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On the Political Roles of Freshwater Science in Studying Dam and Weir Removal Policies: A Critical Physical Geography Approach

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ABSTRACT: Over the last decade, dam and weir removal has been promoted to improve continuity along many river systems. However, such policies raise many socioecological issues such as social acceptability, integration of different river uses, and real impacts on river ecosystems. In this article, we illustrate how critical physical geography can help connect sociopolitical issues with biophysical processes. Our analysis is based on case studies located in different geographic contexts but in any case, a detailed understanding of biological or hydromorphological processes emphasises different social and political issues related to dam and weir removal. For example, riparian vegetation is usually ignored in dam-removal studies (unlike fish or macroinvertebrates) and its response to dam removal raises the issue of how different nonhuman actors are represented (or not) in the debate and weighed in the decision. An accurate understanding of sediment dynamics can also address the sociopolitical process because it identifies effective measures for reaching an objective such as the restoration of sediment fluxes. In our case studies, this understanding demonstrates that removal can be technically possible but ineffective or insufficient. From a sociopolitical perspective, this can increase the number of stakeholders (with diverse power relationships) that need to be included in the debate. We conclude that the diversity of sociopolitical issues associated with dam and weir removal is partially connected to the nature of biophysical processes and patterns and that neither aspect can be analysed separately.

KEYWORDS: Sediment transfer, riparian vegetation, dam removal, critical physical geography, France

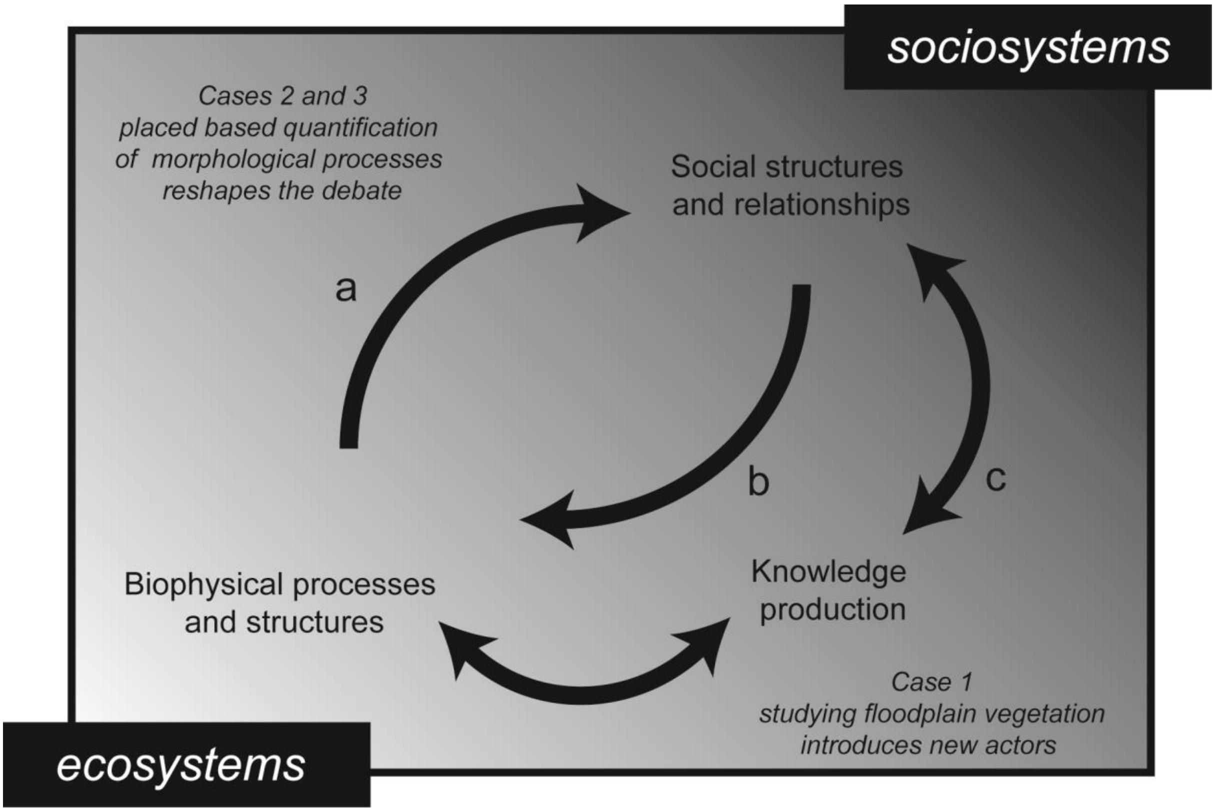
INTRODUCTION

Over the last decade, dam and weir removal has been promoted to restore many river systems, especially in the United States (USA) and the European Union (EU) (Bowman 2002; Feld et al., 2011). In addition to safety and economic issues (mainly regarding old dams considered as dangerous or nonprofitable), the goal of removal, as advocated in the scientific literature, is to improve the state of watercourses based on three main scientific rationales: recover the natural hydrological regime, ensure the movement of migratory species, and transfer sediment (Gregory et al., 2002; Hart et al., 2002). Given these ecological issues, the natural sciences (mainly aquatic ecology, stream hydrology, and fluvial geomorphology) are frequently used to analyse, justify and monitor removal of dams or weirs. Many studies focus on only one issue, such as vegetation recolonisation (Auble et al., 2007), monitoring the response of stream fish (Gardner et al., 2011; Poulos et al., 2014; Kornis et al., 2015) or aquatic macroinvertebrates (Chiu et al., 2013), sediment and nutrient dynamics (Ahearn and Dahlgren, 2005; Grant and Lewis, 2015) or morphological adjustments (Walter and Tullos, 2009; Im et al., 2011; East et al., 2015). Multiple ecological issues are sometimes combined to provide more systemic assessment of an action that is considered an ecological disturbance (Stanley and Doyle, 2003). For example, Doyle et al. (2005) reviewed riparian vegetation, fish, macroinvertebrates, mussels, and nutrient dynamics, while Magilligan et al. (2015) monitored channel morphology, aquatic habitats, and groups of fish.

