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Title: Fenced off: Measuring growing restrictions on resource access for smallholders in the Argentine Chaco

Authors: Olivia del Giorgio ^a, Mathis Loïc Messenger ^{a,b}, Yann le Polain de Waroux ^{a,c}

Affiliations:

^a *McGill University, Department of Geography, Burnside Hall Building, 805 Sherbrooke Street West, Montreal, Quebec H3A 0B9, Canada*

^b *National Institute for Agriculture, Food and Environment (INRAE), RiverLy Unit, 5 rue de la Doua, CS 20244, 69625 Villeurbanne Cedex, France*

^c *Institute for the Study of International Development, Peterson Hall, 3460 McTavish Street, Room 126, Montreal, Quebec H3A 0E6, Canada*

Corresponding author: Olivia del Giorgio

olivia.delgiorgio@mail.mcgill.ca, (514) 653-5038

McGill University, Department of Geography, Burnside Hall Building, Room 315, 805 Sherbrooke Street West, Montreal, Quebec H3A 0B9, Canada

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Olivia del Giorgio: Conceptualization, Investigation, Formal analysis, Data curation, Funding acquisition, Methodology, Project administration, Visualization, Writing - original draft, Writing - review & editing; **Mathis Loïc Messenger:** Formal analysis, Data curation, Methodology, Software, Writing - review & editing; **Yann le Polain de Waroux:** Conceptualization, Supervision, Methodology, Writing - review & editing

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1 **Abstract**

2
3 The rapid expansion of commodity agriculture worldwide is threatening forest ecosystems
4 and the livelihoods of millions of people who depend on them. Forest-dwelling smallholders in
5 agricultural frontier regions are facing mounting pressures due to changes in land control, notably
6 through the privatization and enclosure of natural resources. Impacts of agricultural expansion on
7 smallholders have been mostly measured through deforestation, yet changes in land control and
8 associated pressures on smallholder livelihoods occur well beyond the limits of deforested areas.
9 We propose a novel approach to evaluate changes in access to land for smallholders stemming
10 from gradual changes in land control along commodity frontiers. We apply this approach in the
11 Argentine Gran Chaco, a region that has experienced amongst the highest global rates of
12 deforestation for agriculture in recent years. Our findings suggest that access to natural resources
13 for smallholders has been reduced far beyond what would be expected if only looking at
14 deforestation, and that the degree to which access has decreased differs between livelihoods. As
15 such, this study highlights the fact that forest smallholders are likely facing pressures to shift
16 livelihood strategies well in advance of the actual conversion of forest in their immediate vicinity.

17

18 **Keywords:** Access, agricultural frontiers, deforestation, Gran Chaco, fences

19

20 **1. Introduction**

21

22 Agricultural systems have undergone profound social and economic transformations over
23 the last century, in the transition towards globalized trade and through the increasing involvement
24 of large-scale, often transnational companies in agricultural production (Cotula, 2013). This global
25 restructuring manifests most markedly as processes of agricultural intensification and expansion
26 (Barbier, 2012; Meyfroidt et al., 2018), and has led to large-scale land-use changes that affect both
27 ecosystems and societies in areas suitable for modern agriculture. Of particular concern is the
28 threat that the expansion of commodity agriculture poses to forested ecosystems and to the people
29 whose livelihoods depend on forest resources (Hazell & Wood, 2008; Newton et al., 2020).
30 Between 1980 and 2000, more than 83% of new agricultural land in the tropics came at the expense
31 of forests (Gibbs et al., 2010). Despite widespread corporate commitment to curb deforestation

32 (Donofrio et al., 2017), the rate of commodity-driven forest clearing has continued unabated into
33 the new century: approximately one quarter of global forest loss between 2000 and 2015 can be
34 attributed to deforestation for commodity production, making international demand for primary
35 agricultural products the dominant driver of deforestation (Curtis et al., 2018). In Latin America,
36 pasture and cropland expansion accounted for about half of forest loss between 1985 and 2018
37 (Zalles et al. 2021). The conversion of forests to agriculture has caused severe impacts on
38 biodiversity (Macchi et al., 2020), carbon sequestration (Baumann et al., 2017; Villarino et al.,
39 2017; Harris et al., 2021), and other ecosystem services (e.g., Barral et al., 2020).

40

41 Along with the ecological ramifications of deforestation, changes to the dynamics of
42 resource control that accompany the expansion of large-scale commodity production have
43 implications for the hundreds of millions of forest-dwelling smallholders (hereafter
44 “smallholders”) whose livelihoods depend on access to forest resources and services (Newton et
45 al., 2020). The acquisition of land and the concentration of resources by agribusinesses, two
46 processes linked to the development and expansion of large-scale commodity production,
47 exacerbate existing pressures on forest smallholders (Borras & Franco, 2012). Notably, the
48 prevalence of poverty and tenure insecurity in forested regions of low-income countries
49 accentuates the reliance of smallholders on forest ecosystem services (Scoones, 2015) while
50 simultaneously making them disproportionately vulnerable to dispossession and displacement
51 (Agrawal, 2007). Where smallholders are not fully displaced, they may shift livelihood strategies
52 in order to “hang in” (Dorward et al., 2009), potentially entering into poverty traps where poverty
53 and the absence of property rights reinforce resource degradation (Hazell & Wood, 2008). As such,
54 the appropriation of land and resources by agribusinesses may very well undermine smallholder
55 livelihoods in ways that go beyond their direct displacement from deforested areas. Commodity
56 frontiers, understood as “areas where the production of agricultural commodities (e.g., beef, soy,
57 or palm oil) by large-scale farms expands over other land uses” (le Polain de Waroux et al., 2018),
58 are thus not only environmental transition points, but also social arenas of resource competition
59 characterized by actors with starkly asymmetrical competitive abilities.

60

61 Given the continued expansion of commodity frontiers (Laurance et al., 2014; Zalles et
62 al., 2021), understanding their social outcomes is of critical importance. Yet the spatial

63 representation of commodity frontier impacts remains focused on relatively simple measures such
64 as the amount of deforestation in an area. While deforestation is directly related to habitat
65 modification and can thus be used to assess the potential ecological impacts of commodity frontier
66 expansion (Ochoa- Quintero et al., 2015), a binary measure of deforestation (i.e. forest cover vs.
67 no forest cover) fails to account for the more complex social impacts that stem from gradual
68 changes in resource control dynamics.

69
70 To effectively reduce the vulnerability of smallholders and support their adaptation,
71 policies must address the full range of impacts of commodity frontier expansion on livelihoods,
72 beyond the visible displacement of populations from deforested areas. Accordingly, in this article,
73 we propose a novel spatial measure of access to land that can be used to more comprehensively
74 examine the potential impacts of commodity frontier expansion on smallholder livelihoods across
75 time and space. We start by outlining the conceptual foundations of the proposed approach and
76 then apply it to examine the potential social impacts of a commodity frontier of the Argentine Gran
77 Chaco in South America, a region whose high rates of deforestation are related to large-scale cattle
78 rearing and the production of soybeans for export. We conclude with a discussion on the
79 applicability of the approach and suggest directions for future research.

80

81 **2. Background**

82

83 2.1 Frontiers and access

84

85 Commodity frontier expansion is a multidimensional process characterized not only by the
86 conversion of land to pasture and cropland but also by processes of land control – the “practices
87 that fix or consolidate forms of access, claiming, and exclusion for some time” (Peluso & Lund,
88 2011). These processes take place beyond the visible extent of land-use change, in areas beyond
89 the ‘edge’ of the deforestation frontier. In contemporary frontiers, the arrival of novel actors, the
90 enclosure and privatization of resources, processes of territorialisation and legalization, and the
91 use of force and violence, all act as agents of change in those processes (Peluso & Lund, 2011).
92 Although changes in land control along commodity frontiers can occasionally result in increased
93 returns for some smallholders (Sunderlin et al., 2008), they more frequently result in their partial

94 or complete dispossession in favor of the accumulation and concentration of resources by more
95 powerful actors (Amanor, 2012).

