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To cite this version:

Jesus Nuñez, F. Duponchelle, M. Cotrina-Doria, J.-F Renno, C. Chavez-Veintimilla, et al.. Movement patterns and home range of wild and re-stocked Arapaima gigas (Schinz, 1822) monitored by radio-telemetry in Lake Imiria, Peru. Journal of Applied Ichthyology, 2015, 31, pp.10-18. 10.1111/jai.12972 . hal-02144295

HAL Id: hal-02144295

https://hal.science/hal-02144295v1

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Public Domain

Journal of Applied Ichthyology

J. Appl. Ichthyol. 31 (Suppl. 4) (2015), 10–18
© 2015 Blackwell Verlag GmbH
ISSN 0175–8659

Received: April 22, 2015
Accepted: November 14, 2015
doi: 10.1111/jai.12972

Movement patterns and home range of wild and re-stocked *Arapaima gigas* (Schinz, 1822) monitored by radio-telemetry in Lake Imiria, Peru

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Summary

The objectives of this study were the evaluation of the adaptation capabilities of re-stocked *Arapaima gigas* and their individual behavioural movements (males and females) to the wild environment compared to wild individuals still present in Lake Imiria, Peru and their survival rates. Using radio telemetry (external transmitters, 75 × 17 mm diameter, 35 g in air, ATS, Isanti, MN, USA), adaptation and behaviour of externally tagged, restocked cage-raised (124–143 cm TL, n = 14) and wild *A. gigas* (117–153 cm TL, n = 8), were monitored, focusing observations on individual behaviour and preferential localization in the lake. Home range size determined by minimum convex polygons (MCP_{95}) or Kernel Density Estimation (KDE_{95}) varied from 0.001 to around 4 km^2, but the average KDE_{50} was relatively small (0.1 km^2) in comparison to the tracked fish size (117–153 cm TL), indicating strong residency and presumably territoriality in this species. Also observed was that the habitat was concentrated along the shoreline of the lake and closely related to the presence of aquatic vegetation. Home range localization estimates and apparent travelled distance of wild and restocked fishes were very similar, thereby suggesting a rapid and good acclimation and survival of cultured re-stocked fish to a natural environment.

Introduction

Arapaima gigas (paiche or pirarucu) is an air-breathing, giant fish of the Amazon basin and the largest freshwater fish with scales in the neotropics (Henn, 1912) at over 3.5 m and 250 kg. Although a single species, *A. gigas*, was recognized within the *Arapaima* genus, the number of species has recently increased with re-descriptions and new descriptions (Stewart, 2013a,b). As the taxonomic status of the Peruvian populations is under review (D. J. Stewart, unpubl. data), we will use *A. gigas* in the text that follows. In spite of the tremendous economic and cultural importance of this species, behavioural studies of *A. gigas* in its natural habitat are scarce. Studies on the distribution and migration indicate that its population density is strongly dependent on the morphological and hydrological characteristics of the area, such as flooding duration, surface area of the water body, water depth and connectivity (Queiroz, 2000; Coutinho et al., 2010; Arantes et al., 2013). Similarly, studies on the reproduction and growth (Queiroz, 2000; Godinho et al., 2005; Castello, 2008b; Arantes et al., 2010), and on the population dynamics of this species (Castello, 2008a; Castello et al., 2011) have been carried out in Brazil, but most of this information comes from a single area no larger than 1000 km^2, the Mamirauá Reserve (Amazonas State, Brazil), which represents less than 1% of the total distribution of the species (Castello and Stewart, 2010). As *A. gigas* has been overexploited for decades (Castello et al., 2015), it is now seriously depleted over most of its range and is listed in CITES Appendix II and the IUCN Red List of Threatened Species as an endangered species. In Peru and Brazil, *A. gigas* was introduced into lakes or ponds for aquaculture purposes in many areas to face the decline of wild populations and it was hoped that it would adapt to pond culture and benefit the local people. A few decades ago, Lake Imiria was densely populated by *A. gigas* (according to local people), but by the 2000s was so scarce that its capture was prohibited in hopes of recovery in subsequent years. The population had not recovered by 2008, thus a pilot restocking program (Lorenzen et al., 2010) tested for the possible recovery and enhancement (Cowx, 1994) of the *A. gigas* population in this natural area.

The interest of working in a relatively small area such as Lake Imiria (~38 km^2) was the possibility of quite easily capturing a few individuals of the remaining wild population to compare their behaviour with *A. gigas* cage-raised over a 4-year period and then released into the lake. The purpose of this comparison was to determine if the behaviour of released cage-raised fish was similar to that of wild individuals and to assess how they would survive and adapt to their new environment. Such a comparison could prove insightful, as previous studies of salmon reported different behaviours between wild and cultured populations (Jonsson, 1997; Jonsson and Jonsson, 2006). Additionally we planned to determine, when possible, the gender of tagged individuals using the method based on plasma vitelogenin detection

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(Chu-Koo et al., 2009) to posteriorly analyze if male and female behaviours were similar and if mating pairs were formed during the period of study. Another advantage was that Lake Imiria represented a relatively small natural area with little connectivity to the surrounding river system, allowing a better monitoring of released animals and limiting their possibility of escape.

This study represents the first time that individual behavioural movements and localization of *A. gigas* males and females, home range and total travelled distances for re-stocked cage-reared individuals and wild individuals still present in Lake Imiria were monitored. We also tested survival rates and adaptation capabilities to the wild environment of re-stocked fish in comparison to wild individuals.

