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*Article*

# Where Fire Crosses Borders: Extent, Spread Direction and Joint-Attention Zones of Transboundary Fires in Central South America (2012–2025)

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## Highlights

**What are the main findings?**

- We delineated 360 transboundary fire events (9.23 Mha) along the borders of six South American countries between 2012 and 2025; the Bolivia–Brazil border alone held 73% of the burned area, and three drought years (2019, 2020 and 2024) held 71%.
- Directed crossings were balanced between neighbouring countries, typically took place within 2–3 days of ignition and involved 74% of the transboundary burned area; 94% of that area was natural vegetation.

**What are the implications of the main findings?**

- Transboundary fire is a shared, recurrent hazard rather than a one-way "export" from one country to another, calling for joint prevention and response agreements.
- Eighteen joint-attention zones, covering 6% of the border length but 76% of the burned area near the border, offer a concrete spatial basis for binational fire management.
- Integrated Fire Management of the joint-attention zones, including pre-season prescribed burning, near-real-time binational alerts, and coordination from national governments to local brigades and communities, can turn this evidence into action.

## Abstract

Fires crossing international borders challenge nationally organised fire management, yet remain poorly quantified in South America. We combined national MapBiomas Fire burned-area maps for Argentina, Bolivia, Brazil, Colombia, Paraguay and Peru with VIIRS/MODIS active fires and MapBiomas land cover to delineate and characterise transboundary fire events along 14,934 km of borders between 2012 and 2025. We identified 360 events covering 9.23 Mha. The Bolivia–Brazil border concentrated 73.3% of the burned area, followed by Bolivia–Paraguay (15.0%), Brazil–Paraguay (7.4%) and Argentina–Paraguay (4.2%). Three years (2024, 2019, 2020) accounted for 70.8% of the area and the 52 events ≥10,000 ha for 97.6%. Of the 278 events with active fires, 84 showed a directed border crossing; these accounted for 73.7% of the burned area, were balanced between neighbouring countries and crossed a median of 2.5 days after ignition. Natural vegetation made up 94.0% of the burned area, whereas farmland hosted 18.7% of ignition points. Ranking 25-km border segments by recurrence, burned area and crossings identified 18 joint-attention zones, led by the southern Pantanal, that hold 76.1% of the burned area in the border strip on 6% of the border length. These results provide an empirical basis for binational fire management.

**Keywords:** transboundary fire; burned area; MapBiomas Fire; VIIRS active fire; fire spread direction; Pantanal; Chiquitano dry forest; Gran Chaco; international cooperation; fire management

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## 1. Introduction

Fire is a recurrent ecological and land-management process across the seasonally dry ecosystems of central South America, yet the last decade brought fire seasons of unprecedented severity. In 2019 and 2020, extreme drought and widespread use of fire for land clearing and pasture management produced record burned areas in the Brazilian and Bolivian Pantanal, the Chiquitano dry forest and the Gran Chaco [1–5]. The 2019–2020 drought in the Pantanal was the most severe in decades [6], the Amazon recorded its most intense drought and warmth in 2023 [7], and in 2024 the Pantanal–Chiquitano region again experienced extreme fire activity, with Bolivia's fire emissions more than four times their long-term average [8]. These events are consistent with global evidence that climate change lengthens fire-weather seasons and increases the frequency of extreme fires [9–11], while land-use dynamics remain the main source of ignitions in tropical South America [12,13].

Many of the ecosystems most affected by these fires—the Pantanal wetlands, the Chiquitano and Chaco dry forests, the Cerrado savannas and the south-western Amazon—are shared by two or more countries. Fire does not stop at international borders, but fire prevention, detection, suppression, legal frameworks and land-use policies are organised nationally. Fires that cross borders therefore raise specific problems of attribution, coordination and shared responsibility. Research on cross-boundary fire has mostly been conducted at the scale of land tenures and jurisdictions within countries, especially in the western United States and Mediterranean Europe, where wildfire simulation and network analysis have been used to quantify fire transmission between ownerships and communities [14–17] and to examine how institutional design shapes cross-boundary governance [18]. In South America, regional instruments such as the fire-management protocol of the Leticia Pact for the Amazon [19] and science–policy agendas for the Pantanal [20] explicitly call for international cooperation, yet no systematic, quantitative assessment exists of where, when, how often and in which direction fires cross the region's borders.

Two developments now make such an assessment possible. First, the MapBiomas network has produced annual, Landsat-based (30 m) burned-area maps for several South American countries using harmonised deep-learning approaches [21–23], together with long-term land use and land cover (LULC) maps [24]. Second, the MODIS and VIIRS active-fire products, distributed through the Fire Information for Resource Management System (FIRMS), provide the time and location of active burning several times a day [25–27]. Burned-area maps describe *where* fire burned; active fires describe *when* and, by extension, *in which direction* it spread. Approaches that delineate individual fire events from burned-area or active-fire data and derive their size, duration, spread rate and direction have been developed at global and national scales [28–33], but they have not been applied to fires that cross international borders.

Here we combine national MapBiomas Fire maps, VIIRS and MODIS active fires and MapBiomas LULC to build the first event-level database of transboundary fires along the borders of Argentina, Bolivia, Brazil, Colombia, Paraguay and Peru for 2012–2025. Our objectives were to (i) quantify the extent, timing, size distribution and recurrence of transboundary fires along each border; (ii) reconstruct the country of ignition, direction of spread and timing of border crossings from active-fire detections; (iii) characterise the land cover burned by fires of each country of ignition; and (iv) identify border segments where recurrent burning and repeated crossings call for joint attention by neighbouring countries.

## 2. Materials and Methods

### *2.1. Study Area*

The study area comprises the international borders shared by Argentina (ARG), Bolivia (BOL), Brazil (BRA), Colombia (COL), Paraguay (PRY) and Peru (PER): ten border pairs with a combined length of 14,934 km (Figure 1). Border lines were derived from the FAO Global Administrative Unit Layers (GAUL 2015, level 0) [34] as the boundary of each country lying within 500 m of its neighbour,

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after simplifying country outlines with a 100-m tolerance. The longest borders are Bolivia–Brazil (2913 km), Brazil–Peru (2120 km), Argentina–Paraguay (1832 km), Brazil–Colombia (1575 km) and Colombia–Peru (1432 km). The borders cross a strong climatic and ecological gradient: humid Amazon forests in the north (Bolivia–Peru, Brazil–Peru, Brazil–Colombia, Colombia–Peru and the northern Bolivia–Brazil border), the Chiquitano dry forest, Cerrado savannas and Pantanal wetlands along the central Bolivia–Brazil and Brazil–Paraguay borders, the semi-arid and humid Chaco along the Bolivia–Paraguay, Argentina–Bolivia and Argentina–Paraguay borders, and the Atlantic Forest in the south-east. Most of the region has a pronounced dry season from June to October, when most fires occur [5,13].

