COMPARISON BETWEEN STATIONARY ANTENNA GRID AND PORTABLE ANTENNA PIT SYSTEMS FOR STUDYING FISH HABITAT USE[1]

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In this paper, we compare information on fish habitat use obtained from two passive integrated transponder (PIT) systems: a stationary antenna grid and a portable antenna. In 2007, 53 juvenile salmonids were PIT-tagged and released in Ruisseau Xavier (Quebec). Fish positions were monitored with both antenna systems from July to November. The number of individuals detected and the number of detections differed between the two systems, and they were dependent on the time interval used for the comparisons. While the antenna grid provided a temporally continuous monitoring, the portable antenna provided a spatially continuous coverage. Observed differences in the spatial patterns recorded with the two systems were dependent on fish spatial behaviour. Calculated movement distances of fish were also different between the two antenna systems. The results highlight the importance of considering the spatio-temporal resolution of the PIT systems that are used to monitor fish behaviour in natural rivers.

Dans cet article, nous comparons l'information sur l'usage de l'habitat aquatique obtenu de deux systèmes à transpondeur intégré passif (TIP) : un réseau d'antennes stationnaires et une antenne portable. En 2007, 53 salmonidés juvéniles ont été étiquetés par le TIP et relâchés dans le ruisseau Xavier (Québec). On a surveillé les positions des poissons avec les deux systèmes d'antennes de juillet à novembre. Le nombre d'individus détectés et le nombre de détections ont différé entre les deux systèmes et ils étaient dépendants de l'intervalle de temps utilisé pour les comparaisons. Alors que le réseau d'antennes a fourni une surveillance temporelle continuelle, l'antenne portable a fourni une couverture spatiale continuelle. Les différences observées dans les modèles spatiaux enregistrés par les deux systèmes dépendaient du comportement spatial des poissons. Les distances calculées de déplacement des poissons ont aussi été différentes entre les deux systèmes d'antennes. Les résultats soulignent l'importance de tenir compte de la résolution spatio-temporelle des systèmes de TIP qui sont utilisés pour surveiller le comportement des poissons dans les rivières naturelles.

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Introduction

The understanding of the link between habitat structure and fish populations has been impeded in the past by a lack of appropriate methods for tracking the movements of small individual fish in their natural environment. Passive integrated transponder (PIT) technology has partly resolved this problem in recent times by offering a versatile alternative to traditional telemetry methods (radio or acoustic). Indeed, PIT tags are small and inexpensive, last indefinitely and allow the identification of individual fish. They consist of an electronic microchip encapsulated in biocompatible glass and programmed with an alphanumeric code that is emitted when the tag is activated by an external antenna. The spatio-temporal resolution achieved when tracking PIT-tagged fish in natural settings depends mostly on the type of antenna system used. In natural rivers, stationary PIT systems typically allow the monitoring of fish passage at a single location [*Armstrong et al.* 1996; *Castro-Santos et al.* 1996; *Greenberg and Giller* 2000], while a larger spatial extent is covered in wadable streams with portable PIT antennas [*Morhardt et al.* 2000; *Roussel et al.* 2000; *Zydlewski et al.* 2001; *Cucherousset et al.* 2005; *Linnansaari et al.* 2007]. The main disadvantage of portable systems is that they must be operated manually by a person wading the stream, which is time-consuming, restricts the frequency of surveys, and thus limits the temporal resolution of this type of antenna. Recent developments in PIT systems have combined the advantages of both stationary and portable systems by adapting stationary, single and multiple, antenna systems to natural environments for continuous monitoring of fish with higher spatial and temporal resolution [*Armstrong et al.* 1996; *Greenberg and Giller* 2000;

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Morhardt et al. 2000; *Zydlewski et al.* 2001; *Riley et al.* 2003; *Johnston et al.* 2009]. A flatbed antenna grid designed for continuous remote monitoring of PIT-tagged fish at an intermediate spatial scale has recently been developed and used for the monitoring of juvenile salmonid movements [*Johnston et al.* 2009]. However, the influence of the spatio-temporal resolution of various antenna systems on the data collected and the subsequent conclusions regarding fish spatial behaviour has never been evaluated. Thus, this paper aims at comparing the data obtained using the flatbed antenna grid [*Johnston et al.* 2009] with the data obtained using a portable antenna system [*Roussel et al.* 2000; *Zydlewski et al.* 2001]. The two antenna systems were used in a riffle-pool section of Ruisseau Xavier (Quebec) to study juvenile salmonid movements and habitat use from July to November 2007. A total of 53 fish were captured in the study site and PIT-tagged: 36 juvenile Atlantic salmon *Salmo salar* L. and 17 juvenile brook trout *Salvelinus fontinalis* (Mitchill).

