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Towards sustainable agricultural landscapes: lessons from an interdisciplinary research-based framework applied to the Saint Lawrence floodplain

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Towards sustainable agricultural landscapes: lessons from an interdisciplinary research-based framework applied to the Saint Lawrence floodplain

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Abstract

Floodplains are unique environments that provide a dynamic link between terrestrial and aquatic systems. Intensification of human activity – particularly agriculture and urbanisation – has resulted in the degradation of floodplains worldwide. Restoration and sustainable management of floodplains requires holistic assessment and compromise between stakeholders to successfully balance environmental, economic, and social benefits. Yet, understanding these complex systems sufficiently to provide evidence-based recommendations is a challenge. We present the lessons learned from establishing an interdisciplinary research-based framework on the agricultural floodplain of Lake Saint Pierre, Québec, Canada, whose mandate was to a) understand and define key environmental, agricultural, and socioeconomic attributes of the landscape, b) quantify the trade-offs and synergies between these attributes across different agricultural practices, regions, and land uses, and c) explore novel agri-environmental management practices to assess their role in sustainable floodplain management. Within this manuscript, we explore the benefits that such an approach offers in evaluating sustainable floodplain land use. We found that an interdisciplinary research-based approach demonstrated important benefits such as knowledge transfer, more efficient use of resources (e.g., personnel, funding), and a flexible yet robust research framework. A framework of individual research projects connected to broader interdisciplinary themes allowed a more holistic synthesis of the

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floodplain systems and assessment of agri-environmental practices. By implicitly considering spatial and social scales, we conceptualised not just how redistribution of the land use types can meet sustainable management objectives, but also explored how compromises within existing uses can optimise socio-economic, agricultural and environmental dimensions and move towards a sustainable multifunctional landscape.

Keywords: floodplain; sustainable agriculture; land use change; socio-economics; research framework; multi-use landscapes

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Introduction

Land use conflicts resulting from a growing population, land scarcity, and opposing interests are increasing. This tension can be viewed through the lens of conflicting ecosystem services that humans receive from the environment (Costanza et al. 1997). These ecosystem services are often classified as provisioning services that include food, timber and consumables; regulating services that regulate climate, natural hazards and water quality; supporting services that underpin larger natural processes (e.g. nutrient cycling, soil formation); and cultural services that influence spiritual, aesthetic and recreational values (Millennium Ecosystem Assessment 2005). In the context of ecosystem services and land use change, the land sparing-land sharing debate attempts to provide an optimal approach to agricultural land use across a landscape. The classic example of land sparing assigns intensive agricultural production as the primary use across a limited area (thus prioritising provisioning services) while securing natural areas for conservation elsewhere, rather than sharing land uses in a matrix throughout the landscape (Green et al. 2005, Fischer et al. 2008). However, these two approaches favour different partitioning of ecosystem services, suggesting a need to balance land sharing with land sparing (Grass et al. 2019). An attempt to transcend this dichotomy (Fischer et al. 2014) provided four key principles to guide land use: 1) focus on land scarcity rather than specifically on food production, 2) recognise the limits of its real-world application, 3) consider issues of scale, and 4) explore alternative, more holistic frameworks. These principles invite the practical examination of multifunctional landscapes, rather than a purely quantitative exploration of the land sparing-land sharing debate for a few variables at unique locations.

Other researchers have gone further, arguing that a true multifunctional landscape is needed to optimise the benefits to both producers and the environment (Kremen 2020). These perspectives support the diversification of conventional agricultural landscapes through ecological intensification (i.e. deliberately promoting ecological benefits) as being essential for sustainable land management and for profitable farming enterprises. By also highlighting the social element required for ecological intensification, Erős and collaborators identify the need to integrate aquatic ecosystem components into floodplain management and restoration (Erős & Bányai 2020, Erős et al. 2023). Yet, a globally-accepted solution to this challenge remains elusive, with the optimal approach for a given circumstance being dependent on multiple factors including the characteristics of surrounding ecosystems, the intensity and type of land use change (often agriculture), the identity of affected taxa, and the impact on biodiversity (Gilroy et al. 2014).

Floodplains are unique environments where episodic flood pulses provide a dynamic link between terrestrial and aquatic ecosystems (Thoms 2003). This spatio-temporal dynamic results in periodic nutrient mobilisation and retention, supporting enormous biodiversity (Ward et al. 1999, Geilen et al. 2004) and providing fertile land for food production (Erős & Bányai 2020). Floodplain agriculture has benefited human development for millennia, with cropping generally

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conducted at higher elevations, and pasture production in lower, wetter areas (Verhoeven & Setter 2010). Yet, inherent characteristics make floodplains vulnerable to human activities and land use change, with terrestrial activities impacting the aquatic environment and vice versa. Although current knowledge now recognises the need to restore and manage these sensitive environments, developing region-wide solutions requires considering new approaches that incorporate evidence-based and interdisciplinary research.

In the last decades, the degradation of floodplains worldwide has received much attention (Opperman et al. 2017). Reasons for floodplain degradation include broadscale terrestrialisation (Verhoeven & Setter 2010), drainage and loss of hydrological connectivity (Benton et al. 2003), modification through dikes and dams (Nilsson et al. 2005), and other human alterations (Hein et al. 2016). Agricultural intensification has also contributed to floodplain degradation, through the conversion of perennial crops and pastures to annual crops, the increased use of pesticides and fertilisers, and the simplification of crop rotations (Matson et al. 1997, Tscharntke et al. 2005). These alterations lead to terrestrial habitat fragmentation and biodiversity loss (Jaeger 2000, Boschi & Baur 2008, Emmerson et al. 2016) and, given the inherent terrestrial-aquatic linkages, often produce wide-ranging impacts on aquatic ecosystems, such as increased sedimentation (Sun et al. 2015), nutrient loading (Kaluli et al. 1999), and pesticide contamination (Giroux 2004).

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Protection of floodplains through conservation areas has been a common approach to minimise human disturbance and ongoing degradation (Aber et al. 2012, Gupta et al. 2020). Such an approach is politically difficult to apply and harder to achieve when lands are privately owned. In these cases, alternative options need to be explored to maintain floodplain health, which may include regulations or incentives to landholders (Nelson 1986, Stubbs 2014, Kousky & Walls 2014, Spidalieri 2020). Where agriculture remains viable, agri-environmental practices are often proposed to continue production while minimising negative environmental impacts. Examples of agri-environmental practice can include no-till systems, intercropping, cover cropping, and protection of riparian vegetation (Dosskey et al. 2010, Steven & Lowrance 2011, Farooq & Siddique 2015, Jobe et al. 2018, Gene et al. 2019). These options can offer gains to the producer, such as nutrient retention, erosion control, weed control, and alternative income sources (Snapp et al. 2005, Blackshaw et al. 2008, Vanasse et al. 2017), while simultaneously offering environmental gains such as reducing contamination to water bodies and diversifying habitats across the landscape (Pimentel et al. 1995, Blanco-Canqui et al. 2015). In the context of ecosystem services, this can be viewed as increasing supporting and regulating services, arguably at the expense of provisioning and cultural services.

Although a large variety of agri-environmental practices have been promoted, mandated, or incentivised across the world (Baylis et al. 2008, 2022, Batáry et al. 2015), uptake of voluntary agri-environmental programs has been generally low, with expectation of unreasonable burden and initial costs being cited as contributing factors (Mack et al. 2020, Ocean & Howley 2021, Maas et al. 2021). Much research has been conducted on what drives participation in these programs (Lastra-Bravo et al. 2015), which is increasingly relevant as rising competition for land use is driving the need for multifunctional landscapes (Villamayor-Tomas et al. 2019). Thus, agricultural floodplain management, like many other environmental management strategies, must foster interdisciplinary partnerships and have a sound knowledge of the scientific foundations within these systems (Heikkila & Gerlak 2005).

If we acknowledge that floodplains are complex and dynamic ecosystems, then the challenges in evaluating land use strategies demand a thorough understanding of the various natural and human systems. Other large-scale approaches towards floodplain restoration (e.g. the Danube River floodplain; Stammel et al. 2012) have suggested an approach involving several inter-

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related scientific disciplines is necessary to meet the variety of restoration needs. As such, and in the context of the Lake Saint Pierre floodplain, we ask the questions:

- What advantage does an interdisciplinary research-based approach provide in evaluating sustainable floodplain land use?
- What interdisciplinary spatial and social scales are appropriate to inform regional land-use strategies?

Within this manuscript we test these questions using an interdisciplinary research framework that comprises environmental, agricultural and socio-economic disciplines. We detail the design of the research framework as comprised of individual but connected research projects, to assess agri-environmental practices and inform land management at a large scale. Acknowledging that the nomenclature in integrated research studies can be varied and imprecise (Stock & Burton 2011, von Wehrden et al. 2019), we use the term 'interdisciplinary' within this manuscript (versus 'transdisciplinary' or 'multidisciplinary'). As viewed by Stock and Burton (2011), interdisciplinary research emphasises both integration and cooperation, leading to interpretations that would have otherwise not been achievable. The objective of this paper is thus not to present detailed results of individual projects – as these will be published individually in the coming years – nor to provide a detailed synthesis of the research program as a whole (as provided in Campeau et al. 2023), but rather to identify benefits and shortfalls of how such an approach can be used to holistically conceptualise the challenges of floodplain land use management. This paper presents the backbone on which the individual projects are attached as well as the foundation for upcoming interdisciplinary synthesis work.

