1. METHODS *Study Area – geology, climate, vegetation, land use history*

The Bale Mountains bedrock originates from Tertiary basaltic lava and soils are dark-brown silty loams, rich in organic matter (Yimer, Ledin & Abdelkadir 2006). The Sanetti Plateau >4000 m.a.s.l. was during the last glacial maximum covered by an ice cap, which disappeared at least 2000 years ago (Osmaston et al. 2005, Umer et al. 2007). The climate is tropical alpine with large diurnal fluctuations in temperature; average max/min temperatures at 3400 m on the Northern aspect are ~15 and 5 °C (Johansson and Granström 2014), with larger fluctuations, and night frosts in the dry season (Miehe and Miehe 1994). The dry season normally lasts from December–January, but some rain falls also in the dry season. The dry season on northern aspect is slightly longer, with a mean annual precipitation at 3400 m.a.s.l. of ~1740 mm (Johansson and Granström 2014). On the southern aspect total precipitation is lower, but more evenly distributed throughout the year, with persistent fogs at the treeline (Miehe and Miehe 1994). Some years the dry season extends into March–April due to failure of the south-eastern monsoon (the short "*Belg*" rains), causing regional extended droughts (Miehe and Miehe 1994, Mokria et al. 2017, Mekonnen et al. 2018) (**Table A1.1**).

The montane vegetation forms distinct zones with sharp boundaries (Friis 1986). These zones should have been upward migrating during the last 4000-year general warming trend in Africa (Kebede et al. 2007, Chala et al. 2016), but the distinct treeline (at ~3500 m.a.s.l.) has probably been rather stable (Gil-Romera et al. 2019), due to the contrasting flammability between the highly flammable heathlands above, and the less flammable forests below (Johansson 2013, Johansson and Granström 2014). Increased anthropogenic ignition probably dates back more than 2000 years (Mohammed and Bonnefille 1998, Umer et al. 2007, Gil-Romera et al. 2019). Below 3500 m.a.s.l. *Erica trimera* forms a ~8–12 m tall cloud-forest belt (Friis 1986, Wesche et al. 2008). This closed-canopy forest rarely burns due to lack of surface fuels and a moist interior climate (Johansson 2013). Between ~3500–3900 m.a.sl. shrub-shaped, lignotuberous *Erica trimera* and *Erica arborea* form an almost continuous heathland vegetation belt, interrupted only by small streams, mires and small rocky outcrops (Miehe and Miehe 1994, Fetene et al. 2006). Above ~3900 m.a.sl., the Afroalpine zone is dominated by alpine tussock grasslands and sparse *Helichrysum* dwarf shrub with isolated stunted *Erica trimera* stands in sheltered sites (Friis 1986, Miehe and Miehe 1994).

Until recently the indigenous Bale Oromo inhabitants practised a pure cattle-based transhumant pastoralism, mainly utilizing the heathlands in the dry season. Early 20th–century travel records (Erlanger 1904, Mooney 1963) describe a burnt and grazed ericaceous heathland, quite similar to the present state. The Rinderpest epizootic in the late 1890´s severely decimated livestock and human populations in Bale (Pankhurst 1966). Since the 1950´s population density has rapidly increased (Hillman 1988, Tesfaye et al. 2012). Due to night-time frosts livestock still provide the major source of income at high altitudes. Permanent homesteads are traditionally located below the tree line, and cows, bulls and horses are herded daily up to the heathlands to range freely.

Table A1.1. Extended drought years in the Bale Mountains.

Fire-year	Comment
1973/1974	Regional drought, short rains failure, large areas burnt, including *Erica* forest
1983/1984	Regional drought, short rains failure
1999/2000	Short rains failure, large areas burnt, including *Erica* forest
2007/2008	Short rains failure, burning until April, large areas burnt, including *Erica* forest
2011/2012	Short rains failure, burning until April
2014/2015	Short rains failure, burning until April, one person died

Sources: Jury 2016, Sass-Klaassen et al. 2008, Mokria et al. 2017, Zeleke et al. 2017, Jury 2016, Belayneh et al. 2013, Abera and Kinahan 2011, and personal observations 2005–2016.

2. METHODS *Remote-sensed imagery acquisition and handling*

Aerial photos were bought from the Ethiopian Mapping Authority (EMA). Satellite images were provided by USGS and ESA. Images were resampled, mosaicked, aligned and re-projected to coordinate system UTM zone 37N (WGS84). Image resolution differed between years, but in order not to bias our random sample selection that is carried out using a standard 500m grid system (**Figure 3**) across all years, we pansharpened 30 m images to 15 m, and then resampled them to 20 m to give most images a resolution of 20 m. No distortions were introduced due to resampling. Exception was made for the 1973 image (60 m) due to lack of high resolution data in the 70's, as well as for the aerial imagery from 1968 and 1984 due to difficulties in interpreting B&W imagery. To compare delineation accuracy between high-resolution panchromatic aerial photos, and the 20 m resolution satellite images, we used the delineated stand borders from the 1984 aerial photos and superimposed them on the 1987 satellite image, and stand borders largely matched (+/- 10 m). We resampled the pansharpened Landsat images to 20 m to keep as many of the images as possible within the same spatial resolution so the random sampling analysis is not biased. Keeping the spatial unit was necessary since the same standard grid was used to randomly select points that identify patches that were further analysed throughout the research timeframe.