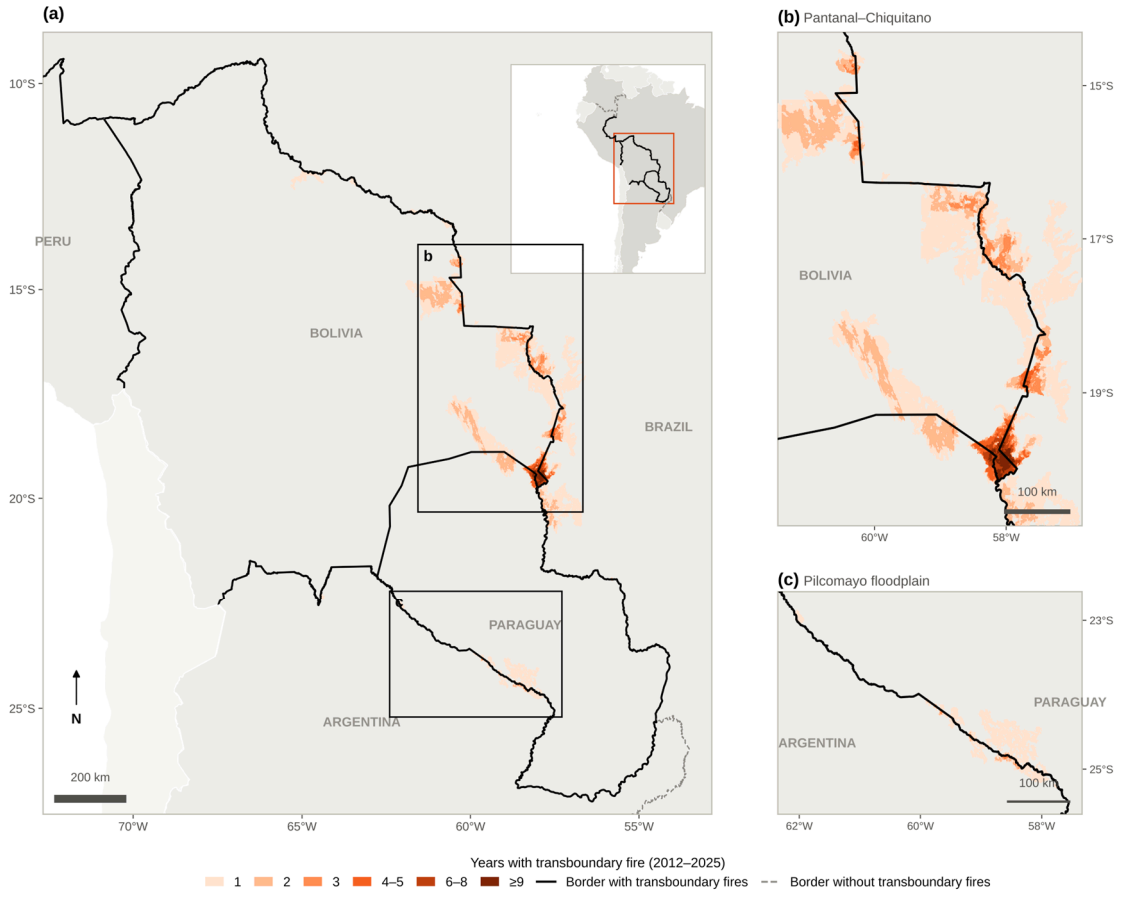



**Figure 1.** Study area and recurrence of transboundary fires, 2012–2025. (**a**) Borders between Argentina, Bolivia, Brazil, Colombia, Paraguay and Peru; solid lines show borders with at least one transboundary fire event and dashed lines borders without events. Shading shows the number of years in which a 500-m cell was burned by a transboundary event. The inset locates the study area in South America. (**b**) Detail of the Pantanal–Chiquitano sector of the Bolivia–Brazil–Paraguay borders. (**c**) Detail of the Pilcomayo floodplain on the Argentina–Paraguay border. Event footprints are the aggregated burned-area polygons (Section 2.3). Borders: FAO GAUL 2015; background: Natural Earth.

### *2.2. Data*

Table 1 summarises the datasets. Burned area was obtained from the annual burned-area vector collections of the MapBiomas Fire initiatives of each country [35], all derived from Landsat imagery at 30 m [21,22]. The national products cover different periods, so the analysis was restricted to 2012–2025, when VIIRS 375-m active fires are available for dynamics; within this period the national products were available for all countries and years except Peru in 2012 and 2025 and Paraguay in 2025. Active fires were obtained from FIRMS [27] as annual country files from the standard processing archive, complemented by near-real-time (NRT) data where the standard archive was not yet

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available. We used VIIRS S-NPP 375-m detections (VNP14IMG) with nominal or high confidence and MODIS Collection 6.1 1-km detections (MCD14ML) with confidence ≥30%, retaining only detections of presumed vegetation fires (type 0) [25,26]. Land cover in the year preceding each fire was obtained from the MapBiomas LULC collections of each country [24,35]. All raster processing was carried out in Google Earth Engine [36], and all vector and statistical analyses in Python with an Albers equal-area projection (standard parallels 5° S and 42° S, central meridian 60° W).

**Table 1.** Datasets used in this study.

| Data | Product (source) | Resolution | Period used | Use |
|---|---|---|---|---|
| Burned area | MapBiomas Fire annual burned-area vectors: Collection 1 (Argentina, Bolivia, Colombia, Paraguay, Peru); Collection 5.1 (Brazil) [35] | 30 m (Landsat) | 2012–2025 (Peru 2013–2024; Paraguay 2012–2024) | Delineation of transboundary events |
| Active fires | VIIRS S-NPP 375 m (VNP14IMG) and MODIS C6.1 (MCD14ML), FIRMS standard and NRT [25–27] | 375 m; 1 km | VIIRS 2013–2025; MODIS 2012–2025 | Ignition country, direction, timing, duration, spread rate, FRP; MODIS for cross-validation |
| Land cover | MapBiomas LULC: Argentina Collection 3; Bolivia, Brazil, Paraguay and Peru harmonised public collections [24,35] | 30 m | Year before each fire (2011–2024) | Land cover burned by country of ignition |
| Boundaries | FAO GAUL 2015, level 0 [34] | Simplified 100 m | – | Border lines, country allocation, border segments |
| Cartography | Natural Earth 1:50 m [37] | 1:50 m | – | Map context |

### *2.3. Delineation of Transboundary Fire Events*

For each year and border pair, all annual burned-area polygons of the two national products that intersected a strip of 5 km on each side of the border were retrieved in full (i.e., without clipping, so that the complete burn scar of a fire reaching the strip was retained). Polygons were simplified with a 15-m tolerance (half a Landsat pixel) and interior holes smaller than 0.1 ha were filled. Polygons of both products were then grouped into connected components, treating polygons separated by ≤150 m as contiguous; each component with an area ≥1 ha constitutes a fire event, whose area is the geometric union of its polygons (no double counting where the national products overlap). Each national product was taken to represent burned area in its own country; where the two products overlapped near the border, the overlapping area was allocated to each country in proportion to the area mapped by each product, so that country areas sum to the event area. An event was classified as **transboundary** when it had ≥1 ha in each of at least two countries. Events involving three countries were assigned to the border pair formed by the two countries with the largest areas.

To support the active-fire analysis, each event was aggregated with a morphological closing of 375 m (a buffer of +187.5 m followed by −187.5 m, equivalent to the ArcGIS *Aggregate Polygons* tool), joined with the original geometry and simplified with a 15-m tolerance. This merges parts of the same scar separated by less than one VIIRS pixel and increased the total event area by 8.1% (from 9.23 to 9.98 Mha) because unburned islands and narrow gaps were included. A further 375-m buffer around the aggregated polygon defined the search zone for active-fire detections, accounting for VIIRS geolocation uncertainty. Unless stated otherwise, the burned areas reported here are the original (non-aggregated) event areas.

### *2.4. Active-Fire Dynamics*

Active-fire detections of the same year as the burned-area map that fell within an event's search zone were assigned to that event (to the nearest aggregated polygon if several zones overlapped). VIIRS was used for 2013–2025; for 2012, MODIS records were not available in the processing run, so the nine 2012 events have no dynamics. Detections within one pixel of the border (375 m for VIIRS, 1

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km for MODIS) were flagged as ambiguous because their country cannot be determined unequivocally. Detections were split into episodes separated by gaps of more than 3 days without detections, and episodes with fewer than two detections were discarded. The episode analysed for each event was the one containing a border crossing with the highest cumulative fire radiative power (FRP) or, if none crossed, the episode with the highest FRP.

The **country of ignition** was the country of the non-ambiguous detections of the first satellite overpass of the episode (detections within 1 h); when that overpass included non-ambiguous detections in both countries, the event was classified as **simultaneous**. When the first overpass held only ambiguous detections, the origin was inferred from the first non-ambiguous detections (10 events, flagged). A **directed crossing** (e.g., BOL→BRA) required at least two non-ambiguous detections in each country within the same episode, with the origin determined as above; events whose active fires remained on one side of the border were classified as **no crossing detected** (the burned area crossed the border, but the active-fire record did not capture the crossing), and events whose origin could not be established as **undetermined**. The start and end of the episode were represented by the centroids of the first and last overpass detections, from which we derived the start-to-end bearing (geodesic azimuth) and distance. For each event we computed the episode duration (days between the first and last detection, inclusive), the lag between ignition and the first detection in the receiving country, the fraction of night-time detections, FRP statistics (mean, 90th percentile and maximum, in MW [38]) and three spread-rate metrics: the rate of the farthest front (distance of the farthest detection from the start divided by the time elapsed), the 90th percentile of the distance/time ratio of detections observed ≥0.5 days after ignition (ROS p90, km day$^{-1}$), and the area growth rate (event area divided by duration, ha day$^{-1}$). Times were converted to local solar time. A quality flag was assigned: *high* for directed crossings with a non-inferred origin and ≥10 detections, *medium* for events with a determined class and ≥3 detections, and *low* otherwise.

To assess the robustness of the direction classification to the sensor, all events of 2013–2025 were also processed with MODIS, and the two classifications were compared using the percentage agreement and Cohen's κ [39], the agreement in the country of origin for events classified as directed by both sensors, the difference in start dates and Spearman's correlation of episode durations.

### *2.5. Land Cover Burned*

To characterise what burned and on which side of the border, each event was split into its country pieces, and each piece was intersected with the LULC map of its own country for the year before the fire (t − 1). Class areas were obtained from the proportion of 30-m pixels in each class (Earth Engine frequency histogram) multiplied by the exact vector area of the piece. The MapBiomas legends of the five countries were harmonised into six macroclasses: forest formation (MapBiomas classes 1, 3, 5, 6, 49), open forest/savanna (4), non-forest natural formation (10, 12, 13, 50, 66, 81), wetland/flooded grassland (11, 32, 82), farming and plantations (9, 14, 15, 18–21, 35, 36, 39–41, 46–48, 62, 72) and other land cover (urban, bare and water classes). The first four macroclasses constitute natural vegetation. Pixels without data or with codes outside these lists (1.4% of the area) were reported as *no data*. The burned area of each event was then related to its country of ignition (Section 2.4), distinguishing the area burned in the country of ignition (*own country*) from that burned in the neighbouring country. The land cover at each ignition point was also extracted.