96
97 In spite of the multi-dimensionality of commodity frontiers, the evaluation of their impacts
98 continues to rely on relatively unidimensional metrics. The land-use and land-cover changes that
99 characterize frontier expansion have been, and continue to be, at the forefront of academic interest.
100 Most studies have used deforestation as an indicator of the expansion trends and spatial extent of
101 commodity frontiers (Arvor et al., 2013; le Polain de Waroux et al., 2018; Walker, 2003). Land-
102 cover changes have also been used as indicators of environmental degradation, namely of
103 biodiversity loss, habitat fragmentation, and reduction in carbon storage capacities (Baumann et
104 al., 2017; Chaplin-Kramer et al., 2015; Piquer-Rodríguez et al., 2015) and, to a lesser extent, as
105 indicators of displacement pressures on local populations (Paolasso et al., 2012). However, with
106 the exception of a few studies that have mapped the location of large-scale land deals (e.g.,
107 Anseeuw et al., 2012; Messerli et al., 2014), the spatial and temporal distribution of land control
108 dynamics occurring within commodity frontiers have received limited attention (but see Faingerch
109 et al., 2021).

110
111 The notion of *access* to resources provides a useful point of departure to disentangle the
112 complex effects of land control dynamics occurring in commodity frontiers. Several theories and
113 frameworks place *access*, “the ability to benefit from things” (Ribot & Peluso, 2003), as a central
114 factor for explaining differences in both livelihood pathways and land-use outcomes (Batterbury
115 & Bebbington, 1999). The ‘Capitals and Capabilities’ framework, building on Amartya Sen’s
116 Capabilities approach (Sen, 1989), posits that livelihood choices must be understood in terms of
117 people’s access to different forms of capital (financial, social, physical, natural, and human)
118 because it is access to those capitals that gives them the capability to act (Bebbington, 1999). The
119 ‘Environmental Entitlements’ framework echoes this approach in the importance that it places on
120 access, with a greater emphasis on land-use outcomes. Leach, Mearns, and Scoones (1999)
121 contend, in presenting the framework, that it is access to resources, rather than simply resource
122 abundance, that explains key resource management and governance issues. This disaggregated
123 ‘entitlements’ approach acknowledges that access to and control over resources are socially
124 differentiated, as are people’s ability to interact with and modify their environment (Leach et al.,

125 1999). Lastly, Ribot and Peluso's Theory of Access proposes that how access to land and resources
126 is gained, maintained, and controlled depends on access mechanisms, including rights-based
127 mechanisms, technology, capital, markets, knowledge, authority, social identities, and social
128 relations (Ribot & Peluso, 2003).

129
130 Ultimately, the livelihood implications for smallholders of commodity frontier expansion
131 depend on whether they are able to maintain their access to land and resources as the frontier
132 progresses into later stages of development, which are marked by processes of resource
133 appropriation and consolidation (Barbier, 2012). Where smallholders are not able to compete for
134 land and resources, they may lose access to them. Loss of access occurs not just through the
135 destruction of these resources (when a forest is cleared, for example) but also through physical or
136 institutional exclusion resulting from the reinforcement of claims by fencing, privatization, or
137 violence (Li, 2014; Makki, 2014). In response, smallholders may need to shift their livelihood
138 strategies, for example by engaging in contract farming, wage labor, and migration for off-farm
139 work (Reardon et al., 2009). If pressure is exerted strongly on all livelihood options, they may be
140 forced to leave the area. Along with the existence of resources (i.e., resource quantity, or amount
141 of forest and land), then, an important question becomes: to what degree are smallholders able to
142 maintain access to resources and the land they are on? By asking how and where access to land
143 and resources is changing with the expansion of control by outside actors, it is possible to start
144 disentangling the potential impacts of these changes on different livelihood activities and in
145 different locations. In this study, we use a commodity frontier of the Argentine Gran Chaco as a
146 case study to examine the changes in access that accompany frontier expansion.

147

148 2.2 Commodity frontiers and access loss in the Argentine Gran Chaco

149

150 The Gran Chaco ecoregion of South America, a dry woodland region covering more than
151 one million km² across Bolivia, Paraguay, and Argentina (Olson et al., 2001), has experienced
152 amongst the highest global rates of deforestation for agriculture in the last decades (Zalles et al.,
153 2021). Deforestation in the Gran Chaco has been driven by an increase in export-oriented
154 production of soybeans, principally destined to overseas markets such as China, Russia, and the
155 European Union (Piquer-Rodríguez et al., 2018), as well as by domestic and international demand

156 for beef (le Polain de Waroux et al., 2019). The shift towards intensive production of agricultural
157 commodities by capitalized agribusinesses has resulted in the development of a number of
158 commodity frontiers, the expansion of which have had profound impacts in the Argentine region
159 of the Gran Chaco (Brown et al., 2006). Between 1985 and 2013, more than 142 000 km² of the
160 Chaco's forests was replaced by croplands (38.9%) or grazing lands (61.1%) (Baumann et al.,
161 2017).

162
163 Along with high levels of deforestation, the expansion of commodity frontiers in the Gran
164 Chaco has also been accompanied by important socioeconomic changes (Gorenstein & Ortiz,
165 2016). In contrast to smallholders with a longer history in the region, the social actors that have
166 recently become established there (namely agribusiness but also speculators and other investors)
167 are integrated into global markets and have access to important streams of technological and
168 financial capital (Gasparri, 2016). The arrival of these new actors introduces fundamental
169 asymmetries with smallholders — in relation to capital, access to knowledge and technology, and
170 government lobbying capacity — which have resulted in an increasingly polarized distribution of
171 land and natural resources (Rivas & Rivas, 2009). Associated with the concentration of resources
172 are practices of claiming and exclusion, in particular privatization and enclosure, that create both
173 physical and institutional barriers across a landscape where resource use by smallholders is
174 oftentimes communal (Altrichter & Basurto, 2008). Resource claims made by large-scale
175 commodity producers are reinforced by inequitable legal disputes and mechanisms of intimidation
176 (such as violence, verbal threats, and the killing of animals) (Goldfarb & van der Haar, 2016). In
177 combination, the mechanisms used by actors engaged in commodity production to consolidate
178 control over resources have ultimately resulted in the dispossession of many smallholders (Estrada,
179 2010).

180
181 Dispossession often results in the displacement of smallholders who are evicted from their
182 homes as forests get converted to pasture or cropland (Gorenstein & Ortiz, 2016). It may however
183 take subtler forms, implying a gradual loss in the ability to control access to resources that are
184 fundamental to smallholder livelihoods (Altrichter & Basurto, 2008). For example, the fencing of
185 a plot of land by outsiders and the strengthening of their claim to that land through violence and
186 intimidation may impede smallholders from accessing a water source, or from hunting game and

187 collecting forest products. Consequently, along with displacement pressures, the emergence of
188 barriers to resource access that are associated to the enclosure and privatization of land may
189 pressure smallholders to adapt by shifting livelihood strategies (Cáceres, 2015).