However, removal is not just a technical question but it also raises sociopolitical issues, such as social acceptability and integration of different river uses. Several authors have discussed cultural, sociological, economic, and political issues involved in dam removal. Studies have examined reasons for conflicts (and the underlying values behind them) (Lejon et al., 2009; Jorgensen and Renofalt, 2012) and reasons for agreement and *disagreement about dam removal (Gosnell and Kelly, 2010). Multiple social, cultural, and* political structures and processes have been identified as key components of such restoration projects (Germaine and Barraud, 2013; Germaine and Lespez, 2014; Magilligan et al., 2017). Fox et al. (2016) analysed cultural dynamics, micropolitics, and competing interpretations of nature that help to explain resistance to removals in New England, USA.

Natural and social-science studies provide a large amount and a wide range of knowledge about dam removal. However, ecosystem and social issues are often analysed separately. We illustrate how a critical physical geography framework, among others, can help connect sociopolitical issues with biophysical processes. 'Critical physical geography' was recently coined to describe a body of work that analyses environmental issues via the physical characteristics of landscapes and the dynamics of social relationships (Figure 1). It is fundamentally an integrative perspective that studies the coevolution of socioecosystems and feedback within these systems with a thorough understanding of the interconnectedness of biophysical processes and power relations within society (Lave et al., 2013; Lave, 2015). In general, the main goals are to assess the influence of power relations within societies on physical landscapes (Figure 1b), combine radical analysis of societal structures and processes with biophysical facts (Figure 1a) and encourage scientists to consider the sociopolitical context of their own practices and associated politics of scientific knowledge production (Tadaki et al., 2015; Tadaki, 2016; Blue and Brierley, 2016; Lave, 2016) (Figure 1c). Thus, the approach shares several similarities with environmental geography and is similar to earlier studies in political ecology (Blaikie and Brookfield, 1987) as it includes the physical dimension of environmental issues. It wants to keep focus on explaining the biophysical. Regarding dam and weir removal, we used a portion of the critical physical geography framework (i.e. arrows 'a' and 'c' in Figure 1) to demonstrate that a thorough understanding of biological or hydromorphological processes produced by physical geographers is crucial for each potential or completed project. Indeed, this understanding through science activity can identify certain place-based biophysical characteristics that emphasise different social and political issues ('arrow a') and raises the question of knowledge that is used in removal policy ('arrow c').

Figure 1. Examples of potential relationships between ecosystems and sociosystems studied in critical physical geography



Note: understanding how (a) biophysical processes influence social relationships and (b) social relationships influence biophysical processes. The relationships are often studied as (c) how to integrate social determinants in the understanding of biophysical processes. Study cases are used in italics to illustrate the relationships.

Our analysis is based on three case studies located in different geographic contexts: two low-/medium-gradient small rural rivers in north-western France (Vire and Orne; Case 1), a large dynamic gravel-bed river in the southern French Alps (Durance; Case 2) and a small coastal gravel-bed river that flows into the Mediterranean Sea (Gapeau; Case 3) (Figure 2; Table 1). We analysed the influence of dam and weir removal from a biological viewpoint (i.e. tree growth in case 1) and from a physical viewpoint (i.e. sediment transport in cases 2 and 3). These analyses are included in the discussion to highlight the sociopolitical implications. We used three cases because they stress different aspects of Critical Physical Geography framework. Case 1 illustrates how Critical Physical Geography helps scientists to think about how knowledge production through science is political because it introduces new actors ('arrow c' in Figure 1) and cases 2 and 3 illustrate that placed-based biophysical conditions can play a crucial role in shaping the debate in removal policies implementation ('arrow a' in Figure 1). For each case, we present the biophysical issues and, then, the sociopolitical, socio-ecological and socio-geomorphological issues are discussed.

Figure 2. Locations of the catchments studied in France.

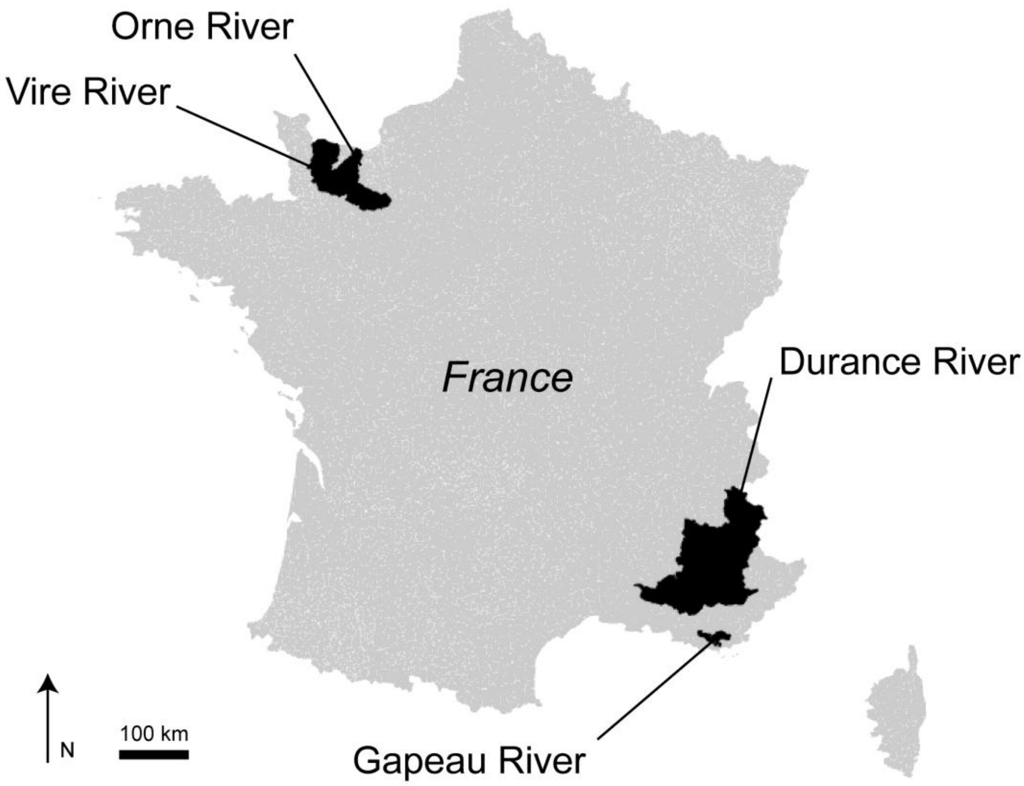


Table 1. General characteristics of the rivers and sites studied.

