COST Action: ES1306

SHORT TERM SCIENTIFIC MISSION – FINAL REPORT

Assessing historical sediment connectivity in a mesoscale catchment by using multi-temporal aerial photographs

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1. RATIONALE

There are several papers in the literature dealing with the study of how historical land use changes effect on connectivity (e.g. López-Vicente et al. 2013; Lizaga et al. 2016). The adopted approach consists usually on appling the index of sediment connectivity (IC; Borselli et al 2008; Cavalli et al 2013) using a unique Digital Elevation Model (DEM, usually the most recent), and modified the weighting factor (W) parameter (related to the impedance to sediment fluxes and based on land use characteristic) according to vegetation pattern variations. However, the morphology related to the different land use (e.g. terraces) plays a relevant role in the assessment of the IC given its topography-based nature. Within this context, the objective of this STSM was to develop a workflow to extract historical IC maps from historical aerial photos taking into account the land use and the landscape properties at the period in which the IC is assessed. The specific objectives of the STSM were: O1. To extract historical ortophotomaps and point clouds from historical imagery (aerial photos); O2. To evaluate the opportunities that these products provide to assess historical connectivity indices (e.g. elaboration of land use maps and topographic models); O3. To develop and apply a workflow to assess historical connectivity in contrasted sub-catchments in the Upper River Cinca (Southern Pyrenees).

2. DESCRIPTION OF THE WORK CARRIED OUT DURING THE STSM

Based on the specific objectives listed above, the main work carried out during the STSM in Padova was divided in two phases: (PH1) Data preparation and (PH2) Methodological design and application. (PH2) is also composed by two main tasks: (PH2.1) Selection of scenarios of human impacts and (PH2.2) Assessing sediment connectivity under those scenarios. In the following sections we present all details of each of the phases.

2.1 Data preparation (PH1)

To study the effect of the land use and consequent changes on connectivity we analyzed three different periods (years): 1957, 1977 and 2012. For the years 1957 and 1977 (considered historical periods) we have applied Structure from Motion Photogrammetry (SfM) in the original black and white aerial photograms in order to obtain orthophotos and point clouds. Additionally, for the year 2012 (considered the contemporary), we have used the LiDAR dataset and complementary color aerial imagery (PNOA-LIDAR provided by National Geographic Spanish Institute). Figure 1 shows an example of these data sets for one of the study sub-catchments.

