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EDITORIAL

Recent advances and future directions in soils and sediments research

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1 Introduction

In 2010, the Journal of Soils and Sediments (JSS) reached a milestone: its 10th anniversary. This prompted us to think about where the academic community has come in its understanding of the behaviour of soils and sediments within landscapes. The rapid growth of the journal and the number of papers published in it, and other related journals, suggests, probably correctly, that there is much interest in the topics of soils and sediments.

In the January 2011 editorial (Xu and Owens 2011), we presented an overview of some of the main developments in the past 10 years and provided some future directions of JSS for 2011 and beyond. In that editorial we indicated that a more comprehensive editorial would be published in the journal on the recent advances and future directions of soils and sediments research. The following sections are presented to fulfill this commitment and start a dialogue with the journal subject editors, authors and readers in these important areas of soils and sediments research.

The dawn of the next decade of JSS is a good time to reflect on progress to-date and, more importantly, to consider where research needs to go in the years ahead; a time of rapid environment change, a time of rapid population growth, and a time when society is increasingly looking to science to provide the understanding (and solutions) to the problems that we face.

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2 Historical development of the Journal of Soils and Sediments

Before we move into the particular sections below, it is timely to have a historical perspective of JSS establishment and development over the past decade (2001–2010). Here we would like to separate the 10 years into two periods: the first five years (2001–2005) involved the establishment of JSS, whereas the second five years (2006–2010) involved the consolidation and rapid expansion of JSS. In the 2001–2005 period, JSS published four issues per year, with a total of 149 peer-reviewed research and review articles as well as 65 editorials and commentaries published. Of these, there were 73 (49.0%) articles in the Soils area, 65 (43.6%) in the Sediments area, and 11 (7.4%) in the Intercompartment area involving both soils and sediments research. Since the start of the second period in 2006, one of us (Xu) has become the Editor-in-Chief for Soils, together with the other two Editors-in-Chief: Prof. Förstner (Sediments) and Prof. Salomons (Intercompartment) who retired from JSS at the end of 2010 (Xu and Owens 2010). JSS published four issues each year in 2006 and 2007 (in total 66 research and review articles), six issues each year in 2008 and 2009 (106 articles), and eight issues in 2010 (152 articles), with a total of 324 research and review articles as well as 61 editorials and commentaries published in the second five year period of JSS. In this period 2006–2010, JSS published 190 articles in the Soils area (58.6%), 113 in the Sediments area (34.9%), and 21 in the Intercompartment area (6.5%).

With the first Impact Factor (IF) for the journal in 2007 of 4.373 (59 articles published in 2005 and 2006, and cited in 2007 for calculating the 2007 IF), published in the Journal Citation Reports by Thomson Reuters (Hollert et al. 2008), JSS was ranked at the top position among the 30 journals in the subject category of Soil Science according to the 2007 IF. This has been followed by the subsequent JSS IF of 2.797 for 2008 (74 articles published in 2006 and 2007, and cited in 2008; ranked 2 of the 31 journals in Soil Science), 2.613 for 2009 (93 articles published in 2007 and 2008, and cited in 2009; ranked 3 of the 31 journals in Soil Science), and 2.574 for 2010 (108 articles published in 2008 and 2009, and cited in 2010; ranked 3 of the 32 journals in Soil Science). In addition, JSS also received the first 5-year IF of 2.358 for 2010, recently published in the Journal Citation Reports by Thomson Reuters. We are pleased to note that despite only 10 years of publication since 2001, and thus being a relatively young journal, JSS has maintained its position as one of the top three journals in Soil Science for the past 4 years (2007–2010) according to the published IF of Thomson Reuters. This occurred at a time of growing competition from more established journals and a rapid increase in the number of articles published by JSS; from 59 for 2005–2006 to 108 for 2008–2009.

In 2011, we restructured JSS into the two major areas of Soils and Sediments, with Xu continuing as the Editor-in-Chief for Soils, and Owens becoming the Editor-in-Chief for Sediments. In the first five of the eight issues published in 2011, JSS published a total of 79 research and review articles by early July 2011. Thus the prediction is that more articles will be published in JSS in 2011 than in any previous year. Perhaps more relevant is the huge increase in the number of manuscripts submitted to JSS, which is likely to be >500 in 2011. This increase, especially in the Soils area, partly reflects the high IFs of JSS within the Soil Science category of Journal Citation Reports; thus JSS is an obvious and very visible journal choice for the soils community. Historically, research on sediments has tended to be published in the geomorphology, hydrology and environmental science literature. Slowly, the profile of JSS is increasing in the sediments community. We anticipate that JSS will continue to attract an increasing number of submissions and publish more papers from the sediments community in the coming years, especially since the areas of Soils and Sediments are closely linked in the context of combating the global climate change challenge and in addressing increasing environmental issues around the world at basin and regional scales.