Materials and methods

Study site

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Lake Saint Pierre is a 50,000 ha fluvial enlargement of the Saint Lawrence River, located between the towns of Sorel-Tracy and Trois-Rivières, Québec, Canada (46.202805, -72.82804). These waterways are part of the Great Lakes-Saint Lawrence drainage basin, the largest body of freshwater in the world (Bartolai et al. 2015), and represent important areas of historical colonial development in Canada, in what remains unceded First Nations territory. Lake Saint Pierre lies within a cool-temperate climate region with a mean annual temperature of 5 °C and mean annual precipitation of 930 mm. It contains a spectrum of wetland ecosystems that support a high diversity of aquatic and terrestrial species; as such, it is a UNESCO biosphere reserve and is recognised under the Ramsar Convention to support breeding and migratory waterbirds (MDDEFP 2013).This unique environment is driven by an annual spring flooding event following snowmelt. Over a period of 5-9 weeks, the rising waters inundate agricultural lands and natural ecosystems surrounding the lake. Although the extent of floodwater coverage varies depending on annual snowpack and spring precipitation, the floodplain is herein defined as land located below the 2-year flood recurrence level, standardised at a 6.79m reference water level at the Sorel-Tracy hydrometric station (Environment Canada Station 022OJ022). When floodwaters reach this level, they extend over approximately 28,000 ha of land (TCRLSP 2017), and our study area becomes the largest wetland in the Saint Lawrence River system (Hudon et al. 2018). The timing, duration, and extent of this annual pulse are naturally highly variable, even though the hydrological regime is partially controlled by upstream dams in the Great Lakes-St Lawrence system (Marty et al. 2010).

Agriculture is the dominant economy in the region, occupying approximately 22.8% (5,022 ha) of the floodplain (Jobin & Brodeur 2023). The floodplain is farmed by 151 agricultural enterprises, many of which are small, family-owned businesses. The majority of these have less than 20% of their total cultivated areas located in the floodplain zone itself, with the remainder in higher elevations (TCRLSP 2017). In 1950, perennial crops and pastures represented 80% of floodplain agriculture (5,331 ha), compared to only 20% of annual crops (1,360 ha; Dauphin & Jobin 2016). In recent decades, this proportion has shifted heavily towards annual crop production: in 2016, perennial crops only accounted for 10% of floodplain agriculture (493 ha), while annual crops contributed 90% (4,324 ha; Jobin & Brodeur 2023). Annual crops are predominantly corn, soybean, and small-grain cereals, generally grown using conventional practices which rely on chemical fertilisers, pesticides, and annual soil tillage. Crop fields are long and narrow (approximately 50 m wide) and bounded by ditches to facilitate drainage. Overall, soils have poorly developed profiles and lie on sandy sedimentary parent material, overlain by alluvial-deposited loam with high organic matter.

Administratively, the Lake Saint Pierre floodplain includes 21 municipalities, an Abenaki First Nations reserve, several agricultural and environmental government agencies (provincial and federal), National Defence of Canada lands, and many NGOs and community groups representing conservation, agricultural, and cultural interests such as hunting and fishing (TCRLSP 2017). This administrative complexity and the variety of competing interests pose substantial challenges to the governance of Lake Saint Pierre. Over the past several decades, a variety of anthropogenic pressures, including increased agricultural intensification, land use change, and water flow modifications, have had major ecological impacts on the lake and floodplain. Multiple stressors have led to environmental degradation in the form of reduced water quality and increased turbidity, nutrient and pesticide concentrations, and *Escherichia coli* levels (Simoneau 2017), as well as the loss of wetland habitats (Dauphin & Jobin 2016). Environmental degradation is often exemplified by the population collapse of yellow perch (*Perca flavescens*), a flagship species subject to a fishery moratorium in place since 2012 and one of the primary drivers of the subject research program. However, while many species are in decline (e.g. brown bullhead, grassland, and wetland birds), others have seen substantial increases in their populations, especially generalists and some invasive species (Jobin et al.

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1996, NABCIC 2012, Ouellet-Cauchon et al. 2014). These important species shifts are dramatically altering trophic interactions and ecological processes, which may threaten the sustainability of key species and populations under stress (Newbold 2018, Fisher & Burton 2018).

The Lake Saint Pierre strategic research cluster

To promote sustainable management of the Lake Saint Pierre floodplain ecosystem, recommendations were delivered by a reference group representing 53 stakeholder organisations (TCRLSP 2017). Three Québec Ministries (Agriculture, Fisheries and Food; Forests, Fauna and Parks; and Environment and Fight against Climate Change) cooperatively launched a strategic research cluster (in original French: *le pôle d'expertise multidisciplinaire en gestion durable du littoral du Lac Saint-Pierre*). The stated mandates of this research cluster were to: (1) develop crops and agricultural practices adapted to the specific context of the cultivated floodplain of Lake Saint Pierre that would enhance ecological integrity; (2) evaluate the performance and impacts of agricultural activities and restoration projects socially, economically, environmentally, and on wildlife; and (3) propose to the government a management strategy based on the research results to promote sustainable agriculture on the Lake Saint Pierre floodplain. The research cluster was initially funded across three years; later expanded to five years (2018 -2023).

To address the interdisciplinary nature of the issues, three research themes were developed within the research cluster: *agriculture*, *environment*, and *socio-economics*. The research cluster was established with 30 researchers from a consortium of three universities (Université Laval, Université du Québec à Trois-Rivières, and McGill University), and five partner research institutions (Université du Québec à Rimouski, Université du Québec à Chicoutimi, the

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Research and Development Institute for the Agri-environment, the National Institute of Scientific Research, and Natural Resources Canada). Researchers involved in the research cluster had expertise across ecology and environmental sciences, agricultural sciences, economy, human geography and socio-political sciences.

To answer our stated research questions (i.e. what are the benefits offered from an interdisciplinary approach, and what spatial and social scales are appropriate for this approach), it was necessary to design a research framework that extended the collaborative nature of the research cluster beyond simply multidisciplinary (Stock & Burton 2011), or 'studies that co-exist in a context' (Petts et al. 2008). To achieve this, we held workshops with stakeholders including researchers, government advisors, community groups and producers to canvas goals and priorities of the research cluster. With these in mind, the research cluster workshopped research methods and identified complementary outcomes to design research locations, themes and questions that would maximise the interdisciplinary nature of the integrated research.

Results

Development of the experimental framework and research themes

The focus of the research cluster was assessment of the agricultural, environmental and socio-economic dimensions of the proposed agri-environmental practices. These practices included: a) alternative floodplain crops (14 crops, including flax, American elderberry, honeysuckle, milkweed and sunflower); b) planting of floodplain pastures; c) intercropping of annual crops with annual ryegrass (*Lolium multiflorum*), winter wheat (*Triticum aestivum*) and legumes (*Lotus corniculatis*, *Trifolium repens*, *Vicia villosa* and *Melilotus officinalis*); d) sowing *Phalaris arundinacea* perennial buffer strips on field margins; and e) cover cropping on bare soils (e.g. where high flood years did not permit an annual crop) using a mix of species. Researchers within the agriculture theme conducted field-based studies that examined crop survivorship,

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yield, nutritional content and other production-based values. Researchers within the environment theme used field-based and remote sensing studies across a range of land use types to evaluate variables such as water quality, terrestrial and aquatic biodiversity, soil chemistry, toxicology, and aquatic primary productivity. Researchers within the socio-economic theme accessed primary data to assess economic outcomes and obtained views on agricultural practices and agri-environmental alternatives from interviews with producers.

The research cluster integrated 25 individual projects within the three research themes (agriculture, environment, and socio-economics) to develop a regional-scale experimental framework that aimed to maximise the usefulness of the results to decision-makers and stakeholders. Each project was designed by researchers within each theme and had specific hypotheses and objectives pertinent to each researcher's expertise. In addition, the research cluster as a collective developed the following interdisciplinary research questions that addressed the agriculturally-focused mandate while intrinsically incorporating environmental and socio-economic dimensions:

1. What are the multifunctional outcomes (socio-economic, environmental and agricultural) of implementing improved agri-environmental practices?
2. What are the cost-benefit and socio-technical challenges in applying agri-environmental practices and alternatives to crop production?
3. How do flood dynamics impact agricultural production and producers?
4. How do flood dynamics influence the transport, mobilisation, and retention of nutrients and contaminants?
5. How do regional land-use scenarios affect environmental benefits, with or without agriculture?
6. What year-to-year and regional variability is present, and how does it impact strategies

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to improve agricultural sustainability?

