RFID tracking for monitoring deadwood mobility in a small coastal Mediterranean mountainous river: implementation and preliminary results

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RFID TRACKING FOR MONITORING DEADWOOD MOBILITY IN A SMALL COASTAL MEDITERRANEAN MOUNTAINOUS RIVER: IMPLEMENTATION AND PRELIMINARY RESULTS

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Abstract

Rivers transport a wide variety of materials, ranging from submillimeter-sized sediment particles to entire trees. The transported deadwood constitutes a vital component of wooded river ecosystems. The inputs of wood constantly alter the morphology of watercourses and influence river flow. Given the inherently complex and diverse nature of river systems, a thorough exploration of their diversity is justified to identify recurring trends in the dynamics of deadwood transport. This need becomes imperative in regions already facing prolonged episodes of drought, frequent heatwaves, and an increase in extreme precipitation events. In the specific context of the Massane River, a small Mediterranean mountain river, our study aimed to lay the groundwork for a long-term monitoring of deadwood transport by the watercourse. We began by conducting an inventory of large woody debris present in the riverbed. Subsequently, we adapted an RFID-based tracking system to monitor deadwood movement. Finally, we measured the distances traveled by wood pieces displaced following the initial rise in water levels, a consequence of RFID tagging of wood pieces. This sequential approach indicated that approximately one-third of the total deadwood stock volume was likely to be transported during an ordinary flood event. The use of RFID technology effectively enabled the downstream tracking of wood movement and revealed that even a moderate flood event could transport recently deposited wood pieces nearly 4 kilometers. This work marks the initiation of a long-term monitoring effort to trace the movement of deadwood from the river's source to its estuary and examine the relationship between flood event types and the extent of wood transport.

Keywords: Rivers, Runoff, Floods, Large woody debris, Coarse wood, Radio telemetry, Tracking, Displacement length

Version française

Résumé

Les rivières transportent une grande variété de matériaux, allant des particules de sédiments de taille submillimétrique aux arbres entiers. Le bois mort transporté constitue un élément vital des écosystèmes fluviaux boisés. Les apports de bois modifient constamment la morphologie des cours d'eau et influent sur le débit fluvial. Étant donné la nature intrinsèquement complexe et diversifiée des systèmes fluviaux, une exploration approfondie de leur diversité est justifiée pour identifier les tendances récurrentes dans la dynamique du transport du bois mort. Ce besoin devient impératif dans les régions déjà confrontées à des épisodes prolongés de sécheresse, des vagues de chaleur fréquentes

et une augmentation des événements de précipitations extrêmes. Dans le contexte spécifique de la rivière de la Massane, une petite rivière de montagne méditerranéenne, notre étude visait à poser les bases d'une surveillance à long terme du transport du bois mort par le cours d'eau. Nous avons commencé par réaliser un inventaire des débris ligneux volumineux présents dans le lit de la rivière. Par la suite, nous avons adapté un système de suivi basé sur la technologie RFID pour surveiller le mouvement du bois mort. Enfin, nous avons mesuré les distances parcourues par les morceaux de bois déplacés suite à la montée initiale du niveau de l'eau, conséquence du marquage RFID des morceaux de bois. Cette approche séquentielle a indiqué qu'environ un tiers du volume total du stock de bois mort était susceptible d'être transporté lors d'un événement de crue ordinaire. L'utilisation de la technologie RFID a efficacement permis le suivi aval du mouvement du bois et a révélé qu'un événement de crue modéré pouvait transporter des morceaux de bois récemment déposés sur près de 4 kilomètres. Ce travail marque le début d'un effort de surveillance à long terme visant à retracer le mouvement du bois mort depuis la source de la rivière jusqu'à son estuaire et à examiner la relation entre les types d'événements de crue et l'étendue du transport du bois.

INTRODUCTION

The deadwood plays a key role in the functioning of habitats that succeed along the land-to-sea continuum (Maser and Sedell, 1994; Naiman et al., 1999). Fallen branches and trees in riparian forests create structurally rich riverbanks (Naiman and Décamps, 1997), offering habitats for various species including insects (Parisi et al., 2021), amphibians (Herbeck and Larsen, 1999), mammals (Radu, 2006), and birds (Mikusinski and Angelstam, 1997). Deadwood's role persists as it enters the riverbed, providing crucial shelter, spawning areas, and foraging opportunities for aquatic life (Angermeier and Karr, 1984; Anderson et al., 1984). Releasing organic substances, deadwood also contributes to major biogeochemical cycles, enriching surrounding water with essential nutrients (Bilby and Likens, 1980). Downstream, deadwood maintains its ecological importance (Sleeter and Coull, 1973) and served as a long-term carbon sink (Canuel and Hardison, 2016), contributing to climate change mitigation (Mcleod et al., 2011; Russell et al., 2015; Zeng, 2008).

Rivers act as natural conduits for large woody debris (Harmon et al., 1986). A comprehensive understanding of the dynamics of deadwood transport in rivers is crucial for identifying areas prone to debris accumulation (Comiti et al., 2016). This knowledge provides the necessary foundation for developing strategies for flood mitigation and responding to extreme flood events (Mazzorana et al., 2018; Nicholson et al., 2012).