### *2.6. Joint-Attention Border Segments*

To translate event-level results into spatial priorities, each border line was divided into segments of approximately 25 km (597 segments). For each segment, we defined an analysis zone of 5 km on each side of the border (flat-capped buffer) and computed, using only events of the same border pair: the number of years with at least one event (≥1 ha of event footprint within the zone), the number of events, the event footprint area within the zone per kilometre of border and the number of directed crossings whose crossing point fell in the zone. Ignition points were assigned to the nearest segment within 20 km. For segments with at least one event (*active* segments), a **joint-attention index** (JAI)

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was computed as the mean of the percentile ranks of (i) years with events, (ii) burned area per kilometre and (iii) directed crossings, so that recurrence, magnitude and cross-border spread weighed equally. Segments with JAI ≥ the 90th percentile of active segments were assigned **Priority I** and those with JAI ≥ the 75th percentile **Priority II**; the remaining active segments were Priority III. Contiguous Priority I–II segments were merged into **joint-attention zones**, numbered Z1–Z18 by decreasing burned area.

### *2.7. Statistical Analysis*

Temporal trends in the annual number of events and burned area were tested with Kendall's τ. Differences among border pairs in event area, duration, ROS p90 and FRP p90 were tested with the Kruskal–Wallis test [40], with $\varepsilon^2$ as the effect size [41]; differences between directed and non-crossing events were tested with the Mann–Whitney U test [42]. The balance of crossing directions on each border was assessed with two-sided binomial tests against an equal probability of both directions. Differences in burned land cover among countries of ignition were tested with Kruskal–Wallis and pairwise Mann–Whitney tests with Holm correction [43] and Cliff's δ [44], and the association between country of ignition and dominant macroclass with a $\chi^2$ test and Cramér's V. Analyses were performed with SciPy [45], GeoPandas and Shapely; statistical significance was set at $\alpha = 0.05$. Medians and interquartile ranges (IQR) are reported because all event metrics were strongly right-skewed.

## 3. Results

### *3.1. Extent and Temporal Pattern of Transboundary Fires*

We identified 360 transboundary fire events between 2012 and 2025, which burned a total of 9.23 Mha (Table 2, Figure 1). Events occurred on seven of the ten border pairs; none were found on the Argentina–Brazil, Brazil–Colombia or Colombia–Peru borders. Of the total area, 53.6% burned in Bolivia (4.95 Mha), 33.8% in Brazil (3.12 Mha), 11.2% in Paraguay (1.03 Mha) and 1.4% in Argentina (0.13 Mha), while Peru contributed only 1.3 kha. The Bolivia–Brazil border was by far the most affected: it had events in all 14 years, 194 events (53.9%) and 6.77 Mha (73.3% of the total), equivalent to 2324 ha per kilometre of border. It was followed by Bolivia–Paraguay (14 events, 1.38 Mha, 15.0%), Brazil–Paraguay (38 events, 0.68 Mha, 7.4%) and Argentina–Paraguay (58 events, 0.39 Mha, 4.2%). The Argentina–Bolivia, Bolivia–Peru and Brazil–Peru borders had frequent but small events, which together burned only 10.6 kha. Nine Bolivia–Brazil events also extended into Paraguay, adding 319 kha in that third country.

**Table 2.** Transboundary fire events by border pair, 2012–2025. Country split gives the percentage of the burned area in each country.

| Border | Length (km) | Events | Years with events | Burned area (kha) | Share (%) | Country split (%) | Median event (ha) | Largest event (kha) |
|---|---|---|---|---|---|---|---|---|
| Bolivia–Brazil | 2,913 | 194 | 14 | 6,767.7 | 73.3 | BOL 59.2 / BRA 36.1 / PRY 4.7[a] | 413 | 582.4 |
| Bolivia–Paraguay | 753 | 14 | 9 | 1,381.5 | 15.0 | BOL 68.2 / PRY 31.8 | 408 | 853.0 |
| Brazil–Paraguay | 1,189 | 38 | 10 | 682.8 | 7.4 | BRA 99.4 / PRY 0.6 | 57 | 579.7 |
| Argentina–Paraguay | 1,832 | 58 | 12 | 391.3 | 4.2 | PRY 69.2 / ARG 30.8 | 147 | 265.0 |
| Argentina–Bolivia | 826 | 16 | 5 | 7.8 | 0.1 | ARG 92.0 / BOL 8.0 | 50 | 6.7 |
| Bolivia–Peru | 1,036 | 37 | 10 | 2.7 | <0.1 | BOL 52.6 / PER 47.4 | 43 | 0.2 |
| Brazil–Peru | 2,120 | 3 | 3 | 0.1 | <0.1 | BRA 96.0 / PER 4.0 | 16 | 0.1 |
| **Total (10 borders)** | **14,934** | **360** | **14** | **9,233.8** | **100.0** | **BOL 53.6 / BRA 33.8 / PRY 11.2 / ARG 1.4** | **124** | **853.0** |

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Borders without transboundary events: Argentina–Brazil (1259 km), Brazil–Colombia (1575 km) and Colombia–Peru (1432 km). [a] Includes 319 kha burned in Paraguay by nine three-country events.

The annual number of events ranged from 7 (2025) to 53 (2020), and the annual burned area from 3.9 kha (2018) to 2.61 Mha (2024) (Figure 2). Three years—2024 (2.61 Mha), 2019 (2.27 Mha) and 2020 (1.66 Mha)—accounted for 70.8% of the 14-year total, and 2021 added a further 1.13 Mha. The country composition of these peak years differed: Bolivia dominated in 2019 (79.7% of the year's area), Brazil in 2021, and 2020 and 2024 combined large areas in both countries. Neither the number of events (Kendall's $\tau = 0.17$, $p = 0.41$) nor the burned area ($\tau = 0.19$, $p = 0.39$) showed a significant monotonic trend; instead, the series is dominated by episodic extreme years. The Bolivia–Brazil and Argentina–Paraguay borders had events in 14 and 12 of the 14 years, respectively, and the latter showed peaks in event numbers in 2020 (18) and 2022 (17) (Figure 2c).




**Figure 2.** Temporal pattern of transboundary fires, 2012–2025. (**a**) Number of events per year by dynamic class (Section 2.4); † 2012 events have no active-fire dynamics. (**b**) Burned area per year by the country where the area burned. (**c**) Burned area (colour, logarithmic scale) and number of events (cell labels) by border pair and year.

### *3.2. Event Size*

Event size spanned six orders of magnitude, from 1 ha to 853 kha, with a median of 124 ha (IQR 24–1632 ha) (Figure 3). Almost half of the events (174; 48.3%) were smaller than 100 ha, whereas the 52 events of ≥10,000 ha (14.4%) accounted for 97.6% of the burned area. The ten largest events (2.8%) accounted for 53.0% of the area and the largest 5% for 72.8%. The largest event (2019, Bolivia–Paraguay) burned 853 kha along 71 km of border, 74% of it in Bolivia, and spread from Bolivia into Paraguay over 60 days. It was followed by two 2024 events of 582 kha (Bolivia–Brazil, simultaneous ignition, 89 days) and 580 kha (Brazil–Paraguay, Brazil→Paraguay, 10 days); the latter accounted for 84.9% of the burned area on the Brazil–Paraguay border. Eight of the ten largest events occurred on the Bolivia–Brazil border, four of them in 2019–2020. Event size differed among border pairs (Kruskal–Wallis $H = 39.6$, $p < 0.001$, $\varepsilon^2 = 0.13$ for events with active fires), with the largest medians (all events) on the Bolivia–Brazil (413 ha) and Bolivia–Paraguay (408 ha) borders and the smallest on Bolivia–Peru (43 ha) and Brazil–Peru (16 ha).

