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REVIEW PAPER

Flood-Fire Interplays in Wetlands: The Rising of an Actionable Field of Study

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Abstract
Floods and fires are part of the ecological regime in many wetlands, yet their interconnectedness is poorly explored. Climate extremes, such as droughts and heatwaves, are increasing fire frequency and intensity, while changing rainfall patterns make floods more unpredictable. These events shape wetland physiognomy, species composition, and functioning. Different wetlands experience varying fire exposure; seasonally inundated grasslands burn almost annually, whereas tropical forests rarely catch fire. Some wetlands are more resilient to fire, drought, and floods than others. Communities dependent on wetlands possess ecological knowledge that supports adaptation, enhancing ecosystem resilience. Though often studied separately, floods and fires in wetlands are interrelated. In addition to environmental aspects, social, cultural and associated traditional knowledge dimensions must be included in conservation processes for these environments. A holistic understanding is crucial for conservation. Researchers from sixteen countries propose a new field of study on flood-fire interactions to improve wetland management and sustainability.

Keywords Biodiversity · Catastrophes · Climate changes · Opposite forces · Wetland · Wildfires

Introduction

Fire and water are two opposing forces deeply embedded in our imagination about nature (Elemental, 2023), but until now, they have mainly been studied in isolation. Historically, we have seen significant advances in fields of study such as fire ecology (Cooper 1961), wetland ecology (Junk et al. 1989), and, more recently, flood ecology (Humphries et al. 2024), each having established chairs in the universities and with specific journals publishing mainly on these subjects (Pereira et al. 2024). However, the interactions between flooding and fire in wetlands require an integrated approach to understand and mitigate their combined impacts (Langhill & Abizaid, 2020; Cunha Ávila et al. 2021), especially in the context of global climate change (IPCC, 2023, Pereira et al. 2024). Ecosystems subject to both flood and fire are relatively common. For instance, seasonal and inter-annual variations in water level can promote fire-prone vegetation and play a key role in the functioning of classic wetland systems such as the Everglades and the Pantanal (Damasceno-Junior et al. 2025; Lockwood et al. 2003).

The interplay between flooding and fire shapes vegetation in diverse ways. It influences species' richness

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and abundance (Arruda et al. 2016; Correa et al. 2022; Ferreira et al. 2024a; Oliveira et al. 2014), monodominance patterns (Manrique-Pineda et al. 2021), phenological cycles (Ferreira et al. 2023), and functional diversity (Ferreira et al. 2024b). Faunal assemblages are also affected, with documented changes in abundance (e.g., arachnids; Arrua et al. 2023) and shifts in community composition (Lugo-Carvajal et al. 2023). In Amazonian floodplains, for example, wildfires can alter fish communities, reduce tree seed dispersal and slowing forest regeneration. Such cascading effects ultimately compromise ecosystem functioning and the provision of critical services (Lugo-Carvajal et al. 2023).

Ecosystems subject to both flood and fire are relatively common. Seasonal and inter-annual variations in water level can promote fire-prone vegetation and play a key role in the functioning of wetland systems (Lockwood et al. 2003). However, the mechanisms linking fire and flood are complex, and depend on climate, geomorphology, and human activities. For instance, In the Pantanal, floods play a central role in regulating vegetation biomass and, consequently, the amount of fuel available for fires. Rather than simply reducing terrestrial vegetation during inundation, periodic inundation can stimulate plant growth and lead to the accumulation of large amounts of biomass once the water recedes. This relationship is highly complex and depends on the intensity, duration, and spatial extent of floods, as well as on geomorphology and climatic variability (Ivory et al. 2019). The north-to-south flood pulse of the Paraguay River creates spatial and temporal asynchrony between rainfall, inundation, and vegetation growth, with northern and upland areas responding more directly to rainfall, while central and southern floodplains experience delayed effects. These differences influence how temperature and soil moisture anomalies interact to determine when and where accumulated biomass becomes highly flammable, shaping the spatial patterns of fire activity across the Pantanal (Libonati et al. 2022).

