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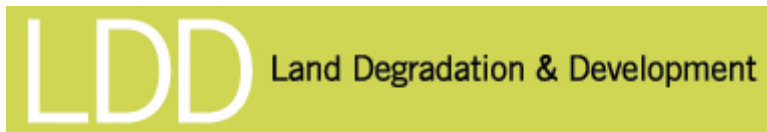


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**Interannual evolution of hydrosedimentary connectivity
induced by forest cover change in a snow-dominated
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3 **1 Interannual evolution of hydrosedimentary connectivity induced by forest cover**
4 **2 change in a snow-dominated mountainous catchment**

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11 6 Running title: Influence of forest cover change on hydrosedimentary connectivity

12
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15 8 **ABSTRACT (250 words)**

16
17 9 Hydrosedimentary connectivity is a key concept referring to the potential fluxes of water and sediment
18 moving throughout a catchment. In forested catchments, these fluxes are prone to be altered by
19 anthropogenic and natural disturbances. In this study, we modelled the interannual spatiotemporal
20 evolution of hydrosedimentary connectivity influenced by forest cover change over the last four decades in
21 the Mont-Louis catchment, a medium snow-dominated mountainous catchment in Eastern Canada, which
22 has seen 62% of its total surface affected by forest disturbances between 1979 and 2017. Using a
23 geomorphometric index of connectivity (IC) and a historical forest cover database, we produced one IC map
24 per year, considering anthropogenic and natural disturbances affecting the forest cover of the studied
25 catchment. To account for vegetation recovery, forest disturbances have been weighted with local
26 hydrological recovery rates. In four decades, the mean IC in the Mont-Louis catchment dramatically
27 increased by 35% in response to different types of disturbances. The spatial evolution of IC in the whole
28 catchment and at the sub-catchment scale revealed the strong influence of the location of the disturbances
29 on the hydrosedimentary connectivity to the main channel. The results also highlight the sharp contrast
30 between IC computed from topography-based impedance to those computed from vegetation-based
31 impedance. Forest disturbances appears to be prone to connect hillslopes with the hydrological network
32 by producing pathways for sediment and water. Finally, the proposed reproducible framework might be
33 useful to anticipate the potential impact of harvesting and prevent damages to fish habitat and sensitive
34 river reaches.
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46 27 Keywords: forest cover change, hydrosedimentary connectivity, forest management, river sensitivity,
47 28 index of connectivity

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1. Introduction

The concept of hydrosedimentary connectivity, widely used in geomorphology, refers to water and sediment fluxes occurring across the landscapes over a time period (Heckmann et al., 2018; Wohl, 2017). The consideration of hydrosedimentary connectivity in catchments goes back to the beginnings of the discipline (Gilbert & Dutton, 1880), because the degree of connectivity between the landscape compartments, such as hillslopes and river channels, might explain the trajectory of geomorphic forms and processes in both space and time.

Even though fluxes of matters have been first described and qualitatively assessed for decades, their (semi)-quantification only started in the beginning of the 21st century (Wohl et al., 2019). Among the tools and indexes aiming to address hydrosedimentary connectivity that have been developed (for a review, see Heckmann et al., 2018), the index of connectivity (IC) first proposed by Borselli et al. (2008) and then recently refined (Cavalli et al., 2013; Crema & Cavalli, 2018; Trevisani & Cavalli, 2016) resulted in a flourishing series of studies proving its efficiency to (semi)-quantify hydrosedimentary connectivity in various environmental contexts and purposes (Czuba & Foufoula-Georgiou, 2015; Grischott et al., 2017; Manuel López-Vicente & Ben-Salem, 2019; Nicoll & Brierley, 2017; Prosdocimi et al., 2017).

According to Cavalli et al. (2013), IC describes *“the degree of linkage that controls sediment fluxes throughout landscapes and in particular between sediment sources and downstream areas”*. It refers to structural connectivity, which address the potential of connectivity between system components. On the other hand, functional connectivity refers to the actual fluxes of water and sediments (Heckmann et al., 2018; Wainwright et al., 2011). The advantage of the IC is that it can be computed using only a digital elevation model (DEM). Thus, the inferred connectivity depends on (i) slope, (ii) distance from source to target and (iii) a weighting factor (W) called impedance, defined as the resistance to sediment flows and runoff. The impedance is controlled by different factors related to local characteristics of the catchment such as topography and land use. Using the appropriate W then represent the most challenging part of the IC computation (Borselli et al., 2008; Cavalli et al., 2013; Zanandrea et al., 2020).

Different ways have been proposed to address the impedance. Initially, W was derived from the USLE/RUSLE C-factor (Renard, 1997; Wischmeier & Smith, 1978) to represent soil cover and potential of erosion. In the standalone software SedInConnect 2.3 developed by Crema and Cavalli (2018), a straightforward way to assess W has been implemented. It is calculated by deriving a roughness index (RI) from the DEM, based on the residual topography that considers differences between smoothed and non-smoothed terrain at a few meters scale. Other approaches emphasize on the role that land use/vegetation cover may have on the impedance, by deriving W from Manning's n (Foerster et al., 2014; Goldin, 2015; Hooke & Sandercock, 2017; Llana et al., 2019; M. López-Vicente et al., 2013; Persichillo et al., 2018). It has

62 also been shown that the consideration of vegetation cover in the IC is especially important in forested
63 catchments, given that topography-based W alone is not prone to represent the strong impact of forest
64 cover in sediment and water retention (Zanandrea et al., 2020).

65 Hence the necessity to use the most appropriate W, in consideration to local characteristics of the studied
66 catchment when assessing IC, emerges as a key issue. For instance, while a topography-based W is likely to
67 better represent the impedance in Alpine bare slopes (Cavalli et al., 2013), a land cover-based W is more
68 adequate in vegetated catchments (Persichillo et al., 2018; Schopper et al., 2019; Zanandrea et al., 2020).

69 Moreover, when land use and/or vegetation cover are used to determine the impedance driving the IC, the
70 critical issue of the dynamic state of connectivity emerges. Indeed, it is widely recognized that connectivity
71 is prone to evolve over time, on account of topography (Calsamiglia et al., 2018; Llana et al., 2019) and
72 especially land use/vegetation cover variations (Brierley et al., 2006; Czuba & Foufoula-Georgiou, 2015;
73 Moreno-de-las-Heras et al., 2020; Wohl, 2017; Wohl et al., 2019), yet few studies have incorporated land
74 use changes in the IC computation to assess its impact on the evolution of hydrosedimentary connectivity
75 through time (Table 1). In order to evaluate the impact of land degradation on the evolution of
76 hydrosedimentary connectivity, these studies produced diachronic land use maps and derived them into
77 diachronic impedance maps, using either Manning's n, C-factor and satellite remote-sensed indices to
78 eventually implement them in the IC computation.

79 **Table 1: Recent studies assessing the evolution of hydrosedimentary connectivity induced by land**
80 **use/vegetation cover change, using IC (Cavalli et al., 2013).**

81 The production of diachronic land use maps usually relies on historical aerial photographs, generally
82 acquired once a decade during the 20th century, limiting the frequency at which hydrosedimentary
83 connectivity can be computed. To our knowledge, one date per ten year is the highest temporal resolution
84 of land use maps that have been used to assess the evolution of sediment connectivity in a single catchment
85 for periods of more than 50 years (López-Vicente et al., 2017). Thus, these studies result in semi-dynamic
86 connectivity, as they only consider a few land use maps over longer period to quantify the evolution of
87 connectivity. Therefore, semi-dynamic connectivity does not allow to encompass the fine spatiotemporal
88 trajectory of connectivity induced by the historical land degradation as hydrosedimentary connectivity may
89 be altered yearly at the scale of a watershed.

90 These considerations become even more relevant for forested catchments subject to frequent forest cover
91 change induced by anthropogenic and/or natural perturbations. In the southern part of the province of
92 Québec (Eastern Canada), most catchments have been affected by forestry for at least a century (Pinna et
93 al., 2009), and even more intensively in the last four decades (Boucher et al., 2009). With a dense
94 hydrological network, steep hillslopes and wide floodplains on the valley bottom, rivers of the Appalachian

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3 95 Mountains are prone to be geomorphologically impacted by the potential evolution of the
4 96 hydrosedimentary connectivity induced by historical forest cover changes.

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7 97 Taking advantage of a detailed historical forest cover database covering almost four decades produced by
8 98 the Minister of Forests, Wildlife and Parks (MFFP, 2018), this study aims to precisely quantify the
9 99 spatiotemporal evolution of hydrosedimentary connectivity induced by forest cover change in the Mont-
10 100 Louis catchment, a medium (~300 km²) snowmelt-dominated forested watershed located in the
11 101 northernmost part of the Appalachians mountains. The originality of this study lies in the fact that we
12 102 compute the yearly evolution of hydrosedimentary connectivity over the last four decades, from a set of 38
13 103 forest disturbance maps (FDM), rather than a quasi-dynamic connectivity from a few land use maps. First,
14 104 the FDMs are translated into 38 W rasters according to local hydrological recovery (HR) rates assessed by
15 105 Plamondon et al. (2004; 2002), which accounts for canopy height/density, basal area, disturbance type and
16 106 snowmelt rate, as vegetation regrows (Talbot et al., 2006; Zhang et al., 2012). Then, the yearly evolution of
17 107 hydrosedimentary connectivity in the Mont-Louis catchment is computed using the IC proposed by Cavalli
18 108 et al. (2013), in which W rasters are implemented as a dynamic impedance.

25
26 109 In this paper, we propose that historical forest cover change imply a (i) temporal evolution and (ii) spatial
27 110 variability of hydrosedimentary connectivity and present illustrations supporting these propositions. This
28 111 study also demonstrates that an accurate portrait of the spatiotemporal evolution of the IC can be easily
29 112 depicted at the catchment scale, and that our workflow can be used as an efficient tool to better understand
30 113 how forest cover change impacts hydrosedimentary connectivity, in space and time.

31 114 **2. Study area**

32 115 The Chic-Chocs range is located in the northeastern part of the Appalachians mountains, in the Gaspé
33 116 Peninsula, Quebec, Canada. The Appalachians were formed by three orogenesis, resulting in an extensively
34 117 deformed shale and limestone structure (Héту & Gray, 1980). The Mont-Louis watershed drains about 300
35 118 km² on the northern part of the mountain range, the catchment's headwater reaches over 900m in altitude
36 119 and the 45 km river flows north down to the Saint-Lawrence river (Figure 1). The upstream reaches of the
37 120 river are mostly confined within steep hillslopes, canyons and a bedrock bed (slope ~ 0,017). As the valley
38 121 widens and the slope decreases (0,0025), a wide floodplain (≈400 m) appears, alongside with Holocene
39 122 deposits in the valley bottom.

40 123 Since the first settlements in the XVIII^e century, the whole Gaspé Peninsula has been increasingly exploited
41 124 for its wood resources (Boucher et al., 2009). In the Mont-Louis catchment, the first major logging company,
42 125 the *Mont-Louis Seigniory* has been operating from 1924 to 1958 (Pelletier, 2014). Other companies have
43 126 been conducting logging activities in the catchment since then, but they only started in the mid 1990's
44 127 (MTES, 2020).

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3 128 A qualitative assessment of historical aerial photographs reveals that in 1963, most of the catchment was
4 129 covered with mature forest. Only a few minor cuts could be identified and vegetation cover data from 1979
5 130 (MFFP, 2018) shows that disturbances were still low. It thus indicates that between the *Mont-Louis*
6 131 *Seigniorie* operations and the most recent period of logging (mid 1990's), forest cover was mostly mature
7 132 throughout the catchment and that the intensified logging beginning in the 1990's massively degraded the
8 133 forest cover. Throughout the study period (1979-2017) more than 60% of the catchment's surface has been
9 134 affected by natural (wildfires, insects, diseases) or anthropogenic anthropic (logging, thinning, plantations)
10 135 disturbances.
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18 137 **Figure 1. Mont-Louis catchment location. a) Mont-Louis topographic map and sub-catchments. b) Gaspé**
19 138 **peninsula and Mont-Louis catchment location. c) Gaspé peninsula location in Canada.**

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140 3. Material and methods

141 3.1. Forest disturbance maps production

142 The forest cover changes in the Mont-Louis watershed have been characterized using a highly detailed
143 spatiotemporal database from the fifth Ecoforestry Inventory (EFI). It is carried out every 10 years to
144 produce a set of maps depicting an accurate portrait of the forest's state, all over the Southern part of
145 Quebec (MFFP, 2018). This inventory is updated yearly and describes the types of forest stands according
146 to their species, the density and the age and height of the stands. These data are produced by aerial
147 photographs interpretation with a spatial resolution of 30cm.

148 In addition to the stand's characteristics, both anthropogenic (logging/reforestation) and natural (wildfires,
149 insects, diseases) forest disturbances are annually mapped since the early 1970's. Wildfires are mapped
150 from satellite imagery, insects and diseases are mapped from a combination of satellite imagery, aerial
151 surveys along with aerials photographs and anthropogenic disturbances are mapped through the
152 collaboration of several stakeholders related to the agroforestry industry during field surveys. Because the
153 types of disturbances will be considered in the computation of the IC, it is worth noting that there are up
154 to 50 different harvest types and reforestation operations occurring in Quebec. These disturbances range
155 from clear-cutting and partial cuts to commercial thinning and plantations.

156 These spatial data are publicly available in GIS format since 2017. We merged them in a single shapefile of
157 overlaying polygons and clipped to Mont-Louis catchment boundaries. Each polygon represents a single
158 disturbance two attributes have been used in this study: year of occurrence (Figure 2a) and type of

159 disturbance. In Mont-Louis catchment, the first recorded disturbance occurred in 1979. In 2017, 63 % of
 160 the catchment area has been affected by disturbances.

161

162 **Figure 2: Processing of the spatiotemporal ecoforestry database. a) Example of the 2016 forest**
 163 **disturbance map (FDM) resulting in the b) 2016 impedance raster (W_{HR}), with a zoom-in illustrating c)**
 164 **the high spatial resolution of W_{HR} , which depends on the different types of disturbances (1-5), and d)**
 165 **the associated orthophoto (2016).**

166 Then for the study period (1979-2017), an annual time series of FDM (Figure 2a) is extracted from the raw
 167 shapefile. Each FDM corresponds to the cumulated disturbances that took place in the catchment from the
 168 first year (1979) to the considered year. When several disturbances occur at the same location, only the
 169 latest is considered.

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171 3.2. Yearly connectivity computation

172 3.2.1. Index of connectivity

173 The computation of hydrosedimentary connectivity maps is performed using the software SedInConnect
 174 2.3 (Crema & Cavalli, 2018), which computes the IC as defined by Cavalli et al. (2013):

$$175 \quad IC = \log_{10} \left(\frac{D_{up}}{D_{dn}} \right)$$

176 where D_{up} and D_{dn} are the upslope and the downslope component, respectively.