Flatbed Antenna Grid Description

The two antenna systems were used in a riffle-pool section of Ruisseau Xavier (Quebec) to study juvenile salmonid movements and habitat use…

A brief description of the flatbed antenna grid is given here; we refer the reader to *Johnston et al.* [2009] for technical details. The flatbed antenna grid is an antenna array buried in the substrate of a stream. It is composed of 242 antennas that cover a stream section approximately 100 m long by 10 m wide and detect half-duplex 23-mm PIT tags (Texas Instruments (TIRIS) model RI-TRP-RRHP, 134.2 kHz; available from Texas Instruments, Dallas, TX 75243). Figure 1a shows the study site, the distribution of fish positions recorded with the antenna grid system, and the location of all the antennas, since all the antennas in the system detected at least one fish during the study period. The detection range of antennas is typically 20 to 40 cm in height depending on the antenna type (see *Johnston et al.* [2009] for a description of the antenna types). When a tag is detected by any of the antennas, the date (dd/mm/yy), time (hh:mm:ss), antenna ID, and fish ID (tag number) are recorded. Since all antennas are georeferenced, it is possible to interpolate fish positions by converting antenna ID into spatial coordinates. Antennas are activated sequentially and the interrogation of all antennas requires 33 s. Overall, the detection field of the antenna grid covered 27% of the wetted area of the site at a discharge of 0.07 $m^3 s^{-1}$. The antenna grid was used to record the position of PIT-tagged juvenile salmonids from 17 July to 19 November 2007.

Portable Antenna Description and Surveys

The tagged fish were tracked periodically using a portable antenna that was constructed following the design described by *Roussel et al.* [2000] and *Zydlewski et al*. [2001]. The portable antenna consists of a circular antenna (coil inductor loop) mounted on a wand and connected to a portable backpack unit that includes a reader, palmtop, and batteries. The detection range of this antenna is between 0.7 m and 1 m, depending on the orientation of the transponder. Day/night surveys were conducted at noon and midnight,12 hours apart, in order to measure daytime and nighttime positions of fish in the study site. Eight day/night surveys were performed in 2007: (1) July 28-29, (2) August 9-10, (3) August 22-23, (4) September 3, (5) September 17, (6) October 1, (7) October 18-19 and (8) October 29. When a tagged fish was detected, a coloured, numbered metal washer was placed at its location. The locations were then georeferenced with a total station before removing the washers. The whole surface covered by the antenna grid was surveyed with the addition of a 50-m-long section at the upstream and downstream ends of the study site. The secondary channel was also covered (Figure 1b). The site was surveyed by moving the antenna above the riverbed surface in an upstream direction from bank to bank with the antenna immersed in water when water depth exceeded the detection range. During the portable antenna surveys, the flatbed antenna grid was shut down in order to avoid possible interferences between the two magnetic fields, which could have resulted in a reduction of the detection range for both.

Comparison between the Flatbed Antenna Grid and the Portable Antenna Datasets

Number of Detections and Individuals

The flatbed antenna grid monitored fish positions continuously during four months and provided 128 903 detections over that period. The eight day/night surveys with the portable antenna generated 140 detections. A total of 49 (93%) of the 53 fish initially tagged were detected at least once by the

