

River corridors facing change in Alpine and Mediterranean climate: anthropogenic pressures vs. extreme events vs. climate change, a coupled geomorphic and ecologic point of view

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A. Geographical framework

- Alpine and Mediterranean rivers
 - Physiographical setting:
 - Steep slopes
 - Shallow soils
 - Sparse vegetation cover
 - Climate → hydrology:
 - Infra-annual flow variability: $\times 10^3$
 - Flash floods
 - Torrential regime
 - Riverbed morphodynamics:
 - Coarse sediment supply ($D_{50}=45-90\text{mm}$)
 - High sediment supply and connectivity
 - High energy riverbed morphodynamics

Paillon catchment near Nice (France)



Roya mouth at Ventimiglia (Italy)



A. Geographical framework

- Alpine and Mediterranean rivers
 - Human impacts:
 - Historical land use change
 - Dense occupation of the valley floor
 - Hydropower infrastructures



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Hydropower infrastructures at Paganin
(Roya, France)

Var / Esteron confluence upstream Nice
in 1945 and 2002



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Parc naturel départemental des Rives du Var



B. Theoretical framework

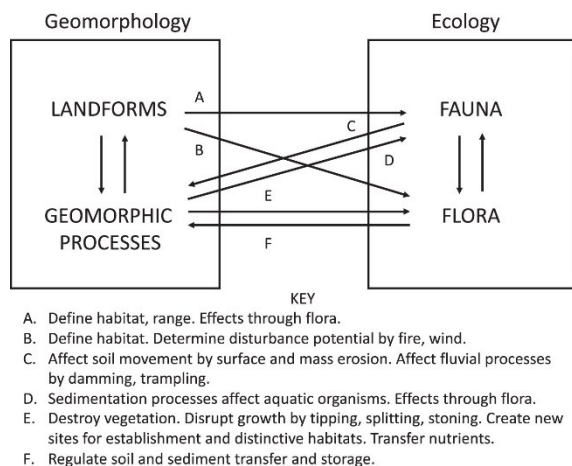
■ Research hypotheses

1. Geomorphology influences ecology

Swanson, 1980

Gregory and Gurnell, 1988

Belletti *et al.*, 2013



Swanson, 1980. In Viles, 2022

2. Alpine and Mediterranean climates: strong drivers that generate contrasted landscapes

→ good place to study:

- Climate change
- Extreme events

Geomorphological variability in space and time → Ecological variability in space and time

B. Theoretical framework

■ Research position(s)

- Physical geography = good framework to work at different scales in space and time

Rhoads, 2004
Dufour and Lespez, 2020

- + human sciences = good framework to study anthropogenic pressures

Bergeret *et al.*, 2015
Serrhini-Naji, 2021
Thibaut *et al.*, 2023

- Systemic approach

Cholley, 1950 *in* Battiau-Queney, 2022
Schumm, 1977
Amoros and Petts, 1993

- Socio-ecosystem

Liu *et al.*, 2007
Dufour *et al.*, 2017

- Source-to-sink

Anthony and Julian, 1999
Sømme *et al.*, 2009

- Sediment continuity

Fryirs *et al.*, 2007

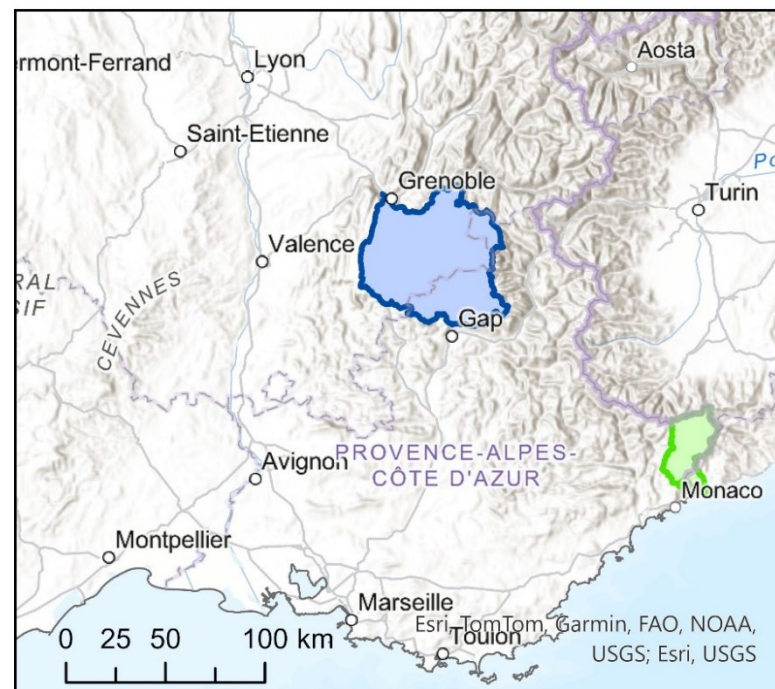
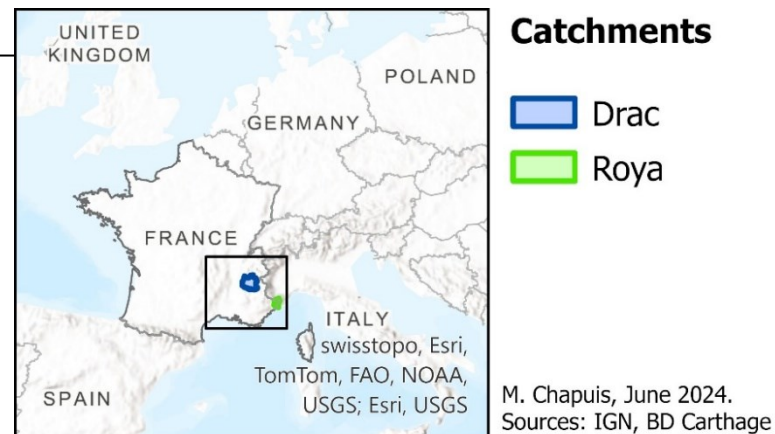
B. Theoretical framework

- General objectives
 - To analyze some of the reciprocal relationships between hydrosystem fluctuations and land use (biocenosis and/or society) → land use planning strategies
 - To better understand physical processes of sediment transport (pluri-annual series, extreme flood events) and their consequences on hydro-eco-systems
 - To evaluate and quantify the success of hydromorphological restoration operations in braided rivers
 - To characterize sediment dynamics at reach and catchment scale, at different temporal scales: pluri-annual survey vs. extreme flood event vs. historical influence of land-use change

Regional setting → climate drivers on river management

D. Geographical setting

- 2 case studies to link geomorphology and ecology
 - **Drac river**
 - Macro-invertebrates
 - **Roya river**
 - Trout spawning habitat morphodynamics
 - Sediment fluxes monitoring
 - Hillslopes' vegetation dynamics



C. Objectives and studied compartments

- 2 case studies to link geomorphology and ecology

- **Drac river**

- Macro-invertebrates

Devreux et al., 2022

Devreux et al., 2023

Devreux et al., in prep.

