MAG saves lives builds futures

IMPACT Shaping practices Influencing policies Impacting lives

REACH | PANDA | AGORA

Advancing the understanding of the relationship between Mine Action, Land Use Change, Environment and Climate

Report Annexes

May 2025

Foreign, Commonwealth & Development Office

IMPACT Shaping practices Influencing policies Impacting lives
REACH PANDA AGORA

About IMPACT Initiatives

Created in 2010, IMPACT Initiatives is a Geneva-based NGO and the largest independent data provider in contexts of crisis. It aims to promote evidence-based decisions, shape practices and influence policies in humanitarian and development settings, to positively impact the lives of communities.

IMPACT Initiatives has an established field presence in over 30 countries and is composed of more than 400 staff. Through our team of assessment, data, geospatial, and thematic specialists, we implement people-centred research and set standards for collecting and analysing rigorous, high-quality data in complex environments.

IMPACT Initiatives takes an initiative-based approach to structuring its programming, with REACH, AGORA and PANDA, in direct partnership with aid actors

MAG saves lives builds futures

About MAG

MAG is a humanitarian, development and peacebuilding organisation that limits the causes and addresses the consequences — both immediate and long-term — of conflict and armed violence.

Our work saves lives, eases suffering, protects human rights and contributes to sustainable peace for the hundreds of millions of people affected. It fosters stable and secure societies and is a key enabler of progress towards the 2030 Sustainable Development Agenda.

We find, remove and destroy landmines, cluster munitions and unexploded bombs from places affected by conflict. We also provide risk education programmes, so people can live, work and play as safely as possible until the land is cleared.

We also help to reduce armed violence by educating communities about the risks of small arms and light weapons, and by assisting in the destroying, marking and safe storage of weapons and ammunition.

MAG uses its expertise, experience and influence to bring about policy changes that benefit communities affected by conflict and armed violence.

Since 1989, we have helped over 20 million people in 70 countries rebuild their lives after war. In 1997, MAG shared the Nobel Peace Prize for its role in banning landmines.

Foreign, Commonwealth & Development Office

Funded by FCDO

Contents

Annex 1. Remote sensing methodology

Methodology on land use analysis

IMPACT conducted a geospatial analysis to assess land use changes in a sample of MAG task sites in Cambodia, specifically in Battambang and Pailin (west, land-mine affected) and Ratanakiri (east, UXO-affected) provinces, released between 2014 and 2023, along with selected control plots. This analysis aimed to understand the trends in land cover change and the environmental impacts of Humanitarian Mine Action (HMA) activities.

The analysis utilized the 30-meter resolution SERVIR Landsat satellite-driven landcover dataset, which offers several advantages:

- The dataset provides consistent annual data, ensuring reliable temporal analysis;

- It accurately reflects regional land cover types;

- The dataset is open access and easy to process, facilitating efficient analysis.

Land use changes were measured at four distinct time intervals:

- 2003 (Baseline year): initial land cover conditions;

- One year prior to HMA task commencement: pre-clearance land use;

- One year post HMA task completion: immediate post-clearance impacts;

- Recent data (2023): long-term changes and current land use.

The analysis was conducted across 2259 different land polygon types and regions: 931 C1 (cancelled task sites), 834 C3 (cleared task sites), and 454 control sites. Control sites were randomly generated land parcels within community areas, which have not been considered as contaminated. The number of task sites and areas per year is shown in Table 1.

The processing began with acquiring annual SERVIR classified imagery for the target region. The next step involved comparing annual classified images to identify land parcels with changed and unchanged land use types for the period of 2003, and the yearly datasets between 2013 to 2023. This processing included converting landcover rasters to polygons and applying the standard ArcGIS Pro intersect function to detect changes. To summarize land cover changes by polygon type and region, the R code was employed to generate Sankey diagrams. These diagrams visually represented transitions between different land cover types over specified time intervals, offering a clear and intuitive understanding of the trends.

Table 1: The number of task sites and areas per land release year

Year	West C1		West C3		West Control		East C1		East C3		East Control	
	number of sites	area (ha)	number of sites	area (ha)	number of sites	area (ha)	number of sites	area (ha)	number of sites	area (ha)	number of sites	area (ha)
2014	44	54,5	48	151,2								
2015	268	822,8	24	37,3								
2016	79	161,4	21	23,3			1	1,8	2	147,1		
2017	62	188,9	20	61,9					14	346,8		
2018	129	535,4	63	43,2					24	194,9		
2019	121	394,1	100	146,7	212	1403,4			20	286,3	242	1559,1
2020	113	350,9	106	227,3					24	278,7		
2021	55	566,8	56	235,6			8	61,2	59	450,7		
2022	59	174,8	68	280,9			5	12,6	57	662,1		
2023	21	29,7	55	188,2			1	4,2	23	361,2		
Total	951	3279,5	561	1395,6			15	79,8	223	2727,9		

Limitations and challenges

- Heterogeneous task sites: the diversity of task sites required a parcel-based analysis approach;

- Resolution issues: the 30-meter resolution may not capture fine-scale changes within smaller task sites;

- Classification challenges: forest overestimation due to tree plantations being classified as forests;

- Comparative limitations: the total number of C1 polygons in the East province was considerably lower due to the nature of the contamination, making comparisons between task site types more complicated and less representative.

A Kappa accuracy assessment was conducted on the 2023 SERVIR land cover dataset using 500 randomly selected points, proportionally representing different land cover classes. The reference classes were identified through a combination of high-resolution images from Google Earth Online and data collected via mapping focus group discussions with community members.

Table 2 presents the confusion matrix, where diagonal values represent correctly classified points, and off-diagonal values indicate incorrectly classified points. The Kappa coefficient was calculated to be 0.79, demonstrating substantial agreement between the classified data and the reference data.

Table 2: Classification confusion matrix

Land cover class	Number of points	Cropland	Tree plantation	Deciduous forest	Evergreen forest	Grass	Rice	Rubber	Shrub
Cropland	200	173	3	3	0	3	6	0	10
Tree plantation	2	0	4	0	0	0	0	0	0
Deciduous forest	124	1	13	95	0	3	3	0	9
Evergreen forest	4	0	0	0	4	0	0	0	0
Grass	27	0	0	0	0	20	4	0	3
Rice	85	0	3	0	0	0	76	0	6
Rubber	2	0	0	0	0	0	0	2	0
Shrub	56	0	7	1	0	0	2	0	46

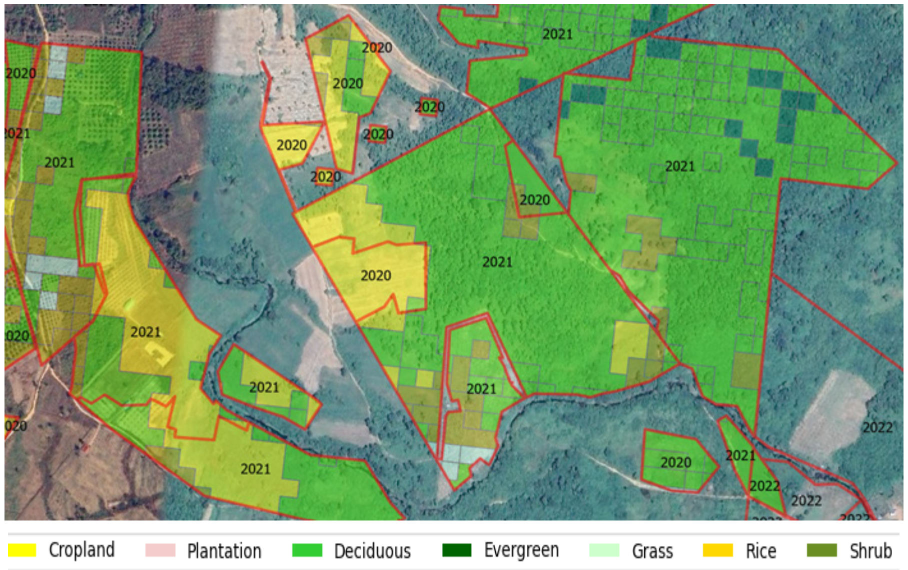


Figure 1: Land cover classification example

Methodology on the analysis of changes in land condition

To assess the environmental impacts of demining, this study will focus on key indicators such as vegetation condition, soil erosion, soil moisture, and carbon sequestration.

Vegetation health

Vegetation indexes were used to assess vegetation conditions, particularly using metrics such as Normalized Difference Vegetation Index (NDVI). Landsat 8 data, with a 30-meter resolution, was used to analyse cropland parcels that had remained in agricultural use for at least five years (2019–2023). NDVI values were averaged within the land parcels and during the rainy seasons (December to April) from 2013 to 2023 to assess long-term trends in vegetation conditions. Satellite images were processed using the GEE code.

Soil moisture

Soil moisture levels were monitored using remote sensing data, which can indicate changes in soil moisture using the Normalized Difference Water Index (NDWI) and Normalized Difference Moisture Index (NDMI) derived from Landsat observations.

Soil moisture was analysed using vegetation indexes such as the Normalized Difference Water Index (NDWI) and the Normalized Difference Moisture Index (NDMI). These indexes, derived from Landsat 8 observations for the period of 2013 to 2023 at 30-meter resolution, helped identify changes in soil moisture levels within cropland parcels that had remained unchanged for at least the last five years.