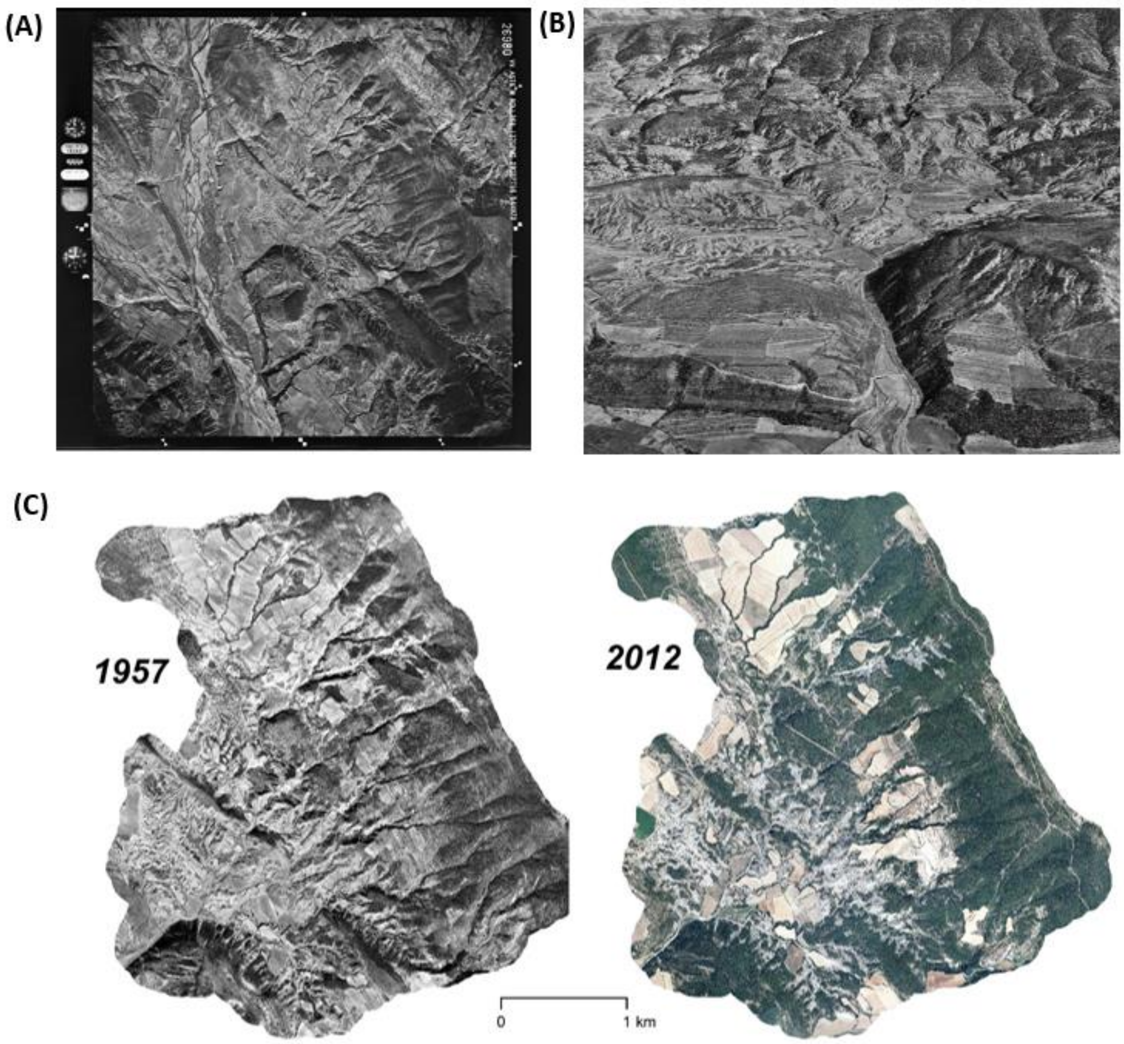

Figure 1. (A) An example of a historical aerial photograph (source: Cartographic and photographic center of the Spanish Army; CECAF). (B) Example of a photo-rendered point cloud. (C) Comparison between an historical black and white orthophotomap obtained by means of digital photogrammetry (left) and recent orthophotomap (in color, right).

Before using these inputs it is very important to analyze their quality since the accuracy of the results of IC are strongly controlled by the topographic base. In this way, to analyze the quality of the historical point clouds we selected one sub-catchment in which all the surface is constituted of bare rock. The topography between “modelled” (historical SfM point cloud) and “real” (contemporary LIDAR point cloud) was compared. The topographical changes between both must be 0 if the accuracy of the historic point cloud is perfect. For both historical periods we obtained errors in elevation around +/-2m, while the registration or georeferencing errors were around 0.5 m. Therefore, we concluded that the image quality of the original aerial photograms and the overlapping of the photograms determine the quality of the point cloud (e.g. presence of blurred area in the photograms cause a bumping surface in the point cloud). Despite this, we observed that increasing the density of the Ground Control Points (GCPs) increase the quality of the resultant point cloud and, consequently, our results indicated the importance of designing a homogenous distribution of GCPs with a distance less than 1 km. Additionally, we have also observed as a co-registration of the point clouds after the whole process may improve substantially the accuracy of the resultant historical point cloud.

Although the use of historical aerial photograms to obtain topographic data by the application of SfM is very limited by the quality and overlap of photograms as discussed above, its applicability is useful in areas that experienced significant topographic changes, both natural-based (e.g. landslides, debris flows) or anthropic induced (e.g. terraces, roads). Therefore, in order to decide on the suitability of the data sets, a first recommended step of the analysis is the evaluation of topographic data sets accuracy in relation to the magnitude of geomorphic changes. Hence we must take into account that the error of this topographic data determines the magnitude of change that is possible to analyze.

2.2 Methodological design and application (PH2)

2.2.1 Selection of scenarios of human impacts

In this section we selected three different scenarios of human impacts taking into account representative changes on land use in mountain catchments, in particular in the southern Pyrenees during the second half of XX century. These scenarios are: (i) Changes on land cover; (ii) Topographic changes on agricultural fields (i.e. terracing) and (iii) Topographic changes associated to infrastructures (i.e. road construction; Figure 2).