177 D_{up} corresponds to the potential for downward routing of the sediment produced upslope. It is expressed
 178 as follows:

$$179 \quad D_{up} = W S \sqrt{A}$$

180 where W corresponds to the impedance factor (i.e. the resistance to runoff and sediment flow;
 181 dimensionless), S is the slope (%) and A is the contributing area (m^2).

182 D_{dn} considers the flow path length that a particle must travel to reach the nearest sink or target. It is
 183 expressed as follows:

$$184 \quad D_{dn} = \sum_i \frac{d_i}{W_i S_i}$$

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3 185 where d_i is the length of the flow path along the i^{th} cell according to steepest downslope direction (m), W_i
4 186 and S_i are the impedance and the slope gradient of the i^{th} cell, respectively.

6
7 187 SedInConnect 2.3 require a DEM as a minimum input. We used a single 10 m DEM and selected the Mont-
8 188 Louis river main channel as the target (Figure 1). The DEM has been filled to remove local depressions and
9 189 to ensure continuity of the flow path lines. The computed IC then represent the connectivity to the main
10 190 channel. As for the impedance factor, the software proposes to compute it directly from the DEM
11 191 (topography-based) as a surface roughness index (W_{Ri}), following the approach of Cavalli et al. (2013). The
12 192 software also allows the user to define its own W raster.

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17 193 While the topography-based impedance factors generally lead to static connectivity, it has been shown that
18 194 connectivity can be highly dynamic over time, especially when considering land use/forest cover change
19 195 (Llena et al., 2019; Moreno-de-las-Heras et al., 2020; Ortíz-Rodríguez et al., 2019; Poepl et al., 2017). Thus,
20 196 to best evaluate the effect of forest cover change on connectivity, this study implement a highly dynamic
21 197 impedance factor in the IC computation, based on hydrological recovery rates.

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26 27 199 **3.2.2. Hydrological recovery as a dynamic impedance factor**

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29 200 In Québec (eastern Canada), as in western Canada and in the United States, eco-forestry data are used to
30 201 estimate the equivalent cut area (ECA) affecting watersheds, in order to achieve forests sustainable
31 202 management objectives (Ager & Clifton, 2005; B.C. Ministry of Forests, 2001; Langevin & Plamondon, 2004).
32 203 The ECA is an index that combines multiples types of forest disturbances and considers vegetation recovery.
33 204 To date, ECA is considered the best index to assess cumulative forest disturbance effects on hydrology (Ning
34 205 et al., 2017; Wei et al., 2016; Wei & Zhang, 2011; Winkler et al., 2017), especially in large watersheds. It has
35 206 been successfully used to demonstrate that cumulative forest disturbances can significantly increase the
36 207 annual runoff (Giles-Hansen et al., 2019; Li et al., 2017; Zhang et al., 2016, 2017). ECA is defined as the area
37 208 that has been anthropically or naturally disturbed (logging, wildfire, insect invasions), weighted by a local
38 209 factor called hydrological recovery (HR). The latter accounts for canopy height and density, basal area
39 210 (related to tree heights and/or disturbance date), snowmelt rate and depends also on the type of
40 211 disturbance. HR generally varies from 0%, basically representing a recent clear-cut, to 100%, representing
41 212 a hydrologically recovered forest stand or an unlogged mature forest (Winkler et al., 2017).

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45 213 Plamondon (2004) assessed the HR rates suitable to snow-dominated resinous Quebec forests, by deriving
46 214 HR rates from snow augmentation coefficient (SAC; equation 1), which is estimated using relationships
47 215 between forest stand characteristics and snowmelt rate, as vegetation regrowth (Hudson, 2000; Langevin
48 216 & Plamondon, 2004; Talbot et al., 2006; Talbot & Plamondon, 2002; Zhang et al., 2012).

217 $SAC = 100\% - HR$ (equation 1)

218 The SAC varies from 0% (when $HR=100\%$) to 100% (when $HR=0\%$).

219 **Figure 3: Temporal evolution of the impedance (W_{HR}) used in this study, depending on disturbance age,**
220 **category and tree height. Values of impedance are directly derived from the snow augmentation**
221 **coefficient rate (SAC) established by Langevin and Plamondon (2004).**

222 We argue that the use of the SACs established by Plamondon (2004) as the impedance factor in the
223 computation of the IC in a snow-dominated forested watershed is a relevant choice, for three reasons. First,
224 as recommended by Cavalli et al. (2013), the SAC (i) preserves the dimensionless aspect of the IC (Martini
225 et al., 2020) and (ii) displays a large distribution of its values from 0 to 1 (Figure 3). The importance of a
226 large distribution of W values, especially when studying the role of forest cover in the IC, has been recently
227 emphasized by Zanandrea et al. (2020).

228 Secondly, as the Mont-Louis watershed is almost exclusively covered by forest, the use of the SAC, which is
229 directly related to forest stand characteristics, might better represent the influence of the forest cover than
230 Mannings' n for instance, when addressing hydrosedimentary connectivity.

231 Last but not least, the SAC is highly dynamic as it evolves yearly with vegetation regrowth (Figure 3). Thus,
232 it better represents the temporal evolution of the impedance induced by the forest cover changes and
233 stands recovery. Furthermore, depending of the type of disturbance, different HR rates are used. Langevin
234 and Plamondon (2004) defined six categories of disturbances. For instance, forest stands affected by a
235 disturbance from the 5th category (e.g. commercial thinning) are considered to recover their initial
236 hydrological characteristics after seven years, while forest stands affected by disturbances from the 1st (e.g.
237 clear-cut) or the 6th category (e.g. insects disease) recover their initial hydrological characteristics after 35
238 years (Figure 3).

239 To implement SACs as the impedance factor in IC computation, an annual time series of 38 W rasters (Figure
240 2b) is derived from the FDM maps (Figure 2a). The 10 m pixels of the W rasters are affected with the SACs
241 values ranging from 0.001 to 1, according to Figure 3. Following Ortiz-Rodriguez et al. (2019) approach and
242 because W must be different from zero, pixels covering undisturbed areas are affected with a W value of
243 0.001 (Figure 2b-c). Maps of connectivity, hereafter called IC_{HR} , are computed annually from 1979 to 2017,
244 with the single 10 m DEM and the associated W rasters, hereafter called W_{HR} (HR referring to the
245 consideration of the hydrological recovery rates).

246 To evaluate the effects of dynamics W_{HR} on hydrosedimentary connectivity, we also computed ICs using a
247 uniform impedance (W_1 ; Zanandrea et al., 2020) and a topography-based impedance (W_{RI} ; Cavalli et al.,
248 2013).

249 Given the large dataset of time-series IC maps produced with our methodology, results are presented by
250 emphasizing on (i) the spatial effects of forest cover changes on IC, (ii) the temporal effects of forest cover
251 changes on the evolution of IC and (iii) the spatiotemporal patterns of IC emerging from forest cover
252 changes.

253

254 4. Results

255 4.1. Comparison of IC spatial distribution from topography-based (W_{RI}) and vegetation-based (W_{HR}) 256 impedances

257 The distributions of IC_{RI} and $IC_{HR}(2017)$ values and their spatial distribution are presented in figure 4 and 5a-
258 c, respectively. We use $IC_{HR}(2017)$ as a reference since it is the most recent computed IC_{HR} map. To evaluate
259 the effects of W_{RI} and $W_{HR}(2017)$, IC_1 - computed using a uniform impedance of 1 - is also shown. To highlight
260 the spatial effects of using different impedances on IC calculation, the maps and violin boxplots are color-
261 scaled using 8 quantiles (Calsamiglia et al., 2018; Crema & Cavalli, 2018; Llena et al., 2019).

262 The distributions of IC_1 and IC_{RI} values are identical (KS test statistic = 0.011; p-value < 2.2e-16), with
263 respective median values of -4.37 and -4.39 (Figure 4). This similarity is also reflected in the spatial
264 distributions of IC_1 and IC_{RI} (Figure 5a-b) that are both exposing relatively simple patterns of connectivity,
265 the most obvious one being dictated by the proximity of the channel. The IC_{HR} shows high values near the
266 channel and lower values further away. Second is a longitudinal decreasing trend, as the level of
267 connectivity appears to be much higher and homogenous in the upper part of the catchment and lower or
268 discontinued downstream. This result suggests that, even when using the roughness index as impedance
269 (W_{RI}), the IC remains mainly controlled by the slope and the distance to the target, i.e. the main channel.
270 Here, the high similarity between IC_1 and IC_{RI} also reveals the irrelevance of the RI in our study.

271 Using vegetation-based impedance ($W_{HR}(2017)$) significantly reduces the overall distribution of IC values
272 (median = -8.20), emphasizing the strong influence of the forest cover on water and sediment retention
273 (Figure 4). Moreover, the consideration of the forest cover seems to disconnect valley hillslopes from
274 channels but connect more remote areas (Figure 5c). As a result, the pattern of connectivity appear more
275 complex and heterogeneous for $IC_{HR}(2017)$ than those of IC_1 and IC_{RI} . Finally, the impact of vegetation on IC
276 is spatially variable (Figure 5d). The absolute difference between IC_{RI} and $IC_{HR}(2017)$ highlight that the most
277 impacted parts are in the middle-west of the catchment, while hydrosedimentary connectivity of the
278 downstream parts seem to be less affected by vegetation cover.

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3 280 **Figure 4: Violin boxplots of IC values over the Mont-Louis catchment, computed with three impedances**
4 281 **(W_1 , W_{RI} , $W_{HR}(2017)$).**

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9 283 **Figure 5: IC maps depending on the impedance. a) Uniform impedance (W_1). b) Topography-based**
10 284 **impedance (W_{RI}). c) Vegetation-based impedance ($W_{HR}(2017)$). d) Absolute difference between**
11 285 **$IC_{HR}(2017)$ and IC_{RI} .**

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14 286 The impact of vegetation on spatial patterns of connectivity can be highlighted at the sub-catchment scale.
15 287 Figure 6 focuses on three sub-catchments (14,15,16) and shows the decoupling/coupling effect of the
16 288 presence (absence) of vegetation on the hydrosedimentary connectivity. While the first series of maps (IC_{RI})
17 289 display patterns of connectivity mainly topography-controlled, the second series of maps ($IC_{HR}(2017)$)
18 290 display reversed patterns, with their upstream part coupled to the main channel and their downstream part
19 291 globally decoupled, due to the harvested areas upstream and mature forest downstream.

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27 293 **Figure 6: Comparison of IC in three sub-catchments (14,15,16) when computed with W_{RI} and $W_{HR}(2016)$.**
28 294 **The 2016 orthophoto reflects the importance of considering the presence (absence) of vegetation.**

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33 296 To explore further the role of the vegetation on IC through the Mont-Louis catchment, Figure 7 plots the
34 297 distributions of standardized IC_{RI} and $IC_{HR}(2017)$ for every sub-catchment. The use of a vegetation-based
35 298 impedance generates wider ranges of IC values for almost all sub-catchment as revealed by the mean IQR
36 299 values of $IC_{HR}(2017)$ (1.36) twice those of IC_{RI} (0.67). These wider ranges reflect the spatially variable impact
37 300 of forest cover consideration over each sub-catchment.

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41 301 For instance, every sub-catchment (except 2, 3 and 10) display a lower mode in $IC_{HR}(2017)$ distribution,
42 302 suggesting that a part of the catchment has seen its connectivity reduced by the consideration of the forest
43 303 cover (decoupling). By contrast, some catchments (e.g. 10-13 and 16) display a higher mode in $IC_{HR}(2017)$
44 304 distribution, suggesting that a part of the catchment has seen its connectivity increased by forest cover
45 305 degradation (coupling).

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49 306 **Figure 7: Distribution of standardized IC values depending on the impedance (W_{HR} and W_{RI}), extracted**
50 307 **from each sub-catchment.**

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312 **4.2. Interannual evolution of IC using a vegetation-based impedance (W_{HR})**

313 Figure 8 summarizes the interannual evolution of IC using the vegetation-based impedance from 1979 to
314 2017 in the Mont-Louis catchment. In Figure 8a, the IC_{HR} mean value is shown within the theoretical range
315 (max, min) of IC mean value that is being computed using uniform impedance of 1 (W_1) and 0.001 ($W_{0.001}$)
316 for max and min, respectively. The standard deviation evolution has been plotted on a distinct vertical scale
317 (Figure 8b) to better visualize the associated trend. Figure 8c displays the distribution of IC_{HR} values over
318 three distinct years, 1979, 1994 and 2012 (black highlighted points in Figure 8a-b), respectively. They are
319 representative of how the distribution of IC_{HR} values evolves in time. The entire time-series of IC_{HR} maps is
320 available online in Supporting Information (Figure S1).

321 Figure 8 suggests that IC_{HR} is highly dynamic in time, as displayed by the evolution of the mean, standard
322 deviation, and distribution of IC_{HR} . The mean IC_{HR} temporal evolution (Figure 8a) reveals that the
323 hydrosedimentary connectivity globally increases over the period. The minimum and maximum value
324 occurs in 1979 and 2012 with values of -10.22 and -8.13, respectively. This corresponds to a significant
325 increase of 35%, according to the theoretical maximum range. The IC_{HR} temporal trajectory can be divided
326 in three phases. First, from 1979 to 1993, the connectivity increases in three marked steps, in 1981, 1986
327 and 1989. Then, from 1989 to 1993, IC displays a slight decrease. The second phase of the trajectory
328 corresponds to a constant increase from 1994 to 2005 (except a discontinuity in 2000). Finally, connectivity
329 reaches a plateau where mean IC_{HR} is roughly constant from 2006 until 2015 where IC_{HR} starts to decrease.
330 As for the standard deviation of IC values over Mont-Louis catchment (Figure 8b), its trajectory displays a
331 decreasing trend from 1986 to 2017, after having drastically increased in 1981.