1/ how can we quantify the success of hydromorphological restoration operations in braided rivers? → need to integrate coupled geomorphical and ecological tools in restoration success assessment

- **Roya river**

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Chapuis et al., 2022a

Chapuis et al., 2022b

Chapuis and Adnès, 2023

Chapuis, submit.

1/ is trout spawning habitats sediment dynamics linked to hydropeaking dam management and/or “natural” floods?

2/ how does a fluvial system react after a >1000yrs return period flood? → climate change effects on river systems sediment dynamics?

3/ what is the effect of land use planning policies on sediment yield on a historical perspective?

D. Methodology

- 2 case studies to link geomorphology and ecology

- Drac river**

- Macro-invertebrates



Fieldwork: samplings, GUS mapping

Belletti et al., 2017

Devreux et al., 2023

- Roya river**

- Trout spawning habitat morphodynamics
 - Sediment fluxes monitoring
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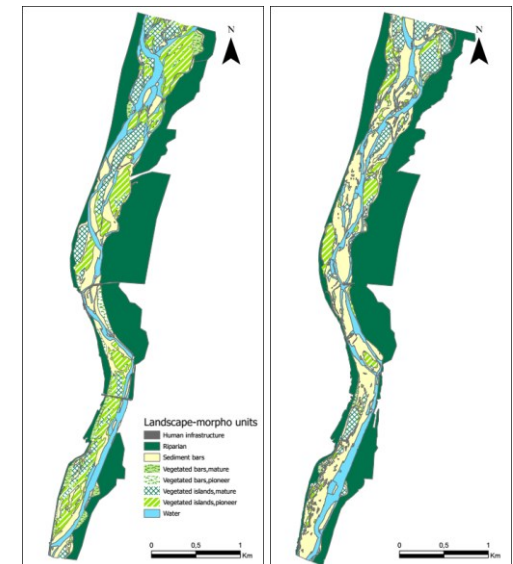
Chapuis & Adnès, 2023

Devreux, 2023

Misset et al., 2023



Liébault et al., 2012



Durance riverscape mosaic in 2012 and 2017. *In Devreux, 2023*

Fieldwork: RFID sediment tracking, passive seismic monitoring, topographic surveys...

D. Methodology

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Devreux et al., 2023

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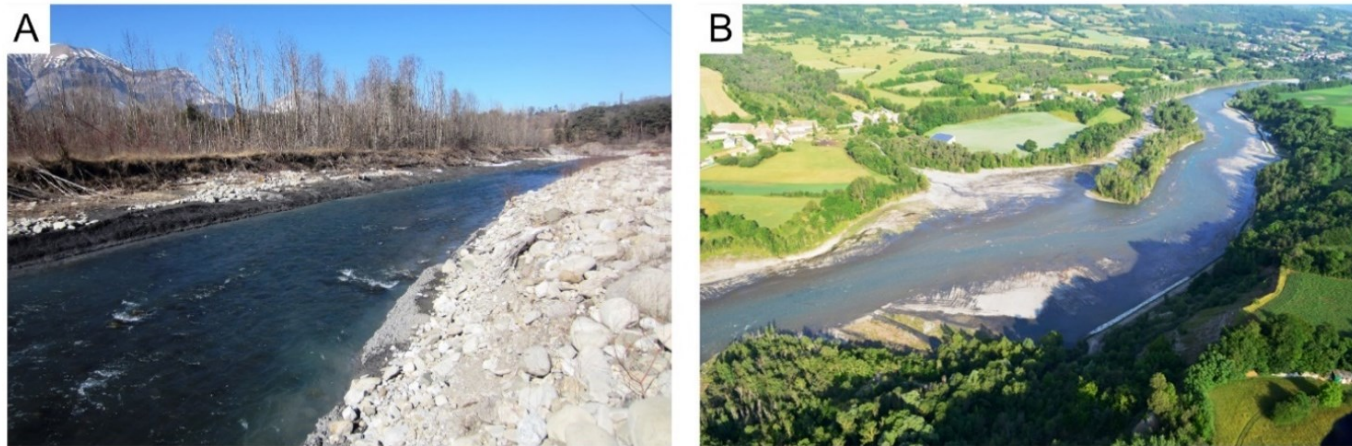


Figure A.1 - Photographies of the restored reach (A) before restoration, in 2012 and (B) after restoration, in 2014. Photographies are from the CLEDA (Communauté Locale de l'Eau du Drac Amont, local authority in charge of the river). *Devreux et al., in prep.*

D. Methodology

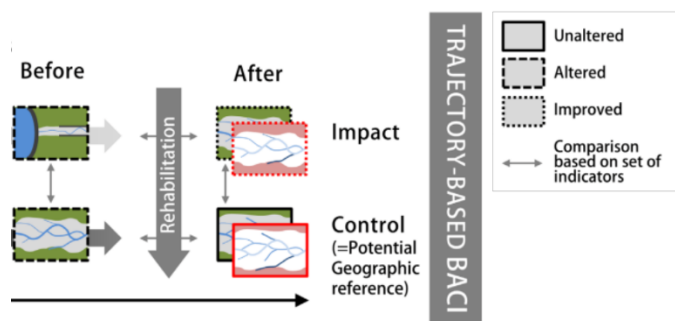
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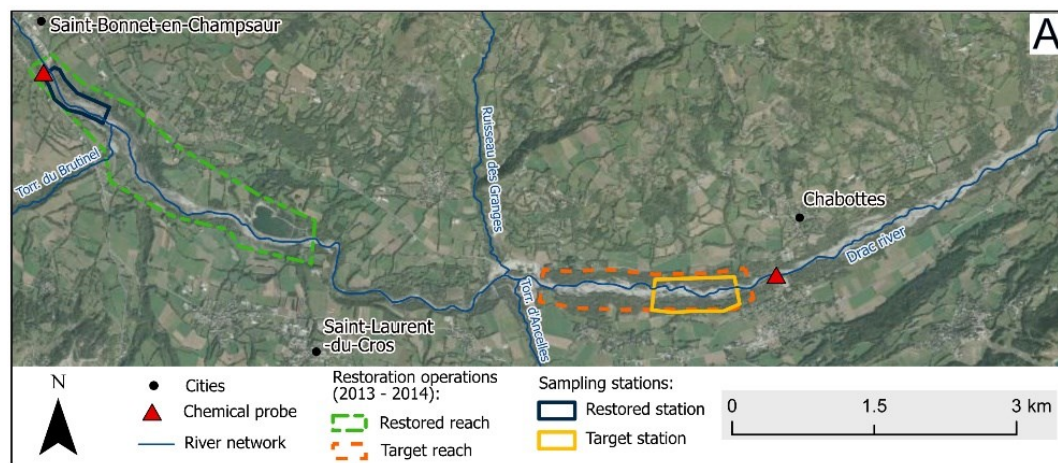
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Devreux *et al.*, 2022: <https://doi.org/10.1016/j.geomorph.2022.108404>
 Devreux *et al.*, 2023



Marteau *et al.*, 2022

BACI approach:
 Before/After - Control/Impact



Devreux *et al.*, in prep.