	River system			
	Vire	Orne	Gapeau	Durance
River length (km)	128	170	50	305
Catchment area (km²)	1970	2930	560	14280
Climate	Oceanic	Oceanic	Mediterranean	Mountainous to Mediterranean
Annual mean daily discharge (m^3/s)*	12.7	24.7	3.9	215
Specific mean discharge (l/s.km²)*	14.8	9.9	7.5	15.1
Mean daily 10-year flood discharge (m^3/s)*	180	320	180	2950
Mean width (m)	20	30	20	240
Mean slope (m/km)	1	2	2	3

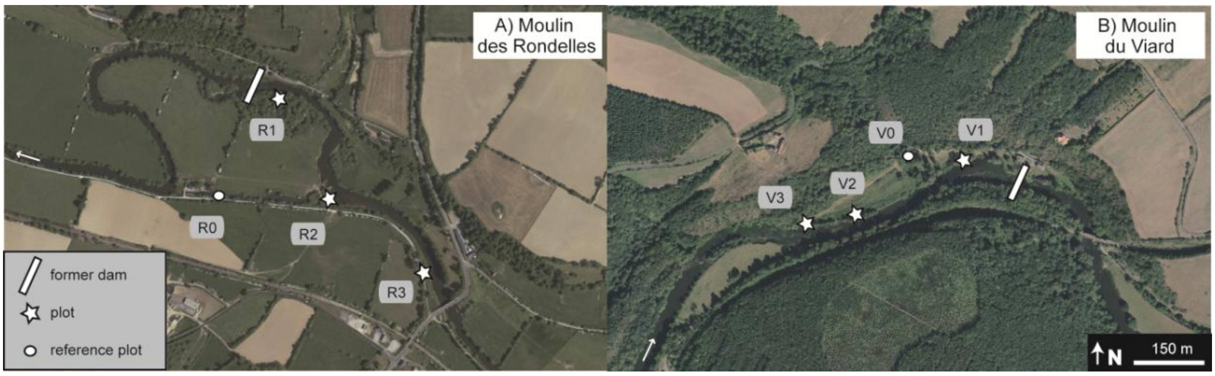
Note: Hydrological data are respectively from Moulin des Rondelles, May sur Orne, Sainte Eulalie and Bonpas gauging stations (source: www.hydro.eaufrance.fr); for the Durance River, discharge includes values before river regulation (source: Juramy and Monfort, 1986).

CASE STUDY 1: RESPONSE OF FLOODPLAIN VEGETATION TO WEIR REMOVAL ALONG THE VIRE AND ORNE RIVERS

Context and method

Ecological assessment of dam and weir removal focuses mainly on channel ecosystems (e.g. fish habitats, macroinvertebrate communities), and floodplain ecosystems are usually ignored or considered less often. When riparian vegetation is studied, it is limited to the recolonisation process in dewatered fluvial landforms (Auble et al., 2007; Michel et al., 2011) and the response of existing floodplain ecosystems to removal is ignored. To obtain a broader perspective of biophysical issues related to dam removal, we studied the influence of variation in water level caused by weir removal on existing vegetation. We used dendrochronological analysis of riparian tree growth following two dam removals along the Vire and Orne Rivers in north-western France (Figure 2). These are low/moderate-gradient small rural rivers that contain migratory fish species (e.g. *Alosa alosa*, *A. falax falax*, *Salmo trutta trutta*, *S. salar*, *Petromizon marinus*, *Lampetra fluviatilis*) and consequently generate concern about fluvial system restoration practices. For each river, we surveyed one site in which a small dam was removed in 1997 (Table 2). At each site, we sampled trees within four plots: three plots along the river upstream of the former dam and one reference plot (i.e. unaffected by the removal) (Figure 3). For each plot, we collected two tree cores at breast height using 5-mm diameter increment borers from three to five dominant trees (total number of trees per river = 18; total number of cores per river = 36). Cored species are common riparian species of these rivers: *Alnus glutinosa* (n= 21), *Fraxinus excelsior* (n= 7), *Tilia platyphyllos* (n = 5), and *Acer pseudoplatanus* (n = 3). The cores were cross-dated and annual ring-widths were measured under a microscope using TSAP-Win software (RINNTECH, Heidelberg, Germany). Significant changes in tree growth patterns were statistically assessed using a Pettitt test (Pettitt, 1979). We also analysed discharge and precipitation data to assess significant changes in these drivers during the study period (i.e. 1981-2012).

Figure 3. Plot location within the sites of A) Moulin des Rondelles and B) Moulin du Viard (source: IGN).



