

## Commentary

# Emerging agricultural expansion in northern regions: Insights from land-use research

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Climate change and socio-economic dynamics are driving rapid agricultural expansion in boreal and Arctic regions, referred to as northern agricultural frontiers, and this has large potential environmental and human implications. Conceptualizing northern agricultural frontiers as resource frontiers and building on lessons from the tropics could help guide research and governance of these emerging landscapes.

## Introduction

Boreal regions—the circumpolar vegetation belt of high northern latitudes covered with forests, other wooded land, and wetlands consisting of cold-adapted species—cover around 21.51 Mkm<sup>2</sup> of the Earth's surface.<sup>1,2</sup> Together with Arctic regions—here defined as the treeless tundra regions north of the boreal regions—they constitute the largest forest biome of the planet and hold vast amounts of carbon stocks both in vegetation and in soils, including in permafrost. As such, these regions are vital for climate regulation. They also hold very rich biodiversity, and northern countries together are home to ~200 million people whose livelihoods depend on these natural environments.<sup>2</sup>

Due to climate change and socio-economic dynamics, new opportunities are emerging across the boreal landscape and, to a lesser extent, the Arctic. The boreal region is experiencing rapid agricultural expansion and intensification, largely driven by governments' willingness to seize the new opportunities offered by warming climate conditions.<sup>3</sup> These emerging “northern, climate-driven agricultural frontiers”<sup>1</sup> offer opportunities for socio-economic development, global food production, and local food self-sufficiency. However, because of the important climate-regulation services and the biodiversity value provided by these regions, these shifting land uses also present important concerns and multiple risks for sustainability.

In recent decades, similar agricultural expansion has occurred in tropical frontiers and has been accompanied by large-scale deforestation and associated

biodiversity loss, carbon emissions, soil erosion, the disruption of hydrological regulation and other ecosystem services, and land conflicts and marginalization of rural communities and Indigenous groups. This transformation has also led to large increases in food production and the emergence of important commodity export-oriented economies. Soy production in Brazil and palm oil in Indonesia are prime examples. Agricultural frontiers also occurred in temperate regions, such as through the recultivation of land abandoned as a result of the collapse of the Soviet Union. This reflects the complexity of the issues that can arise from new agricultural frontiers. These frontiers dynamics have been the focus of intense efforts in land systems and sustainability sciences, as well as in policy interventions in recent years, resulting in valuable learnings. As northern latitudes transform, insights from tropical regions could inform both research and governance. This commentary reflects on what we have learned from tropical frontiers but does not propose blueprint solutions or panacea; rather, it aims to open doors to collaboration and foster fruitful dialog among researchers, practitioners, and stakeholders.

## Northern agricultural expansion and sustainability

Overall, northern regions experience accelerated climate change compared to global trends. Projections suggest that by the end of the 21<sup>st</sup> century, ~76% (55%–89%) of the boreal region could be under feasible temperature conditions for cropping, i.e., with >1,200

accumulated growing degree days per year above 5°C (GDD5).<sup>1</sup> Boreal lands under these temperature conditions would thereby expand from 6.85 Mkm<sup>2</sup> today, to 16.40 Mkm<sup>2</sup> by 2100, thus a ~9.55 Mkm<sup>2</sup> or 140% gain. Whether these lands would satisfy other conditions for agriculture, such as humidity and soil conditions, remains uncertain, and, of course, potential need not imply conversion (indeed, in Canada, only ~8.5%–9.0% of land subject to GDD5 ≥ 1,200 has been converted to agriculture, reflecting the multiple constraints in these regions).<sup>1</sup> Yet, comparing these numbers with the ~2.22 Mkm<sup>2</sup> of net agricultural expansion in the Tropics over the period 1961–2019, accompanied by deforestation rates of 0.07–0.10 Mkm<sup>2</sup> per year over the recent years, shows the magnitude of the challenge (see FAO statistics<sup>4</sup> on “agricultural land,” including permanent pasture, and using a simple definition of “tropical” regions as including Central America and the Caribbean, South America, Africa, and Southern and Southeast Asia). Aggregated numbers also mask large regional heterogeneities in the trends and changes in potential for agriculture.<sup>5</sup> Yet, the potential agricultural land area is vast, with potential for significant transformations likely accompanied by global-scale impacts.