190

191 In this paper, we propose a novel approach to evaluate the potential impacts of expanding
192 commodity frontiers on smallholder livelihoods that builds on the notion of access to land and
193 resources. This approach uses visible features of the landscape to analyze the spatial distribution
194 of people's ability to benefit from resources, thereby addressing an important shortcoming of
195 existing methods using land cover to assess the impacts of frontier expansion and providing an
196 efficient way to diagnose changing pressures on smallholder livelihoods at medium scales. This
197 can then serve to identify areas and livelihoods at risk and target more in-depth livelihood analyses.

198

199 **3. Data and methods**

200

201 Our approach uses the mapping of landscape elements that represent limits to resource use
202 – hereafter 'access barriers' – as a way to approximate access to land and resources for the exercise
203 of certain livelihood activities. These access barriers simultaneously represent physical and
204 institutional limitations to access – i.e., they can act as proxies, for example, for the cost of
205 accessing a space both because it is on private property and one might experience repercussions
206 from infringement, and because a fence makes physical access more difficult. The approach is
207 divided into four parts: i. mapping access barriers; ii. creating a typology of access barriers
208 according to the degree to which they restrict access to space for the performance of different
209 livelihood activities; iii. generating and mapping an index of access to land and resources for
210 different livelihoods; and iv. assessing the potential impact of access changes linked to commodity
211 frontier expansion on the spatial and temporal dynamics of smallholder livelihood activities.

212

213 **3.1 Study area**

214

215 The study area is delimited by the legislative boundaries of the Department of Pellegrini,
216 in the north-west of the province of Santiago del Estero in Argentina (26.2°S, 64.2°W), and spans
217 7,330 km² (Figure 1). In 2019, the Department of Pellegrini was receiving substantive pressure
218 from commodity frontiers advancing from the core agricultural areas of the province of Tucumán.

219 The principal actors directly involved in the conversion of forested land to agriculture were
220 capitalized medium- and large-scale farmers from the province of Tucumán and, to a lesser extent,
221 from Buenos Aires and Córdoba (Estrada, 2010; le Polain de Waroux et al., 2018). The oldest
222 land-cover changes (before 2000) were concentrated in the south-west region of the Department,
223 whereas more recent changes (2010-2019) occurred in the center of the Department. In the south-
224 east and north-east of the Department, a large proportion of the landscape remained forested.
225 Pellegrini therefore presented a range of frontier conditions within a limited area.

226
227 Large-scale commodity producers in Pellegrini expand over areas occupied by small-scale
228 family producers often referred to as *campesinos*, or peasants. Campesinos across the region tend
229 to practice a mix of livestock rearing, hunting, small-scale agriculture, and forest-product
230 harvesting (including wood for fuel, charcoal, and construction, and non-timber forest products
231 such as honey and medicinal plants) (Altrichter, 2006). We focus on charcoal, cattle, goat, and pig
232 production as the four livelihood activities of interest for our analysis of the potential impacts of
233 commodity frontier expansion.

234



Figure 1. Study area. Landsat imagery for 2019 is displayed for the Department of Pellegrini.

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3.2 Mapping access

3.2.1 Mapping, typology, and weighting of access barriers

We employed a methodology similar to that used by Seward *et al.* (2012) to map access barriers using satellite imagery. We considered all visible linear deforestation features within the study area to be potential access barriers and mapped them using the path tool in Google Earth Pro (2018), which provides access to yearly pre-processed Landsat mosaics at 30 m resolution. We mapped features for years 2000, 2010, and 2018 in an additive process, starting from existing features, adding those that appeared in the two subsequent periods and removing those that disappeared, which yielded three individual layers (Figure 2, step 1).

In order to assess how access to livelihood opportunities varied across the study area, we first identified the barriers relevant to campesino access by creating a typology of access barriers. The typology was informed by means of unstructured, conversational interviews with over thirty key-informants conducted between May and August 2019 by the first author (Figure 2, step 2). Once the relevant access barriers (e.g., roads, fences) were identified and typified, we proceeded to visually classify the previously digitized line segments according to barrier type using visual interpretation in combination with a vector dataset of provincial and national roads from the Federal Ministry of Agriculture, Livestock, and Fisheries of Argentina (Figure 2, step 3). We then created a weighting scheme whereby each barrier type was assigned a relative *permeability* for the production of charcoal and for cattle, goat, and pig rearing, respectively (Figure 2, step 4). We refer to permeability as campesinos' (or their livestock's) ability to pass through or overcome a barrier to perform a given livelihood activity, acknowledging that permeability may differ between livelihoods for any barrier type. The weights were standardized between 0 (completely permeable) and 1 (completely impermeable). Altogether, we generated four livelihood-specific barrier maps, each differing in the weighting assigned to the different barrier types, for each time point analyzed, yielding 12 spatial layers.

3.2.2 Generating livelihood-specific access indices

269 Based on the maps of weighted access barriers, we developed a livelihood-specific Access
270 Condition Index (ACI) representing the distribution of access conditions throughout the study area
271 for different livelihood strategies in 2000, 2010, and 2018. We implemented the ACI using a
272 custom spatial analysis workflow developed in the Python programming language with the ESRI
273 Arcpy library (provided with ArcMap 10.6). To calculate the ACI, we first converted the
274 permeability-weighted barrier layers from vector to raster format for each livelihood and year.

275
276 Second, for each 30 x 30 m raster cell, we computed a value representing the cost of
277 crossing existing barriers to access resources in surrounding cells. To do this, we applied a cost-
278 distance function to determine a fictive ‘cumulative barrier friction’ value between each cell and
279 all other cells within a livelihood-specific buffer around it for use as an intermediary step in the
280 index calculation (Figure 2, step 6). We set the radius values for the livelihood-specific buffers
281 according to the typical maximum distances that each activity is conducted at, based on
282 information gathered from interviews and literature (Figure 2, steps 5 and 6). The cost distance
283 function accounts for the cost of sequentially encountering barriers as a person or animal moves
284 through space: with a permeability value of 0 (fully permeable) attributed to all non-barrier cells,
285 the cost distance from the buffer’s center to a point in the buffer becomes a function of the number
286 and permeability of (pixel-wide) barriers crossed. As a result, a higher output value was generated
287 where more barriers and/or less permeable barriers are crossed.

288
289 Third, the ‘cumulative barrier friction’ values for each livelihood were weighted according
290 to the ability to benefit from certain land covers. The cost-distance values for charcoal production
291 were weighted by the availability of forest resources (deforested: 0, forested: 1). Because animals
292 can graze on grass- or croplands as well as in forests, the cost-distance values for pig, goat, and
293 cattle production were weighted as 1 for all landcovers.

294
295 Last, the final ACI value was computed for each cell in the study area by assigning it the
296 land-cover weighted average of the cumulative barrier friction values across all cells in its
297 surrounding buffer. For a given livelihood l at a given time t (here 2000, 2010 or 2018) and
298 location (pixel) p , the ACI can thus be expressed as follows:

299

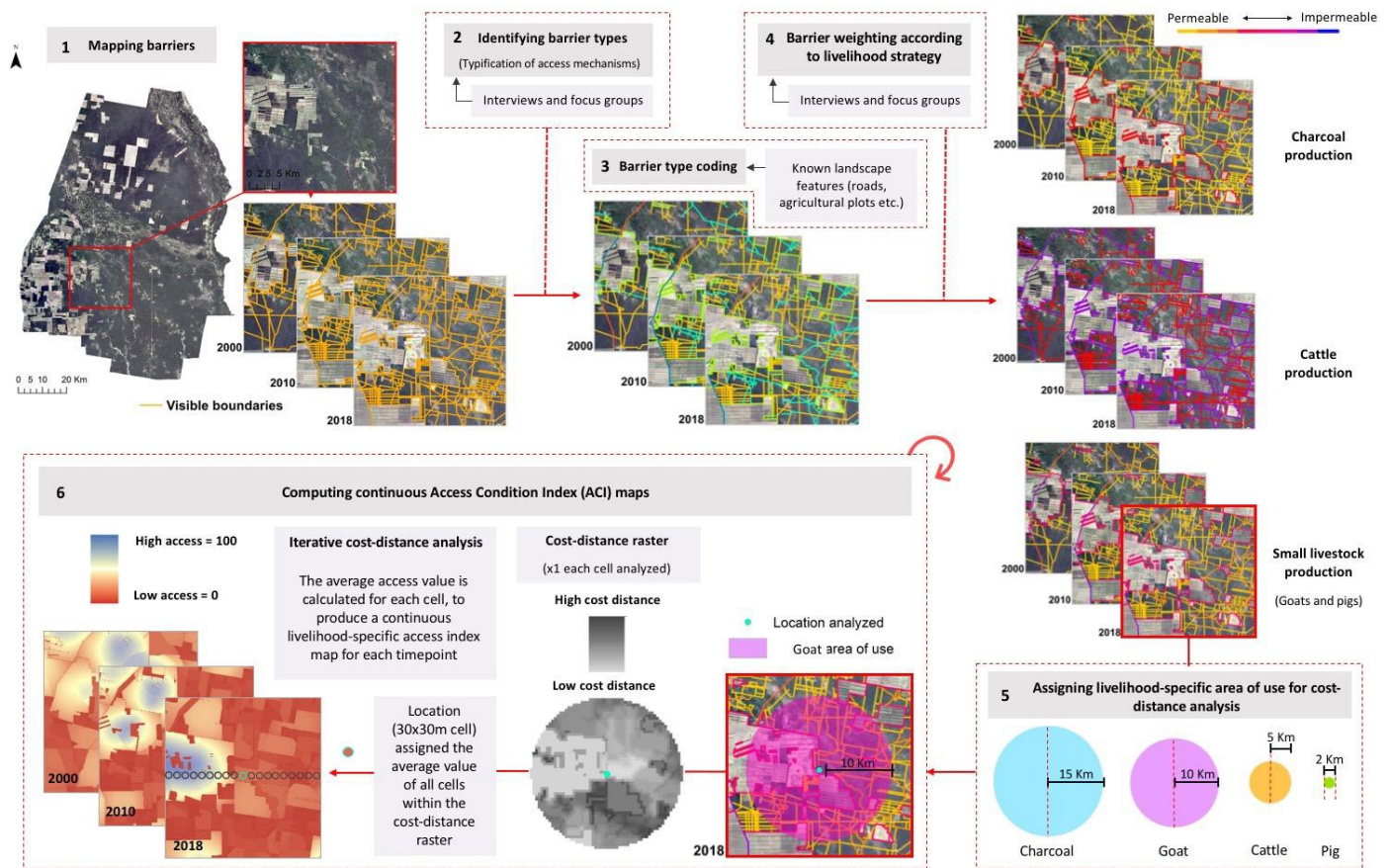
$$ACI_{ll,t,p} = 100 \times \frac{\sum_i^{N_{ll}} (W_{ll,t,i} \times \left(\frac{1}{1 + F_{ll,t,i}}\right))}{N_{ll}} \quad (\text{Equation 1}),$$

300 Where N_{ll} is the number of pixels i within a livelihood-specific radius of activity around p , $W_{ll,t,i}$
 301 is the resource weight (between 0 and 1) assigned to each pixel i according to the livelihood-
 302 specific suitability of the land cover within that pixel at time t (determined in the previous step),
 303 and $F_{ll,t,i}$ is the cumulative barrier friction value calculated based on the number and distribution
 304 of weighted barriers between the focal pixel p and i .

305

306 The analysis resulted in a series of livelihood-specific maps, where the ACI values
 307 represent the relative degree of access to perform a certain livelihood activity from a given
 308 location. The ACI values ranged from 0, representing maximum access restriction within the
 309 buffer, and 100, representing no access restriction (i.e., 100% accessibility).

310



311

312

Figure 2. Schematic workflow for calculating the Access Condition Index (ACI).

313 3.3 Potential impact of access restrictions on livelihoods in the study area

314

315 To evaluate the potential impact of access restrictions on campesino livelihoods, we used
316 community locations from the 2018 national agricultural census of Argentina (CAN 2018 – in
317 progress at the time of this study), which we completed and corrected where necessary. We
318 extracted the ACI values for each campesino community and year by assigning the average ACI
319 value across a developed area polygon around the community. This was done to better approximate
320 conditions experienced across the entire community rather than at an arbitrary, centralized
321 location. We therefore used the census point locations for all 84 communities within the
322 Department limits as a reference to visually map developed areas (deforested areas with apparent
323 residential land uses) associated with each community and year using Landsat imagery. The ACI
324 values for all communities were then examined to identify communities that may have experienced
325 pressures to shift livelihood strategies or that potentially risked displacement, if pressures were
326 exerted on all livelihood options. In order to visually convey spatial differences in ACI values
327 between communities and across years, we manually delimited five sub-regions within the study
328 area based on visual interpretation of community spatial grouping patterns, and assigned each
329 community to the sub-region it was located within. The sub-regions are as follows: Centre-South
330 (CS); Central Belt (CB); Eastern Flank (EF); North-West (NW); and South-West (SW).

331

332 3.4 Comparing approaches

333

334 Lastly, we computed a more conventional index of frontier impacts based on forest extent
335 and forest loss data developed by Hansen *et al.* (2013) and contrasted it with the livelihood-specific
336 ACI. The forest index is specific to each livelihood's area of use (i.e., the radius of the buffer used
337 in generating the ACI) but not specific in the degree to which deforestation represented a restriction
338 to access for the different livelihoods analyzed here. The Forest Index (FI) can thus be expressed,
339 using the same structure as the ACI (*Equation 1*), as follows:

$$340 \quad FI_{ll,t,p} = 100 \times \frac{\sum_i^{N_u}(W_{t,i})}{N_{ll}} \quad (\text{Equation 2}),$$

341 FI thus considers availability of forest resources within a given livelihood buffer for each
342 location analyzed, but differed from ACI in that it does not take into consideration barriers to
343 accessing those resources (i.e. equivalent to $F_{ll,t,i} = 0$ in *Equation 1*). Moreover, $W_{t,i}$ is only

344 dependent on time and location (not livelihood) as it was set to 0 for deforested pixels and 1 for
345 forested pixels for all livelihoods.

346

347 **4. Results**

348

349 4.1 Typology of access barriers

350

351 Interviews indicated that fences represent an important barrier to land and resources for
352 campesinos in the study area. The most common form is the wire fence (*alambrado*), which is
353 made of several rungs of metal wire held taut by wooden posts spaced 2-3 meters apart. In general,
354 the number of rungs reflects the purpose of the fence. Fences with fewer than four wire rungs serve
355 to contain cattle and/or as physical markers of land claims. Fences with more than four wire rungs
356 (averaging six) serve to contain smaller livestock, such as pigs, goats, and sheep. Among
357 campesinos, the wire fence has largely replaced the traditional stick enclosure (*cerco-rama*).
358 Where campesinos wish to enclose land, the high cost of wire and the labour required to erect
359 fences are the main factors limiting the extent to which they are able to do so. In contrast,
360 capitalized agribusinesses and investors do not face such limitations, and thus fence more liberally.
361 Plots that have been converted to agriculture by agribusiness as well as forested land that has been
362 claimed by capitalized actors are consequently almost always delimited by wire fencing. Fences
363 can thus represent both a physical barrier and an institutional one.

