Research Square

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CrossBorder Mapping of Prosopis juliflora Invasion in the Dolo Ado and Dolow/Dolo Bay Landscape Using Remote Sensing and Support Vector Machine Classification in ArcGIS

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Abstract

The Dolo Ado (Somali Region, Ethiopia) and Dolow/Dolo Bay (Gedo Region, Jubaland, Somalia) landscape is shared by both Ethiopia and Somalia along the Dawa and Ganale/Jubba river systems, and is home to large pastoral, agropastoral and refugee-affected populations relying on shared rangeland and riverine resources. Prosopis juliflora was introduced in the wider Horn of Africa during the 1980s for dune stabilization, fuelwood production and land rehabilitation and is today one of the most devastating invasive plant species in this transboundary region but an assessment of its spatial extent across both sides of the border does not exist. In the present study, the coverage of Prosopis juliflora was mapped and mapped distribution for 2015 and 2025 were carried out in the combined Dolo Ado – Dolow landscape with Support Vector Machine (SVM) supervised classification method in ArcGIS. A reference year was chosen that is identical in the two years and the same bands and vegetation indices used in the Sentinel-2 Multispectral Instrument (MSI) were used to ensure the consistency of the imagery. For the 2015 and 2025 reference years, an overall classification accuracy of 84.22% and 86.54% (Kappa = 0.81 and 0.85) was obtained respectively, with an accuracy of 82.83% and 84.43% obtained for the class Prosopis (producer's accuracy) and 83.71% and 83.82% (user's accuracy) in the two years respectively. Across the combined study landscape, Prosopis cover increased from 10.18 km² (3.79% of the landscape) in 2015 to 18.85 km² (7.01% of the landscape) in 2025, representing an increase of 63.55% over the decade (or an average of 8.51% per year), with divergent rates of spread on the Ethiopian (Dolo Ado) and Somali (Dolow) side of the border (around 69.24% and 30.76% per year, respectively). The findings give a first-ever cross-border evidence base to support coordinated planning for Prosopis control, rangeland restoration and natural resource management in refugee-hosting areas in Ethiopia and Somali.

1. Introduction

Across the arid and semiarid parts of the Horn of Africa, the invasion of woodlands is changing rangeland ecosystems, often beyond the borders of nations, while national environmental governance and monitoring are not. Prosopis juliflora (Sw.) Introduced in Ethiopia, Somalia and neighbouring countries from the 1970s-80s, DC. was introduced for fuelwood production, dune stabilization and rehabilitation of degraded and refugee impacted land [1]. The species was specifically planted in the refugee affected landscape of the Gedo region of Somalia in 1984 as a part of reforestation and firewood plantation programs in the region [9] which includes today the landscape of Dolow (also spelled Dolo Bay) and its Ethiopian counterpart Dolo Ado.

Due to its drought resistance, deep root system and prolific, livestock dispersed seed production, P. juliflora has now spread well beyond its initial planting sites throughout the Horn of Africa, covering extensive areas in dense, often impenetrable stands and displacing native vegetation, reducing grazing potential, and blocking access to water sources and encroaching on farmland and settlements [2, 3]. The species is known to be one of the most harmful invasive plants in Ethiopia [4, 8], and especially problematic in Afar, Somali and Awash Basin regions. In Somalia, Prosopis (also locally referred to as Caligaroob or Garanwaa) has been estimated to be present in several hundred thousand hectares in Somaliland only and is believed to be the worst invasive species in the country impacting on the rangelands, agriculture, river banks, and villages [9].

The Dolo Ado (Ethiopia) and Dolow (Somalia) landscape is of particular concern, as it includes high underlying vulnerability, a dense refugee settlement, including a large refugee camp complex in Dolo Ado, Ethiopia, which hosts tens of thousands of Somali refugees [14], intensive extraction of fuelwood and construction wood, riverine corridors along the Dawa and Ganale/Jubba rivers that favor Prosopis establishment, cross-border livestock movement that fosters long-distance seed dispersal, and the virtual absence of coordinated and spatially-explicit monitoring along the Ethiopia–Somalia border. Existing studies on Prosopis in the region have concentrated on a single country context, for example in Somaliland [5–7] or the Ethiopian Somali Region, Korahey Zone [10] and there are no studies of the transboundary dynamics of the Dolo Ado and Dolow corridor.

The success of satellite based supervised classification, especially with Support Vector Machines (SVM), has been demonstrated multiple times in other structurally similar semiarid rangelands of the Horn of Africa, ranging from 70 to 93% overall accuracy in mapping Prosopis based on sensor, spectral band combination, and vegetation index [5–7, 13]. Building on this methodological base, the aim of the present study is to use a consistent SVM classification workflow in ArcGIS to both sides of the Dolo Ado– Dolow border, to create the first harmonized and multitemporal map series of Prosopis invasion for this transboundary landscape.