(i) Changes on land cover. Land cover changes were analyzed in two different sub-catchments during the three study periods (1957, 1977 and 2012). One sub-catchment (Chate) has suffered an important increase of the forested surface occupying former cultivate and bare soil areas; while the other sub-catchment (Soto) hasn’t experimented important changes in land use during the same period. The objective of this scenario is to analyze the effect of the land use changes on sediment connectivity.

(ii) Topographic changes on agricultural fields (i.e. terracing). The effect of the terraces on sediment connectivity was analyzed in a high terraced sub-catchment with an important increase of vegetated area due to the land crops abandonment during the period 1957 - 2012.

In this scenario the objective was to compare the effects of afforestation and terraces construction on sediment connectivity and evaluate which of them have a more decisive role (sensitivity of the changes to IC estimates). The effect of terraces has been performed with the analysis of IC in a catchment (Barranco de los Pocinos) with the presence (i.e. contemporary) and absence (i.e. terraces were filtered out removed from the original data set) of terraces with the same land use map (1957). Additionally, the effect of land use changes is assessed with a unique topography (i.e. contemporary) but with different land use maps (i.e. 1957 and 2012 respectively). This allow to study which of the impacts affects more on connectivity.

(iii) Topographic changes associated to infrastructures (i.e. road construction). Finally, the scenario of infrastructures is focused in a sub-catchment in which a road was built during the period 2006-2012. We compared the IC maps extracted from the contemporary DEM (i.e. 2012 LIDAR dataset) with the historical DEM (i.e. 1957 SfM dataset). In this case we could use historical data extracted from SfM because topographic changes were larger than 5 m, mainly associated with the construction of the road. Due to the errors associated with historical DEM we couldn't compare statistically both times but this exercise allows studying the impact of the road in the connectivity patterns, and identifying hot spots. Therefore, this type of analysis can be a useful tool to plan and asses potential risks associated to these infrastructures (see Figure 5.B.).