Materials and methods

Study site

Lake Imiria is one of the largest lacustrine environments in the Ucayali region (Fig. 1). In contrast to many other oxbow lakes in the Amazon basin, this water body is not an isolated river meander, but a small inundated basin resulting from local tectonic activity that progressively created a depression filled by rain falling into its watershed (Maco García, 2006). The lake has a maximum depth of about 6–10 m with low water transparency, especially during the rainy season. Numerous small islands composed of dense herbaceous and floating vegetation (notably the water hyacinth) accumulate mainly in the north-west bank of the lake, where a narrow canal communicates with the Tamaya River, but with very low flow and water depth during the dry season, making the entrance or exit difficult for large fishes. Such characteristics relatively isolate Lake Imiria from the main rivers in the area (Tamaya and Ucayali). The lake has an average water surface of 38 km² and a pronounced dendritic shape (Fig. 1), with a perimeter of about 200 km composed mainly of herbaceous ridges with variable amounts of floating vegetation and tropical forests. Fourteen villages are spread out along the ridges representing a total of 3000–4000 inhabitants. In 2010 a regional conservation area (1370 km^2) was established to promote biodiversity protection and conservation of the lake and its surroundings (Área de Conservación Regional Imiria). In 2002 the Instituto de Investigaciones de la Amazonia Peruana (IIAP) implemented a project of *A. gigas* captive breeding in the Iquitos – Nauta area, where local fish farmers were given a few juveniles depending on the pond surface available in their farms. A few years later, aquaculture production had increased significantly, reaching around 100 000 *A. gigas* fingerlings in 2010 (Núñez et al., 2011; Chu-Koo et al., 2012). Local exporters of ornamental tropical fish collected most of this production. At the same time, a small part of the produced fry was grown locally in small ponds, lakes or even in salmon-type cage culture systems. One of these cage-culture experiments was carried out in Lake Imiria (Ucayali Government project), resulting in fish as large as 10–12 kg body weight and 100–110 cm total length after approximately 1 year of rearing (Chu-Koo et al., 2012). Two years after the end of that experiment, 500 3-year-old cage-produced *A. gigas* (120–145 cm; 18–30 kg) were selected for this restocking program in Lake Imiria.

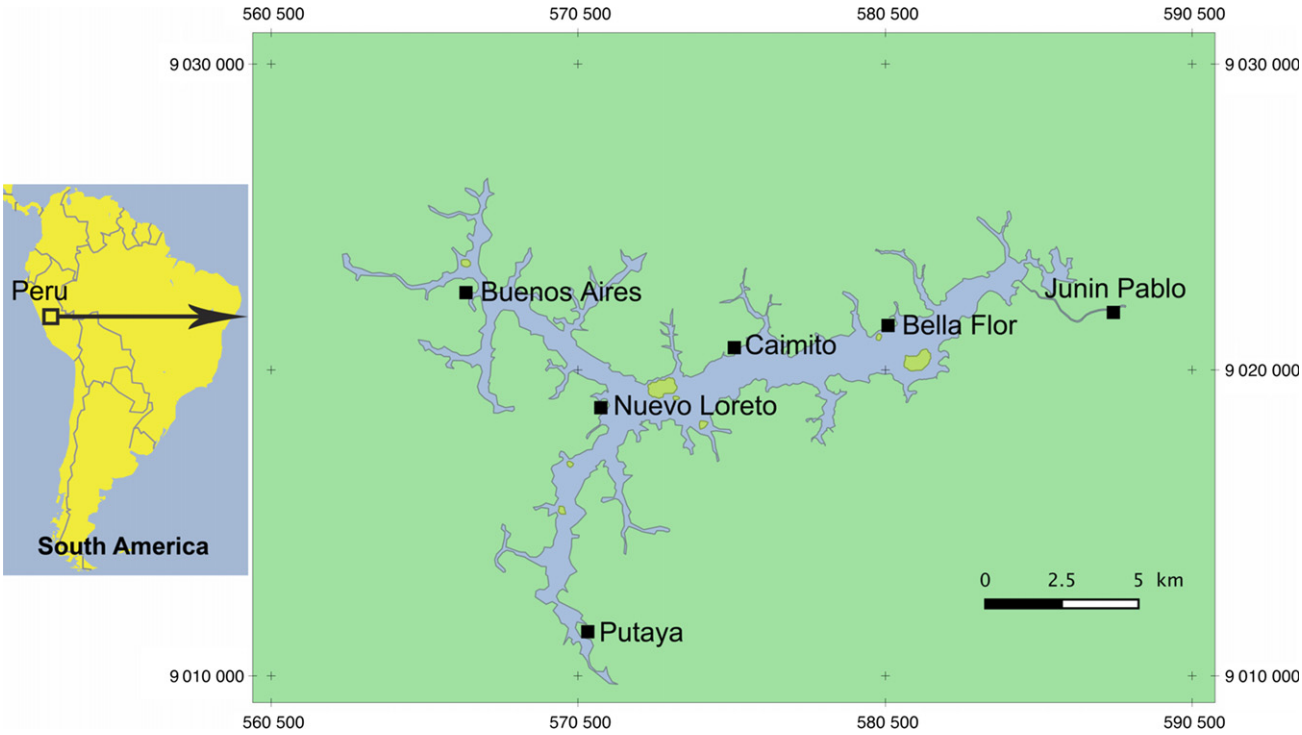

Fig. 1. Localization of study area in the Peruvian Amazon, 50 km southeast of the city of Pucallpa. Map coordinates are expressed in UTM system, zone 18L