D. Methodology

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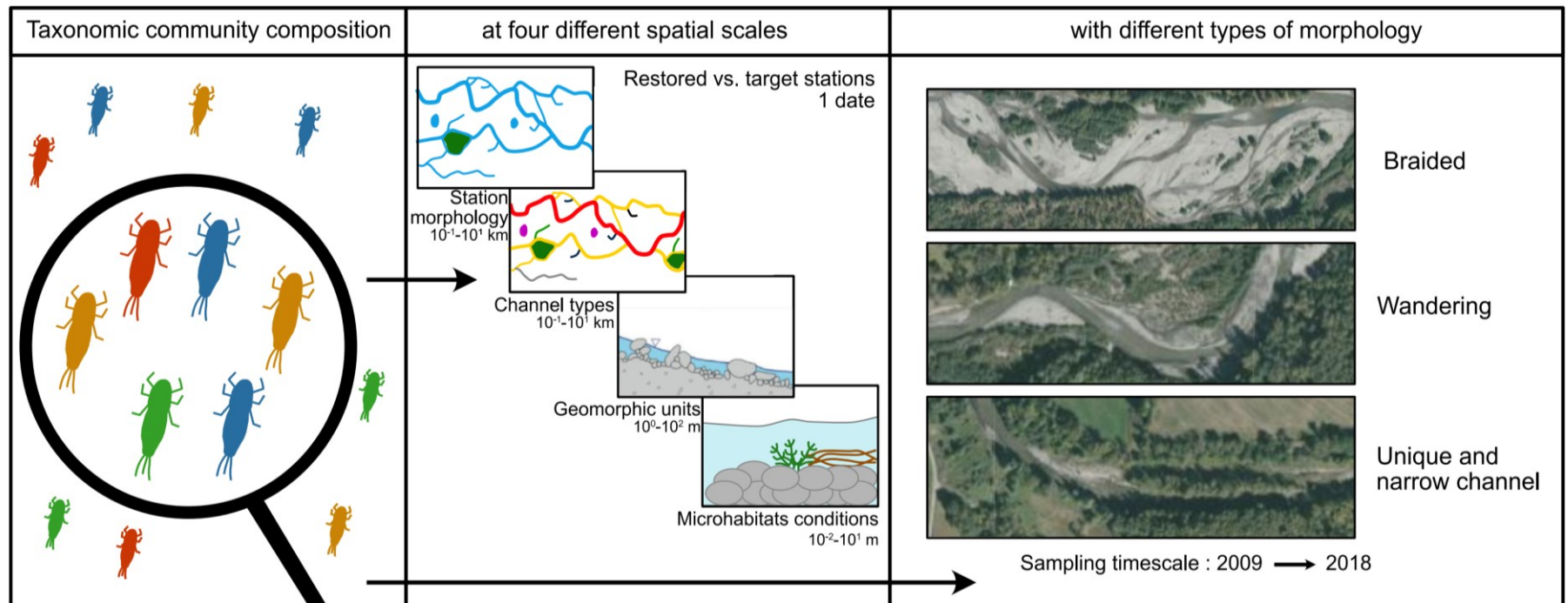
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E. Results

- 2 case studies to link geomorphology and ecology
 - **Drac river**
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Devreux et al., in prep.

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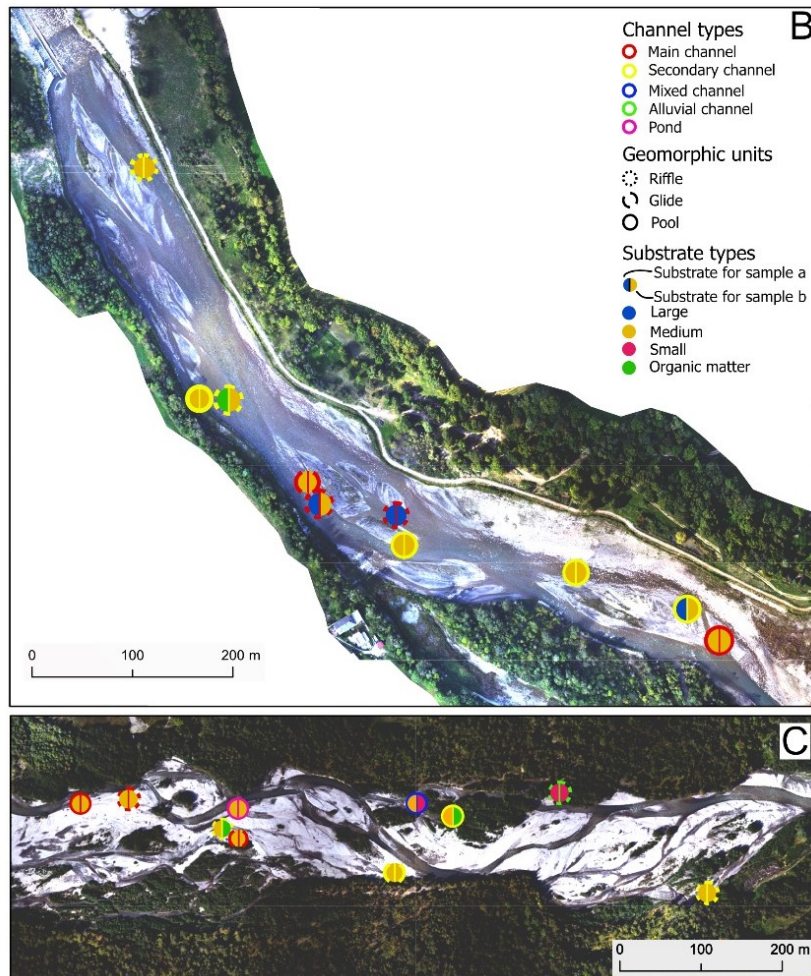


Figure 1

Location of the study area and samples collected at the two reaches. (A) Location of the restored and target reaches and sampling stations (blue and yellow rectangles). Saint-Bonnet-en-Champsaur is located at 44.6 N - 6.0 W in the coordinates system WGS 84. Location and habitat information for each samples on the restored (B) and target (C) stations.

Sample location might not be in water channels due to the differences of discharge and morphology between the orthophotography collection time (2018) and the sampling campaign time (2019).

Data for Figure 1B and C: the orthophotography comes from the district council of Hautes-Alpes.