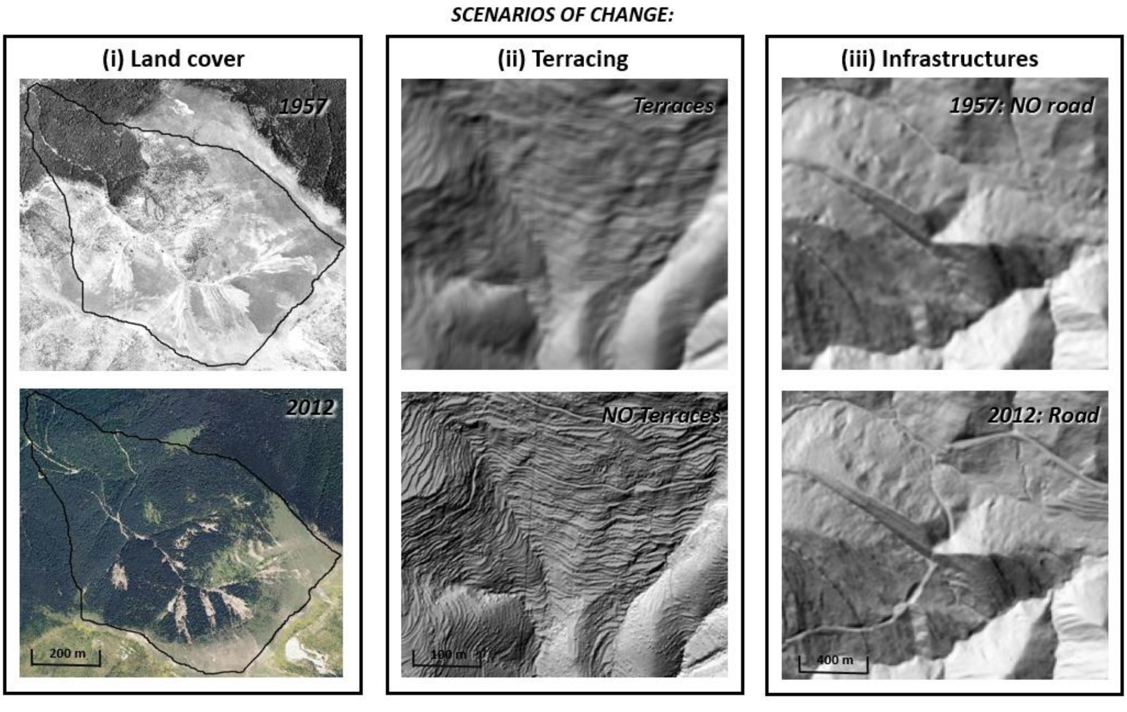

Figure 2. Representation of the three scenarios of human impacts in the study area. (i) Changes on land cover; (ii) Topographic changes on agricultural fields (i.e. terracing) and (iii) Topographic changes associated to infrastructures (i.e. road construction).

2.2.2 Assessing sediment connectivity under representative scenarios

The estimation of sediment connectivity for the different scenarios was made by the application of the Index of Connectivity (IC) developed by Cavalli et al (2013) which is based upon the original approach by Borselli et al (2008). The connectivity index (IC) is defined as the logarithm of the ratio between upslope (D_{up}) and downslope (D_{dn}) components. On one hand, the upslope component is the potential for downward routing of sediment produced upslope, and is estimated by the computation of a weighting factor (W; i.e. impedance to the flux), the slope (S) and the upslope contributing area (A). On the other hand, the downslope component is calculated by the length of the flow path (d) and also by the weighting factor and the slope of each cell of the drainage network. The changes made to the original index by Cavalli et al (2013) can be grouped in: (i) slope factor computation, (ii) contributing area calculation, and (iii) choice of the weighting factor W. Borselli et al. (2008) used the C-factor of USLE-RUSLE models as a weighting factor W. In studies like this, where the evaluation of the role of different vegetation cover and land use changes on sediment connectivity is one of the main objectives, an alternative approach to the C-factor was considered using a parameter related to hydraulic roughness. In this case an option is using the Manning's n roughness coefficient (n). Manning's n represents the resistance to flows in channels and flood plains, with values varying according to different surface characteristics and factors affecting roughness (see Goldin, 2015). In particular for this study (i) an image classification of all study time orthophotos was performed in order to obtain land use maps. (ii) We then applied a different Manning's n values to different land use classes taken in account the coefficient values described in Goldin (2015). It is important to highlight that the number of classes was determined by the characteristics (e.g. number of bands) and resolution of the images. In this case the historical aerial photograms only had one grey band (i.e. black and white) and for this reason we defined three different classes: forest, grassland and bare soil (with respective Manning's n values of 0.4, 0.1 and 0.05). Then, the weighting factor W is computed as $W = 1 - n$. The three land uses classes are representative of the land cover of the study sub-catchments.