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333 **Figure 8: Temporal evolution of IC over Mont-Louis catchment, from 1979 to 2017. a) Mean value of**
334 **IC_{HR} . Black dashed lines corresponds to the theoretical maximum and minimum possible value of the**
335 **mean IC_{HR} . b) Standard deviation of IC_{HR} . c) IC_{HR} distributions for year 1979, 1994 and 2012.**

336 **4.3. Spatiotemporal trends**

337 Figure 9 maps the distribution moments of the IC_{HR} time series to expose elements of the spatiotemporal
338 variability of the hydrosedimentary connectivity. The maps allow to identify where within the watershed
339 the IC_{HR} has been on average high or low (Figure 9a-b), has been highly variable (Figure 9c) and has
340 presented punctual but significant spikes (Figure 9d) during the studied time period. For example, it can be

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3 341 seen that the IC_{HR} is in general higher along the Mont-Louis river in the middle part of the watershed (mean
4 342 and median values) and that the IC_{HR} values are relatively stable over time because of low standard
5 343 deviation values. The distribution moments, however, are not sufficient to get a clear picture of the
6 344 spatiotemporal trends and a better representation is needed.
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12 346 **Figure 9: Spatiotemporal trends over the time-series of IC_{HR} from 1979 to 2017. a) Mean IC_{HR} . b) Median**
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14 347 **IC_{HR} . c) IC_{HR} standard deviation. d) IC_{HR} skewness.**
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18 349 Figure 10 gives a detailed overview of the interannual evolution of the hydrosedimentary connectivity, at
19 350 the catchment scale. Mean IC_{HR} has been extracted per individualized sub-catchments (Figure 10a) and per
20 351 cumulated sub-catchments (Figure 10b). The latter corresponds to the whole drainage area of each sub-
21 352 catchment outlets. Thus, it refers to the longitudinal evolution of the mean IC_{HR} along the main channel.
22 353 These two visualization approaches are complementary, as they allow to observe the spatiotemporal
23 354 evolution of IC_{HR} at two different spatial scales, the sub-catchments themselves and along the main channel,
24 355 respectively.
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30 356 By emphasizing on individualized sub-catchments (Figure 10a), three major observations can be made
31 357 about Mont-Louis spatiotemporal evolution of hydrosedimentary connectivity. First, while all individualized
32 358 sub-catchments display an increasing trend of mean IC_{HR} , this increase occurs in contrasting ways. For
33 359 instance, some sub-catchments (3-6) experienced a rapid and stepped increases of mean IC_{HR} , while others
34 360 (2, 12-16) display a smaller yet continuous increase of the mean IC_{HR} . In the most recent period, some sub-
35 361 catchments (1, 7, 9, 10) even show a slight decrease as vegetation recovers. Second, a global temporal shift
36 362 in mean IC_{HR} occurs around 1990 where almost every sub-catchment sees its mean IC_{HR} exceeding -10. This
37 363 allows us to suggest two main temporal periods in hydrosedimentary evolution. Third, as mentioned (see
38 364 part IV.b), there is a general trend toward the augmentation in IC_{HR} since the mid 1990's. This is even more
39 365 obvious in sub-catchments 1 to 10, where not only are IC values at their highest but also where the increase
40 366 of IC has been sharp and sudden. The upstream and downstream parts of the catchment therefore
41 367 represent two distinct zones that will be discussed later.
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49 368 The evolution of IC_{HR} in cumulated sub-catchments (Figure 10b) makes it possible to visualize the
50 369 spatiotemporal evolution of mean IC_{HR} in Mont-Louis catchment in a different way, i.e. the longitudinal
51 370 evolution of IC_{HR} along the main channel. While this approach globally confirms the observations made from
52 371 Figure 10a (i.e. two main temporal periods and two distinct spatial zones), it also emphasizes the possible
53 372 role of the size of the sub-catchments on the longitudinal evolution of IC_{HR} along the main channel. Indeed,
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373 it appears clearly that the biggest sub-catchment (i.e. 12) causes a longitudinal discontinuity in mean IC_{HR}
374 along the main channel, by drastically decreasing IC_{HR} value, regardless of the year. This suggest that the
375 12th sub-catchment has a strong influence in the intensity of the average hydrosedimentary connectivity to
376 the main channel, most certainly due to its large size.

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378 **Figure 10: Spatiotemporal matrix of mean IC_{HR} computed per a) individualized and b) cumulated sub-**
379 **catchments.**

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381 5. Discussion

382 5.1. The role of the forest cover dynamics on the evolution of hydrosedimentary connectivity

383 Our comparison of the influence of topography based (W_{RI}) and vegetation based (W_{HR}) impedances on the
384 IC validate the premise regarding the lowering effect of forest cover on hydrosedimentary connectivity
385 (Zanandrea et al., 2020). While IC_{RI} and IC_1 have identical distributions (Figure 5), IC_{HR} shows lower values
386 and a greater range, confirming that forest cover globally decreases the level of connectivity throughout
387 the catchment. Moreover, the values of IC_{HR} are more spatially heterogeneous than those of IC_{RI} . This spatial
388 variability is likely due to forest disturbances occurring on various parts of the catchment, eventually
389 followed by vegetation recovery that dims the effects of the initial disturbances. If some parts of the
390 catchment tends to be coupled or decoupled to the main channel by forest disturbances or presence (Figure
391 5;6), some others are not as sensitive, which reveals that IC is not exclusively controlled by forest cover. For
392 instance, the upstream part of the catchment is highly connected to the main channel, whether the W_{RI} or
393 the W_{HR} is used as impedance, and vegetation seems to have very little impact on the level of connectivity
394 (Figure 5). This highlights that in this specific location, connectivity is likely topography controlled. On the
395 other hand, other areas such as the inset in Figure 5 display very low connectivity when using W_{RI} but a
396 higher connectivity when using W_{HR} . In these areas, slopes are more gentles and topography itself is
397 insufficient to dictate the level of connectivity, indicating that hydrosedimentary connectivity is likely
398 vegetation controlled.

399 Although it is widely known that connectivity is temporally dynamic (Czuba & Foufoula-Georgiou, 2015),
400 there is yet a lack of analysis at a temporal resolution allowing the emergence of fine spatiotemporal
401 trajectories. Most studies using the IC to address its temporal evolution are using either C-factor, Manning's
402 n or satellite remote-sensed indices as impedance in order to compute the IC (Table 1), resulting in a semi-
403 dynamic connectivity portrait, which can be an issue for two reasons. Either only a few dates have been
404 used to cover few decades (e.g. Lizaga et al., 2018; López-Vicente et al., 2017; Persichillo et al., 2018), giving

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3 405 an incomplete or flawed understanding of the way IC evolved through time, or multiples dates have been
4 406 used to compute IC over relatively short period of time (Foerster et al., 2014; Ortíz-Rodríguez et al., 2019),
5 407 providing a very limited scope and a lack of context to understand the global evolution of the connectivity
6 408 (Czuba & Foufoula-Georgiou, 2015). There is thus a real need of increasing the temporal resolution to allow
7 409 emergence of spatiotemporal trajectories (Nicoll & Brierley, 2017).
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11 410 In this study, we propose a method that address both these issues. Compared to previous studies (Table 1),
12 411 our framework increases the frequency at which IC is computed from decades to years, hence increasing
13 412 the temporal resolution and allowing to appreciate the whole trajectory of the hydrosedimentary
14 413 connectivity. In Mont-Louis Catchment, three phases have been identified. The first one occurs between
15 414 1979 and 1993, where IC increases in marked steps. These steps are controlled by the sudden occurrence
16 415 of three insect outbreaks affecting areas between 9 and 20 km², mostly close to the channel. The second
17 416 phase occurs between 1994 and 2005, where a gradual increase of IC occurs, due to a regular succession of
18 417 harvested areas of less than 10 km² and a greater spatial heterogeneity than the insect outbreaks. Finally,
19 418 the last phase (2006-2017) is characterized by a plateau and the initiation of a decreasing trend since 2015.
20 419 This is likely due to the combined effect of vegetation regrowth and stabilisation in the total harvested
21 420 surface.
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29 421 It is worth noting that while the use of few dates to address the hydrosedimentary connectivity would have
30 422 identified the global increasing trend of connectivity throughout the Mont-Louis catchment (black points;
31 423 Figure 8a), it would still lacks details on the way this process happened, as it does not account for the distinct
32 424 behavior of the three periods, and mostly, it doesn't grasp the decreasing trend that is most relevant to
33 425 fully understand what is currently happening in the watershed and the relevance of future projections. This
34 426 is specifically what makes the interannual hydrosedimentary connectivity index a potential tool to
35 427 understand how connectivity's dynamic impacts the river's dynamic and to make enlightened decisions
36 428 regarding land use and development.
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44 430 **5.2. Perspectives and limitations of interannual evolution of hydrosedimentary connectivity for** 45 431 **forest management** 46 47 48

49 433 In North America in terms of forest management, the commonly used index accounting for vegetation state
50 434 and recovery is the ECA (Winkler et al., 2017). Its main purpose is to assess the cumulated effects of past
51 435 and current forest disturbances on the water yield and quality. The percentage of ECA is often used as a
52 436 threshold in terms of harvested area in a catchment, generally to avoid fish habitats to be disturbed. For
53 437 instance, the MFFP (Quebec) limits the ECA at 50% for any Atlantic salmon river watershed (MFFP, 2018);
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3 438 Plamondon, 2004). In British Columbia, the threshold is set between 20 and 30% depending on the type of
4 439 watershed (B.C. Ministry of Forests, 2001; Winkler et al., 2017). However, one of the main limit of the ECA
5 440 is the lack of consideration of the disturbance positions (Pike et al., 2010; Wei & Zhang, 2011), as ECA index
6 441 does not account for the distance of the disturbance to the channel, neither for the slope.

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10 442 While using the same indicator of vegetation recovery (i.e. HR) as the ECA, the proposed methodology
11 443 integrates HR as the impedance in the computation of a highly used connectivity index (IC). It provides a
12 444 better picture of the catchment hydrosedimentary sensitivity as well as its evolution in retrospective time.
13 445 More interestingly, however, the methodology could allow to determine the extent to which prospective
14 446 forest harvest may increase the overall hydrosedimentary connectivity at the scale of the catchment but
15 447 also within sub-catchments by integrating the known location and dimension of prospective harvests in the
16 448 computation of IC maps. Furthermore, combined with specific information on the location of fish habitats,
17 449 and the characteristics of the main channel, the resulting maps may highlight river reaches that are more
18 450 likely to be affected by the change in IC resulting from forest disturbances. As a result, the integration of
19 451 the HR as the impedance in the IC computation might challenge the use of a fixed threshold of ECA in
20 452 forestry, by proposing a different picture of a catchment based on the IC. This might be implemented in
21 453 river sensitivity analysis to explain historical river adjustments and to expose potential river changes
22 454 (Lisenby et al., 2019).

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30 455 Sensitivity, as a geomorphic concept, refers to the adjustability of a landform or a process to environmental
31 456 disturbances (Fryirs, 2017). For river systems, more sensitive river reaches are those that are likely to adjust
32 457 to a local or regional perturbation whereas those that are less sensitive are those that are likely to keep
33 458 their characteristics over time. At the scale of a watershed, more sensitive and less sensitive river reaches
34 459 coexist so that heterogeneity in adjustment will occur across the river system. A challenge is to provide
35 460 tools and framework to support river sensitivity analysis at the scale of a watershed (Lisenby et al., 2019).
36 461 It has been recognized that sediment connectivity along a river network control the location, number, form
37 462 and severity of river channel changes to regional perturbation (Czuba & Foufoula-Georgiou, 2015; Lisenby
38 463 et al., 2019). The workflow proposed in this study, generates interannual hydrosedimentary connectivity
39 464 indices leading to maps and representation tools that allow to locate river reaches likely to sustain
40 465 morphological adjustments due to significant longitudinal or temporal change in hydrosedimentary
41 466 connectivity. Combining this information with geomorphological trajectories of river reaches will then allow
42 467 to determine the sensitivity of the reaches to upstream changes in hydrosedimentary connectivity related
43 468 to forest harvesting or degradation.

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52 469 Figure 11 summarizes the complete workflow we used to assess the inter-annual evolution of
53 470 hydrosedimentary connectivity using FDMs. The simplicity of the workflow reflects the relative ease to
54 471 produce multi-temporal IC maps, using data that is generally available all around the world. This may

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3 472 encourage researchers and forest managers to apply it in their areas of study. It requires multi-temporal
4 473 FDMs, ideally from a historical forestry database, tabulated impedance suited to the study area, and a DEM.
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6 474 Thus, our framework would be (i) easily transferrable to any forested watershed covered by detailed spatial
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8 475 historical records on disturbance types (e.g. BC, Alberta and US) and (ii) most likely transferrable to forested
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10 476 watershed non covered by detailed spatial historical records, with an adapted indicator of historical forest
11 477 change, NDVI for instance (Aires et al., 2020; Martini et al., 2020; Ning et al., 2017), which might be
12 478 converted into tabulated impedance.

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17 480 **Figure 11: Synthetic workflow used to assess the interannual evolution of IC using FDMs, tabulated**
18 481 **impedances and a DEM.**

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23 483 Finally, some considerations of the proposed framework must be discussed. First, there is a need to consider
24 484 the temporal window that is used when computing the HR values for the first few years of the time series.
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26 485 In our case, the first recorded forest disturbance in the Mont-Louis watershed was in 1979. Although forest
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28 486 history of that area suggests no disturbance occurred prior to that date, it could be the case that a significant
29 487 disturbance in 1970, for example, was not officially recorded. As a result, the computation of the HR for
30 488 that area could be underestimated at the beginning of the time series as would be the computed
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32 489 hydrosedimentary connectivity. Secondly, although the IC is a straightforward indicator for hydrological
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34 490 connectivity, it remains a potential connectivity as far as sediments are concerned. To fully address
35 491 sediment mobility, there is a need to use both IC and geomorphic analysis to define actual sensitivity of
36 492 river reaches. Integrating geomorphic features, such as lakes and alluvial fans, as well as quaternary
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38 493 deposits within the watershed into the analysis constitute a promising avenue to improve our
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40 494 understanding of sediment availability and mobility that could lead to sensitivity of river reaches (Nicoll &
41 495 Brierley, 2017).

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45 497 **6. Conclusions**

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48 498 The choice and effectiveness of the impedance is one of the most challenging aspect of the IC computation
49 499 and vegetation has long been recognized to influence hydrosedimentary connectivity, in space and time.
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51 500 Yet, very little work has been done to integrate vegetation dynamic in such a model, even though it is
52 501 considered crucial to improve river management.

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55 502 In this study, a detailed historical forest cover database was used to implement a highly dynamic impedance
56 503 in the computation of the IC. It appears that the integration of local HR as an evolutive impedance is an

504 efficient way to model the interannual evolution of the hydrosedimentary connectivity in a forested
505 catchment.

506 On top of validating the fact that RI is not suited to model the impedance in a vegetated catchment, our
507 study provides new inputs in the comprehension of the effects of forest cover change on IC dynamic at a
508 high spatiotemporal resolution.

509 First, the use of vegetation-based impedance reveals that the hydrosedimentary connectivity in a
510 catchment can be very sensitive to the location of the forest disturbances. The presence (absence) of
511 vegetation can induce dramatic decoupling/coupling effects on hillslopes, potentially enhanced by
512 topography. Such effects drastically complexifies the IC patterns at multiple scales within the catchment.