E. Results

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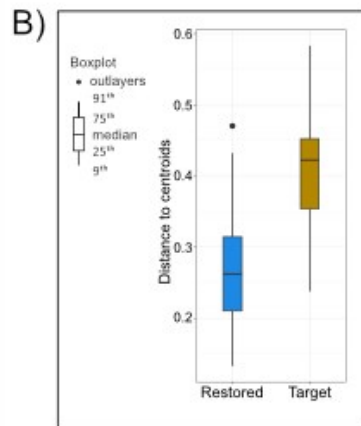
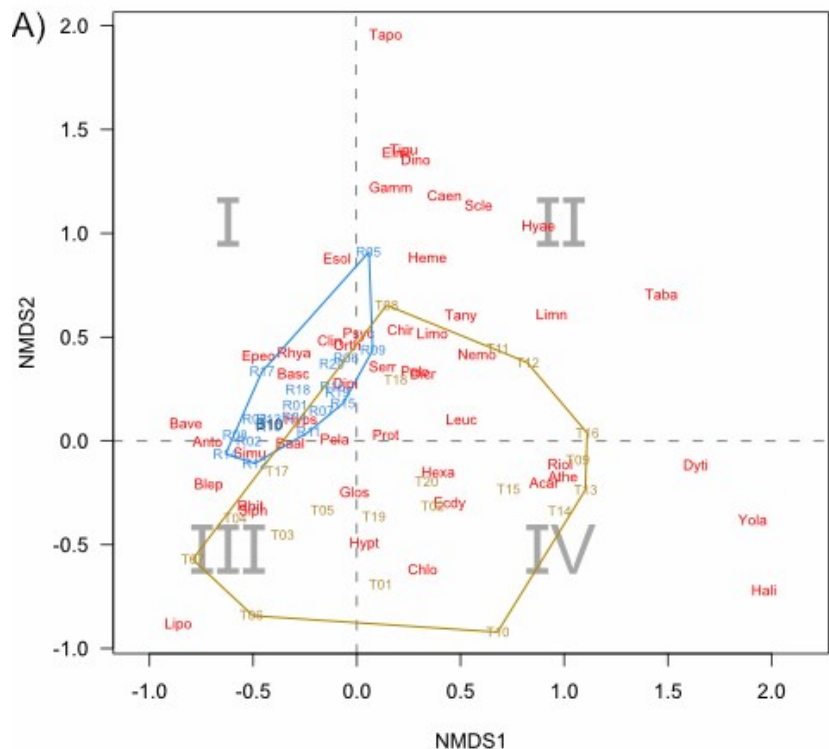


Figure 2

(A) Non-metric Multidimensional Scaling (nMDS) ordination based on the Bray-Curtis distances for all taxa and The quadrants correspond to the habitat conditions:

- quadrant I= fast and connected channels
- quadrant II= slow and mainly connected channels
- quadrant III= fast and main channels with coarse sediments
- quadrant IV= slow and stagnant habitats.

Abbreviations for the taxa names are in given Table A.4 in the Supplementary Materials. Code for samples of the restored station (blue) start with R and code for samples of the target station start with T (brown). NMDS1= first nMDS dimension, nMDS2= second nMDS dimension.

(B) difference in beta diversity for the restored (blue) and target (brown) stations.

Devreux et al., in prep.

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1/ how can we quantify the success of hydromorphological restoration operations in braided rivers? → need to integrate coupled geomorphic and ecologic tools in restoration success assessment

Main conclusions

1/ We need to consider channel types diversity (macroscale habitats) in restored braided rivers' sampling protocol to assess their health status

2/ In the absence of morphogenic flood: inter-annual variability of macroinvertebrates community composition plays a major role compared to the river morphology driver

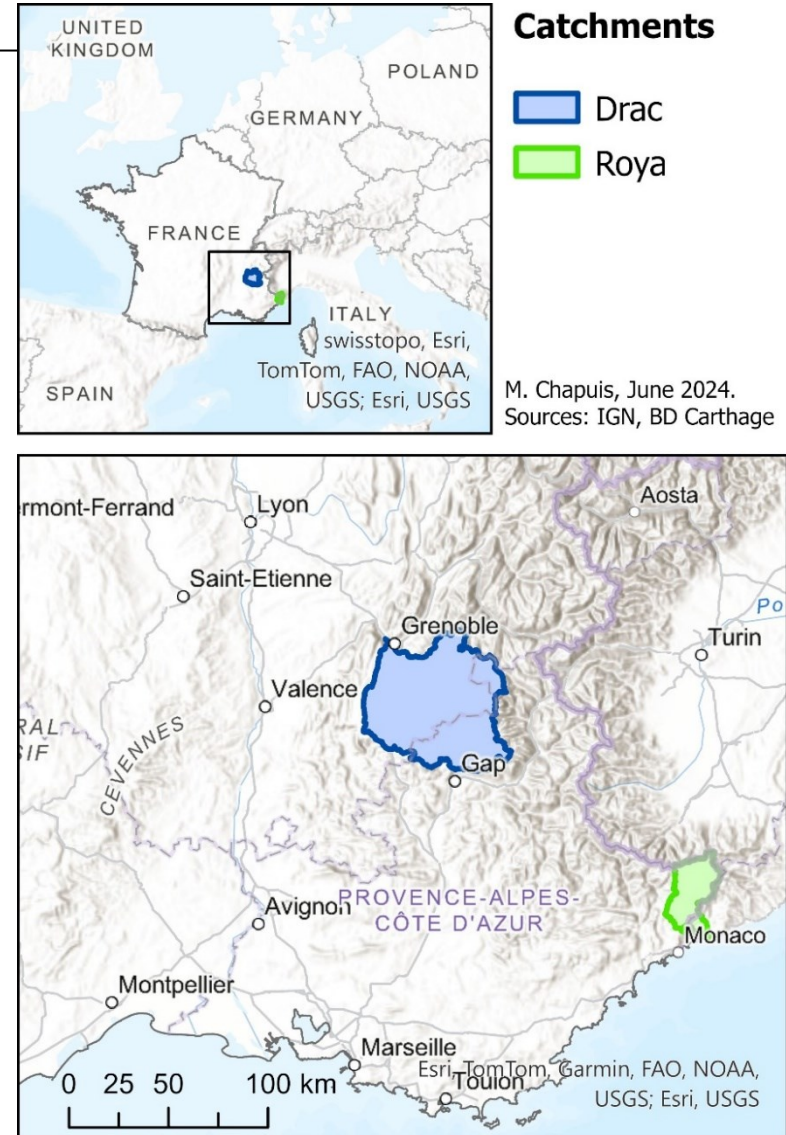
3/ What about human infrastructures (waterwaste treatment plants efficiency)?

Devreux et al., in prep.