Topography is the other factor that determinates the connectivity index parametrization due to on it depends the slope and drainage network characteristics (parameters taken into account both in the estimation of the upslope and downslope components). In this chase, we used different DEMs and in a specific way in each of the scenarios:

(A) In the first scenario, where the objective was analyze the effect of land cover, we used a DEM of 5 m of resolution extracted from a LIDAR airborne dataset with a density 0.5 pts/m corresponding to the year 2012. From the interpretation of the aerial photos we assume that the topographical changes during the study period (1957-2012) were minimum, therefore the IC was assessed just changing the W factor.

(B) In the second scenario we started from a DEM of 1 m of resolution also extracted from the 2010 LIDAR dataset. We use this DEM resolution since the main size of terraces in the study area is around 2 m, for this reason 1 m resolution is considered enough to represent the alteration of the terraces on the topography. First of all, in order to eliminate point cloud noise (i.e. artifacts, vegetation features,) a moving window filter was applied to original 1 m DEM. Then, to simulate the sub-catchment landscape without terraces we eliminate the micro-topography maintaining the macro-topography. To do that, we applied a DEM resampling from 1 m to 5 m and then resampling again to the original resolution of 1 m. Maintain the resolution of the DEM is very important because a coarse resolution implies a reduction in an IC value (Goldin, 2015).

(C) In the third scenario the contemporary topography (i.e. after road construction) was used a DEM with 10 m resolution extracted from the LIDAR 2012 dataset, while to represent the historical topography (i.e. before the construction of the road) we used a DEM with 10 m resolution extracted from a 1957 point cloud obtained by SfM applied to aerial historical photos. A 10 m resolution was selected to minimize the irregularities observed in the historical point cloud (e.g. bumping surface), acting in this way as a filter. At the same time, this resolution was enough to represent the topographical changes due to the road construction, which in some parts was greater than 30 m.