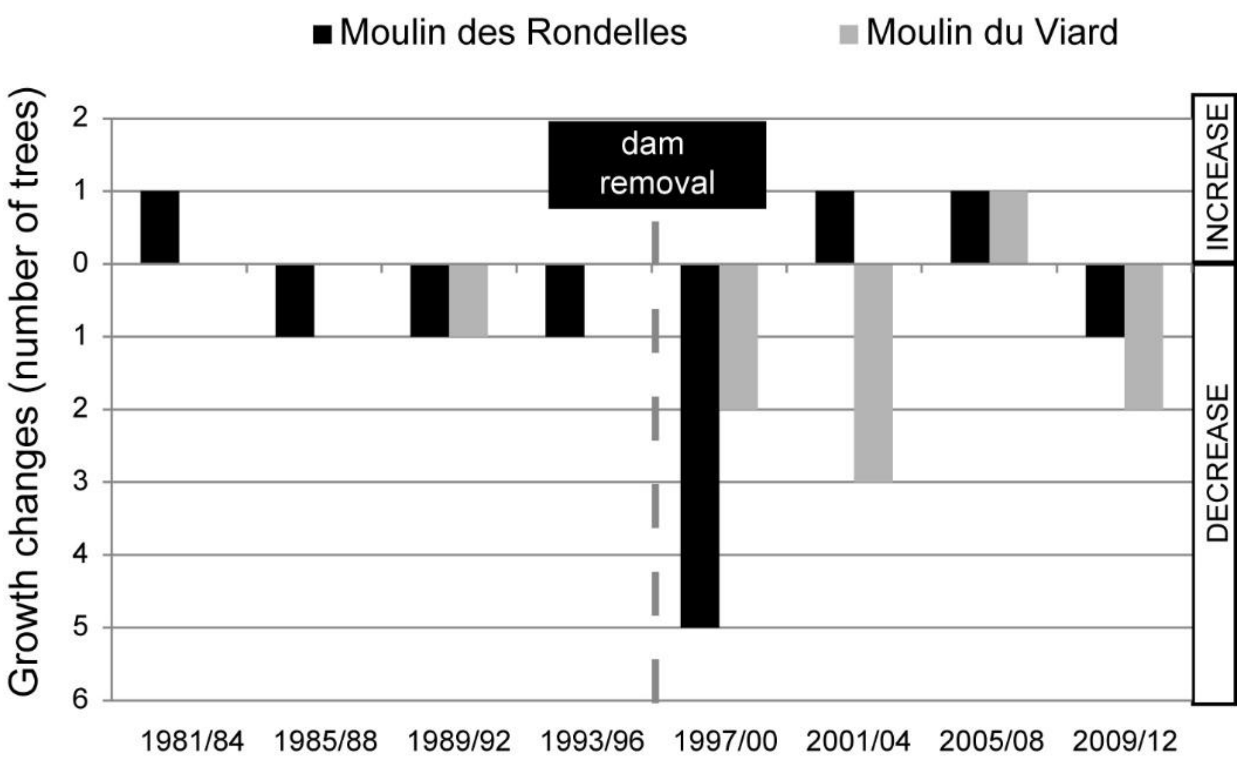
Results

No significant changes in climatological or hydrological conditions were observed during the study period (Depoilly and Dufour, 2015); however, 74% of the trees experienced a significant change in growth during their lifespan. Among the 74%, only 14% of the significant changes occurred before dam removals, while 60% occurred after removals, with the highest frequency in the three to six years immediately after removal (Figure 4).

Table 2. General characteristics of the sites studied along the Vire and Orne rivers

River system	Vire	Orne
Site	Moulin des Rondelles	Moulin du Viard
Distance from the source (km)	80	140
Landscape	Rural, narrow strip of riparian vegetation	Rural, narrow strip of riparian vegetation
Reach gradient ($m.km^{-1}$)	≅ 1	≅ 2
Channel width (m)	15-25	25-35
Dam height (m)	3	2
Year of dam removal	1997	1997

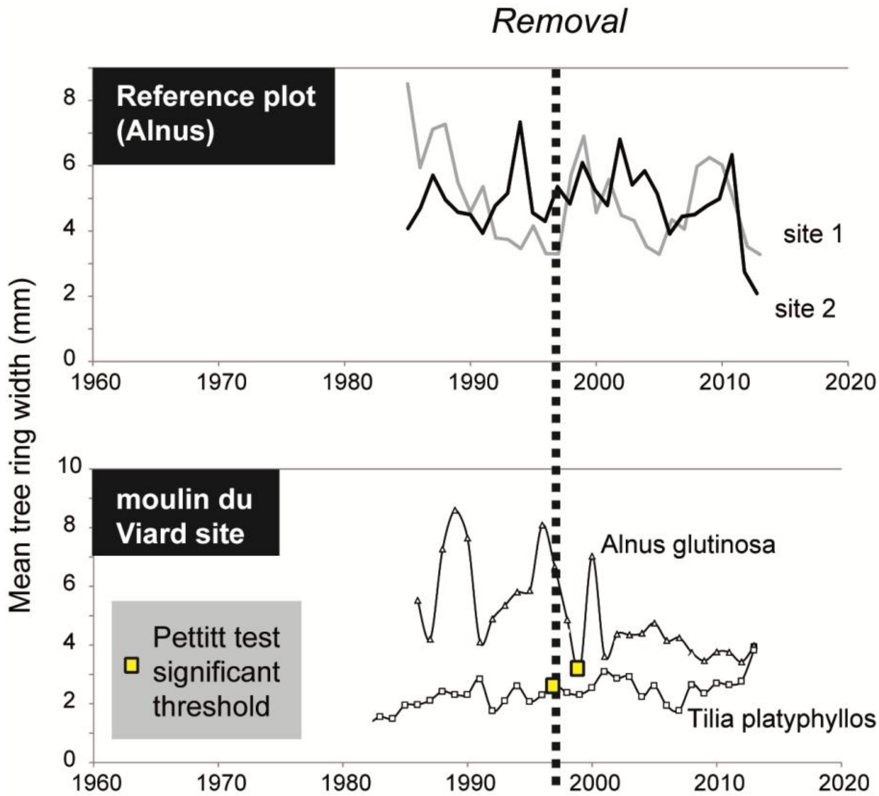
Figure 4. Periods during which significant changes in tree growth occurred along the Vire (Moulin des Rondelles site) and Orne (Moulin du Viard site) rivers.



Note: Values indicate the number of individual trees with an increase or decrease in growth.

At the plot and individual scale, no significant changes were observed in the reference plots following dam removal, although mean growth decreased for phreatophytic species such as *Alnus glutinosa* and slightly increased for mesophytic species such as *Tilia platyphyllos* (Figure 5). The biological response indicates that dam removal seems to modify the hydroecological functioning of the floodplain in the direction of a potential decreasing wetness and thus of potential loss of wetlands.

Figure 5. Multiannual dynamics of riparian tree growth before and after dam removal.



CASE STUDY 2: RESTORATION OF SEDIMENT TRANSFER IN THE GAPEAU RIVER TO FIGHT COASTAL EROSION

Context and method

The Gapeau River is a coastal gravel-bed river system that flows into Hyères Bay in the Mediterranean Sea (Figure 2). A previous geomorphological study identified a sediment deficit in the coastal system of 2200-2700 $m^3.year^{-1}$ during the 20th century (Capanni, 2012). This deficit is a critical management issue because Hyères Bay is a tourist destination, and artificial deposits are needed on the beaches each year to compensate for the deficit (Figures 6a and 6b). Theoretically, this deficit is caused by three main drivers: sea-level rise, changes in coastal processes due to hard defence structures and harbour construction and reduction in fluvial sediment inputs. One option discussed by river managers[1] is to remove some of the small dams and weirs along the fluvial network to restore sediment fluxes (one small dam or weir occurs every 1.2 km along the main stem) (Figure 6c).

To assess the current influence of weirs on sediment transfer, we surveyed the bathymetry in the reservoir of the largest dam in the network (Sainte Eulalie Dam; Figure 5c) to assess its trap efficiency. This 3-m high weir, with an upstream reservoir 700 m in length, is located in the downstream portion of the network, 5.5 km from the mouth. Bathymetric surveys of the reservoir were performed using an acoustic doppler current profiler (RDI teledyne instruments, USA) and a real time kinematic global positioning system (TRIMBLE, California, USA) in September 2007, March 2008 and June 2008. One flood occurred during the first period (September to March) and two floods occurred during the second period (March to June) (return interval of 1.5 year each).

