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Evidence-based Policy for Integrated Control of Forested River Catchments in Extreme Rainfall and Snowmelt

Instrument: Specific Targeted Research Project

Thematic Priority: Specific Measures in Support of International Cooperation, Developing Countries, A.2 Rational Use of Natural resources, A.2.1 Managing humid and semi-humid ecosystems

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New methods for determining wood storage and mobility in large gravel-bed rivers

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SUMMARY

This document reports on the development of new methods for the assessment of wood load and mobility in large rivers. The study site for both investigations was the Piave river (Northeastern Italy) along a 30 km segment featuring gravel bed, braided/wandering characteristics. The use of high-resolution (1:8,000, 10 cm pixel size) aerial photos was tested in 7 subreaches, where GPS-assisted field surveys were used to validate remotely sensed measurements. Results indicate that relative errors in diameter estimation are strongly related to log size, and become acceptable for diameters larger than 15-20 cm. Measurements of log length feature smaller relative errors, which are not influenced by log dimensions. Wood volume calculation based on dimensions of single logs and jams digitalized from the aerial photos showed that wood load per unit of streambed area differ considerably among reaches, with island/braided types exhibiting the highest values, thus representing the most favourable depositional sites for drifting wood.

Furthermore, the first system for monitoring wood movement in large rivers based on active radiotransmitters was successfully tested following a moderate flood event. This new technique seems to be suitable for research activities in braided gravel bed rivers. However, the limited battery life of the implanted tags and their relatively high cost do not allow to adopt such method for long-term programmes.

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1. INTRODUCTION

Abundance, volume and morphological processes associated to in-channel wood have been mostly investigated in small to medium (*sensu* Gurnell et al. 2002) size channels. For example, see Hering et al. (2000), Kazcka (2003), Faustini and Jones (2003), Gomi et al. (2003), Meleason et al., (2005). In such relatively small rivers, the measurement of all wood pieces lying within a certain stream reach is feasible, i.e. not excessively time-consuming due to the limited channel width.

For larger rivers (drainage area >1,000-2000 km^2), fewer are the studies on wood storage and morpho-ecological effects (Abbe and Montgomery, 1996; Gippel et al., 1996; Thevenet et al., 1998; Piegay et al., 1999; Wyzga and Zawiejska, 2005; Gurnell and Petts, 2006). In particular, large gravel bed rivers having a braided pattern pose significant problems because of the considerable extension of their streambed which force researcher to adopt a sampling procedure based on distinct cross-sectional transects (Gurnell et al, 2000a; 2000b) which do not allow to capture the complex pattern of wood deposition and thus limit the reliability of wood storage estimation built on such approach.

In addition, the information – nonetheless very scarce – relevant to wood mobility is available for small mountain channels (Gurnell et al., 2002; Mao et al., in press). Again, the large (up to 1-2 km) channel widths of braided rivers, along with much longer potential transport distances (Fig. 1, Piegay, 2003; Braudrick and Grant, 2000; 2001) hinder the monitoring of wood displacement following flood events.

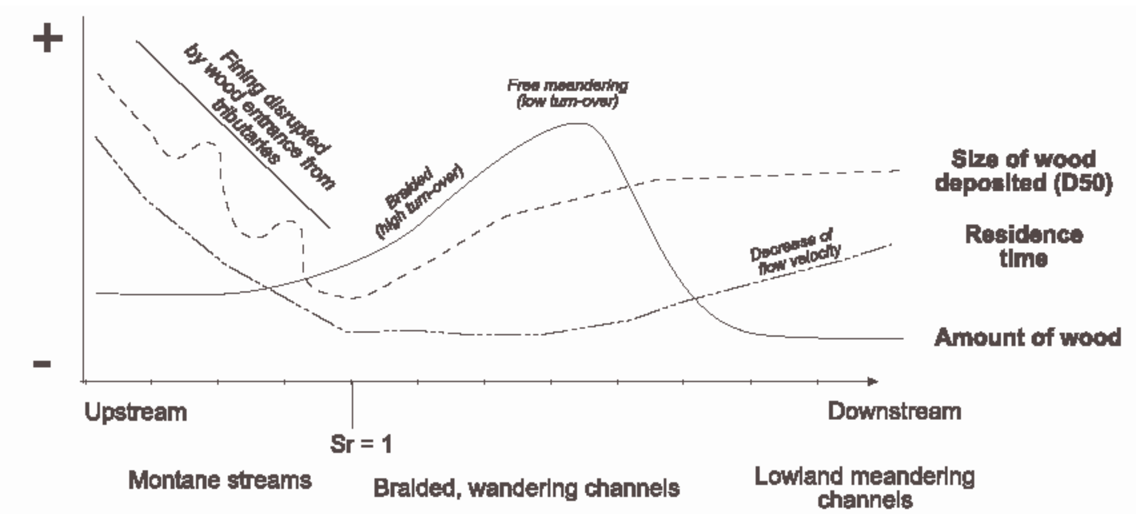


Figure 1 – Variation of in-channel wood characteristics from mountain streams to lowland rivers (Piegay, 2003).

As a consequence, there is a strong need of new methods for a fast and reliable estimation of wood storage and of log mobility in large gravel bed rivers (Pecorari et al., 2007). Attempts to map wood elements with airborne digital multispectral imagery were unsuccessful in the Yellowstone River (Wyoming, US, Marcus et al., 2002), whereas evaluation of wood loading from ordinary aerial photos (higher resolution 0.2 m) was effectively carried out by Herrera Inc. (2005) in the Quinalt river (Washington State, US), where in-channel wood features on average very large dimensions (diameter > 50 cm) due to the pristine conditions of the temperate rainforest covering the basin.

Such topic was not originally present in the UNIPD's task list for the EPIC FORCE project, but it was decided to address methodological issues raised by large rivers as a supplementary activity of the project. Because of this, the research had to be developed at a location easily reachable from the University of Padova, to provide inexpensive and convenient access to the site. Nevertheless, results stemming from the present methodological tests will help carry out evaluation of wood loading in large rivers of Latin America, both in tropical areas subject to ENSO phenomena and hurricanes, and in the temperate regions of the Southern Andes. These methods will complement those developed for smaller mountain streams of Latin America (Andreoli et al., 2007a; 2007b; Comiti et al., 2008; Mao et al., 2008a, 2008b) and will contribute to enhance an effective and sustainable management of in-channel wood coupled to stream restoration (Lenzi et al., 2007a; 2007b).