Fish were followed by conventional radio telemetry, as described in many other species, including fish (Baras and Lagardère, 1995; Lucas and Baras, 2001). The choice of radio telemetry was driven by cost-benefit considerations of the technique when compared to acoustic telemetry and by its relative ease of implementation in a remote area. In such studies the most commonly used parameter is the home range, which describes the amount of area occupied by an individual during a determined period of time (Dunn and Gipson, 1977; Crook, 2004; Økland et al., 2005; Koehn et al., 2009; Nyboer and Chapman, 2013). The home range calculations were made in earlier studies using the Minimum Convex Polygon (MCP) method, but have been replaced progressively by the Kernel Density Estimation (KDE) with the help of new computerized routines in combination with a Geographic information system (GIS) like HoRAE for Openjump, a free online package used in this study (Steiniger and Hunter, 2012). Although its reliability is sometimes questionable, the MCP parameter has nevertheless still been calculated in many recent studies for comparison purposes with previous works (Börger et al., 2006). Therefore, in this study, the MCP parameter will also be provided for comparison purposes.

Transmitters attachment

Wild *A. gigas* were captured directly in the lake by local fishermen using 100 m wide nets (3.5 m high, 40 mm mesh size); on the fishing boat a transmitter attachment was performed immediately after capture. Cage-raised specimens were sampled in the experimental floating cages located in the vicinity of Caimito village (Fig. 2). For practical reasons, not all fish could be tagged on the same day.

All fish were measured for total length (Tables 1 and 2). External radio transmitters (75 × 17 mm diameter, 35 g in air, external whip antenna, Advanced Telemetry Systems, Isanti, MN) were attached with a side saddle harness, below the anterior part of the dorsal fin while the fish laid in lateral recumbence on a soft and humid foam carpet, with its head covered by a damp cloth to reduce holding stress. Local anaesthesia was performed with intra-muscular injections of a 1% lidocaïne sterile solution of 1 ml on each side of the fish. Two assistants held the fish in place during transmitter attachment. Prior to surgery, two holes had been drilled in the epoxy resin coating of the transmitter, and a plastic protected braided wire of stainless steel (2.5 mm in diameter) had been passed through the holes. At time of surgery two large hollow needles were inserted through the dorsal musculature, in between the pterygiophores of the dorsal fin, after removal of two scales at each entry and exit point, then the two ends of the attachment wires were passed through the fish body. After needle removal, the attachment wire was further passed through a pierced plastic attachment plate, to minimize the risks of 'tunnelling' into the fish muscles in the mid- or long term. Finally, the wires were tightened with an aluminium connecting sleeve onto the plastic plate. At the

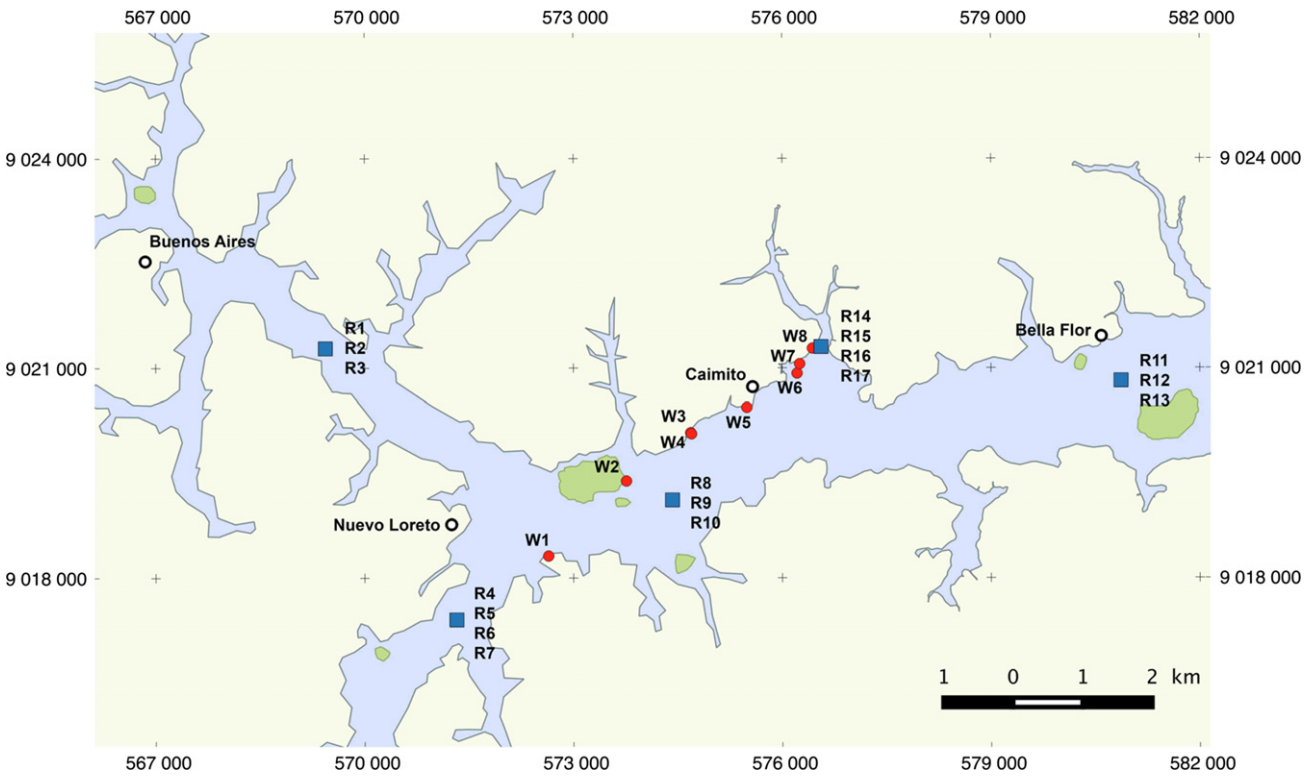

Fig. 2. General view, central part of Lake Imiria where wild fish (W1–W7) were captured, tagged and released (red dots), and restocked fish (R1–R17) were released (blue squares). A total of 8 wild and 17 restocked pirarucus *Arapaima gigas* were monitored until transmitter batteries collapsed (after ca. 18 months). Map coordinates are expressed in the UTM system, zone 18L