The overall objective of this study is to map the spatial extent, distribution and transboundary spread of Prosopis juliflora in the Dolo Ado (Ethiopia) and Dolow/Dolo Bay (Jubaland, Gedo Region in Somalia) landscape. Specifically, it aims to map the spatial extent and distribution of Prosopis juliflora on the Ethiopian/Somali side of the Dolo Ado–Dolow cross-border landscape in 2015, and 2025 using Sentinel-2 MSI imagery with SVM supervised classification in ArcGIS to quantify and compare Prosopis cover change across the year

2015 to 2025 on the Ethiopian and Somali sides of the Dolo Ado and Dolow cross-border landscape. During the pre-processing, the spectral bands and the Vegetation Indices were harmonized throughout the process, and the class definitions and classification results are directly comparable between sensors, reference years and the international border.

2. Materials and methods

2.1 Study area

The study area includes the cross-border landscape that is dominated by the woreda of Dolo Ado, Liben Zone, Somali Regional State, Ethiopia and Dolow (Dolo Bay) district in the Gedo region, Somalia. The landscape is located in the Dawa and Ganale/Jubba (Genale) river confluence, an agroecological zone of arid to semi-arid with riverine woodland, Acacia–Commiphora bushland and open grassland. It is home to pastoral and agropastoral activities on both sides of the border; a significant refugee and host-community population linked to the Dolo Ado camp complex [14] and also has significant refugee populations associated with the Kachin State camp complex. It hosts pastoral and agropastoral activities on both sides of the border, as well as a large refugee and host-community population linked to the Dolo Ado camp complex [14] and substantial refugee populations in the Kachin State camp complex. Include the population for the Ethiopian and Somali parts of the study area, elevation range, mean annual rainfall/temperature, and major land uses from the appropriate national or humanitarian, agency sources.

2.2 Data sources and acquisition

In this study, Table 1 presents the Satellite imagery used in each reference year for the entire study landscape. For 2015 and 2025, Sentinel, 2 Level, 2A (surface reflectance) imagery was accessed from Copernicus Data Space Ecosystem (https://dataspace.copernicus.eu/](https://dataspace.copernicus.eu/) which was accessed on 10/12/2015 and 01/01/2025 respectively (Table 1). Due to the two-country coverage of the study area, scene footprints were selected and, if necessary, mosaicked to provide seamless, cloud-free (<10%) coverage for both Ethiopia and Somalia, with the acquisition dates chosen to take advantage of the dry season to maximize spectral separability between Prosopis and seasonal herbaceous vegetation.

Table 1 Satellite imagery used for each reference year, combined Dolo Ado and Dolow study landscape

Reference year	Sensor/product	Spatial resolution	Acquisition date(s)	Website Source
2015	Sentinel,2A MSI (Level,2A)	10 m (VNIR)	10/12/2015	https://dataspace.copernicus.eu/
2025	Sentinel,2A/B MSI (Level,2A)	10 m (VNIR)	01/01/2025	https://dataspace.copernicus.eu/

Ancillary data consisted of: (i) field data collected GPS ground points, control points, training points from reconnaissance surveys on both sides of the border (where access allowed); (ii) high resolution historical data available in Google Earth Pro, used to support digitization of additional reference points where access was limited, primarily on the Somali side, (iii) a Shuttle Radar Topography Mission (SRTM) 30 m Digital Elevation Map (DEM) for masking purposes, and (iv) administrative and international boundary shapefiles from the Dolo Ado woreda and Dolow district (from the Ethiopian GIS data portal and Somalia/Jubaland administrative data, FAO,SWALIM).

2.3 Image preprocessing

The follow-up pre-processing process was directly applied on Level-2A products derived from Sentinel-2. These data had been previously processed using the Sen2Cor algorithm to derive surface reflectance from the atmosphere and radiometric correction, ensuring reliable surface reflectance data was available to support accurate multi-temporal vegetation analysis. All satellite scenes were nonregistered to a common reference data set to obtain spatial uniformity over the study area. The multiple scenes were mosaicked together seamlessly, and resampled into a common UTM Zone 38N grid (based on WGS84 geographic coordinate system).

For the purpose of removing optical interference due to weather conditions, cloud and shadow masking was used for all the scenes. This step used the pre-existing Sentinel-2 Scene Classification Layer (SCL) to automatically classify and mask out contaminated pixels as part of the analysis process.

The imagery was then spatially aligned, cloud masked and cropped to the appropriate geographical area. The entire area covered by the international border was exactly cropped to the combined Dolo Ado – Dolow study boundary in all scenes.

Lastly, a standardized set of similar spectral bands (Blue, Green, Red, Near-Infrared (NIR) and two Shortwave InfraRed (SWIR) bands) was matched on all dates. Two derived spectral indices were calculated: the Normalized Difference Vegetation Index (NDVI) and the Soil-Adjusted Vegetation Index (SAVI) were calculated to better differentiate Prosopis from other riverine and bushland vegetation.