Any efforts to characterize the spatial distribution and transport of deadwood in river systems provide valuable insights into the natural processes that shape river environments (Pedroli et al., 2002). These insights, in turn, guide initiatives related to river restoration and biodiversity conservation (Roni et al., 2015; Wohl et al., 2015). Quantifying the temporal dynamics of wood in rivers can be achieved using various techniques (MacVicar et al., 2009). Among these, individual tracking techniques offer valuable assessments of wood mobilization, deposition, and transport distance. Visual methods, such as the recognition of individual pieces based on shape, location, and the presence of distinctive features of the debris(Lienkaemper and Swanson, 1987), as well as labeling wood pieces with waterproof acrylic paints (Jacobson et al., 1999) or using vinyl plastic number tags for identification (Haga et al., 2002), have provided valuable information on individual wood movement. However, these visual methods are limited in accuracy and durability. In contrast, radio telemetry using RFID facilitates real-time data collection through remote sensing, enables precise location tracking of multiple pieces of deadwood simultaneously (Schenk et al., 2014), all without frequent replacements or maintenance efforts.

Originally conceived to enhance military radar systems (Hanbury Brown, 1994), RFID has evolved into a widely utilized practical identification tool across various fields, including logistics, supply chain management, and ecological conservation. RFID technology has played an important role in

monitoring animal movements, migration patterns, and behaviors, providing valuable insights for habitat preservation and species conservation (Harrison and Kelly, 2022; Kissling et al., 2014; Skov et al., 2008). More recently, their use in tracking the movement of wood (MacVicar et al., 2009; Ravazzolo et al., 2015; Schenk et al., 2014) and pebbles (Cassel et al., 2020, 2017) has expanded their range of applications to the study of processes in river environments.

In the present work, we relied on this approach for characterizing the transport of deadwood along a small mountainous forested Mediterranean river. The Mediterranean forests, despite covering only a small area of the world's forests, harbor a remarkable diversity of woody species (Gauquelin et al., 2018). However, climate change poses challenges as this region experiences shifts in precipitation patterns, with overall decreases in precipitation and an increase in extreme rainfall (Zittis et al., 2019). River flow and discharge are expected to decrease significantly, leading to water scarcity, more frequent droughts and severe flood events (Tramblay and Somot, 2018). These changes are likely to influence the timing and magnitude of wood inputs, causing fluctuations in wood transport and deposition dynamics within these river systems.

The overall objective of this study is to initiate RFID tracking to monitor the mobility of deadwood in the Massane River, a small mountainous river that originates in the foothills of the French Pyrenees and flows into the Mediterranean Sea. The study aims to achieve three specific objectives: quantifying the distribution of deadwood in the riverbed, developing an RFID tracking protocol for individual pieces of deadwood in a forested and rugged environment, and gaining insights from the first significant flood event that resulted in the movement of the RFID-tagged deadwood pieces.

MATERIAL AND METHODS

Study site

The Massane River, depicted in Figure 1, originates at an elevation of 970 meters in the Eastern Pyrenees foothills and meanders for 22.02 kilometers before it reaches the Mediterranean Sea. The watershed area covering this region spans 17.2 square kilometers. As the river flows from its source to the confluence with the Source of Alemanys at an elevation of 610 meters, it traverses the National Nature Reserve of the Massane Forest (336 ha), covering a distance of 5.2 kilometers. In this particular section, the river exhibits a steep gradient of 6.5%, flanked by 18.4 hectares of riparian forest. The most prevalent tree species in this area are beech (*Fagus sylvatica*) and alder (*Alnus glutinosa*). While beech trees can be found throughout this section of the river, alder trees are limited to altitudes below 800 meters.

Deadwood stock in the upper river stretch

In June 2021, a survey was conducted in the river section that crosses through the reserve, as shown in Figure 1. The purpose of the survey was to assess the quantity and distribution of deadwood along the watercourse. The surface area of the channel in this section of the river is estimated to be 4.9 hectares. Data collection involved measuring various parameters for each piece of wood found in the riverbed, including length, average diameter, tree species, degradation state, and geographical position. The measurements of individual wood pieces, including fallen tree trunks and branch sections, were used to calculate volumes using a cylinder equation. Deadwood was quantified as cubic meters per hectare (m^3 ha^{-1}) and pieces per hectare (pieces ha^{-1}).

For this study, deadwood was defined as individual logs with dimensions of at least 0.1 meters in diameter and 0.4 meters in length. This specific definition was chosen to standardize wood size in relation to the stream bank's full width (Comiti et al., 2006). In certain areas, like Lavail Gorge, the river narrows significantly, with a distance of only 2.5 meters between the rocky walls that enclose the waterway. To assess the degradation process, a scale from 1 to 4 was used to characterize the decay stage of the deadwood pieces. The state of decay was determined based on external appearance and wood density, as follows:

- Stage 1: Recently recruited pieces of dense wood with intact bark, leaves, or buds at the ends of branches.
- Stage 2: Dense wood with more than 70% of its bark intact and no signs of abrasion from river scouring.
- Stage 3: Pieces of wood that are still dense, have spent several months in the riverbed, lost more than 70% of their bark, and show clear signs of abrasion.
- Stage 4: Completely rotten wood that decomposes upon contact or under weak pressure.