3 Soils research

There have been a number of editorials and review papers published in JSS on the trends, challenges and developments in soils research within forest ecosystems for the past five years (Chen and Xu 2006, 2008, 2010; Xu et al. 2009). Currently, JSS Soils area consists of five subject sections:

(1) Soil organic matter dynamics and nutrient cycling;
(2) Global change, environmental risk assessment, and sustainable land use;
(3) Remediation and management of contaminated or degraded lands;
(4) Ecotoxicology; and
(5) Soil and landscape ecology.

Global challenges such as climate change have continued to attract growing interest and indeed increasing numbers of submissions and publications in Soils Section 1 (e.g. Blumfield et al. 2006; Huang et al. 2008; Pan et al. 2008; Xu et al. 2008; Sun et al. 2010), Section 2 (e.g. Ge et al. 2008; Zheng et al. 2008; Ibell et al. 2010; Liu et al. 2010; Xing et al. 2010) and Section 5 (e.g. He et al. 2008, 2009; Zhang et al. 2009a, b; Curlevski et al. 2010). Local and regional environmental issues have been addressed in all the five Soils sections, with increasing numbers of submissions and publications in Soils Section 2 (e.g. Burton et al. 2010; Chen et al. 2010; Jiang et al. 2010; Sigua and Coleman 2010), Section 3 (e.g. Liu et al. 2008; Wang et al. 2010) and Section 4 (e.g. Li and Wong 2010; Li et al. 2010).

3.1 Soils and climate change

Climate change has been one of the greatest challenges confronting all the people of the world, and attracted much attention and efforts from both the scientific community and the public in combating this truly global challenge. Climate change, particularly rising atmospheric carbon dioxide (CO_2) and global warming, has been well established in the literature (Xu and Chen 2006; Xu et al. 2009; Frank et al. 2010; Lacis et al. 2010; Schiermeier 2010) and this pattern is projected to intensify in the coming decades (Xu et al. 2009; Doak and Morris 2010; Zhao and Running 2010; Crimmins et al. 2011; Min et al. 2011). However, the impact of climate change, particularly complex atmospheric CO_2, temperature and water interactions, on plant photosynthesis and tree growth remains elusive (Xu et al. 2009; Jung et al. 2010; Piao et al. 2010; Schiermeier 2010). Plant photosynthesis is an important biological process, subject to CO_2 or water limitation (Xu et al. 2009). Recent research findings (Helliker and Richter 2009; Mahecha et al. 2010) have highlighted that there is a global convergence towards an optimum temperature of 21.4°C at photosynthesizing leaves within forest canopies during the growing season. Moreover, there is also a global convergence in temperature sensitivity of respiration in terrestrial ecosystems (including tropical, subtropical, temperate and boreal forest ecosystems) (Mahecha et al. 2010). Despite the global temperature convergence for plant photosynthesis at the leaf level (Helliker and Richter 2009) and for respiration at the ecosystem level (Mahecha et al. 2010), there is a strong relationship between photosynthesis and respiration in terrestrial ecosystems (Mahecha et al. 2010). This highlights the importance of plant photosynthesis in driving the dynamic CO_2 exchange between the atmosphere and the terrestrial ecosystems, and hence the feedbacks between the changing climate and the terrestrial carbon (C) cycle at both local and global scales.

3.2 Soil carbon and nutrient dynamics

Terrestrial ecosystems respond non-linearly to climate change with multiple factors over long periods (Scheffer et al. 2009; Dillon et al. 2010; Doak and Morris 2010; Drake and Griffen 2010; Sun et al. 2010), and can have tipping points or critical boundaries at which a sudden shift to a contrasting dynamic regime might occur (Rockström et al. 2009; Scheffer et al. 2009; Dillon et al. 2010; Doak and Morris 2010; Drake and Griffen 2010). Significantly, more C is stored in the world's soils than in the above-ground biomass and atmosphere (Davidson and Janssens 2006; Fontaine et al. 2007; Gruber and Galloway 2008; Heimann and Reichstein 2008; Piao et al. 2009). Soil C dynamics and N cycling are closely linked, important biogeochemical processes underpinning the positive feedbacks between terrestrial ecosystems and global warming (Davidson and Janssens 2006; Gruber and Galloway 2008; Heimann and Reichstein 2008; Schulze et al. 2009; Xu et al. 2009). In the past decade, there have been significant and exciting developments in testing and applying advanced chemical and bio-molecular techniques for unravelling soil C and N cycling processes in terrestrial ecosystems, such as those of stable isotope methods (Blumfield et al. 2004; Bengtson and Bengtsson 2007; Burton et al. 2007; Strand et al. 2008; Xu et al. 2009), nuclear magnetic resonance (NMR) spectroscopy (Mathers et al. 2000; Mao et al. 2002; Chen et al. 2004; Fontaine et al. 2007; Xu et al. 2009), and bio-molecular approaches (He et al. 2005, 2006, 2007; Bastias et al. 2007; Di et al. 2009). In the first application of ^{14}N-NMR to soil humic acid (HA) studies, it was discovered that there was the surprising existence of inorganic nitrate-N in soil HA, with the HA nitrate-N closely related to soil N availability and rather responsive to ecosystem management (Mao et al. 2002). The nature of the HA nitrate-N is not yet known, but it is biologically related and highly sensitive to ecosystem management and environmental changes (Xu et al. 2009).