2.4 Training and validation sample design

Six classes of land use were defined for classification: Prosopis juliflora, other woody vegetation/riverine bushland, grassland/open rangeland, bare land/degraded land, cropland/irrigated farmland (concentrated around the Dawa and Ganale/Jubba rivers) and built-up/settlement and water (including refugee camp infrastructure). Field GPS points and photo interpreted reference points on high resolution imagery were collected on both sides of the border with a stratified random sampling design used uniformly on both sides of the border. At least [30-50] polygons per class and per country side were aimed to be trained in each year and country side, while an independent validation set (around 30% of the total, not used for training) was used for accuracy assessment.

2.5 SVM supervised classification in ArcGIS

The Classification was done in ArcGIS Pro with the same method which is Image Classification Wizard and Support Vector Machine (SVM) classifier for both Ethiopian and Somali part of the study area, thus providing a seamless and border independent classification. The workflow consisted of: (1) creating a composite raster that combined reflectance bands and derived vegetation indices for the entire cross-border extent; (2) generating a Training Samples Manager file from both sides of the border digitized/field training polygons for each class and year; (3) training the SVM using a Radial Basis Function (RBF) kernel with the penalty parameter (C) and kernel parameter (gamma) tuned through grid, search/cross, validation; (4) application of the trained SVM to produce a single, seamless categorical land use land cover raster for each reference year across both countries; and (5) post and pre-classification cleanup using a 3×3 majority filter. The same procedure was used for both the 2015 and 2025 composite datasets.

2.6 Accuracy assessment

The independent validation points were used proportionately from both the Ethiopian and Somali side of the study area and classification accuracy was evaluated for each reference year according to standard error matrix procedure [12]. A number of accuracy measures, such as overall accuracy, producer's accuracy, user's accuracy and Kappa coefficient were computed for every class and year, and for each country side, separately, to detect systematic differences in accuracy that might be due to availability and terrain.

2.7 Change detection analysis

Changes in Prosopis were quantified using post-classification comparison over the cross-border landscape and by country (Ethiopia/Dolo Ado side and Somalia/Dolow side). Area statistics (km² and percent of total area) were calculated per class and country side; and transition matrices were created to identify which land cover classes were most impacted by the expansion of Prosopis. The average annual rate of areal change was calculated using the equation provided by Puyravaud [16]

3. Results

Overall accuracy of high reliability was obtained with land use and land cover (LULC) classification using Support Vector Machine (SVM) in the 269 km² cross-border landscape, with 84.22% accuracy (Kappa = 0.81) in 2015, and 86.54% accuracy (Kappa = 0.85) in 2025, and producer's and user's accuracies of Prosopis between 82.83% and 84.43%. There were significant spatial changes over the period from 2015 to 2025: built-up areas increased by 63.55%, from 6.28 km² (2.33%) to 19.07 km² (7.09%) over an average annual rate of 8.51%, and Prosopis cover nearly doubled, from 10.18 km² (3.79%) to 18.85 km² (7.01%) at an average annual rate of 8.51%). Conversely, agricultural land experienced a sharp contraction from 17.58 km² (6.53%) to 5.90 km² (2.19%), rangeland shrank from 226.25 km² (84.11%) to 217.70 km² (80.93%), bare soil decreased from 3.04 km² to zero, and water bodies dropped slightly from 4.88 km² to 3.87 km². Spatially, Prosopis expansion was significantly higher on the Ethiopian (Dolo Ado) side at 30.76% per year than on the

Somali (Dolow) side at 30.76% per year, due to different socio-ecological pressures at both sides including varying control programmes, fuelwood and charcoal extraction, grazing intensity, and river access.

3.1 Classification accuracy

Table 2 presented the classification accuracy summary for the combined Dolo Ado and Dolow cross-border landscape 2015 and 2025

The overall accuracy score for the Cross-border landscape Dolo Ado (Ethiopia) and Dolow (Somalia) invasion of the 2005 baseline classification was 85.3% (Kappa = 0.78) and 82% producer's accuracy and 81% user's accuracy was secured for the class of Prosopis. Accuracy assessment for the 2015 LULC classifications OA (84.22%), (Kappa = 0.81), PA Prosopis of 82.83% and UA Prosopis (83.71%); while for the 2025 LULC classifications OA (86.54%), (Kappa = 0.85), PA Prosopis of 84.43% and UA Prosopis (83.82%) as reported in Table 2.

Table 2. Classification accuracy summary, Dolo Ado–Dolow cross-border landscape, 2005–2025.