[1] P. Doucelance, Water Agency, Pers. Com.

Figure 6. a) Coastal erosion in Hyères Bay; b) Artificial sediment supply to beaches; and c) Small weir (Sainte Eulalie Weir) along the Gapeau River.

Results

Bathymetric surveys of the Sainte Eulalie weir reservoir demonstrate that the dam does not trap sediments (Table 3). A net storage of 480 m^3 was observed from September 2007 to March 2008, but the balance was negative (-650 m^3) during the second period. Visual observations, regularly spaced in the reservoir, indicate that the sediments contain sand and pebbles. In the nine months studied, the reservoir lost approximately 80 m^3 of sediment, which passed through the weir. This indicates that the modest dimensions of the weir do not create a break in the slope high enough to limit sediment mobility. The weir may be nearly full of sediment because it existed before 1896 according to old maps and has not been recently dredged. Regardless of the reason for the transfer, in this situation weir removal would not restore sediment transfer because it still occurs. Capanni (2012) demonstrated that the decrease in sediment fluxes in the downstream part of Gapeau catchment is due more to a decrease in upstream production than to intermediate trapping behind dams. In this context, weir removal would not restore sediment continuity.

Table 3. Volume of sediment eroded and deposited in the Sainte Eulalie Reservoir of the Gapeau River.

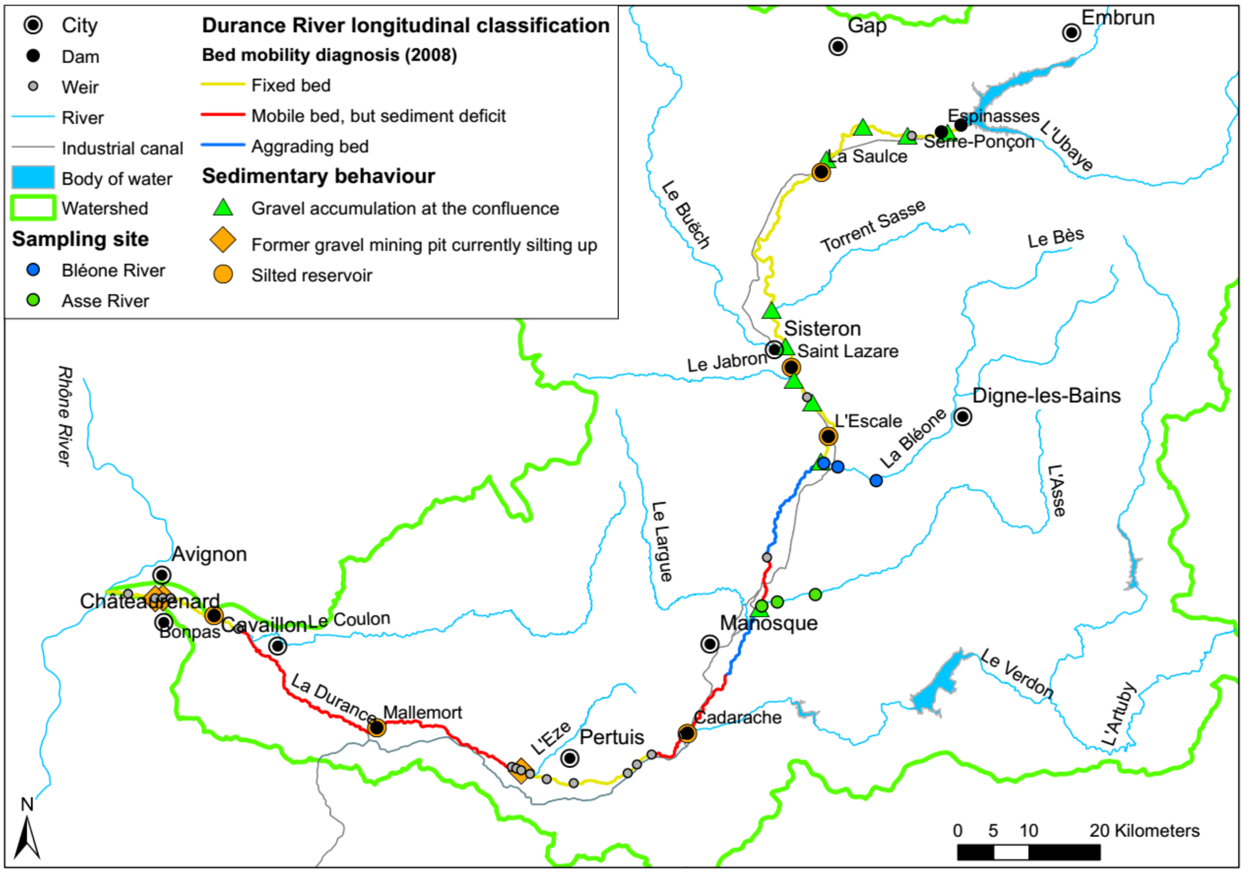
Period	Erosion	Deposition	Balance
September 2007 – March 2008	20 m^3	500 m^3	+ 480 m^3
March 2008 – June 2008	700 m^3	50 m^3	- 650 m^3
September 2007 – June 2008	200 m^3	120 m^3	- 80 m^3

Case study 3: Restoration of sediment transfer in the Durance River to decrease channel incision

Context and method

The Durance River is a steep, large wandering gravel-bed river that flows across the southern French Alps (Figure 2). Between 1950 and 1980, the fluvial system was deeply modified by river regulation and sediment mining. Flow diversion decreased mean annual discharge from 180 m^3/s to 40 m^3/s. Gravel mining, which occurred mostly in the downstream portion, was estimated at 60 million m^3 over 40 years. Because of these drivers, the current morphological functioning is defined by sediment accumulation and riverbed aggradation in the middle reach where tributaries still provide coarse sediments, with a sediment deficit and bed incision in the downstream reach (Figure 7). This deficit causes management issues such as embankment undermining, which increases flood risk, and degradation of channel substrate quality, which impacts the fish population. A potential solution discussed by river managers is to increase sediment transfer from upstream to downstream by solving the discontinuity problem generated by the Cadarache Dam (Figure 7).

Figure 7. Durance River morphological diagnosis regarding sediment behaviour and bed mobility.



Note: Cadarache Dam is located between an excess of coarse sediment upstream and a deficit of sediment downstream. Sediment sampling sites are located on two tributaries, the Bléone River and the Asse River, whose confluences show gravel accumulation and determine aggrading reaches.