3.3 Soil microbes in C and nutrient cycling

Recent literature reviews on greenhouse gas emissions (Liu and Greaver 2009; Schulze et al. 2009) and terrestrial C and N cycles (Gruber and Galloway 2008; Heimann and Reichstein 2008; Xu et al. 2009) have highlighted that soil microbial populations (Mitchell et al. 2009) play a central role in regulating the major greenhouse emissions of CO_2 (Bond-Lamberty et al. 2007; Arnone et al. 2008; Bowman et al. 2009; Dorrepaal et al. 2009), methane (CH_4) (Raghoebarsing et al. 2006; Dunfield et al. 2007; Kennedy et al. 2008; Megonigal and Guenther 2008), and nitrous oxide (N_2O) (Horz et al. 2004; Leininger et al. 2006; Di et al. 2009; Erguder et al. 2009; Martens-Habbena et al. 2009), particularly in the context of climate change and management options for reducing greenhouse gas emissions (Di et al. 2009; Ravishankara et al. 2009; Schulze et al. 2009) and increasing C sequestration in terrestrial ecosystems (Magnani et al. 2007; Houlton et al. 2008; Lewis et al. 2009; Reich 2009; Rotenberg and Yakir 2010). Labile soil C and N pools and dynamics are more sensitive to climate change (Davidson and Janssens 2006; Fontaine et al. 2007; Arnone et al. 2008; Trumbore and Czimczic 2008; Dorrepaal et al. 2009) and management regimes (Mao et al. 2002; Magnani et al. 2007; Di et al. 2009), and closely linked to the greenhouse gas emissions (Di et al. 2009; Liu and Greaver 2009; Schulze et al. 2009), although more recalcitrant soil C and N pools (Davidson and Janssens 2006; Fontaine et al. 2007; Trumbore and Czimczic 2008; Xu et al. 2009) are important for soil C sequestration in terrestrial ecosystems. The recent work (e.g. Di et al. 2009) on ammonia-oxidizing bacteria (AOB) and archaea (AOA) has highlighted that despite the large number and abundance of AOA in agricultural soils nitrification is driven by AOB rather than by AOA, and AOB is much more sensitive and responsive to management practices. Overall, there have been few studies in testing, developing and applying both advanced chemical technologies and innovative bio-molecular approaches for quantifying important soil C and N cycling processes and their interactions with both climate change and management options (Ambebe and Dang 2009; Xu et al. 2009).

4 Sediments research

It can be argued that academic research on sediments is increasing; both in volume and in breadth. This statement is demonstrated by several recent (in academic terms) initiatives including, but not limited to:

- the European Sediment Network (SedNet);
- the International Sedimentation Initiative (ISI);

- the International Commission on Continental Erosion (ICCE);
- the International Association for Sediment Water Science (IASWS); and
- the World Association of Sedimentation and Erosion Research (WASER).

Coupled with these initiatives is a series of publications that focus on sediment research. There are several useful reviews that consider the history of these initiatives and publications, and some of the developments made. For example, Petticrew (2009) reviews developments made by IASWS since 1976 as documented in over 500 publications, and Fig. 1 shows some of the themes and topics that have been addressed. In many respects, Fig. 1 encapsulates the main themes addressed in JSS, albeit described by different phrases, such as: sediment quality and impact assessment; physical and biogeochemical processes; hillslope and river basin sediment dynamics; sediment-ecology interactions; and sediment management. This overlap in research areas is not entirely surprising given the role played by key individuals in both organizations (e.g. Förstner 1977, 2002). The following sections consider some of the recent developments in these themes and offer some future research directions, although both are far from exhaustive.