The experimental framework was designed such that each individual research project would contribute to one or more of the interdisciplinary research questions, as well as producing independent practical or academic results. A project was deemed appropriate if it i) addressed one or more of the above questions, and ii) targeted one or several of the agricultural, environmental or social scales of the Lake Saint Pierre floodplain (see below). No further constraints were imposed on the conceptual or methodological approaches for conducting research, therefore providing independence to the individual projects.

Relevant agricultural and environmental spatial scales

Designing an experimental framework at an appropriate spatial scale is essential to assess cost-benefits in the context of land sparing/land sharing and landscape multifunctionality (Fischer et al. 2014). Across an administratively complex region such as Lake Saint Pierre, it is challenging to apply results from a traditional experimental plot scale to the entire floodplain. Likewise, it is impractical to replicate small-scale experiments sufficiently to cover the full range of spatio-temporal variability across the region. To address this challenge, we created a network of common field sites at nested spatial scales (Fig. 1). Through workshops conducted with researchers and other stakeholders, our 25 intersecting research projects were conducted in four regions around Lake Saint Pierre. Regions and field sites were selected primarily to standardise the average flooding duration, and further by accessibility during key sampling periods, landholder permission, and the willingness of landholders to trial agri-environmental practices. Common field sites were shared as much as possible between research projects to increase the spatial overlap of data from different projects and reduce the experimental variability when comparing results between sites. Some research projects were designed to be applied across multiple spatial scales; for example, alternative crops were trialled at both the

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regional scale and across an elevation gradient to assess whether results regarding production at different parts of the floodplain were consistent across regions.

Floodplain scale:

The floodplain scale included research questions that aimed to characterise broadscale descriptors across the entire floodplain. This scale was mostly investigated by the environment theme, and primarily used remote sensing and aquatic sensors to characterise hydrology, water quality, and interannual changes in flood regimes.

Regional scale:

Four regional study areas were established to obtain a representation of the floodplain diverse landscape. These areas were selected based on regional differences (e.g., soil characteristics, hydrology, agricultural productivity, stakeholder involvement) that could potentially impact proposed sustainability strategies. These regional study areas were jointly selected by the research team, based on the diversity of land use types in the floodplain area delimited by the 2-year flood recurrence boundary and the availability of suitable experimental farmland. The four regional study areas were located in the municipalities of Baie-du-Febvre, La-Visitation-de-l'Île Dupas, Pierreville, and Saint-Barthélemy (Fig. 1B).

Land use gradient:

Within each of the four regional study areas, we compared six types of land use that represented a gradient of anthropogenic intensity: a) conventional cropping (annual crops of corn and soybean), b) agri-environmental cropping (annual crops of corn and soybean with intercropping, cover crops, and/or perennial buffer strips), c) recently sown forage cropping, d) old forage cropping, e) wet meadows (not used for agriculture), and f) silver maple swamps. In particular, the comparison between conventional and agri-environmental cropping was designed

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to quantify the agricultural and environmental costs and benefits of transitioning to agri-environmental practices. The full land use gradient was used to investigate the environmental and socio-economic contributions to regional land-use strategies. Environmental variables across the land use gradient were sampled at the same elevation (6.2 m) to standardise for intra-annual flooding duration. The 6.2 m reference elevation is well within the Lake Saint Pierre's floodplain, which is legally defined as land below an elevation of 6.79 m.

Elevation gradient:

For certain research projects (see Table 1), an elevation gradient was established within land use categories to test the effects of flood duration on experimental variables, particularly those relating to success of alternative crops, crop productivity, and aquatic ecology. This approach was required to evaluate the agricultural and economic potential of establishing alternative crops and cover crops in areas with different flood regimes. Trials in low-elevation zones were established below the 6.2 m reference level where flooding is expected to occur on average almost every year. Trials in high-elevation zones were established between 6.2 m and 6.79 m elevation where flooding is expected to have a recurrence period of about once every two years on average. When flooding reached the 6.2 m level, the mean flood duration at this elevation was 21 days (1960-2018; unpublished data).

Ex-situ experiments:

Certain research projects, such as those related to toxicology, required controlled experimental conditions. To this end, samples were taken from specific field locations across land use gradients and elevation zones and analysed in the laboratory. Laboratory analyses examined *in-vitro* toxicology with model organisms, and soils collected from the experimental plots.

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[Note to publisher: Figure 1 here]

Relevant socio-economic scales

Spatial scales are similarly relevant to socio-economic research projects, albeit at a different granularity to those in the agriculture and environment themes. Three unique spatial scales were defined that best represented scales at which different operational, economic and policy drivers apply.

Local scale:

At the local scale, individual producers and farming businesses play a crucial role in shaping landowners' practices and operations. At this scale, we delved into the economic implementation costs of agri-environmental practices. We were able to explore the impact of these implementations on farm profitability, socio-technical challenges that arise from changing practices as well as factors that influence adoption rates among producers.

Regional scale:

At the regional scale, we addressed inquiries that encompass both private and collective economic costs and benefits associated with changes in land use scenarios. Additionally, we collected qualitative data to understand the incentives and challenges faced by agricultural advisors (e.g., agronomists and other agricultural professionals) when attempting to encourage changes among producers. This scale also facilitates discussion of the socio-political dynamics surrounding collective floodplain management.

Provincial scale:

At the provincial scale, we encountered policy and environmental programs that involve a wide array of stakeholders and governmental representatives. At this level, we explored the value

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attributed to agricultural practices that enhance environmental factors such as ecological services. We interviewed producers regarding the design and framing of government incentive programs, and the legislation aimed at promoting changes in agricultural practices.

By examining these three scales, we gained a comprehensive understanding of the intricacies involved in fostering sustainable agri-environmental practices. Although each scale brings its own set of limitations and spatial resolution, they collectively allow for a holistic approach toward achieving effective and impactful change in the agricultural sector.

Management and context of individual research projects

Research activities were conducted at different times of the year, depending on the project, variables, and objectives. For example, sampling for aquatic floodplain invertebrates was conducted during spring flood conditions, whereas crop yields were taken at the end of the growing season. Certain variables were collected to link environmental and agricultural projects at the land-use gradient scale, including vegetation height and biomass during flood periods which allows integration of both perch habitat and crop/pasture variables. Most socio-economic projects were conducted year-round but qualitative input from the producers and other stakeholders (e.g. interviews) was collected during winter months.

Overall, more than 180 environmental, agronomic, and socio-economic variables were quantified throughout the program, including crop yields, soil properties, monetary cost-benefits, vegetation biomass, and water quality indicators. We classified these variables through the lens of competing ecosystem services, as defined by the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005): provisioning (e.g. providing food, fibre, energy), cultural (e.g. aesthetic, accessibility, education), regulating (e.g. biocontrol, carbon sequestration, soil retention), and supporting (e.g. nutrient cycling, primary production). Table 1

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provides examples of research projects conducted at the various experimental scales.

[Note to published: Table 1 to ideally be published nearby to previous paragraph]

Adaptability of experimental framework

Given the dynamic nature of the floodplain ecosystem and often-unpredictable effects on the agricultural landscape, the experimental framework needed to be flexible and adaptable. From an administrative perspective, it was essential to include contingency funds in the research cluster's budget to allow for the addition or modification of unplanned components. From a research perspective, regular coordination between researchers allowed for rapid exchange of new information. For example, early observations from research activities revealed unexpected floodplain-scale heterogeneity, which led research teams to alter their original experimental designs and render them more robust. In particular, remote sensing data obtained from satellite and drone imagery in 2019 highlighted unexpected patterns in water turbidity and floodplain vegetation growth that challenged early assumptions of regional hydrodynamics (Box 1). Throughout the length of the project, spatial coverage and span of field activities allowed the research team to detect and communicate a host of unexpected issues, including difficulties with drainage, turbidity, and crop implantation.

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The variability in flooding events in 2019 (very long), 2020 (average) and 2021 (very short) were significant, both for landholders and for researchers. The prolonged flood and resulting short growing season of 2019 prevented the sowing of corn, which changed experimental treatments and farming activities alike. Corn was replaced by a cover crop of annual ryegrass or winter wheat but soybean was sown under conventional management or with agri-environmental practices. In 2020, a dry spring provided conditions that were difficult for the establishment of pastures, whereas late-summer extreme rainfall flooded many fields and destroyed experimental plots in low-elevation zones. These atypical events also hindered the evaluation of the impact of agricultural practices on aquatic organisms. For example, yellow perch larvae and some zooplankton species were able to access the floodplain and begin their development during the longer flood of 2019, but not during the shorter floods of 2020. This meant that the impact of agronomic treatments on these variables could not be consistently measured across the years. Researchers had to adapt year-to-year to incorporate this variability.

Despite the abovementioned interannual variability and other unexpected disruptions including the Covid-19 pandemic, the experimental framework provided a flexible basis for adapting the research activities while maintaining the integrity of the overall experimental design.

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Box 1: Adaptability of experimental framework in response to new information

On the Lake Saint Pierre floodplain, the timing, duration and extent of the spring flood is an important driver of both ecological processes and agricultural practices. High interannual variability in flooding is common; in particular, the flood of 2019 represented an extreme event of high and long-lasting flood, whereas 2020 and 2021 had earlier and shorter flooding events (Fig. 2A).