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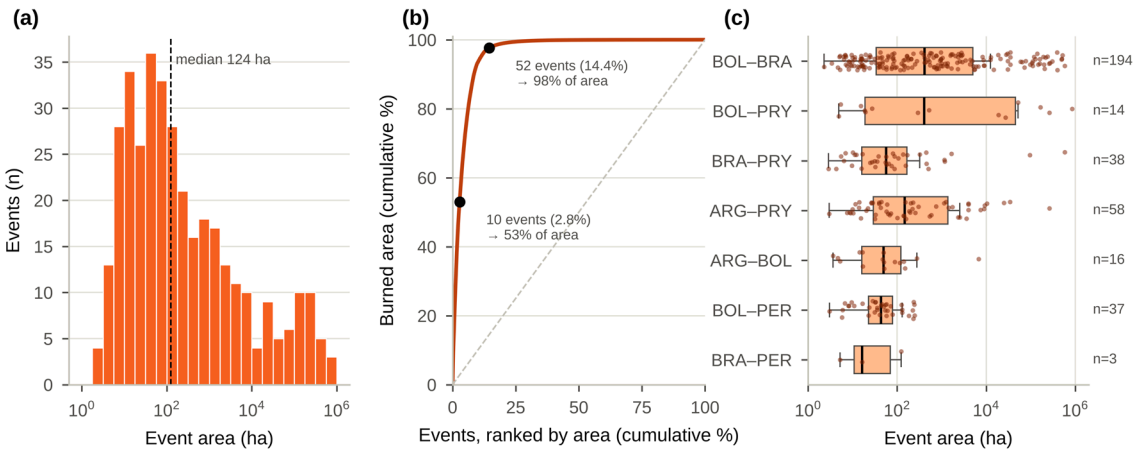



**Figure 3.** Size distribution of transboundary fire events. (**a**) Histogram of event area (logarithmic bins); the dashed line marks the median. (**b**) Concentration curve: cumulative share of the burned area against events ranked from largest to smallest; the dashed diagonal indicates equal contribution of all events. (**c**) Event area by border pair (boxes: IQR and median; whiskers: 1.5 × IQR; points: individual events).

### *3.3. Ignition, Direction and Timing of Border Crossings*

Active fires were detected in 278 events (77.2%), which accounted for 96.3% of the burned area; the 82 events without detections comprised 73 small VIIRS-era events and the nine 2012 events. Among events with active fires, 164 (59.0%) showed no crossing in the active-fire record, 84 (30.2%) a directed crossing, 20 (7.2%) a simultaneous ignition on both sides of the border and 10 (3.6%) were undetermined (Table 3, Figures 4 and 5). Although directed crossings were a minority of events, they accounted for 73.7% of the total burned area, and directed and simultaneous events together for 89.5%. Directed events were much larger (median 9836 vs. 72 ha; Mann–Whitney $p < 0.001$) and longer (median 10 vs. 1 day; $p < 0.001$) than events with no crossing detected. According to the quality flag, 79 events had high, 127 medium and 72 low confidence.

**Table 3.** Active-fire dynamics of transboundary fire events by border pair (events with active fires, VIIRS 2013–2025).

| Border | Events with active fires | Directed crossings (A→B / B→A) | Simultaneous | No crossing detected | Undetermined | Duration, median (p90) (days) | ROS p90, median (km day$^{-1}$) | FRP p90, median (MW) | Lag to crossing, median (days) |
|---|---|---|---|---|---|---|---|---|---|
| Bolivia–Brazil | 151 | 56 (29 / 24 + 3[a]) | 10 | 78 | 7 | 3.0 (33.0) | 2.46 | 22.1 | 1.7 |
| Argentina–Paraguay | 46 | 15 (9 / 6) | 4 | 27 | 0 | 3.0 (15.0) | 1.71 | 29.2 | 3.5 |
| Bolivia–Peru | 28 | 1 (0 / 1) | 0 | 24 | 3 | 2.0 (5.2) | 0.59 | 13.9 | 8.6 |
| Brazil–Paraguay | 26 | 7 (3 / 4) | 2 | 17 | 0 | 1.0 (7.5) | 2.55 | 13.1 | 1.5 |
| Argentina–Bolivia | 14 | 1 (1 / 0) | 2 | 11 | 0 | 1.0 (3.7) | 0.65 | 10.5 | 2.0 |
| Bolivia–Paraguay | 10 | 4 (3 / 1) | 1 | 5 | 0 | 6.5 (23.1) | 10.56 | 39.3 | 5.7 |
| Brazil–Peru | 3 | 0 (0 / 0) | 1 | 2 | 0 | 1.0 (1.8) | 1.76 | 9.1 | – |
| **All borders** | **278** | **84** | **20** | **164** | **10** | **2.0 (20.3)** | **2.20** | **20.4** | **2.5** |

A and B refer to the first and second country in the border name. [a] Includes three crossings involving Paraguay (three-country events). ROS p90, 90th-percentile spread rate; FRP p90, 90th-percentile fire radiative power.

Crossing directions were balanced on every border (Figure 5a,b). On the Bolivia–Brazil border, 29 events spread from Bolivia into Brazil and 24 from Brazil into Bolivia (binomial $p = 0.58$); on

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Argentina–Paraguay, 9 and 6 ($p$ = 0.61); on Brazil–Paraguay, 3 and 4 ($p$ = 1.0); and on Bolivia–Paraguay, 3 and 1 ($p$ = 0.63). Overall, Bolivia was the country of ignition in 32 directed crossings and Brazil in 28, Paraguay in 13, Argentina in 10 and Peru in 1. The burned area involved was nevertheless asymmetric for some pairs: the 24 Brazil→Bolivia crossings burned 2.05 Mha against 1.72 Mha for the 29 Bolivia→Brazil crossings, and three Bolivia→Paraguay events burned 1.14 Mha. Paraguay was the receiving country of fires totalling 1.97 Mha, almost twice the area of crossings it originated (1.06 Mha).

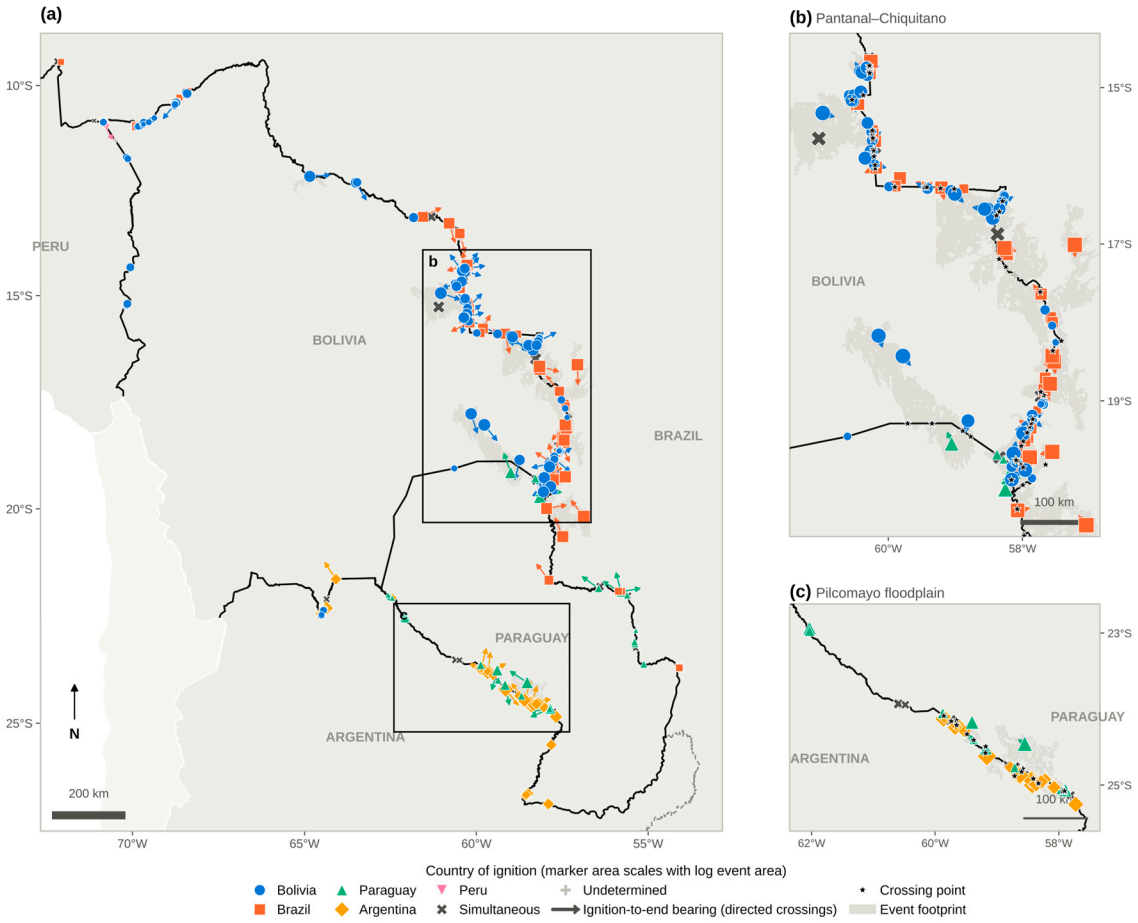



**Figure 4.** Ignition and spread of transboundary fires. (**a**) Ignition points coloured by country of ignition (marker area scales with the logarithm of event area), simultaneous and undetermined events, start-to-end bearing of directed crossings (arrows) and border-crossing points (stars). (**b**) Pantanal–Chiquitano sector. (**c**) Pilcomayo floodplain. Grey shading shows event footprints.