Stages 1, 2, and 3 represent deadwood that can be mobilized during floods, while Stage 4 represents non-transportable wood that will inevitably decay when the river rises again. Stages 1 and 2 specifically capture recent recruitment of deadwood into the river.

RFID tracking in the field

RFID system description

RFID technology, originally developed for managing inventory, logistics, and various applications like microchipping domestic animals, gates, and access points, is typically employed in scenarios where the tagged object is mobile, while the reader, connected to a powered main PC, remains stationary. Although embedded solutions exist, they often require carrying a laptop or tablet, which can be cumbersome, power-consuming, and fragile. Due to the absence of an off-the-shelf solution, we undertook the development of a lightweight and compact reading device designed for pedestrian use over long distances in rugged natural environments (Plate I).

In our system, we utilized active RFID tags equipped with onboard batteries, enabling signal exchanges at a frequency of 433.92 MHz over distances of up to 100 meters. To capture, read, and record the information received by the receiver, we employed an Arduino AT Mega 2560 microcontroller board. The RS232 PC serial port signals from the RFID reader were converted into logic-level data using a serial adapter RS232/TTL module connected to the universal asynchronous reception and transmission (UART) serial port 1 of the board. Subsequently, the identification number and received signal strength indicator (RSSI) level of the detected tag were displayed in real-time via the I2C (Integrated Circuit Interface) port of the microcontroller on an LCD I2C 20x40 Arduino module (Plate I). Data was further stored on a micro SD card as a text file using a micro-SD reader/writer module connected to the serial peripheral interface (SPI) port of the microcontroller. The recording frequency matched the emission rate of the tags, which transmitted one signal every 2 seconds. Each acquisition was timestamped and included latitude and longitude data collected from a GPS module (Adafruit Ultimate GPS Breakout) connected to the UART2 port of the AT Mega board. A 12V 6800 mA rechargeable li-ion battery provided power for the system, enabling operation for more than 8 hours. The complete detection system, including the protective casing, had a weight of 550 grams and dimensions of 13x12x12 cm.

All RFID equipment used in this study was designed by ELA Innovation in France. The tags employed were PUCK IDs® tags, the receiver was the SCIEL READER lite® reader, and the antenna used was the semi-directional SLENDER III® antenna. Detailed technical specifications can be found on the manufacturer's website at https://elainnovation.com/. We procured the equipment from the CIPAM company.

Experimental Setup

The tagged wood used in the experiment consisted of beech logs measuring 0.6 m in length and ranging in diameter from 0.11 to 0.15 m. A total of fifty freshly cut logs were equipped with RFID tags, each with a base measuring 57 mm and a height of 20 mm (Plate I). These RFID tags were inserted into

pre-drilled slots in the wood and securely affixed using silicone glue. On July 17, 2021, starting from the source of the river, these tagged wood logs were systematically placed at 100-meter intervals along the riverbed.

After installation and prior to the occurrence of the next flood event, data collection involved measuring the received signal strength indicator (RSSI) levels at various distances within the study environment. This data collection aimed to capture the signal propagation patterns within the complex terrain of the study site while ensuring the RFID tags remained operational. The data files recorded by the reading systems were processed to calculate the distances between different detector positions and the tagged wood logs. These distances were determined using the Haversine equation, which accounts for the curvature of the Earth.

To characterize the attenuation of RSSI as the radio signal propagates, we employed a simplified equation based on the Free Space Path Loss (FSPL) model, as shown below:

$$RSSI = RSSI_0 - 10 \times n \times log_{10}(d) \quad (1)$$

$RSSI$ represents the received signal strength indicator level. $RSSI_0$ is the received signal strength level at a reference distance of 1 meter. n is the attenuation parameter, which is a parameter that determines the rate of power decrease of the signal with distance. d is the distance, in meters, between the transmitter and receiver of the signal. The parameter n can vary depending on the environment, obstacles, and propagation path characteristics. In a free space environment, without obstacles or reflections, the typical value of n is generally close to 2.

Analysis of tag travel distances and transport outcomes

After the initial significant rainfall events that occurred following the installation of the tags, we conducted surveys along the river to locate the marked wood logs. Using the data collected by the RFID reading system, we retrieved the GPS coordinates corresponding to the reader's position that corresponded to the best-recorded RSSI level for each tag.

To determine the distances covered by the tags, we obtained the geo-referenced course of the river from the repository maintained by the French national administration service for water data (http://www.sandre.eaufrance.fr/geo/CoursEau/Y0110540). We then applied the Haversine formula to calculate the distances between consecutive points on this route. By summing the lengths of these consecutive intervals, we could calculate the distance between each geo-referenced point on the river and the position of the river's source.

With knowledge of the distance between the source and the tag at time 't' (i.e., before the rainfall event) and the distance at time 't+dt' (i.e., after the rainfall event), we were able to calculate the travel distance of the tags during the time interval 'dt' by taking the difference between the two distances. The assessment of wood transport was quantified in terms of meters traveled per flood event. Additionally, we carefully recorded whether the logs ended up isolated or in a logjam, either within or outside the river's main channel after their transport.