An *a priori* assumption of this system was that local water turbidity was related to local sediment run-off from agricultural fields and would thus be an important predictor of aquatic productivity and habitat quality for aquatic fauna. Many of the proposed agri-environmental practices trialled in the project (e.g., intercropping and buffer strips) aimed to reduce the impact of exposed agricultural soils to the aquatic environment.

However, early observations from in-situ water quality measurements and Sentinel-2 remote sensing imagery during the 2019 high floods revealed that the turbidity in certain regions was heavily influenced by sediment load in tributary rivers and flow patterns on the floodplain. As such, local turbidity was not always strongly connected to land use in the floodplain as had been assumed. Some natural areas were fed highly turbid water from upstream, whereas some agricultural areas had relatively low turbidity (Fig. 2B).

The interdisciplinary information exchange within the research cluster resulted in improved knowledge of floodplain flow dynamics under different flood regimes. This knowledge allowed the research cluster to quickly adjust the experimental framework to adapt to this new information.

[Note to publisher: Figure 2 here]

Discussion

Practical benefits

A coordinated interdisciplinary approach facilitated the elaboration of transversal research questions. In turn, this allowed for a more complete assessment of floodplain issues based on robust and current science. Using a collaborative approach optimised the use of resources and knowledge, avoided duplication of efforts, encouraged financial leverage with funding organisations and led to other research avenues and collaborations. For example, when considering the use of perennial buffer strips, researchers from the three research themes coordinated efforts to collect agricultural (plant biomass, establishment success), environmental (flood levels, use of the buffer strips by fish), and socio-economic data (costs of implementation, farmers' perception) in the same experimental plots to understand the efficacy of this agri-environmental practice under different perspectives.

Conceptualising management trade-offs

Engagement with researchers, producers and a variety of actors allowed us to conceptualise a holistic model of how compromises between floodplain stakeholders can move towards a sustainable, multifunctional landscape for Lake Saint Pierre. Ongoing results from individual research projects will refine this model and allow the recommendation of management options that have a high likelihood of creating successful change.

The core of the land use conflict in the Lake Saint Pierre floodplain is between those provisioning and cultural services that directly benefit the local community and economy, and the supporting and regulating services that have an indirect benefit to society, but a direct benefit to terrestrial and aquatic ecosystems. If we represent these ecosystem service groups as a gradient on one axis, and a gradient of land use types on another axis, we can conceptualise a matrix of land use scenarios that support the full range of ecosystem services

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(Fig. 3). At one endpoint of this matrix are scenarios such as farming, that prioritise provisioning and cultural services over supporting and regulating services. Conversely, at the other endpoint are scenarios such as nature reserves, which prioritise support and regulating services over provisioning and cultural services. The traditional ‘land sparing’ approach to balancing these services has been to partition different land uses that support different ecosystem services across the landscape. However, by using a land use/ecosystem service matrix, we can conceptualise trade-offs and synergies within land uses, and hence lead to a more equitable balance of ecosystem services at the landscape scale. In our example in Fig. 3, pathway 1 (top right quadrant) identifies a hypothetical but realistic compromise whereby natural areas traditionally dedicated to support and regulatory services could incorporate innovative commercial strategies (e.g. maple syrup collection, ecotourism) to move towards provisioning and cultural services, which could promote regional economic diversity. Likewise, pathway 2 (bottom left quadrant) offers a compromise where conventional annual cropping incorporates agri-environmental practices (e.g. perennial buffer strips) to move towards support and regulatory services, such as improved biodiversity.

The land use/ecosystem matrix also highlights combinations of non-viable or impractical scenarios (grey quadrants; Fig. 3). The top left quadrant conceptualises that conventional agricultural practices do not reconcile easily with the dynamism and heterogeneity that are needed to maintain supporting and regulating services in a floodplain, such as biodiversity, soil and water quality. Likewise, the bottom right quadrant highlights that natural areas with high conservation priority are not compatible with provisioning and cultural services such as recreational activities or farming. Thus, the compromise in the centre of this matrix represents a strong attractor. The benefits of integrating different ecosystem services into agricultural systems has been frequently identified (Falkenmark et al. 2007), but remains difficult to implement in practice.

[Note to publisher: Figure 3 here]

Recent trends towards a dominance of annual crop production have inadvertently established the Lake Saint Pierre floodplain as a 'land sparing' scenario, which comes with potential risks for the spectrum of ecosystem services. On one hand, setting aside large areas for conservation to offset crop production should benefit support and regulating services in this highly dynamic ecosystem. However, land dedicated to support and regulating services is vulnerable to the tragedy of the commons (i.e., depletion of shared services). For instance, public lands may be appropriated by a small group of people for hunting or recreation. On the other hand, farming these highly fertile lands supports provisioning and cultural services. However, intensive agricultural practices in a floodplain imply a constant struggle against the dynamic nature of the system, and require continuously dredging ditches and watercourses, and maintaining dams and drainage structures to avoid losing crop production. Thus, seasonally flooded land dedicated to provisioning and cultural services is vulnerable to climatic uncertainties and bears heavier environmental costs.

Our experience with the complexity of the Lake Saint Pierre system favours the idea that these landscapes should be managed in an adaptive manner at different agricultural, environmental and social scales, rather than through the lens of the land sharing-land sparing dichotomy. Using ecosystem services to represent the spectrum of benefits that can be provided, we conceptualise that floodplain sustainability can be improved not just by changing the proportions of land use types across a gradient, but by working towards compromises within land use types.

Challenges of an interdisciplinary research-based approach

Despite the numerous benefits of an interdisciplinary research-based approach, there are challenges when applying such an approach across multiple management scales. First, a research cluster as defined here needs resources dedicated to project coordination, stakeholder

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engagement and communication, which may only be merited if the scope of the project or number of collaborators is sufficiently large. Practically, coordination efforts can be disproportionately but necessarily high, particularly in dynamic landscapes such as floodplains where variability and unpredictability are the norm. Second, challenges in matching experimental designs can prevent studies from being conducted at the same temporal or spatial scales. For example, we found that the high floods in the first year of the program limited access to certain locations for studies conducted in the spring, but remained suitable for field access and data collection in the fall. Part of this challenge is determining an appropriate duration for the project: in the case of Lake Saint Pierre, it became evident that longer-term studies were needed to fully encompass the temporal and spatial variability of the ecosystem. An initial study duration of three years was too short to evaluate the success of experiments on agricultural units (e.g., crops, buffer strips); this was expanded to five years to accommodate this need but came at an additional cost to funding agencies. Finally, the project could have benefited from exploring different scopes at the socio-economic theme. Although the research examined opinions and perspectives from farmers and agricultural advisors, it did not explore management perspectives from other stakeholders such as environmental and watershed not-for-profit organisations.

Research at multiple spatial and social scales

Conducting coordinated research at multiple experimental scales facilitates the identification of key drivers at different spatial, temporal, and socio-economic levels. For example, by superimposing detailed information on flooding patterns, fish habitat use, support to biodiversity, water and soil quality, and crop productivity at different elevations, the research cluster can produce valuable information on which areas should be prioritised for agriculture or conservation. Traditional assessment of agricultural variables such as yield, productivity and

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nutritional content typically occurs at the field-scale. In the context of assessing agri-environmental practices across the Lake Saint Pierre floodplain, we examine broader spatial scales than traditionally investigated to assess how changes to floodplain agriculture may impact receptors (farmers, environmental variables) at the field, regional and floodplain scales. Again, the use of an interdisciplinary research group is essential to collect relevant data at different scales and incorporate these into our understanding of the floodplain system as a whole. Alternative approaches that do not consider the multiple disciplines within a research-based framework run the risk of an incomplete understanding of a complex system, and thus a vulnerable basis for decision-making.

While the intent of the experimental framework was to integrate all three themes across the same spatial scales, the administrative and policy reality made this challenging. Having the same theoretical basis, it was relatively straightforward for agricultural and environment projects to share field sites that spanned land use gradients, elevation gradients, and were spread over different regions of the floodplain. However, we learned that the socio-economic theme was inherently different: some projects were reliant on economic data collected from defined administrative boundaries that did not necessarily align with the field constraints of the agriculture projects. Likewise, perspectives and values from farmers could vary at a local level, that did not match other parts of the framework. While this misalignment did not prevent the research cluster from using the socio-economic results in both conceptual and practical ways, it highlighted that – much like the dynamics of the floodplain –social dynamics can be more variable than predicted.