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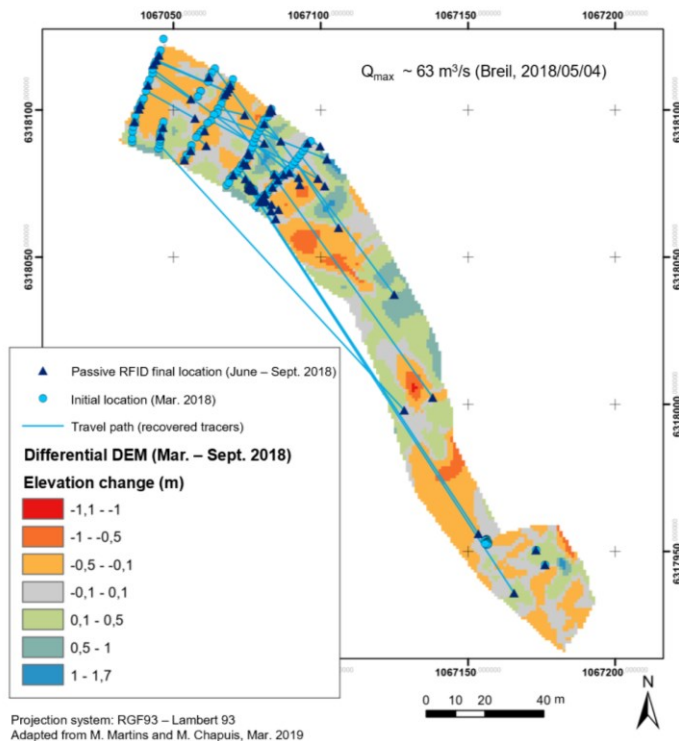
Chapuis *et al.*, 2022
Chapuis and Adnès, 2023
Chapuis, *submit.*



E. Results

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Fig.2. Passive RFID tracking at Lamberta bridge for trout habitat dynamics monitoring



Liébault et al., 2012

Trout spawning habitats

- Intense mobility of alluvial sediments ($\emptyset \sim \leq 512$ mm), even for small floods ($< Q_2$) prior to Oct. 2nd 2020 flood
- Frequent mobility of spawning material ($\emptyset < 64$ mm)
- Sediment mobility driven by boulders (inherited from past glacial activity), and by riverbed macroforms.

Chapuis et al., 2023

E. Results

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 - Sediment fluxes monitoring

Liébault et al., 2024

Oct. 2nd 2020
≥ 1000-year rainfall
 → ~1000-year flood
 → fluvial metamorphosis:
 single-thread → braided

Chapuis et al., 2022

Year of survey	2019	2020	2021
Q_{\max} at Breil (m ³ /s)	133	140	[1000;1500]
Nb of tracers found	17	16	4
Max. dist. of transport (m)			
Ambo/Fontan	240	632	5860
Pertus	166	50	-
Lamberta	-	2875	474

Table 1: RFID tracking and sediment transport distances

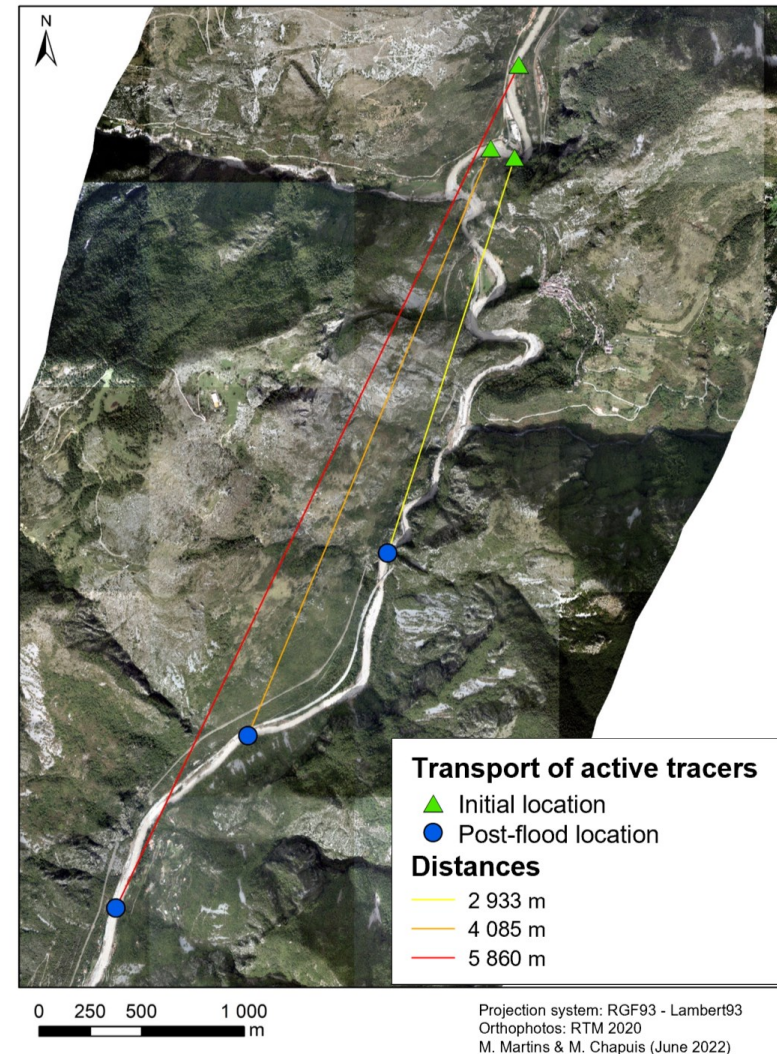
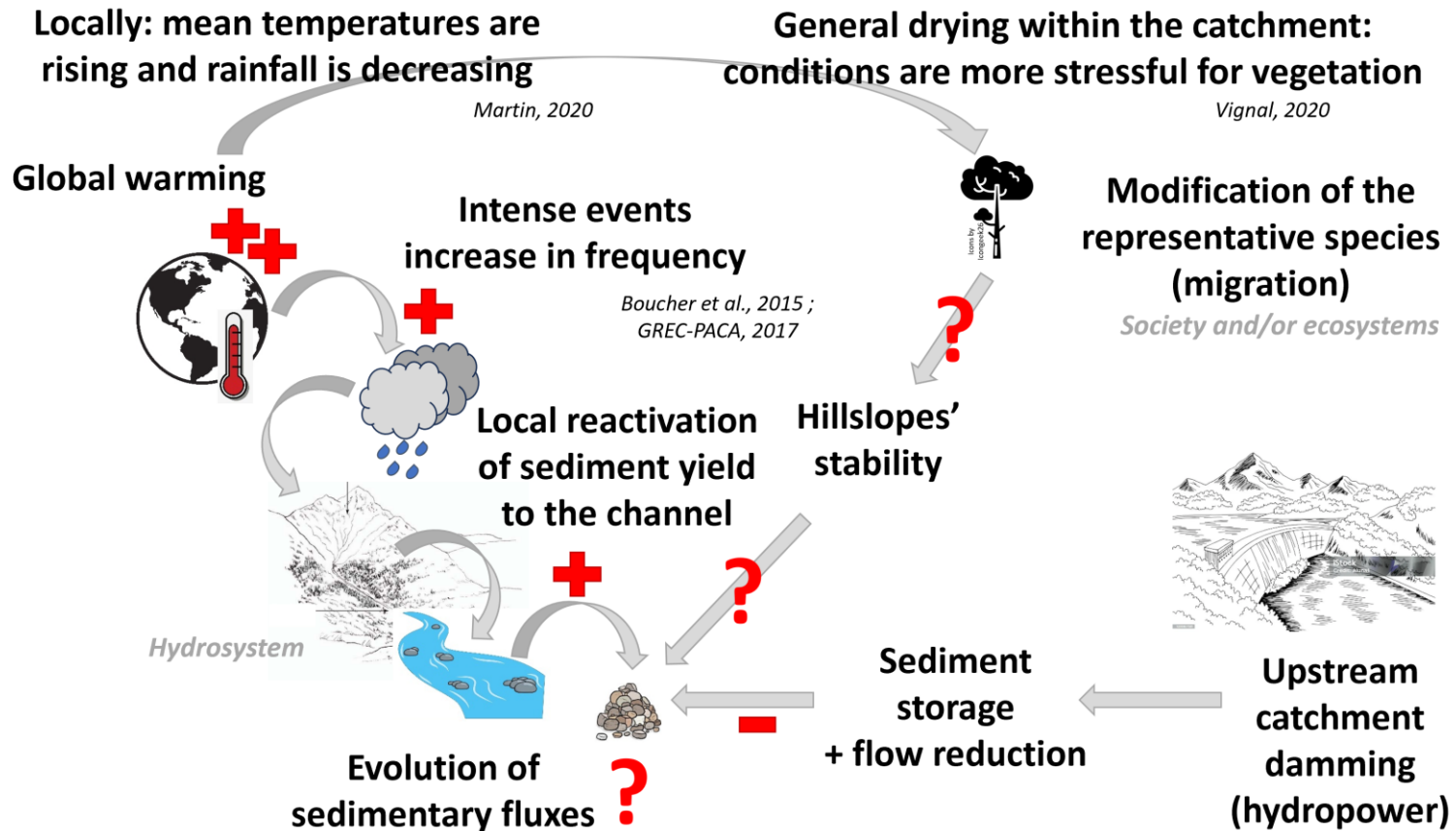