4.1 Sediment quality and impact assessment

One of the core areas of sediment research has been the quality of the sediment (mainly from a chemical perspective) and the impact of "contaminated" sediment on the environment. This comes from an increasing realization that

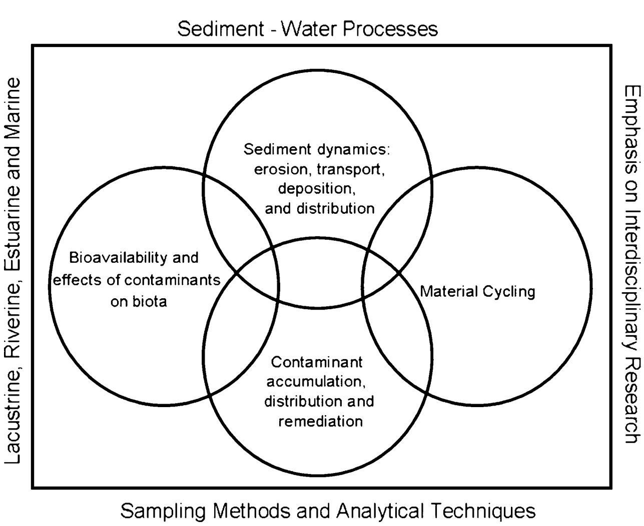

Fig. 1 The dominant themes addressed by IASWS over the last 30 years as documented in >500 publications. The inclusion of topics surrounding the box is implicit throughout all themes (from Petticrew (2009), reproduced with permission of CSIRO Publishing)

sediments act as a vector and reservoir of anthropogenic contaminants. Muir and Howard (2006) estimate that there are 8.4 million substances commercially available at present. As such, there is much research on ways to identify and measure contaminants, and to assess their impacts. The sections below consider some of these developments; other aspects are considered in Section 4.2.

4.1.1 Analytical techniques and protocols

A continuing area of research is likely to be ways to improve analysis of sediments and associated chemicals. This demand comes from a growing list of synthetic chemicals within the environmental and a need for greater precision and accuracy of measurement for assessment and regulation purposes. As such, there will be a constant drive to improve analytical methods, including, for example, the coupling of different techniques (i.e. "hyphenated techniques") such as the use of high performance liquid chromatography—inductively coupled plasma—mass spectrometry (HPLC-ICP-MS). These advances can be made through developments in full computerization of instrumental control and advances in engineering, thus enabling linkage interfaces between different separation and detection instruments (Parkinson and Dust 2010). Despite such advances, sample collection and preparation are crucial to maintain consistency and preserve the integrity of the samples under investigation (Parkinson and Dust 2010). Too often, the ways in which samples are collected, stored and prepared are less than ideal, and indeed sometimes inadequate. Despite excellent advances in analytical techniques, more emphasis needs to be placed on ensuring adequate sampling (including the use of appropriate statistical design; e.g. Church et al. 1987), storage (e.g. Phillips and Walling 1995) and preparation (e.g. Condron and Newman 2011; Reid et al. 2011) protocols; instruments will always give values, but are these values meaningful in terms of what information they are providing about the real environment?

4.1.2 In-situ field methods

The development of instruments that are able to measure properties in the field—i.e. field-portable, in situ equipment—will likely receive increasing interest. Good examples of this include equipment to measure radionuclide and metal contents in soils and sediments within the field (e.g. He and Walling 2000), and the in-situ measurement of sediment particle size and shape in aquatic systems. In the case of the latter, use of equipment such as the Laser In-Situ Scattering and Transmissometry (LISST) within waterbodies has greatly improved our understanding of the transport of composite particles and associated contaminants within channel (e.g. Williams et al. 2007) and floodplain (e.g. Thonon et al. 2005) environments, and particle movement and settling within estuarine and marine environments (e.g. Braithwaite et al. 2010). Techniques for in-situ, real-time analysis of inorganic and organic chemicals are also showing potential (Parkinson and Dust 2010), but clearly there is need for further developments in this area.

4.1.3 Sediment impacts on ecosystem and human health

One area that does merit further attention, is the link between sediment and human health. While there is a considerable body of research on the impacts of sediment on aquatic ecosystems (mainly in terms of aquatic organisms like invertebrates and fish: Bilotta and Brazier 2008; Hallare et al. 2011; Kemp et al. 2011), there is fairly limited research on the impacts of sediment on humans. The indirect link between sediment-associated contaminants and human health has been known for a long time in terms of the role of sediment as a component within the food-chain (i.e. habitat for organisms lower in the food-chain), but the direct link has received less attention. Perhaps the largest body of information has come from research on the link between airborne particulates (e.g. $PM_{2.5}$) and human health, in terms of respiratory and other health problems. Most of this work has been undertaken in urban and peri-urban areas (e.g. Ostro et al. 2006; Taylor and Owens 2009; Jiménez et al. 2010), although other studies have been undertaken near agricultural and mining sites (e.g. Csavina et al. 2011). Recent work has also demonstrated the link between sediment-associated pathogens and human health (e.g. Droppo et al. 2010). The direct role of sediment quantity (e.g. $PM_{2.5}$) and composition/quality (e.g. metals, radionuclides, pathogens) on human health and well-being is, therefore, likely to be a growing area of research.