3. Summary of results

All the results obtained in this STSM will be used to prepare a poster presentation for the European Geosciences Union and will be published in a peer-reviewed international journal. In this section we only present a summary of the main outcomes of this STSM. These are presented in **Figures 3**, **4** and **5**. Each figure represents the results of each scenario analyzed.

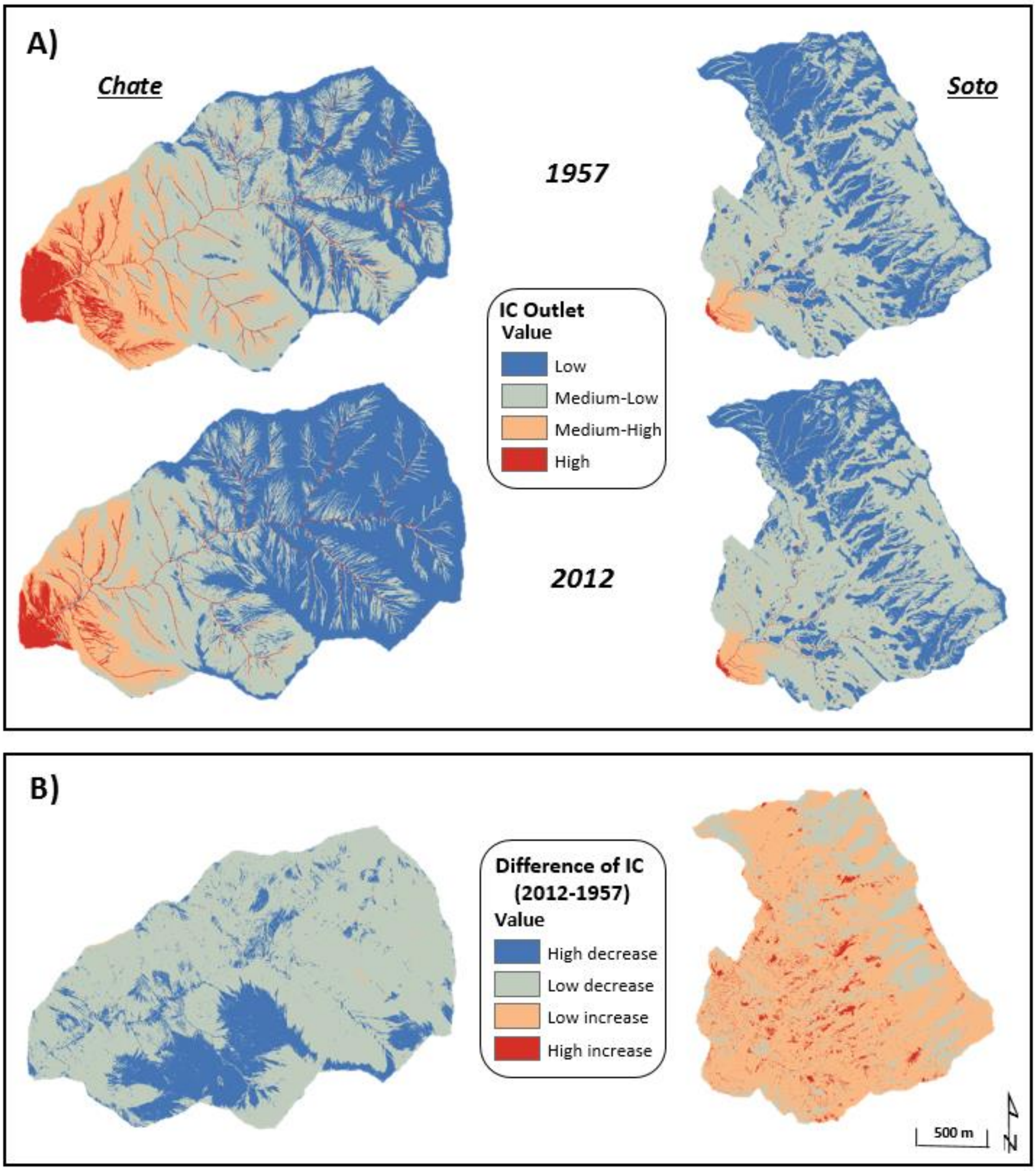

Figure 3. Effect of land cover changes on sediment connectivity (first scenario). A) Connectivity Index (IC) maps for the two study periods (1957 and 2012) for the two study sub-catchments: Chate (relevant changes on land use) and Soto (minimum changes). B) Maps of the difference of the ICs for both sub-catchments between the two study periods (2012-1957). In the case of the Chate catchment (left) an overall reduction of the connectivity index can be observed in the whole basin (light blue), observing high values of reduction in the areas in which there has been an increase in the forest cover (dark blue). In the case of the Soto basin (right) most of the surface suffers small variations in the value of the IC (light blue and orange), while there are small areas that experience a high increase of the IC, which is explained by the establishment of farmlands in previously forested areas.