513 Second, the use of interannual forest cover data allows to define the complete trajectory of the
514 hydrosedimentary connectivity over decades, which is a major step in the establishment of an accurate
515 portrait of the spatiotemporal evolution of the IC at a catchment scale.

516 We argue that the combination of high spatial and high temporal resolution of IC (Figure 10) could help
517 forest managers to plan appropriate decisions by considering hydrosedimentary sensitivity when
518 anticipating harvests. In that regard, the proposed workflow might be used as a tool. However, further
519 research may also consider the availability of sediments and geomorphic sinks in the catchment to establish
520 the actual hydrosedimentary fluxes. Such knowledge could eventually lead to river sensitivity analysis at a
521 high spatiotemporal resolution.

522

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526 **Conflict of interest statement:** The authors declare no conflict of interest.

527 **Data availability statement:** The data used in this study are publicly available.

528 Quebec ecoforestry inventory: <https://mffp.gouv.qc.ca/le-ministere/acces-aux-donnees-gratuites/>

529 SedInConnect 2.3: https://github.com/HydrogeomorphologyTools/SedInConnect_2.3

530 The codes (R scripts) used to process the ecoforestry inventory into impedance rasters are available from
531 the corresponding author upon request.

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Table 1: Recent studies assessing the evolution of hydrosedimentary connectivity induced by land use/vegetation cover change, using IC (Cavalli et al., 2013).

Year	Author	Environmental context	Change type	Impedance method	Period (yr)	Temporality	Key findings
2014	Foerster et al.	Mediterranean mountainous (Spain)	Seasonal vegetation change	C-factor (continuous)	<1	2 dates	Connectivity depends on the spatial distribution of vegetation
2017	Lopez-Vicente et al.	Mediterranean mountainous (Spain)	Cultures turned to forest	C-factor (14 classes)	67	6 dates	-Changes in connectivity mainly depends on the changes in vegetation -Afforestation promotes lower and more stable connectivity
2018	Persichillio et al.	Mediterranean semi-mountainous (Italy)	Agricultural practices	Derived Manning's n (7 classes)	58	5 dates	Vegetation dynamics influences connectivity in a non-linear way
2018	Martinez-Murillo et al.	Mediterranean mountainous (Spain)	Wildfires, salvage logging	C-factor, Normalized Burn Ratio and vegetation recovery	4	6 dates Pre/post fire	-Wildfires increases connectivity -Connectivity decreases with vegetation recovery
2018	Lizaga et al.	Mediterranean semi-mountainous (Spain)	Natural afforestation	C-factor (5 classes), total aerial biomass and roughness	53	2 dates	Agricultural lands abandonment decreases connectivity
2019	Ortiz-Rodriguez et al.	Semi-arid mountainous (Mexico)	Wildfires	Land use mapping (6 classes) and fire severity based on NDVI (3 levels)	<1	2 dates Pre/post fire	Wildfires significantly increases connectivity
2019	Llena et al.	Mediterranean mountainous (Spain)	Natural afforestation	Derived Manning's n (3 classes)	53	2 dates	Land cover changes directly affects impedance to water and sediment connectivity
2020	this study	Snow-dominated mountainous (Canada)	Anthropic and natural forest disturbances	Derived hydrological recovery rates (21 classes)	38	38 dates	Connectivity dynamic strongly depends on forest disturbances location Connectivity is highly variable in time

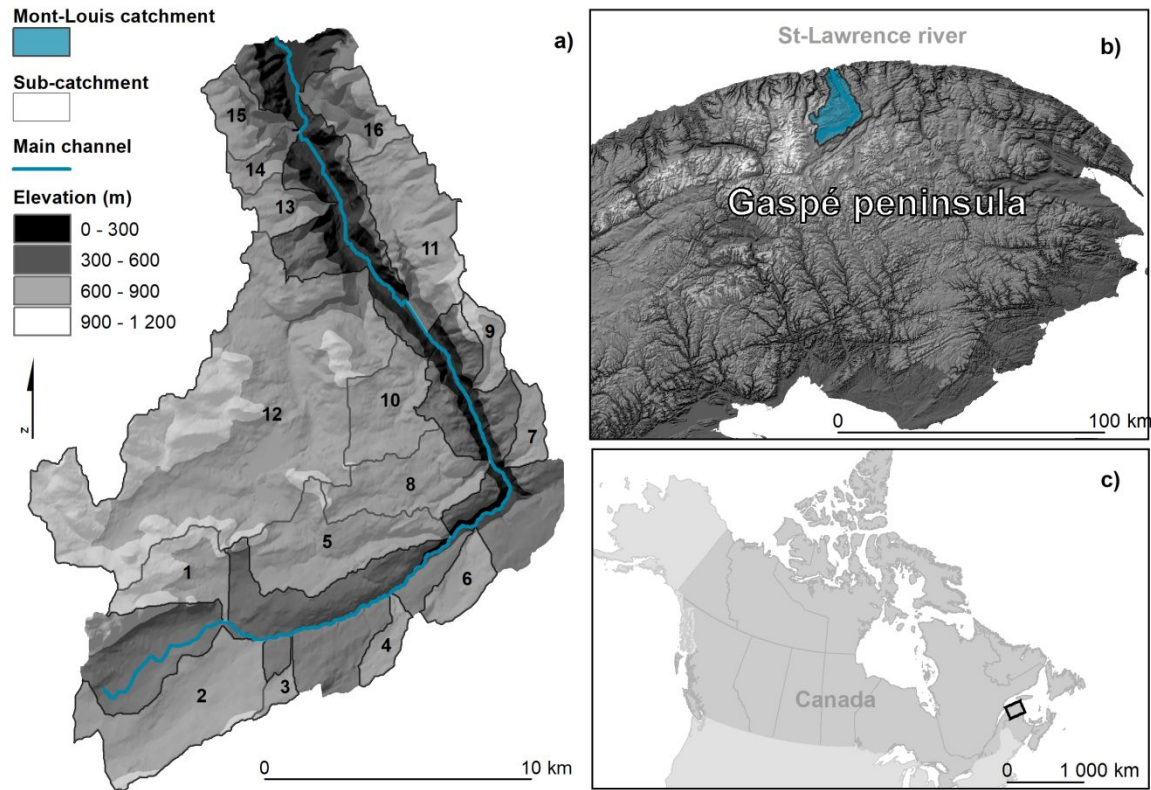


Figure 1. Mont-Louis catchment location. a) Mont-Louis topographic map and sub-catchments. b) Gaspé peninsula and Mont-Louis catchment location. c) Gaspé peninsula location in Canada.

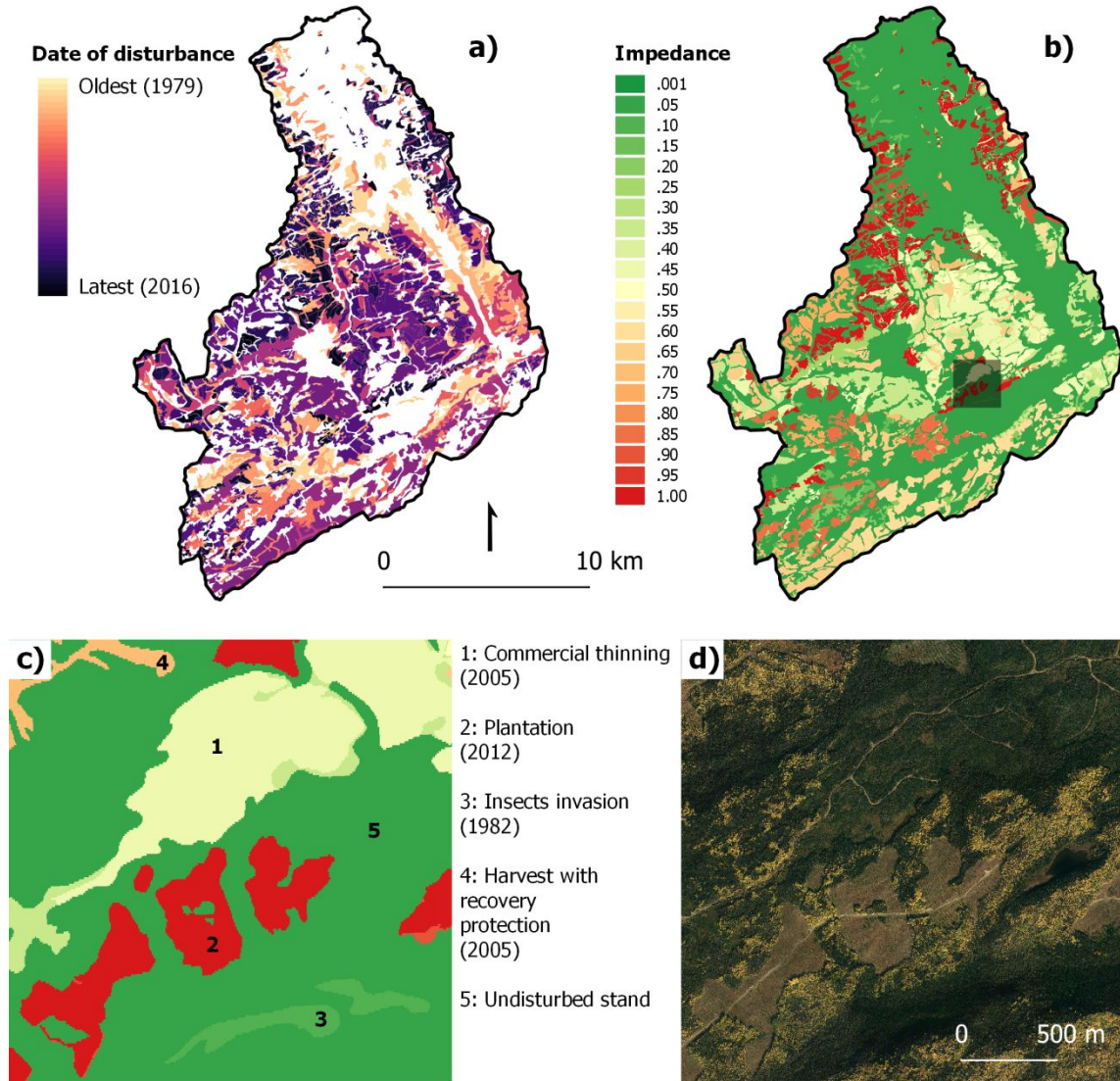


Figure 2: Processing of the spatiotemporal ecoforestry database. a) Example of the 2016 forest disturbance map (FDM) resulting in the b) 2016 impedance raster (W_{HR}), with a zoom-in illustrating c) the high spatial resolution of W_{HR} , which depends on the different types of disturbances (1-5), and d) the associated orthophoto (2016).

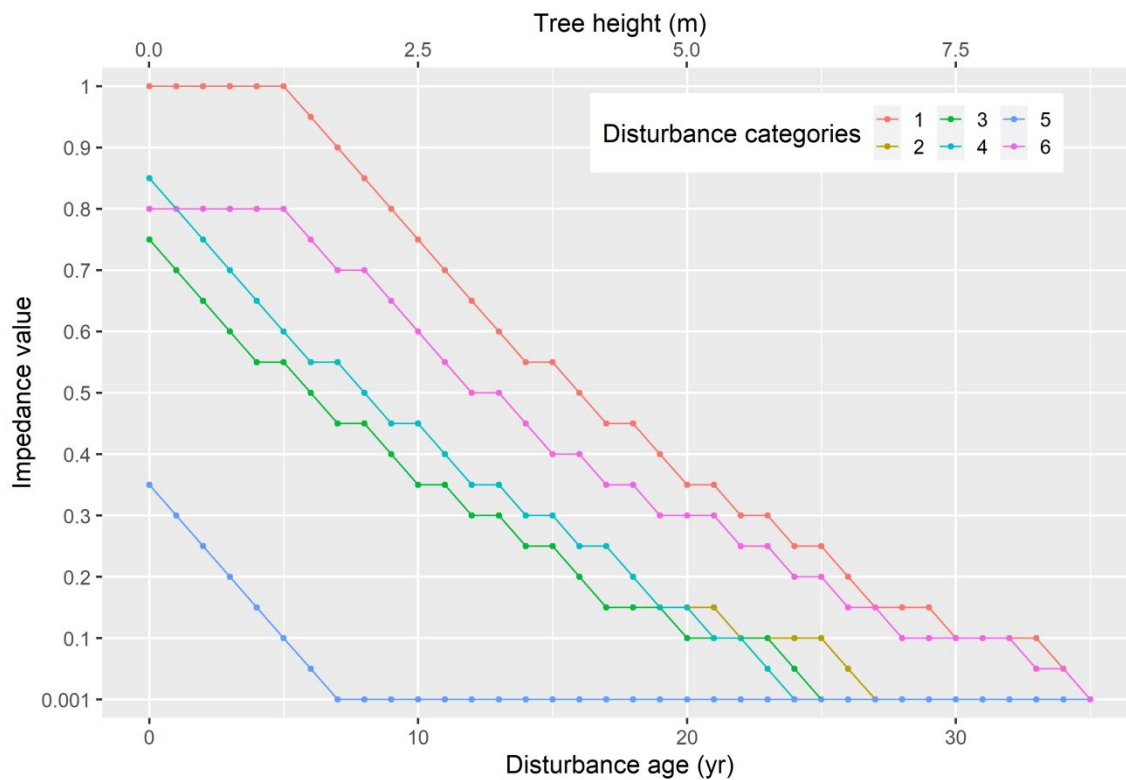


Figure 3: Temporal evolution of the impedance (W_{HR}) used in this study, depending on disturbance age, category and tree height. Values of impedance are directly derived from the snow augmentation coefficient rate (SAC) established by Langevin and Plamondon (2004).