These ecological impacts also have direct and indirect consequences for human communities in wetland regions. Flooding and Fire significantly influence health, socio-ecological systems, and local economies (Napreenko et al. 2021; Oliveira et al., 2022; Lugo-Carvajal et al. 2023; Lorenz et al. 2024). However, information on the synergistic effects of these phenomena remains sparse or underexplored. Given the growing recognition of their importance, this paper proposes establishing a new field of study dedicated to understanding flood-fire interactions. This initiative aims to address the critical need for a holistic perspective on these interconnected natural processes and their influence on wetland ecosystems.

Fire-prone Tropical Wetlands Under Human-induced Changes

Wetlands cover approximately 6% of the Earth's surface and play an important role in supporting biodiversity and providing essential ecosystem services (Davidson et al. 2019). Many of these wetland ecosystems are also exposed to fire, especially in tropical and sub-tropical regions, where seasonal variation in rainfall enables both flooding and fire to occur in the same location at different times. The resulting plant and animal communities require adaptations to survive both waterlogging and fire, and it is important to recognize this when understanding their functioning and predicting their response to global change (Power et al. 2016; McLauchlan et al. 2020). For example, some animals respond differently to fire due to their exposure to flooding (Arrua, 2023). However, this is not always the case. In the case of ants, fire alone determines their composition and occurrence in the Pantanal wetlands (Arruda et al. 2022). Notable wetland regions, such as the Pantanal (Brazil, Bolivia, and Paraguay), Chaco (Paraguay, Argentina, and Bolivia), Orinoco in Venezuela, the Everglades in the United States, the Okavango Delta in Botswana, Moxico wetlands in Angola, Kakadu in Australia, and the Kilombero Valley Floodplains Ramsar Site in Tanzania (see Figs. 1 and 2), are strongly influenced by the complex interplay between flooding and fire. The fact that both agents are inherent components of many wetland ecosystems is not always well understood by scientists, practitioners, and policymakers, which complicates preparation for and management of catastrophic events that can negatively affect the economy, public health, and biodiversity (Kelley et al. 2019; Bowman et al. 2020; Gallagher et al. 2021; Libonati et al. 2022). Consequently, these challenges have sparked ongoing debates at both political and academic levels, highlighting the urgent need for effective fire management in fire-prone wetlands. Protected areas within the Pantanal wetlands have been shown to be effective in reducing fire occurrences, particularly in flooded areas (Moreira et al. 2024). This finding underscores the importance of stakeholders considering both factors together to make effective decisions regarding management and conservation.

In this context, tropical wetlands experience markedly different impacts depending on wildfire type (Smith et al. 2001). For example, field studies in the Florida Everglades, Pantanal, and Indonesian peatlands report that surface fires lead to moderate losses in plant biomass, slight shifts in community structure, and only transient changes in soil carbon and nutrients (Kumar et al. 2022; Lockwood et al. 2003; Silviana et al. 2019).