Several works have described the potential sustainability impacts of agricultural expansion and intensification in boreal regions, yet their characterization and quantification remain a pressing gap in research. Environmental impacts include conversion or degradation of natural habitat with large biodiversity impacts; further greenhouse gas emissions



from vegetation clearing but also mainly from soil carbon, with accelerated mineralization of organic carbon especially in peat soils; soil erosion and nutrient leaching; and water pollution.<sup>2,6</sup> Once triggered, these changes can cascade: melting permafrost, for example, can result in the release of nutrients that in turn modify the vegetation composition.<sup>7</sup> Socio-economic impacts include changes in food systems, livelihoods, employment, Indigenous land claims, and migration, with both winners and losers.<sup>2</sup> Northern ecosystems are especially fragile, with low self-recovery capacity when disturbed.<sup>3</sup> Northern frontiers are also embedded in geopolitical tensions; e.g., with potential contraction of food production in some low-latitude regions and increases in northern regions, power in agricultural markets will likely be redistributed.<sup>8</sup> These dynamics, although here-above envisioned over a large time-scale, are already underway in many regions.<sup>3</sup>

Mitigating the negative impacts and fostering the desirable ones requires us to understand how and by whom the agricultural expansion frontier is happening, and who gains and loses from these changes. Research on frontiers in other regions can provide useful theoretical and empirical starting points on this.

### Northern agricultural frontiers as resource frontiers

Agricultural expansion frontiers have been conceptualized under the broader framing of “resource frontiers,” i.e., places with an imbalance between abundant natural resources and a comparative lack of production factors (capital, labor) to exploit these resources, inducing a rapid expansion of resource use.<sup>9</sup> Often, the resource is land suitable for a set of land uses, giving rise to “land-use frontiers.” “Deforestation frontier” is also a term frequently used to characterize places with rampant deforestation, generally overwhelmingly related to agriculture, but such agricultural expansion can also take place in other, non-forest ecosystems such as grasslands and savannas. In land-use frontiers, pathways of expansion and intensification are intrinsically linked, presenting not only tradeoffs but also potential synergies for interventions. For example, policies restricting land-use expansion can induce intensification

on already used lands, with potential positive or negative human consequences, possibly improving livelihoods of farmers or marginalizing them if intensification happens through large-scale agricultural investments.

Frontiers involve much more than land-use change. Frontiers have been described as a process of pushing back so-called “wilderness” to create a space for development by “taming the natural world,” as well as spaces facing rapidly expanding forces and constituting places of opportunities for multiple actors.<sup>10,11</sup> The “resource” in these frontiers can be newly discovered, but it can also be “reinvented,” i.e., being given a new value due to technological, institutional, socio-economic, environmental, or cultural changes.<sup>12</sup> For example, soybean agricultural frontiers emerged when new soy varieties and cropping techniques allowed farmers to overcome soil and climatic constraints in drier and poorer soils of South America.<sup>12</sup> Mineral resource frontiers can emerge in places where mineral resources gain sudden value, such as graphite or lithium resources in the context of renewable energy. This makes frontiers typical spaces of “territorialization,” i.e., spaces where institutional actors, including governments and corporations, turn places into “territories” that they can understand, monitor, regulate, and exploit by naming, surveying, mapping, and delineating land. Through these processes, frontiers are also places of interface and friction between different worlds, e.g., subsistence and capitalist economies, different cultures, socio-political systems, and mode of relations to nature.<sup>13</sup>

Contemporary frontiers are increasingly driven by commodity production operated by large-scale, capitalized actors, giving rise to so-called “corporate” or “commodity” frontiers.<sup>12</sup> Echoing this, agricultural expansion and intensification in northern frontiers appear to be driven by a diverse combination of actors, including public and private actors, with northern governments providing enabling conditions as they see opportunities to foster agricultural growth, as well as private, corporate actors, more than local populations, driving land-use change.<sup>2</sup> Conceptualizing agricultural expansion in northern regions as a frontier process helps us understand who is operating

this expansion, why, and the typical ways in which it might occur.