4.2 Physical and biogeochemical processes

Process-based research tends to be at the small- to medium-scale. In part, this is due to the detailed level of observation or measurement required for the detection of the interactions between physical, chemical and biological processes. Process-based research will always be central to a scientific discipline because it provides the basic understanding which is utilized by the other parts of the discipline (i.e. sediment quality and impact assessment, hillslope and river basin sediment dynamics, sediment–ecology interactions, sediment management).

4.2.1 Sediment–water interface

In aquatic systems (i.e. freshwater, lacustrine, estuarine, marine) the boundary between deposited sediment and the overlying water column will always be critical. Indeed, the boundary between two media/components of a system (particle–solution, freshwater–saltwater, hillslope–channel) is often the most important, and complex, to understand. Research on physical and biogeochemical processes at the sediment–water interface is likely to remain one of the most important sediment research areas. This interface is key in terms of controlling the mobilization of aqueous sediment, and in regulating chemical exchanges between sediments and porewaters and the overlying water. Recent developments include understanding the role that micro-organisms play in stabilizing the deposited sediment. For example, studies (e.g. Garcia-Aragon et al. 2011) have demonstrated the role of periphyton, biofilms and extracellular polymeric substances (EPS) in stabilizing channel bed sediment from erosion and resuspension, thereby limiting the remobilization of contaminated sediment. Indeed Gerbersdorf et al. (2011) argue that such process understanding should be part of sediment quality assessment. Much of this work on the hydrodynamic and biogeochemical processes operating at the sediment–water interface has involved the use of experimental facilities, such as flumes and within laboratories (e.g. Rex and Petticrew 2008; Garcia-Aragon et al. 2011). A challenge facing researchers is to undertake such work in the field in order to confirm the laboratory-based results in more realistic settings.

4.2.2 Sediment–chemical interactions

An understanding of the processes that control the interactions between sediments and chemicals is central to our ability to understand and mitigate contaminated sediment dynamics in aquatic systems. Thus there is a considerable body of research concerned with examining the fractionation and speciation of chemicals associated with sediment (e.g. Tallberg et al. 2009; Sutherland 2010; Condron and Newman 2011; Reid et al. 2011), and the persistence of chemicals and compounds in deposited sediments (e.g. Byrne et al. 2010; Tamtam et al. 2011). Studies have also investigated the role of microbial activity in the sorption of chemicals to sediment, and how this may change due to variations in, for example, temperature and redox (e.g. Huang et al. 2011). Further research is likely to focus on improving our understanding of chemical sorption and desorption to sediment under changing environmental conditions, including the role of changing flow regimes such as floods (Wölz et al. 2010), and the role of thermodynamic and kinetic processes.

4.3 Hillslope and river basin sediment dynamics

4.3.1 Sediment fluxes in river basins and coastal environments

Sediment dynamics within landscapes may have the longest history within academic sediment research. Soil erosion on hillslopes and sediment transport in rivers has been investigated for many decades (e.g. Middleton 1930; Hjulstrom 1935; Einstein 1950). For example, there was a rapid expansion of research on soil erosion and sediment loss from agricultural fields due to the "Dust Bowl" crisis in the USA in the 1930s. More recent developments are trying to link sediment dynamics on hillslopes with those in river channels and in coastal environments (Salomons 2005). The coupling of terrestrial, freshwater and coastal environments has developed from the recognition that water, sediment and chemicals flow between these environments. As a physical rule, flows have been down-slope and down-river, towards the global ocean, but anthropogenic activities now mean that water and materials move in complex patterns, often with transfers between river basins. Much of this need for spatially integrated coupling has been driven by legislation (such as the EU Water Framework Directive) and the need to address problems at the downstream end of river basins, such as sedimentation in harbours and estuaries (e.g. Netzband et al. 2002) and in sensitive environments such as barrier reef systems (e.g. Nunny et al. 2006), by adopting a river basin-scale approach (Owens 2005a). For example, in Australia there has been much research on rivers that supply sediment and chemicals to the Great Barrier Reef (e.g. McCulloch et al. 2003), which has required research to follow sediment from source to sink, and to quantify intermediate storage elements (e.g. Amos et al. 2009). The renewed interest in understanding sediment fluxes in river basins has also been prompted by the realization—although Earth scientists have known this for decades—that sediment fluxes are responsible for delivering chemical elements, in particular nutrients and C, to the global ocean (Milliman and Farnsworth 2011), and are therefore an important component of global environmental change (including coastal eutrophication and global climate change).

4.3.2 Sediment response to disturbance

Another major growth area in research has been to investigate how sediment and associated chemical fluxes respond to disturbances and pertubations, which can be both natural and anthropogenic in origin (e.g. Walling and Fang 2003; Syvitski et al. 2005; Middelkoop et al. 2010; Batalla and Vericat 2011). Generally, most research to date has tended to consider each element of change—such as the impact of mining, or reservoir construction or climate change—in relative isolation. However, in reality, most landscapes are affected by multiple stressors which may have cumulative and synergistic effects (Owens et al. 2010). The assessment of how landscapes respond to present and future "cumulative effects" (Gunn and Noble 2009) may represent one of the greatest challenges facing researchers, and is likely to require interdisciplinary thinking and collaboration.