same time a blood sample was obtained from the caudal vein and placed in a 1.5 ml heparinized Eppendorf-type tube. All tagging and blood sampling procedures lasted approx. 1.30 min. The blood sample was then centrifuged for 3 min at 10 000 ***g*** and supernatant plasma was collected and stored frozen until posterior use for sex determination according to the methodology developed for *A. gigas* (Chu-Koo et al., 2009).

Radio tracking

Tracking began on 5 August 2009 and lasted circa 18 months until the transmitter batteries died. Wild fish were released at the same location where they were caught; restocked fish (from cage-bred stock) were released in five different locations in Lake Imiria (Fig. 2). We started active tracking approx. 1 week following release, to allow recovery from potential stress accompanying fish capture, handling and tagging. Fish were successively relocated approx. every 15 days during the battery life period using a 3-element Yagi antenna and a Lotek Biotracker receiver (Lotek Wireless Inc., Newmarket, Ontario, Canada) using the homing method, i.e. the operator followed the shoreline at the vicinity of the last recorded fish position until finding the signal of its specific frequency. The operator then moved towards the direction of the strongest signal until its strength changed suddenly, as the fish moved rapidly because of immediate boat proximity and recorded the GPS position of the boat. Fish bearings were recorded with a GPS Garmin unit (Garmin International, Inc., Olathe, KS) with an overall accuracy of ±8 m. This procedure was repeated for each frequency until all tagged fish were located.

Fish movement analysis

All fish locations were plotted with the open source Geographic Information System (Quantum GIS, QGIS 2.0, <http://www2.qgis.org/en/site/index.html>) to visualize fish movements over the entire period of survey. Home range area (HR) and total travelled distance were determined with the package HoRaE integrated in Openjump v. 1.6.3 (Jump Open source Mapping Platform, <http://www.openjump.org/>) known as MOVEAN extension (Steiniger and Hunter, 2012). Home ranges (Dunn and Gipson, 1977; Horne and Garton, 2006) were calculated using two methods: the $MCP_{0.95}$, a line connecting the outermost points for each fish, as well as the KDE at 95 and 50% that produces concentric lines (isopleths) corresponding to a fixed percentage of presence (typically 50 and 95% for comparison purposes) during the tracking period as previously described for other species (Silverman, 1986; Worton, 1989; Lowe et al., 2003; Vokoun, 2003; Horne and Garton, 2006; Topping et al., 2006). The 95% isopleth corresponds to the largest area used by a fish over the study period where 95% of the locations are found, while the 50% isopleth represents the core range area of an individual (Worton, 1989) and corresponds to the area where 50% of the locations are found; only aquatic areas were considered (Fig. 3). The total distance travelled by a fish is calculated as the sum of the linear distances between each pair of consecutive fixes, except when the line between two particular fixes crossed the shoreline. In this particular case, it was assumed that the minimal distance between the two locations was around the shoreline.

Table 1
Travelled distance (km), Maximum Convex Polygon (MCP_{95}), Kernel Density Estimation (KDE_{50} and KDE_{95}) of wild, tagged pirarucu, *Arapaima gigas*F (female) or M (male) in the fish code indicates fish gender, W (wild)

Fish code	Total length (cm)	Travelled distance (km)	MCP_{95} (ha)	KDE_{95} (ha)	KDE_{50} (ha)
W 334 F	153	30.825	67.0	346.0	31.1
W 264 M	153	8.719	70.0	96.7	19.6
W 134 M	154	2.680	1.4	1.5	0.3
W 063 M	152	9.107	16.2	39.8	7.6
W 114 M	138	2.213	0.7	1.0	0.2
W 235 M	148	2.414	0.6	0.7	0.2
W 124 M	151	1.328	0.4	0.4	0.1
W 046 M	117	1.768	1.4	0.8	0.2
Mean	144.7	4.0	13.0	20.1	4.0
Std dev.	13.4	3.4	25.8	36.8	7.4

Table 2
Travelled distance (km), Maximum Convex Polygon at 95% (MCP_{95}), Kernel Density Estimation (KDE_{50} and KDE_{95}) of cage-raised restocked pirarucu, *Arapaima gigas*. F (female) or M (male) in the fish code indicates fish gender, C (Cage-raised)

Fish code	Total length (cm)	Travelled distance (km)	MCP_{95} (ha)	KDE_{95} (ha)	KDE_{50} (ha)
C 185 F	134	30 825	24.2	9.1	2.2
C 315 F	133	4857	12.8	3.8	2.8
C 394 F	128	2872	44.2	18.0	1.6
C 404 F	143	16 486	189.2	76.8	12.0
C 104 F	134	5570	8.4	7.6	1.7
Mean	134.4	12.1	55.8	23.1	4.1
Std dev.	5.4	11.7	75.9	30.5	4.4
C 096 M	135	3967	84.2	7.0	2.5
C 286 M	133	9349	115.2	41.6	10.7
C 304 M	127	2654	2.1	2.7	0.6
C 375 M	137	9868	55.7	67.6	15.0
C 214 M	141	2293	1.2	0.9	0.7
C 084 M	131	7759	4.6	14.3	4.3
C 364 M	134	17 342	400.5	225.6	22.8
C 023 M	127	10 142	7.2	19.9	2.5
C 355 M	124	6040	29.0	2.4	0.9
Mean	132.1	7.7	77.8	42.4	6.7
Std dev.	5.4	4.7	127.7	72.1	7.8

Statistics

Comparisons of means for travelled distance, mean MCP and KDE areas and between male and female and group origin were performed after Levene's test of homogeneity of variances, using *t*-test at alpha = 0.05 by two independent readers.