### Insights from tropical and other land-use frontiers

With this background in mind, I here turn to five insights from recent research on resource, land use, and agricultural and deforestation frontiers in other regions of the world (Table 1). These insights concern generalized knowledge about land-use dynamics (insights 1 and 5), potentially transferrable knowledge from observing frontiers in other regions (insights 2, 3, and 5), methodological advances that could inspire research in northern regions (insights 2 and 4), and reflections on governance of these frontier processes (insights 1, 2, 3, and 5). This is not a comprehensive review—only a hint at the potential for cross-fertilization between research across distinct regions.

First, frontier dynamics take place in and reshape complex social-ecological systems, with multiple interactions between natural processes, socio-economic and cultural dynamics, technologies, and governance systems.<sup>9</sup> These interactions can lead to abrupt changes, structural transformations or “regime shifts,” such as the emergence of rapid, large-scale agricultural expansion, or, conversely, structural shifts from deforestation dynamics to reforestation dynamics, known as “forest transitions.” These complex social-ecological dynamics mean that land-use change in one place often causes further indirect or spillover effects elsewhere. Seemingly rational interventions, such as intensifying agriculture or forestry in order to spare land for nature elsewhere, could trigger counteracting rebound effects by making agriculture more productive and thus incentivizing actors to expand to capture new markets, resulting in further agricultural or forestry expansion. Similarly, interventions to achieve an environmental goal in one place can lead to displacing pressure elsewhere, counteracting the initial intentions, i.e., leakage effects. Yet, contextual generalizations of typical chains of mechanisms causing certain land-use change sequences under a specified set of conditions can help us understand the possible pathways and how to influence them.<sup>9</sup>

Second, frontier dynamics cannot be fully understood by only investigating

**Table 1. Five insights for understanding and governing northern land-use frontiers**

Insight	Challenge	Proposition	Examples
1	frontiers are complex social-ecological systems, with interactions, feedbacks, and non-linear dynamics	look for spillovers and build adaptive governance, based on causal understanding	policies to support agricultural intensification can result in a rebound effect triggering further expansion; policies to restrict agriculture in certain areas can result in leakage to other areas <sup>9</sup>
2	actors' agency can trigger surprising, emerging frontiers	understand actors' decision-making and goals to identify emergent frontiers; frontiers are easier to steer when they emerge rather than when they are highly active	in Northern Mozambique, actors from previous waves of agricultural investments have been struggling and failing, but leave legacies that could trigger sudden frontier emergence; <sup>11</sup> investors in Eastern and Southern African frontiers have very varied logics and assets, and understanding this can help adjusting interventions to these heterogenous actors <sup>10</sup>
3	private, corporate actors and complex supply chains challenge traditional territorial public governance	explore hybrid public-private, territorial-supply chain governance	governance interventions to stop cocoa-driven deforestation in West African frontiers build on public, private, and non-governmental organizations (NGOs), as well as international organizations implementing territorial and supply-chain actions, including sustainability standards and certification systems supported by NGOs, public policies such as the nationally developed and internationally supported strategies for Reducing Emissions from Deforestation and Degradation, and watchdog and transparency initiatives from scientists, NGOs, and civil society. <sup>14</sup>
4	theories of change and interventions require causal understanding	use robust causal inference methods to assess causal effects and causal mechanisms of interventions	research using robust impact evaluation methods typically show that protected areas are located in areas with low pressure, so that a naive evaluation of their impacts typically overestimates their effectiveness in controlling land-use changes <sup>15</sup>
5	there's tradeoffs and winners and losers	acknowledge trade-offs and embed local communities in research and governance	across a large sample of case studies, conservation interventions where Indigenous peoples and local communities play a central role, such as in community-based natural resource management schemes and community and Indigenous lands designation, have overall more positive outcomes for both well-being and conservation than do interventions controlled by external organizations that supersede customary institutions <sup>16</sup>