4.3.3 Sediment tracing and fingerprinting

Given the increasing recognition that sediment can be a major aquatic problem and is an important vector for associated contaminant and nutrient transport (Förstner and Owens 2007), there is growing interest in trying to determine where the sediment has come from and how it moves through aquatic systems (i.e. from headwaters to the coastal zone). Consequently, there has been a growth in the number of studies concerned with sediment tracing and fingerprinting. Much of the early tracer work utilized environmental fallout radionuclides, such as caesium-137 (^{137}Cs) and unsupported lead-210 ($^{210}Pb_{un}$). One could argue that the use of these radionuclides is now well-established—although Parsons and Foster (2011) have recently questioned this, by casting doubt on some of the underlying assumptions of, for example, ^{137}Cs—and that most investigations are of the case-study type. Scientific developments are presently focussing on testing additional radionuclides, such as beryllium-7 (^{7}Be) and thorium-234 (^{234}Th) (e.g. Blake et al. 1999; Saari et al. 2010), and in developing new tracers, such as rare earth elements (REE) and natural and artificial fluorescence (e.g. Polyakov and Nearing 2004; Granger et al. 2007, 2011; Stevens and Quinton 2008; Spencer et al. 2011). Many of these newer tracers are showing considerable promise, particularly for tracing sediment movement on hillslopes, although further refinement and testing are required to prove their suitability at medium to large spatial scales such as the landscape and river basin scales, and at the interface between freshwater and brackish/saltwater environments.

Similarly, "sediment fingerprinting" is unquestionably a major growth area in sediment dynamics research, in part because the approach is able to address, often simultaneously, both scientific understanding and management decision-making needs. Recent developments have focused on improving some of the statistical and modeling aspects of the approach (e.g. Collins et al. 2010a, b), in addition to testing new "fingerprint" properties such as colour parameters, DNA, and total and compound-specific stable isotopes (e.g. Mahler et al. 1998; McConnachie and Petticrew 2006; Granger et al. 2007; Gibbs 2008; Martínez-Carreras et al. 2010) so as to fingerprint the origin of both the inorganic and organic components of sediment. Some further research is, however, needed to test the robustness of the fingerprinting approach, including improvements in developing procedures to account for tracer property uncertainty within the statistical and modeling stages; often the uncertainties associated with sediment source results are not reflecting the real-world situation, and can be misleading. Furthermore, there is a pressing need to examine the conservative nature of the fingerprint properties; at present, a "black-box" approach is typically used whereby there is little understanding of the processes affecting sediment properties between upstream sources and downstream sampling location (Fig. 2).

4.4 Sediment-ecology interactions

There is a long history which has shown how fine-grained sediment and associated contaminants and nutrients can be detrimental to aquatic organisms (for recent reviews see: Bilotta and Brazier 2008; Jones et al. 2011; Kemp et al. 2011). Indeed, sediment toxicity is often assessed using aquatic organisms (Hallare et al. 2011). Some recent developments have focused of other aspects of ecological interactions with sediments. A few examples are given below.

4.4.1 Link between vegetation and sediment dynamics

The feed-back between vegetation and sediment redistribution has been at the forefront of soils and sediments research for several decades and continues to be one of the largest research areas in soil science, physical geography and geomorphology research groups. Even today, vegetation is usually identified as a primary factor in controlling soil erosion (e.g. De Baets et al. 2011), channel bank erosion (e.g. Eaton and Giles 2008) and sediment redistribution within the landscape (e.g. López-Vicente et al. 2011). The recent explosion of interest in the effects of wildfires on soil erosion, and sediment and chemical transport through river channels (e.g. Owens et al. 2006; Petticrew et al. 2006; Blake et al. 2010; Smith et al. 2011) is another example of this type of work, albeit from a natural disturbance-response perspective.

4.4.2 In-channel sediment-vegetation dynamics

Several studies have documented the role of in-channel vegetation in controlling sediment deposition and stabilizing the channel bed. Recent flume-based and field studies (e.g. Wharton et al. 2006; Heppell et al. 2009; Harvey et al. 2011; Jones et al. 2011; Salant 2011) have also demonstrated that both macrophytes and periphyton are important in controlling sediment deposition and resuspension within river channels. According to Harvey et al. (2011) "physical-biological interactions and resulting effects on sediment and nutrient redistribution are arguably some of the principal drivers of ecological function and hydrogeomorphic evolution of aquatic systems….. and deserve more study".