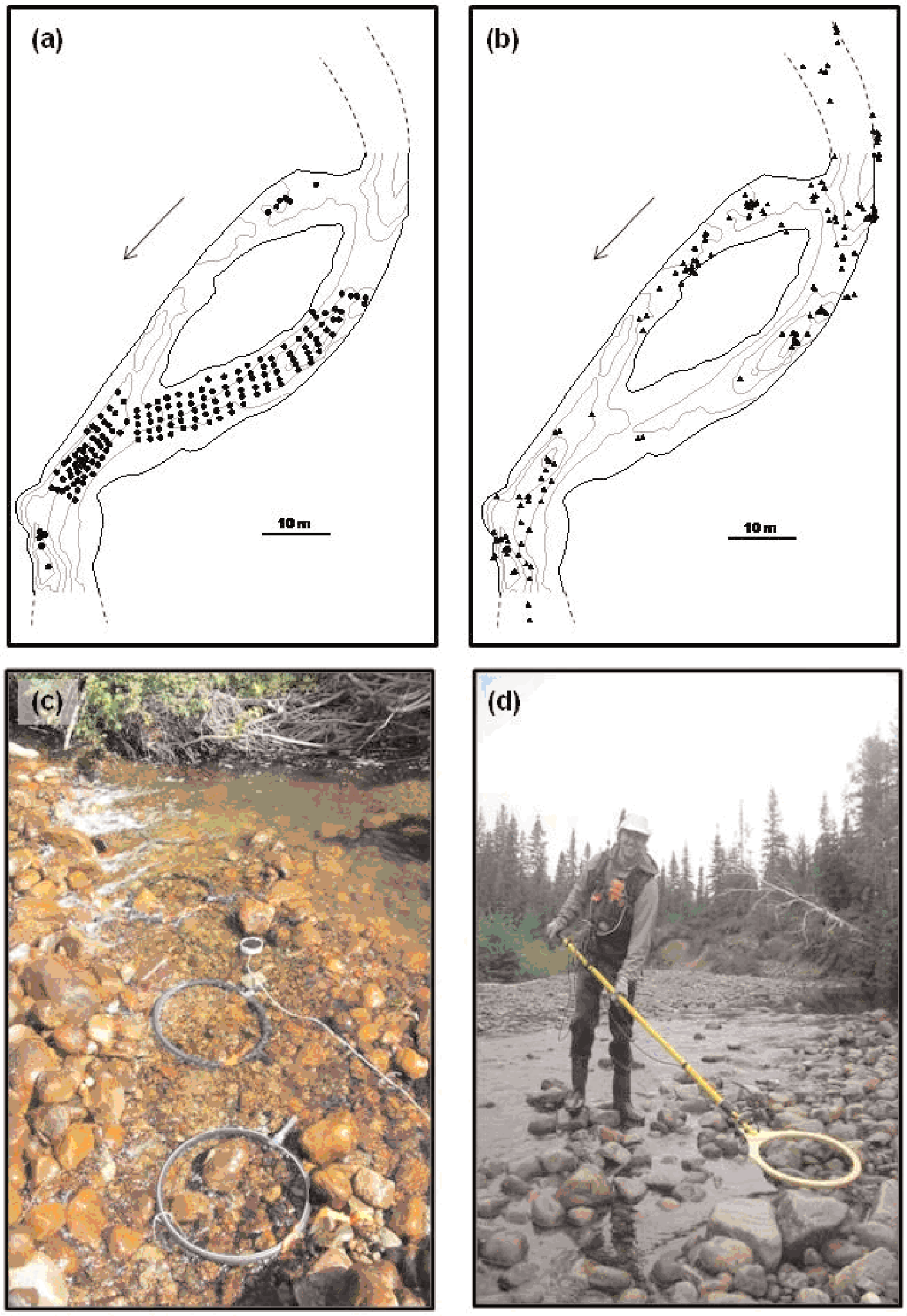

Figure 1: Map of the study site showing its structure: a riffle-pool sequence, a gravel bar and a secondary channel. Also showing is the distribution of fish positions recorded with (a) the antenna grid system and (b) the portable antenna system. Isocontours of water depth at a discharge of 0.07 $m^3 s^{-1}$ are displayed each 20 cm. Dotted lines delineate approximate water line. Some points are outside the water line because the discharge was higher than 0.07 $m^3 s^{-1}$ when some of the portable antenna surveys were conducted. Arrow indicates flow direction. Photographs of (c) the antennas of the flatbed before burying in the substrate and (d) the portable antenna.