Crossings were fast. The median lag between the first detection and the first detection in the receiving country was 2.5 days (third quartile 6.0 days); 24% of directed crossings occurred within 1 day, 46% within 2 days and 79% within 7 days (Figure 5c). The shortest median lags were on the Brazil–Paraguay (1.5 days) and Bolivia–Brazil (1.7 days) borders and the longest on Bolivia–Paraguay (5.7 days; the single Bolivia–Peru crossing took 8.6 days). Ignitions were strongly seasonal: 79.9% of events with active fires started between July and October and 54.0% in August–September, and events that started in July–October accounted for 92.5% of the burned area (Figure 5d). July ignitions were only 11.2% of events but 42% of the burned area, reflecting the early start of the largest Pantanal and Chiquitano fires. On the Argentina–Paraguay border, a secondary group of events started in the austral summer (December–March).

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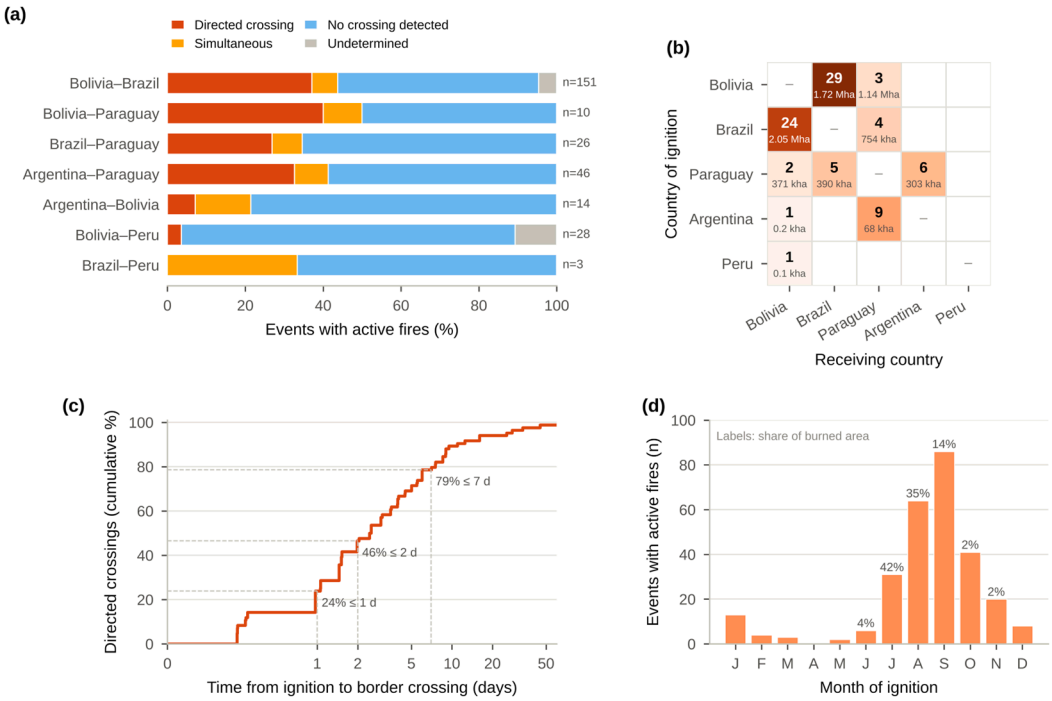



**Figure 5.** Direction and timing of border crossings. (**a**) Dynamic class of events with active fires by border pair. (**b**) Origin–receptor matrix of directed crossings: number of events (bold) and burned area of those events. (**c**) Cumulative distribution of the time from ignition to the first detection in the receiving country (logarithmic axis). (**d**) Number of events with active fires by month of ignition; labels give each month's share of the burned area.

The direction classification was moderately robust to the sensor. Of the 210 events of 2013–2025 with detections from both sensors, VIIRS and MODIS agreed on the dynamic class in 60.0% of cases (Cohen's $\kappa = 0.43$); among the 49 events classified as directed by both, the country of origin agreed in 89.8%. Start dates had a median difference of 0 days (90th percentile of the absolute difference, 28 days), and durations were strongly correlated (Spearman $\varrho = 0.88$, $p < 0.001$). Disagreements arose mainly between *no crossing detected* and *directed*, as expected from the coarser MODIS footprint and its lower sensitivity to small fires.

### *3.4. Fire Behaviour*

The median episode duration was 2 days (90th percentile 20 days), but the 18 events (6.5%) that lasted 30 days or more accounted for 53.8% of the burned area. Event area was strongly correlated with duration (Spearman $\varrho = 0.78$) and moderately with FRP p90 ($\varrho = 0.50$) (Figure 6a). Directed and simultaneous events burned longer and with higher FRP than events with no crossing detected (Figure 6b,c). Across all events with active fires, the median FRP p90 was 20.4 MW, the median ROS p90 was 2.2 km day$^{-1}$ and the median fraction of night-time detections was 0.20, indicating that many fires remained active through the night. Fire behaviour differed among border pairs (Figure 6d,e; Table 3). Differences were largest for spread rate (Kruskal–Wallis $H = 27.5$, $p < 0.001$, $\varepsilon^2 = 0.16$), which was highest on the Bolivia–Paraguay border (median ROS p90 10.6 km day$^{-1}$), intermediate on Bolivia–Brazil and Brazil–Paraguay (2.5–2.6 km day$^{-1}$) and lowest on Bolivia–Peru (0.6 km day$^{-1}$). Differences in duration ($H = 18.8$, $p = 0.002$, $\varepsilon^2 = 0.05$) and FRP p90 ($H = 18.4$, $p = 0.003$, $\varepsilon^2 = 0.05$) were significant but small, with the most intense fires on Bolivia–Paraguay (39.3 MW) and Argentina–Paraguay (29.2 MW).

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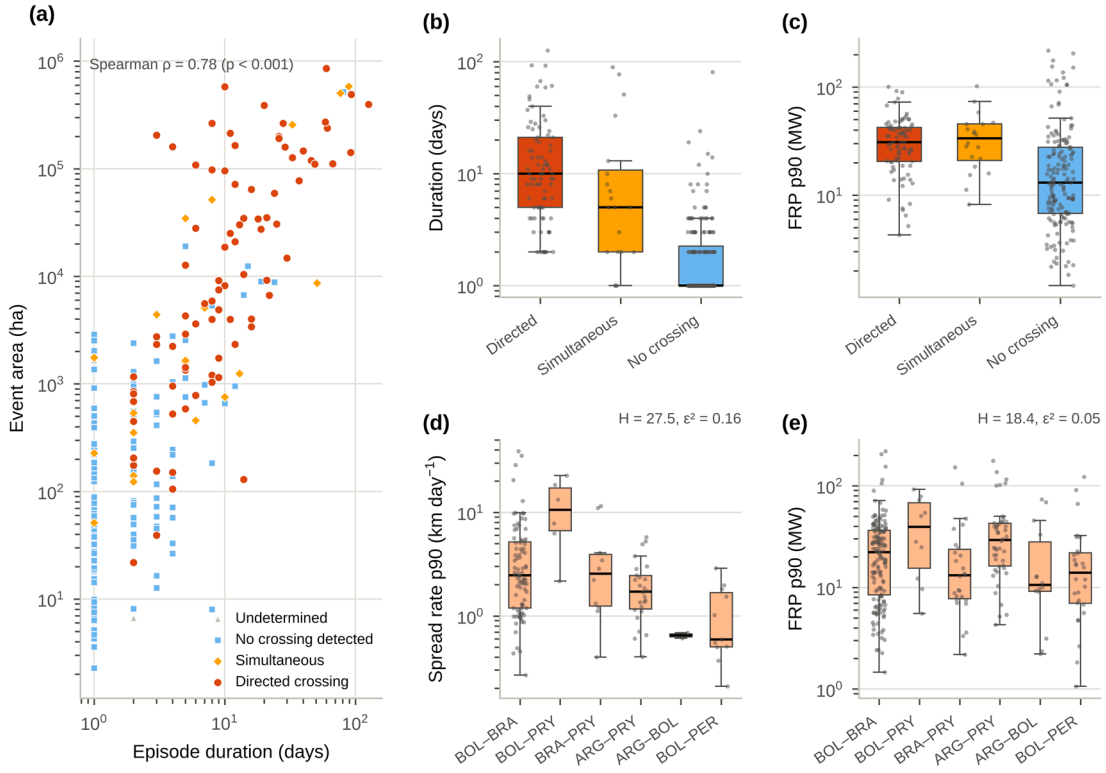



**Figure 6.** Behaviour of transboundary fires (VIIRS, events with active fires). (**a**) Event area versus episode duration by dynamic class. (**b**) Episode duration and (**c**) 90th-percentile fire radiative power (FRP p90) by dynamic class. (**d**) 90th-percentile spread rate (ROS p90) and (**e**) FRP p90 by border pair, with Kruskal–Wallis $H$ and $\varepsilon^2$. Boxes show the IQR and median; whiskers extend to 1.5 × IQR. Brazil–Peru (three events) is omitted from (**d**,**e**).