Challenges and opportunities for floodplain sustainability

The dynamic properties of floodplains, including a strong interannual variation, highlight the need for longitudinal studies whereby the same plots are monitored over multiple years under

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varying hydrological conditions. Although local water levels are monitored constantly at hydrological stations, the practical consequences of different flooding regimes are best understood through more detailed field-level observations. Data collected across the diverse conditions of 2019-2021 illustrate how farmers adapt their practices in response to variable environmental conditions. This adaptive capacity may be particularly important for provisioning services under future climatic conditions. Climate projections suggest increased precipitation and extreme events across the Great Lakes watershed in coming decades, particularly in winter and spring (Xue et al. 2022). These conditions are likely to result in earlier and longer flood regimes, and to exacerbate some of the issues observed during this project, such as delayed sowing, changing crop, soil erosion, and reduced development and production of traditional annual crops (e.g., Mendelsohn & Massetti 2017). Alternative management practices, such as those trialled in our study, have been identified as an approach to mitigate some of these challenges (Smit & Skinner 2002).

The techno-economic challenges of changing agricultural practices are associated with divergent interests, legal issues, and misaligned responsibilities of actors (Heikkila & Gerlak 2005). Our research cluster operated in a socially, legally, and politically complex context where improving the sustainability of the Lake Saint Pierre floodplain is conceptually supported by many actors, although land-use conflicts are prevalent (TCRLSP 2017). Although the recurrent floods play a major role in the agricultural practices of Lake Saint Pierre, producers experience floods in varied and complex ways and have diverging attitudes and opinions toward land management. They also express different opinions and solutions for the ecological rehabilitation of the floodplain. These contrasting opinions and solutions testify to a heterogenous agricultural community (Ruiz et al. 2021), divided between claiming a right to produce and wanting to participate in the ecological rehabilitation effort (Lévesque et al. 2020).

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As such, current challenges for the ecological rehabilitation of the floodplain are not shaped by a singular relationship between producers and the floodplain, but by varied ways in which producers envision their farming system and how their individual values elicit their responses to change. This echoes other studies showing that a better understanding of farmers' sensitivity to environmental issues may be more important to changing practices than the biophysical characteristics of the farms (Knowler & Bradshaw 2007). Finally, the way in which information is presented to farmers and other stakeholders impacts acceptance (Doyon & Saulais 2022). One of the ultimate benefits of an interdisciplinary research cluster is thus not just determining the types of land use management that can lead to improved sustainability, but also incorporating the social component that is crucial for a better adherence to new practices and regulations.

Conclusion

We have detailed an experimental framework employed by an interdisciplinary research cluster, that aimed to demonstrate benefits of this approach to inform sustainable land use. Demonstrated practical advantages included knowledge transfer across disciplines, efficient use of resources (e.g. personnel, funding), and synthesis of results to provide holistic recommendations. In the context of dynamic floodplain systems, this approach allowed researchers to adapt to variable conditions and changing assumptions as they were revealed, resulting in a robust experimental foundation.

An interdisciplinary research approach provided an improved understanding of how the natural, agricultural, and human elements interact in the complex Lake Saint Pierre floodplain system. As well as advancing scientific outcomes in the individual themes, this approach allowed a synthesis of information that could be communicated to decision-makers and allowed for a better understanding of how the practicalities of agricultural systems are affected by

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environmental variability. The inclusion of a socio-economic dimension, which is rarely incorporated within agri-environmental experimental frameworks, proved to be essential for understanding the perspective of producers and agronomic advisors, which is crucial for informing regulatory changes and predicting acceptability of change. Our use of different spatial scales allowed the practical outcomes of agri-environmental practices – such as alternative crop yield at different field elevations - to be integrated with larger, regional scale processes such as floodplain-level hydrological dynamics.

Beyond practical and policy implications for agri-environmental practices, our framework proposes not just examining the redistribution of the land use gradient to meet sustainable management objectives, but also exploring compromises within existing uses to optimise socio-economic, agricultural and environmental dimensions. Quantifying this is dependent on a sound scientific understanding of the systems and a holistic conceptualisation of land use management, which is underpinned by cooperative research conducted at relevant spatial and experimental scales.

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References

Aber, J. S., F. Pavri, and S. W. Aber. 2012. Conservation and Management: Wetland Planning and Practices. Wetland environments: a global perspective (pp. 218–230). Wiley-Blackwell, Oxford.

Bartolai, A. M., L. He, A. E. Hurst, L. Mortsch, R. Paehlke, and D. Scavia. 2015. Climate change as a driver of change in the Great Lakes St. Lawrence River Basin. Journal of Great Lakes Research 41:45–58.

Batáry, P., L. V. Dicks, D. Kleijn, and W. J. Sutherland. 2015. The role of agri-environment schemes in conservation and environmental management. Conservation Biology

29:1006–1016.

Baylis, K., J. Coppess, B. M. Gramig, and P. Sachdeva. 2022. Agri-environmental Programs in the United States and Canada. Review of Environmental Economics and Policy. 16(1):83-104.

Baylis, K., S. Peplow, G. Rausser, and L. Simon. 2008. Agri-environmental policies in the EU and United States: A comparison. Ecological Economics 65:753–764.

Benton, T. G., J. A. Vickery, and J. D. Wilson. 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology & Evolution 18:182–188.

Blackshaw, R. E., K. N. Harker, J. T. O'Donovan, H. J. Beckie, and E. G. Smith. 2008. Ongoing development of integrated weed management systems on the Canadian Prairies. Weed Science 56:146–150.

Blanco-Canqui, H., T. M. Shaver, J. L. Lindquist, C. A. Shapiro, R. W. Elmore, C. A. Francis, and G. W. Hergert. 2015. Cover crops and ecosystem services: insights from studies in temperate soils. Agronomy Journal 107:2449–2474.

Boschi, C., and B. Baur. 2008. Past pasture management affects the land snail diversity in nutrient-poor calcareous grasslands. Basic and Applied Ecology 9:752–761.

Campeau, S., Ruiz, J., Bourgeois B., Damar, H., Halde, C., Proulx R., Rodriguez, M.A., Maire, V., Mazzei R., Vaillancourt, M., Poulin, M., Vanasse, A., Seguin, P., Bertolo, A., Bordeleau, P.-A., Bregar, A., Cabana, G., Tamini,L.D., Decelles, A.-M., Doyon, M., Duchesne-Pelletier, R., Fournier, V., Fugère, V., Gravel, V., Guillemette, F., Head, J., Kallenbach, C., Lewis, N., Martin, C., Mundler, P., Prasher, S., Qi, Z., Roy, A., Tremblay, M and C. Watson, 2023. Synthèse et recommandations des recherches du Pôle d'expertise multidisciplinaire en gestion durable du littoral du lac Saint-Pierre. Université du Québec à Trois-Rivières, Université Laval, Université Mc Gill. Report for the ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec et au ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des

Journal Pre-proof

Parcs.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253–260.

Dauphin, D., and B. Jobin. 2016. Changements de l'occupation du sol dans la plaine inondable du lac Saint-Pierre entre les années 1950 et 1997. Le Naturaliste Canadien 140:42–52.

Dosskey, M. G., P. Vidon, N. P. Gurwick, C. J. Allan, T. P. Duval, and R. Lowrance. 2010. The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams1. JAWRA Journal of the American Water Resources Association 46:261–277.

Doyon, M., and L. Saulais. 2022. Impact du design de questions sur la perception des compensations proposées et les intentions de participation au PAD: étude de préfaisabilité. CIRANO Project Reports 2022rp-15, CIRANO.

Emmerson, M., M. B. Morales, J. J. Oñate, P. Batáry, F. Berendse, J. Liira, T. Aavik, I. Guerrero, R. Bommarco, S. Eggers, T. Pärt, T. Tscharntke, W. Weisser, L. Clement, and J. Bengtsson. 2016. How Agricultural intensification affects biodiversity and ecosystem services. Advances in Ecological Research (pp. 43-97). Elsevier.

Erős, T., and Z. Bányai. 2020. Sparing and sharing land for maintaining the multifunctionality of large floodplain rivers. Science of The Total Environment 728:138441.

Erős, T., V. Hermoso, and S. D. Langhans. 2023. Leading the path toward sustainable freshwater management: Reconciling challenges and opportunities in historical, hybrid, and novel ecosystem types. WIREs Water 10:e1645.

Falkenmark, M., C. M. Finlayson, L. J. Gordon, E. M. Bennett, T. M. Chiuta, D. Coates, N. Ghosh, M. Gopalakrishnan, R. S. de Groot, G. Jacks, E. Kendy, L. Oyebande, M. Moore, G. D. Peterson, J. M. Portuguez, K. Seesink, R. E. Tharme, and R. Wasson. 2007. Agriculture, water, and ecosystems: avoiding the costs of going too far. *in* D. Molden (editor). Water for food water for life: A comprehensive assessment of water

Journal Pre-proof

management in agriculture (pp 233–277) Routledge, London.

Farooq, M., and K. H. M. Siddique. 2015. Conservation agriculture: concepts, brief history, and impacts on agricultural systems. *in* M. Farooq and K. H. M. Siddique, editors. Conservation Agriculture: concepts, brief history, and impacts on agricultural systems (pp 3–17). Springer International Publishing.

Fischer, J., D. J. Abson, V. Butsic, M. J. Chappell, J. Ekroos, J. Hanspach, T. Kuemmerle, H. G. Smith, and H. von Wehrden. 2014. Land sparing versus land sharing: moving forward. Conservation Letters 7:149–157.