4.4.3 The role of aquatic organisms as biogeomorphic agents

Perhaps some of the most exciting recent and on-going research has investigated how aquatic organisms, such

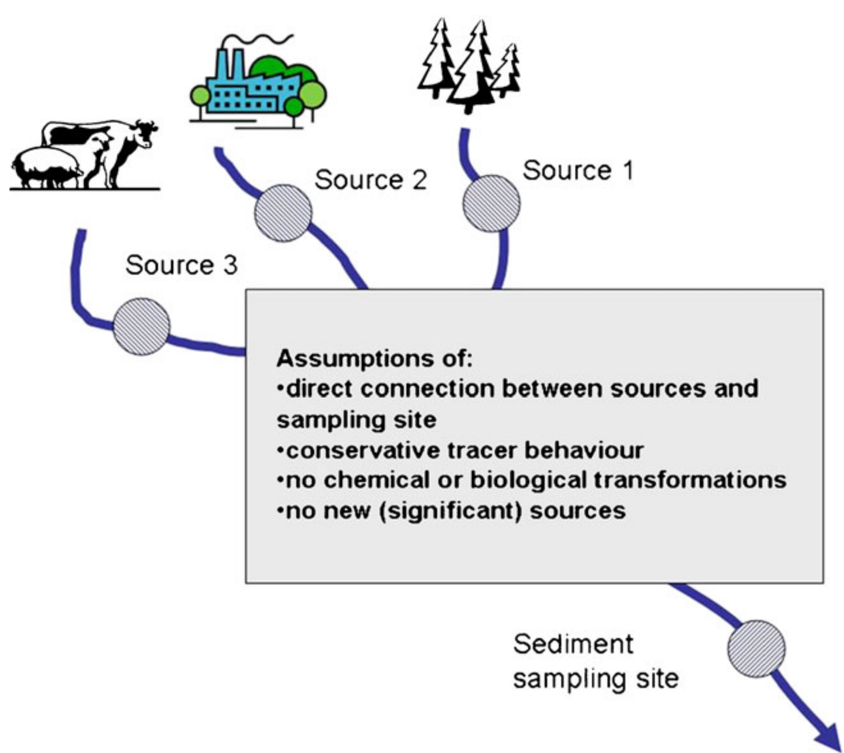

Fig. 2 Black-box approach adopted by many sediment fingerprinting studies, in which a direct connection between sources and downstream sediment is often assumed. In reality there may be important processes between upstream sources and downstream sediment collection which could influence the behaviour of fingerprint properties, thereby compromising their effectiveness or negating their use

as fish and macro-invertebrates, influence the environment in which they live (De Vries 2011). Good examples of this include work on the role of salmonids on disturbing channel bed sediment to make redds (nests). Much of this work has focused on the Pacific coast of North America, where salmon returns from the Pacific Ocean to natal streams and rivers are of epic proportions. In British Columbia, ca. 30 million sockeye salmon returned to the Fraser River alone in 2010. Such migrations represent one of the few significant natural, upstream movements of biomass and nutrients in river systems. Rex and Petticrew (2008) and Petticrew and Albers (2010) have demonstrated how organic material derived from rotting salmon interact with fine-grained sediment—much of which is derived by suspension from the channel bed during redd construction by the salmon—to create composite particles or flocs. These flocs, which are larger and heavier than ambient suspended sediment, settle onto the channel bed, thereby enabling important marine-derived nutrients to be retained within the channel environment in headwater streams, as opposed to being flushed downstream. Similarly, Hassan et al. (2008) have shown how spawning salmon are important in terms of bedload transport and in modifying the channel morphology through the construction of redds. Such work clearly shows how aquatic organisms regulate their environment so as to maintain optimum (physical and chemical) habitats.

4.5 Sediment management

There has been an increase in the amount of science to address management issues (Petticrew 2009). In many respects this comes from shifts in the needs of national and international funding bodies, which are often driven by concerns associated with financial accountability (from the tax payer) and by the need to address real and present environmental concerns (from local and national governments). While there use to be a difference between "applied" research (usually funded by industry and government) and "blue-sky" research (usually funded by national research councils), the distinction is now less clear and the latter is often driven by the requirements of governments and industry. While this inevitably has some drawbacks, there are many positive aspects (e.g. increased outreach and engagement with the public) and opportunities (e.g. collaboration with colleagues from other disciplines, such as the social and health sciences).