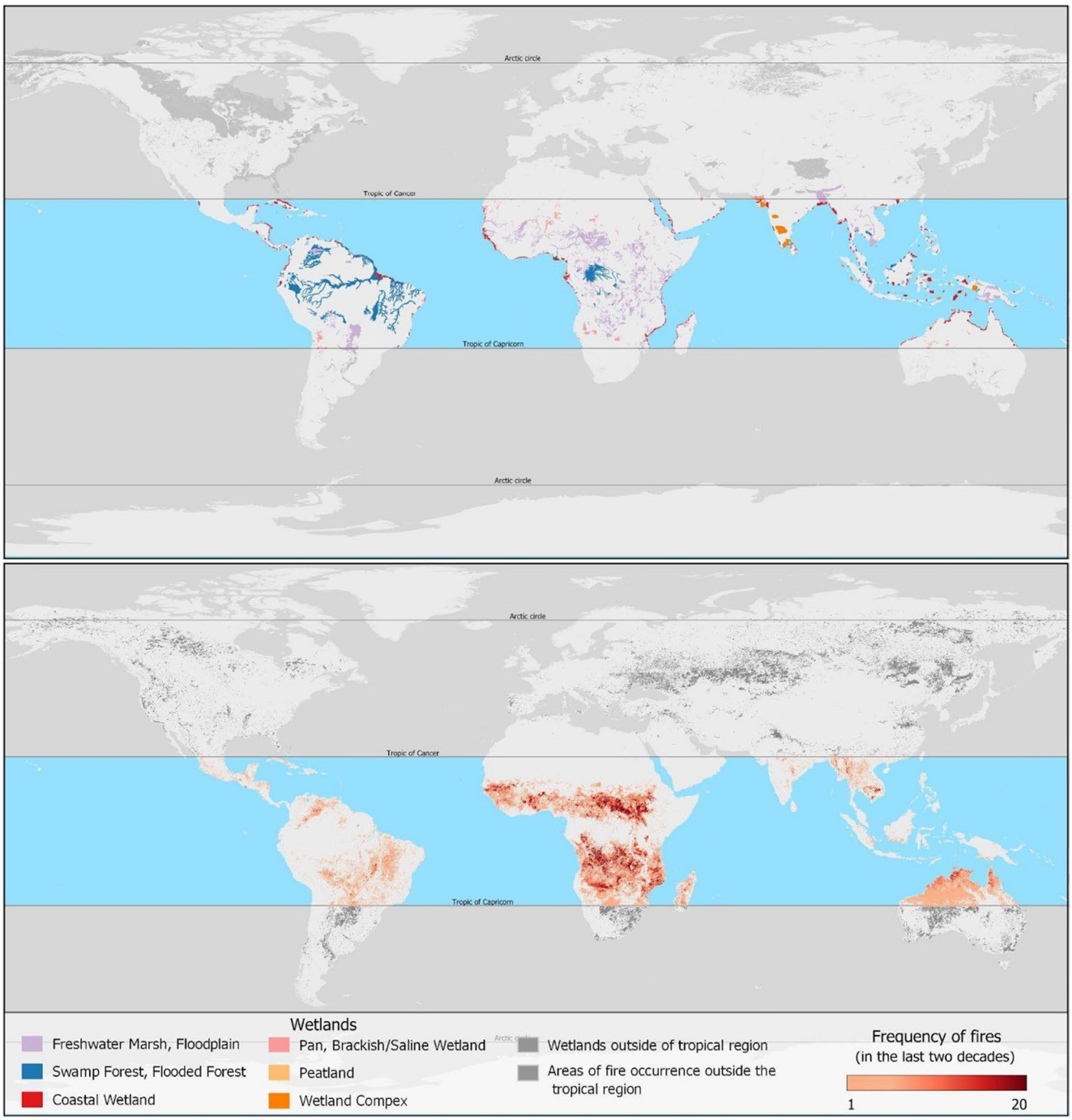

Fig. 1 Patterns of wetlands and fires in the tropics. The top figure shows the main wetlands in the tropics according to Lehner & Doll 2004. The bottom figure shows the distribution and frequency of active fires counts in the tropics, data from the Modis Terra and Aqua satellites over the last two decades (2003–2023) (Giglio et al. 2021).

Surface fires can burn over waterlogged soil without affecting the underlying peat, and peatlands that burn regularly are found across all continents (Damasceno-Junior et al. 2021; Grosvenor et al. 2024; Lourenco et al. 2023). However, when human activities lower the water table and peatlands are drained, ground fires that consume peat soil can devastate ecosystems and generate massive GHG emissions (Pereira et al. 2024). In regions such as Sumatra and Kalimantan in Southeast Asia, drainage reduces the capacity of peatlands to store water and carbon, making them more vulnerable to flooding during the rainy season and to fires during the dry season (Page and Hooijer 2016; Turetsky et al. 2015).