Fischer, J., B. Brosi, G. C. Daily, P. R. Ehrlich, R. Goldman, J. Goldstein, D. B. Lindenmayer, A. D. Manning, H. A. Mooney, L. Pejchar, J. Ranganathan, and H. Tallis. 2008. Should agricultural policies encourage land sparing or wildlife-friendly farming? Frontiers in Ecology and the Environment 6:380–385.

Fisher, J. T., and A. C. Burton. 2018. Wildlife winners and losers in an oil sands landscape. Frontiers in Ecology and the Environment 16:323–328.

Geilen, N., H. Jochems, L. Krebs, S. Muller, B. Pedroli, T. Van Der Sluis, K. Van Looy, and S. Van Rooij. 2004. Integration of ecological aspects in flood protection strategies: defining an ecological minimum. River Research and Applications 20:269–283.

Gene, S. M., P. F. Hoekstra, C. Hannam, M. White, C. Truman, M. L. Hanson, and R. S. Prosser. 2019. The role of vegetated buffers in agriculture and their regulation across Canada and the United States. Journal of Environmental Management 243:12–21.

Gilroy, J. J., F. A. Edwards, C. A. Medina Uribe, T. Haugaasen, and D. P. Edwards. 2014. Surrounding habitats mediate the trade-off between land-sharing and land-sparing agriculture in the tropics. Journal of Applied Ecology 51:1337–1346.

Giroux, I. 2004. La présence de pesticides dans l'eau en milieu agricole au Québec, Québec, Ministère de l'Environnement, Direction du suivi de l'état de l'environnement, Envirodoq no ENV/2004/0309, collection no QE/151.

Journal Pre-proof

Grass, I., J. Loos, S. Baensch, P. Batáry, F. Librán-Embid, A. Ficiciyan, F. Klaus, M. Riechers, J. Rosa, J. Tiede, K. Udy, C. Westphal, A. Wurz, and T. Tscharntke. 2019. Land-sharing/-sparing connectivity landscapes for ecosystem services and biodiversity conservation. People and Nature 1:262–272.

Green, R. E., S. J. Cornell, J. P. W. Scharlemann, and A. Balmford. 2005. Farming and the fate of wild nature. Science 307:550–555.

Gupta, G., J. Khan, A. K. Upadhyay, and N. K. Singh. 2020. Wetland as a sustainable reservoir of ecosystem services: prospects of threat and conservation. *in* A. K. Upadhyay, R. Singh, and D. P. Singh, editors. Restoration of wetland Ecosystem: a trajectory towards a sustainable environment (pp 31–43). Springer, Singapore.

Heikkila, T., and A. K. Gerlak. 2005. The Formation of large-scale collaborative resource management institutions: clarifying the roles of stakeholders, science, and institutions. Policy Studies Journal 33:583–612.

Hein, T., U. Schwarz, H. Habersack, I. Nichersu, S. Preiner, N. Willby, and G. Weigelhofer. 2016. Current status and restoration options for floodplains along the Danube River. Science of The Total Environment 543:778–790.

Hudon, C., M. Jean, and G. Létourneau. 2018. Temporal (1970–2016) changes in human pressures and wetland response in the St. Lawrence River (Québec, Canada). Science of The Total Environment 643:1137–1151.

Jaeger, J. A. G. 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. Landscape Ecology 15:115–130.

Jobe, A., A. Kalra, and E. Ibendahl. 2018. Conservation Reserve Program effects on floodplain land cover management. Journal of Environmental Management 214:305–314.

Jobin, B., and P. Brodeur. 2023. Changements de l'occupation du sol de la plaine inondable du lac Saint-Pierre de 1950 à 2016 et perspectives pour la restauration des milieux naturels. Le Naturaliste canadien 147:14.

Journal Pre-proof

Jobin, B., J.-L. DesGranges, and C. Boutin. 1996. Population trends in selected species of farmland birds in relation to recent developments in agriculture in the St. Lawrence Valley. Agriculture, Ecosystems & Environment 57:103–116.

Kaluli, J. W., C. A. Madramootoo, X. Zhou, A. F. MacKenzie, and D. L. Smith. 1999. Subirrigation systems to minimize nitrate leaching. Journal of Irrigation and Drainage Engineering 125:52–58.

Knowler, D., and B. Bradshaw. 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32:25–48.

Kousky, C., and M. Walls. 2014. Floodplain conservation as a flood mitigation strategy: Examining costs and benefits. Ecological Economics 104:119–128.

Kremen, C. 2020. Ecological intensification and diversification approaches to maintain biodiversity, ecosystem services and food production in a changing world. Emerging Topics in Life Sciences 4:229.

Lastra-Bravo, X. B., C. Hubbard, G. Garrod, and A. Tolón-Becerra. 2015. What drives farmers' participation in EU agri-environmental schemes?: Results from a qualitative meta-analysis. Environmental Science & Policy 54:1–9.

Lévesque, A., J. Dupras, and J.-F. Bissonnette. 2020. The pitchfork or the fishhook: a multi-stakeholder perspective towards intensive farming in floodplains. Journal of Environmental Planning and Management 63:1987–2003.

Maas, B., Y. Fabian, S. M. Kross, and A. Richter. 2021. Divergent farmer and scientist perceptions of agricultural biodiversity, ecosystem services and decision-making. Biological Conservation 256:109065.

Mack, G., A. Ferjani, A. Möhring, A. von Ow, and S. Mann. 2020. How did farmers act? Ex-post validation of linear and positive mathematical programming approaches for farm-level models implemented in an agent-based agricultural sector model. Bio-based and Applied Economics Journal, 8(1), 3-19.

Journal Pre-proof

Marty, J., M. R. Twiss, J. J. Ridal, Y. de Lafontaine, and J. M. Farrell. 2010. From the Great Lakes flows a Great River: overview of the St. Lawrence River ecology supplement. Hydrobiologia 647:1–5.

Matson, P. A., W. J. Parton, A. G. Power, and M. J. Swift. 1997. Agricultural intensification and ecosystem properties. Science 277:504–509.

MDDEFP. 2013. Le lac Saint-Pierre: un joyau à restaurer. Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs. Gouvernement du Québec.

Mendelsohn, R. O., and E. Massetti. 2017. The use of cross-sectional analysis to measure climate impacts on agriculture: theory and evidence. Review of Environmental Economics and Policy 11(2):280–298

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Biodiversity synthesis. Washington, DC: World Resources Institute.

NABCIC. 2012. The State of Canada's Birds. North American Bird Conservation Initiative Canada. Environment Canada, Ottawa.

Nelson, R. W. 1986. Wetlands policy crisis: United States and United Kingdom. Agriculture, Ecosystems & Environment 18:95–121.

Newbold, T. 2018. Future effects of climate and land-use change on terrestrial vertebrate community diversity under different scenarios. Proceedings of the Royal Society B: Biological Sciences 285:20180792.

Nilsson, C., C. A. Reidy, M. Dynesius, and C. Revenga. 2005. Fragmentation and Flow Regulation of the World's Large River Systems. Science 308:405–408.

Ocean, N., and P. Howley. 2021. Using choice framing to improve the design of agricultural subsidy schemes. Land Economics 97:933–950.

Opperman, J. J., P. B. Moyle, E. W. Larsen, J. L. Florsheim, and A. D. Manfree. 2017. Floodplains. First edition. University of California Press.

Ouellet-Cauchon, G., M. Mingelbier, F. Lecomte, and L. Bernatchez. 2014. Landscape

Journal Pre-proof

variability explains spatial pattern of population structure of northern pike (Esox lucius) in a large fluvial system. Ecology and Evolution 4:3723–3735.

Petts, J., S. Owens. and H. Bulkeley. 2008. Crossing boundaries: interdisciplinarity in the context of urban environments. Geoforum 39:593-601.

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117–1123.

Ruiz, J., A. Dumont, M.-P. Maurice, and S. Campeau. 2021. Entre sentiment de responsabilité et aversion pour l'arbre : les bandes riveraines vues par les agriculteurs. VertigO.

Simoneau, M. 2017. Qualité de l'eau des tributaires du lac Saint-Pierre : évolution temporelle 1979-2014 et portrait récent 2012-2014. Publication gouvernementale, Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, Direction générale du suivi de l'état de l'environnement, Québec. https://belsp.uqtr.ca/id/eprint/1204/.

Smit, B., and M. W. Skinner. 2002. Adaptation options in agriculture to climate change: a typology. Mitigation and Adaptation Strategies for Global Change 7:85–114.

Snapp, S. S., S. M. Swinton, R. Labarta, D. Mutch, J. R. Black, R. Leep, J. Nyiraneza, and K. O'Neil. 2005. Evaluating cover crops for benefits, costs and performance within cropping system niches. Agronomy Journal 97:322–332.

Spidalieri, K. 2020. Where the wetlands are—and where they are going: legal and policy tools for facilitating coastal ecosystem migration in response to sea-level rise. Wetlands 40:1765–1776.