NDWI was calculated as:

$$NDWI = (Green - NIR) / (Green + NIR),$$

where Green and Near Infrared (NIR) bands were used to detect the presence of surface water and changes in soil moisture. NDWI is particularly useful for assessing flooding impacts, as it highlights areas with standing water or increased moisture content.

NDMI was computed as:

$$NDMI = (NIR - SWIR) / (NIR + SWIR),$$

where Shortwave Infrared (SWIR) was used alongside NIR to detect variations in soil moisture and vegetation water content.

Landsat 8, 30 m resolution, calculated for cropland parcels remaining cropland for at least the last 5 years (2019-2023). Similar to NDVI, vegetation index values were averaged within the land parcels and during the rainy seasons (December to April) from 2013 to 2023 to assess long-term trends in vegetation conditions. Satellite images were processed using the GEE code.

Vegetation loss and carbon sequestration

To analyse vegetation loss and its implications for carbon sequestration, tree canopy height was measured using GEDI L2A Raster Canopy Top Height (2019-2023), which contains aboveground biomass density (AGBD) measurements in megagrams per hectare (Mg/ha). The biomass was calculated using the standard model:

AGB = Canopy Height * 0.5 (Baccini et al., 2012; Saatchi et al., 2011)

where AGB represents aboveground biomass (Mg).

Carbon stock was then estimated using the formula established by the IPCC (2006):

C = AGB * 0.47

where C represents the carbon stock in megagrams (Mg), and 0.47 is the standard carbon fraction of biomass.

Finally, the stored carbon was converted into CO_2 equivalent to assess sequestration potential:

CO_2eq = C * 3.67 (Brown, 1997; FAO)

where CO_2eq represents the total CO_2 sequestration or loss in megagram.

Data extracted from Google Earth Engine (GEE code) was further processed in R to analyse biomass trends and summarize changes over time. Statistical processing included:

- Calculating biomass differences year by year;
- Identifying cumulative biomass loss and gain over the study period;
- Determining the year of highest biomass loss per polygon.

Carbon Sequestration analysis using Net Primary Production

Net Primary Productivity (NPP) is the amount of carbon that remains after accounting for plant respiration. It represents the net energy available for plant growth and biomass accumulation. This analysis utilized the Modis MOD17A3HGF V6.1 dataset with a 500-meter resolution from 2011 to 2023 to estimate NPP across different land use types.

The data processing algorithm followed a similar approach to the canopy height analysis. NPP values were extracted from MODIS data for each year and averaged within land parcel boundaries to assess spatial and temporal variations. The analysis included calculating yearly NPP differences to track vegetation recovery and productivity trends. The results were further processed in R to examine changes over time and compare patterns between different land cover types. This approach aims to improve understanding on how land clearance and subsequent land use decisions influence ecosystem productivity and carbon cycling.

Context analysis

A broader context analysis complemented these environmental assessments by examining population trends in settlements in target areas. Using gridded population data from World Pop was analysed, comparing: 2003, 2013 and 2020 (the most recent year available). This analysis provided insights into settlement patterns, helping to evaluate the socioeconomic dimensions of land transformation.

Limitations

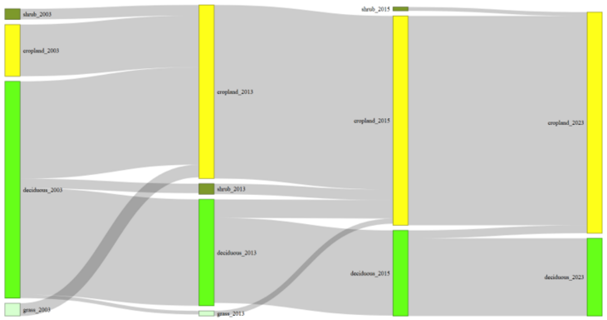
The analysis primarily depends on open-source satellite imagery with resolutions between 10 to 30 meters. This resolution may limit the detail of land cover classification within some task sites, particularly those as small as 25 x 25 meters. Moreover, the research is constrained by the lack of in-situ data collection, which makes it impossible to directly verify soil moisture and soil erosion mapping results derived from remote sensing.

Annex 2. Land cover change analysis

West provinces

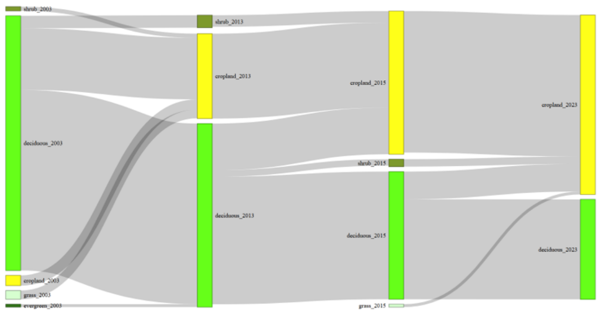
HMA tasks commenced in **2014**

C1 plots



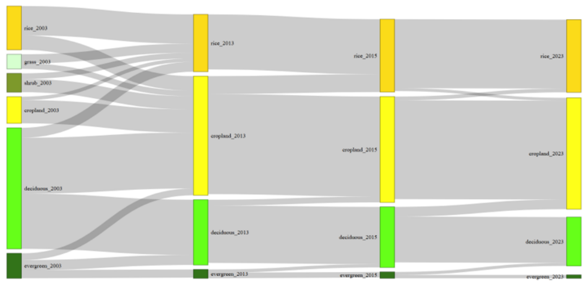
	2003	2013	2015	2023
cropland	9,4	31,2	37,6	40,1
deciduous	39,3	19,3	15,4	14,1
grass	2,3	0,6	0,0	0,0
shrub	1,9	1,7	0,0	0,0

C3 plots



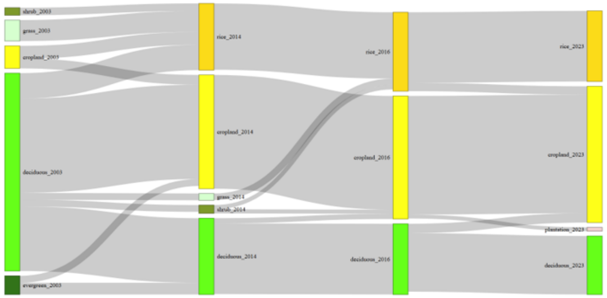
	2003	2013	2015	2023
cropland	5,4	44,8	75,8	95,1
deciduous	134,9	97,2	67,6	53,0
evergreen	1,5	0,0	0,0	0,0
grass	4,6	0,0	0,0	0,0
shrub	2,2	6,6	3,4	0,0

Control plots

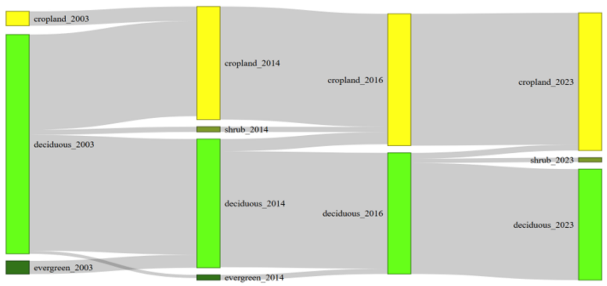


	2003	2013	2015	2023
cropland	149,1	665,6	591,8	622,6
deciduous	676,3	364,6	338,5	272,6
evergreen	139,4	45,6	31,2	18,8
grass	81,6	0,0	0,0	0,0
rice	244,3	320,0	407,0	406,1
shrub	105,0	0,0	0,0	0,0

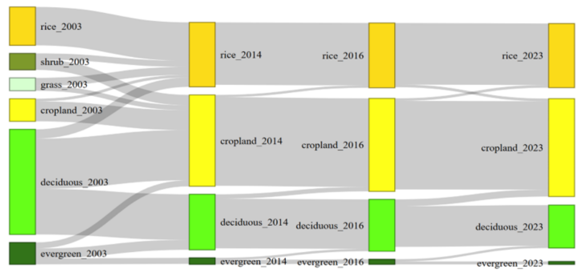
HMA tasks commenced in **2015**



	2003	2014	2016	2023
cropland	65,9	325,0	360,1	399,0
plantation	0,0	0,0	0,0	11,2
deciduous	579,1	223,4	207,0	171,3
evergreen	54,7	0,0	0,0	0,0
grass	61,5	19,9	0,0	0,0
rice	0,0	195,3	225,7	206,6
shrub	22,1	19,7	0,0	0,0



	2003	2014	2016	2023
cropland	2,1	16,0	19,0	20,0
deciduous	31,9	18,7	17,6	16,1
evergreen	1,9	0,5	0,0	0,0
shrub	0,0	0,8	0,0	0,6