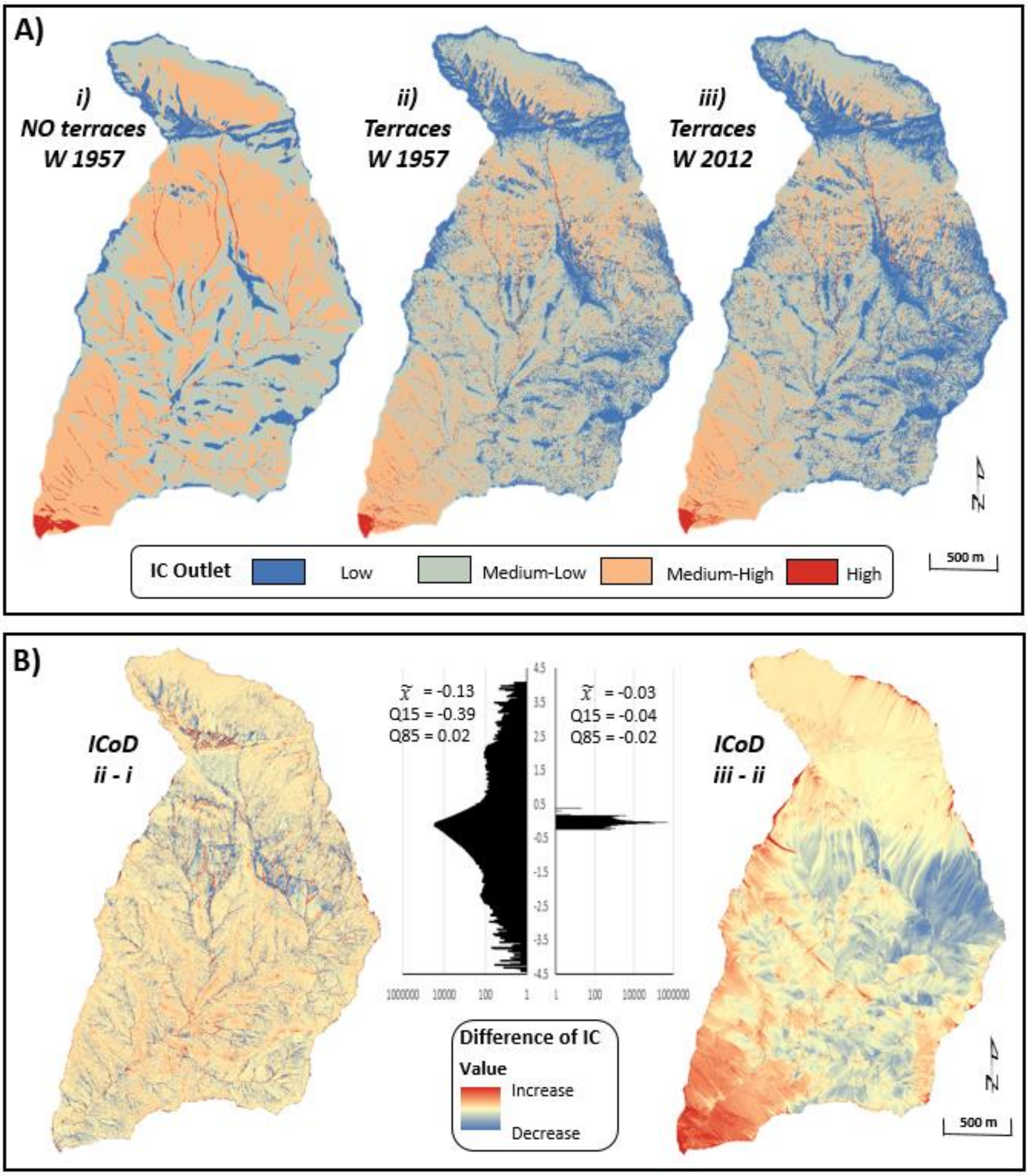

Figure 4. Effects on IC due to topographic changes on agricultural fields, mainly terracing, and effects of land use changes. A) IC maps for different catchment conditions: i) IC map assessed from the DEM without terraces and a weighting factor W extracted from the 1957 land use map; ii) IC map obtained from the DEM with terraces (2012) and a weighting factor W extracted from the 1957 land use map; and iii) IC map assessed from the DEM with terraces (2012) and a weighting factor W extracted from 2012 land use map. B) Connectivity indices of Differences (ICoD) maps comparing the effect of terracing on connectivity (i.e. terraces; left); and the effect of land use changes on connectivity (right) in a terraced landscape. The map on the left shows a very dendritic pattern; this can be related to the changes in the IC that are more concentrated in the space due to the disconnection caused by the terraces (i.e. decrease) and the variation on the drainage network. On the other hand, the map on the right has a patched pattern due to the changes in the land cover: in the medium part of the catchment there is a clear decrease of the IC due to the increase of forested cover meanwhile in the lower part it can be seen an increase due to the decrease of vegetated cover, also observed in a central firewall. The statists show as both, the topographic changes due to the terraces and the ones associated to land use changes contribute to a decrease of OC IC. Even so, it is clear as the topographic changes due terraces have a higher effect on the IC than the changes on land use.