2. STUDY SITE: THE PIAVE RIVER

The Piave river basin (drainage area 3899 km^2) lies in the Eastern Italian Alps, and the main channel overall flows south for 220 km from its headwaters to the outlet in the Adriatic Sea, northwest of Venice. The climate is temperate humid with an average annual precipitation of about 1350 mm. However, marked differences in precipitation (ranging from 1000 mm to 2000 mm) related to elevation and proximity to the sea exists within the basin. Considerable annual variations in the rainfall amount are also present, but the data did not show any significant trend (Surian, 1999).

The drainage basin is mainly composed of sedimentary rocks (predominantly limestone and dolomite), but volcanic and metamorphic substrates are also present. The river course can be divided into three reaches. The upper section, where the river is mostly incised in the bedrock and presents a narrow channel.. In the middle course the gravel riverbed is instead very wide and characterized by a multithread and wandering channel pattern, whereas the lower course features a sand-bed, meandering channel artificially straightened at places (Surian, 1999).

Figure 2 – The Piave river at the entrance in the "Vallone Bellunese" (left) and at the confluence with its main tributary (Cordevole river, right) close to the downstream end of the study reach.

The present physiographic setting of the river results mainly from drainage system evolution during the Late Glacial and the Holocene (Surian, 1999; Surian, 2006). Following retreat of the Wurmian glacier, around 15 500±16 000 years BP, a phase of valley aggradation occurred. Surian (1996) established that, in the large synclinal between Ponte nelle Alpi and Busche (Figs. 2-3) called "Vallone Bellunese" which is the location of the study reach in this research, this phase lasted up to 8000±9000 years BP.

After this period of aggradation, the river began to incise into the deposits to form a series of terraces. Channel characteristics of the Piave within the Vallone Bellunese (drainage area 3,200 km^2) are the following: mean gradient 0.4%; width 100 m - 1,000 m, median grain size 20 - 50 mm, braided and wandering planform types.

Flows in the Piave River have been regulated for irrigation and hydroelectric power generation over a long period. During 1930s-1950s dams were built along its channel network, intercepting sediments from 54% of the basin area. The volume of water diverted has increased substantially since the early 1960s. The present regime of water regulation and diversion alters both the flow duration characteristics and volume of annual runoff in the river. Furthermore, between 1960s and 1990s, intense gravel mining was carried out in the main channel and in its main tributaries, leading to intense channel narrowing and vegetation encroachment (Comiti et al., 2007; Da Canal et al., 2007).

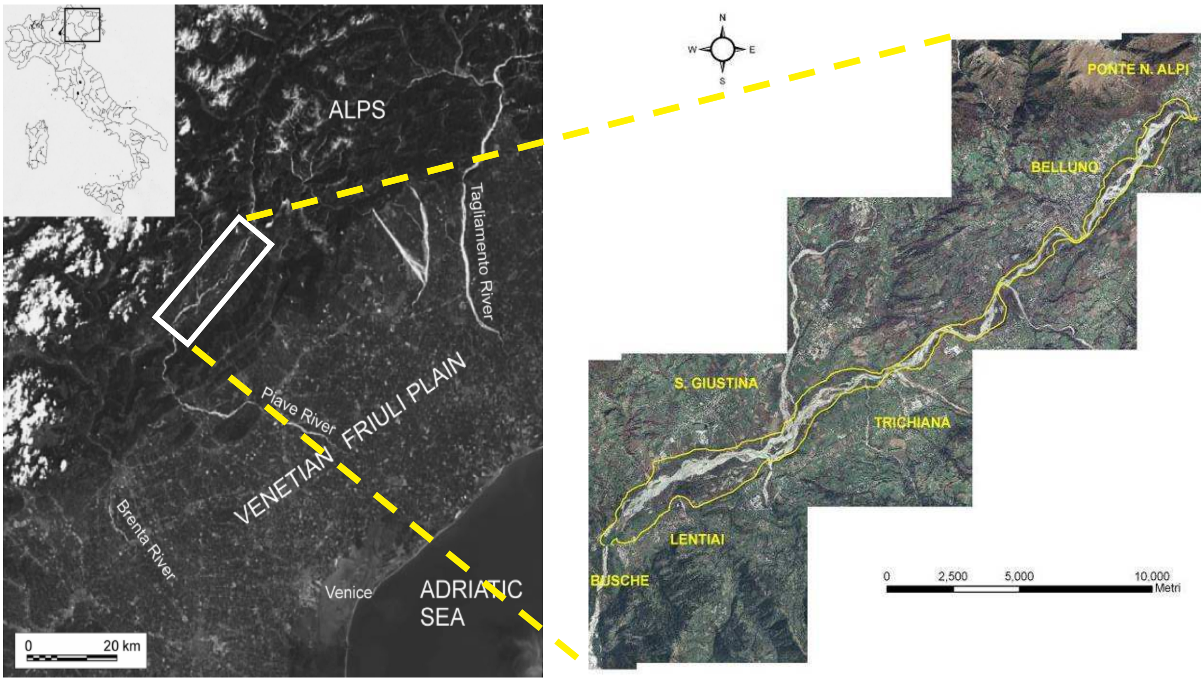


Figure 3 – Location of the study reach in the Piave river (from Surian 2006, modified)

3. ESTIMATION OF WOOD STORAGE BY AERIAL PHOTOS

3.1 Aerial photos

High-resolution (1:8,000 scale, 10 cm pixel, Fig. 4) aerial color photos were contracted to the "Compagnia Generale Ripreseaeree Spa" (http://www.blomasa.com/cgr/it) for the 30km-long study reach. This scale represents a trade-off between photo resolution and cost (i.e. number of frames). A larger scale (i.e., higher resolution) flight would have been desirable, but the large channel width (up to 1 km) forced to adopt a 1:8,000 scale in order to use a single strips of pictures to cover the entire channel width.

The original images were scanned at 1,800 dpi to attain the required resolution. A further limitation was image file size, which could not reach unmanageable dimensions, which in this case resulted around 815 Mbyte for each frame.