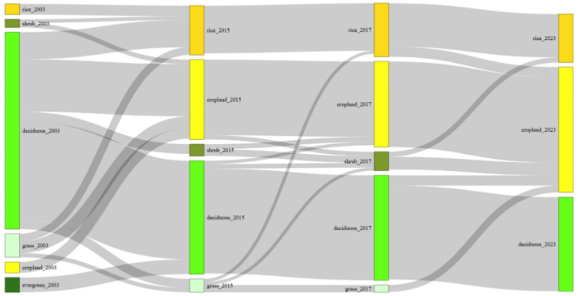
	2003	2014	2016	2023
cropland	143,5	580,9	591,4	622,5
deciduous	668,2	352,8	329,3	272,6
evergreen	139,1	38,0	27,2	18,4
grass	81,6	0,0	0,0	0,0
rice	244,1	409,8	411,8	407,7
shrub	104,9	0,0	0,0	0,0

Cropland | Plantation | Deciduous | Evergreen | Grass | Rice | Shrub | Rubber

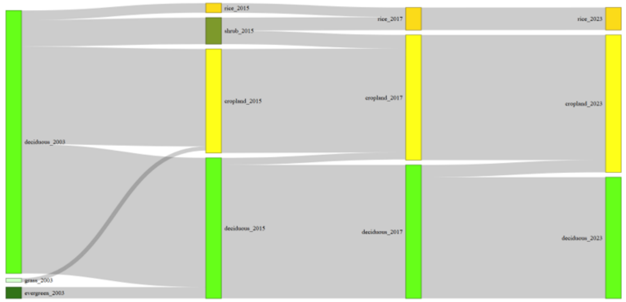
West provinces

C1 plots | C3 plots | Control plots

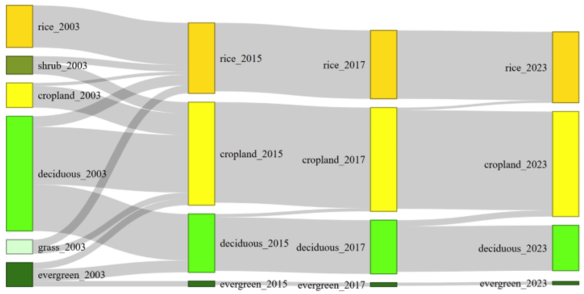
HMA tasks commenced in **2016**



	2003	2015	2017	2023
cropland	0,0	0,0	0,4	0,0
plantation	0,0	0,0	0,0	0,3
deciduous	1,5	1,6	1,4	0,2
evergreen	0,2	0,0	0,0	0,0
grass	0,0	0,0	0,0	0,4
rice	0,0	0,0	0,0	0,0
shrub	0,0	0,1	0,0	0,8

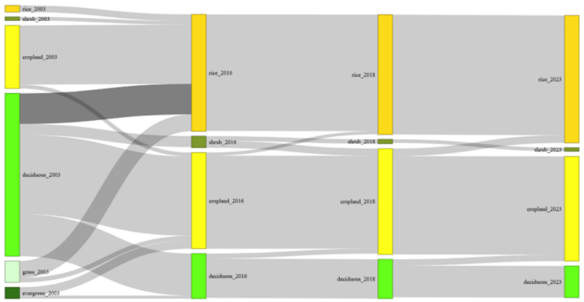


	2003	2015	2017	2023
cropland	0,0	8,4	10,3	11,3
deciduous	21,7	11,6	11,0	10,0
evergreen	0,9	0,0	0,0	0,0
grass	0,3	0,0	0,0	0,0
rice	0,0	0,8	1,9	1,9
shrub	0,0	2,2	0,0	0,0

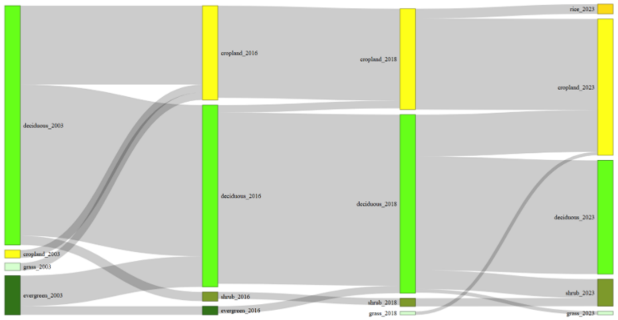


	2003	2015	2017	2023
cropland	142,6	597,2	602,0	608,8
deciduous	665,1	338,5	311,3	262,9
evergreen	138,8	31,7	22,7	18,5
grass	81,6	0,0	0,0	0,0
rice	244,1	409,0	396,8	411,2
shrub	104,3	0,0	0,0	0,0

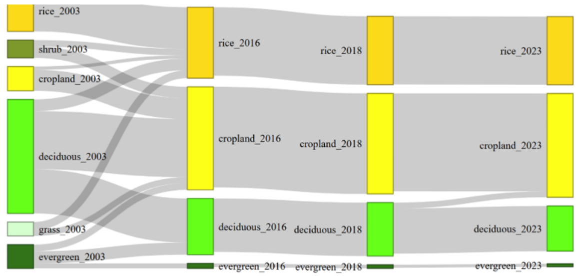
HMA tasks commenced in **2017**



cropland	43,7	66,5	72,7	72,4
deciduous	112,6	31,2	27,2	21,9
evergreen	7,9	0,0	0,0	0,0
grass	14,8	0,0	0,0	0,0
rice	4,6	80,9	82,7	88,1
shrub	2,5	7,5	3,1	2,5



	2003	2016	2018	2023
cropland	1,6	19,6	20,7	28,3
deciduous	49,7	37,8	37,1	23,6
evergreen	8,1	1,8	0,0	0,0
grass	1,6	0,0	0,0	0,7
rice	0,0	0,0	0,0	2,0
shrub	0,0	1,9	1,4	5,6



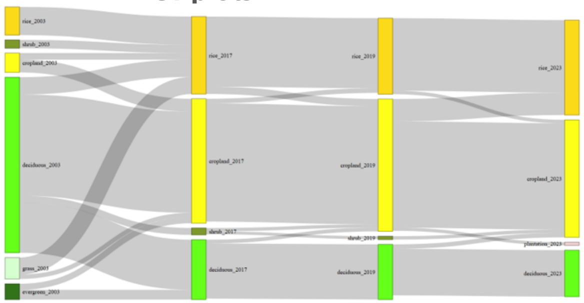
	2003	2016	2018	2023
cropland	141,8	603,4	589,3	608,7
deciduous	667,8	329,3	312,9	264,4
evergreen	138,8	29,2	21,3	17,6
grass	81,4	0,0	0,0	0,0
rice	243,3	415,4	400,9	399,3
shrub	104,1	0,0	0,0	0,0

Cropland | Plantation | Deciduous | Evergreen | Grass | Rice | Shrub | Rubber

West provinces

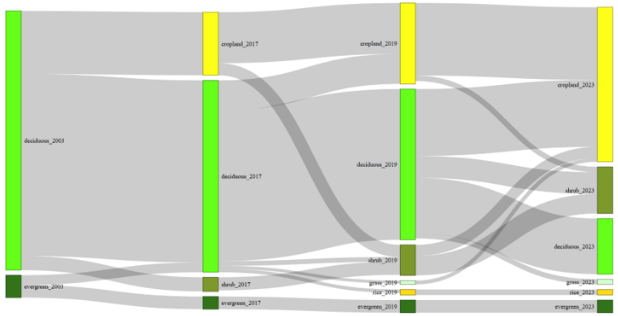
HMA tasks commenced in **2018**

C1 plots



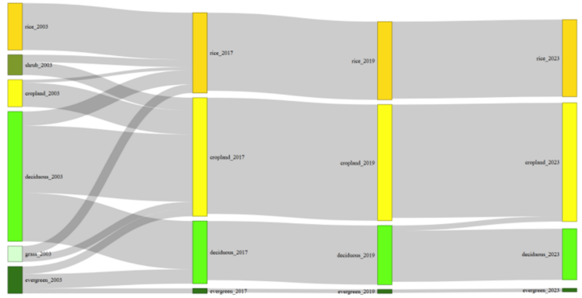
	2003	2017	2019	2023
cropland	38,0	244,7	260,5	231,1
plantation	0,0	0,0	0,0	6,2
deciduous	345,3	117,7	108,5	91,5
evergreen	30,9	0,0	0,0	0,0
grass	42,2	0,0	0,0	0,0
rice	55,4	152,2	147,0	186,6
shrub	16,4	13,4	5,7	0,0

C3 plots



	2003	2017	2019	2023
cropland	0,0	9,5	12,2	23,3
deciduous	39,0	28,9	22,7	8,4
evergreen	3,4	1,9	1,9	1,9
grass	0,0	0,0	0,4	0,8
rice	0,0	0,0	0,5	0,8
shrub	0,0	2,1	4,5	7,0

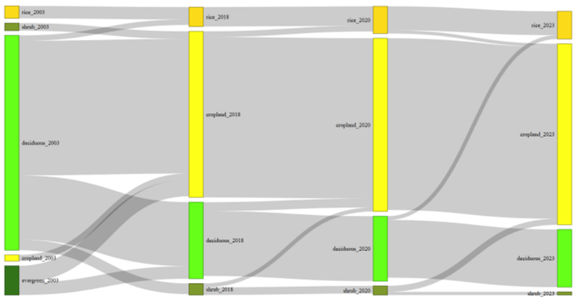
Control plots



	2003	2017	2019	2023
cropland	140,0	613,1	601,1	614,1
deciduous	671,1	324,1	306,1	264,3
evergreen	138,9	25,6	20,5	18,0
grass	81,4	0,0	0,0	0,0
rice	242,4	415,4	404,2	398,7
shrub	104,4	0,0	0,0	0,0