364

365 Roads were identified as another important barrier for campesinos and their livestock for
366 several reasons. According to Article 25 of the National Transit Law of Argentina (24.449),
367 enforced at the provincial level through the penal code of Santiago del Estero (6.906, art. 155), the
368 owners of property bordering on public roads must have fences that prevent animals from entering
369 the road area, lest they be sanctioned. Moreover, public roads, which include small municipal
370 roads, are fenced by the federal government along both sides. Roads themselves hinder livestock
371 movement by making crossings dangerous: campesinos reported losing livestock due to collisions
372 with vehicles. Finally, campesinos also reported that incidents of livestock robbery were more
373 common near roads due to non-local transit. This combination of physical characteristics and

374 social dynamics consequently make roads a composite type of barrier from the point of view of
375 campesino access in the study area.

376
377 A third type of access barrier for campesinos are *deslindes*, demarcations in the form of
378 deforested strips of land. In general, these demarcations serve to define the limits of claimed land,
379 but they can also physically function as access passageways for properties. Access passageways
380 are also seen as resource claims however, as they signify an active form of occupancy (Law
381 26.737). The extent to which these *deslindes* constituted barriers to access depended, according to
382 informants, on livelihood activities. Livestock tends to cross back and forth freely through
383 demarcations, but campesinos' access to harvest forest product (e.g., timber for charcoal) depends
384 on the legitimacy and authority associated to the claim made through any given demarcation.
385 Demarcations hence oftentimes represent institutional rather than physical barriers to access for
386 campesinos.

387

388 4.2 Coding of access barriers

389

390 Because the insufficient resolution of the satellite imagery and a lack of available field
391 validation data across the department did not allow us to distinguish between fences and
392 demarcations, we classified any barrier located within the forest matrix (as opposed to roads or the
393 edges of farmland, which are systematically fenced) as a single category representing either a fence
394 or a demarcation. We hereafter refer to these barriers as “internal barriers”. Roads were coded
395 according to whether they were provincial, national, or municipal in order to capture differences
396 in the volume of transit (and thus risk to livestock), as well as in the probability of theft. Farmland
397 was identified visually from Landsat images for each timestamp in Google Earth. The municipal
398 road dataset was outdated so we used it minimally for coding, and classified any internal barrier
399 that was not a straight line as a municipal road. The municipal data were thus only used to identify
400 municipal roads that bordered straight-line farmland boundaries.

401

402 4.3 Weighting of access barriers

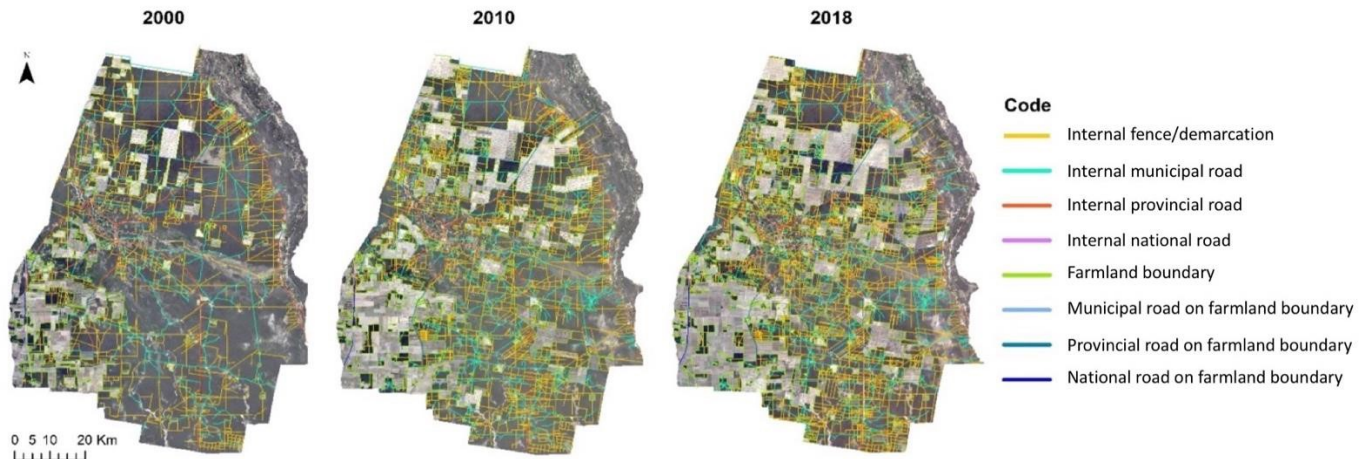
403

404 The permeability value assigned to each barrier type was set to reflect a combination of the
405 barriers' own characteristics and of the characteristics of the livelihood activity under

406 consideration. For example, most fences have only three wires and are therefore relatively
407 permeable for small livestock, but relatively impermeable for cattle. The permeability value of
408 access barriers was also set according to whether these were internal (i.e., flanked on both sides
409 by forest) or bordered farmland. Using fences again as the example, internal fences were weighted
410 as more permeable for goats and pigs than fences bordering agricultural plots because of the
411 heightened risks associated with animals crossing into open farmland (e.g., of animals being killed
412 or claimed by farm owners as their own, both of which were reportedly frequent occurrences).

413
414 Because we considered overlapping barrier types (e.g., a road intersecting a farmland
415 boundary) as having a cumulative effect, the classification process resulted in the following
416 ranking, with gradually decreasing permeability: internal (i.e., within the forest matrix)
417 fences/demarcations; internal municipal roads; internal provincial roads; internal national roads;
418 fence on farmland boundary; municipal roads on farmland boundary; provincial roads on farmland
419 boundary; and national roads on farmland boundary (Figure 3). To account for the combined
420 fence/demarcation barrier type, we assumed that half of the internal fence/demarcation barriers
421 were demarcations and that the other half were fences. Given that the former do not impede
422 movement but that the latter represent a complete restriction for cattle movement, internal
423 fences/demarcations received an intermediate permeability ranking (0.5) for cattle production
424 activities. Because boundaries with farmland and roads were assumed to be completely fenced, all
425 other barrier types were assigned permeability scores of 1 (complete access restriction) for cattle.
426 The same rationale was used in weighting barriers for small livestock and charcoal production.

427
428 The final barrier permeability weighting scheme is provided in Table 1. A detailed
429 description of the rationale behind barrier permeabilities and weightings, as well as additional
430 details on the radii assigned to the different livelihood buffers, are available in the Supplementary
431 Information (Appendixes A – C). The code necessary to reproduce this study is available through
432 a GitHub repository link provided in Appendix E.



433

434 Figure 3. Distribution of barrier types in the Department of Pellegrini for 2000, 2010, and 2018,

435 classified based on the barrier typology developed in this study.