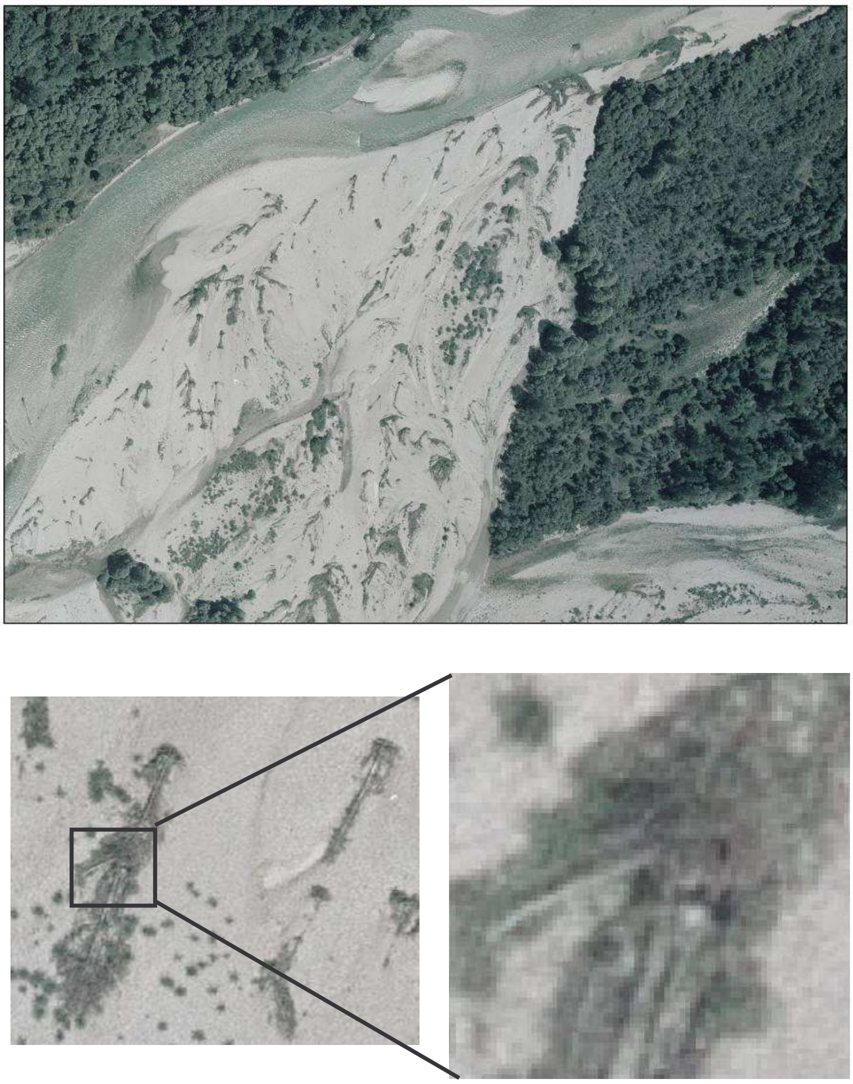


Figure 4 – The aerial photos used to estimate wood storage, viewed at different scales.

3.2 Methods

Seven subreaches were selected within the study reach (Fig. 5). They were identified based on channel uniformity and to represent the two dominant morphological patterns, i.e. braided and wandering (Tab. 1). The aerial photos covering these sections were rectified using ESRI ArcGIS 9.2© (Pecorari et al., 2007; Pecorari, 2008).

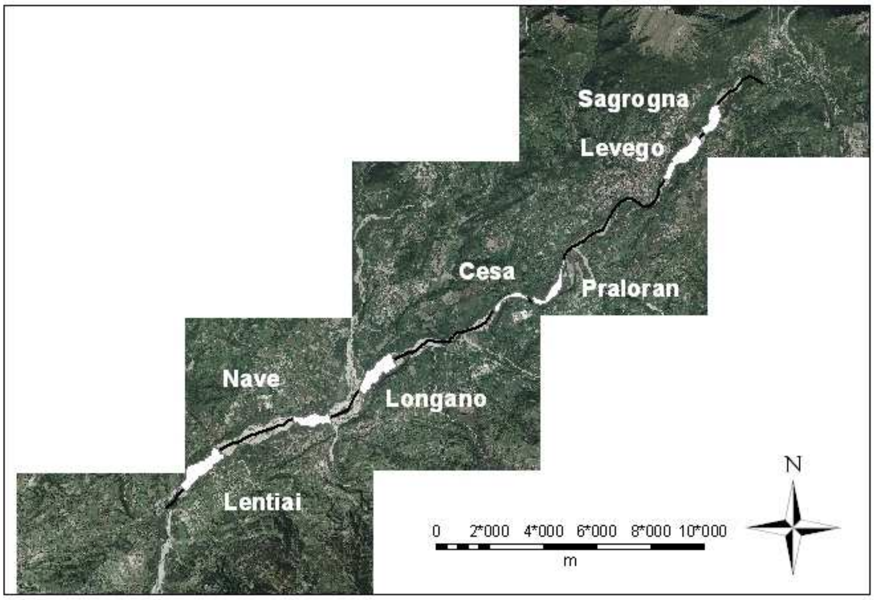
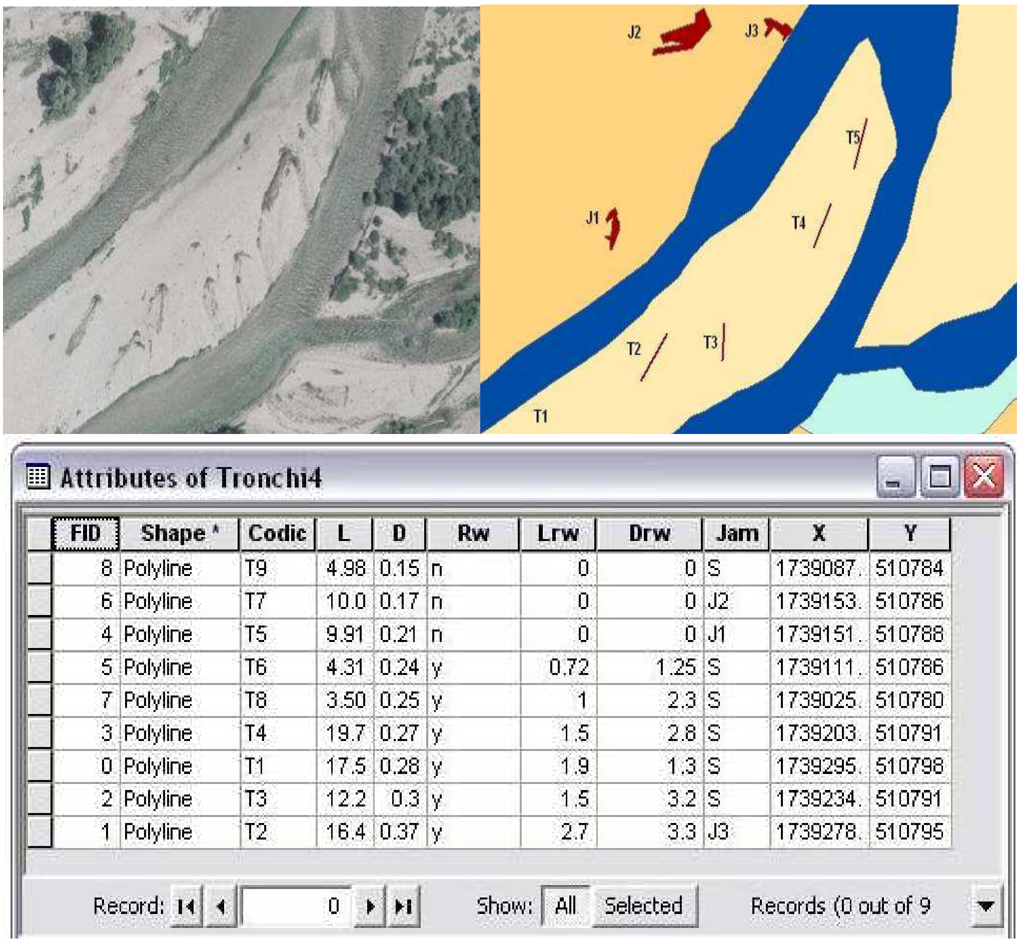