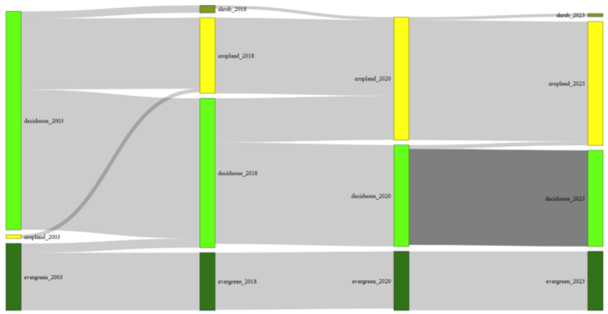
HMA tasks commenced in **2019**

C1 plots



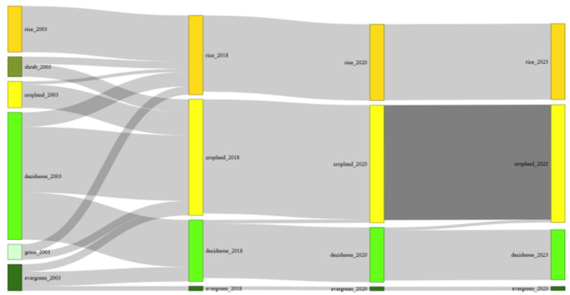
	2003	2018	2020	2023
cropland	8,7	234,4	246,1	257,2
deciduous	305,2	108,8	92,2	81,9
evergreen	41,5	0,0	0,0	0,0
rice	17,6	25,3	35,7	39,4
shrub	10,7	15,2	10,8	4,5

C3 plots



	2003	2018	2020	2023
cropland	1,9	37,6	61,7	62,2
deciduous	109,9	75,1	51,0	48,3
evergreen	33,6	29,0	28,7	29,6
shrub	0,0	3,7	0,0	1,5

Control plots



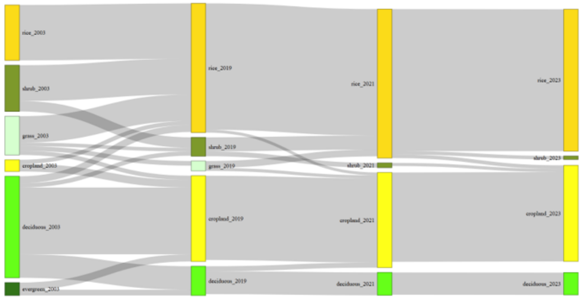
	2003	2018	2020	2023
cropland	139,2	611,8	620,5	621,5
deciduous	670,6	324,4	288,0	264,5
evergreen	138,8	23,8	19,2	20,7
grass	81,6	0,0	0,0	0,0
rice	242,8	417,7	401,8	400,4
shrub	104,8	0,0	0,0	0,0

Cropland | Plantation | Deciduous | Evergreen | Grass | Rice | Shrub | Rubber

West provinces

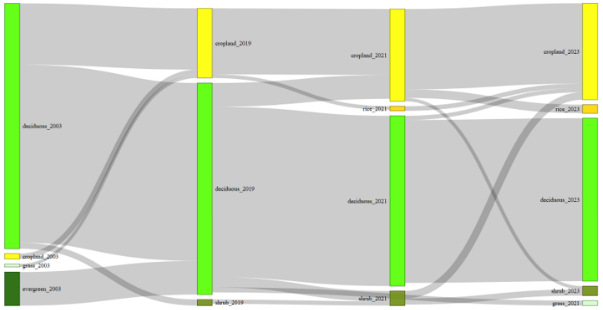
HMA tasks commenced in **2020**

C1 plots



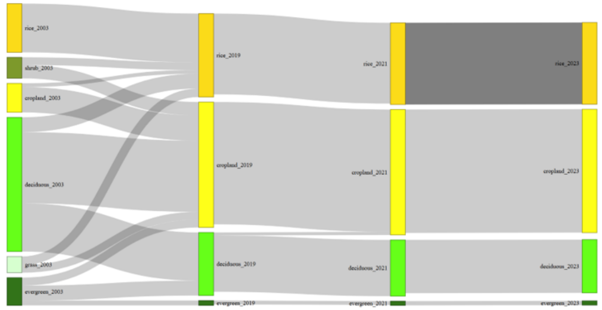
	2003	2019	2021	2023
cropland	14,8	108,8	120,7	121,8
deciduous	128,7	37,0	29,0	28,2
evergreen	16,3	0,0	0,0	0,0
grass	49,1	5,8	0,0	0,0
rice	70,2	163,0	186,8	180,0
shrub	58,6	23,2	6,1	4,4

C3 plots



	2003	2019	2021	2023
cropland	4,1	53,3	68,7	73,8
deciduous	187,7	161,9	130,2	124,7
evergreen	25,7	0,0	0,0	0,0
grass	2,3	0,0	3,8	0,0
rice	0,0	0,0	2,8	6,5
shrub	0,0	4,6	11,2	7,3

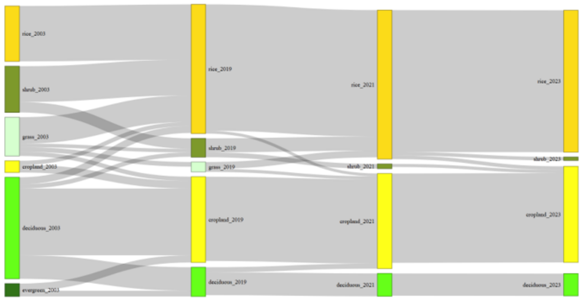
Control plots



	2003	2019	2021	2023
cropland	144,6	624,3	624,2	614,1
deciduous	667,7	313,9	279,8	264,8
evergreen	138,1	24,4	19,2	21,4
grass	80,6	0,0	0,0	0,0
rice	242,6	415,6	402,2	407,0
shrub	104,7	0,0	0,0	0,0

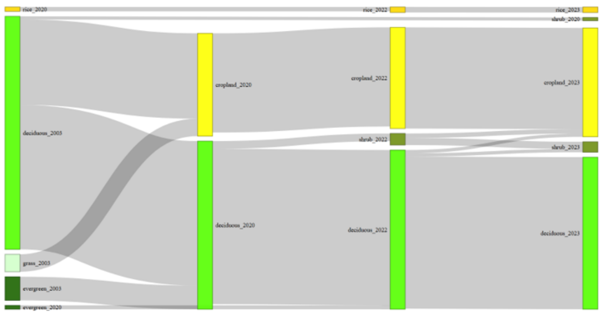
HMA tasks commenced in **2021**

C1 plots



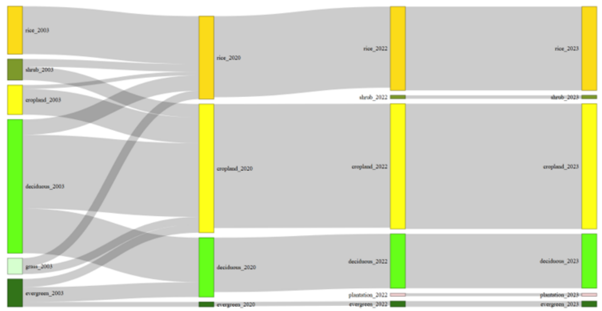
	2003	2019	2021	2023
cropland	14,8	108,8	120,7	121,8
deciduous	128,7	37,0	29,0	28,2
evergreen	16,3	0,0	0,0	0,0
grass	49,1	5,8	0,0	0,0
rice	70,2	163,0	186,8	180,0
shrub	58,6	23,2	6,1	4,4

C3 plots



	2003	2020	2022	2023
cropland	0,0	85,1	82,2	90,1
deciduous	193,0	139,3	131,9	126,0
evergreen	19,6	0,0	0,0	0,0
grass	14,4	0,0	0,0	0,0
rice	0,0	0,0	3,6	4,6
shrub	0,0	2,6	6,4	8,6

Control plots

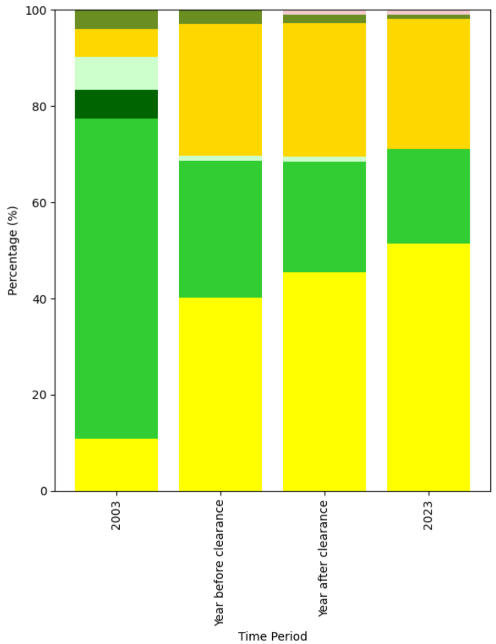


	2003	2020	2022	2023
cropland	146,3	638,6	615,6	621,6
plantation	0,0	0,0	0,0	14,4
deciduous	663,5	294,7	270,2	269,8
evergreen	137,4	23,7	21,5	27,8
grass	79,3	0,0	0,0	0,0
rice	237,5	411,6	402,5	415,8
shrub	104,4	0,0	0,0	16,9

