than absolute temperature tolerance. The Wels catfish has a physiological optimum of 25–27 °C and, while tolerating lower temperatures, might be inhibited by [5,47] and, therefore, behaviorally avoid them. Indeed, over half the fish seem to, at least temporarily, move upstream of the confluence in the Po River, potentially avoiding the Dora Baltea's colder water.

Hydrodynamic differences between the Po and Dora Baltea Rivers might also constitute a barrier to Wels catfish expansion. Although offering flow refuges and a superficially suitable catfish habitat, the Dora Baltea bottom slope is higher than the mainstem Po (about 0.22% vs 0.18%; [23]), resulting in it being a more fast-flowing and turbulent watercourse, with a coarser substrate. Typically, Wels catfish inhabit large rivers, lakes and coastal areas with low salinity [5], all environments characterized by relatively un-challenging hydrodynamic environments. Sometimes sensitive to higher flows, Wels catfish have been described to be displaced [48] or show lower activity and hide during high flows [49], but limited effects and maintained activity during higher discharges have also been reported [16,48]. The effect of flow on catfish behavior and habitat use is likely very site dependent. Whether hydrodynamic conditions keep them out of the Dora Baltea remains an open question.

The Wels catfish displayed high site fidelity throughout the study, with all fish displaying linear home ranges of under 2 km. Similar results have been reported for Wels catfish in riverine habitats elsewhere [14,17,21]. Ref. [21] studying Wels catfish movements in Tagus River, Portugal, similarly found that, while most tagged fish expressed high site fidelity, a minority performed relatively long-distance movements of over 10 km. This is a pattern relatively common in movement ecology and may be related to individual physiological differences between fish [50]. Perhaps, with a larger sample size, we would also have observed some fish embark on longer dispersing movements. It is also possible that juveniles, not tagged in this study, are more likely to be disperse [6]. Future studies, tracking a higher number and a larger size–age range of Wels catfish, will have to explore these dispersal dynamics in the Po River. In addition, mapping the prey availability in relation to catfish movements might shed light on their behaviors, including their avoidance of the Dora Baltea River.

The complex hydromorphology of the study area prevented us from using logged radio data to accurately position the detected fish within the study area, as river banks and boulders often partly blocked or attenuated the radio signal from the sheltered tagged fish [37]. As Wels catfish often use large stones, banks and thick vegetation as resting areas [17], we instead used peaks in detection strength for fish present in the study area to define activity peaks. When the fish move out to explore less-sheltered areas, this results in a higher signal strength for detected signals. This is a relative and not an absolute measure of activity, as the catfish can easily be active also within habitats sheltered from the antennas without presenting peaks in detection strength.

The Wels catfish has restricted vision but a sensitive olfactory sense, an electroreceptive system, well-developed hearing, and can orient itself using hydrodynamic cues, making it able to hunt even in complete darkness [5,51,52] and suitable for nocturnal predation. Indeed, in this study in the Po River, we found activity peaks predominantly but not exclusively in the evening and at night. Although local and temporal exceptions exist [17,19,20], this is in agreement with several previous telemetry studies estimating catfish activity based on movement (change in position; [17–19]), as well as with feeding experiments in captivity [20].

No direct interactions between tagged Wels catfish and tagged marble trout could be detected. Although the catfish did not make important excursions into marble trout habitat in the Dora Baltea, most tagged marble trout visited, or even resided for longer time periods, within the home range of the tagged catfish. Wels catfish have been reported to predate on adult Atlantic salmon, with 35% of passing salmon being predated at a fishway

in France. Even an 80 cm salmon, an animal with few natural aquatic predators in European rivers, was predated by a 160 cm catfish [14], offering a worrying precedent for marble trout conservation. Indeed, predation on a marble trout (30 cm total length) by a 10 kg Wels catfish caught by an angler along the Po River downstream of the study site was recently reported [53].

To date, active systematic removal activities have been carried out only in the lower portion of the Po River catchment [54], some 30 km downstream of the study site. The most recent abundance data available on Wels catfish population in the Po River show stable values in the proximity of the study site, but a significant increase at river reaches upstream of the Po–Dora Baltea Rivers junction, demonstrating a progressive upstream colonization of the main watercourse [23]. Since the current study, no Wels catfish specimen has been reported to have been caught during electrofishing surveys in the Dora Baltea River [55]. In September 2022, however, an angler reported the capture of a Wels catfish in the Dora Baltea, in close proximity to the confluence with the Po River [53]. This is in line with the sporadic summer visits to the tributary among our tagged fish.

In conclusion, here, we describe the first radiotelemetry study on Wels catfish in Italy, focusing on their behavior and habitat use at an invasion front, the confluence between the Po River and the Dora Baltea. The catfish did not venture far up into the Dora Baltea River but were relatively resident within a limited home range and were mainly active in the evening and at night, with some overlap with the habitat use of marble trout. These results may inform fishery management [56]. Overlap between marble trout and Wels catfish ranges in the Po River suggests that removal efforts may do well to focus on areas close to habitats of species under conservation concern. The high site fidelity of the Wels catfish might make this more likely to be temporarily successful.

Author Contributions: Conceptualization, D.N. and C.C.; methodology, D.N., C.C., O.C. and G.F.; investigation, C.C., O.C. and G.F.; data analysis, D.N. and C.C.; original draft preparation, D.N.; writing—review and editing, D.N., C.C., O.C. and G.F.; project administration and funding acquisition, G.F. and C.C. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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

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