RESULTS

Deadwood distribution and quantification

The survey conducted in June 2021 revealed that a total of 368 pieces of wood, equivalent to 75 pieces per hectare (ha^{-1}), were present in the channel of the upper river stretch, representing a combined volume of 32.9 m^3 (7.7 m^3 ha^{-1}) (Figure 2). Across the entire 5.2-kilometer stretch of the river, these wood pieces were distributed widely. Only a few areas, notably near the Couloumates cabins (Figure 2A), were observed to have a scarcity of deadwood.

The majority of the deadwood, both in terms of the number of pieces and volume, originated from beech trees (82-78%) and alder trees (12-13%). Wood pieces with a length smaller than the width of the river at its narrowest point, which is 2.5 meters, constituted 74% of the counts and 34% of the total deadwood volume (Figure 2B). The most common state of degradation observed was stage 3, characterized by wood pieces that had spent some time in the riverbed, shedding over 70% of their bark, and displaying evident signs of abrasion. This stage accounted for 85% of the overall deadwood volume. Stage 4, indicative of completely rotten wood, comprised 6% of the total deadwood volume.

RFID tracking

Between the completion of the inventory and September, there were no rainfall events that caused the marked logs to move. During this period, the recordings of RFID tag signals in the intricate study site environments showed notable background noise. This led to very low received signal strength indicator (RSSI) measurements for short distances between RFID tags and the reader, as illustrated in Figure 3A. This was partly due to the presence of obstacles that weakened the signal's range but primarily because the reader's reception antenna was semi-directional. Consequently, when the antenna was not aligned with the tag, the RSSI value decreased. To address this issue and apply the signal attenuation model, we filtered the data to retain only the highest RSSI values within a 5-meter range (Figure 3A).

255 This analysis, conducted on all the tags in place at the time of measurement (Figure 3B),
256 indicated that the best RSSI value was around -90 dB. The average value of the attenuation parameter,
257 'n,' was 5.1, with extreme values ranging from 3.5 to 6.7, and a mean detection range of 134 meters,
258 lying between the extreme values of 73 and 220 meters.
259 The monitoring of the tags allowed us to detect that one tag went missing in the vicinity of the
260 Couloumates cabins, and two others malfunctioned before the onset of the first flood. We replaced the
261 faulty tags, while the missing one was not replaced.
262

263 ### Tag travel distances

264 Initially, starting from the source, tagged wood logs were positioned at 100-meter intervals in
265 the riverbed (Figure 4A). An episode of rainfall occurred on September 16th and 18th, 2021. The daily
266 precipitation accumulations recorded at the meteorological station within the reserve during these days
267 did not exceed 22 mm per day. However, the cumulative effect was substantial enough to induce the
268 movement of deadwood within the river. The position of the tags after this event (Figure 4B) indicates
269 that the majority of the marked logs were displaced, sometimes over long distances. Three marked
270 wood pieces exited the reserve boundaries.
271 The observed maximum value was 3840 meters (Figure 5). Individual analysis of travel distances
272 confirmed that nearly all of the marked pieces moved, some (e.g., tags 2B3, 2BD, 2DB, 2E2) by a few
273 meters, and others (e.g., tags 2B9, 2C3, 2D3, 2E1) over several kilometers. The median value was 790
274 meters. Fifty percent of the tagged wood travelled between 330 m and 1550 m. Deadwood that was
275 susceptible to transport was mobilized by the rising water level, with no observable effect of the initial
276 position of the wood piece on the distance traveled. Of the logs, half ended up isolated, while the other
277 half became part of logjams. Location categorization revealed that 65% remained within the river's main
278 channel, while 35% were deposited outside the main channel after transport.
279

280 ## DISCUSSION

281 ### Reflections on study scope

282 Our study provides quantitative insights into the stock and condition of deadwood in a small
283 coastal Mediterranean mountainous river. It demonstrates the efficiency of RFID tracking in evaluating
284 deadwood mobility and introduces additional findings on the transport of these materials following an
285 initial flood event. However, it is essential to consider these results within the context of inherent
286 limitations stemming from methodological choices. These limitations encompass the dimensions and
287 context of deadwood assessment in the riverbed, the reliability of the RFID tracking equipment, and the

sampling and methodology used to evaluate deadwood transport. Firstly, the selected dimensions of deadwood logs may influence the interpretation of the total deadwood stock in the river. However, this choice does not undermine the main findings of our study, which primarily focused on 'large wood debris' significantly impacting fluvial dynamics. Besides, this decision enables a comparative analysis with data previously collected by the reserve's managers (Magdalou et al., 2009). A minor yet tangible limitation concerns the reliability of the RFID tracking equipment. Malfunctions, such as the lack of waterproofness of tags or unexpected battery depletion, may affect result precision and data interpretation. The interpretation of signal loss in cases where a wood piece was not retrieved raised questions about the possibility of it being transported beyond search limits or ceasing activity without movement. Without visual confirmation of the presence of a wood piece that was no longer emitting a radio signal, we assumed that the last flood event had caused its movement. However, the tagged log was excluded from further tracking. Nevertheless, such incidents fortunately remained infrequent. The final limitation pertains to the sampling and methodology employed to evaluate deadwood transport. This includes the introduction of specific logs, which might not precisely emulate the behavior of naturally occurring deadwood. While this limitation narrows our focus to recently recruited isolated deadwood stocks, rather than encompassing the entire stock in the river, our findings hold value in addressing this specific aspect. The approach also holds significance as it initiates a tracking process for deadwood from its entry into the riverbed, adding another dimension to our understanding of its mobility.