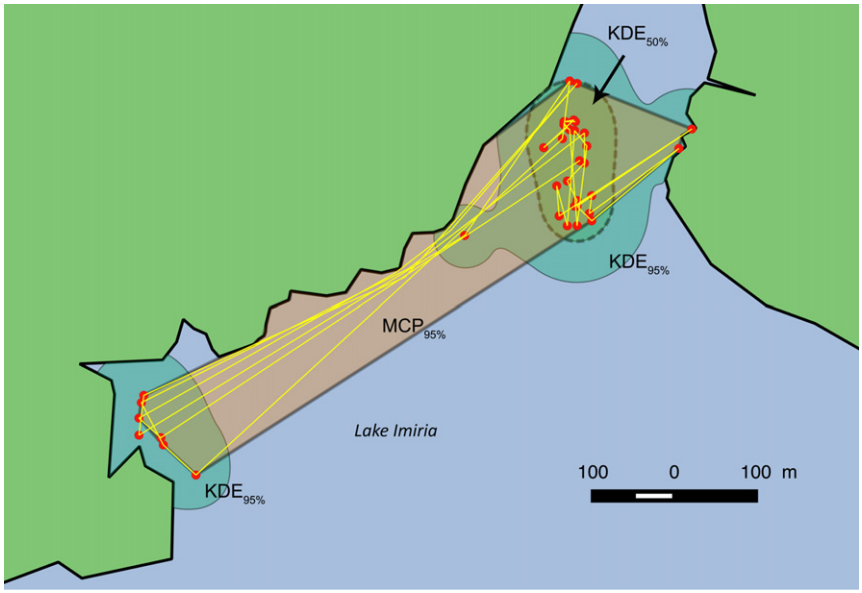

Fig. 3. Example of Track length calculation (yellow line), 95% Minimum Convex Polygon ($MCP_{95\%}$) and Kernel Density Estimation ($KDE_{50\%}$, $KDE_{95\%}$) for one pirarucu, *Arapaima gigas,* after an 18-month period. Tracks correspond to restocked female #104, fixed 38 times from 7/08/2009 to 28/01/2011 (average time between each fix 14.1 days)

Results

Tracking

Radio-tagged *A. gigas* ranged from 117 to 153 cm total length (mean ± SD = 145.8 ± 12.7) for wild individuals and from 124 to 143 cm (132.9 ± 5.3) for restocked ones. Overall 'survival' of tagged fish averaged 83% after approx. 18 months of tracking, as five out of 29 fish disappeared (two wild and three restocked). It is uncertain whether these missing fish were captured by poachers, died of other causes, emigrated outside of the lake, or if the absence of detection resulted from transmitter malfunctions.

A total of 946 detections were obtained, 316 from wild fish and 630 from restocked ones. On average, the time between two consecutive fixes of a particular fish was 13.7 ± 1.5 days. The mean detection number per individual fish was 37.05 ± 8.5 for wild fish and 39.5 ± 6.8 for restocked fish. There was no significant correlation between the number of relocations for a single fish, which ranged from 28 to 52, and the corresponding home range ($KDE_{50\%}$: $r^2 = 0.003$, P = 0.905 for a linear correlation), indicating that a lower number of fixes for some *A. gigas* does not influence the size of home range calculations.

Preferential localization

The distance from the centre of $KDE_{50\%}$ to the shoreline (Fig. 4), as calculated for all individuals on the $KDE_{0.50}$ projected envelopes, was low and similar for wild and restocked fish (31 ± 17 and 39 ± 20 m, respectively; P = 0.709) indicating a marked preference for the vicinity of the shoreline. No significant differences were observed between male and female preferences.

Travelled distance

Apparent travelled distances were calculated for each individual over the entire survey period. Maximal and minimal travelled distances were 30.83 and 1.33 km for wild fish (Table 1) and 17.34 and 2.87 km for restocked fish (Table 2). In both groups there was high individual variability; no statistical differences were found in terms of travelled distance between wild and restocked fish (P = 0.856), nor between male and female groups for restocked fish (P = 0.758). No statistical test was computed for wild fish since there was only a single female in this group. Nevertheless, it is worth noting that a single wild female had covered a total distance about thrice as long as that covered by a male that travelled the longest distance and about thirty times more than the male that had travelled the shortest distance (Table 1).