### *3.5. Land Cover Burned and Country of Ignition*

Natural vegetation made up 94.0% of the transboundary burned area: forest formations 39.0%, non-forest natural formations 26.8%, wetlands and flooded grasslands 22.6% and open forest/savanna 5.5%; farming and plantations contributed only 1.5% and other land cover 3.0%. The composition differed markedly among countries of ignition (Figure 7). The share of forest in the burned area of each event differed among countries (Kruskal–Wallis $H = 59.1$, $p < 0.001$), with median shares of 88.8% for fires ignited in Argentina, 48.1% in Paraguay, 21.5% in Peru, 13.2% in Bolivia and 5.2% in Brazil, and the dominant macroclass was associated with the country of ignition ($\chi^2 = 119.9$, df = 24, $p < 0.001$, Cramér's V = 0.35). Fires ignited in Bolivia burned mainly Chiquitano and Pantanal forest in Bolivia (52.9% forest, 26.1% non-forest natural formation and 18.2% wetland), whereas those ignited in Brazil burned mainly non-forest natural formations (45.7%), savannas (20.3%) and wetlands (17.5%) of the Brazilian Pantanal and Cerrado, and only 6.0% forest. Fires ignited in Paraguay and Argentina burned almost exclusively Chaco forest in their own countries (89.1% and 92.9%).

Of the area burned by events with a known country of ignition (8.05 Mha), 1.98 Mha (24.6%) burned in the neighbouring country. This spill-over share was highest for fires ignited in Paraguay (48.4%), followed by Brazil (26.5%), Argentina (16.2%), Bolivia (15.6%) and Peru (6.9%). The land cover burned on the other side of the border reflected the receiving landscape: almost half (48.2%) of the area burned in Bolivia and Paraguay by fires from Brazil consisted of wetlands and flooded grasslands. In contrast to the burned area, ignition points were frequently located on farmland: 18.7% of all ignition points (52 of 278) fell on farming and plantations, rising to 23.5% for Bolivia and 38.5% for Peru (Figure 7b), against 1.5% of the burned area.

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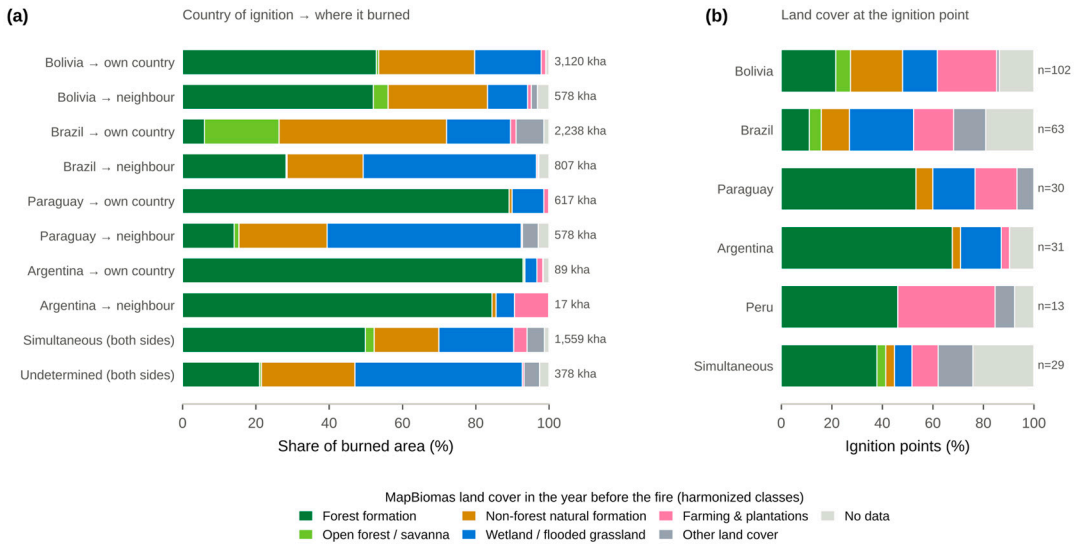



**Figure 7.** Land cover burned by transboundary fires according to the country of ignition (MapBiomas, year before the fire, harmonised macroclasses). (**a**) Composition of the area burned in the country of ignition (own country) and in the neighbouring country; values give the burned area. *Undetermined* includes events without active fires. (**b**) Land cover at the ignition point.

### *3.6. Recurrence Hotspots and Joint-Attention Zones*

Of the 597 border segments, 144 (24.1%; 3594 km) had at least one transboundary event. Recurrence was high: 30 segments had events in five or more years, and the two most recurrent segments, both within the southern Pantanal zone Z1, had events in 12 of the 14 years (Figure 1). The joint-attention index identified 15 Priority I segments (374 km; 13 on Bolivia–Brazil and 2 on Argentina–Paraguay) and 21 Priority II segments (524 km). Priority I segments held 55.5% of the event area within the border zones and 47.4% of the 78 directed crossings located on segments; Priority I and II together—6.0% of the total border length—held 76.1% of the area and 74.4% of the crossings (Figure 8).

Contiguous Priority I–II segments formed 18 joint-attention zones (Table 4). Z1, in the southern Pantanal between Puerto Suárez–Corumbá and the Bolivia–Brazil–Paraguay tri-border, stands out with 149 km of border, events in 12 years, 28 events, 746 kha burned within the zone and 13 directed crossings—more than three times the area of any other zone. Zones Z1, Z2, Z8, Z10 and Z11 together form a southern Pantanal tri-border complex (1.05 Mha). A second cluster lies in the northern Pantanal and Chiquitano around San Matías (Z3, Z5 and Z14; 0.19 Mha) and a third along the Chiquitano–Mato Grosso and Iténez–Guaporé border (Z4, Z7, Z9 and Z15; 0.16 Mha), where crossings were particularly frequent (18 directed crossings). On the Argentina–Paraguay border, Z6, Z12 and Z13 follow the Pilcomayo floodplain (89 kha). Finally, two zones in the south-western Amazon—Z17 on the Pando–Acre border and Z18 at the Bolivia–Brazil–Peru tri-border—burned little area but had events in 9 and 10 years, respectively, and Z18 had the third-highest number of events of all zones (16).

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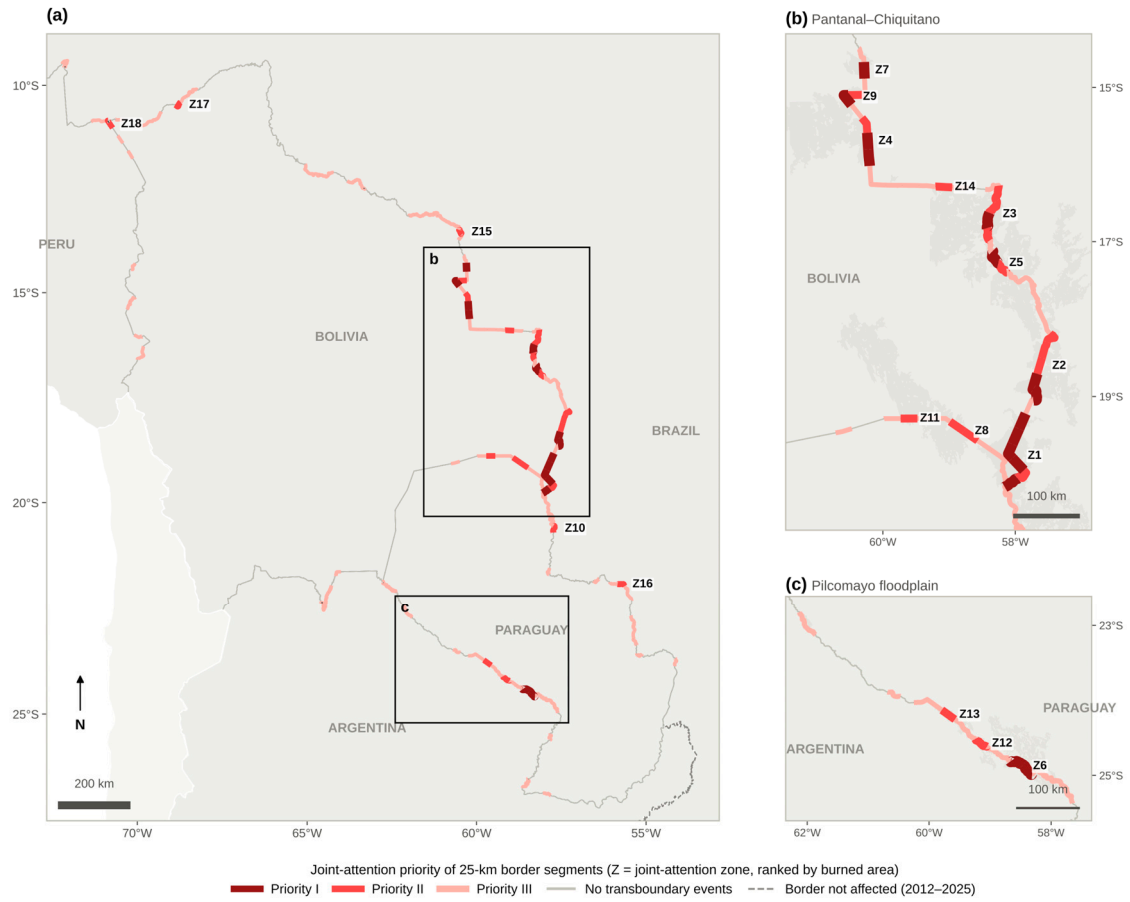