Main study findings

Deadwood stocks

Our study revealed a significant decline in both the number of deadwood pieces and the total volume of deadwood in the river when compared to data recorded between 2001 and 2008 (Magdalou et al., 2009). Additionally, the observed ongoing trend of increased predominance of beech and alder at the expense of other tree species at that time has become more pronounced. These differences and shifts reflect natural variability in annual wood inputs and river flows emphasizing the amplified impact of climatic disturbances on tree mortality and the decline in the riparian forest stand.(Allen et al., 2010; Carnicer et al., 2011; Ruiz-Benito et al., 2013).

The river's narrow width acts as a natural filter, allowing primarily wood pieces smaller than 2.5 meters in length to be transported over long distances during annual floods. Nevertheless, the amount of deadwood mobilized by an annual flood remains substantial, representing approximately one-third of the total stock volume, according to our estimates. The tagged wood pieces used in our study

provided valuable insights into the maximum distances that logs can travel during floods, as small isolated logs are more responsive to changes in water flow and may travel longer distances compared to larger logs (Ruiz-Villanueva et al., 2016).

RFID Reliability

During the current survey, the recovery rate of tagged logs reached 96%, a figure higher than typically reported in the literature (MacVicar et al., 2009; Ravazzolo et al., 2015; Schenk et al., 2014). This performance can be attributed to two key factors: pre-flood monitoring of the RFID beacon group and the river's configuration. The monitoring of RFID beacons before the flood event ensured the continued activity of the maximum number of tagged logs. Furthermore, the Massane River, being a small river with a single channel, significantly simplified the process of recovering tagged wood pieces by reducing the width of possible search areas. The RFID tag reading system demonstrated remarkable robustness in traversing the river. The RFID signal interpretation and recording module, weighing less than 600 g, accounted for only a small fraction of the total weight of the reading system, which included the 2 kg detection antenna. However, this weight discrepancy was compensated by the antenna's excellent long-distance detection capabilities. Despite variations in the maximum detection range from one RFID tag to another due to natural obstacles and wave reflections disrupting the radio signal propagation locally, the system consistently performed well. The 'n' values for the attenuation parameter were consistently higher than the characteristic value for signal propagation in an obstacle-free open space. Values exceeding 5 should be considered relative, as they are rarely achievable in real-world conditions. These artifacts result from the limitations of the model used to represent the datasets collected for certain tags. Typically, the recovered logs were visually confirmed. In all instances, a higher or near -120 dB RSSI value indicated the presence of the marked log within a distance of less than 10 meters. With GPS measurements having an accuracy of about 5 meters, the badge's position could be determined with a margin of error of less than 15 meters in the worst-case scenario.

Wood mobility

We observed a significant absence of deadwood in the river section adjacent to the Couloumates cabins (Figure 2A). Notably, one of our tagged logs disappeared before any rise in the river's water level. This particular area serves as a bivouac site for hikers. Despite our efforts to locate the log for which we had the GPS position, we suspect that the log, along with its RFID tag, might have been removed from the river to be burned. However, apart from this unexpected incident, the RFID monitoring proved to be effective and precise.

353 The rise in river water levels following the September rainfall prompted the displacement of
354 almost all marked pieces. In contrast to previous studies based on introduced wood in steep-gradient
355 watercourses (Millington and Sear, 2007, and others), our research reveals the potential for wood to
356 travel considerable distances—up to 17% of the river's total length—even with a minor increase in the
357 water level (Steeb et al., 2017). The arrangement of the logs, initially evenly spaced along the
358 watercourse into the riverbed, was significantly altered, revealing areas with varying degrees of
359 clustering. Wood logs were transported downstream until they were deposited either on rock outcrops,
360 incorporated into logjams, or ejected onto the banks outside the riverbed. These positions assumed a
361 more natural state (Plate II), indicating a stability gradient likely developed due to the transport and
362 deposition conditions of the wood pieces. This new situation provides a more accurate representation
363 of flood-induced changes in deadwood mobility.
364 Following this initial movement, 37% of the pieces remain isolated in the riverbed, highly
365 mobilizable, and 28% caught in a logjam inside the main channel of the river can be considered as
366 potentially easily mobilizable during a typical flood event. Pieces of wood trapped in logjams or
367 deposited on the riverbanks can be remobilized during more intense flood events, provided these flood
368 events occur before the degradation process is complete. This is highly probable since it takes at least a
369 decade for a piece of beech wood to completely degrade in this environment (Charles et al., 2022).
370 Continuing the monitoring will help determine the pace at which deadwood continues its downstream
371 journey and whether flood intensity and contextual factors (isolated/trapped-in-a-logjam; in/out of the
372 riverbed) influence the mobilization and transport of wood (Oettel et al., 2022).
373 The daily precipitation accumulations that triggered the movement of deadwood were relatively low.
374 The measuring station located at Mas d'en Tourens, 14 km from the source, did not record any
375 significant rise in the water level. These precipitation events followed a long period of drought, resulting
376 in substantial runoff. The rains were brief but intense enough to cause a noticeable rise in the water
377 level in the upper reaches of the watercourse. This event, by causing the disintegration of water
378 reservoirs formed by logjams and the creation of new ones, had a localized effect on both accelerating
379 and slowing down the river's flow rate. These observations highlight the challenge of linking deadwood
380 movement to flood events, emphasizing the localized effects of precipitation even in small-scale areas.