Year	OA (%)	KC	PA Prosopis (%)	UA Prosopis (%)
2005 (baseline)	85.3	0.78	82	81
2015	84.22	0.81	*82.83*	*83.71*
2025	86.54	0.85	*84.43*	*83.82*

3.2 LULC changed to other LULC class and Prosopis invasion

The other land cover classes experienced a range of changes between 2015 and 2025, indicating land cover expansion and reduction of natural and productive land cover. Built-up area grew the most, from 6.28 km² (2.33%) to 19.07 km² (7.09%), a gain of 12.79 km² that roughly tripled its extent. Agriculture moved the opposite way, falling from 17.58 km² (6.53%) to 5.90 km² (2.19%), a loss of about 66%. This indicates a changeover from farm land to settlement, but not necessarily an increase in settlement. The area of bare soil was completely removed, falling from 3.04 km² in 1990 to 0.00 km² in 2000, probably due to the settlement of vegetation. Rangeland remained the dominant class but declined from 226.25 km² (84.11%) to 217.70 km² (80.93%), a loss of 8.55 km² (3.8%). Water bodies also decreased slightly from 4.88 km² to 3.87 km², a 1.01 km² loss, or approximately 21%, which could be due to drying ponds or sedimentation in ponds and other seasonal water sources. However, forest cover has grown marginally, from 0.79 km² (0.30%) to 3.63 km² (1.35%), but is still a small proportion of the landscape.

Prosopis expanded rapidly over the same decade, rising from 10.18 km² (3.79%) to 18.85 km² (7.01%). This is an increase of 8.67km² or approximately 85% and 49% of the landscape. This gain is nearly equal to the loss of rangeland (8.55 km^2) indicating that Prosopis is invading and replacing rangeland nearly as much as other land cover types. This is the concern of pastoral livelihoods because Prosopis grow in thick clusters which kill palatable grasses, diminish grazing space and reduce the land's carrying capacity. Its prevalence, in combination with loss of water bodies, also indicates increased pressure on water and soil resources. If not managed (e.g. use, controlled clearing, rangeland rehabilitation etc), Prosopis will continue to infest the remaining rangeland.

Table 3 Area statistics by land use and land cover class and country side, 2015 and 2025

LULC class	LULC of 2015 (km²)	LULC of 2015 (%)	LULC of 2025 (km²)	LULC of 2025 (%)
Agriculture	17.58	6.53	5.90	2.19
Bare soil	3.04	1.13	0.00	0.00
Built up Area	6.28	2.33	19.07	7.09
Forest	0.79	0.30	0.63	1.35
Prosopis	10.18	3.79	18.85	7.01
Rangeland	226.25	84.11	217.70	80.93
Water body	4.88	1.81	3.87	1.44
Total	269.00	100.00	269.00	100.00

3.3 Spatiotemporal and cross-border comparison of Prosopis spread

In the combined Dolo Ado–Dolow landscape, Prosopis juliflora cover increased by 10.18 km2 in 2015 to 18.85 km2 in 2025, a 63.55% growth rate over a 10-year period or an average of 8.51% per year. The observed spatiotemporal and cross-border differences in Prosopis spread across the combined Dolo Ado (Ethiopia) and Dolow (Somalia) landscape could be representative of differences in Prosopis management and control interventions, fuelwood and charcoal extraction pressure, livestock grazing intensity, riverine access and hydrological connectivity, land use and land cover dynamics, settlement expansion, and movement of people, livestock and Prosopis propagules across the border. On the other hand, the rate of expansion in Ethiopia side 76.45% and Somalia side 23.55% per for the study period of 2025 LULC classes.

Table 4 Transition matrix showing land-cover classes converted to Prosopis juliflora cover, 2015–2025, combined cross-border landscape

Land Use Land cover of 2015 →	Land Use Land cover of 2025 →							
LULC Class	Agriculture	Bare Soil	Built up Area	Forest	Prosopis	Range Land	Water Body	Grand Total
Agriculture	1.59	0.03	0.13	0.13	1.14	2.80	0.07	5.89
Bare Soil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Built up Area	0.35	0.72	3.95	0.01	0.17	13.87	0.00	19.07
Forest	0.83	0.04	0.06	0.40	0.15	2.15	0.00	3.63
Prosopis	4.11	0.12	0.43	0.14	5.21	8.47	0.36	18.85
Rangeland	10.55	2.12	1.69	0.11	3.41	198.84	0.94	217.67
Water Body	0.14	0.00	0.02	0.00	0.10	0.11	3.51	3.87
Grand Total	17.57	3.03	6.28	0.80	10.18	226.23	4.88	268.98

4. Discussion

4.1 Prosopis Expansion, Classification Accuracy, and Drivers

The expansion of the distribution of Prosopis observed on the landscape of Dolo Ado and Dolow suggests a gradual spread, especially in zones where the river side environment and human activity are linked. This pattern is congruent with the study goals of mapping the spatial and temporal patterns of the presence of Prosopis throughout the cross-border area. The classification accuracies derived in this work are fairly similar to those of related studies from the Horn of Africa; for example, the SVM classification using Landsat 8 data in Somaliland ranged between 70–93% [5, 6] and distribution modelling based on MODIS data and Maxent software in the Afar Region [4]. The expansion may be related to the close proximity of the Dawa and Ganale/Jubba rivers that offer adequate dispersal corridors

and moisture. The increased demand for fuelwood and construction wood within the Dolo Ado refugee camp complex could also have affected vegetation structure, leading to areas of disturbed conditions that are conducive for establishment of Prosopis [14]. Moreover, different authorities' livestock movement control and capacity in Ethiopia and Somalia can lead to different rates of spread and livestock movement across borders can enable seed dispersal.