Fig. 2 Some examples of wetlands that are subject to flooding and fire. (**a**) Moxico in Angola in the Lungwevungu Plains (António, T.E.M.); (**b**) Burnt young oil palm plantation at the peatland area, Indonesia. (Saharjo, B. H.); (**c**) Cameia National Park, Angola (Meller, P); e (**d**) Pantanal in Brazil. Trees burnt show how intense the wildfire was (Pereira, A.M.M)

Indonesia provides a compelling case of the complex interplay between fire, surface and ground water, and carbon in tropical peatlands. This dynamic is highly dependent on context: small variations in groundwater level or vegetation structure can determine whether a fire remains superficial or penetrates the peat. Feedback between fire and hydrology further amplify vulnerability—extreme floods alter fuel loads, while severe fires damage soil structure and disrupt evapotranspiration. To mitigate these risks, Indonesia established regulations requiring companies to maintain groundwater levels within 40 cm of the surface. Yet enforcement remains challenging, and peat fires continue to account for roughly half of the country's greenhouse gas emissions reported to the UNFCCC in 2022 (UNFCCC, 2023) (See Box 1 for different fire behavior). The Indonesian case highlights how nonlinear and interdependent processes among water, fire, and carbon complicate both emission estimates and management strategies. Understanding these interactions is critical for designing effective policies that prevent peatlands from shifting from carbon sinks to sources of global climate forcing.

These examples raise fundamental questions about when fire is destructive and when it plays a natural role in ecosystem functioning. Understanding this distinction is essential to developing more effective fire management strategies tailored to the unique vulnerabilities of each ecosystem. Likewise, while wetland ecosystems are adapted to inundations, extreme flooding can have catastrophic impacts, and like with fire, researchers need to provide better guidance on the thresholds of potential concern for different wetlands globally. This underscores the importance of studying these processes together.

Box 1: Fire in wetlands can assume different behaviors depending on the type of surface and available fuels. Adapted from Prevfogo (2018).

- Surface fire: It is the most common type of wildfire, burning vegetation at ground level such as leaf litter, grasses, forbs, and small shrubs. Unlike crown fires (see below), which spread through the canopy, surface fires usually move along the ground and are easier to control, though they can still cause significant ecological damage and threaten wildlife and human structures.
- Crown fire: It is a type of wildfire that spreads through the canopy of trees, often ignited by a surface fire. These fires move rapidly from treetop to treetop, fueled by dense foliage, making them extremely intense and difficult to control. Crown fires can cause severe damage to forests and pose serious risks to wildlife and human structures.
- Ground fire: It is a type of wildfire that burns underground, consuming buried organic matter such as peat and humus. Ground fires can smolder for long periods without visible flames, making them difficult to detect and extinguish. They spread slowly and may persist for months, sometimes reigniting under favorable conditions.

The Emergence of a New Field of Study Through an International Participatory Process

We conceived the idea for this new field of study during the 60th Annual Meeting of the Association for Tropical Biology and Conservation (ATBC), held in Kigali, Rwanda, in 2024. The initial outline emerged from long-term ecological research on flood-fire dynamics in the Pantanal wetlands in Brazil. Based on this, a core team of seven researchers from the Federal University of Mato Grosso do Sul (Brazil) and one from the Humboldt Institute (Colombia) invited scientists worldwide with expertise in fire in wetlands, particularly those from regions facing challenges similar to the Pantanal and other tropical wetlands, to participate in a one-day workshop at ATBC. The process unfolded in three main stages: (i) before the conference, (ii) during the event, and (iii) after the conference through online collaboration.

The workshop brought together a diverse group of scientists from Brazil, Rwanda, Tanzania, Indonesia, Colombia, Uganda, South Africa, the U.S., Germany, Puerto Rico, Brunei, Kenya, Ecuador, the UK, China, Angola, and Cameroon, in addition to participants drawn from related conference presentations. The goal was to establish a shared understanding of key terms and foundational principles, beginning with presentations of regional experiences and followed by a structured discussion process that laid the groundwork for this emerging field of study. Through this co-design process, the workshop identified key topics, knowledge gaps, and guiding principles for integrated flood-fire studies. Subsequently, the group engaged in a structured discussion process as follows: The process was structured into three main phases:

Visioning Session (in-person)

The first phase took place during an in-person workshop (first two hours), where participants gathered to outline a shared vision and define the general direction of this emerging research field. To stimulate collective reflection, five participants presented case studies (10 min each) from Brazil (two), Indonesia (one), and Germany (one), demonstrating that the interplay between fire and flood is a global phenomenon, present across both the Global South and Global North. This session helped establish a common ground for identifying shared challenges, opportunities, and potential pathways for integrative research across diverse socioecological contexts.