We analysed sediment size and lithology to test if it is possible to transfer sediments from Durance tributaries to the in-deficit downstream reach. The abrasion during sediment transport decreases the size of bed material. Durance tributaries supply coarse limestone particles, which are abraded more during transport than metamorphic particles supplied by other subcatchments. Thus, a risk exists of providing the downstream reach with sediments too small to compensate for the coarse-bedload deficit.

The size of tributaries' sediments was assessed by *in situ* measurement. At three sites in each of the two tributaries, 400-particle Wolman samples were collected from coarse surface bed material (Wolman, 1954). Sampling sites were located less than 9 km upstream of each confluence in the Durance River mainstream. We measured grain size along the *b*-axis and tested each particle with hydrochloric acid to assess whether it had limestone lithology. To model particle abrasion during transport, we used the D_{90}, D_{50}, and D_{10} from the corresponding grain size distributions.

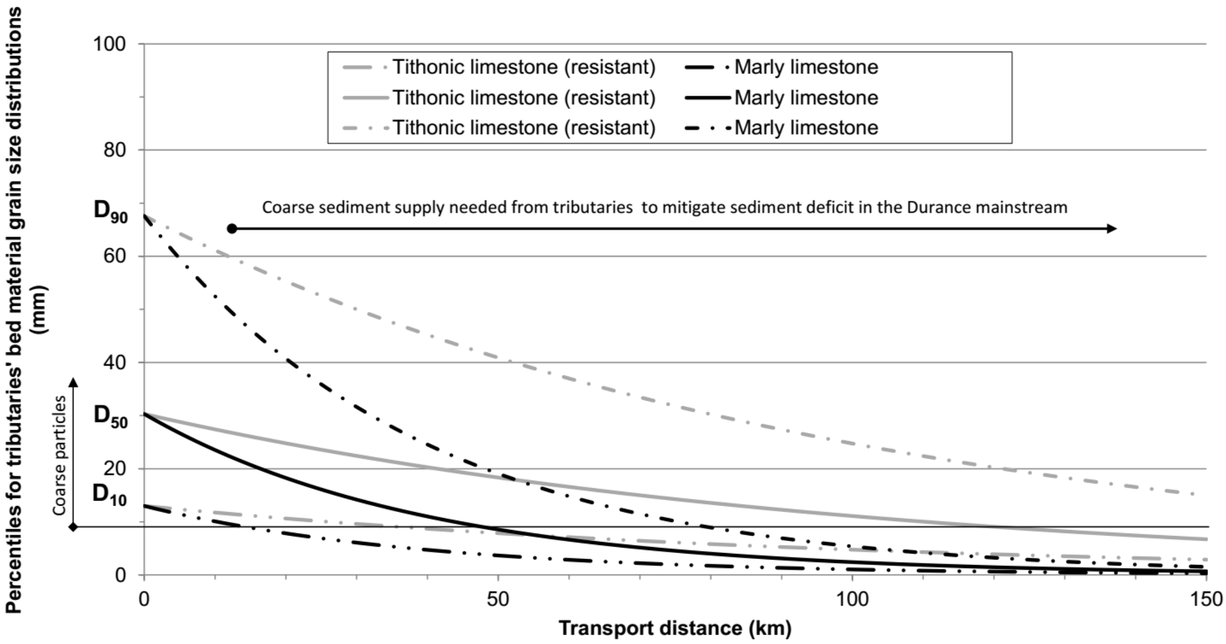
No abrasion rate values were available for the studied tributaries' bed material, but values for similar lithologies were available for bed material of the Buëch River, another Durance tributary located

17 km upstream (Attal, 2003). Limestone abrasion rates there ranged from 1.0 (for Tithonic and Cretaceous limestone assumed to be resistant) to 2.5 (marly limestones assumed to be less resistant), which demonstrates the diversity of limestone lithology in the two tributaries' catchments (Chapuis, 2012). Particle size as a function of transport distance was then calculated.

Results

Grain size measurements and abrasion modelling of the Durance Riverbed load indicate that the sediments in the aggraded reaches would be too small when they enter the sediment-deficient reach (Figure 8). They would not restore coarse-sediment continuity and counteract morphological processes due to sediment deficit. To counteract the deficit, intermediate sediment sources must be reactivated to help sediment arrive downstream of the aggraded reach. There are no major tributaries between aggraded and in-deficit reaches of the Durance River that can provide a substantial amount of coarse sediment. Thus, sediments can come only from floodplain/terrace deposits, which can enter the channel via lateral erosion, which increases in the presence of a gravel bar in the active channel (Constantine, 2006). Although sediment transfer from the upstream aggraded area cannot directly reduce bed degradation in the downstream sediment-deficient reach, it could help settle gravel deposits on the intermediate reach and increase lateral erosion and sediment input, which could decrease the sediment deficit. To initiate this positive feedback loop, dam removal must also include removal of bank protection along the intermediate reach to enable lateral erosion after gravel bar restoration.

Figure 8. Decrease in modelled sediment grain size (D_{90}, D_{50}, and D_{10}) in Durance River due to abrasion during transport.



Note: Curves represent Tithonic (grey) and Marly (black) limestone lithology. We considered particles to be coarse when their *b*-axis exceeded 8 mm (vertical arrow). The horizontal arrow corresponds to the sediment-deficient reach downstream of the confluences in Figure 7.

DISCUSSION

In this section we discuss how physical geography, by studying the previously mentioned biological and hydromorphological processes related to dam and weir removal, raise several social and political issues, two of which are described in detail. First, using cases 1, 2 and 3, we discuss how definition of the removal goal is influenced by knowledge production and the weight of specific actors (see 'arrow c' in Figure 1). This issue stresses that Critical Physical Geography helps scientists to think about how science is political. Second, using cases 2 and 3, we discuss that the removal can be insufficient or ineffective (i.e. removal will likely fail to realise by itself restoration objectives that are sediment transfer), which indicates that new stakeholders should be included in the restoration plan (see 'arrow a' in Figure 1). This issue stresses that placed-based biophysical conditions can significantly contribute to shape the social component of freshwater management.

Science is political: Removing for what? Who is speaking?