Regarding restocked fish, only one fish stayed in the southern part of the lake, with the maximum distance between release point and centre of KDE_{50} around 2 km for

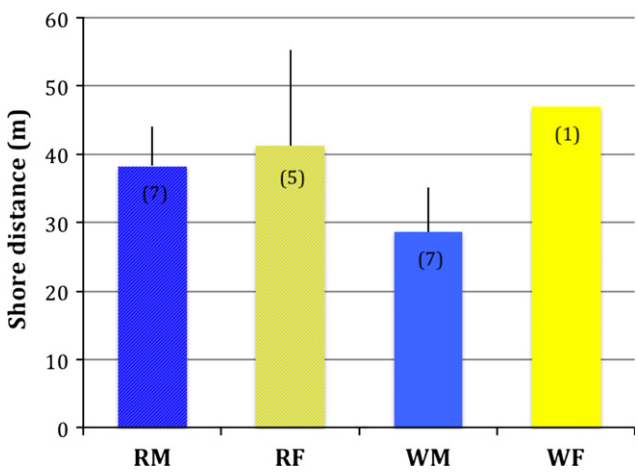

Fig. 4. Mean distance from core of Home Range (KDE_{50}) gravity center and the lake, closest to the shoreline. R: restocked (shaded), W: wild pirarucu, *Arapaima gigas*, F: Females (yellow), M: males (blue). Fish numbers in parentheses. Bars = standard deviation of the mean except for WF

only one fish; the distance for other *A. gigas* was between 0.2 and 0.75 km (results not shown).

Home range

Substantial home range variability was observed for wild *A. gigas*: from 0.4 to about 70 ha while relying on MCP_{95}, from 0.4 to about 350 ha while relying on $KDE_{0.95}$ and from 0.1 to about 31 ha when relying on KDE50% (Fig. 5). Restocked fish showed similar variability: from 1.2 to approx. 400 ha, 0.9 to about 225 ha, and 0.6 to about 23 ha for $MCP_{0.95}$, $KDE_{0.95}$ and $KDE_{0.50}$, respectively (Fig. 6).

Neither male-female restocked fish mean HR comparisons ($MCP_{0.95}$, $KDE_{0.95}$ and $KDE_{0.50}$) nor wild male vs restocked male HR means revealed any significant differences. No statistical test was computed for wild females since there was only a single female in this group. Nevertheless the sole wild female that could be tagged occupied a much broader range (based on KDE_{50} and KDE_{95}) than all wild males. Its HR revealed an overlapping of approx. 50% of the total area with the HR of a wild male, which could indicate the formation of a mating pair.

Discussion

Although the low number of tagged individuals (only one wild female) and the relatively small size and age ranges available for this study, our findings in Lake Imiria give interesting indications of young adult *A. gigas* behaviour in such an environment. Nevertheless, additional studies with *A. gigas* showing wider age and size ranges and new tracking technologies will be needed to further understand their behaviour in the wild.

Preferential localization

One of the first results indicates in Lake Imiria that wild or restocked *A. gigas* are highly sedentary. In a previous work on wild tagged fish in the lower Amazon (close to Santarem) in Brazil (Crossa et al., 2003), a strong sedentary behaviour was also reported for this species. Additionally, those authors reported a limited migratory behaviour that could be explained by trophic migrations: *A. gigas* would follow their prey in river systems for a while, but would return after a few months to their initial living zone.

Our findings also indicate a strong preference for locations near the shoreline, where floating vegetation appeared to be a constant parameter in the locations selected by *A. gigas*. Possible explanations could be the suitability of these environments for resting, hiding from fishermen and also for foraging on their piscine prey, which abound in these vegetated shoreline ecotones (Frankiewicz et al., 2001; Petry et al., 2003). Such preferences were also observed in other large tropical predatory fishes in both rivers (Økland et al.,