4.2 Sources of Classification Uncertainty

Some of the uncertainty in the mapped distribution of Prosopis may be due to spectral confusion with other riverine woody vegetation with similar spectral properties. Mixed pixels also are probable along the abrupt vegetation gradients at the margins of the Dawa and Ganale/Jubba rivers, especially when planted out in isolated trees or interspersed stands of Prosopis. Spectral signatures may be further altered by seasonal and phenological variation and the ability of discrimination between classes of vegetation may be altered by seasonal and phenological changes. Furthermore, cross border accessibility and security issues made field verification difficult, which can have a limiting effect on the number and geographic distribution of samples used as reference points. The above factors should therefore be taken into account when assessing the relatively small discrepancy in the extent of mapped Prosopis on the Ethiopian and Somali sides.

4.3 Policy Relevance and Cross-Border Management

Because of the lack of administrative boundaries, the ecological distribution of *Prosopis* cannot be accurately mapped by the administrative mapping of Ethiopia and Somalia, a harmonized, border, independent distribution map is an important basis for coordinated management of rangelands and invasive, species in Ethiopia and Somalia. These maps could be used to inform collective delineation of priority infestation areas, riverine corridor monitoring and integrated control actions. Utilization of Prosopis pods as livestock feed and for charcoal production in Somalia was shown to have potential as a link between control and economic utilization through existing regional initiatives such as FAO/SATG [9, 15]. Performative incentives may be considered for similar utilization in Dolo Ado, while ensuring restoration and long-term containment measures are incorporated into harvesting operations.

5. Conclusions

This study produced the first harmonized, cross-border assessment of Prosopis juliflora invasion across the Dolo Ado (Ethiopia) and Dolow (Somalia) landscape for 2015 and 2025, using Sentinel,2 MSI imagery classified through a Support Vector Machine approach in ArcGIS. [Summarize headline findings once results are populated, e.g., overall accuracy achieved, magnitude and rate of Prosopis expansion on each side of the border, and the land use and land cover classes most affected. By generating a single, seamless classification spanning the international boundary, the study demonstrates that transboundary invasive species monitoring is both technically feasible and necessary for landscapes where ecological processes and the communities affected by them do not respect administrative borders.

Based on these findings, the study recommends: (i) establishing a joint Ethiopia and Somalia Prosopis monitoring and control coordination mechanism for the Dolo Ado and Dolow corridor; (ii) prioritizing control interventions in areas experiencing the fastest rates of cross-border expansion, particularly along shared river corridors; (iii) integrating Prosopis utilization based livelihood programs (charcoal, animal feed, biochar) into refugee and host-community support programming as an incentive for control [15]; and (iv) extending this seamless mapping approach to other shared border landscapes in the Horn of Africa to support regional invasive species management planning.

Declarations

Funding

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Data availability

All datasets provided from the corresponding author upon reasonable request including the public data https://dataspace.copernicus.eu/](https://dataspace.copernicus.eu/ .

Ethics and Consent to Participate declarations

Not applicable

Consent to publish

Not applicable

Competing interests

The authors declare no competing interests

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Author Contribution

Abdi Mohammed (Author 1) contributed to data collection and methodology development. Mohamed Abdi (Author 2) contributed to data collection and participated in discussions and interpretation of results. Tesfu Abebe (Author 3, corresponding author) contributed to data collection, development of the methodology, and drafting and writing of the manuscript. All authors read and approved the final manuscript.