antenna grid, while 35 individuals (66%) were detected using the portable antenna. Over the eight 24-hour periods of portable surveys, there was a higher total number of individuals detected with the portable system than with the antenna grid (Figure 2a). A higher number of individuals were detected at nighttime with a lower or equal number of fish detected during the day. From survey 5 on, the number of fish detected with the portable antenna increased because more fish were present in the study site following a second tagging campaign. The higher number of individuals detected with the portable system was mostly due to the larger surface covered, as there were many fish detected just outside the antenna grid and in the secondary channel (Figure 1b). When analysing the data of the portable antenna surveys over the surface overlapping the antenna grid, there was still a higher total number of individuals detected with the portable antenna, but the difference between the two systems was smaller (Figure 2b). For three out of the eight day/night surveys, a higher number of fish were detected at night with the portable system than with the antenna grid, while an equal number of fish were detected for two surveys and a lower number for the remaining three surveys. For the daytime surveys, a lower number of fish were detected with the portable antenna for all occasions except for survey 8. Similarly, the relative efficiency [*Cucherousset et al*. 2008] (calculated as the number of individuals detected by each system divided by the total number of individuals detected over the 24-hour periods, expressed as a percentage) indicated a lower efficiency for daytime surveys compared to nighttime and to the antenna grid (Table 1). Overall, the relative efficiency was constantly higher for the portable system than for the antenna grid except for tracking occasion 4. Nighttime relative efficiency of the portable antenna was nevertheless close to that of the antenna grid. Thus, over short periods of time (i.e. 24 hours), the number of individuals detected was slightly higher with the portable antenna due to the continuous spatial coverage offered by this system (i.e. fish detected between antennas of the grid), while over longer periods (i.e. months) a larger number of fish were detected with the antenna grid system due to a higher temporal resolution.

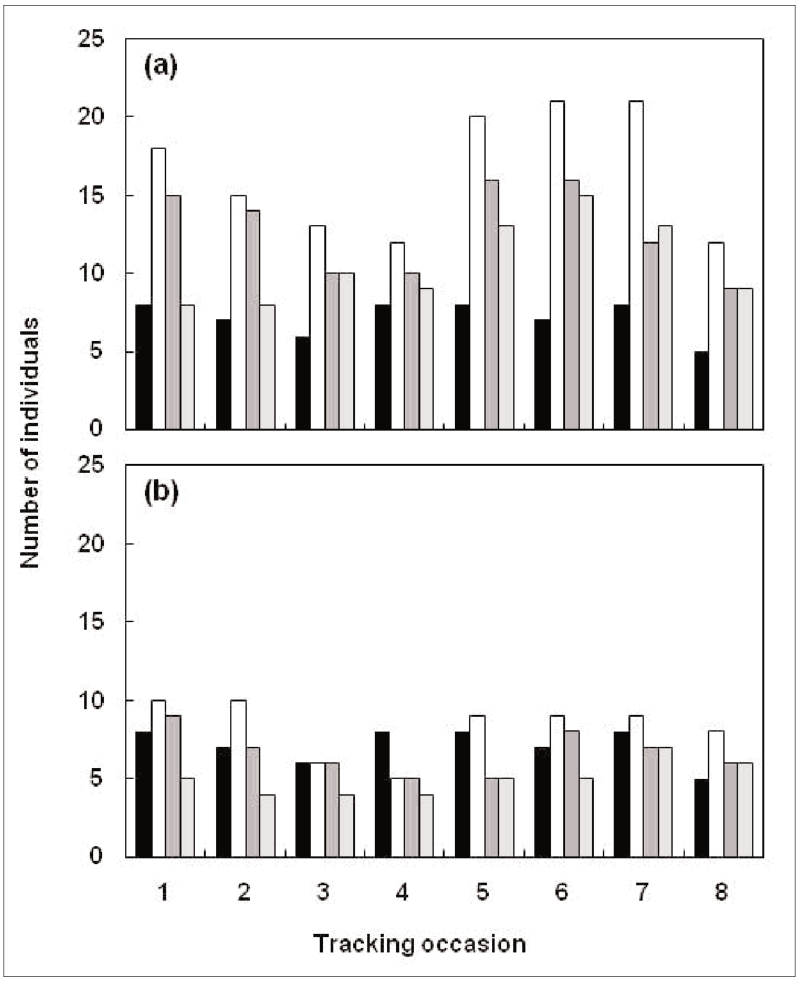

Figure 2: Number of individuals detected with the antenna grid (black bars) over eight 24-hour periods compared with (a) total number detected with the portable antenna (white bars), number detected at night (grey bars) and number detected during the day (light grey bars) and (b) total number detected with the portable antenna when restricted to the grid area (white bars), number detected at night (grey bars) and number detected during the day (light grey bars).