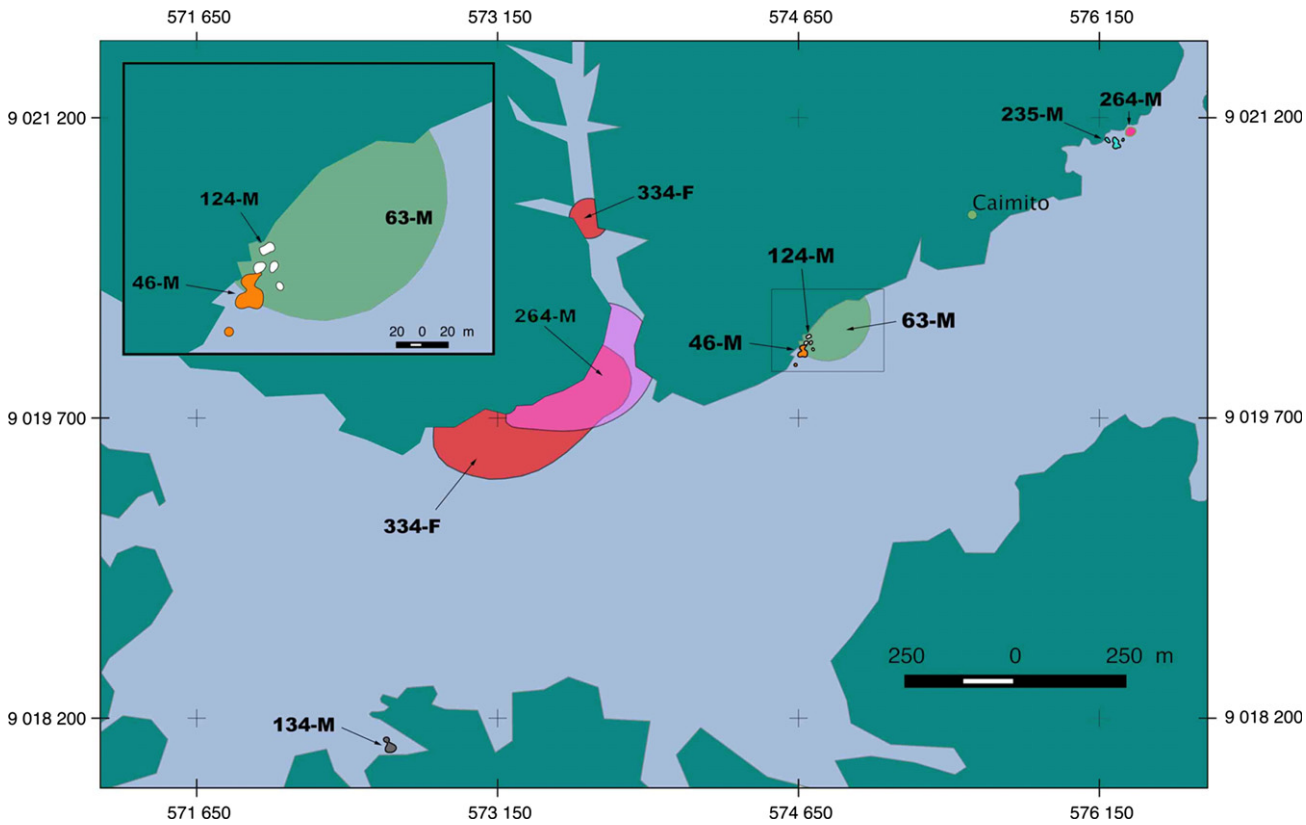

Fig. 5. Home ranges (KDE_{50}) of wild pirarucus, *Arapaima gigas*. Largest ranges partially overlapping and correspond to male 264 and female 334. Insert = an area where calculated home ranges of three males partially overlap. Map coordinates expressed in UTM system (Universal Transverse Mercator projection) zone 18L, where coordinates are expressed directly in meters

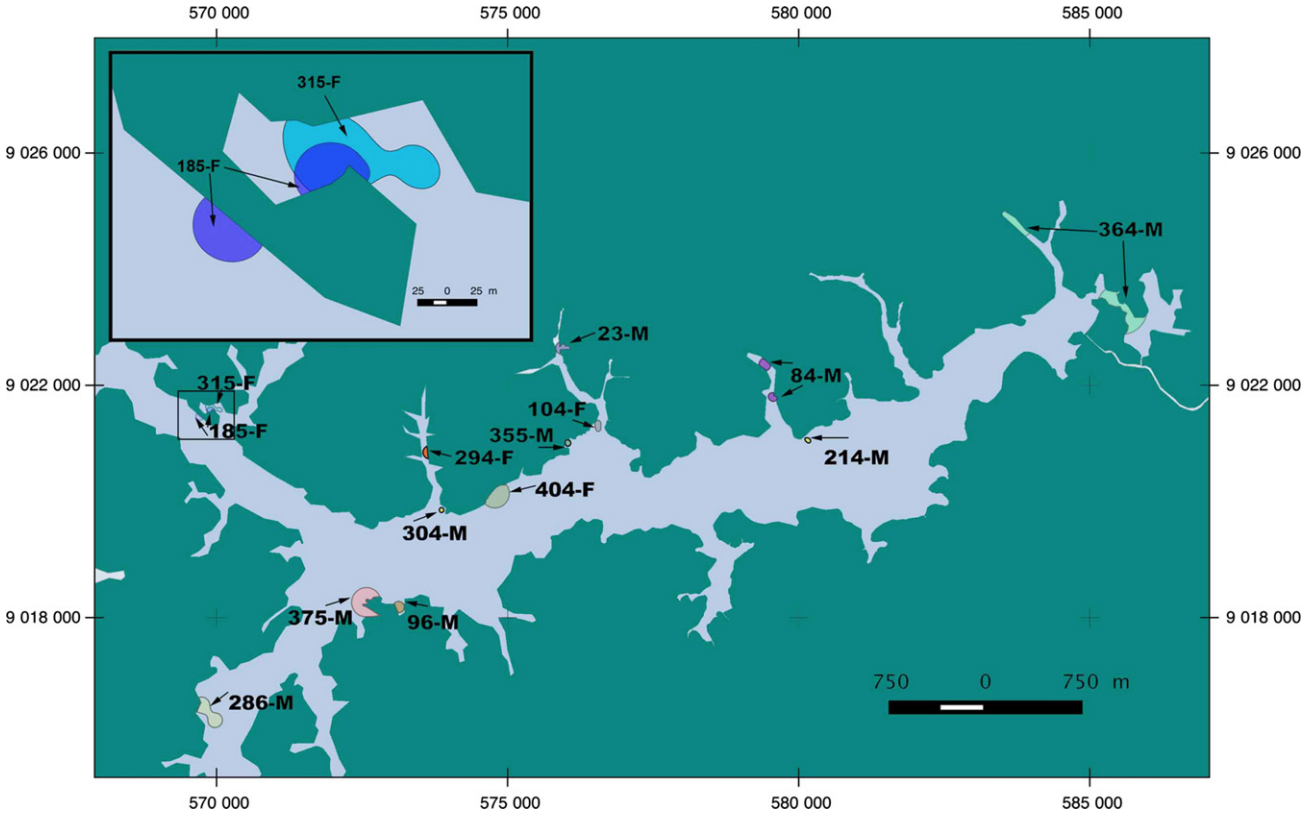

Fig. 6. Home ranges (KDE_{50}) of restocked pirarucu, *Arapaima gigas*. Insert = area where calculated home ranges of two females partially overlap. Map coordinates expressed in UTM system, zone 18L

2005) and lakes (Nyboer and Chapman, 2013). The importance of floating vegetation for the distribution of *A. gigas* in Lake Imiria is particularly interesting because abundance has been found to be unrelated to macrophyte cover in the Mamirauá Reserve in Brazil (Arantes et al., 2013) despite the positive correlation observed between macrophyte cover and the abundance of other predatory fishes (Petry et al., 2003). When comparing *A. gigas* abundance between lakes (Arantes et al., 2013), it appeared that macrophyte cover was less important than surface, depth and volume. Nevertheless it can become an important factor within a given lake, as in the present study.