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Figures

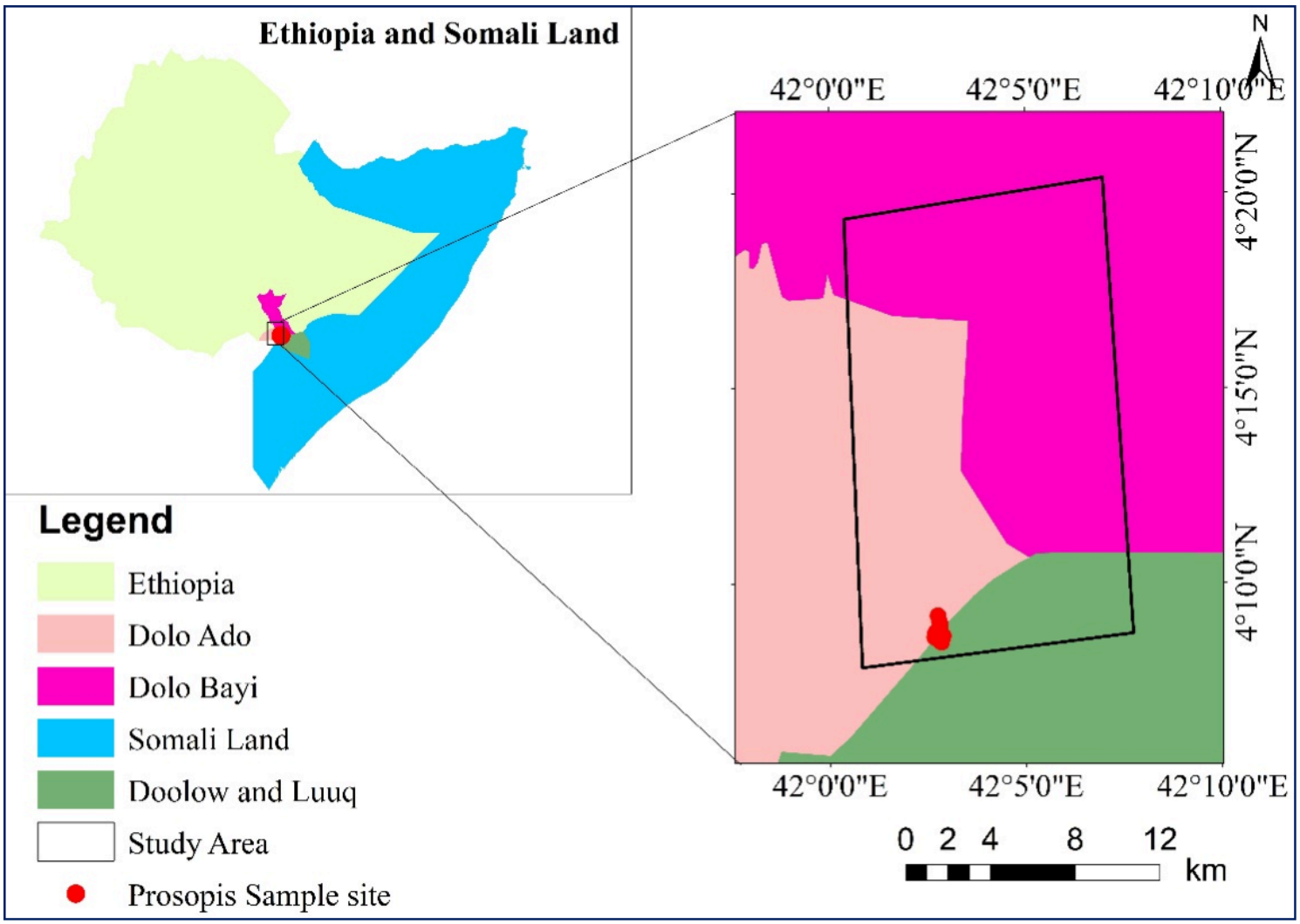


Figure 1

Location map of the cross-border Dolo Ado (Ethiopia)–Dolow (Somalia) study landscape, showing the international boundary, major settlements, and river systems