381

382 ## Implications of the study

383 Understanding the storage of deadwood, the processes governing it, and the dynamics of its
384 transport is a prerequisite for the choice of effective river management strategies, particularly in the
385 face of significant climate changes (Benda and Sias, 2003). Such strategies aim to reduce the risk of

watercourse obstruction, enhance flood prevention measures, and support river restoration efforts (Wohl et al., 2015). In the context of our study, which focuses on a small coastal Mediterranean mountainous river in its natural state, several key observations are worth highlighting. A substantial portion of the deadwood in this river consists of relatively small pieces. When isolated within the riverbed, these pieces have the potential for long-distance transportation even during minor water level rising events. The river's narrow width leads to the fragmentation of larger tree pieces before they can be transported. This fragmentation process reduces the risks typically associated with exceptionally large pieces that could damage infrastructure. Occurrences of logjams and resulting barriers in the river play a crucial role in mitigating the impacts of rising water levels during flood events. These logjams contribute to the natural regulation of river flow and help preserve essential stream habitats. This work sets the stage for the continuation of investigations, determining whether the tagged wood pieces will persist in their downstream journey. It aims to establish a clear link between the intensity of flood events and induced movements, while also evaluating the durability of RFID tagging. In essence, these initial findings underscore the importance of preserving natural river environments with minimal human intervention. Allowing natural processes, such as deadwood accumulation and logjam formation, to continue enhances the resilience of river ecosystems and their ability to manage flood events effectively. This approach aligns with sustainable river management practices and contributes to the overall health and stability of these vital ecosystems.

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542 Plate & Figure captions:

543 Plate I: RFID System. The detection system is mounted on a carrying rack to traverse the river in search
544 of tagged badges; RFID tags are inserted inside the pieces of wood. When a tag is detected, the reading
545 system displays the tag's identification code, the signal reception strength indication (RSSI), and the
546 geographic coordinates of the detection point on a liquid crystal display. All information is stored on a
547 micro SD card.

548 Plate II: After the initial movement, the RFID tagged wood pieces assumed a more natural position than
549 when initially introduced into the riverbed. Wood logs are found in large logjams, wedged between
550 rocks, beneath large logs, or simply deposited directly on the riverbed.

551 Figure 1: Study Site – Location and course of the Massane River. The polygon delineates the boundaries
552 of the National Nature Reserve of the Massane Forest.

553 Figure 2: Deadwood in the upper river riparian forest - (A) Mapping of the locations of large wood pieces
554 along the riverbed within the boundaries of the Massane Forest National Nature Reserve; (B) Boxplots
555 of length and volume distributions of individual wood pieces.

556 Figure 3: RFID-tagged wood logs. (A) Example of received signal strength indication (RSSI) levels vs.
557 distance between RFID tag and reader system. Each point represents an individual measurement; solid
558 points indicate values used for free space path loss (FSPL) signal model calibration. (B) RSSI_0 levels,
559 signal attenuation parameters (n), and maximum detection distance of RFID tags in field conditions.

560 Figure 4: RFID-tagged wood log locations. (A) Pre-flood, (B) Post-flood event. The polygon outlines the
561 boundaries of the National Nature Reserve of the Massane Forest.

562 Figure 5: Barplot of RFID-tagged wood log travel distances. The x-axis labels indicate the initial tag
563 positions relative to each other, from the source of the river to the exit of the river from the Reserve.
564 Color and color tone of the bars represent whether a log was located inside (blue) or outside (green)
565 the watercourse and its context, whether isolated (light tone) or aggregated within a logjam (dark tone)
566 after displacement.