**Figure 8.** Joint-attention priority of 25-km border segments and joint-attention zones (Z1–Z18, ranked by burned area). (**a**) All borders; (**b**) Pantanal–Chiquitano sector; (**c**) Pilcomayo floodplain. Priority I and II segments have a joint-attention index ≥ the 90th and 75th percentiles of active segments, respectively. Grey shading in (**b**) shows event footprints.

**Table 4.** Joint-attention zones formed by contiguous Priority I–II border segments, ranked by burned area within the zone (5 km on each side of the border).

| Zone | Border | Location (lat, lon) | Sector | Length (km) | Priority I segments | Years with events | Events | Burned area in zone (kha) | Directed crossings |
|---|---|---|---|---|---|---|---|---|---|
| Z1 | Bolivia–Brazil | 19.8° S, 58.0° W | Southern Pantanal, Puerto Suárez–Corumbá to BOL–BRA–PRY tri-border | 149 | 5 | 12 | 28 | 745.8 | 13 |
| Z2 | Bolivia–Brazil | 18.6° S, 57.6° W | Pantanal, Corumbá–Puerto Suárez to Mandioré–Gaíba lakes | 124 | 2 | 9 | 24 | 213.9 | 5 |
| Z3 | Bolivia–Brazil | 16.6° S, 58.4° W | Northern Pantanal–Chiquitano (San Matías) | 100 | 1 | 7 | 13 | 104.9 | 3 |
| Z4 | Bolivia–Brazil | 15.7° S, 60.2° W | Chiquitano–Mato Grosso | 75 | 2 | 9 | 15 | 78.8 | 8 |
| Z5 | Bolivia–Brazil | 17.3° S, 58.3° W | Northern Pantanal (south of San Matías) | 50 | 1 | 4 | 4 | 75.9 | 2 |
| Z6 | Argentina–Paraguay | 24.9° S, 58.5° W | Lower Pilcomayo floodplain | 50 | 2 | 6 | 12 | 57.5 | 4 |
| Z7 | Bolivia–Brazil | 14.8° S, 60.3° W | Chiquitano–Guaporé | 25 | 1 | 7 | 10 | 44.3 | 7 |

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| Zone | Border | Location (lat, lon) | Sector | Length (km) | Priority I segments | Years with events | Events | Burned area in zone (kha) | Directed crossings |
|---|---|---|---|---|---|---|---|---|---|
| Z8 | Bolivia–Paraguay | 19.4° S, 58.8° W | Chaco–Pantanal (Otuquis–Río Negro) | 50 | 0 | 3 | 3 | 44.0 | 2 |
| Z9 | Bolivia–Brazil | 15.1° S, 60.4° W | Chiquitano–Guaporé | 50 | 1 | 7 | 11 | 31.2 | 2 |
| Z10 | Brazil–Paraguay | 21.0° S, 57.8° W | Paraguay River (Fuerte Olimpo) | 25 | 0 | 2 | 2 | 22.5 | 1 |
| Z11 | Bolivia–Paraguay | 19.3° S, 59.6° W | Chaco–Pantanal transition | 25 | 0 | 2 | 2 | 21.8 | 1 |
| Z12 | Argentina–Paraguay | 24.6° S, 59.2° W | Middle Pilcomayo | 25 | 0 | 2 | 2 | 17.0 | 1 |
| Z13 | Argentina–Paraguay | 24.2° S, 59.7° W | Middle Pilcomayo | 25 | 0 | 3 | 5 | 14.7 | 2 |
| Z14 | Bolivia–Brazil | 16.3° S, 59.1° W | Chiquitano–Mato Grosso dry border | 25 | 0 | 3 | 4 | 12.7 | 1 |
| Z15 | Bolivia–Brazil | 13.9° S, 60.4° W | Iténez–Guaporé | 25 | 0 | 4 | 5 | 7.2 | 1 |
| Z16 | Brazil–Paraguay | 22.3° S, 55.9° W | Amambay dry border | 25 | 0 | 5 | 7 | 6.4 | 3 |
| Z17 | Bolivia–Brazil | 10.7° S, 67.7° W | Pando–Acre | 25 | 0 | 9 | 13 | 3.6 | 1 |
| Z18 | Bolivia–Peru | 11.0° S, 69.5° W | BOL–BRA–PER tri-border (Bolpebra) | 25 | 0 | 10 | 16 | 1.5 | 1 |

## 4. Discussion

### *4.1. A Concentrated and Episodic Phenomenon*

This study provides the first systematic, event-level quantification of fires that cross the international borders of central South America. Transboundary fire proved to be both spatially concentrated and temporally episodic. Spatially, the Bolivia–Brazil border—particularly its Pantanal and Chiquitano sectors—and the Bolivia–Brazil–Paraguay tri-border accounted for the large majority of the burned area, in line with the regional hotspots identified by national and ecoregional studies [2–5]. Temporally, three years accounted for 71% of the area, and these years coincide with the extreme droughts of 2019–2020 in the Pantanal [6] and 2023–2024 in the Amazon and surrounding regions [7,8]. The absence of a monotonic trend over 14 years should therefore not be read as stability: the transboundary fire regime is driven by rare extreme seasons in which a few very large, long-lasting fires—six of the ten largest events lasted 60 days or more—burn most of the area. This heavy-tailed size distribution, with 14% of events accounting for 98% of the area, is characteristic of extreme wildfire events [10,11] and implies that preventing or rapidly containing a small number of fires in drought years could avoid most of the transboundary burned area.

The contrast between borders also reflects their ecosystems and land use. The Amazonian borders with Peru and Colombia had few or no transboundary events, and those on Bolivia–Peru were small, frequent and slow (ROS p90 0.6 km day$^{-1}$), consistent with the humid forests and small-scale fire use that likely prevail in that region. In contrast, the flammable grasslands and wetlands of the Pantanal and the dry forests of the Chiquitano and Chaco supported fast and intense fires: the Bolivia–Paraguay border, with only 14 events, combined the highest spread rates and FRP and the largest single event of the period.

### *4.2. Shared Responsibility: Balanced Directions and Rapid Crossings*

Crossing directions were balanced on every border. Neither Bolivia nor Brazil—nor any other country—acted predominantly as an "exporter" of fire; the 29 Bolivia→Brazil and 24 Brazil→Bolivia crossings are statistically indistinguishable from an even split. Transboundary fire is therefore better

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framed as a shared, reciprocal hazard than as a one-directional externality, which provides a constructive basis for cooperation. Asymmetries appeared in the area involved rather than in the number of crossings: Brazil-originated crossings into Bolivia burned more area than the reverse, and Paraguay received fires totalling almost twice the area of those it originated, mostly in the Chaco–Pantanal transition near the tri-border. Cross-boundary fire transmission studies in the United States and Europe have similarly found that fire exchange among jurisdictions is often reciprocal and concentrated in a small number of source–recipient links [14–17].

Crossing speed has direct operational implications. Half of the directed crossings occurred within about two days of the first detection and four out of five within a week. This leaves little time for the formal diplomatic channels through which cross-border assistance is usually requested and argues for pre-agreed protocols that allow neighbouring fire services to share alerts automatically, communicate directly at the local level and act across the border during the first days of a fire [18,19]. Ignitions are also predictable in time: four out of five events with active fires started between July and October, and the July ignitions—early in the dry season—produced the largest and longest fires. Pre-season coordination, joint fire-danger monitoring and restrictions on agricultural burning during drought years should therefore be synchronised across borders.