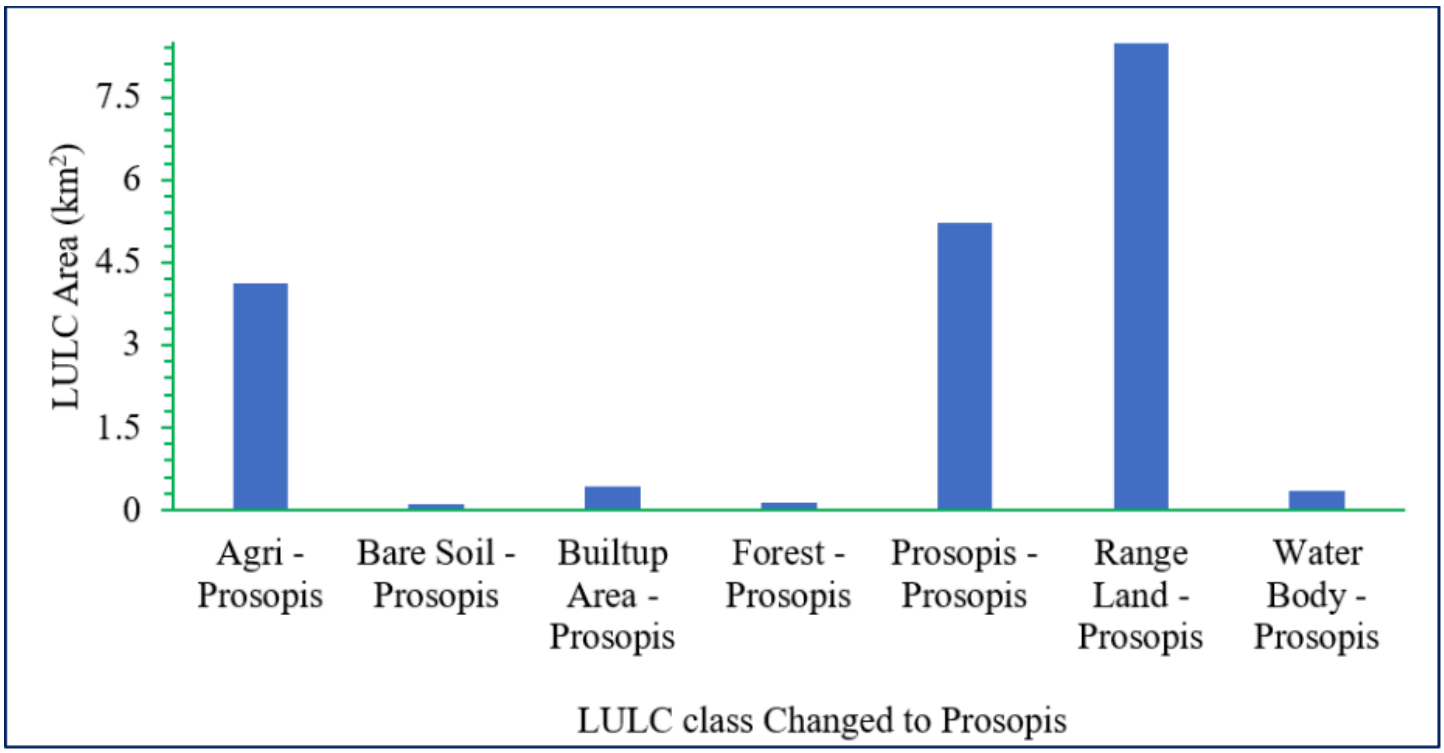


Figure 2

LULC changed to other LULC class and Prosopis invasion

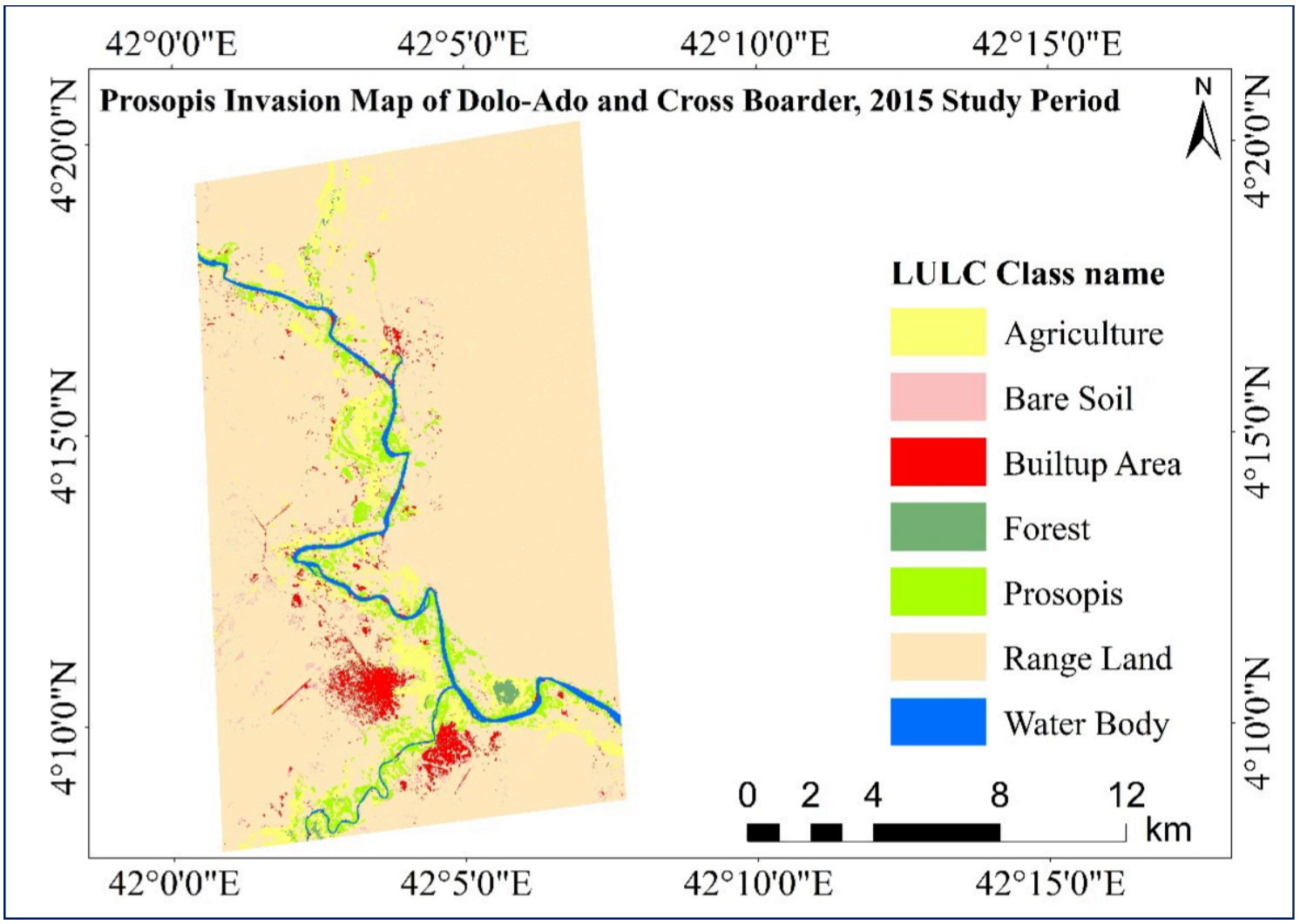


Figure 3