Figure 4: active RFID tracking 2021 survey

E. Results

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 - Hillslopes' vegetation dynamics



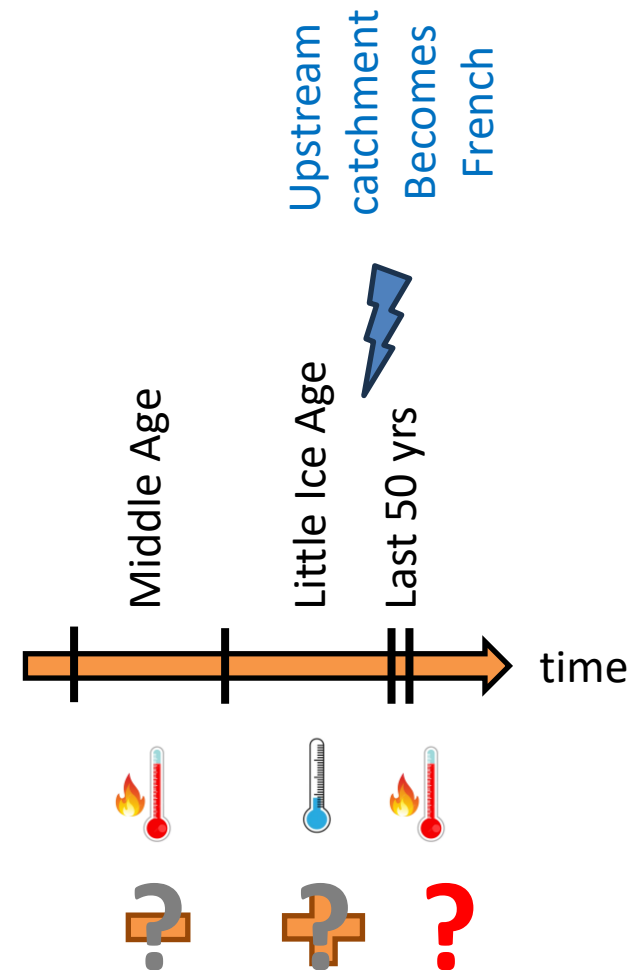
Adapted from Chapuis, *submit.*

E. Results

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France (after 1860)	Italy
Upstream catchment after 1860	Full catchment then only downstream after 1860
Rural exodus after the Middle Age (when?)	Maintain agriculture and rural activities on hillslopes
Landuse planning: complex and limited until after WWII	Agricultural terraces on hillslopes are still well attended
Vegetation encroachment of hillslopes (trees)	

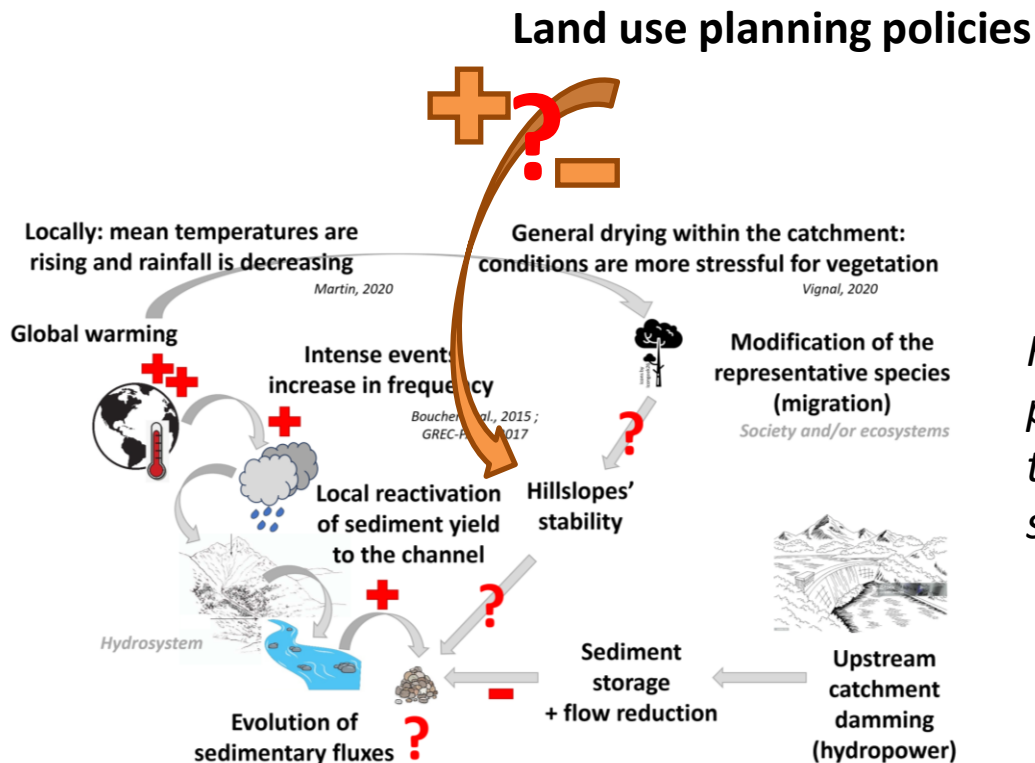
Adapted from Vignal, pers. comm.



Adapted from Purdue, pers. comm.

E. Results

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Hypothesis: land use planning policies influenced sediment yield to the channel through hillslopes' stability on an historical perspective

E. Results

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Main conclusions

The Roya river displays a unique example of sediment tracking experiment undertaken on a bi-national catchment, before and after a 1000 yrs return period flood event.