These findings substantiate three concrete management actions. First, given the reciprocal nature of fire crossings, response obligations must also be reciprocal. Mutual-aid agreements should be established symmetrically, incorporating pre-authorized cross-border entry for personnel and equipment, shared command protocols, and cost-allocation frameworks independent of fire origin attribution. Second, pronounced fire seasonality facilitates preemptive interventions. Integrated Fire Management (IFM) encompasses prevention, prescribed and cultural burning, suppression, and restoration. Within recurrent border corridors, IFM can prioritize fuel-reduction measures, such as prescribed burns in fire-adapted grassland and savanna mosaics alongside firebreaks on historical crossing paths. Implementing these measures before July mitigates the early-season ignitions responsible for the most extensive events and enables the alignment of burning calendars and drought-year restrictions across jurisdictions. Third, although farmland accounted for 18.7% of ignitions, it represented only 1.5% of the total burned area, identifying agricultural burning as a primary target for prevention. Joint outreach initiatives, unified permitting systems, and binational technical assistance for rural producers can directly address the source of transboundary fires. Finally, the efficacy of these interventions requires empirical evaluation, as prescribed burning protocols in the Pantanal must be carefully calibrated to regional flood pulses, dynamic fuel loads, and distinct national regulatory frameworks.

### *4.3. What Burns and Where Fires Start*

Transboundary fires burned overwhelmingly natural vegetation—forests, wetlands and natural grasslands—confirming that their main impact falls on ecosystems of high conservation value, including the Pantanal wetlands and the Chiquitano and Chaco forests [3,4,20]. The country of ignition determined much of what burned: Bolivian ignitions mainly affected Chiquitano and Pantanal forests, Brazilian ignitions mainly natural grasslands, savannas and wetlands, and Paraguayan and Argentinian ignitions Chaco forests. A quarter of the area burned by fires with a known origin did so in the neighbouring country, and for Paraguayan ignitions almost half, showing that the ecological consequences of fire use extend well beyond the jurisdiction where the fire started. Although farmland made up only 1.5% of the burned area, it hosted almost one in five ignition points—a pattern consistent with agricultural and pasture burning that escapes into adjacent natural vegetation, widely reported as the dominant ignition source in the region [1,12,13]. The land-cover differences between countries also call for differentiated responses: integrated fire management and prescribed burning in fire-adapted Pantanal grasslands and Cerrado savannas [3], and strict prevention of fire entry into fire-sensitive Chiquitano and Chaco forests.

### *4.4. Joint-Attention Zones as a Basis for Binational Fire Management*

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Because transboundary fire is highly spatially concentrated, targeted interventions along a small fraction of the border can yield significant landscape-scale effects. The 36 Priority I–II segments, which make up 6% of the border length, held three quarters of the burned area and of the directed crossings near the border. The 18 joint-attention zones derived from them provide a spatially explicit agenda for binational action: the southern Pantanal tri-border complex (Z1, Z2, Z8, Z10 and Z11), which involves three countries and concentrates more than 1 Mha of burned area, is the clearest candidate for a trinational fire-management arrangement. Similarly, the San Matías and Chiquitano–Guaporé zones combine large areas with frequent crossings and could be addressed through Bolivia–Brazil agreements involving Mato Grosso; the Pilcomayo zones call for Argentina–Paraguay coordination in the Chaco; and the south-western Amazon tri-border zones (Z17 and Z18), although small in area, burn almost annually and could serve as pilot areas for community-level cooperation already promoted under the Leticia Pact [19].

To operationalize this agenda, potential collaborative interventions include shared early-warning systems based on active fires, binational brigades and mutual-aid agreements for initial fire suppression. Further strategies should encompass harmonized burning permits and calendars, coordinated fuel management and standardized monitoring of burned area using the MapBiomas Fire products across all involved countries. Furthermore, the JAI is deliberately simple and transparent; its equal weighting of recurrence, magnitude and crossings can be adapted by stakeholders to emphasise other criteria, such as the exposure of vulnerable communities or protected areas.

*The efficacy of these instruments relies fundamentally on structural articulation across multiple levels of government. National governments provide the legal basis by establishing cross-border mutual-aid agreements, harmonizing burning regulations, and allocating funding. Subnational authorities, such as the states of Mato Grosso and Mato Grosso do Sul in Brazil, license agricultural burning, run regional fire services and civil defense. Concurrently, local brigades, rural producers, Indigenous peoples, and traditional communities provide crucial first-response capabilities during the critical initial days of a fire. These local stakeholders possess traditional ecological knowledge of fuels and fire behavior that satellite data cannot supply. Therefore, joint training, shared communication channels, and the formal recognition and support of community brigades are essential to bridge these governance levels.4.5. Methodological Considerations and Limitations*

Several methodological choices and data limitations should be considered when interpreting these results. First, the definition of transboundary events depends on the 5-km strip, the 150-m contiguity tolerance and the 1-ha thresholds. The strip determines which scars are retrieved, but complete scars were retained, so large events extending far from the border are fully represented; the tolerance may merge separate fires burning close to each other in the same year, which is inherent to annual burned-area maps without dates. Event-delineation algorithms based on dated burned area or active fires could separate such fires [28–31]. Second, the national MapBiomas Fire products are produced by different teams and collections, and their accuracy and mapping of the border vicinity may differ; overlapping polygons were counted once and allocated proportionally, and small discrepancies can create or remove marginal transboundary events. The GAUL boundaries are generalised and do not always match national cartography, which may affect the allocation of area close to rivers that form the border. Third, Paraguay and Peru products were not available for 2025 (and Peru for 2012), so 2025 is incomplete for those borders.

Fourth, the active-fire record is incomplete: clouds, smoke, the timing of satellite overpasses and small or low-intensity fires lead to omissions [25,26], so 82 events had no detections and many of the 164 events classified as *no crossing detected* may have crossed between overpasses or without detectable active fires. The direction of a crossing is inferred from the first overpass and from detections ≥375 m from the border; with only two VIIRS overpasses a day, fires ignited close to the border may appear as simultaneous. The cross-validation with MODIS showed moderate agreement for the dynamic class ($\kappa = 0.43$) but high agreement for the country of origin among directed events (90%), suggesting that the origin of large, well-observed crossings is robust, whereas the separation between directed and non-crossing small events is uncertain. Spread rates derived from active fires are coarse and

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should be interpreted as relative indicators [28,32,33]. Fifth, the land cover was obtained from national LULC collections whose legends were harmonised into broad macroclasses; some codes could not be mapped (1.4% of the area as no data), and the year $t - 1$ may not represent land cover at the time of ignition in rapidly changing landscapes. Finally, the analysis identifies where fires start but not why; attributing ignitions to specific land uses or actors would require field information and complementary data. Despite these limitations, the combination of high-resolution burned area, active fires and land cover provides a consistent, reproducible and updatable basis for monitoring transboundary fires, and the event database and code are provided to facilitate its use by fire agencies and researchers.

## 5. Conclusions

Between 2012 and 2025, 360 fires crossed the borders of Argentina, Bolivia, Brazil, Paraguay and Peru, burning 9.23 Mha, mostly of natural vegetation. Transboundary fire was concentrated on the Bolivia–Brazil border and the Bolivia–Brazil–Paraguay tri-border, in a few drought years and in a few very large, long-lasting fires. Crossings were balanced between neighbouring countries and occurred within days of ignition, showing that transboundary fire is a shared and reciprocal hazard that requires rapid, pre-agreed cooperation rather than attribution of blame. Eighteen joint-attention zones, covering 6% of the border length but three quarters of the burned area near the border and of the observed crossings, provide a concrete geographic basis for binational and trinational fire-management agreements, with the southern Pantanal tri-border as the highest priority. Pre-season IFM, near-real-time binational alerts and coordination from national governments to local brigades and communities can turn this basis into action. The approach relies on open, regularly updated datasets and can be repeated every fire season to monitor transboundary fire and evaluate the effect of cooperation.

**Supplementary Materials:** The following supporting information can be downloaded at the website of this paper posted on Preprints.org. Dataset S1: joint-attention border segments (GeoPackage).

**Author Contributions:** Conceptualization, A.R.M., A.A.C.A. and V.L.S.A.; methodology, A.R.M., V.L.S.A. and W.V.d.S.; software, A.R.M.; validation, V.L.S.A. and W.V.d.S.; formal analysis, A.R.M.; investigation, A.R.M. and V.L.S.A.; data curation, A.R.M. and W.V.d.S.; writing—original draft preparation, A.R.M.; writing—review and editing, V.L.S.A., A.A.C.A. and W.V.d.S.; visualization, A.R.M.; supervision, A.A.C.A.; funding acquisition, A.A.C.A. and A.R.M. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| FIRMS | Fire Information for Resource Management System |

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| | |
|---|---|
| FRP | Fire radiative power |
| GAUL | Global Administrative Unit Layers |
| IQR | Interquartile range |
| JAI | Joint-attention index |
| kha | Thousand hectares |
| LULC | Land use and land cover |
| Mha | Million hectares |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NRT | Near real time |
| ROS | Rate of spread |
| VIIRS | Visible Infrared Imaging Radiometer Suite |
| ARG, BOL, BRA, COL, PER, PRY | Argentina, Bolivia, Brazil, Colombia, Peru, Paraguay |

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