land-use patterns. Frontiers typically involve actors aiming to seize opportunities and capture, sometimes create, land rent before others do, navigating between moving too early, when the conditions are not yet ripe, and moving too late, when competition has become too rife.<sup>12</sup> Understanding and governing these frontiers thus requires an understanding of the heterogenous motivations, logistics, and decision-making processes of actors driving land-use changes—in particular, private actors such as investors and business managers who carry increasing weight in these contexts.<sup>10</sup> Before a large-scale, rapidly expanding frontier emerges, previous waves

of pioneers might have attempted to develop commercial agriculture in such places and failed. These waves might be hard to notice because they might not have led to visible outcomes, but they still might leave very important material and human legacies that explain and shape sudden, apparently “surprising,” frontier emergence and thus provide important early-warning signals.<sup>11</sup> Understanding these dynamics requires on-the-ground, mixed methods research.

Third, with growing interconnections between distant places and a prominent role played by private, corporate actors in shaping frontiers dynamics, multiple approaches have emerged to leverage

the potential of supply chains to foster more sustainable land-use practices. This includes, for example, eco-certification systems, multi-stakeholders initiatives such as roundtables, and voluntary codes of conducts or commitments from corporate actors that produce, trade, process, and retail commodities.<sup>17</sup> Increasingly, the governance of land-use dynamics in these frontiers builds on hybrid schemes involving combinations of territorial interventions including spatial and land-use planning, where public actors typically play a key role,<sup>18</sup> and supply-chain interventions. For example, to halt deforestation associated with cocoa expansion frontiers in West Africa,

transnational companies have committed to implement zero-deforestation requirements across their suppliers (smallholders and intermediary traders), articulating their efforts with public policies to address deforestation.<sup>14</sup> Alignment of interests and coordination among these multiple actors remain key challenges. If northern regions become increasingly integrated into global food systems as suppliers of commodities, such hybrid, public-private, and territorial-supply chains approaches might become increasingly important to organize agricultural development and promote sustainable land management.

Fourth, methodologically, much progress has been achieved on assessing the effectiveness of policy interventions in frontiers through formalizing the use of impact-evaluation methods relying on counterfactually based statistical or econometric approaches to estimate causal effects of certain interventions.<sup>15</sup> Such methods build on a clear theory of change, combined with in-depth investigation of the causal mechanisms in operation. These approaches, when used wisely, can provide robust answers on the effectiveness of interventions such as land zoning for habitat conservation, extension programs or supply-chain approaches for the promotion of sustainable agricultural techniques, or community-based natural resource management, accounting both for direct and indirect spillover effects such as leakage.

Finally, research on land use and sustainability in tropical regions shows that decisions and interventions often result in trade-offs, producing winners and losers across heterogeneous sets of actors. An increasing body of evidence highlights the importance of developing solutions in partnership with Indigenous and local communities, showing that community-based solutions are not only fairer but also more effective to achieve sustainability.<sup>16</sup> These insights might be valuable in northern frontiers contexts, where Indigenous land claims and complex, fragmented land tenure are not necessarily well acknowledged in policies targeting agricultural expansion.<sup>2</sup>

## Conclusion

Agricultural expansion and intensification in northern regions raise critical challenges related to biodiversity and ecosystem services, local livelihoods, economic development, and geopolitical tensions. The provided insights are only a few starting points for cross-fertilization of research and governance initiatives across different frontiers contexts. Key research avenues on frontiers remain, such as understanding how to identify emerging frontier dynamics, better estimate sustainability impacts, and better channel changes toward desirable outcomes before they lead to rampant negative externalities. Conversion of prime natural ecosystems can have largely irreversible impacts, and even when restoration is feasible, it might not lead to the full recovery of the ecosystems' values. A key lesson from tropical frontiers is that when large-scale, capitalized agribusiness agriculture gains momentum and reaches full speed, it becomes extremely difficult to steer. Proactive governance in emerging frontiers is key to developing trajectories toward sustainable land systems.

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