436

437 Table 1. Barrier permeability weighting according to barrier type and livelihood

<i>Livelihood</i>	No barrier	Internal fence/demarcation	Internal municipal road	Internal provincial road	Internal national road	Farmland boundary	Municipal road on farmland boundary	Provincial road on farmland boundary	National road on farmland boundary
<i>Charcoal</i>	0	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.5
<i>Cattle</i>	0	0.5	1	1	1	1	1	1	1
<i>Goats</i>	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
<i>Pigs</i>	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8

438

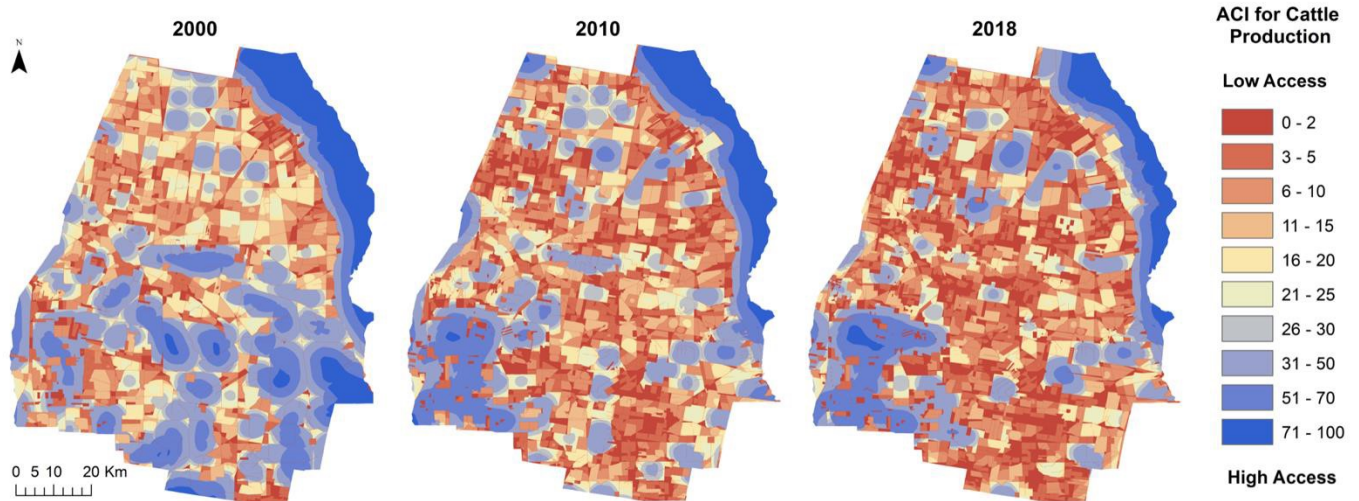
439 4.4 Potential impacts of access restrictions on communities in the study area

440

441 There were noticeable differences in access conditions between regions, between
 442 communities within regions, between years, and between livelihoods. Figure 4 shows that
 443 continuous areas of high access for cattle, notably in the south-East of the study area, became
 444 increasingly fragmented by varying degrees of access restrictions between the three time points.
 445 Contrary to the general patterns of increasing access restrictions across the study area, the ACI
 446 increased (i.e. decreased access) in areas where forest was converted to agriculture (i.e. in the
 447 south-West). This is due to land parcel agglomeration by agribusiness, where internal fences are
 448 removed once a plot is deforested and cultivated. Because communities do not occur within
 449 agricultural plots, the ACI values for those areas do not reflect campesinos' actual lived conditions.
 450 While the index was mapped continuously for illustrative purposes, the ACI values that are of
 451 interest for the assessment of smallholder impacts are those within areas that are inhabited by

452 smallholders, and that thus represent the degree of access to perform a given livelihood activity
453 from their place of residence outwards over the area of use.

454



455

456 Figure 4. Access Condition Index values for cattle production. The higher the ACI value at a
457 location, the greater the degree of access to resources from that location to perform a given
458 livelihood activity.

459

460 Figure 5 shows ACI values averaged across developed areas of known campesino
461 communities. Across years, access to land and resources was greatest for communities in what we
462 call the Eastern flank (average cumulative ACI across livelihood categories = 32.5) and the Central
463 belt (22.3), and most restricted in the North-West (16.3). Cumulative access also varied between
464 communities within regions, in particular in the Eastern flank (Figure 5, panel a). Across all four
465 livelihoods, the access index decreased by 22% on average between 2000 and 2010 (Wilcoxon
466 signed rank test, $p < 0.01$), and by 14% between 2010 and 2018 (Wilcoxon signed rank test, p
467 < 0.01). In other words, access to land and resources needed to conduct core livelihood activities
468 became more restricted from 2000 to 2018 for forest-dwelling campesino communities in the study
469 area (Figure 5, panels b and d).

470

471 Changes in the access index were not uniform across the four livelihoods considered.
472 Across all years, access to land for pig rearing was greatest relative to the other livelihoods
473 analyzed, while access to land for charcoal production was the most restricted. Moreover, the
474 relative access between livelihoods varied both between communities and between regions. The

475 level of access to space for charcoal production was maintained between 2000 and 2018 in the
476 Eastern flank (albeit slightly reduced), while it became almost completely restricted across all
477 other regions. Access to space for goat production also became severely restricted between 2000
478 and 2018 for all communities in the North-West, most in the Center-South, and for some in the
479 South-West (Figure 5, panels a.1-a.3).