Spatial Positioning of Fish

The spatial patterns of fish positions recorded with the two systems were highly dependent on the spatial behaviour of each fish. For each individual, the distance between the two farthest locations was calculated with the dataset of the antenna grid, the dataset of the portable antenna and both datasets combined for the entire period. For some individuals, the spatial distribution of the recorded positions was similar between the antenna grid and the portable antenna, while for most fish the extent of the recorded positions was larger with the antenna grid (Figure 3a). The total extent calculated with both datasets combined was generally larger than for each system taken separately (Figure 3b, c). For the antenna grid data, no information was added by the portable surveys for six individuals (35% of the 19 individuals for which the extent could be calculated with both datasets). Conversely, adding the antenna grid data to the portable recordings did not provide a better sampling for three individuals (18%) only. The antenna grid system was thus slightly better at recording the extent of fish habitat use. Since the antenna grid provides a continuous tracking, there were a higher number of detections for each fish, and thus higher variability in fish habitat use could be documented even if a smaller surface was covered.

Differences in the central positions (weighted mean location) were also apparent between the two datasets. For 52% of the individuals, the overall central positions calculated with the antenna grid and the portable antenna were located within 10 m of each other (mean ± S.D.: 13.96 ± 15.41 m; median: 9.17 m; $n = 21$). The situation was similar when comparing daytime and nighttime central positions, where 45% (mean ± S.D.: 21.64 ± 22.24 m; median: 11.55 m; $n = 20$) of daytime and 41% (mean ± S.D.: 19.27 ± 19.77 m; median: 13.76 m; $n = 22$) of nighttime central positions calculated with the antenna grid were located within 10 m of those obtained with the portable antenna. This indicates that for the remaining individuals, the location of the recorded positions differed by more than 10 m between the two datasets. The biggest differences in central positions were for individuals for which there were a relatively low number of detections, either with the portable antenna or with the grid system (Figure 4a, b). However, the opposite was not true because for some individuals there were a

Table 1: Relative efficiency (%) of the flatbed antenna grid and of the portable antenna over eight 24-hour periods restricted to the grid area. The relative efficiency is the number of individuals detected by either of the two systems (N_{ind} grid or N_{ind} portable) over the total number of individuals detected over 24 hours (N_{ind} grid + N_{ind} portable).

	Relative Efficiency (%)			
Tracking Occasion	Antenna Grid	Portable Antenna Total	Portable Antenna Night	Portable Antenna Day
1	66.7	83.3	75.0	41.7
2	58.3	83.3	58.3	33.3
3	60.0	60.0	60.0	40.0
4	100.0	62.5	62.5	50.0
5	66.7	75.0	41.7	41.7
6	70.0	90.0	80.0	50.0
7	66.7	75.0	58.3	58.3
8	62.5	100.0	75.0	75.0
mean ± S.D.	**68.9 ± 13.2**	**78.6 ± 13.4**	**63.9 ± 12.4**	**48.8 ± 13.1**

low number of detections and the distance between the central positions was nevertheless small. The influence of the number of detections was found to be dependent on the overall space use of individuals (Figure 4c). For fish that used a restricted space, positions recorded with either one of the two antenna systems were generally located in the same area. For mobile individuals using a large surface of the site, a low number of detections caused a considerable difference in the space use patterns recorded. This effect was evidenced by a significant positive correlation between the central position distances and the total extent ($r = 0.65$, $p = 0.01$, $n = 14$). This is consistent with the observed underestimation of the extent of habitat use with both antenna systems (Figure 3b, c).

Day/Night Movements

Juvenile salmonids typically exhibit day/night activity patterns according to feeding rhythms that change with the water temperature, season and life stage [*Rimmer et al.* 1983; *Valdimarsson et al.* 1997; *Metcalfe et al.* 1998]. It was thus important to compare the results of the two antenna systems regarding the study of daily fish movements. Three approaches were used to compare daily movements calculated with both datasets.