Figure 5 – Location and boundaries of the 7 subreaches.

Table 1 – Area and morphological pattern of the 7 subreaches.

Reach name	Area (ha)	Morphology
Sagrogna	45.89	Wandering
Levego	78.67	Braided
Praloran	46.65	Wandering
Cesa	23.17	Wandering
Longano	85.41	Braided
Nave	51.37	Braided
Lentiai	97.73	Braided

In each subreach, the different morphological units (high and low bars; pioneer and established islands; channels) were identified and mapped. Each wood element visible from the pictures and having diameter > 10 cm was digitalized as a polyline of its length (Fig. 6), thus creating a database containing an identification code, log length, log diameter (measured by the ArcGIS tape function), presence and dimensions of rootwads, status as single element or part of a jam, and in case the identification code of the jam, and finally NE coordinates. Jams were also mapped but in a different database



Attributes of Tronchi4

FID	Shape *	Codic	L	D	Rw	Lrw	Drw	Jam	X	Y
8	Polyline	T9	4.98	0.15	n	0	0	S	1739087.	510784
6	Polyline	T7	10.0	0.17	n	0	0	J2	1739153.	510786
4	Polyline	T5	9.91	0.21	n	0	0	J1	1739151.	510788
5	Polyline	T6	4.31	0.24	y	0.72	1.25	S	1739111.	510786
7	Polyline	T8	3.50	0.25	y	1	2.3	S	1739025.	510780
3	Polyline	T4	19.7	0.27	y	1.5	2.8	S	1739203.	510791
0	Polyline	T1	17.5	0.28	y	1.9	1.3	S	1739295.	510798
2	Polyline	T3	12.2	0.3	y	1.5	3.2	S	1739234.	510791
1	Polyline	T2	16.4	0.37	y	2.7	3.3	J3	1739278.	510795

Record: 0 Show: All Selected Records (0 out of 9

Figure 6 – Example of the georeferenced database created through ArcGis 9.2.

3.3 Errors

In order to estimate the accuracy of the photographic method, a field survey involving measurement of logs (n=66, length and diameter) in selected plots within 6 subreach was performed few days before the aerial photos were taken. Log positions were also taken by a GPS receiver, thus allowing to compare the same logs seen on the georeferenced photos (Pecorari et al., 2007; Pecorari, 2008).

Results (Fig. 7) show the relative error in diameter is very high (on average 52%) up to 15-20 cm, and diameters are consistently overestimated by the photo measurements. This is likely due to the blurred boundaries of small logs viewed against the background of gravel and sand on the streambed. However, for logs > 15 cm (n=38), the average error decreases to 28%, and for logs > 20 cm (n=27) to 15%.

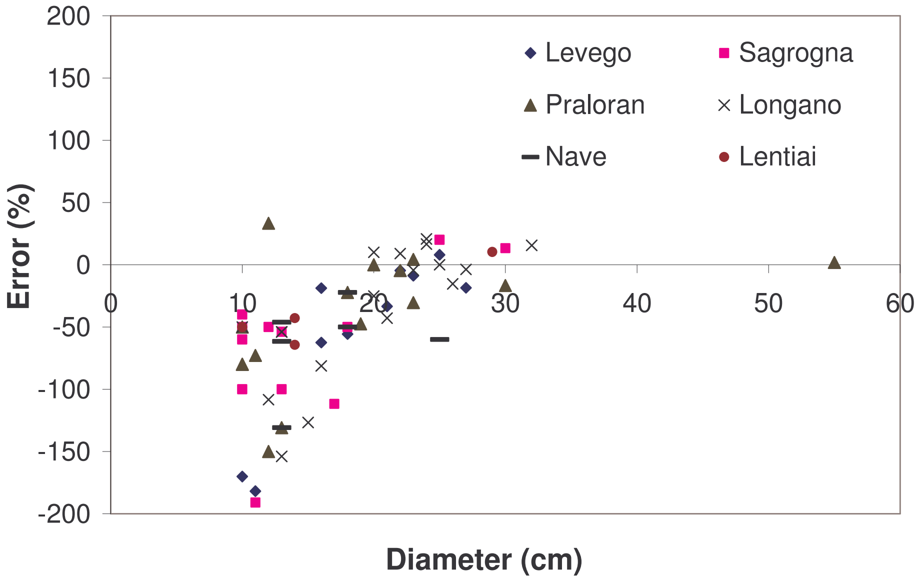


Fig. 7 – Differences in log diameter measured by field survey and by interpretation of aerial photos. Positive and negative errors represent under and over estimation from the photos, respectively.

As to log length (Fig. 8), the average relative error is 26% considering all the elements, with a predominant underestimation by aerial photos, and no clear effect of length on the error is visible. However, large errors are featured by some logs, possibly due to their distal, narrow end which can be misinterpreted from the pictures.