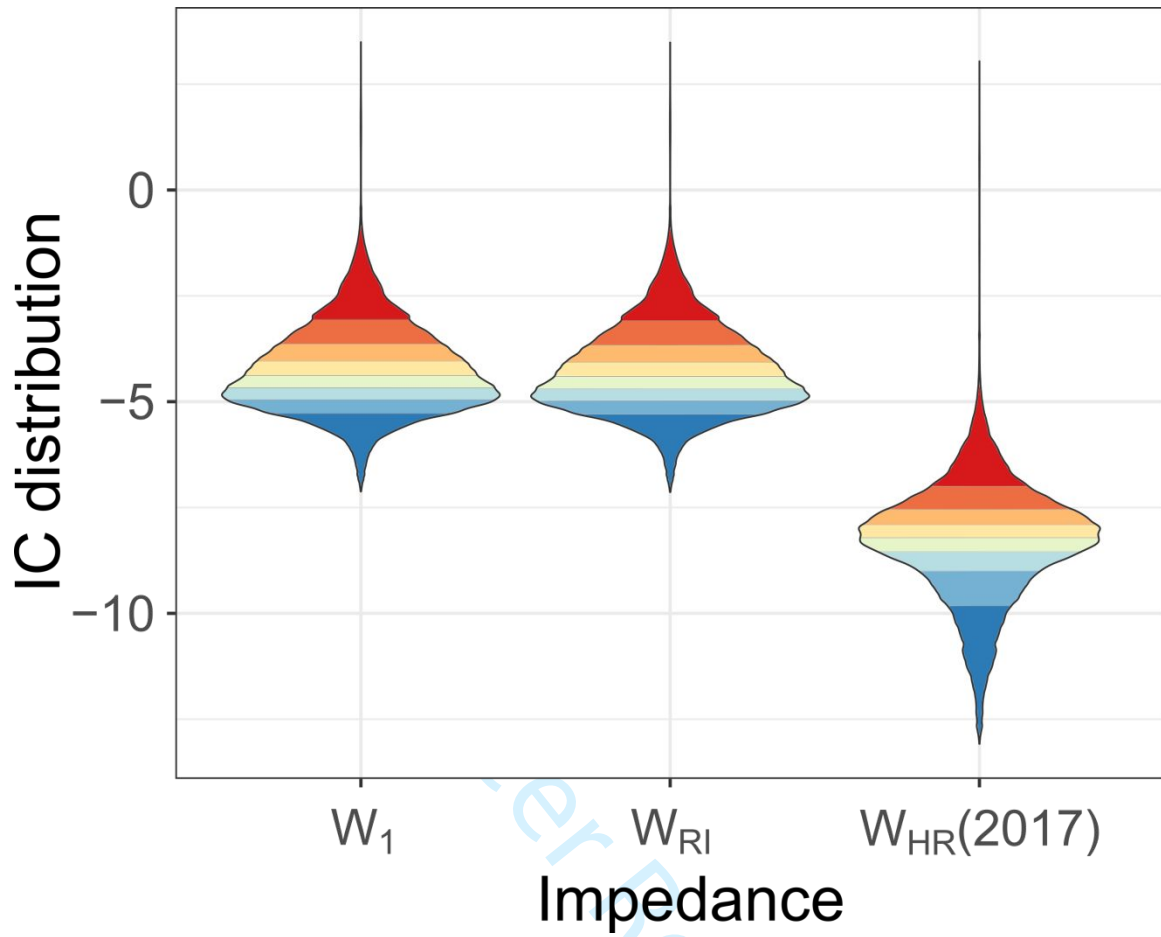


Figure 4: Violin boxplots of IC values over the Mont-Louis catchment, computed with three impedances (W_1 , W_{RI} , $W_{HR}(2017)$).

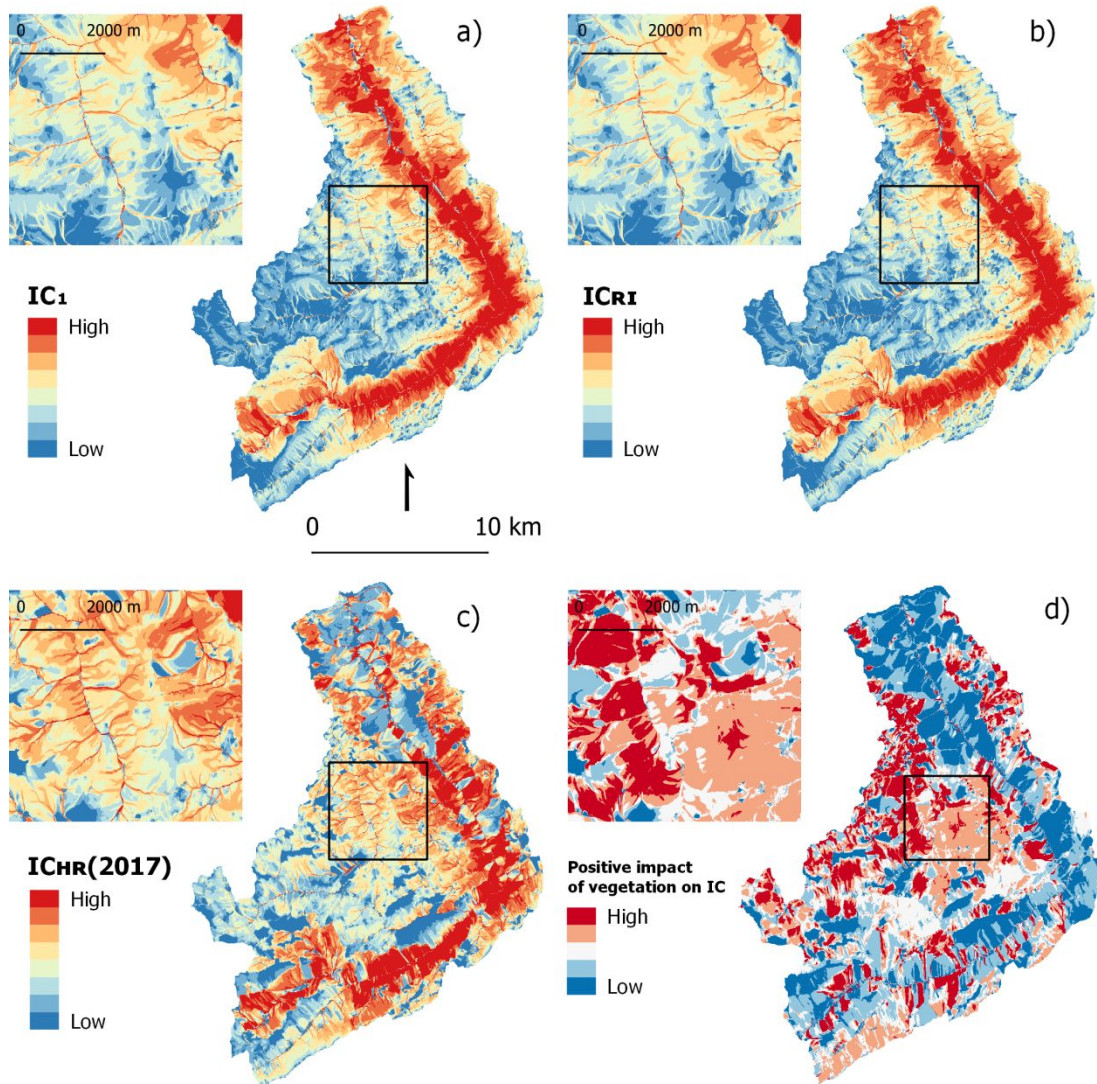


Figure 5: IC maps depending on the impedance. a) Uniform impedance (W_1). b) Topography-based impedance (W_{RI}). c) Vegetation-based impedance ($W_{HR}(2017)$). d) Absolute difference between IC_{HR(2017)} and IC_{RI}.

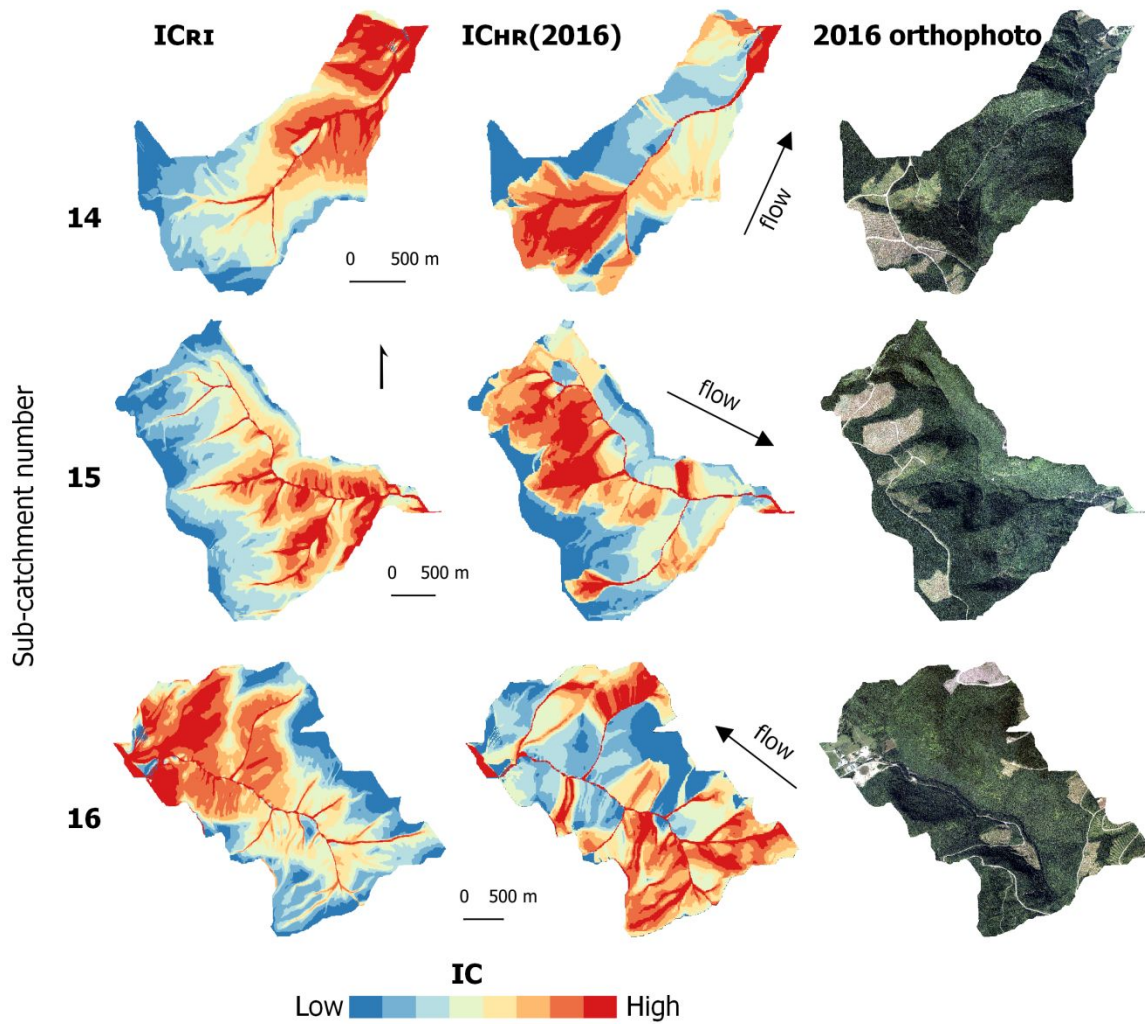


Figure 6: Comparison of IC in three sub-catchments (14,15,16) when computed with W_{Ri} and $W_{HR}(2016)$. The 2016 orthophoto reflects the importance of considering the presence (absence) of vegetation.

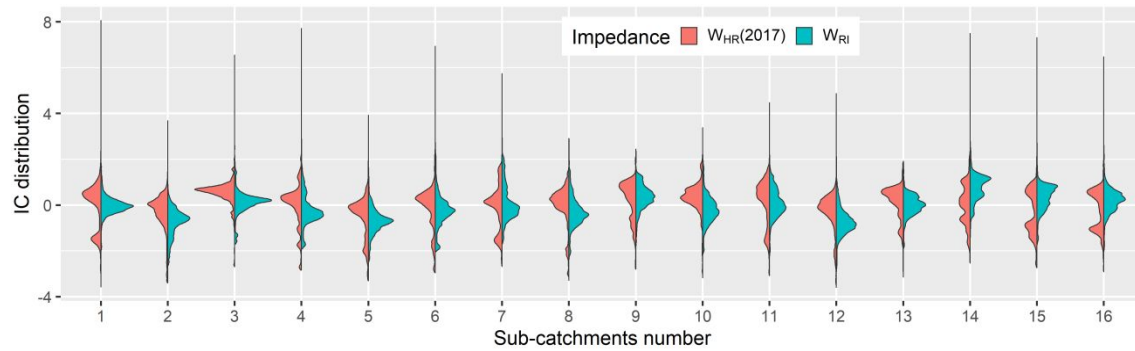


Figure 7: Distribution of standardized IC values depending on the impedance (W_{HR} and W_{RI}), extracted from each sub-catchment.

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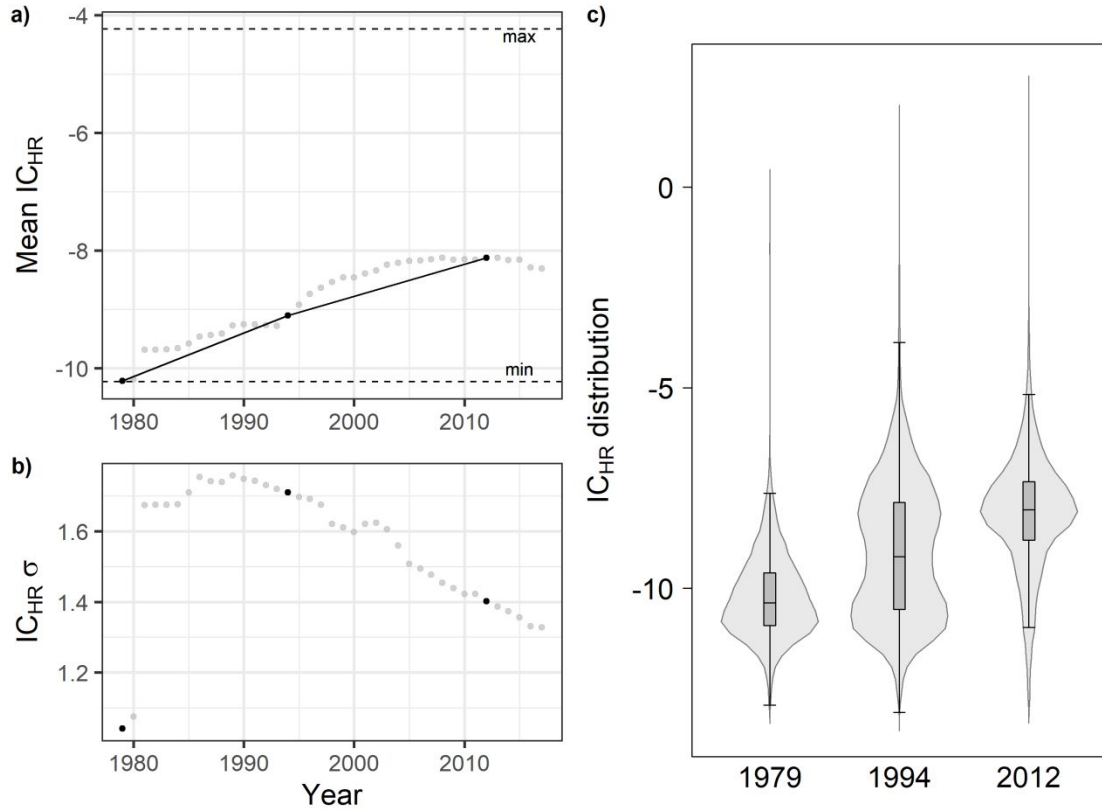


Figure 8: Temporal evolution of IC over Mont-Louis catchment, from 1979 to 2017. a) Mean value of IC_{HR} . Black dashed lines corresponds to the theoretical maximum and minimum possible value of the mean IC_{HR} . b) Standard deviation of IC_{HR} . c) IC_{HR} distributions for year 1979, 1994 and 2012.