The first approach was to compare the day/night distances obtained with the two antenna systems for the dates of the portable antenna surveys. For the portable antenna data, straight-line distances were calculated between day/night positions, as there was a single location at daytime and nighttime for each individual detected. For the antenna grid data, there was often more than one position per day or night; so

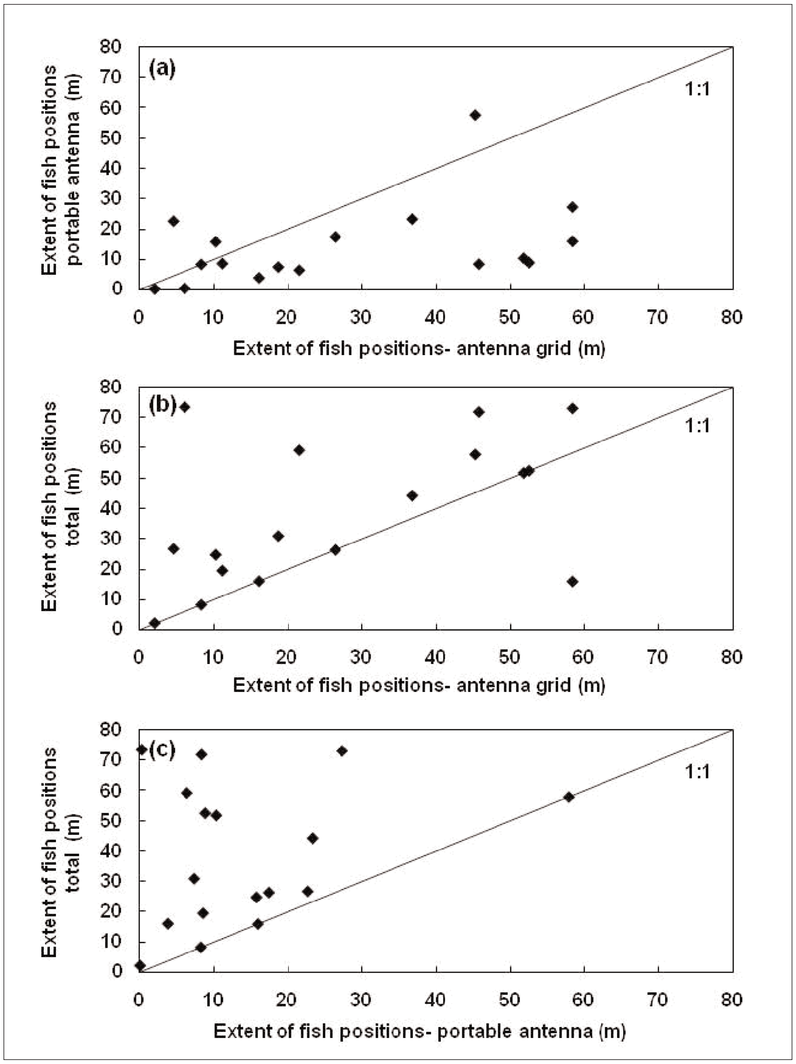

Figure 3: Maximum extent of fish positions: (a) measured with the antenna grid compared with the portable antenna, (b) measured with the antenna grid compared with the total extent of both datasets (pooled data) and (c) measured with the portable antenna compared with the total extent of both datasets.