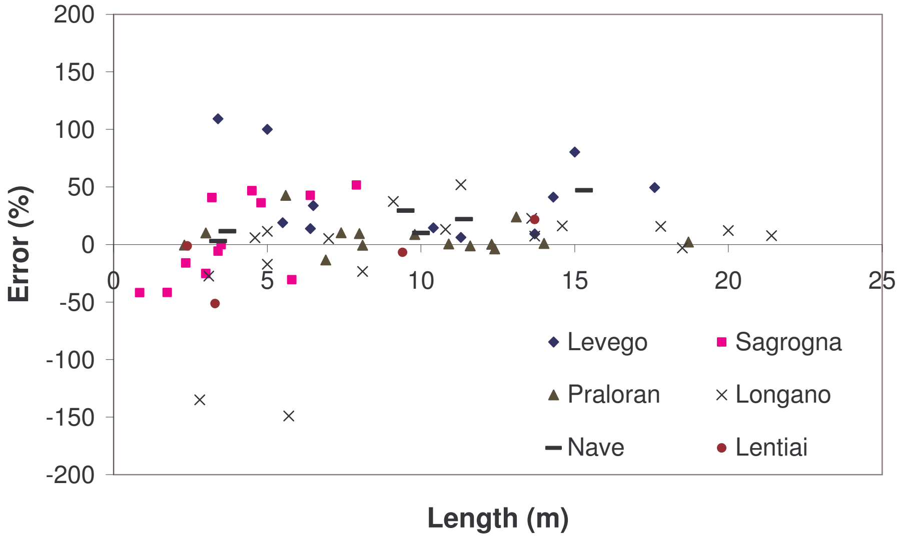


Fig. 8 – Differences in log length measured by field survey and by interpretation of aerial photos. Positive and negative errors represent under- ad overestimation from the photos, respectively.

With reference to jams (Fig. 9, n=59), the average error in evaluating their extension through aerial photos is 66%, but decreases to 48% for jams > 24 m^2 (n=52). In this case most of the errors arise from the shape of the jam area, which in the field is approximated to a rectangle, whereas photos allows to define it more precisely from a geometric perspective. However, vegetation (grass and shrubs) growing on jams makes hard to interpret the actual jam boundaries from aerial photos.

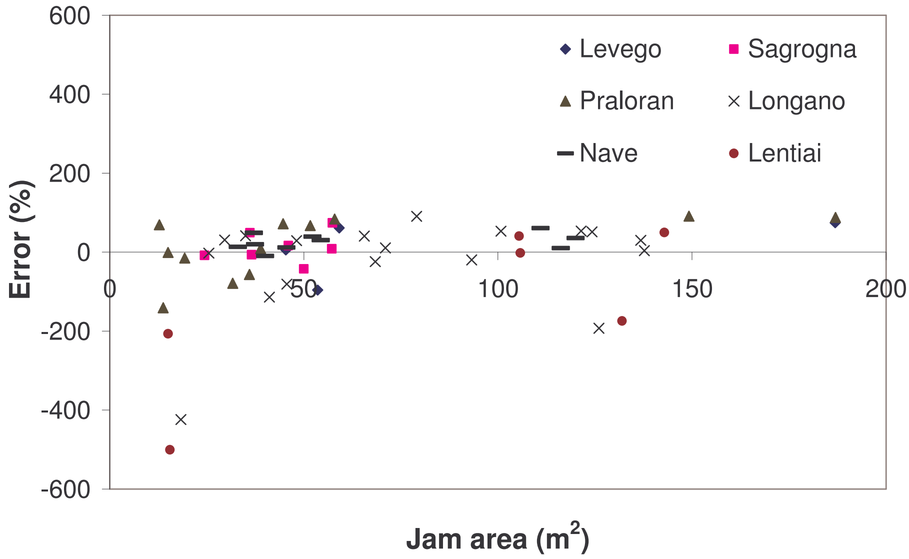
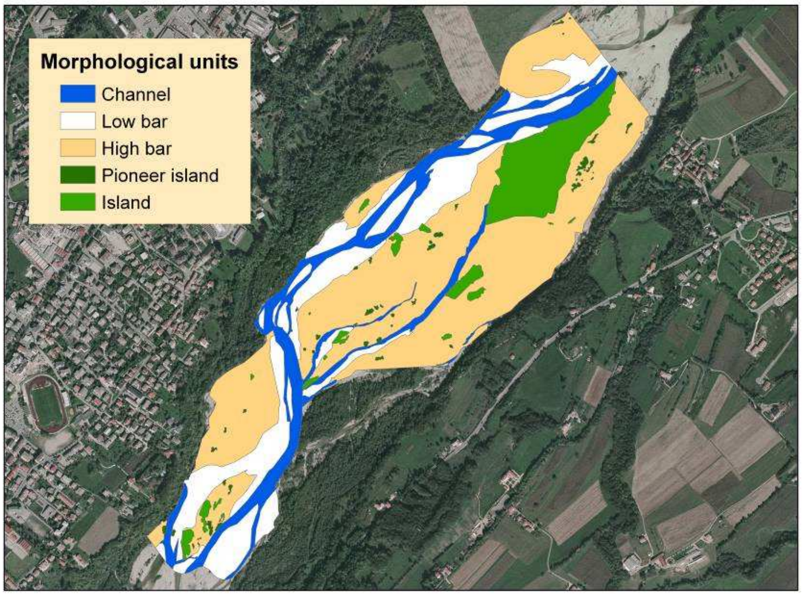


Fig. 9 – Differences in jam area measured by field survey and by interpretation of aerial photos. Positive and negative errors represent under- ad overestimation from the photos, respectively.

3.4 Wood storage maps

Figure 10 shows an example of wood distribution on different morphological units on a braided reach. Similar maps were created for all the 7 subreaches (Pecorari, 2008).