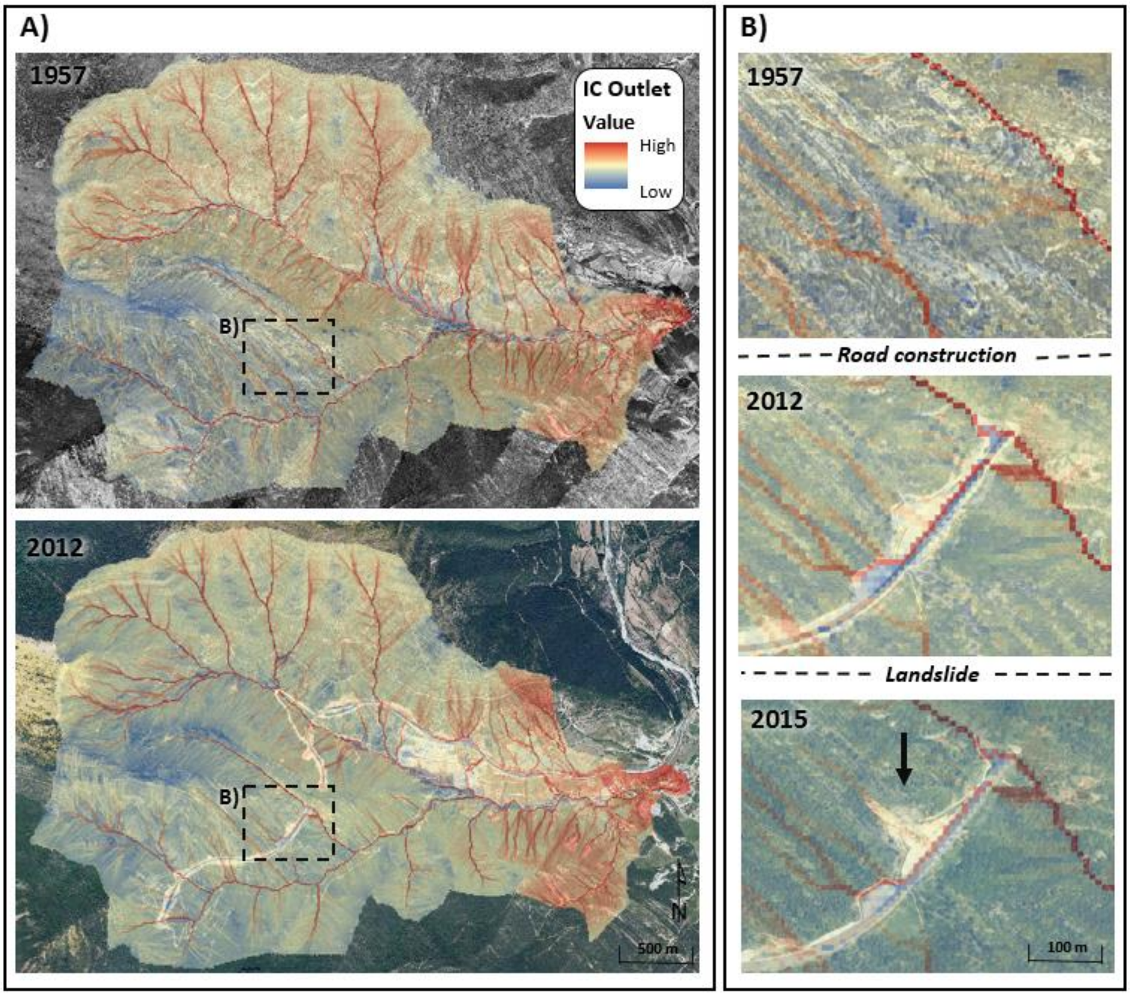

Figure 5. Topographic changes associated to infrastructures (i.e. road construction). A) IC map obtained by the DEM and land use map of 1957 (top; before road construction); and IC map assessed by the DEM and land use map of 2012 (bottom; after road construction). B) Zoom on a hot spot generated by the road construction. The road cut artificially the drainage network producing an increase of the potential connectivity upslope; the morphological variation due to road construction led to an increase of erosional activities uphill the road; this is also highlighted by IC map (functional connectivity). This is a good example of the use of IC as a useful tool to plan and assess potential risks associated to these infrastructures (e.g. identifying hots spots).

4. DESCRIPTION ABOUT HOW THE RESULTS CONTRIBUTE TO THE ACTION AIMS

This stay strengthen the links with Working Group 2 (Measurements) and Working Group 4 (Indices). In terms of WG2, different methods to characterize landscapes historically were critically analyzed and evaluated. Historical ortophotomaps and point clouds are relevant not just for the application of indices but also for a better understanding on how landscapes change. In relation to WG4, this STSM has provided a different way in how historical IC can be assessed and compared. Additionally, the PhD supervisor, Dr. Vericat, and the supervisor of the STSM, Dr. Cavalli, are interacting in the different WG2 & 4ThinkTank Meetings, the results can be used for future interactions and discussions with other Connecteur WGs (e.g., WG2 and 3). Finally, the preliminary results of this STSM will be presented as a poster in the EGU (see Llena et al, 2017) and, once finalized, will be published in a peer-reviewed publication in an international journal.

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5. REFERENCES

Borselli, L., Cassi, P., Torri, D. 2008. Prolegomena to sediment and fl ow connectivity in the landscape : A GIS and fi eld numerical assessment. , 75, pp.268–277.

Cavalli, M., Trevisani, S., Comiti, F., Marchi, L. 2013. Geomorphometric assessment of spatial sediment connectivity in small Alpine catchments. *Geomorphology*, 188, pp.31–41.

Goldin, B. 2015. *GEOMORPHOMETRIC ANALYSIS AND SEDIMENT DYNAMICS IN MOUNTAINOUS BASINS : SPATIAL AND TEMPORAL SCALES*. Università degli Studi di Padova.

Lizaga, I., Quijano, L., Palazón, L., Gaspar, L., Navas, A. 2016. ENHANCING CONNECTIVITY INDEX TO ASSESS THE EFFECTS OF LAND USE. *Land Degradation and Development*. (Accepted article).

López-Vicente, M., Poesen, J., Navas, A., Gaspar, L. 2013. Predicting runoff and sediment connectivity and soil erosion by water for different land use scenarios in the Spanish Pre-Pyrenees. *Catena*, 102, pp.62–73.

Llena, M.; Cavalli, M.; Vericat, D.; Smith, M. 2017. Assessing historical sediment connectivity in a mesoscale catchment using multi-temporal aerial photographs. Geophysical Research Abstracts Vol 19, EGU General Assembly. (Accepted).