This constitutes a perfect occasion to explore the effects of:

- 1/ land use planning policies on sediment yield on a historical perspective**
- 2/ climate change effects on river systems sediment dynamics.**

F. Conclusions – take-home messages

- Aiming at a long term and sustainable river corridor management requires to consider the complexity of forms and processes affecting the various compartments of the hydrosystem
- We need to consider biotopes (i.e. geomorphology) and biocenosis (both fauna, vegetation and human needs), at different spatial and temporal scales.
- **Only by achieving transdisciplinary approach we will be able to produce valuable and operational knowledge for long term and sustainable river corridor management**

F. References

- Amoros C., Petts G. E., 1993. *Hydrosystèmes fluviaux*. Masson (in French), 300 pp.
- Anthony E. J., Julian M., 1999. Source-to-sink sediment transfers, environmental engineering and hazard mitigation in the steep Var River catchment, French Riviera, southeastern France. *Geomorphology*, vol. 31 (1–4), pp. 337-354. [https://doi.org/10.1016/S0169-5555\(99\)00088-4](https://doi.org/10.1016/S0169-5555(99)00088-4)
- Battiau-Queyry Y., 2002. La géomorphologie des origines à nos jours: une science jeune arrivée à maturité (Geomorphology from the origin to the present time). In: Bulletin de l'Association de géographes français, 79e année, 2002-21 (mars). *Géomorphologie et géographie aujourd'hui. Eau et territoire*, sous la direction de Y. Battiau-Queyry, I. Roussel et R. Laganier, pp. 4-14. <https://doi.org/10.3306/bagf.2002.2250>
- Belletti B., Dufour S., Piégay H., 2015. What is the relative effect of space and time to explain the braided river width and island patterns at a regional scale? *River Res. Applic.*, 31, pp. 1–15. <https://doi.org/10.1002/rra.2714>
- Belletti B., Rinaldi M., Bussetini M., Comiti F., Gurnell A. M., Mao L., Nardi L., Zezza P., 2017. Characterising physical habitats and fluvial hydromorphology: A new system for the survey and classification of river geomorphic units. *Geomorphology*, vol. 283, pp. 143-157. <https://doi.org/10.1016/j.geomorph.2017.01.032>
- Bergeret A., George-Marcelpoul E., Delanoy J.-J., Piazza-Morel D., 2015. L'outil-frise: une expérimentation interdisciplinaire: Comment représenter des processus de changements en territoires de montagne ?, *les Carnets du Labex ITEM* (in French), <https://hal.science/hal-01230027/>
- Boucher O., Dufresne J.-L., Vial J., Brun E., Cattiaux J., Chauvin F., Salas y Mélia D., Voldoire A., Bopp L., Braconnot P., Ciais P., Yiou P., Guilyardi E., Mignot J., Guivarch C., 2015. Projection des changements climatiques futurs. *La Météorologie*, n°88, pp. 56–68. https://lameteorologie.fr/issues/2015/88/meteo_2015_88_56
- Brigode P., Vigoureux S., Delestre O., Nicolle P., Payrastre O., Dreyfus R., Nomis S., Salvan L., l'équipe « post-event surveys » d'HyMeX, 2021. Inondations sur la Côte d'Azur: bilan hydro-météorologique des épisodes de 2015 et 2019. *LHB*, 107:1, 1-14. <https://doi.org/10.1080/27678490.2021.1976600>
- CEREMA, 2021. RETEX technique ALEX. Inondations des 2 et 3 octobre 2020. Expertise hydrologique. Rapport d'étape (54 p.) et Consensus hydrologique (58 p.).
- Chapuis M., Martins M., Tourade F., Adnès C., Vignal M., Lebourg T., Fox D., 2019. Évolution des flux sédimentaires des frayères dans un torrent alpin. *Rencontres SHF - Changement global et morphodynamique des rivières, des bassins versants à la mer*, nov. 2019, Paris, France. <https://hal.science/hal-02960437>
- Chapuis M., Martins M., Adnès C., Devreux L., Lebourg T., 2022a. Suivi des flux sédimentaires grossiers en contexte torrentiel méditerranéen. *Colloque TSMR – CFBR « Transport sédimentaire : rivières & barrages réservoirs »*, mars 2022, Saclay, France. <https://hal.science/hal-02959661>
- Chapuis M., Martins M., Adnès C., Tissot L., Martin N., Salvan L., Dreyfus R., Compagnon F., Douvnet J., Brigode P., Fox D., 2022b. Catchments' reactions to the Oct. 2nd 2020 heavy rainfall in the Maritime Alps (France): sediment transport measurements, sediment connectivity model in the Roya river and reconstruction guidelines. *IS Rivers 2022 Conference*, juil. 2022, Lyon, France. <https://hal.science/hal-03855452>
- Chapuis M., Adnès C., 2023. Pluri-annual bedload monitoring in a Mediterranean mountain stream prior and after a ~200-year flood. *Gravel-Bed Rivers 9 conference (GBR9)*, janv. 2023, Villarrica, Chile. <https://hal.science/hal-03975995>
- Chapuis M., *submit*. Coupled hydro- and sediment fluxes, a proxy for the interactions between climate and society at catchment scale ?, *Revue Méditerranée* (in French).
- Devreux L., 2023. Outils d'évaluation de l'état de santé des hydrosystèmes en tresses restaurés. Thèse de doctorat, Université Côte d'Azur, 401 p., <https://theses.hal.science/tel-04152884>
- Devreux L., Chapuis M., Belletti B., 2022. Hydromorphological analysis on restored Alpine braided rivers. *Geomorphology*, 415, pp. 108404. <https://hal.science/hal-03794714>
- Devreux L., Belletti B., Chapuis M., 2023. Tools to assess the health status of restored braided hydrosystems. Scientific Advances in River Restoration Conference, 06-08 Sept. 2023, Liverpool, UK. https://www.therrc.co.uk/sites/default/files/SARR/sarr_programme_abstracts_vsn_22.pdf (p.47)
- Devreux L., Belletti B., Marmonier P., Dolédec S., Chapuis M., *in prep*. Restoring braided rivers: the need to account for geomorphological heterogeneity. *River Research and Applications*.
- Dufour S., Rollet A.J., Chapuis M., Provansal M., Capanni R., 2017. On the political roles of freshwater science in studying dam and weir removal policies: A critical physical geography approach. *Water Alternatives* 10(3): 853-869. <https://hal.archives-ouvertes.fr/hal-01614436>
- Dufour S., Lespez L., 2020. Géographie de l'environnement: La nature au temps de l'anthropocène. Armand Colin (in French). <https://doi.org/10.3917/arco.dufou.2020.01>
- FRYC K. A., Brierley G. J., Preston N. J., Kasai M., 2007. Buffers, barriers and blankets: The (dis)connectivity of catchment-scale sediment cascades. *Catena*, 70(1), 49-67. <https://doi.org/10.1016/j.catena.2006.07.007>