Retrospective analysis of tree ring growth over a 30-year period in riparian vegetation of the Orne and Vire rivers indicates a significant decrease in tree growth following weir removal. The decrease in growth of a phreatophytic species such as *Alnus glutinosa* and the reverse response of a mesophytic species such as *Tilia platyphyllos* can be due to changes in hydrological connectivity, which greatly influences the hydroecological functioning of the floodplain in the direction of decreasing wetness and thus of potential loss of wetlands. This raises two sociopolitical issues.

One issue is how different nonhuman actors are represented (or not) in the debate and weighed in the decision. This has been discussed for several decades (e.g. Callon, 1986; Serres, 1990; Latour, 1991) and remains a subject of discussion within the social sciences. A detailed review of these debates is beyond the scope of this article. However, in case study 1, the removal potentially places improvement of aquatic habitats in opposition with degradation of floodplain wetlands. Since both are ecologically valuable to biodiversity and the provision of ecosystem services (Millennium Ecosystem Assessment, 2005), how does one rank fish and tree populations in relation to aquatic and floodplain habitats? Migratory fish are protected and promoted by several regulations, such as the EU Habitats Directive or the Convention on the Conservation of European Wildlife and Natural Habitats. However, alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* are also identified in Appendix I of the EU Habitats Directive as a priority (code 91E0). It has already been demonstrated that dam removal can have contradictory effects on ecosystem conservation, such as supporting undesired species (Kornis et al., 2015). For Stanley and Doyle (2003), dam removal "must be seen as a trade-off. Some of the results may be considered beneficial, while others are costly. (…) Potential trade-offs will depend strongly on context. The specific nature of the trade-offs will depend on the size and configuration of the dam and reservoir, local legacies, and the composition of the resident biota". Assessing ecological issues in a decision-making process depends on how the nonhuman actors are represented (or not) in the debate. Thus, it also depends on which epistemic community drives the decision-making process. The history of environmental sciences and management practices provides several examples of system components that scientists and/or managers have ignored and undervalued, such as soil fauna (Decaëns et al., 2006), grasslands (Bond and Parr, 2010) and saproxylic species (Genot, 2008). Concerning implementation of dam removal policy in France, we did not directly analyse the existence and the potential causes of such bias but, as a perspective, we can at least mention that fishermen exerted a great influence on water policies during the 1960s (Bouleau, 2009), and the national institution responsible for water and aquatic ecosystems (i.e. ONEMA, now called AFB for Biodiversity French Agency) was created in 2006 from the national institution in charge of fish (the *Conseil Supérieur de la Pêche*). Determining how this is related to the apparent preference given to channel habitats in restoration practices and whether there are some epistemic communities that influence this preference remain an issue. We believe that showing how dam removal influences riparian trees emphasises that a thorough understanding of biophysical processes can challenge certain items of information found in policies, which can be considered within the scope of scientific practice.

The case studies raise the second issue, related to scientific practice, which emphasises the need to address differences and uncertainty in producing science and expertise (Lespez et al., 2016). Much of the literature demonstrates how scientific knowledge can be shaped by natural and social contexts and how this knowledge can selectively shape management practices and, consequently, material landscapes (e.g. Bouleau, 2014; Linton and Budds, 2013). Awareness and study of relationships between the physical landscape and research is a part of critical physical geography research (Tadaki et al., 2015). Thus, all components of a biophysical system are not known equally well. For example, Clark and May (2002) identified a common bias in conservation research literature: vertebrates are studied more than invertebrates, and mammals and birds are studied more than fish and reptiles. Regarding fluvial systems, Blue and Brierley (2016) study of the values embedded in scientific framing of river health. Concerning dam removal, a conservative bibliographic query in the Web of Science database for 1950-2015 identified nearly six times as many articles with ['dam removal' AND 'fish'] (n = 17) in the title as ['dam removal' AND 'vegetation'] (n = 3). Concerning geomorphological issues, despite the large number of studies describing potential effects of dams (and their removal) on river systems, only a few focus on effects of small dams and weirs (Salant et al., 2012; Fencl et al., 2015). Thus, science activities sometimes reduce the complexity of the studied systems and exclude some issues (Tadaki and Sinner, 2014).

One argument for removal concerns restoration of sediment continuity; however, effective assessments demonstrating sediment deficits or dynamics are rarely performed. When sediment deficit is properly assessed, analysis often concerns a small reach located just downstream to the dam, which makes it difficult to identify physical and local effects of the weir and the real influence on longitudinal dynamics at a larger scale. Focus is placed on the restored reaches, which often ignores catchment characteristics (they are used to present the context but rarely integrated in the assessment) or effective connections between restored reaches and the upstream portion of the fluvial system (especially, sediment continuity of the entire catchment). The assessment of sediment dynamics along the Gapeau River also illustrates the role of scientific expertise. Consequently, even though weir removal is technically possible, it would be ineffective to supply additional sediment to the coastal area because dams and weirs along the river are too small to trap sediments. This highlights the difficulty in transferring knowledge about dams' effects to weirs, and many calls to remove weirs use arguments and literature about the effects of dams.