Stammel, B., Cyffka, B., Geist, J., Müller, M., Pander, J., Blasch, G., Fischer, P., Gruppe, A., Haas, F., Kilg, M. and P. Lang. 2012. Floodplain restoration on the Upper Danube (Germany) by re-establishing water and sediment dynamics: a scientific monitoring as part of the implementation. River Systems 20:55-70.

Journal Pre-proof

Steven, D. D., and R. Lowrance. 2011. Agricultural conservation practices and wetland ecosystem services in the wetland-rich Piedmont-Coastal Plain region. Ecological Applications 21:S3–S17.

Stock, P., and R. J. F. Burton. 2011. Defining terms for integrated (multi-inter-trans-disciplinary) sustainability research. Sustainability 3(8):1090-1113.

Stubbs, M. 2014. Conservation Reserve Program (CRP): status and issues. Library of Congress, Congressional Research Service Washington, DC, USA.

Sun, Y., Y. Zeng, Q. Shi, X. Pan, and S. Huang. 2015. No-tillage controls on runoff: A meta-analysis. Soil and Tillage Research 153:1–6.

TCRLSP. 2017. Cohabitation agriculture-faune en zone littorale au lac Saint-Pierre. Table de Concertation Régionale du Lac Saint-Pierre. Fiche synthèse.

Thoms, M. C. 2003. Floodplain–river ecosystems: lateral connections and the implications of human interference. Geomorphology 56:335–349.

Tscharntke, T., A. M. Klein, A. Kruess, I. Steffan-Dewenter, and C. Thies. 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecology Letters 8:857–874.

Vanasse, A., A. Charles, and N. Tremblay. 2017. Méta-analyse sur la contribution des cultures de couverture à la dynamique de l'azote, à la qualité des sols et aux rendements des grandes cultures | Grandes cultures. Rapport Innov'Action IA214152.

Verhoeven, J. T. A., and T. L. Setter. 2010. Agricultural use of wetlands: opportunities and limitations. Annals of Botany 105:155–163.

Villamayor-Tomas, S., J. Sagebiel, and R. Olschewski. 2019. Bringing the neighbors in: A choice experiment on the influence of coordination and social norms on farmers' willingness to accept agro-environmental schemes across Europe. Land use Policy 84:200–215.

von Wehrden, H., M. H. Guimarães, O. Bina, M. Varanda, D. J. Lang, B. John, F. Gralla, D.

Journal Pre-proof

Alexander, D. Raines, A. White, and R. J. Lawrence. 2019. Interdisciplinary and transdisciplinary research: finding the common ground of multi-faceted concepts. Sustainability Science 14:875-888.

Ward, J. V., K. Tockner, and F. Schiemer. 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. Regulated Rivers: Research & Management 15:125–139.

Xue, P., Ye, X., Pal, J. S., Chu, P. Y., Kayastha, M. B., and C. Huang. 2022. Climate projections over the Great Lakes Region: using two-way coupling of a regional climate model with a 3-D lake model, Geoscientific. Model Development 15, 4425–4446, https://doi.org/10.5194/gmd-15-4425-2022.

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Tables

Table 1. Examples of research projects and variables collected at nested spatial extents. Note that some projects (*) were designed to act as a link between multiple experimental scales.

Experimental Scales	***Research Project***	***Variables***	***Ecosystem Services***
Floodplain	Flooding duration and extent	Water depth, residence and drainage time	Supporting ,Regulating
	Water quality	Water turbidity, conductivity and suspended solids	Supporting ,Regulating
	Land-use and land-cover characteristics	NDVI: pasture, fodder and crop areas; forested and protected areas; road and hydrology networks	Provisioning ,Cultural
	Cost-benefit of agri-environmental practices	Economic status of agricultural land-use scenarios	Provisioning ,Cultural
	Governance and ecosystem services	Management trade-offs and synergies	Provisioning ,Cultural
	Socio-technical attributes of agri-environmental practices	Factors that motivate or limit adhesion to new practices or regulations	Provisioning ,Cultural
Regions Within the Floodplain	Forage crop production*	Implantation success of managed grasslands	Provisioning ,Cultural
	Agri-environmental cropping practices*	Implantation success of cover crops, enlarged buffer strips and modified production schedules	Provisioning ,Cultural
	Aquatic biodiversity	Fish and zooplankton communities; environmental DNA	Supporting ,Regulating
	Water quality*	Dissolved oxygen, pH, nutrients, dissolved organic carbon, pesticides	Supporting ,Regulating
	Terrestrial biodiversity	Breeding bird, pollinator and singing insect communities	Supporting ,Regulating
	Socio-technical challenges and opportunities	Interviews and focus groups with stakeholders	Provisioning ,Cultural
Land-use Type Within Region	Crop production*	Grain yield, plant biomass, plant height, ground cover, establishment success, weed populations	Provisioning ,Cultural
	Phytoprotection*	Pest insect density, presence of diseases	Supporting ,Regulating

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	Soil quality	Ammonium, nitrate, available phosphorus, carbon, water capacity	Supporting ,Regulating
	Aquatic biodiversity	Fish growth, condition and abundance; fish larvae and eggs; zooplankton abundance	Supporting ,Regulating
	Sediment quality	Zooplankton egg bank; plant seed bank; pesticide ecotoxicity	Supporting ,Regulating
	Ecosystem processes	Primary productivity, bacterial metabolism, CO_2/CH_4 fluxes	Supporting ,Regulating
	Socio-technical analysis of agri-environmental practices	Farm profitability	Provisioning ,Cultural
Elevation Zones Within Land-use Types	Alternative crops*	Crop yield, winter survival, revenue	Provisioning ,Cultural
	Conventional crop production*	Crop yield, revenue, biomass, plant height, establishment success	Provisioning ,Cultural
	Cover crops *	Plant biomass, plant height, ground cover, botanical composition, establishment success, weed pressure	Provisioning ,Cultural
	Drainage ditch management	Sediment load, excavation cost, buffer strip width, plant growth and survivorship	Supporting ,Regulating

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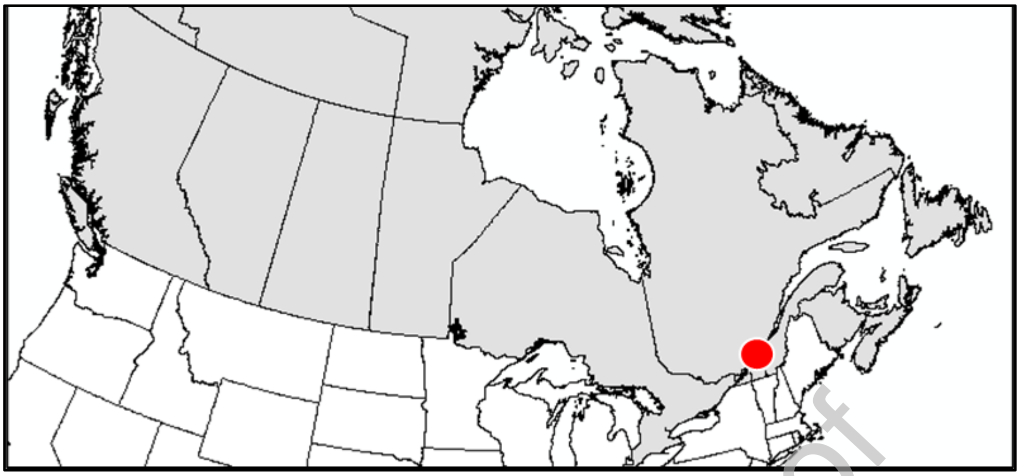
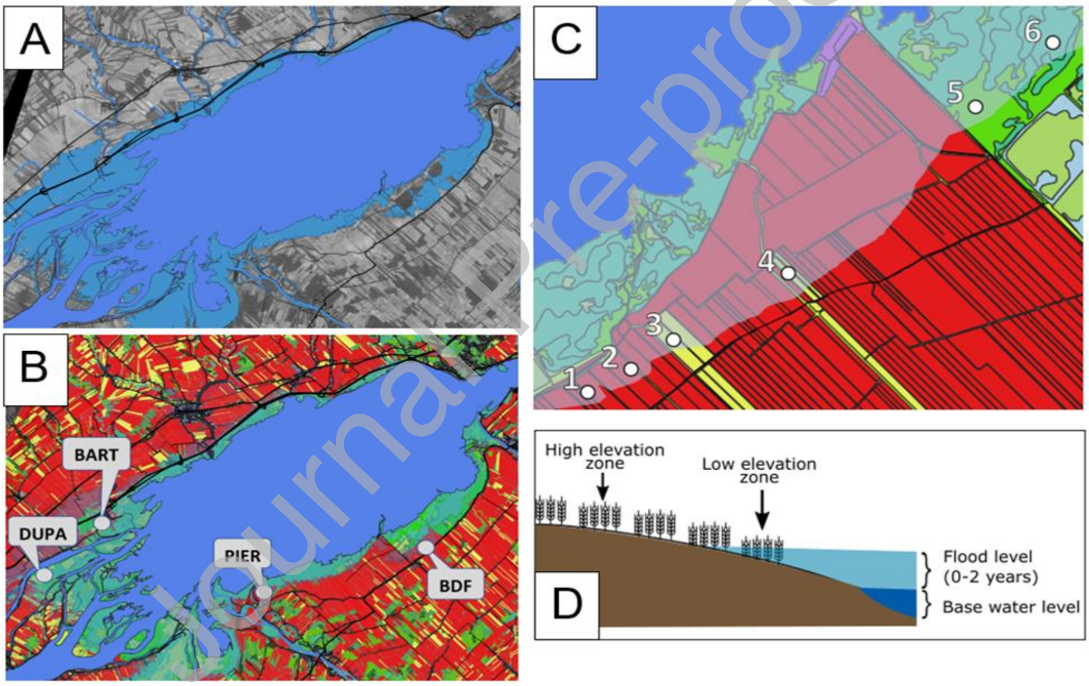
Figures (in order)