- GREC-PACA, 2017. Les ressources en eau et le changement climatique en Provence-Alpes-Côte d'Azur. Les cahiers du GREC-PACA, édités par l'Association pour l'innovation et la recherche au service du climat (AIR), juil. 2017, 52 p., ISBN : 9782956006053. <http://www.grec-sud.fr/publications/les-ressources-en-eau-et-le-changement-climatique-en-provence-alpes-cote-dazur/Hart-346>
- Liébault F., Melun G., Piton G., Chapuis M., Passy P., 2024. Channel change during catastrophic flood: example of the storm Alex in the Vésubie and Roya valleys. *Geomorphology*, 446, pp. 109008. <https://doi.org/10.1016/j.geomorph.2023.109008>
- Liu J., Dietz T., Carpenter S. R., Alberti M., Folke C., Moran E., Pell A. N., Deadman P., Kratz T., Lubchenco J., Ostrom E., Ouyang Z., Provencher W., Redman C. L., Schneider S. H., Taylor W. W., 2007. Complexity of Coupled Human and Natural Systems, *Science*, American Association for the Advancement of Science, 317, 1513-1516. <https://www.science.org/doi/10.1126/science.1144004>
- Martin N., 2020. Cartographies climatiques à 25 m des températures et des précipitations dans la vallée de la Roya. Congrès final du projet Concert-Eaux, [en ligne], 11 déc. 2020. <https://www.youtube.com/watch?v=tFC-xgCO3TE>
- Melun G., Liébault F., Piton G., Chapuis M., Passy P., Kuss D., Martins C., 2022. Crues exceptionnelles de la Vésubie et de la Roya (Oct. 2020): caractérisation hydrogéomorphologique et perspectives de gestion. *IS Rivers 2022*, ZABR, GRAIE, Juil. 2022, Lyon, France. [https://www.graie.org/graie/graiedoc/doc_telech/isrivers2022/A5/A5_ISRivers22%20\(3\).pdf](https://www.graie.org/graie/graiedoc/doc_telech/isrivers2022/A5/A5_ISRivers22%20(3).pdf). <https://hal.science/hal-04261090>
- https://www.researchgate.net/publication/363108141_Crues_exceptionnelles_de_la_Vesubie_et_de_la_Roya_Oct_2020_caracterisation_hydrogeomorphologique_et_perspectives_de_gestion
- Misset C., Recking A., Legout C., Bakker M., Bodereau N., Borgniet L., Cassel M., Geay T., Gimbert F., Navratil O., Piégay H., Valsangkar N., Cazilhac M., Poiré A., Zanker S., 2020. Combining multi-physical measurements to quantify bedload transport and morphodynamics interactions in an Alpine braiding river reach. *Geomorphology*, vol. 351, pp. 106877. <https://doi.org/10.1016/j.geomorph.2019.106877>
- Misset C., Recking A., Legout C., Bakker M., Bodereau N., Borgniet L., Cassel M., Geay T., Gimbert F., Navratil O., Piégay H., Valsangkar N., Cazilhac M., Poiré A., Zanker S., 2020. Combining multi-physical measurements to quantify bedload transport and morphodynamics interactions in an Alpine braiding river reach. *Geomorphology*, vol. 351, pp. 106877. <https://doi.org/10.1016/j.geomorph.2019.106877>
- Payrastre O., Nicolle P., Bonniaff L., Brigode P., Astagneau P., Baise A., Belleville A., Bouamara N., Bourgin F., Breil P., Brunet P., Cerbelaud A., Courapied F., Devreux L., Dreyfus R., Gaume E., Nomis S., Poggio J., Pons F., Rabab Y., Sevez D., 2022. The 2 October 2020 Alex storm in south-eastern France : a contribution of the scientific community to the flood peak discharges estimation. *LHB, Taylor & Francis*, pp. 20282891. <https://doi.org/10.1080/27678490.2022.2082891>
- Piton G., Queffelec Y., Liébault F., Kuss D., Carladou S., Robert Y., Martins C., Guitet C., 2021. Alpes-Maritimes – Gestion post-Tempête Alex : Réflexions sur l'estimation de la période de retour des changements morphologiques majeurs associés aux crues extrêmes. Note technique, version 4, INRAE & ONF-RTM, 9 p.
- Piton G., Cohen M., Flipo M., Nowak M., Chapuis M., Melun G., Robert Y., Andréis N., Liébault F., 2024. Large in-stream wood yield during an extreme flood (Storm Alex, October 2020, Roya Valley, France): estimating the supply, transport, and deposition using GIS. *Geomorphology*, 446, pp. 108981. <https://doi.org/10.1016/j.geomorph.2023.108981>
- Regione Liguria, 2021. Progetto "Concert-Eaux" – WP 4_3 Modalità di gestione dei sedimenti del tratto terminale del Fiume Roa. Rapport technique (en italien), Regione Liguria, Dipartimento Ambiente e Protezione Civile – Settore Assetto del Territorio, 55 p. <https://www.concert-eaux.eu/it/notizie-it/prodotti-it/category/8-wp-4-studi-analisi-ed-attivita-derivate?download=148:concert-eaux-4-3-1-piano-gestione-sedimenti-ri-it>
- Rhoads B. L., 2004. Whether Physical Geography? *Annals of the Association of American Geographers*, 94(4), 748–755. <http://www.jstor.org/stable/3694094>
- Schumm S.A., 1977. *The Fluvial System*. John Wiley and Sons, New York, 338 p.
- Serrhini-Najji G., 2021. Monographie historique du transport sédimentaire en Cévennes: une approche par les hybrides. Master thesis (in French), Université de Technologie de Compiègne, 75 p.
- Sømme T. O., Helland-Hansen W., Martinsen O.J., Thurmond J.B., 2009. Relationships between morphological and sedimentological parameters in source-to-sink systems: a basis for predicting semi-quantitative characteristics in subsurface systems. *Basin Research*, 21: 361-387. <https://doi.org/10.1111/j.1365-2117.2009.00397.x>
- Swanson K. J., 1980. Geomorphology and ecosystems. In: *Forests: fresh perspectives from ecosystem analysis*. Proceedings of the 40th annual biology colloquium; 1979 Nov. 27-28. Waring, Richard H., ed, Oregon State University Press: 199 p., <https://andrewsforest.oregonstate.edu/sites/default/files/ter/pubs/pdf/pub579.pdf>
- Thibaut K., Ayral P.-A., Ozer P., 2023. Development of the chrono-systemic timeline as a tool for cross-sectional analysis of droughts—application in Wallonia. *Water*, 15(23), Article 23. <https://doi.org/10.3390/w15234150>
- Vignal M., 2020. L'impact du changement global sur la flore du Sud-Est de la France : Modélisation multiscale de la répartition de 25 espèces à l'horizon 2100 par la dynamique de population. Thèse de doctorat, Université Côte d'Azur, 474 p. + vol. d'annexes, <https://theses.hal.science/tel-03105744>

River corridors facing change in Alpine and Mediterranean climate: anthropogenic pressures vs. extreme events vs. climate change, a coupled geomorphic and ecologic point of view

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