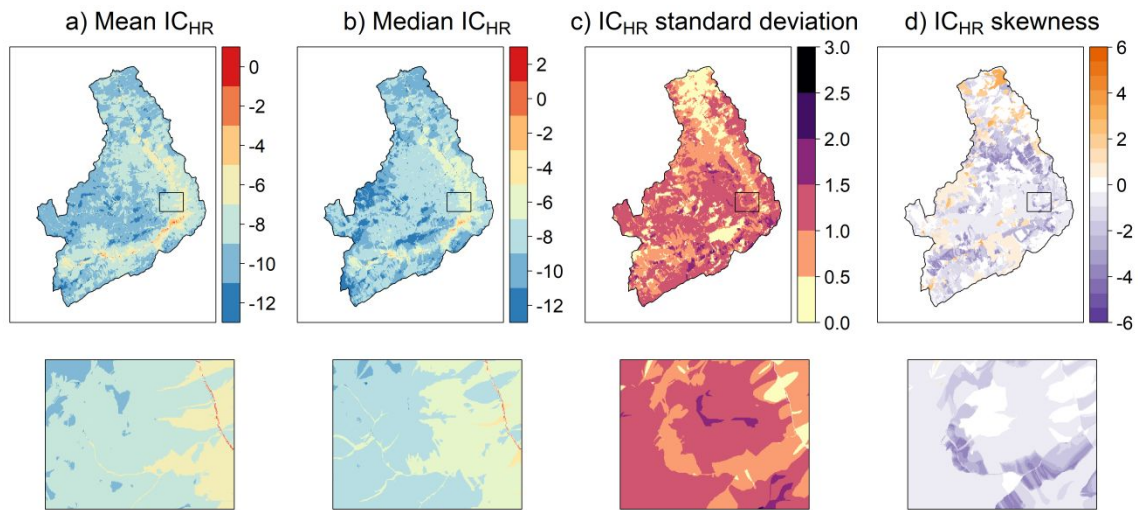


Figure 9: Spatiotemporal trends over the time-series of IC_{HR} from 1979 to 2017. a) Mean IC_{HR} . b) Median IC_{HR} . c) IC_{HR} standard deviation. d) IC_{HR} skewness.

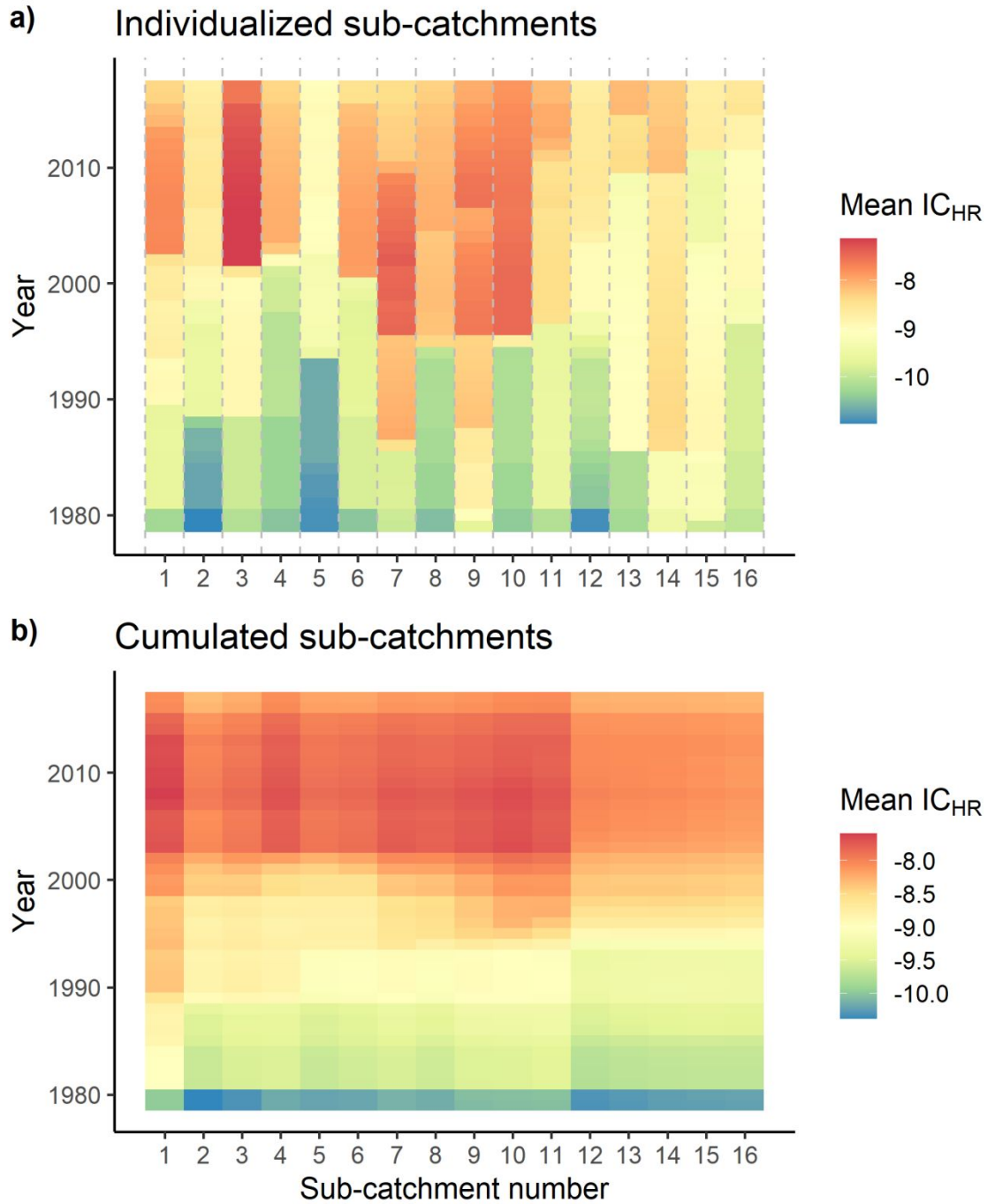


Figure 10: Spatiotemporal matrix of mean IC_{HR} computed per a) individualized and b) cumulated sub-catchments.

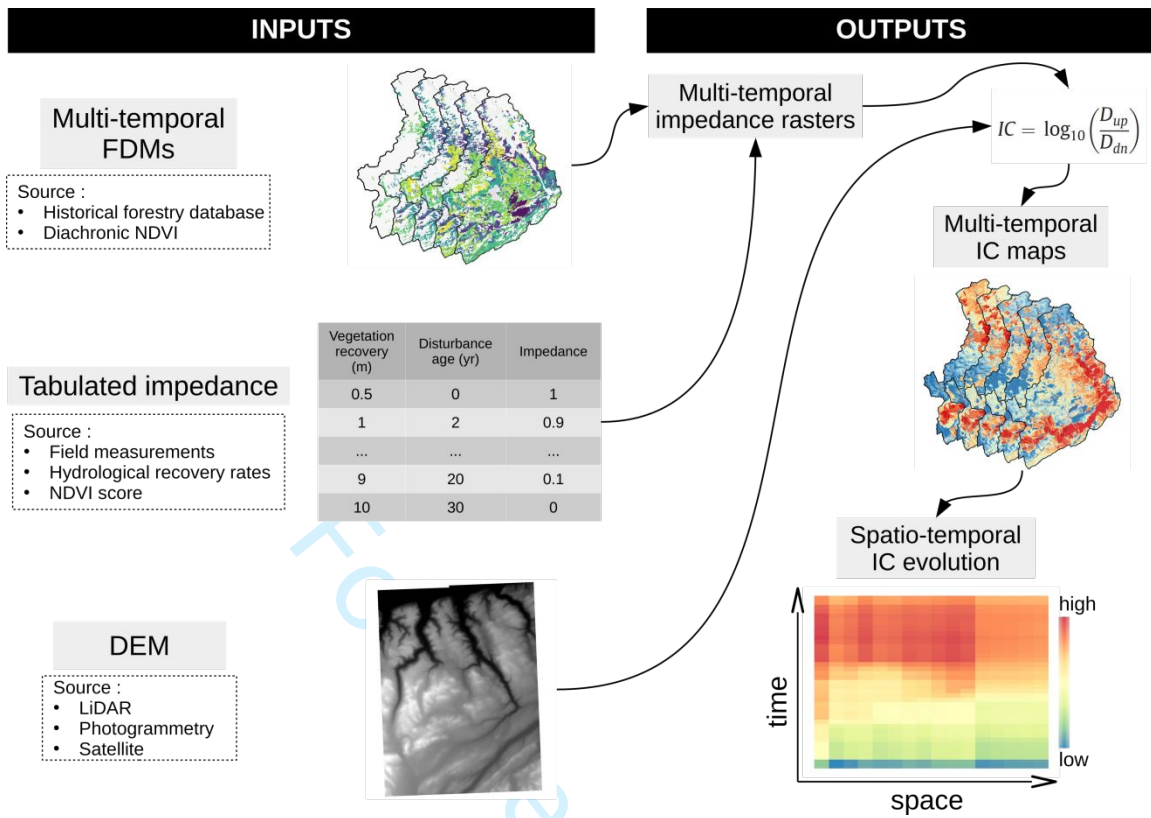


Figure 11: Synthetic workflow used to assess the interannual evolution of IC using FDMs, tabulated impedances and a DEM.

Figure Caption

Figure 1. Mont-Louis catchment location. a) Mont-Louis topographic map and sub-catchments. b) Gaspé peninsula and Mont-Louis catchment location. c) Gaspé peninsula location in Canada.

Figure 2: Processing of the spatiotemporal ecoforestry database. a) Example of the 2016 forest disturbance map (FDM) resulting in the b) 2016 impedance raster (W_{HR}), with a zoom-in illustrating c) the high spatial resolution of W_{HR} , which depends on the different types of disturbances (1-5), and d) the associated orthophoto (2016).

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Figure 6: Comparison of IC in three sub-catchments (14,15,16) when computed with W_{RI} and $W_{HR}(2016)$. The 2016 orthophoto reflects the importance of considering the presence (absence) of vegetation.

Figure 7: Distribution of standardized IC values depending on the impedance (W_{HR} and W_{RI}), extracted from each sub-catchment.

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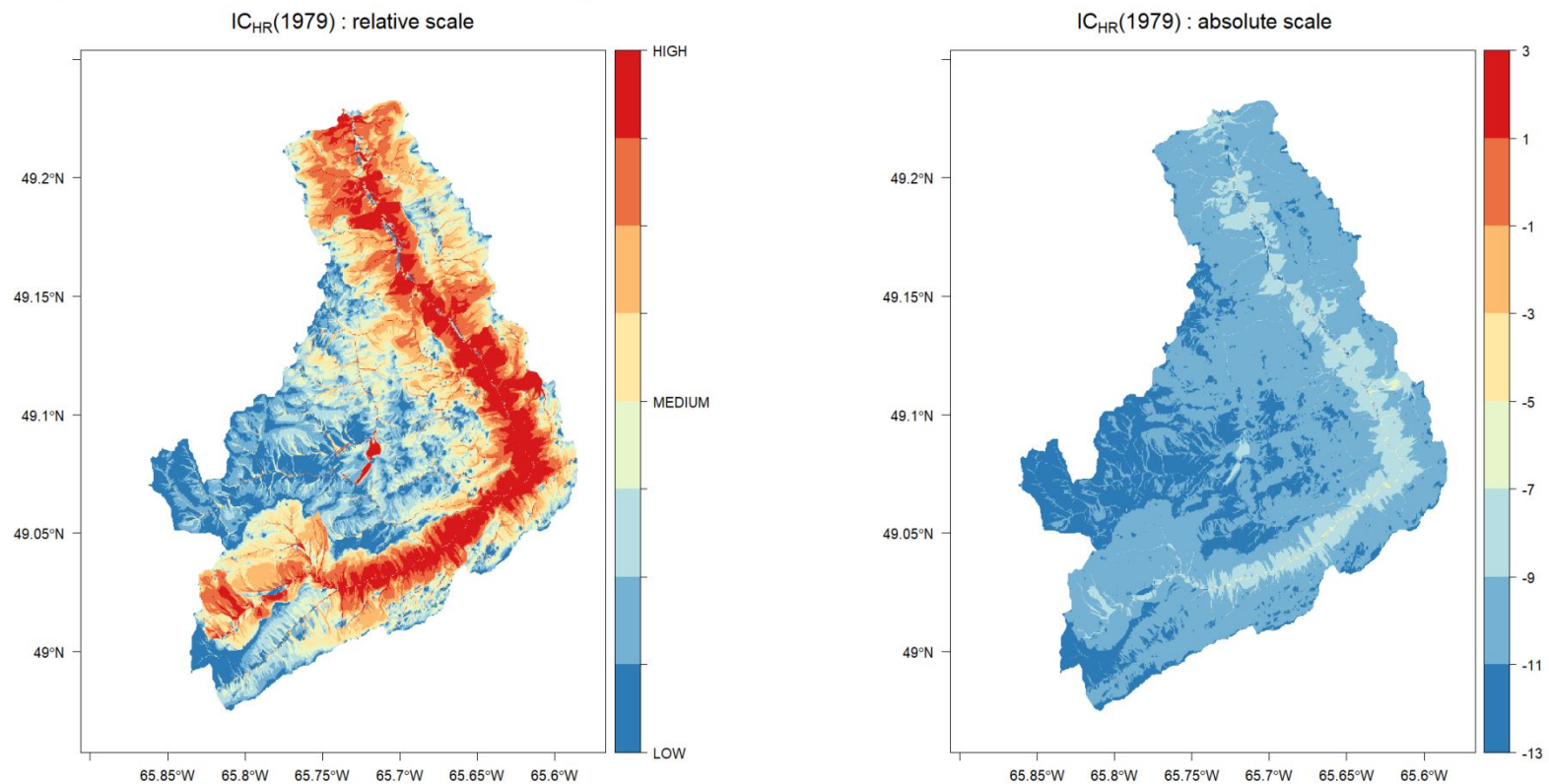
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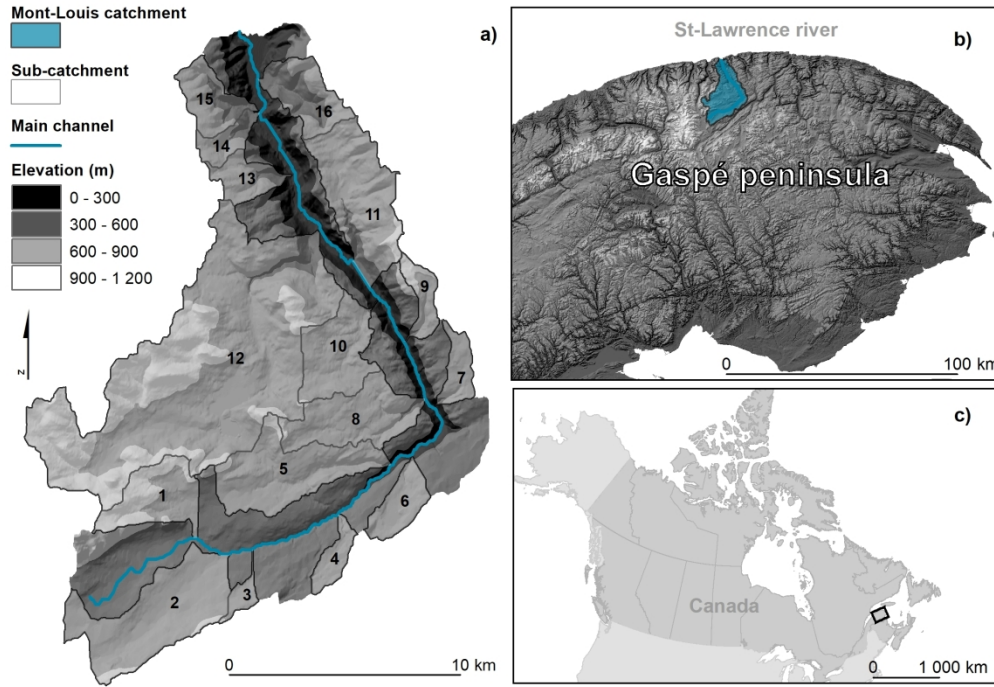
Figure 11: Synthetic workflow used to assess the interannual evolution of IC using FDMs, tabulated impedances and a DEM.