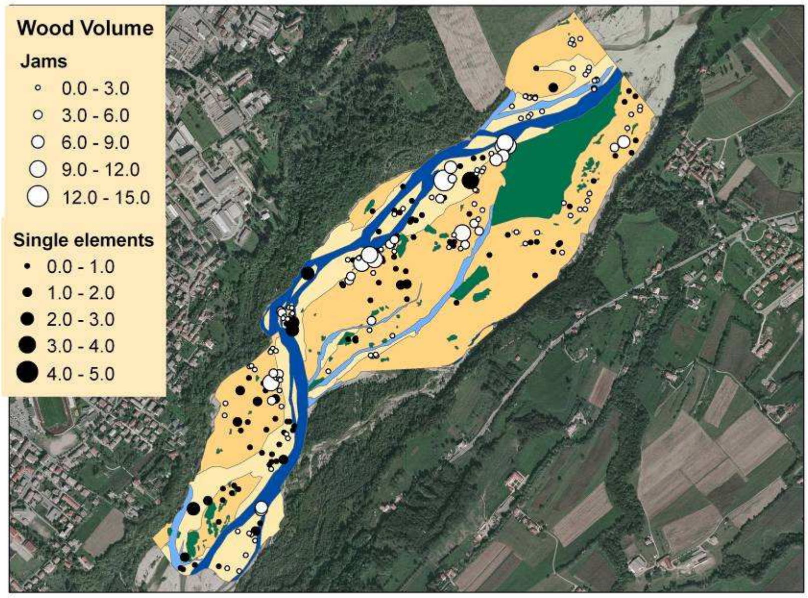


Fig. 10 – Photo interpretation of morphological units (above) and wood storage (below) for the Levego subreach. Circle size reflects jam and single wood volumes in m^3.

Single wood elements in the Piave present a mean diameter of 28 cm and a mean length of 7.5 m. Fig. 11 show the relative distribution of log diameter and length for all the subreaches analysed together.

The analysis based on aerial photos led to estimate the average – putting together the 7 subreaches – wood load in the range 3.7 – 9.1 m^3/ha, depending on how wood jam volume is computed. Such values are very similar to those reported for the Tagliamento river (drainage area 2,500 km^2; wood load 2-12 m^3/ha; Gurnell et al. 2000a) which lies very close to the Piave and features similar morphological patterns and riparian forests. On the other hand, such wood storage values are remarkably smaller when compared to two French rivers of comparable size, i.e. the Drôme (drainage area 1,620 km^2; wood load 16-64 m^3/ha; Piegay et al., 1999) and the Ain (drainage area 3,640 km^2; wood load 112 m^3/ha; Piegay and Marston, 1998).

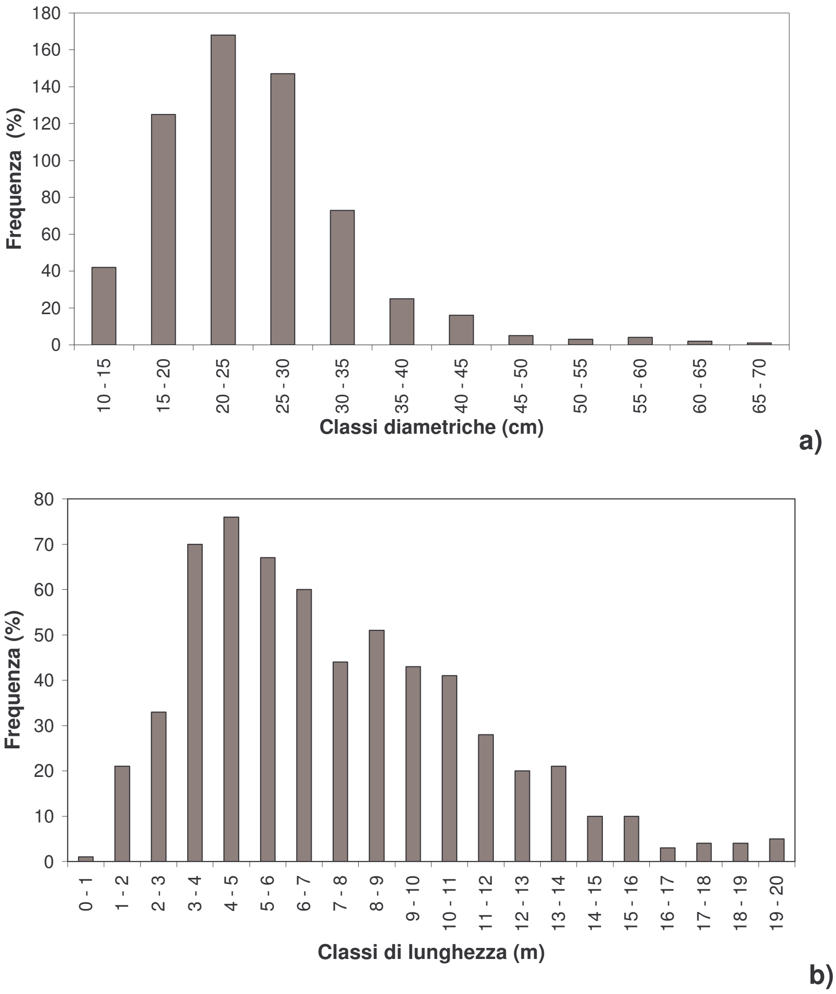


Fig. 11 – Log diameter (a) and length (b) distribution histograms derived from aerial photo measurements.

The information derived from maps for the seven subreaches allowed to infer how wood storage differ in magnitude among the subreaches examines (Fig. 12). Morphological pattern and channel width appear to be the dominant factors in controlling where wood tend to accumulate.

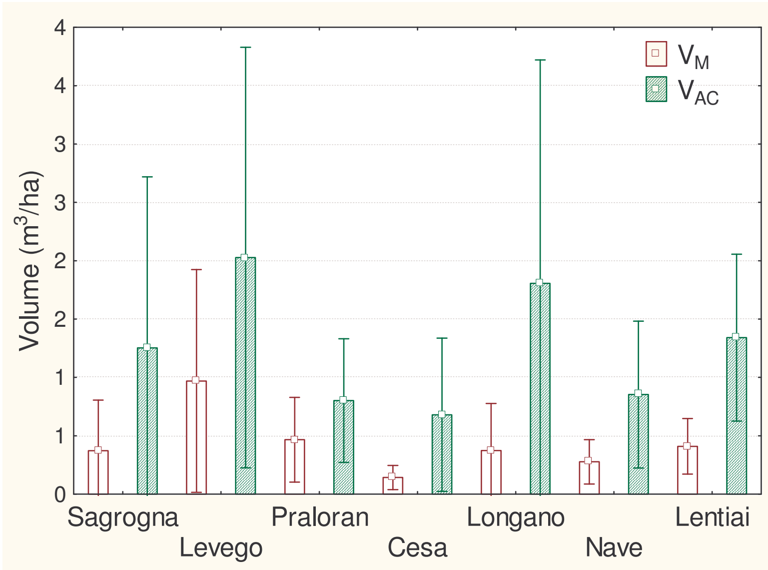


Fig. 12 – Wood load (in m^3ha^{-1}) for the 7 subreaches. V_M is calculated from single logs visible from the photos (lower estimate), and V_{AC} includes evaluation of jam volume (upper estimate). Whiskers represent the variability of wood load among distinct morphological units (bars, channels, islands) within each subreach.