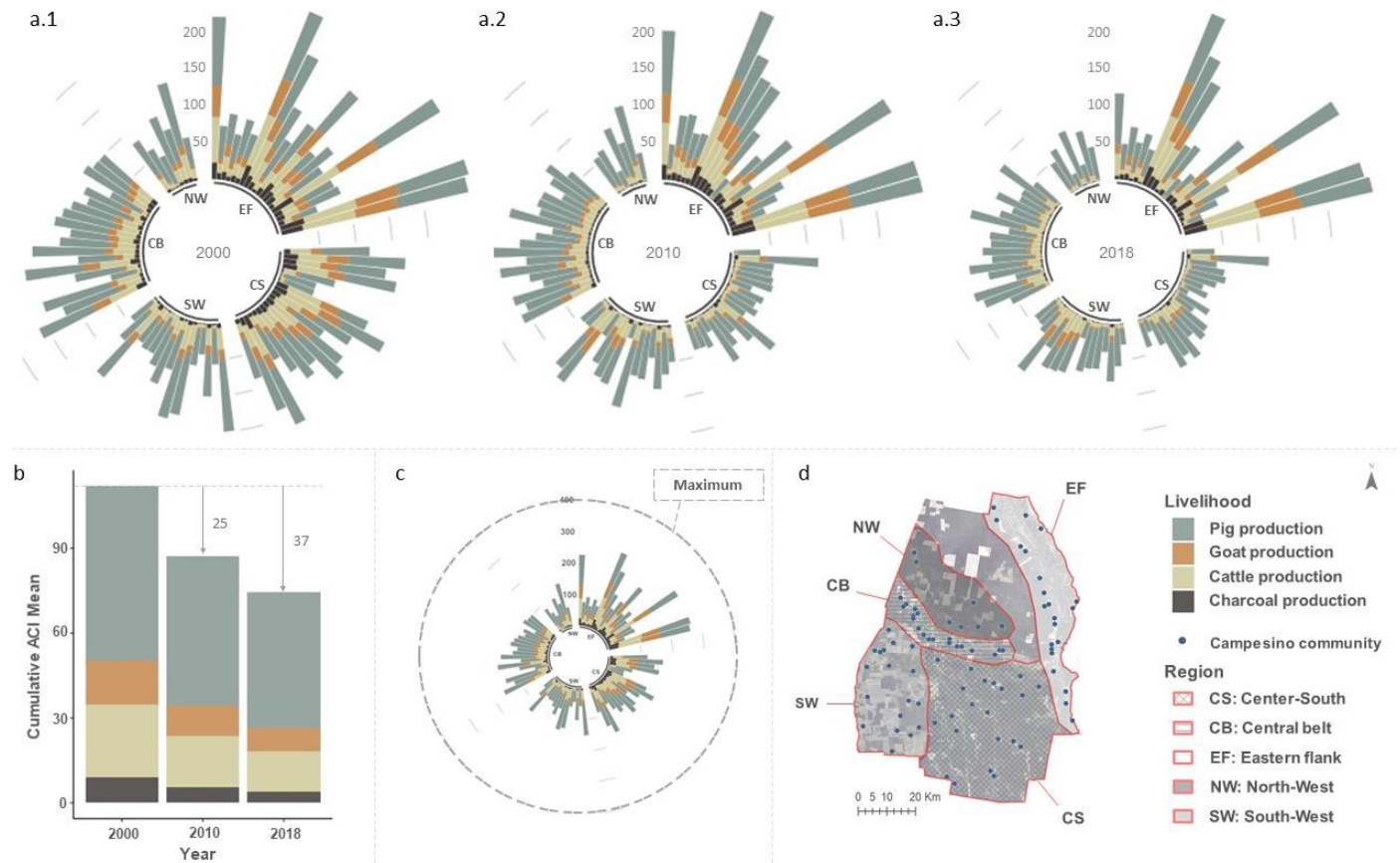
480

481 Finally, it should be noted that the community ACI values were already low in 2000. The
482 cumulative ACI mean across all communities for 2000 was 113 out of a maximum total cumulative
483 ACI mean of 400 (Figure 5, panel c). In other words, in 2000, communities had on average only
484 28% of their total potential access in a fully forested, unfenced landscape. The mean cumulative
485 ACI dropped to 88 (+- Sd) in 2010, and 76 (+- Sd) in 2018, or 22% and 19% of the total potential
486 access, respectively. The ACI values for all communities in the study area are provided in Table
487 1. of Appendix D.

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Figure 5. Results of the access analysis. Panels a.1, a.2, and a.3, show access conditions in 2000, 2010, and 2018, where each stacked bar represents the ACIs (by livelihood) for a community and communities are grouped radially by geographic region. Panel b shows the mean cumulative ACI for all communities at each time point. Panel c shows the maximum cumulative community ACI (outer ring = 400), compared to the actual community ACI values in 2000. Panel d shows the point locations of the campesino communities and the extent of the regions, the delimitation of which was conducted for visualization purpose by the authors based on the spatial grouping patterns of communities.

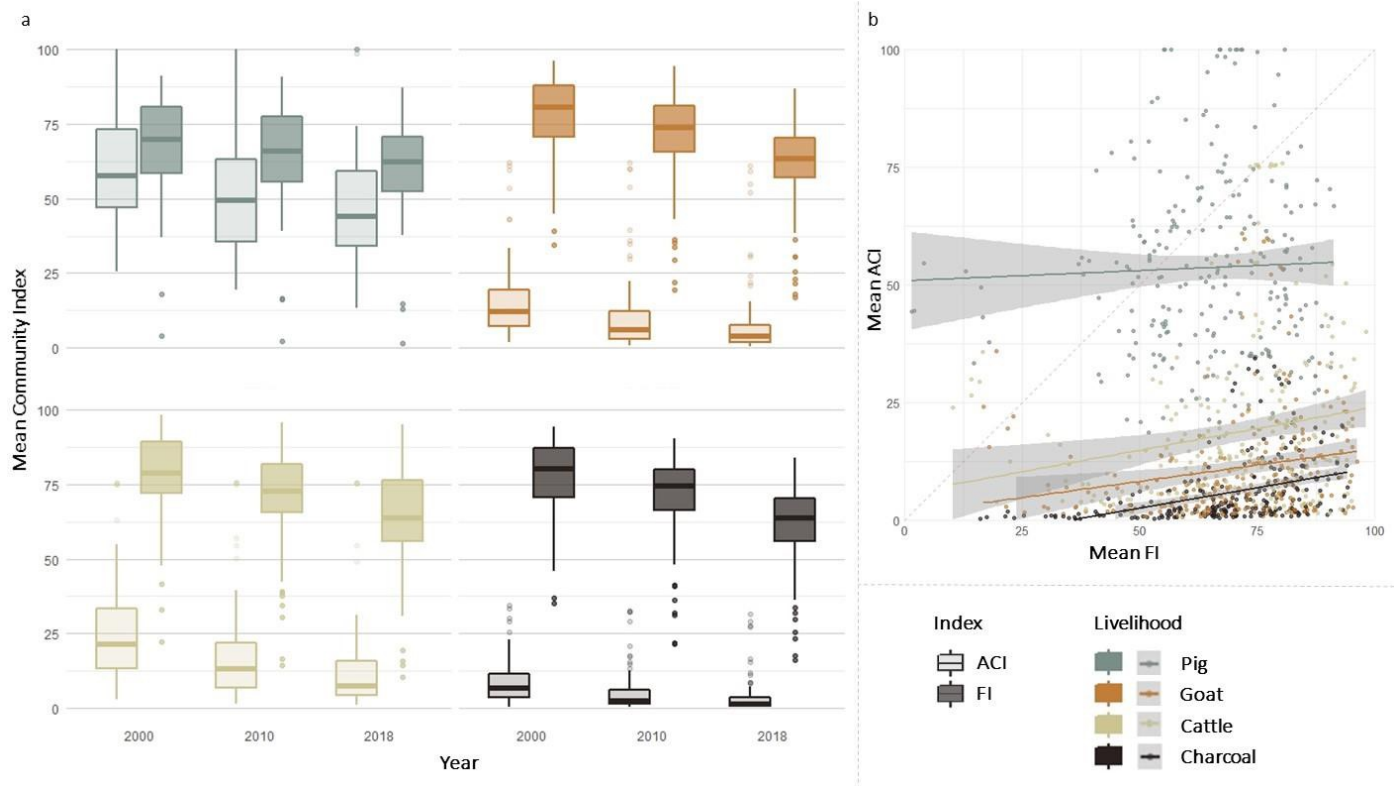
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4.4 Comparing approaches for analyzing commodity frontier impacts

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The median FI was greater than the median ACI for each of the four livelihoods considered in the analysis (Figure 6, panel a). The FI was significantly correlated to the ACI for all livelihoods save for pig production (Spearman's rank correlation (SRC): p-value = 0.91), and most strongly correlated to charcoal production (SRC: rho = 0.56, p-value <0.001) (Figure 6, panel b). Notwithstanding, the FI did not vary significantly between cattle, goat, and charcoal production livelihoods (Kruskal-Wallis, p-value = 0.61).

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Figure 6. Comparison of approaches. Panel a shows box plots for access condition index (ACI, light boxes) and deforestation index (FI, dark boxes) per period (2000, 2010, and 2018). Panel b shows a comparison of the FI and ACI for each livelihood across all periods.

516 5. Discussion

517

518 5.1 A novel index of access

519

520 The livelihood-specific access condition index (ACI) developed here provides a way to
521 quantify the degree to which access to land and resources for different livelihood activities is
522 restricted through space and changes over time. Based on the density, spatial arrangement, and
523 permeability of access barriers around a location, the ACI provides a proxy of access to the space
524 and resources that are necessary for performing a given livelihood activity, and allows the
525 identification of areas of higher potential pressure on livelihoods. Overall, our analysis shows that
526 access for campesino smallholders in the study area decreased between 2000 and 2018 for all four
527 livelihoods across the study area. Access conditions also varied noticeably among livelihoods. This
528 variation points to the importance of a livelihood-specific framework in evaluating access
529 dynamics. Compared to the ACI, the FI estimated higher degrees of access to land and resources

530 across activities. The large differences in magnitude and spatial distribution between the ACI and
531 the FI demonstrate how approaches that rely on deforestation as an indicator of access conditions
532 may be underestimating the extent and intensity of the social impacts of commodity frontier
533 expansion. Our results therefore also highlight the importance of representing spatial processes of
534 claiming and exclusion taking place within frontier areas when approaching the social impacts of
535 commodity frontier expansion.