SUPPLEMENTARY MATERIAL

Inter-annual evolution of hydrosedimentary connectivity induced by forest cover change in Mont-Louis catchment

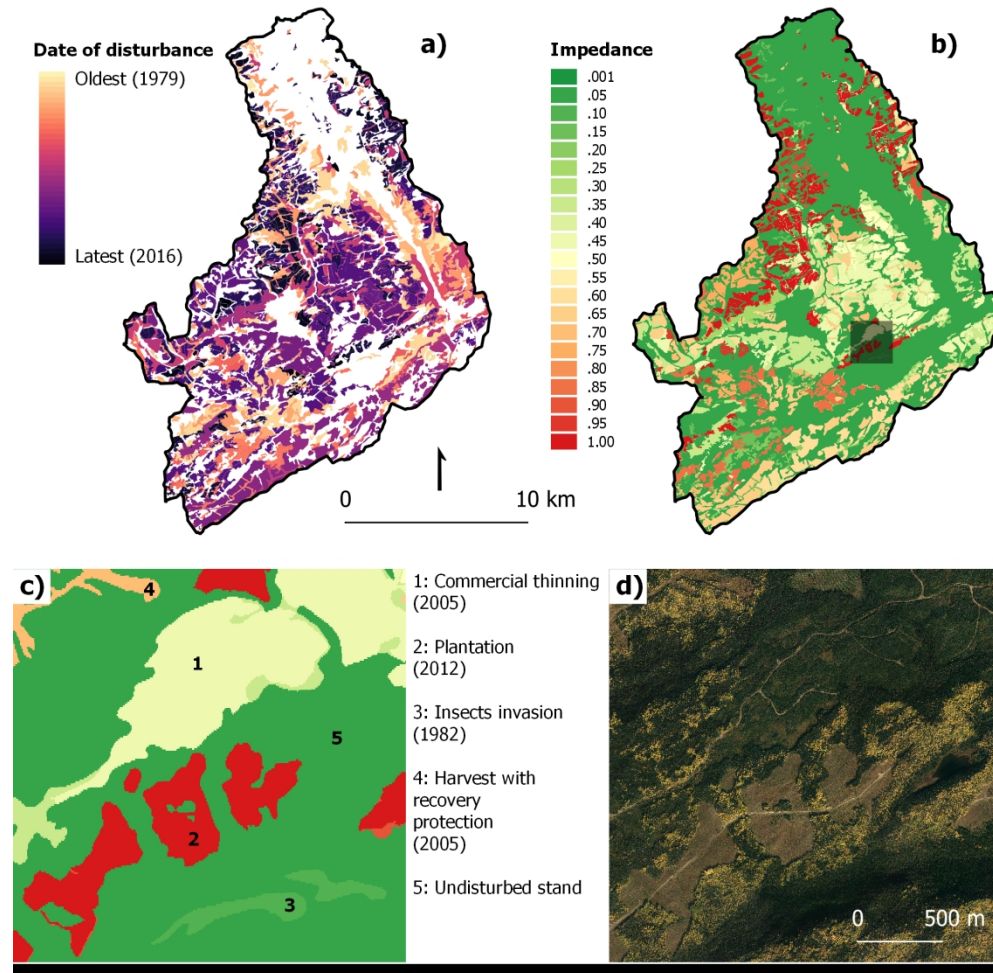


35 This animation corresponds to the entire time-series of IC_{HR} maps produced in this study, with two different scales. It thus represents the
36 interannual evolution of hydrosedimentary connectivity induced by forest cover change in the Mont-Louis catchment.
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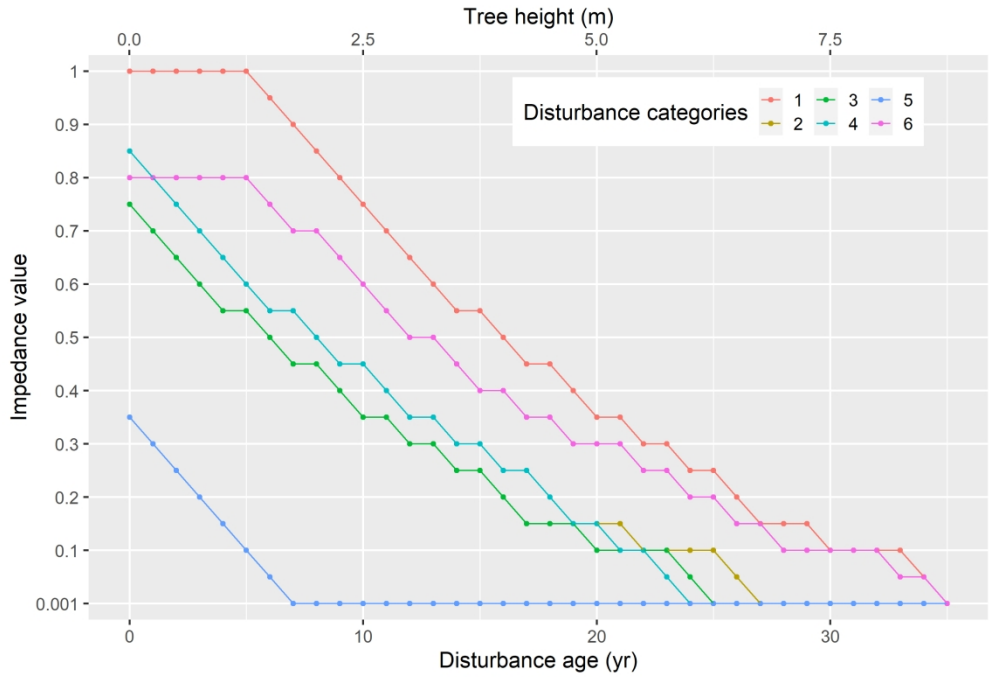
Mont-Louis catchment location. a) Mont-Louis topographic map and sub-catchments. b) Gaspé peninsula and Mont-Louis catchment location. c) Gaspé peninsula location in Canada.

215x150mm (300 x 300 DPI)

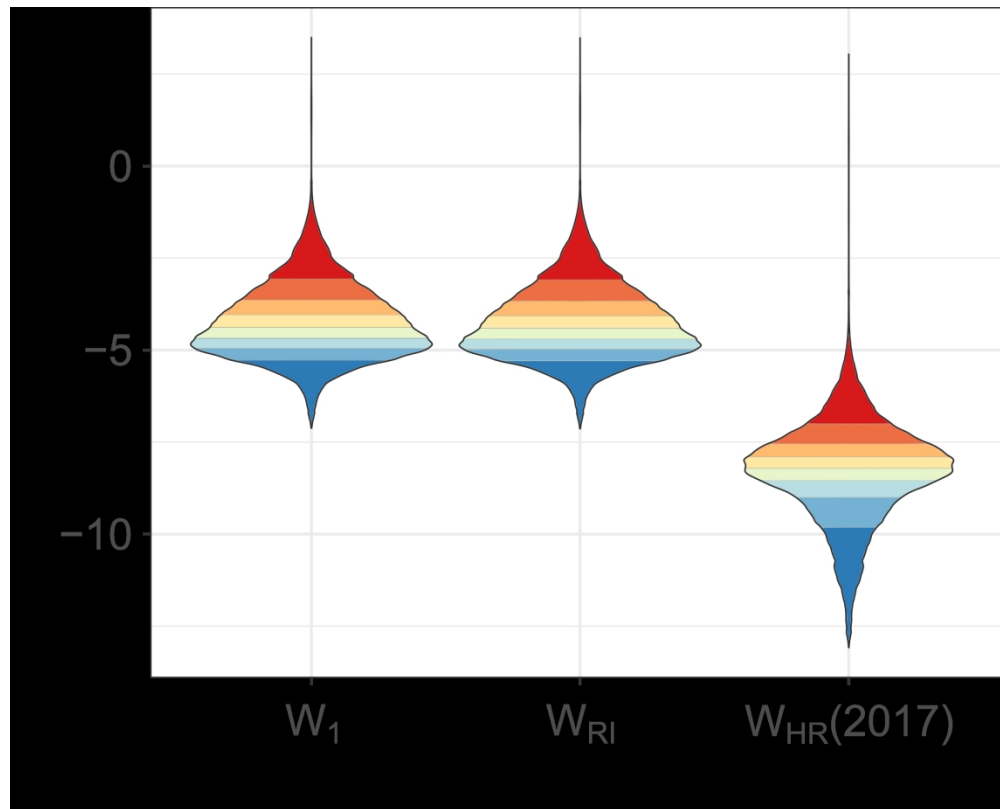


Processing of the spatiotemporal ecoforestry database. a) Example of the 2016 forest disturbance map (FDM) resulting in the b) 2016 impedance raster (W_{HR}), with a zoom-in illustrating c) the high spatial resolution of W_{HR} , which depends on the different types of disturbances (1-5), and d) the associated orthophoto (2016).

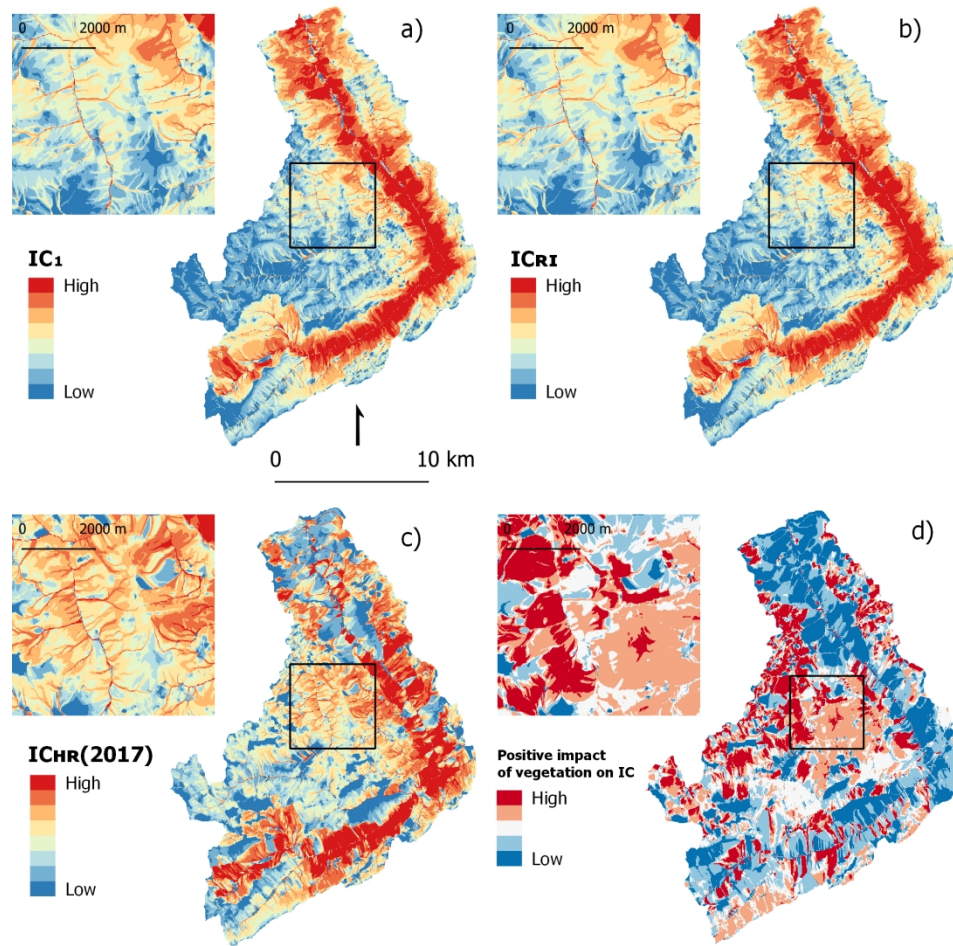
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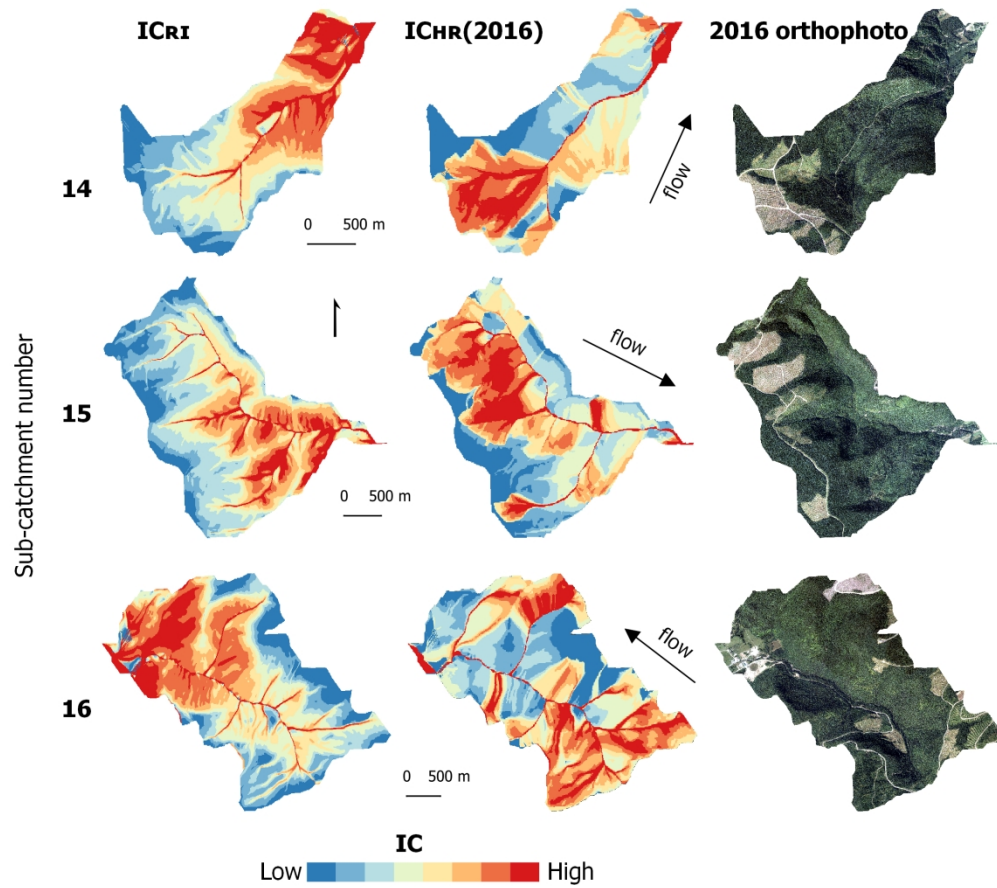
Temporal evolution of the impedance (W_{HR}) used in this study, depending on disturbance age, category and tree height. Values of impedance are directly derived from the snow augmentation coefficient rate (SAC) established by Langevin and Plamondon (2004).