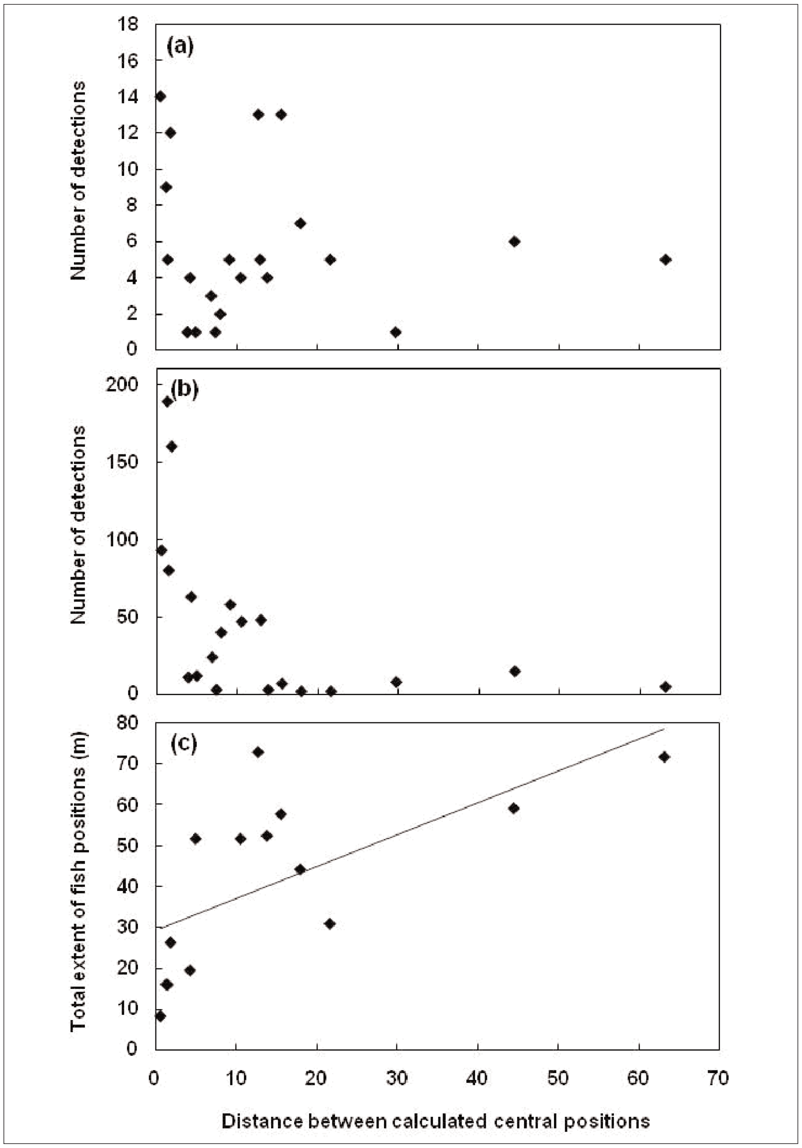

Figure 4: Distance between central positions (m) of fish calculated with the portable antenna and the antenna grid relative to the number of detections for (a) the portable antenna surveys and (b) the antenna grid and (c) relative to the total extent of fish positions.

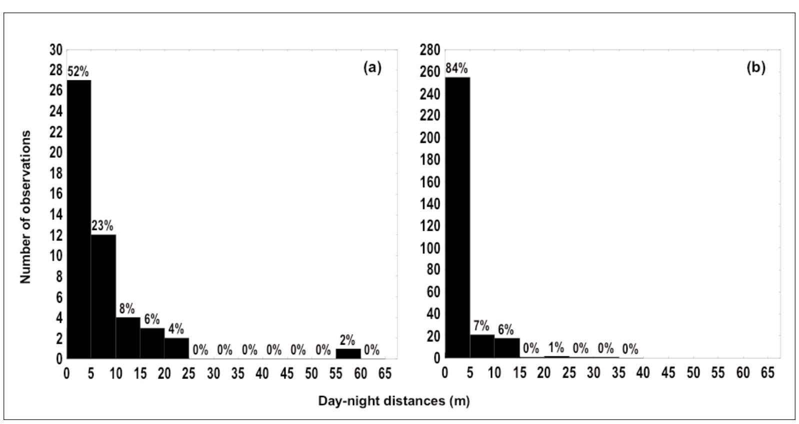

Figure 5: Day/night movement distances over the whole study period for (a) the portable antenna surveys and (b) the antenna grid.

it was necessary to first calculate a mean day and a mean night position and then calculate the distance between these two positions. For the eight day/night surveys, distances calculated with the portable antenna dataset were significantly longer (on average 5.25 m or 77% longer, $n = 14$) than those determined from the antenna grid data for the same dates (Mann-Whitney test, $Z = 2.61$, $p < 0.01$). There was, however, a low number of individuals that were detected with both antenna types on the same dates.