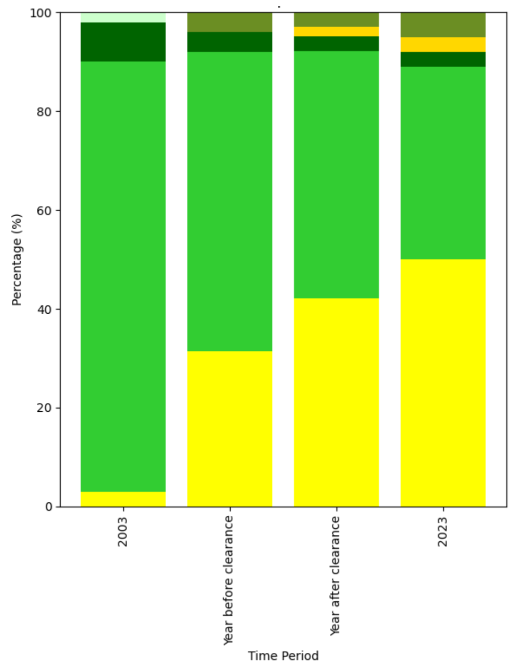
Cropland | Plantation | Deciduous | Evergreen | Grass | Rice | Shrub | Rubber

Figure 2: Overall West provinces land cover change trends (%)

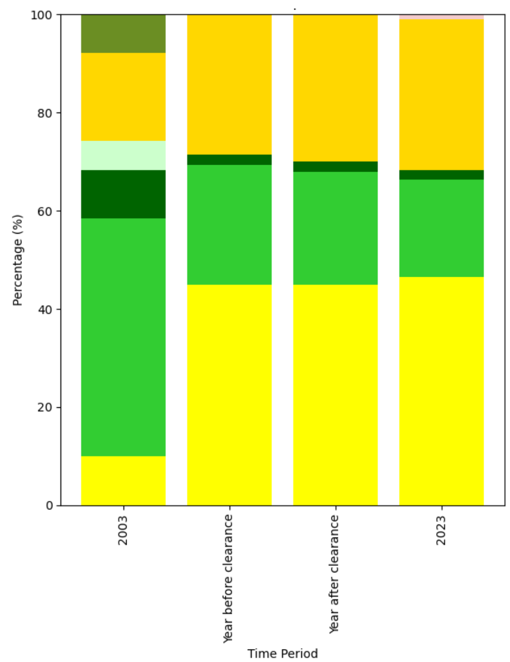
C1 plots



C3 plots



Control plots



Landcover Type	2003	Year before clearance	Year after clearance	2023
Cropland	11	41	49	55
Plantation	0	0	1	1
Deciduous	68	29	25	21
Evergreen	6	0	0	0
Grass	7	1	1	0
Rice	6	28	30	29
Shrub	4	3	2	1

Landcover Type	2003	Year before clearance	Year after clearance	2023
Cropland	3	31	43	50
Deciduous	88	60	51	39
Evergreen	8	4	3	3
Grass	2	0	0	0
Rice	0	0	2	3
Shrub	0	4	3	5

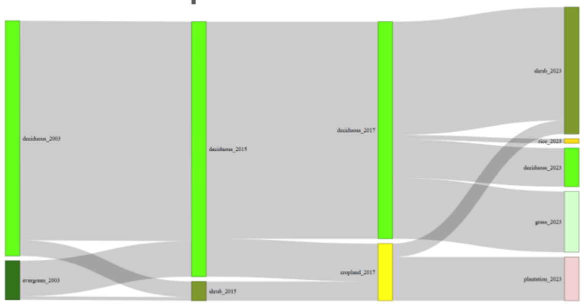
Landcover Type	2003	Year before clearance	Year after clearance	2023
Cropland	10	44	45	47
Deciduous	49	24	23	20
Evergreen	10	2	2	2
Grass	6	0	0	0
Rice	18	28	30	31
Shrub	8	0	0	0
Plantation	0	0	0	1

Cropland Plantation Deciduous Evergreen Grass Rice Shrub Rubber

East province

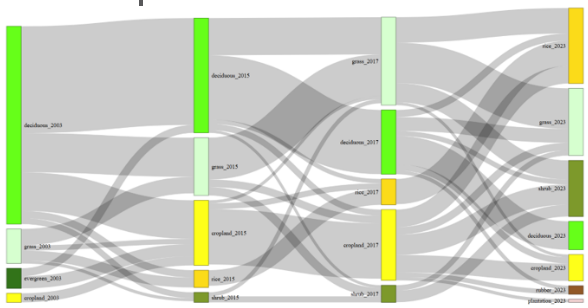
HMA tasks commenced in **2016**

C1 plots



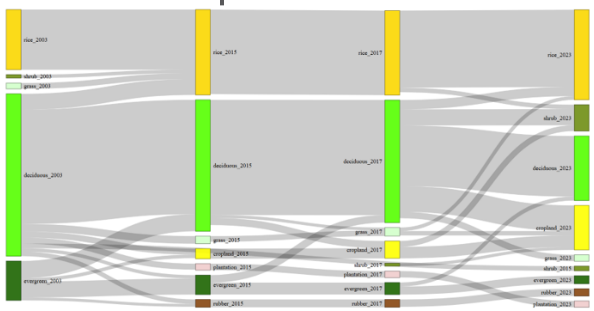
	2003	2015	2017	2023
cropland	0,0	0,0	0,4	0,0
plantation	0,0	0,0	0,0	0,3
deciduous	1,5	1,6	1,4	0,2
evergreen	0,2	0,0	0,0	0,0
grass	0,0	0,0	0,0	0,4
rice	0,0	0,0	0,0	0,0
shrub	0,0	0,1	0,0	0,8

C3 plots



	2003	2015	2017	2023
cropland	4,9	35,1	37,2	14,2
plantation	0,0	0,0	0,0	1,8
deciduous	106,8	62,0	34,7	15,3
evergreen	10,8	0,0	0,0	0,0
grass	18,7	30,0	46,5	36,3
rice	0,0	9,3	13,9	40,7
rubber	0,0	0,0	0,0	4,6
shrub	0,0	4,8	9,3	30,3

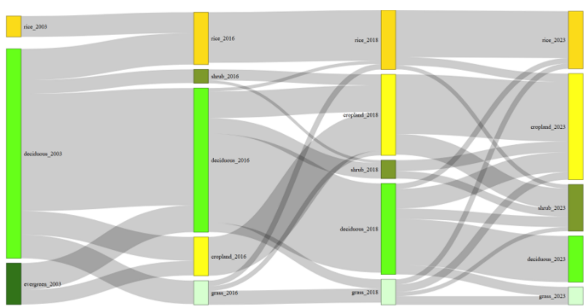
Control plots



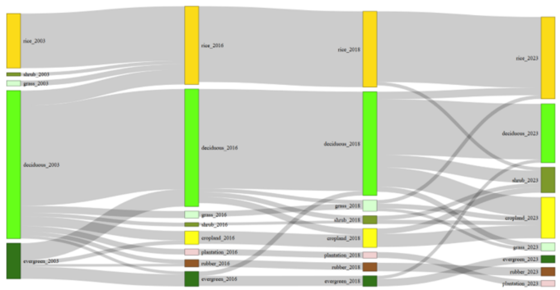
	2003	2015	2017	2023
cropland	0,0	52,7	96,5	248,3
plantation	0,0	33,4	36,4	35,3
deciduous	906,5	733,7	684,4	360,5
evergreen	219,5	108,4	66,3	44,9
grass	32,9	42,2	47,8	35,8
rice	335,8	476,6	472,1	503,0
rubber	0,0	40,8	43,8	41,1
shrub	19,4	26,2	0,0	147,1

HMA tasks commenced in **2017**

No plots



	2003	2016	2018	2023
cropland	0,0	47,3	100,0	130,9
deciduous	258,5	177,8	110,1	56,9
evergreen	51,1	0,0	0,0	0,0
grass	0,0	28,9	28,8	22,0
rice	25,8	64,5	73,3	71,0
shrub	0,0	16,8	22,7	57,5



	2003	2016	2018	2023
cropland	0,0	81,6	116,6	251,2
plantation	0,0	34,1	37,1	36,0
deciduous	907,4	720,3	636,2	360,5
evergreen	218,2	91,2	61,9	44,9
grass	33,0	42,7	57,2	49,0
rice	334,9	479,7	464,9	501,9
rubber	0,0	40,8	43,9	51,6
shrub	20,0	23,2	45,3	155,8

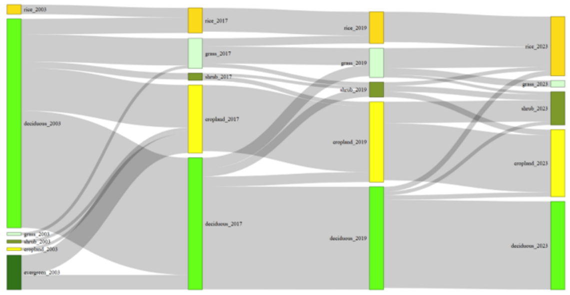
Cropland | Plantation | Deciduous | Evergreen | Grass | Rice | Shrub | Rubber