Violin boxplots of IC values over the Mont-Louis catchment, computed with three impedances (W_1 , W_{RI} , $W_{HR}(2017)$).

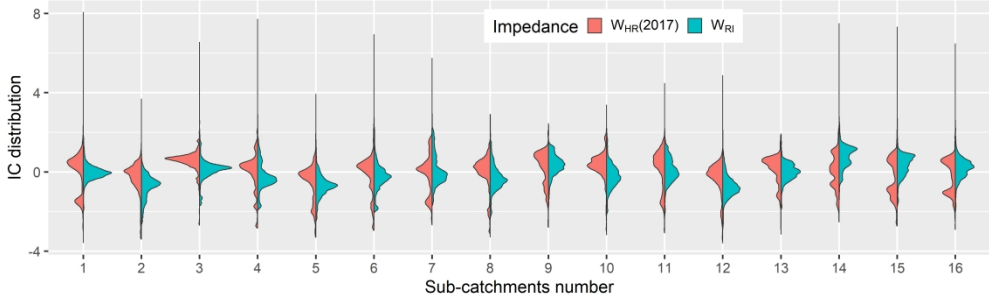


IC maps depending on the impedance. a) Uniform impedance (W_1); b) Topography-based impedance (W_{RI}); c) Vegetation-based impedance ($W_{HR(2017)}$); d) Absolute difference between $IC_{HR(2017)}$ and IC_{RI} .

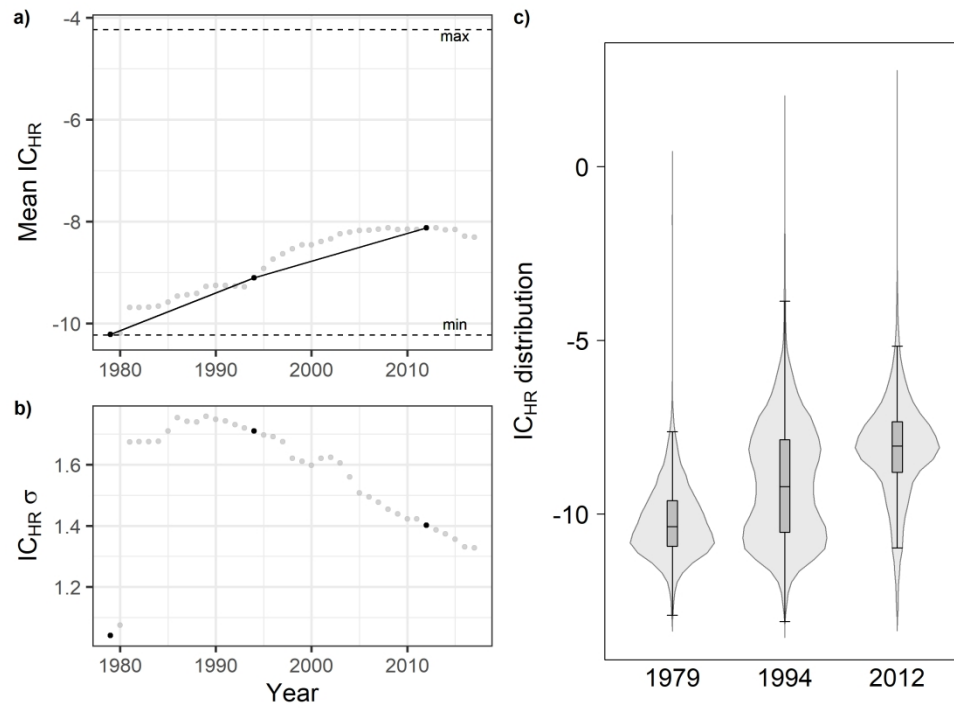


Comparison of IC in three sub-catchments (14,15,16) when computed with W_{RI} and $W_{HR}(2016)$. The 2016 orthophoto reflects the importance of considering the presence (absence) of vegetation.

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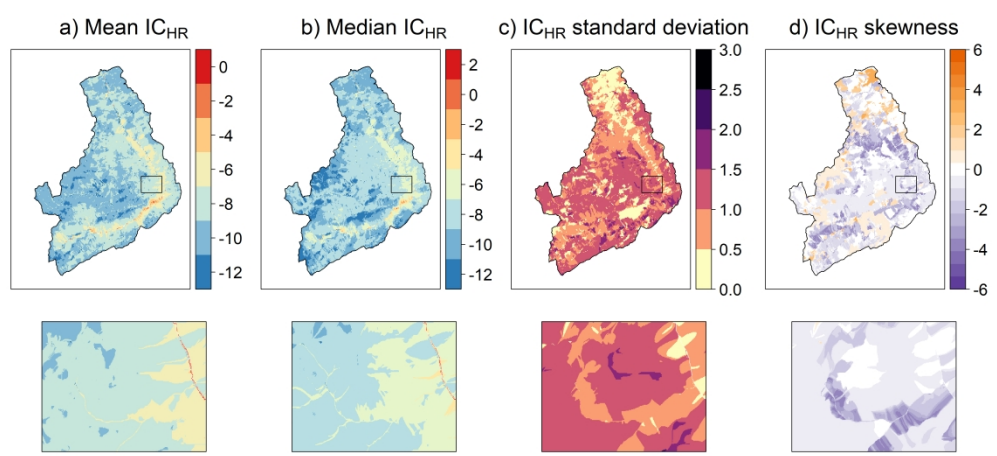


Distribution of standardized IC values depending on the impedance (W_{HR} and W_{RI}) and extracted from each sub-catchment.

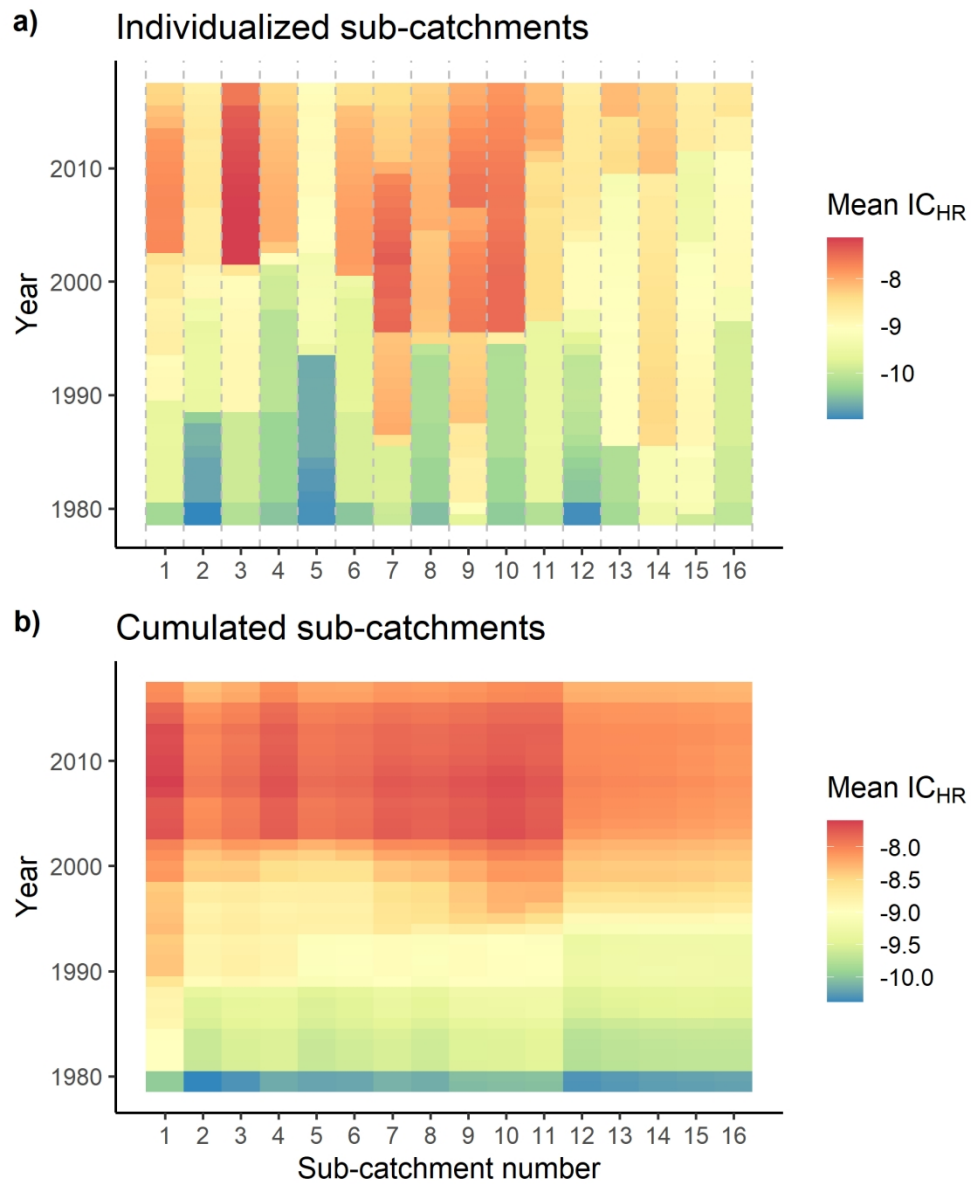


Temporal evolution of IC over the Mont-Louis catchment from 1979 to 2017. a) Mean value of IC_{HR} ; the black dashed lines correspond to the theoretical minimum and maximum mean IC_{HR} values. b) Standard deviation of IC_{HR} . c) IC_{HR} distributions for 1979, 1994, and 2012.

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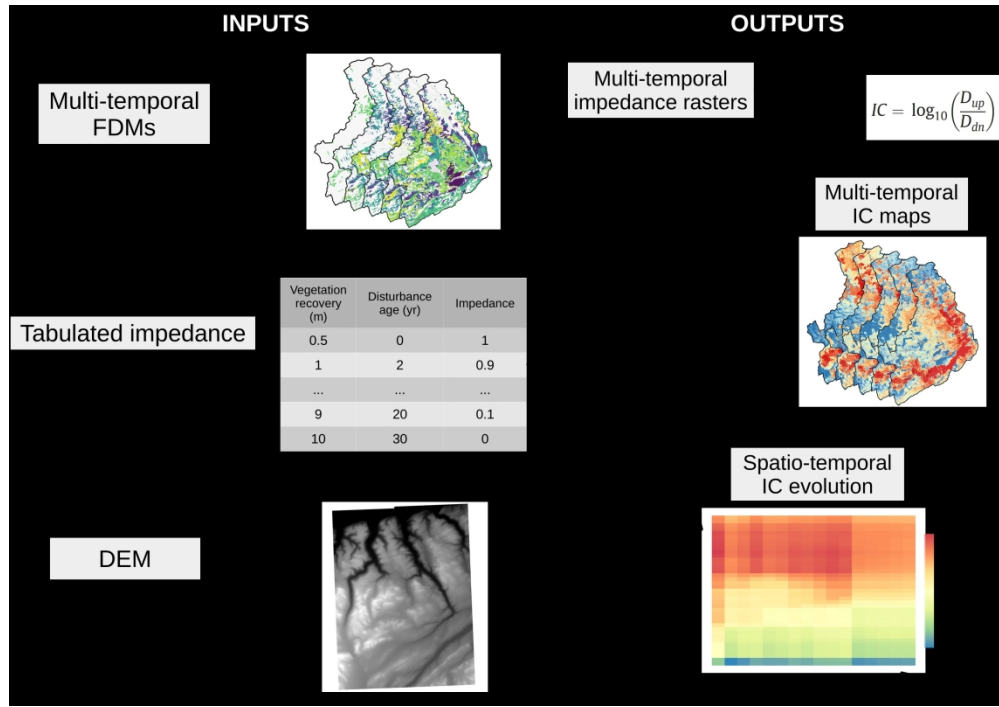
Spatiotemporal trends over the IC_{HR} time-series from 1979 to 2017. a) Mean IC_{HR}; b) Median IC_{HR}; c) IC_{HR} standard deviation; d) IC_{HR} skewness. The insets show details of the area indicated on the catchment map.



45 Spatiotemporal matrix of mean IC_{HR} computed per a) individualized and b) cumulated sub-catchments.

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Synthetic workflow used to assess the interannual evolution of IC using FDMs, tabulated impedances and a DEM.