Brainstorming (in-person)

The second phase also occurred during the workshop (after breakfast, for another two hours) and focused on collectively identifying the main themes, knowledge gaps, and priorities for advancing the new field. Conducted in an open circle format, this activity allowed all participants to express their views and experiences freely. Two participants acted as rapporteurs, while another served as facilitators to guide and balance the discussion. Special attention was given to fostering a multilingual and inclusive environment, encouraging participants to speak in Portuguese, Spanish, English, or any language they felt comfortable with. This approach ensured equitable participation and helped to capture the diversity of perspectives within the group. All suggestions were carefully recorded and synthesized into a preliminary list of topics relevant to the emerging field, later refined and summarized in Table 1 during the following phase.

Collaborative Writing (remote)

The third phase was conducted remotely using online collaborative platforms that enabled real-time co-authoring of the manuscript. Participants contributed through "comment boxes," where they proposed revisions, added arguments, and discussed priorities openly. A coordination team based in Brazil mediated the process, facilitating dialogue, synthesizing consensus points, and incorporating the agreed-upon changes into successive manuscript versions, and incorporating the agreed-upon changes into successive manuscript versions. The list of topics in Table 1 remained dynamic throughout this stage – participants were encouraged to suggest modifications or re-prioritize themes based on emerging discussions. Regular updates on deadlines and manuscript versions ensured transparency and continuity. This iterative and participatory workflow fostered shared authorship and collective ownership, resulting in a manuscript that genuinely reflects the diversity of knowledge, experiences, and perspectives of the entire team.

Why Do We Need a New Field of study?

The increasing frequency and intensity of floods and fires worldwide — and their impact on wetlands and vulnerable communities — underscore the urgent need for a new area of scientific inquiry (see box 1). Current approaches often fail to account for the compounded effects of these disturbances, resulting in inadequate risk assessment and management strategies.

Table 1 Key topics Raised by the participants of the workshop on "Opposite ecological forces: exploring the interplay of floods and fires in tropical Wetlands" that took place at ATBC meeting, in Kigali, Rwanda, 2024

Understanding patterns, Processes, mechanisms, and consequences
Classification and Mapping: Recognizing the need to consider different types of wetlands and identifying criteria for mapping fire-prone and non-fire-prone wetlands.
Magnitude and Frequency: Examining the magnitude, scale, frequency, and seasonality of floods and fires, including how flood seasons influence fire periods and the intervals between extreme events.
Biodiversity Dynamics: Understanding how flood/fire dynamics define and control vegetation composition and structure, to predict taxonomic and functional biodiversity changes as these drivers change.
Carbon and Climate Change Mitigation Potential: Map and identify wetlands that increase the global emissions of carbon when burned, such as the peatlands. Mapping and identification of high carbon potential wetlands and their contribution to emissions when degraded/burned using the IPCC 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.
Trade-offs and Synergies: Exploring the trade-offs and synergies between flood and fire, and their consequences.
Compound Effects: Studying the combined effects of flood, fire, drought, hurricanes, etc.
Regime Shifts: Investigating regime shifts and the relative roles of flood and fire, as well as the reversibility of these shifts.
Human Dimension and Management
Evolution and History of Human Use of wetlands, and the interaction with fire: Archaeological evidence.
Understanding Catastrophes: Defining what constitutes a catastrophe (both from a human and an ecological perspective) in the context of flood-fire interactions.
Changing Flood-fire Regimes and Community Responses: Assessing the implications of changing flood and/or fire regimes for human communities and their adaptation to climate change
Social and Cultural Aspects: Considering the social and cultural dimensions of floods and fires is crucial, particularly regarding human migration and nomadism, traditional governance practices, and techniques for harvesting, cultivating, or hunting food in wetlands. Wetlands also serve as sites of cultural identity and local ecological knowledge production and transmission. Additionally, understanding the use of flood and fire management—or adaptive practices to these disturbances—to control pests and diseases is essential.
Community Strategies and Livelihoods: It is essential to assess how communities cope with and adapt to opposing forces, while diversifying research on floods and fires by integrating diverse forms of knowledge, such as local ecological knowledge and insights from conservation and management practitioners. Evaluating how livelihoods are influenced by the interactions between floods and fires is crucial for promoting sustainable management practices that support both ecosystems and communities.
Management Practices: It is important to discuss how floods and fires can—or cannot—be managed to improve practices in cattle grazing, agriculture, and small-scale fisheries, recognizing that some fires are human-induced during hunting or pasture management. Additionally, certain wetlands and peatlands are naturally prone to fires, and their management should differ from strategies applied to human-induced fires.
Future of Wetlands: Understanding how the interactions between people, fire, and floods might transform wetlands under climate change raises important questions. Exploring different scenarios can provide valuable insights, especially when incorporating knowledge from local communities who have experienced or may face these changes. This approach highlights the importance of ensuring that wetlands and the communities that depend on them remain integral parts of a resilient system.
Practical experiences: It is essential to identify and learn from both successful and unsuccessful examples of adaptive environmental management, including nature-based solutions such as ecological restoration and biological conservation initiatives in wetlands influenced by the dual ecological pressures of floods and fire regimes.
The development of new technologies for assessing monitoring, application, and management of floods and fire-affected wetland.