East province

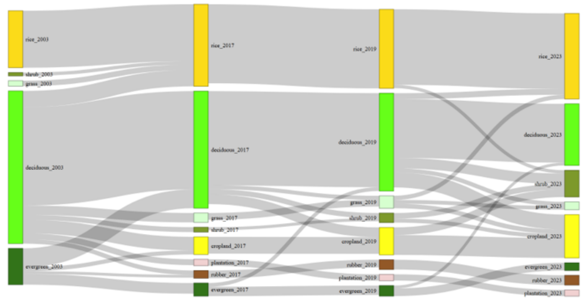
	C1 plots	C3 plots	Control plots

HMA tasks commenced in **2018**

No plots



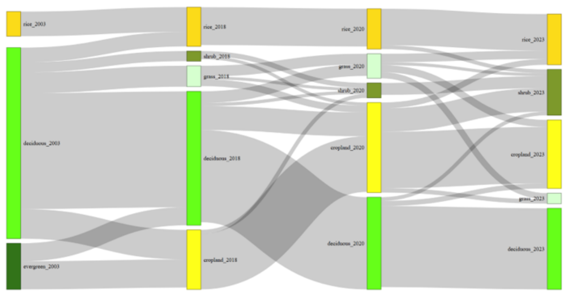
	2003	2017	2019	2023
cropland	2,1	49,7	58,6	49,0
deciduous	152,5	96,2	75,0	64,3
evergreen	25,1	0,0	0,0	0,0
grass	2,1	21,9	20,4	4,7
rice	6,9	18,3	23,1	43,2
shrub	2,1	4,7	10,8	24,3



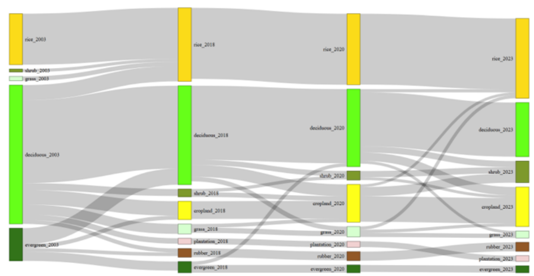
	2003	2017	2019	2023
cropland	0,0	102,9	154,5	253,5
plantation	0,0	34,5	37,5	36,3
deciduous	892,4	684,4	571,7	360,5
evergreen	211,9	62,2	54,9	45,1
grass	31,7	54,9	62,7	46,6
rice	333,1	479,7	462,2	500,4
rubber	0,0	41,9	45,1	57,3
shrub	19,8	28,4	47,9	156,4

HMA tasks commenced in **2019**

No plots



	2003	2018	2020	2023
cropland	0,0	61,7	95,6	73,3
deciduous	204,3	143,2	98,6	86,7
evergreen	49,3	0,0	0,0	0,0
grass	0,0	22,4	23,7	11,3
rice	26,4	42,0	40,4	54,2
shrub	0,0	10,8	16,0	49,1



	2003	2018	2020	2023
cropland	0,0	118,0	242,8	254,3
plantation	0,0	35,0	38,1	37,0
deciduous	891,8	636,2	498,5	347,7
evergreen	209,7	58,2	49,7	44,5
grass	28,1	63,7	62,3	45,0
rice	327,6	472,3	456,3	512,5
rubber	0,0	48,1	55,5	57,7
shrub	19,1	44,7	54,0	138,8

Cropland | Plantation | Deciduous | Evergreen | Grass | Rice | Shrub | Rubber

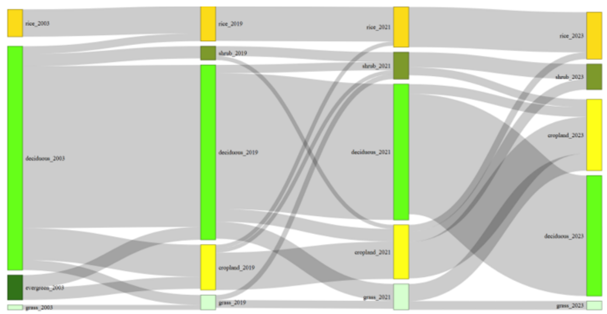
East province

C1 plots

HMA tasks commenced in **2020**

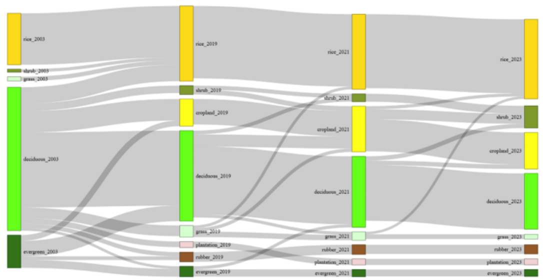
No plots

C3 plots



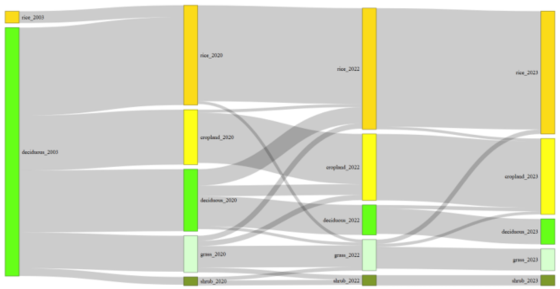
	2003	2019	2021	2023
cropland	0,0	42,1	51,7	68,1
deciduous	214,0	167,1	129,8	115,1
evergreen	23,7	0,0	0,0	0,0
grass	4,6	14,1	23,7	8,4
rice	26,1	33,4	37,0	44,8
shrub	0,0	11,7	25,7	24,4

Control plots

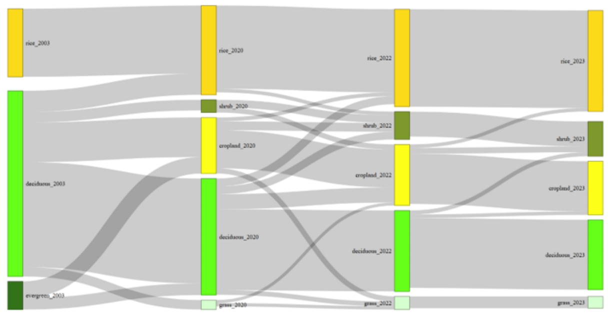


	2003	2019	2021	2023
cropland	0,0	171,7	289,1	230,5
plantation	0,0	35,2	38,7	38,2
deciduous	906,8	571,7	448,7	352,3
evergreen	206,8	65,9	45,6	43,8
grass	26,9	67,5	53,5	29,9
rice	325,0	475,5	475,4	503,2
rubber	0,0	50,3	61,2	58,0
shrub	19,5	47,1	49,2	140,3

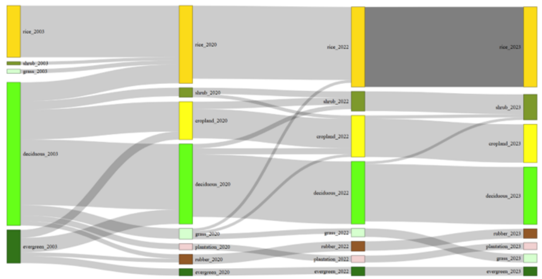
HMA tasks commenced in **2021**



	2003	2020	2022	2023
cropland	0,0	12,7	15,2	17,5
deciduous	57,3	14,3	6,9	5,8
grass	0,0	8,3	7,2	5,0
rice	2,7	23,0	27,8	28,3
rubber	0,0	0,0	0,0	0,0
shrub	0,0	1,8	2,2	2,4



	2003	2020	2022	2023
cropland	0,0	86,9	94,6	83,1
deciduous	287,8	180,6	125,4	108,2
evergreen	43,5	0,0	0,0	0,0
grass	0,0	14,6	20,3	18,2
rice	105,6	138,4	147,3	156,5
shrub	0,0	16,4	43,1	53,9

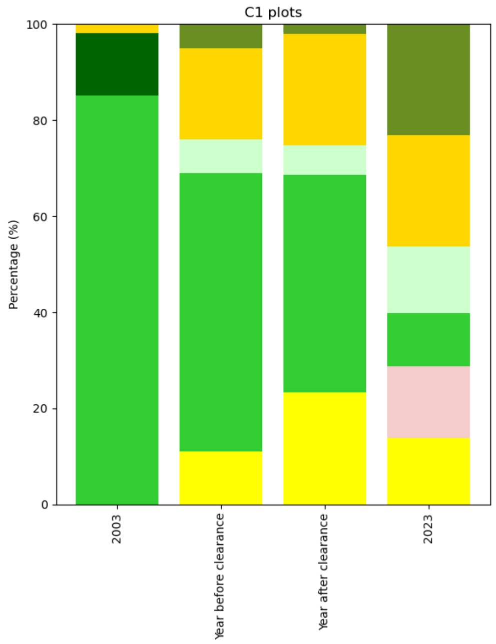


	2003	2020	2022	2023
cropland	0,0	236,3	258,5	238,8
plantation	0,0	35,6	39,0	42,7
deciduous	892,2	498,5	389,7	357,6
evergreen	206,9	43,3	44,3	55,0
grass	25,5	64,6	32,5	52,6
rice	322,1	484,5	473,3	499,1
rubber	0,0	50,6	61,4	58,6
shrub	19,4	52,7	111,0	158,7