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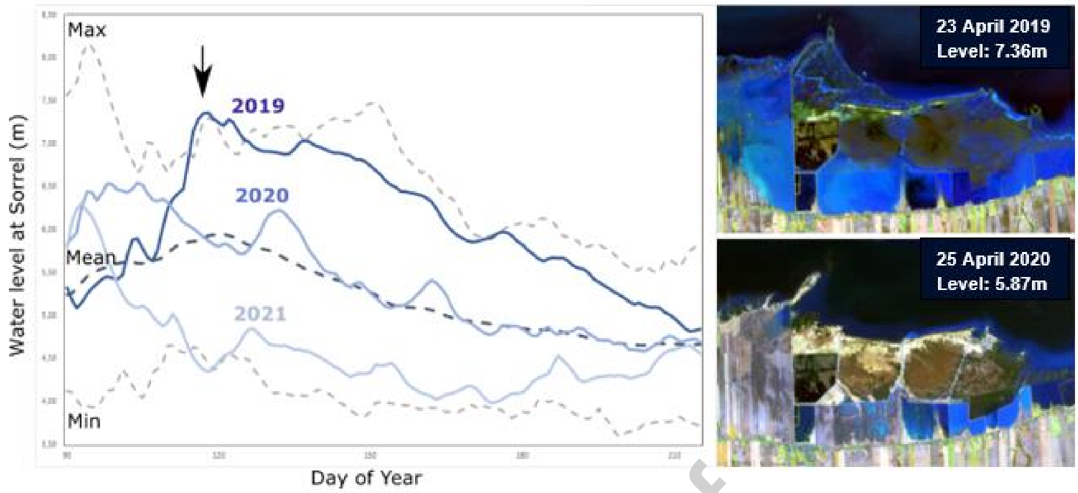

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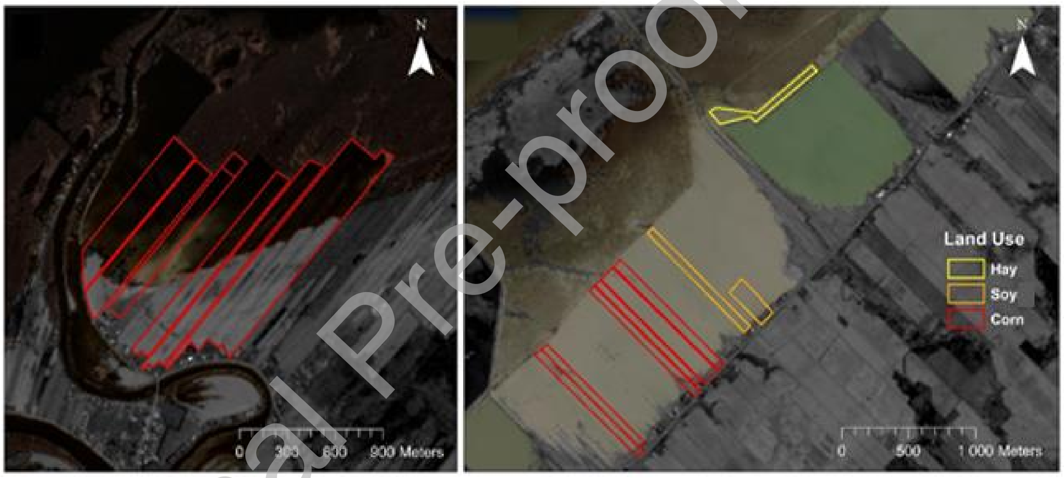

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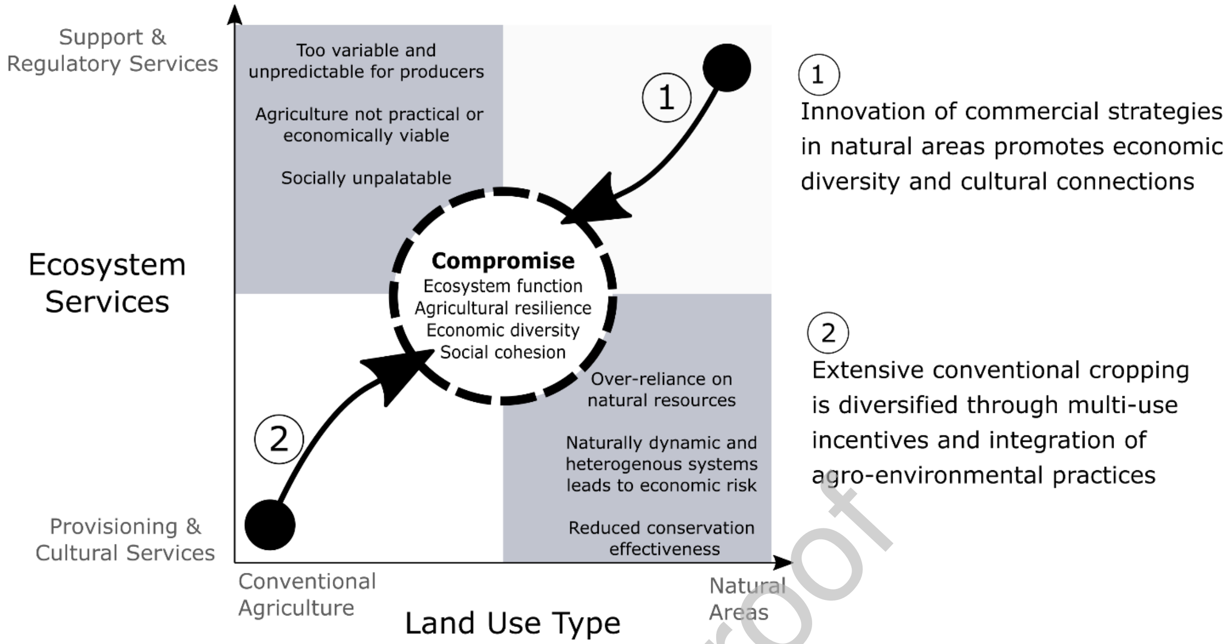

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Figure Captions

Fig. 1. Conceptual representation of nested spatial scales within the experimental framework: The top panel shows the location of the study area, with (A) **Floodplain**, showing Lake Saint Pierre (blue) and the 2-year recurrence area (light blue); (B) **Study regions within the floodplain** and associated land cover. Labels identify the four study areas: BDF (Baie-du-Febvre), PIER (Pierreville), BART (Saint-Barthélemey), and DUPA (Île Dupas); (C) **Land use type within regions**: land use represented by annual crops (red), hayfields (yellow), and natural areas (green) with numbers indicating 1) conventional cropping, 2) agri-environmental cropping, 3) recently sown forage cropping, 4) old forage cropping, 5) wet meadows, and 6) silver maple swamps; (D) **Elevation zones within land-use type,** comparing low elevation zones of fields, where flooding occurs near-annually, with high elevation zones between 6.2 and 6.79 m elevation (0 -2 year flood recurrence).

Fig. 2. Spatial and temporal variability of the Lake Saint Pierre floodplain system: (A) Temporal water level variability between day-of-year 90 (March 31) and 212 (August 31) as measured at the Sorel hydrometric station. Water levels for 2019, 2020 and 2021 are represented by blue lines, with dashed grey lines representing historical (1966-2018) maximum, mean, and minimum levels. The arrow indicates 23-25 April, where Sentinel-2 imagery shows the difference in flood regimes between 2019 (upper right) and 2020 (lower right) in the Baie-du-Febvre study region. Blue colours represent inundated land, with darker shades indicating greater water depths; (B) **Spatial variability in water turbidity,** (left) black low turbidity water in agricultural land of the Pierreville study region, related to the low sediment load of incoming floodwaters, and (right) brown high turbidity water in the Baie-du-Febvre study region, related to the strong sediment load from upstream agricultural tributaries. Images are Sentinel-2 true colour composite images from 6 May 2019.

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Fig. 3. Conceptualisation of land management trade-offs and synergies at the landscape scale in the context of land use and ecosystem services. The white quadrants represent current or potential land management states; grey quadrants represent non-viable or impractical states. Circled numbers indicate pathways from which endpoint scenarios (solid circles) can reach a compromise to optimise social, agricultural, economic, and environmental costs and benefits.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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