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569 Plate I

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572 Plate II

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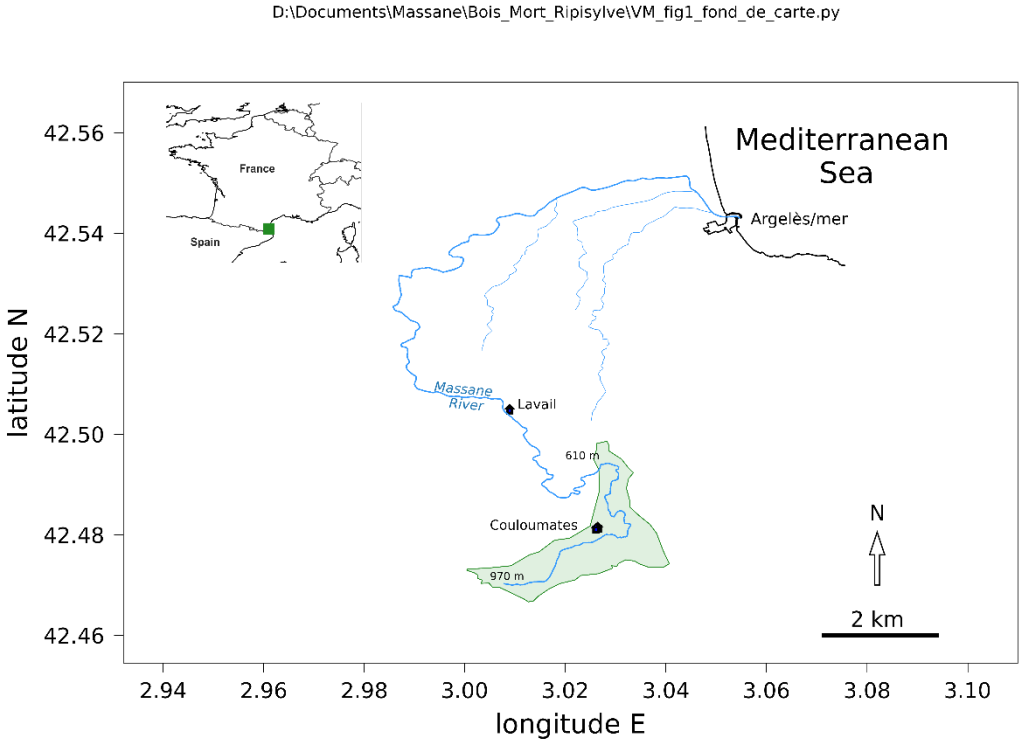
575 Figure 1



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577 Figure 2

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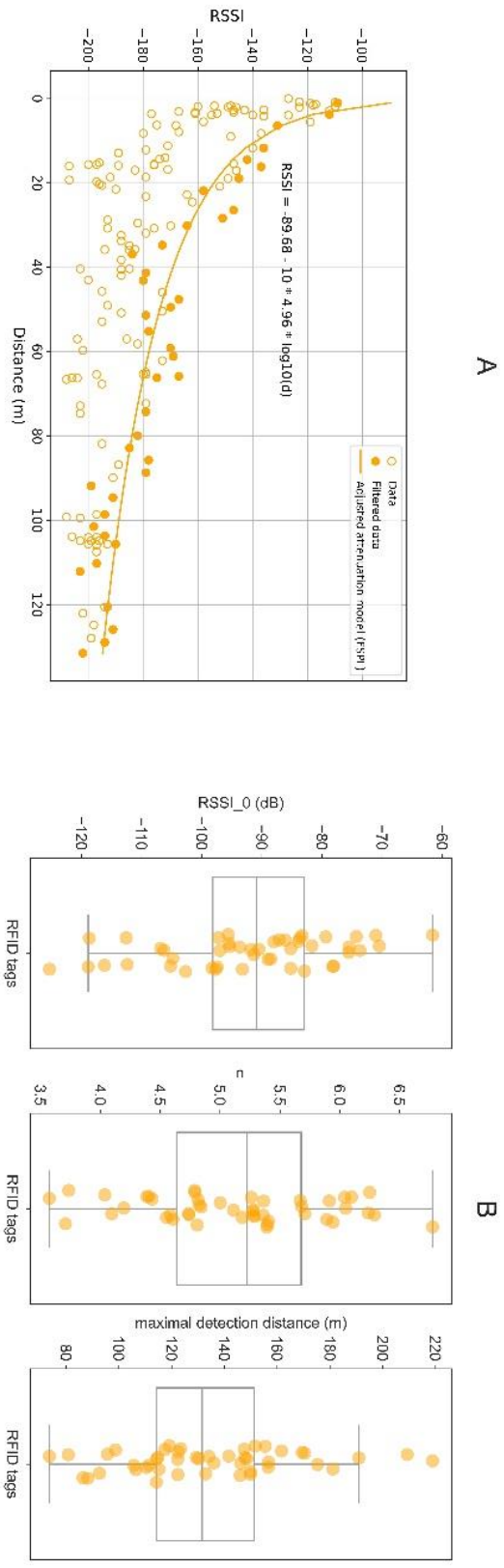
579 Figure 3