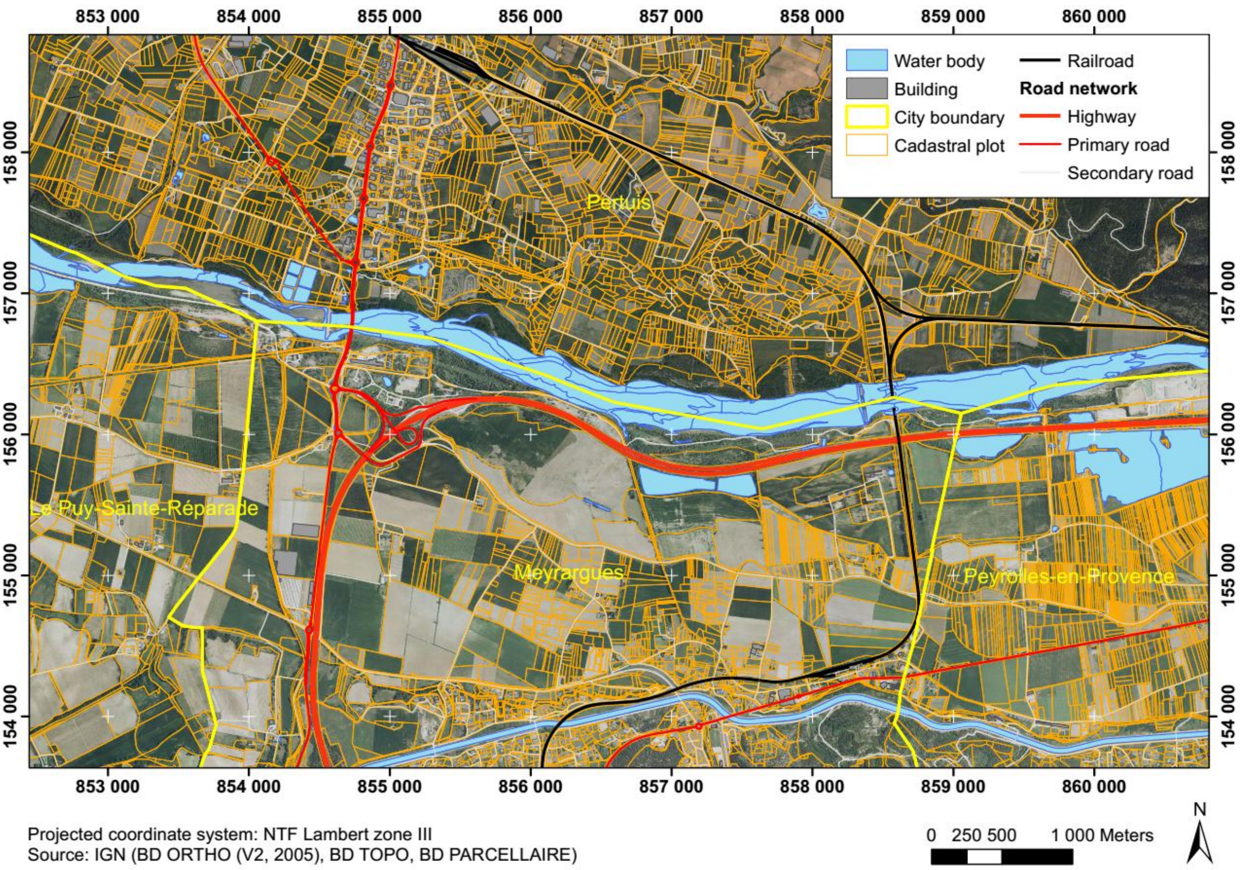
There are differences in the amount of knowledge about each component in fluvial systems (e.g. fish versus trees) and uncertainty in the knowledge about less-studied components. For example, the observed decrease in *Alnus glutinosa* growth is statistically significant but is more an indication of potential change in floodplain wetness than a true assessment of wetland losses. Also, it is known that removing barriers can be necessary but not sufficient to improve fish communities. For example, Zitek et al. (2008) found that connectivity restoration measures along the Pielach River (Austria) were effective only when morphological conditions of reaches were optimal.

Biophysical placed-based conditions shape the social component of removal policy

From an applied science perspective, the assessment of sediment dynamics along the Gapeau River demonstrates that the sediment deficits observed downstream of dams and weirs, especially near the coast, are related to a huge decrease in sediment production at the catchment scale and not to intermediate sediment trapping. This indicates that a more effective measure to restore sediment supplies to coastal areas would be to increase upstream sediment erosion (in floodplain deposits and/or hillslopes). Likewise, in the Durance River, longitudinal sediment transfers can be restored, but due to the distances between sediment sources and sediment-deficient downstream reaches, this longitudinal flux is insufficient, and further action is required. Consequently, locally preserving an erodible corridor (Piégay et al., 2005) is needed to create intermediate sediment inputs.

From a sociopolitical perspective, quantitatively demonstrating that removal is not enough or necessary indicates the need to focus on a land area much larger than only that around individual dams. In the Gapeau River, most upstream floodplains and hillslopes are private land covered by woodlands, crops, vineyards, and cities. In the Durance River, the potential erodible corridor is a combination of public and private lands located in the floodplain along the entire river. Land cover of the floodplain consists of woodlands, crops, transport infrastructures, and cities and is fragmented among many landowners (cadastral plots, Figure 9). In both cases, increasing bank erosion requires developing a specific plan to negotiate with the dam owner, other landowners and, above all, many other stakeholders at the catchment scale. This potentially increases the complexity of the decision-making process and the risk of conflicts due to the diverse relationships among stakeholders and between each stakeholder and the fluvial system (Sabatier et al., 2005; Jorgensen and Renofalt, 2012; Germaine and Lespez, 2014; Fox et al., 2016). In addition, the proposed action, working to increase erosion, is traditionally negatively perceived, as erosion has been fought in most countries for centuries (Dotterweich, 2013). Quantitative analysis of sediment dynamics provides technical solutions, but these solutions extend beyond dams' spatial boundaries and consequently generate new sociopolitical implications that may cause concern for river managers.

Figure 9. Durance River floodplain land uses: Example from the area around Peyrolles-en-Provence, France.



Conclusion: Doubly open minds encouraged by critical physical geography

The case studies demonstrate the influence that scientists have on political processes. By providing biophysical knowledge, they can introduce new actors (human and nonhuman) into the debate. They also illustrate how diverse sociopolitical issues associated with dam removal are partially connected to the nature of biophysical processes and patterns. We did not explore all possible results that critical physical geography can provide and, in several aspects, our analysis remains unsophisticated and far too simple. However, this framework can help physical geographers to broaden our 'classic' vision of dam removal (but also of other environmental issues). Those studying dam and weir removal should have 'doubly open minds'. For the social sciences, the need exists to be (more) aware that certain sociopolitical issues associated with dam and weir removal are connected to the nature of biophysical processes and patterns and require greater focus on the diversity of biophysical contexts, especially on upstream-to-downstream and channel-to-floodplain interactions. The three case studies demonstrate how a thorough understanding of biophysical processes helps to define potential functioning (and thus management options) that respects place-based conditions (Dufour and Piégay, 2009; Brierley et al., 2013; Lespez et al., 2015). Moreover, they show that this understanding requires including multiple stakeholders (with potential diverse power relationships) and, thus, implies a complex decision-making process (more complex than that to remove a dam at a single site). For the natural sciences, the need exists to focus more on sociological, political and cultural issues and to be more aware of how knowledge production, dissemination, and use influence sociopolitical processes (Blue and Brierley, 2016). Notably because, by providing biophysical knowledge, new actors (human and nonhuman) can be introduced into the debate. Increasing this awareness most likely implies that physical geographers participate in critical approaches that analyse the roles of scientists in environmental issues and that these issues are integrated into educational programmes. It is a change of the way in which we do science (Gibbons, 1994; Gros, 2006).

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