536
537 Our approach provides a readily applicable way to better represent these processes, notably
538 in regions where tenure data is lacking, and allows for a nuanced assessment of access restrictions
539 that is informed by both changes in tenure conditions (e.g., privatization) and the physical
540 enclosure of resources. Moreover, our approach complements tenure-based mapping approaches
541 (e.g., Faingerch et al. 2020) by allowing the mapping of access conditions in a way that does not
542 depend on participatory mapping techniques, which rely on participants recognizing and orienting
543 within a cartographic representation of space, and that is spatially exhaustive and scalable to larger
544 extents. Five points should be noted about the calculation of the ACIs for future applications.
545 Firstly, we relied on the high mapping accuracy (94%) of Seward *et al.* (2012), who employed a
546 very similar methodology, albeit with a higher resolution (1 m), as an indirect confirmation of the
547 mapping accuracy. Where possible, ground-truthing barrier presence through field surveys would
548 improve the index's accuracy. Secondly, the resource weighting used here was kept purposely
549 simple, but future applications of the approach may include more complex resource weightings
550 by, for example, using full land cover classifications (rather than a binary forest-non-forest
551 classification) to account for the differential value of land covers for specific livelihood activities.
552 Thirdly, the manual vectorization of all visible line segments does limit, to a certain degree, the
553 spatial extent at which the methodology can be applied. However, given the simplicity of the
554 process and public availability of input data, we are confident that the approach can be readily
555 applied at the provincial level (on the order of 10^5 km²), and can thus serve to inform policy for
556 large administrative units. Fourthly, it is possible that non-physical barriers to access are missed
557 through this approach. However, fieldwork conducted by the first author, as well as other studies
558 that have examined control dynamics in the region (e.g., Cáceres 2015, Cáceres et al. 2010,
559 Altrichter & Basurto 2008), suggest that the most prevalent mechanisms used by actors in the Gran
560 Chaco to control access to resources are the enclosure or demarcation of claimed land and

561 resources. Consequently, the risk of substantially underestimating access restrictions in the region
562 is low. Finally, the calculation of ACIs over a large area is computationally intensive. However,
563 this issue can easily be solved by calculating the ACI only over locations of interest, such as
564 settlements, which considerably reduces computing time.

565

566 5.2 Potential smallholder impacts

567

568 The calculation of changes in access for smallholder communities point to some potential
569 impacts of frontier expansion, and thereby demonstrate the usefulness of this methodology for
570 approaching the multiple dimensions of smallholder dispossession. First, trends in ACI let us
571 identify threats to certain livelihoods in spatial and temporal terms. Our findings indicate that the
572 viability of charcoal production, one of the few income-generating activities of the rural poor in
573 Argentina (Fasano, 2010) is likely becoming precarious across the study area. This result aligns
574 with those of Rueda *et al.* (2015), who found lower charcoal production in the Department of
575 Pellegrini between 2003 and 2011 compared to departments to the East where the commodity
576 frontier was younger. Our results also suggest that relative differences in the degree of access
577 restriction between activities may be generating pressures for smallholders to shift livelihood
578 strategies. For example, considering the relatively low access restrictions for pig production, there
579 may have been pressure to transition from charcoal production to that activity. Similar to findings
580 presented by Cáceres *et al.* (2010, 2011), ACI trends also suggest that campesinos are likely under
581 pressure to shift from goat to cattle production, and that the overall feasibility of livestock
582 production has greatly decreased. Moreover, in areas where communal or open access grazing is
583 no longer an option due to high levels of fencing, campesinos may be resorting to rearing pigs in
584 small enclosures instead. Finally, where a greater number of livelihood activities are severely
585 restricted, campesinos may have experienced displacement pressures, particularly in the North-
586 West, where the majority of communities lost access to land almost entirely for charcoal, cattle,
587 and goat production, and saw a notable decrease in access for pig production. These displacement
588 pressures could be contributing to the rural-to-urban migration that is producing the growth of
589 regional cities (Sacchi & Gasparri, 2016). By identifying heterogeneous restrictions to different
590 livelihood activities, the approach can be followed up with survey-based fieldwork targeted to

591 hotspots of potential smallholder livelihood impact. Ongoing work by the authors uses household
592 livelihood surveys to examine these hypothesized impacts in greater detail.

593

594 **6. Conclusion**

595

596 The expansion of commodity frontiers in the Argentine Gran Chaco has been characterized
597 by the large-scale appropriation and accumulation of land and forest resources by outside agents.
598 Frequently, resource accumulation has taken the form of deforestation to make way for pasture or
599 cropland, a process which has resulted in the displacement of many campesino communities
600 (Cáceres, 2015). Nevertheless, processes of resource appropriation and exclusion are not restricted
601 to deforested areas. Within the forest matrix, enclosure and privatization are being used by
602 capitalized, often politically powerful actors as means to assert control over land and resources.
603 These process of changes to land control, and their potential impacts on smallholder livelihoods,
604 have not been accounted for in research that quantifies the spatial dynamics of commodity frontier
605 expansion. To fill this gap, we presented a novel approach for the spatial analysis of commodity
606 frontier impacts that builds on the idea that the ability to access land and resources is an indicator
607 of the social impacts of commodity frontier expansion.

608

609 By evaluating the degree to which livelihood activities have been restricted by the
610 emergence of barriers limiting access to land, we were able to identify campesino communities
611 that have likely experienced pressures to shift their means of production due to high restrictions
612 on access to land for particular livelihood activities. We also identified communities where people
613 may have experienced pressure to move away entirely, as they experienced severe access
614 restrictions for multiple livelihood activities simultaneously. Ultimately, the access barriers that
615 are emerging at the advancing edge of commodity frontiers are negatively impacting smallholder
616 livelihoods in the Argentine Gran Chaco. The approach proposed here serves to highlight that these
617 impacts are also being felt heterogeneously in regions that have not yet experienced widespread
618 deforestation for commodity production. Our findings thus point to the importance of effective
619 policy aimed at reducing campesino vulnerability beyond hotspots of deforestation.

620

621 In addition to its suitability for the investigation of the social impacts of commodity frontier
622 expansion in the Gran Chaco, the proposed approach provides methodological advancements for
623 the study of commodity frontiers more generally. We demonstrated that the magnitude of
624 commodity frontier impacts on smallholder livelihoods can be severely underestimated when using
625 deforestation as the sole indicator of commodity frontier dynamics. The discrepancies in impact
626 estimation between the two approaches point to two shortcomings of the more traditional
627 approach. Firstly, while a deforestation-based measure may capture impacts incurred by
628 smallholders within late-stage frontier situations, it fails to capture the impacts of the early-stage
629 processes of claiming and exclusion that precede large-scale land cover changes. Secondly, a
630 binary deforestation-based approach does not account for variations in impact according to
631 livelihood strategy. The approach introduced in this study addresses these shortcomings by
632 analyzing changes in land control, rather than land cover, and by disaggregating the potential
633 impacts of these changes by livelihood. In doing so, it provides a way to more accurately
634 characterize the potential social impacts of commodity frontiers and identify specific areas or
635 livelihoods experiencing greater pressure. Because it requires a relatively limited amount of field
636 data, the method can be seen as an efficient diagnosis and appraisal tool to be used in tandem with
637 other, more field-intensive approaches to the estimation of social impacts of agricultural expansion
638 and deforestation.

639

640 Given the continued expansion of commodity frontiers into forested regions, now and into
641 the future, it is of critical importance that their impacts for forest smallholder livelihoods be
642 assessed not just from a point of view of resource abundance, but rather through the lens of access
643 to land and resources. Doing so will allow accurate targeting of policies aimed at reducing
644 smallholder vulnerability in contexts where the expansion of commodity production occurs into
645 regions with high levels of rural poverty and tenure insecurity.

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