Our proposal focuses on understanding flood–fire interactions and aims to:

I. llanning the logistics of working and living in environments affected by floods and fires involves significant challenges, as these areas are often inaccessible for much of the year (Fig. 3). Furthermore, effective fire management requires substantial resources. Long-term studies—spanning seasons and years—are essential to understanding these phenomena and their impacts. Operating in remote and hard-to-access locations is also costly, which can limit our ability to monitor and comprehend their dynamics.

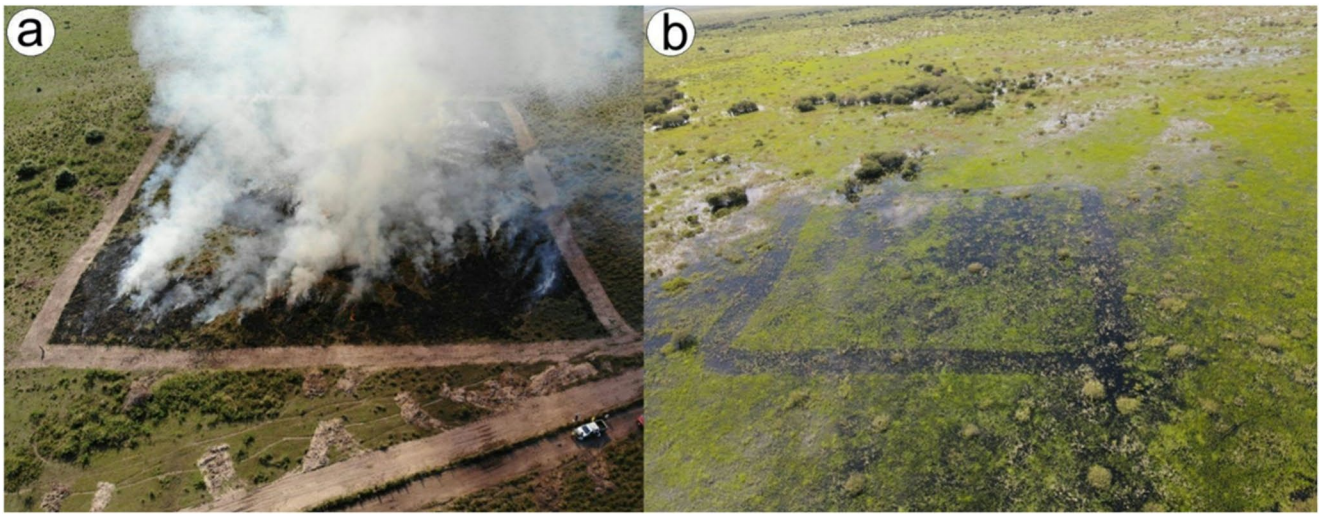

Fig. 3 Experiment using controlled fire in a wetland (Brazilian Pantanal) during the dry (a) and flooding phase (b) as part of a Long-Term Ecological Research Network

Box 2. Definitions of a new field of study.