Wood is more abundant in braided channel more than in wandering reaches. Wood is mostly located on bars (rather equally in high and low ones), but a considerable fraction of wood is associated to islands in the wider braided reaches. A strong negative correlation is present between single wood elements volume and relative area occupied by low flow channels, whereas wood jam volume is strongly correlated with the relative area of islands. Therefore, wood loading is higher in more complex river reaches as observed in the Tagliamento (Gurnell et al., 2000a, 2000b) and in the Quinalt river (Herrera Inc. 2005).

4. MONITORING OF WOOD MOBILITY

4.1 Equipment

A VHF system (purchased from Telonics Inc, US) for tracking wood elements was investigated in the Piave river (Pecorari, 2008). The system comprises (Fig. 12):

- 10 implantable transmitters with internal antennas. These are single frequency, microprocessor controlled pulsed transmitters, designed for operation in the 140 - 220 MHz frequency range, originally developed for animal tracking. The transmitters are 2.3 cm large and 7.4 cm long, and their weight is 38g. The operating temperatures ranges from -20° to 50° C. Transmitters can be programmed to cycle through up to eight sequential time periods or "duty cycles" in order to extend transmitter life. Within each duty cycle, the transmitter can either be "on" or "off". Pulse rates can be uniquely defined for each "on" duty cycle. Each duty cycle can be defined from eight seconds to approximately 50 months in length. Duty Cycle timing begins at the moment the magnet is removed to initialize the transmitter. Upon completion of the last programmed Duty Cycle Period, the transmitter begins again at the first duty cycle. The unit has a dual water barrier. This double barrier system makes the implant less subject to mechanical damage and reduces the chance for long moisture penetration over the life of the transmitter. In the present study, transmitters were programmed to work on frequencies in the range 148 - 148.5 Mhz, and to work at the low power mode to prolong the operational life (claimed by the manufacturer as 19 months for a pulse rate of 60 ms at 25°C). Once transmitters' batteries die, they could be replaced if sent to the manufacturing company, but it is dubious if this operation would be cheaper than purchasing new units. The cost of each transmitter with the Duty Cycle option is around 300$.

- 1 receiver with headphones. The receiver can be tuned for operation within any user-specified 4 MHz band between 142 and 220 MHz. The TR-4 is microprocessor-controlled, allowing up to 100 channels to be programmed within the specified 4 MHz band. The cost of the receiver is about 1000$.

- 1 directional handheld antenna. For a transmitter to be located it is necessary to utilize a directional antenna and to obtain a bearing to the transmitter based upon the direction of maximum signal strength. Using a directional antenna the researcher can either follow the bearing to the transmitter or obtain multiple bearings to the transmitter from several points and locate the transmitter by a triangulation of the bearings. This is a paddle (loop) antenna designed for "close in work" at short range (maximum distance <200-300 m). A coaxial cable connect the antenna to the receiver. The cost of the antenna plus cable is around 200$.

Therefore, the cost of the durable equipment (receiver and antenna) is relatively low (1,300$), whereas the consumable units are quite expensive (300$) taking into account their limited lifespan.

Figure 12 – The radiotrasmitters, receiver and antenna used in this research.

4.2 Methodology

The spatial scale of this wood transport study was set to be around <10-20 km, because larger scales (the Piave river then flows to the Adriatic Sea for ~100 km) would require different tracking methods (e.g., GPS transmitters). Such spatial scale fits the temporal scale fixed by the limited lifespan of the transmitters (<2-3 yr). Within this short period, the chance of having a high-magnitude flood is low and consequently large (>15 cm, with rootwads attached) wood elements are likely to feature shorter travel distances mostly associated to around-bankfull events.

In November 2005, the VHF transmitters were implanted in 10 logs resting on two opposite lateral gravel bars (3 on the left-side bar, 7 on the right-side) of the Piave river downstream of Belluno (Praloran subreach in Fig. 5). The river reach (250m wide) presents a wandering pattern (Figs. 13-14) derived from a former braided morphology, as typically encountered in human-impacted channels in the Alps. The site was selected for its easy accessibility even during high water stages and for the availability of several relatively large logs within a short distance but on different morphological units (higher bars with sand deposition, and lower bare gravel bars). The geographical position of the logs was determined by GPS, and two cross-sections were surveyed in order to measure the relative elevation of bar surfaces.

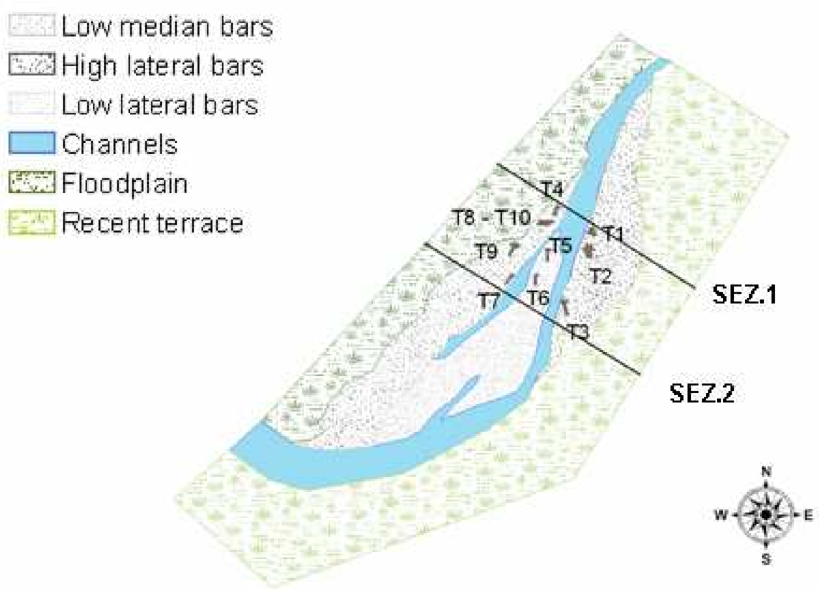


Figure 13 – Location of the 10 radiotrasmitters on the Piave streambed (Praloran subreach).