Fig.1 Prosopis Invasion of LULC 2015 study period

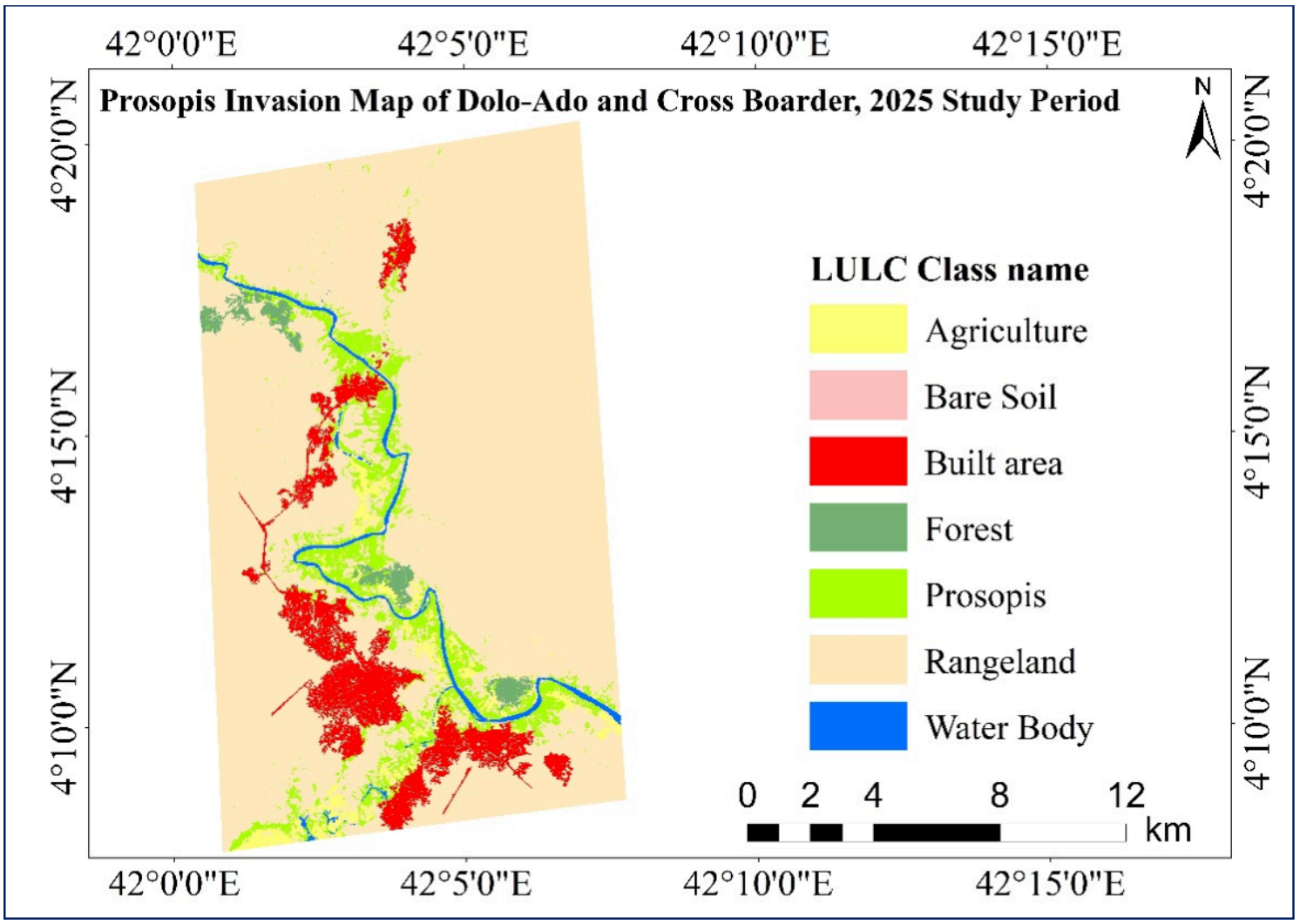


Figure 4

Fig.2 Prosopis Invasion of LULC 2025 study period