The second approach was to compare the distributions of all calculated day/night distances between the two antenna systems. For the portable antenna dataset, the distances used were the same as those used in the previous analysis except that all the calculated distances were included without considering if the fish were detected on both systems on the same dates. For the antenna grid dataset, day/night distances were calculated for each day of the study period whenever there was available data allowing such calculation. Similar to the results obtained in the previous comparison, this analysis indicated that day/night distances were shorter for the antenna grid dataset (mean ± S.D.: 2.68 ± 4.30 m; median: 1.01 m; $n = 302$) than for the portable antenna dataset (mean ± S.D.: 6.55 ± 8.96 m; median: 3.70 m; $n = 52$) (Mann-Whitney test, $Z = 3.63$, $p < 0.01$) (Figure 5).

The third approach was to compare mean day/night distances per individual averaged over the whole study period. For the portable antenna dataset, straight-line distances were calculated between the overall mean daytime and mean nighttime positions obtained by using all the positions of any given individual recorded over the eight day/night surveys. The same approach was used with the antenna grid dataset over the 128 days of the study period. For each individual fish, there was thus one mean day/night distance calculated with the portable antenna dataset and one mean day/night distance calculated with the antenna grid dataset. Surprisingly, individual mean distances were found to be higher with the antenna grid (mean ± S.D.: 16.42 ± 17.15 m; median: 7.93 m) than with the portable antenna (mean ± S.D.: 5.31 ± 8.35 m; median: 3.16 m) (Wilcoxon matched-pairs test, $Z = 2.90$, $p < 0.01$, $n = 19$). This discrepancy, relative to what was found with the two preceding analyses, is due to the influence of individuals for which there was a high number of detections. Fish that moved frequently, but over short distances, generated a high number of detections on the antenna grid, and this contributed to the reduction of the overall mean movement distance calculated in the previous comparisons. It is also noticeable that the mean day/night distance calculated over the whole study period for individual fish was similar to the distribution of movement distances for the portable antenna dataset (mean distance: 5.31 m vs. 6.55 m), while it was different for the antenna grid dataset (mean distance: 16.42 m vs. 2.68 m). This result further highlights the impact of the temporal resolution of the antenna systems on the conclusions that can be drawn about fish movements.

Conclusions

Fixed PIT systems have been developed to offer continuous monitoring of fish passage at specific locations, while portable systems are more versatile but offer a limited temporal resolution. In this study, differences in the fish habitat use datasets obtained with these two different antenna systems were shown over the same study site. The continuous monitoring of PIT-tagged fish positions with the antenna grid provided not only a higher number of detections compared to the portable antenna surveys but also allowed the detection of a higher number of individuals. Nevertheless, over short periods (i.e. 24 hours) a slightly higher number of fish were detected with the portable antenna because individuals not located on the antennas of the grid (i.e. located between antennas or outside the antenna grid area) could be detected. The spatial patterns of fish positions recorded with the two systems were highly dependent on individual spatial behaviour. Both antenna systems tended to underestimate the extent of fish space use, and the number of detections considerably influenced the calculated central positions. The antenna grid system was, however, slightly better at recording the extent of fish habitat use due to continuous tracking. For fish that used a restricted space, both antenna systems performed equally, which was apparent through similar locations of point positions. The antenna grid system recorded short and frequent movements of fish in the study site that were impossible to monitor with periodic portable antenna surveys. This was reflected by observed differences in the movement distances between the two systems.

The results highlight the importance of considering the spatio-temporal resolution of the PIT antenna systems that are used to monitor fish behaviour in natural rivers. In addition to the spatio-temporal resolution, other important aspects have to be considered when choosing the appropriate system to use in a study. These include the cost, the time required to implement the system, study duration, site structure and temporal variations in habitat conditions. Stationary flatbed antenna grid systems are more costly, require some time for installation but allow long-term, continuous monitoring of fish under habitat conditions where portable surveys cannot easily be conducted (e.g. flood, ice cover). On the other hand, portable antenna systems are less costly and can be used in many study sites and habitat types, but surveys are periodic and time-consuming. Stationary and portable antenna systems thus complement each other, and combining both is believed to provide a complete representation of fish habitat use.

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