All logs derive from poplar (*Populus nigra*) trees most likely deposited during the November 2002 flood event (peak discharge of 1775 m^3s^{-1}, recurrence interval 10-15 yr based on a 1926-2007 flow series). Characteristics of the logs are reported in Tab. 2.

a)   b)

Figure 14 – Pictures of the study reach with two of the tagged wood elements.

Table 2 – Characteristics (length L, diameter D, absence/presence or rootwad RW) of the 10 logs tagged with radiotransmitters.

LOG	L (m)	D (m)	Side	RW
T1	10	0.30	left	yes
T2	11	0.40	left	yes
T3	10.7	0.36	left	yes
T4	9.35	0.42	right	yes
T5	17.6	0.24	high bar on right	yes
T6	13	0.15	high bar on right	yes
T7	14.45	0.18	right	yes
T8	9	0.12	right	yes
T9	4.9	0.24	right	Yes
T10	4.75	0.31	right	No

A hole of sufficient size was previously drilled at the base of logs, near the rootwad (Fig. 15). This location is both to have a sufficient diameter for the transmitter and to guarantee that in case of breakage the basal portion would be traceable. The smaller and more mobile distal portion would be more difficult to track using the present instrumentations. After a transmitter was inserted into the hole, silicon gel was used to close the opening and prevent possible slipping out of the unit. The correct functioning of the system was tested soon after the transmitters were sealed into the logs, also to practice with the use of the directional antenna.

Figure 15 – Installation of radiotransmitters into the selected logs.

4.3 Preliminary results

Unfortunately, the 2005 fall season was very dry and no significant events occurred, such that a only a peak discharge <200 m^3s^{-1} was measured at the Busche weir (Fig. 3). As a comparison, the 1.5-yr frequency peak discharge is estimated around 500 m^3s^{-1}. Also the 2006 spring snowmelt runoff did not reach a sufficient stage to mobilize the tagged logs. In September 2006, the largest event of the year (388 m^3s^{-1}) did not reach the logs, but the bar erosion taking place near the tagged log T3 (Fig. 16) caused its recruitment into the flow and its transport downstream.

The T3 log was tracked walking downstream along the river bed once the flood had receded, and the log was found deposited on a median bar within a braided reach, indicating a travel length of about 4 km (Fig. 17). Between the initial and the final locations, the rivers features the narrowest section of the valley (Cesa subreach, Fig. 5) where the wandering pattern almost becomes a single-thread with alternate bars. Therefore, depositional sites along this reach are less frequent than on the upstream and downstream reaches.

No more high flows occurred until November 2007, when a peak discharge of 401 m^3s^{-1} was measured at Busche. Interestingly, this even higher flow did not remobilize the log T3, which is now probably "anchored" to the bar by its rootwad. The other tagged logs were not mobilized either, because the water stage just reached the base of some logs on the right bar.

Figure 16 – The log T3 before (left) and after (right) the 2006 event.

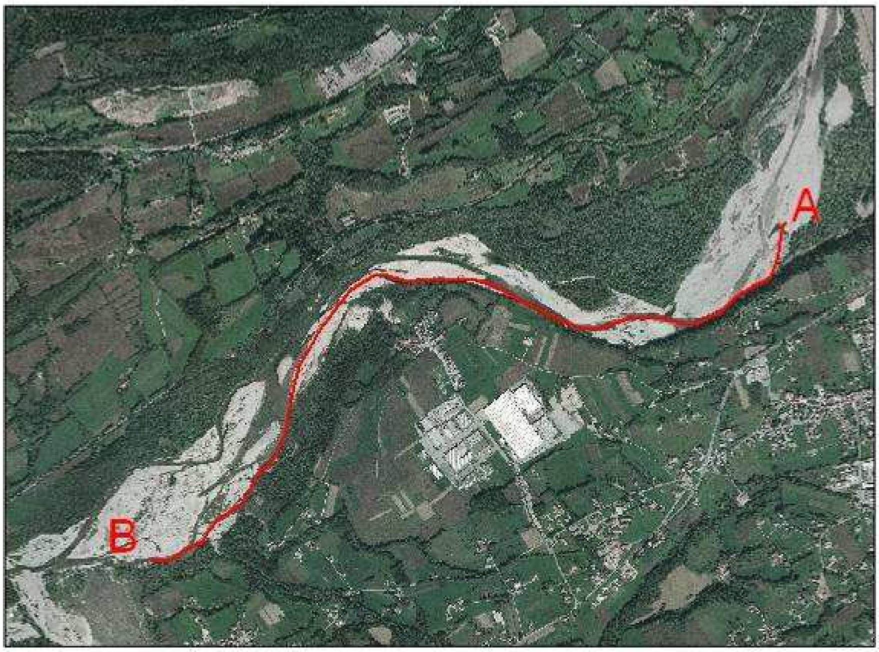


Figure 17 – The travel distance of log T3 during September 2006 event; A marks the initial location, B the depositional site.

It is noteworthy that the installed transmitters were still working by December 2007, i.e. 25 months after their installations, a period longer than expected despite the cold temperatures that occurred during the 2005-2006 winters (below -10° C).

5. CONCLUSIONS

Interpretation and analysis of aerial photographs using a GIS software is a suitable method to estimate wood load in large gravel bed rivers, where a complete field survey would be excessively time-consuming and expensive. Nonetheless, a calibration of the method through some sampling plots established in the field is advantageous to learn about measurement errors and about qualitative characteristics of wood elements (e.g., tree species, decay status).

Requisites for the application of the method are that i) photos must be taken during low flows, when most bars are exposed; ii) photos should be taken before or after the vegetative period to avoid disturbances from grass and shrubs growing on wood jams, as well as from tree leaves on islands; iii) channels must be wide enough to have negligible areas covered by vegetation on bank and islands; iv) required photo resolution is a function of log diameter distribution, but 10 cm is probably the minimum value acceptable for reasonable estimation.

Finally, log displacement following ordinary flood events in large rivers can be tracked by active radiotransmitters for research activities, even though their relatively high cost together with the limited battery life make the system not optimal for long-term monitoring programmes. However, there is a strong need for further research on wood transport both in the field and in the laboratory, in order to understand where drifted wood come from and how far it will go during both ordinary and infrequent flood events.

These results will be help set up future monitoring programmes for wood load in large gravel bed rivers of Latin America, thus adding to the methods already developed for smaller mountain streams within the framework of the EPIC FORCE project.

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