- Flood-fire interactions refer to the integrated study of coupled fire and flood regimes in wetland and floodplain systems, and their biodiversity, ecological, social, cultural, and climatic implications. This field recognizes that fire and flood are not isolated disturbances but interdependent processes that jointly shape landscapes, biogeochemical cycles, and human livelihoods across diverse regions of the world.
- By integrating these dimensions, research on flood-fire interactions establish an interdisciplinary and inclusive field that bridges multiple forms of knowledge, including local, traditional, and Indigenous perspectives. The field aims to advance both science and policy, fostering adaptive management and equitable strategies for coexistence with complex disturbance regimes in a changing climate.

Principles for Building the Flood-Fire Field of Study

To effectively address flood-fire interactions, the new discipline should be built on the following principles:

I. **Interdisciplinary collaboration**: Encourage collaboration across various disciplines, including hydrology, meteorology, chemistry, ecology, urban planning, economy, anthropology, and other social sciences, to develop a holistic understanding of flood-fire interactions.
II. **Co-designing with local communities and other stakeholders**: Engage a diverse range of stakeholders, including scientists, policymakers, practitioners, indigenous communities, and community members, in the co-design of the discipline. That ensures a research agenda is relevant, actionable, and aligned with real-world needs.
III. **New perspectives**, **curriculums**, **and professionals**: Attract and train professionals with diverse backgrounds and perspectives. Producing actionable science requires scientists to hold a distinct set of competencies, including interdisciplinary collaboration, system thinking, and effective communication skills. Training programs and curricula should be designed to develop these competencies.
IV. **Actionable science**: Focus on producing knowledge with the needs of a specific end-user in mind. This involves not only conducting high-quality research but also effectively communicating findings to decision-makers and practitioners, setting a common agenda, and conflict-solving strategies.
V. **Inclusiveness**: Explicitly incorporate principles of diversity and inclusion as a foundational tenet of flood–fire interaction science. Actively pursue approaches that promote participation and representation across academia, practitioner communities, and local populations, with particular attention to underrepresented groups, including women, youth, early-career researchers, and specific ethnicities.
VI. **Dialogues among science**, **art**, **and communication**: Combining scientific principles with artistic expression and community involvement offers a valuable opportunity to enhance research and education. Beyond classroom exercises, incorporating art and creativity into scientific methods and science communication serves as a powerful tool to broaden engagement, foster innovation, and integrate diverse forms of knowledge. Through dialogic communication and art–science collaborations, this approach deepens understanding of the ecological, social, and cultural dimensions of flood and fire events, inspiring innovative strategies for management and adaptation.

Take-home Message

We present the results of a multi-stakeholder workshop in which we proposed the need for a new field of study: integrated flood-fire studies. This process identified key topics, knowledge gaps, and guiding principles for developing the field. Wetland floods and fires are often treated as separate phenomena, but our aim is to address both the biophysical and human dimensions of flood-fire interactions, meeting the needs of wetland managers, conservationists, practitioners, and local communities. Wetland restoration approaches with social–ecological implications, as well as investments promoting sustainable practices, should also be considered to ensure the relevance and effectiveness of this emerging field.

While we propose this new field, it cannot exist in isolation. Bringing together diverse perspectives and expertise is essential to understanding the complex interactions between flooding and fire. The topics outlined here highlight existing gaps, but it is the collaborative process itself that will ultimately shape the discipline. Understanding flood-fire dynamics also requires long-term field research and large-scale experiments, which are particularly challenging in remote tropical wetlands or in countries with limited infrastructure. Continued collaboration and research are therefore essential to fully address these complexities and advance knowledge in this proposed field.

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Data Availability Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Declarations

Competing interests The authors declare no competing interests.

Financial Interests The authors have no relevant financial or non-financial interests to disclose.

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