Travelled distance

Our results also suggest that travelled distance are not influenced by fish gender, at least for restocked fish. Although the only wild female tagged showed a larger travelled distance than all tagged wild males, general conclusions cannot be drawn for wild specimens from this single observation. Longer movements or migrations of *A. gigas* are hypothesized as linked to trophic or spawning migrations (Lucas and Baras, 2001; Crossa et al., 2003; Castello, 2008a) rather than to movements inside the home-range or shifts between successive home ranges (Leigh and Zampatti, 2013). It must also be emphasized that reported travelled distances most likely under-estimated the actual distances travelled by the fish, owing to the 2-week interval between successive fixes (Baras, 1998; Rowcliffe et al., 2012). Nevertheless in this study, reported values remain comparable between all tracked fish since the time intervals between two consecutive fixes was quite similar for all fish. The very small travelled distances observed in some individuals seem to be related to the characteristics (relative isolation) of Lake Imiria. A previous study in a river network in the lower Amazon near Santarem, Brazil (Crossa et al., 2003), showed that most tagged wild *A. gigas* travelled relatively small distances, but that a few travelled around 80 km and returned to their initial area only after a few months. Another molecular study in Brazil on wild *A. gigas* populations sampled along the amazon axis has also emphasized the relatively sedentary behaviour of this species, which exhibits low (but significant) to high gene flow between populations separated by distances of less than 100 km and 25 km, respectively (Araripe et al., 2013). These results confirm the sedentary behaviour of the species and suggest that high river connectivity might foster larger movements in some individuals.

In Lake Imiria, the detailed observation of cumulated apparent travelled distance as a function of elapsed time after tagging revealed a more contrasting situation among all fish: i) some travelled long distances during the first 60 days following tagging, then short movements within their KDE_{50} HR; ii) other fish displayed relatively moderate

but continuous movements throughout the survey, and iii) a group showed seemingly random variations of cumulated travelled distances during the entire survey period (results not shown). Contrasting movements have also been observed in other large freshwater predatory fish. The Murray cod, *Maccullochella peelii* travelled distances varying from 2 km to more than 50 km over an 8-month period (Leigh and Zampatti, 2013), with a clear relationship between travelled distance and fish size (Koehn et al., 2009). The same was observed in the tucunaré, *Cichla temensis*, where the largest males also showed the highest propensity to travel over long distances (Hoeinghaus et al., 2003). By contrast, many other tracking studies found no relationship between fish size and travelled distance, and sometimes with higher between-individual variability than here (e.g. 0.5–105 km) during a six-month survey of *Hydrocynus vittatus* (Økland et al., 2005).

Home range

There was no home range gender difference in restocked *A. gigas* (comparison was not possible between genders in wild fish, since we had only one wild female) or between wild and restocked males, suggesting that restocked and wild fish had similar patterns of space utilization. High HR variability with no correlation between home range and fish size, has also been reported in other large tropical predatory species such as *Lates calcarifer* (Heupel et al., 2011; Nyboer and Chapman, 2013), *Lates niloticus* (Nyboer and Chapman, 2013) or *H. vittatus* (Økland et al., 2005). In Lake Imiria, even when the water level dropped during the dry season, *A. gigas* could find suitable habitats year round, which probably favoured their strong sedentarity, as attested by the very small home ranges observed for the majority of tagged fish. Nevertheless, as for total travelled distance, it must be pointed out that the mean observed home ranges are undoubtedly underestimated because of the significant delay between two successive positions (15-day sampling interval) as previously reported in other studies (Crook, 2004; Rowcliffe et al., 2012). Yet this underestimation is likely to be lower than for travelled distance (Baras, 1998). Monitoring the home range through the use of automatic receivers (acoustic telemetry) could be a new and useful tool to obtain more accurate information in future studies.

The results presented here are the first in *A. gigas*, comparing the movements and home ranges between wild and restocked fish in a natural environment.

The sedendarity of the species and Lake Imiria characteristics certainly contributed to the good survival of restocked fish by limiting the movement of introduced *A. gigas* to other surrounding areas. These results attest the relevance of restocking this valuable species in other similar environments where wild populations have been decimated. It must be emphasized, however, contrary to previously thought (Hrbek et al., 2005), that *A. gigas* is not formed of a single Amazon basin population. Several natural populations showing substantial degrees of genetic differentiation have been found in the Brazilian Amazon (Araripe et al., 2013) and in the Peruvian Amazon (Garcia-Davila et al., 2012). In order to preserve local genetic resources, further restocking programs should systematically be accompanied by genetic analyses, evaluating the compatibility between the natural genetic variability of *A. gigas* in the area to be restocked and that of the fish used for restocking. In other words, adults or juveniles produced in captivity for restocking programs must be genetically as close as possible to the individuals still present in the area intended for restocking.

In addition to population genetics considerations, studies are also needed to further evaluate the reproductive success and interactions between wild and restocked fish.

Acknowledgements

This work was funded by the Ucayali regional Government (Gobierno Regional del Ucayali) and carried out as part of the scientific collaborations between the Instituto de Investigaciones de la Amazonía Peruana (IIAP) and the Institut de Recherche pour le Développement (IRD), both part of the research network known as Red de Investigación sobre la Ictiofauna Amazónica (RIIA) (http://www.riiaamazonia.org). The authors wish to thank all of the technical team and field assistants from the indigenous Shipibo-Conibo people of the Caimito community who helped us during this study.

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