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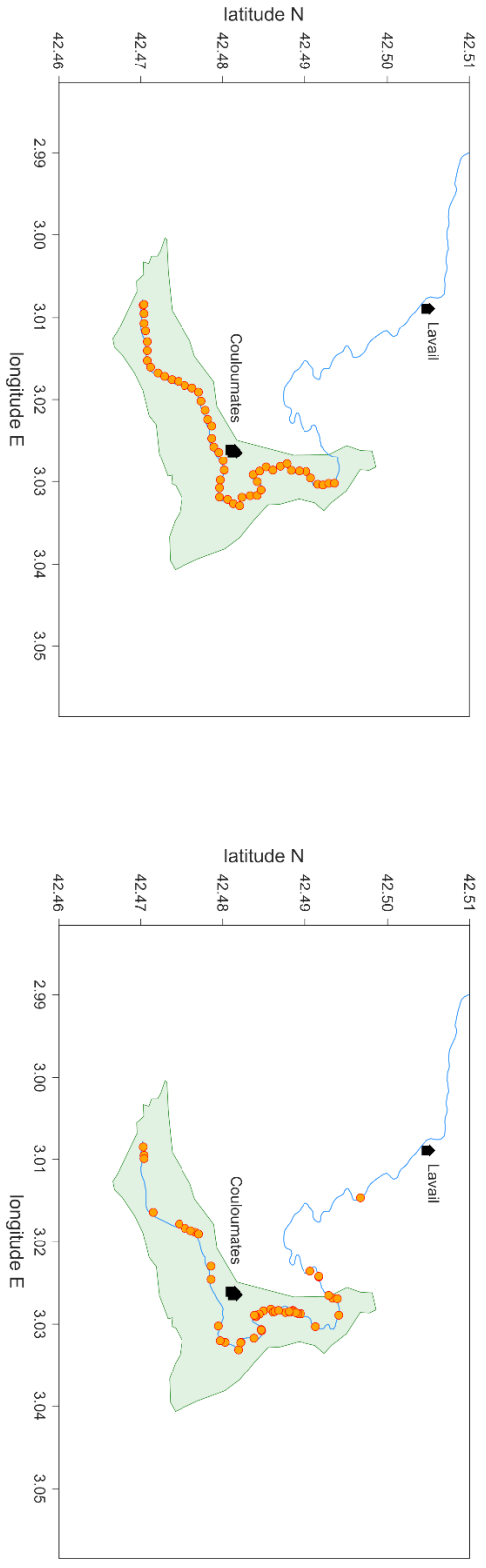
581 Figure 4



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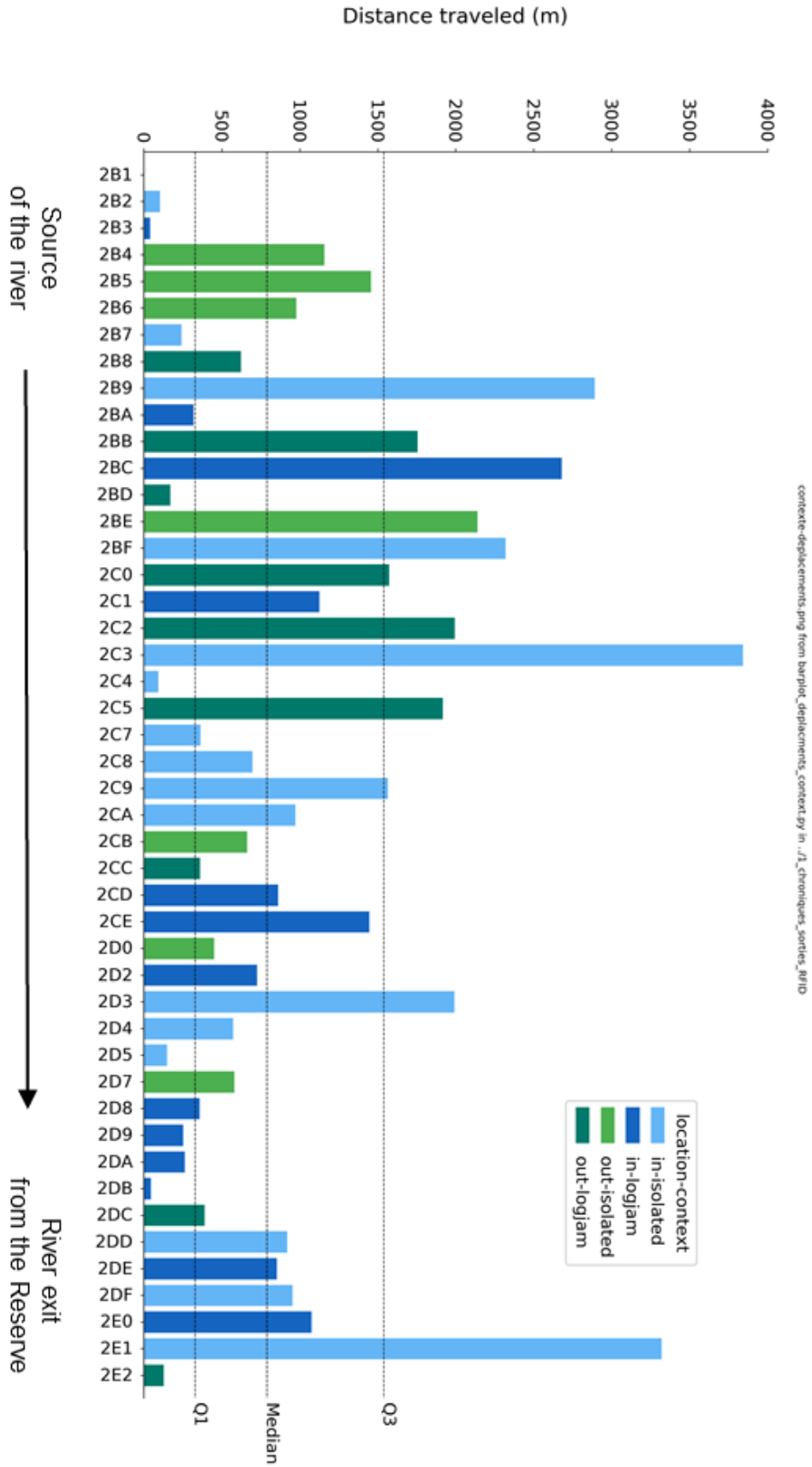
583 Figure 5



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