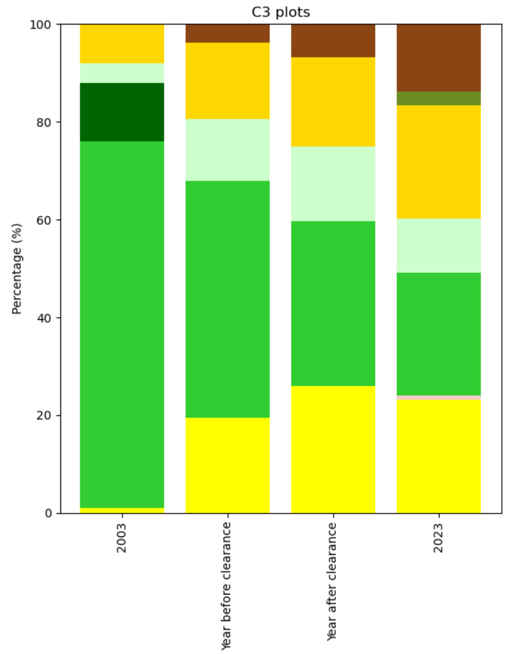
Cropland | Plantation | Deciduous | Evergreen | Grass | Rice | Shrub | Rubber

Figure 3: Overall East provinces land cover change trends (%)

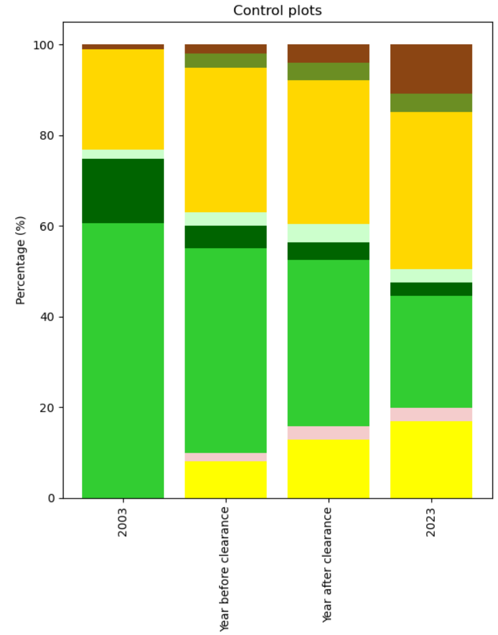
C1 plots



C3 plots



Control plots



Landcover Type	2003	Year before clearance	Year after clearance	2023
Cropland	0	11	23	15
Plantation	0	0	0	16
Deciduous	91	58	45	12
Evergreen	14	0	0	0
Grass	0	7	6	15
Rice	2	19	23	25
Shrub	0	5	2	25
Rubber	0	0	0	0

Landcover Type	2003	Year before clearance	Year after clearance	2023
Cropland	1	20	27	25
Plantation	0	0	0	1
Deciduous	75	50	35	27
Evergreen	12	0	0	0
Grass	4	13	16	12
Rice	8	16	19	25
Rubber	0	0	0	3
Shrub	0	4	7	15

Landcover Type	2003	Year before clearance	Year after clearance	2023
Cropland	0	8	13	17
Plantation	0	2	3	3
Deciduous	60	45	37	25
Evergreen	14	5	4	3
Grass	2	3	4	3
Rice	22	32	32	35
Rubber	0	3	4	4
Shrub	1	2	4	11

Cropland Plantation Deciduous Evergreen Grass Rice Shrub Rubber

Annex 3. Methodological limitations, lessons learned, and recommendations for further research

This section addresses the structural limitations encountered in the methodology used for analysing land conditions and provides recommendations for further research. It explores how far the current analysis has gone in providing reliable insights versus the additional research needed to fill existing gaps. This section discusses the potential advancements in research methods and applications, including mobilizing additional secondary data on soil type, land management policies and practices, deforestation trends, performing more in-depth remote sensing analysis, and interviewing various expert profiles. The types of information gathered, along with the limitations and challenges encountered with each research method, are summarized below.

Remote sensing-based landcover change assessment

Methodological challenges and limitations

- **Landcover dataset:** several datasets were tested, with Sentinel-2 data presenting challenges due to image availability, which provides good coverage with atmospheric correction only starting from 2017. High-resolution data, accessed through online platforms like Google Earth had gaps in observations over several years, making it difficult to distinguish abandoned lands from active cropland. However, it offered good visual disaggregation between forest and tree plantations, though classified with lower accuracy in SERVIR datasets. Manual correction with high resolution due to changes in small patterns was inefficient and not feasible within the project timeline.

- **Data processing:** the final landcover dataset was split into land parcels with detected changes, containing a large number of objects that required R coding to process summary statistics.

- **Land cover change visualization:** Sankey diagrams were selected as the best option to visualize complex landcover change dynamics, tracking each landcover typology change.

- **Resolution issues:** the study primarily relies on open-source satellite imagery with resolutions of 30 meters, limiting the detail of land cover classification within smaller task sites, particularly those as small as 25 x 25 meters. Fine-scale changes within these smaller sites may not be accurately captured, leading to potential misclassification or over/underestimation of subtle land use changes.

- **Heterogeneous task sites:** the diversity of task sites required a parcel-based analysis approach, complicating the comparison of land cover changes across different regions and task site types. The varying sizes, shapes, and environmental contexts of the task sites introduce complexity in standardizing the analysis and interpreting the results.

- **Classification challenges:** SERVIR land cover was selected as the most reliable, consistent annual dataset from 2003 to 2023, validated on a regional level for specific regional landcover types. Forest overestimation due to tree plantations being classified as forests presents a significant challenge, leading to inaccurate assessments of vegetation loss, deforestation and reforestation. Using high-resolution historical imagery limited the number of observations available to clearly differentiate between abandoned and active croplands, though it was easy to distinguish visually between forest and tree plantations when such imagery was available.

- **Comparative limitations:** the total number of C1 polygons in the East province was considerably lower due to the nature of the contamination, making comparisons between task site types more complicated and less representative. This imbalance affects the robustness of the comparative analysis and may introduce biases in the findings. Different numbers of task sites and areas were released in different years. Control plot selections were challenging, as many pre-selected areas were later identified as mine-contaminated areas. To mitigate this, we initially pre-selected twice as many plots as required. However, approximately 50% of these plots were found to be interfered with demining activities (conducted, in progress, planned) and were ultimately excluded from the analysis.

Suggestions for improvement

- **Improve classification reflecting local knowledge:** enhance the accuracy of land cover classification by integrating local knowledge and expertise.

- **Balanced sampling and comparative analysis:** ensure a balanced sampling of task sites across different regions and contamination types to facilitate more representative comparisons. Increasing the number of C1 polygons in the East province or adjusting the analysis to account for the imbalance can improve the robustness of the findings.

- **Advanced technologies:** integrate advanced technologies such as LiDAR (Light Detection and Ranging) and UAV (Unmanned Aerial Vehicles) for detailed topographic and vegetation analysis. These technologies can complement satellite imagery and provide even higher-resolution data, particularly relevant for smaller task sites.

Remote sensing-based environmental condition assessment

Methodological challenges and limitations

- **Resolution issues:** data ranged between 30 to 500 meters, leading to potential misclassification or over/underestimation of land condition changes, particularly for Net Primary Production analysis using the Modis dataset.

- Heterogeneous task sites: the diversity of task sites required a parcel-based analysis approach, complicating the comparison of land cover conditions across different regions and task site types. Changing landcover types over time also complicated the comparative analysis. We addressed these by only including in the agriculture land condition analysis agriculture land parcels that remained cropland for at least last 5 years (from 2018) with the field size of at least 0.5 ha.

- Lack of in-situ data: the research is constrained by the lack of in-situ data collection, making it impossible to directly verify soil moisture and soil erosion mapping results derived from remote sensing techniques. Ground-truthing is essential for validating remote sensing data and ensuring the accuracy of the environmental assessments.

- Contamination uncertainties in the surrounding area: in the current research, it was challenging to include the entire community area in the analysis from both perspective of addressing more holistic approach and to get the relevant baseline data for comparison with clearance impact, due to uncertainty about which parts of the land were still contaminated or had been cleared by other mine actors. The intense contamination resulted in nearly half of the randomly generated polygons falling into contaminated or previously contaminated areas.

- Inconsistent dataset: the number of available cloud-free satellite images varies across different years, complicating the analysis of trends.

- **Net Primary Production (NPP) analysis:** surrounding pixel activity indicated a rise in nearby task sites, affecting biodiversity loss signals and impacting the value for the task site, at such resolution it is difficult to identify biodiversity loss specifically within the task site boundaries.

Suggestions for improvement

- **Ground-truthing and in-situ data collection:** incorporate ground-truthing and in-situ data collection to validate remote sensing results. Establishing field surveys to measure soil moisture, vegetation health, and other environmental indicators will enhance the reliability of the remote sensing analysis.