4.5.1 Using sediment archives to inform management decisions

It is well known that changes in land use and land management, and river use and management influence sediment and associated contaminant dynamics within aquatic systems (Walling and Fang 2003; Owens 2005b; Förstner and Owens 2007). What is less clear is the magnitude of such changes, and how such changes may be manifest in the future. In many situations, the instrumental record provided by monitoring networks is often of insufficient length to answer such questions. In this context, the record contained within sedimentary environments contains much promise, both from a scientific and a policy-development perspective. Sedimentary records contained within floodplain, reservoir, lake and salt marsh environments, among others, can be used to provide information on: (a) "background" conditions (i.e. fluxes and concentrations) prior to a disturbance (e.g. land use change, climate change, river dredging activities); (b) the magnitude and rate of response to this disturbance; and (c) the likely trajectory into the future given anticipated conditions (e.g. Owens and Walling 2003; Walling et al. 2003; Bindler et al. 2011). A good example of how this can be used to inform policy is provided by Foster et al. (2011) who show how lake and reservoir sediments can be used to reconstruct sediment yields and thereby identify the likely reduction required to return to background (or desirable) levels (Fig. 3). Further research is needed to identify "background" conditions (Bindler et al. 2011) and to improve the temporal resolution available from such archives.

4.5.2 Buffering features to regulate sediment and associated chemical fluxes

Another growth area of research, that has been driven by a management perspective, is the role of natural (e.g. wetlands, floodplains, riparian forests) and artificial (e.g. constructed riparian vegetative strips) buffering features in the landscape to regulate material fluxes (e.g. water, sediment and chemicals). Such features have typically been used to regulate flows between hillslopes and river

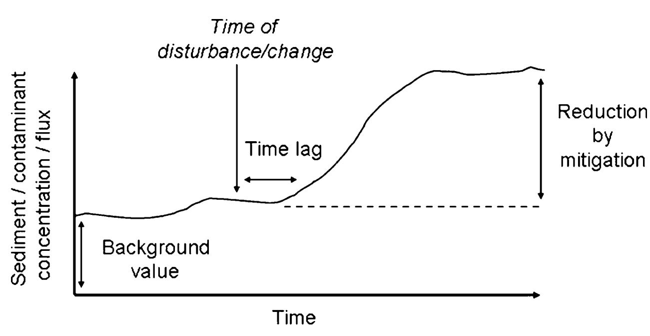

Fig. 3 The concept of using paleolimnological reconstruction of sediment and contaminant dynamics within river basins and other aquatic systems to inform management and policy decision-making (modified from Foster et al. 2011)

channels, often with the aim of trying to improve surface water quality. Many studies (e.g. Owens et al. 2007; Clinton 2011) have investigated the efficiency and design of buffer zones. While such features are no doubt useful, in many situations they may not be in optimal locations or of suitable design (e.g. Dosskey et al. 2011). Much guidance on buffer design and location has been based on research undertaken in temperate environments, such as the UK and USA. Such guidance may not be entirely appropriate in contrasting environments, such as those that have peak surface flows (during annual periods of snowmelt) over frozen soils and when vegetation cover is minimal (e.g. Steward et al. 2011). Further research is required to evaluate buffer features in such contrasting conditions. In addition, much of the research has focused on relatively small sections of the landscape, such as river reaches, and the effectiveness in reducing sediment loads at larger spatial scales has been questioned (e.g. Verstraeten et al. 2006). Thus, research is needed to assess the role of buffer features at the larger scale, such as the landscape and river basin scales. This may require a combination of field testing and spatial extrapolation techniques, such as modeling and GIS (e.g. Moriasi et al. 2011). Finally, we lack a good understanding of the resilience of such features to environmental disturbances (e.g. large-scale forest harvesting and mining) and to future environmental changes (e.g. anticipated changes in precipitation and land cover); we are planning for the present situation, rather than thinking of what might be needed in the near future.

4.5.3 Decision support frameworks

Ultimately, the management of natural resources (i.e. water, soil, sediment) comes down to making decisions, often underpinned by a good understanding of the main processes involved. As such, there has been a considerable amount of work on designing appropriate decision support frameworks to aid with decision making. Such frameworks have used different approaches, including conceptual (White and Apitz 2008; Granger et al. 2010), risk-based (Apitz 2008a) and adaptive (Apitz 2008b; Owens 2009) structures, among others. These all have various advantages and disadvantages. A current trend seems to be for more ecosystem services-based approaches (e.g. Apitz 2011). Frameworks which are inclusive, more realistic, and wholistic are likely to offer consider promise, especially if they are transparent for all to see the mechanisms and principles behind them. Challenges still remain in translating such frameworks into products that are usable by managers and policy-makers. This requires dialogue and understanding, and the ability to embrace new ideas and approaches.

5 Conclusion

This article has identified some of the main areas of current research and has illustrated areas where further research is needed. Much of this recent progress has come about because of a shift towards more collaborative, and intra- and inter-disciplinary research; something at the heart of the Journal of Soils and Sediments. The review above is far from complete, maybe only touching the tip of the iceberg. We hope, however, that it will encourage researchers to think carefully about what is needed in order to make real progress in our understanding of soils and sediments within landscapes, and ultimately how we can protect them and the ecosystems in which they reside, particularly in the context of climate change, which is expected to intensify with significant impacts on both soils and sediments in the coming decades.

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