- **Balanced sampling and comparative analysis:** ensure a balanced sampling of task sites across different regions and contamination types to facilitate more representative comparisons.

- **Longer timelines:** develop a more comprehensive understanding of gradual trends and recovery processes through longer timelines.

- **Scale-Up Analysis to the regional level:** analyzing data at a regional scale allows for a more comprehensive understanding of land conditions and environmental impacts. It can reveal how local factors interact with broader regional trends, providing insights into the overall health and sustainability of the land.

- **Collaborate with other mine action actors** to share data and insights on contaminated and cleared areas. This can help create a more comprehensive and up-to-date map of land conditions.

Community consultations

Methodological challenges and limitations

Data collection method

- **Reliance on MFGDs and KIIs:** while these methods are effective for gathering qualitative data, they may not capture the full extent of environmental impacts and land use changes. These methods rely heavily on subjective perceptions and may miss out on objective measurements and broader trends.

- **Variability in engagement:** the study covered multiple villages, but the number of participants and their engagement levels varied, leading to inconsistencies in the data and potential biases in the findings. Female MFGDs had usually a lower number of participants and age diversity. Less involvement of youth participants, who also showed less engagement in the conversation.

- **Sampling approach:** selecting villages with more contaminated fields led to uncertainty about which land parcels the community reflected on. In sites with fewer affected fields, it might be challenging to find knowledgeable participants.

- **Differences in facilitation and note-taking:** while usually MAG's facilitators focus more on evidence collection and confirmation, putting into notes the information confirmed by at least three participants. Environmental impact assessments benefit more from diverse perceptions and experiences, even those mentioned by only one MFGD participant. Also, on broader environmental topics, people tended to talk a lot rather than answering directly to specific potential mine contamination questions, making it difficult for note-takers to summarize the relevant information and for facilitators to keep the conversation on track.

- **Work with map** – pre-processing preparation time, printing and post-processing (challenges with photo copy quality).

Participant understanding and representation

- **Participant understanding:** some participants had limited understanding of environmental issues and geography or lacked confidence in working with maps, affecting the accuracy and depth of the data collected. In our research, we aimed to compare the impact of different Humanitarian Mine Action (HMA) techniques applied by specialized operators. However, community discussions often shifted to self-clearance methods, such as burning vegetation and manual removal. This made it challenging to clearly identify which method they were referring to during discussions.

- **Regional representation:** focusing on specific villages may not fully represent the broader regional impacts of land clearance. Different regions might have varying environmental conditions and land use practices, which can influence the outcomes of clearance activities.

- **Gender dynamics:** MFGDs were divided into male and female MFGDs. In some cases, women were less confident in engaging with maps, than men. Women's responses tended to focus more on health and water access, while men discussed agricultural practices. As the positive observation was for male and female facilitators working in pairs, switching the note-taker and facilitator roles in female and male MFGDs. No concern for male/female note-taker present in the MFGDs.

- **Language barriers:** communities speaking their own languages posed communication challenges.

Memory and historical tracking

- **Reliance on community knowledge and memory:** this reliance can introduce inaccuracies, especially when tracking historical timelines and specific events. Participants might have difficulty recalling precise details or might provide biased accounts based on their personal experiences.

- **Historical timeline tracking:** difficulty in clearly reflecting on when specific events occurred can affect the accuracy of the data. Participants might struggle to remember exact dates or sequences of events. If there were many cleared fields within community was hard to get the participants memory of clearance timeline

- **Awareness of clearance method applied:** while the communities in both provinces are highly aware of the different clearance methods used around their community, it was unclear how easily they can recollect which specific method was applied to particular fields.

Suggestions for improvement

Data collection method

- **Balanced sampling and comparative analysis:** ensure a balanced sampling of task sites across different regions and contamination types to facilitate more representative comparisons. This could include the development of participatory tools designed to keep the focus of the conversation where it is needed? Timeline exercises, transect walks etc.

- **Integration of quantitative and qualitative approaches**, potentially through partnerships with scientific researchers, allowing to involve in-situ sampling (e.g. soil quality, soil contamination with denomination remaining), remote sensing and community consultation - to obtain a comprehensive understanding of environmental impacts. This will also help to cross-reference community knowledge with historical records and objective data to enhance accuracy.

Participant understanding and representation

- **Participant understanding:** enhancing participant understanding through pre-survey training, explanation of environmental impacts and clearance techniques applied by MAG to make participants to be familiar with the maps, simplified mapping tools easy to understand can improve the quality of data collected.

- **Provide examples of environmental impact** and observed environmental changes, use the map for clear documenting the concern

- **Use more visual aids for historical tracking**, like historical imagery or mapping results; use maps and provide specific examples of environmental impact and observed environmental changes for clear documentation

- **Clarify Focus During Discussions**: ensure that discussions remain focused on the specific HMA techniques applied by specialized operators. This can be achieved by providing clear guidelines and prompts to participants at the beginning of each MFGD.

Annex 4. Streamlining environmental consideration into non technical surveys

This section outlines recommendations for improving MAG's pre- and post-clearance data collection by suggesting specific questions to enhance understanding of environmental impacts. It focuses on integrating topics such as intended land use, awareness of environmental risks, existing sustainable land management practices, and baseline soil characteristics into existing survey tools to support more informed planning and monitoring.

Pre-Clearance Forms (Forms A and B)

Environmental Baseline

Existing questions

- Form A/B, Section 8.3.1: Does the CHA [Confirmed Hazardous Area] prevent access or use of natural resources, water, forest foraging, rangeland grazing?

- Form A/B, Section 9.1: Does the community have alternative resources/ infrastructure instead of the blocked one?

Suggested additional questions

- What is the current soil type in the area?

- Are there any existing sustainable land use measures in place?

Intended Land Use

Existing questions

- Form B: What crop might you grow? Did you think you might use the land for livestock production/grazing?

Suggested additional questions

- What are the intended uses of the land post-clearance? Is the land expected to be used for nature preservation/collecting natural/medicinal herbs?

- Are there plans for sustainable agricultural practices?

Post-Clearance Forms (Forms G and H)

Environmental Impact

Existing questions

- Form G, Section 6.2.4: Has a recreation facility been built on the cleared land?

- Form G, Section 6.3: Has the cleared land given access to, or use of, natural resources?

- Form G/H, Agriculture Post Clearance use: Have you planted a crop on the cleared land? Are there any areas of the cleared land not being used? If yes, what are the reasons for the land not being used?

Suggested additional questions

- Have there been any changes in soil quality since clearance?

- What erosion control measures have been implemented?

- If land degradation is observed or deterioration of natural resources concerning the clearance or the changed land use.

Sustainable Practices

Existing questions

- Form G/H, Agriculture Post Clearance use: Have you planted a crop on the cleared land? Are there any areas of the cleared land not being used? If yes, what are the reasons for the land not being used?

Suggested additional questions

- Have farmers received training on sustainable agricultural practices?

- Are there any reforestation programs in place?

- If the land is preserved for conservation/reforestation, if it's helped to apply sustainable agriculture practices.

Disaster Risk Management

Existing questions

- FCDO HH survey, Resilience section 1: Since clearance completed, have any of the following events or shocks significantly affected your household? (with hazard event options). How well do you believe you recovered from that event? How well do you think you would have recovered from that event if it had occurred before clearance?

- FCDO HH survey, Environment section: Compared to before clearance, do you feel the environment (forest cover, soil and water quality, air quality) has changed?

Suggested additional questions

- Post-clearance form: Do you see any implications of hazardous events affecting the cleared land?

- Keep the open questions allowing survey participants to provide specific examples and additional explanations.

- Clarify the area to reflect on and provide examples of observed environmental changes, using the map for clear documenting the concern.

Minimize Soil Compaction and Vegetation Loss

Use clearance techniques that reduce soil compaction and preserve vegetation. This can help maintain soil fertility and moisture retention.

Existing questions

- Form H, Section 7 (Environment - forest cover, soil and water quality, air quality).

Suggested additional questions

- Detailed questions on specific clearance techniques and their environmental impact and community suggestions for mitigation measures

Erosion Control Measures

Suggested additional question

- to baseline form – If any existing erosion control measure existing/applied

Farmer's Capacity Building

Existing questions

- Form G, Section 6.6 (Agriculture production)

Suggested additional questions

- Questions on training and education needs for sustainable practices.

Community Awareness and Participation

Existing questions

- Form A, Section 6 (Safety Information)

Suggested additional questions

- Are community members aware of the environmental risks associated with clearance activities? What measures are in place to mitigate these risks?

Long-term monitoring of environmental Impact

Suggested additional questions into post-clearance form

- Have there been any changes in soil quality since clearance?

- What erosion control measures have been implemented?

IMPACT Shaping practices Influencing policies Impacting lives

REACH | PANDA | AGORA

www.impact-initiatives.org

@IMPACT Initiatives

+41 22 566 29 63

9 chemin de Balexert
1219 Geneva
Switzerland

geneva@impact-initiatives.org

MAG saves lives builds futures

www.maginternational.org

@mag-mines-advisory-group

+44 (0) 161 236 4311

Suite 3A, South Central
11 Peter Street
Manchester, M2 5QR
United Kingdom

info@maginternational.org