Table A1.2. Used imagery information summary (note, 1999 and 2015 were not used in the time-series)

Jan. Year	Sensor	Resolution	Bands used	Tiles	Image Dates	Source	ID
1968	Aerial photos	2-5m	B&W	26	Nov 30, Dec5 1967	EMA	
1973	Landsat MSS	60m	Green, Red, NIR	1	Jan 30 1973	USGS/EROS	LM11800551973030AAA04
1984	Aerial photos	2-5m	B&W	26	January 17 1984	EMA	
1987	SPOT1	10/20m	B&W/ Green, Red, NIR	4	Dec 15, 31 1986 Jan 30, 1987	SPOT1-5 ESA archive	11403368612310745582P 11403378612310746062P 11403368701300808522P 11413368612150753481X
1995	SPOT3	20m	Green, Red, NIR	2	Jan 16, 1995	SPOT1-5 ESA archive	31403369501160752162X 31403379501160752242X
1999	SPOT4	20m	Green, Red, NIR	3	Jan 02, 28 1999	SPOT1-5 ESA archive	41403369901020742562I 41413369901280742471I 41413379901280742551I
2000	Landsat 7 ETM+	30m, pansh. to 15m*	Green, Red, NIR	2	Feb 05, 14 2000	USGS/EROS	LE71680552000036EDC00, LE71670552000045EDC00
2006	SPOT4	20m	Green, Red, NIR	4	Dec 4 2005 Jan 1 2006	SPOT1-5 ESA archive	21403370601040758152X 21403360601040758062X 21413370512040754112X 21413360512040754022X
2008	SPOT4	20m	Green, Red, NIR	4	Feb 11, 12 2008	SPOT1-5 ESA archive	41403370802120738422I 41413370802110758002I 41413360802110757522I 41403360802120738342I
2011	SPOT4	20m	Green, Red, NIR	5	Nov 19 2010 - Jan 25 2011	SPOT1-5 ESA archive	41423371011190718141I 41393361012190740191I 41413361101100716151I 41403361101250727112I 41403371101250727192I
2015	Landsat 8 OLI	30m, pansh. to 15m*	11 bands	2	Jan 5, 14 2015	USGS/EROS	LC81680552015005LGN01 LC81670562015014LGN01
2017	Landsat 8 OLI	30m, pansh. to 15m*	11 bands	2	Jan 3, 10 2017	USGS/EROS	LC81670552017003LGN01, LC81680552017010LGN01

Jan. Year=the January year of the (Nov–April) dry season, MSS=mobile satellite services, OLI=operational land imager, B&W=black-and white, NIR=near infrared, EMA=Ethiopian mapping authority, USGS=US geological services, EROS=Earth resources observation and sciences. *30 m images pansharpened to 15 m, then resampled to 20 m.

2. METHODS *Remote-sensed imagery, continued:*
Aerial photos were georeferenced using ArcMap 10.6, using GCP's taken from Google Earth of stable features in the landscape such as roads, streams, boulders and other landforms. A minimum of 8 points were used for each image to reach a total root mean square error (RMSE) of less than 5 m when possible, and an optical check was done for each image to check its local accuracy in the heathland zone against a backdrop of satellite images. Sample points for patch size quantification were selected using a 500 m grid system, with 556 and 791 gridpoints outside/inside the park respectively **(Figure 3)**. We used the Sampling Design Tool for ArcGIS (2007) to randomly select new sample points from the grid for each analysed year (i.e. no replication in time). For each year we selected 54 random points outside and 54 points inside the Bale Mountains National Park (BMNP) (representing 9.7% and 6.8% of all gridpoints), since we did not want to have fewer sampling points in the smaller area outside the park. When two random points landed on the same patch (occurred 14 times), the second point was ignored for the main analyses. In the first analysis of proportion of points on burnt/young stands, duplicates were included.

3. *Ground truthing*
In June 2018 four 2–4 km long line transects (total 14.6 km) inside the park were mapped by gps using the same methods as previously for outside the park. A gps point was recorded when crossing a border between two stands of different age. Dominant heights of *E. arborea* and *E.trimera* were recoded, with stand age (based on our established age-height relations and park scout´s memory of burn year). We recorded slope, aspect, area cover of grass/herb lawn, total *Erica* cover and % cover of *E. arborea* and *E.trimera*. In these transects the oldest stand was ~25 years old and one stand was <1 year old. The proportion of young stands (<4 years) was 26%. The transect data was verified against Google Earth CNES/Airbus images from February 2018. Borders between young and mature stands fitted with Google Earth images (max error +/- 20 m), but borders between two mature stands of different age were less clearly distinguishable. This implies that mature stands in our main analyses can be composed of two stands originating from different fire years, and hence mature stands were excluded from all statistical analyses. As ground truthing data for the area outside the park we used our previously collected data from 2007/2008 and 2016, validated against historical Google Earth images from the same years.

4. *Test of Flammability threshold age*
Thirty-four of the delineated burnt patches were investigated for their age at the time of the fire, by analysing three image pairs less than 3 year apart in time: 1999/2000, 2006/2008, 2015-2017. Pre-fire age-class of each stand was estimated by checking the age-class of the same stand in the 1–2 year predated image. Results showed that 33 of the fires burnt in mature (>5 year old) stands, and only one fire occurred in a stand which was classified as young (1-3 year old) in 1984, which means that it was between 4–6 years old when it burned in 1987. No young stands burned. This confirmed our hypothesis that stands <5 years old cannot burn, and therefore act as fuel-breaks in the landscape. P-value from Chi^2 test = ($\chi 2$ = 13.534, DF = 1, p = 0.00023).

Table A1.3 Numbers of burnt and non-burnt stand per age class.

	1999-2000	2006-2008	2015-2017
Burnt Mature	9	15	1
Burnt Young	0	0	0
Nonburnt Mature	32	25	36
Nonburnt Young	22	15	25

Pooled > x <- matrix (c (25, 0, 93, 62), n col = 2) > χ2 Pearson's Chi-squared test with Yates' continuity correction data

RESULTS

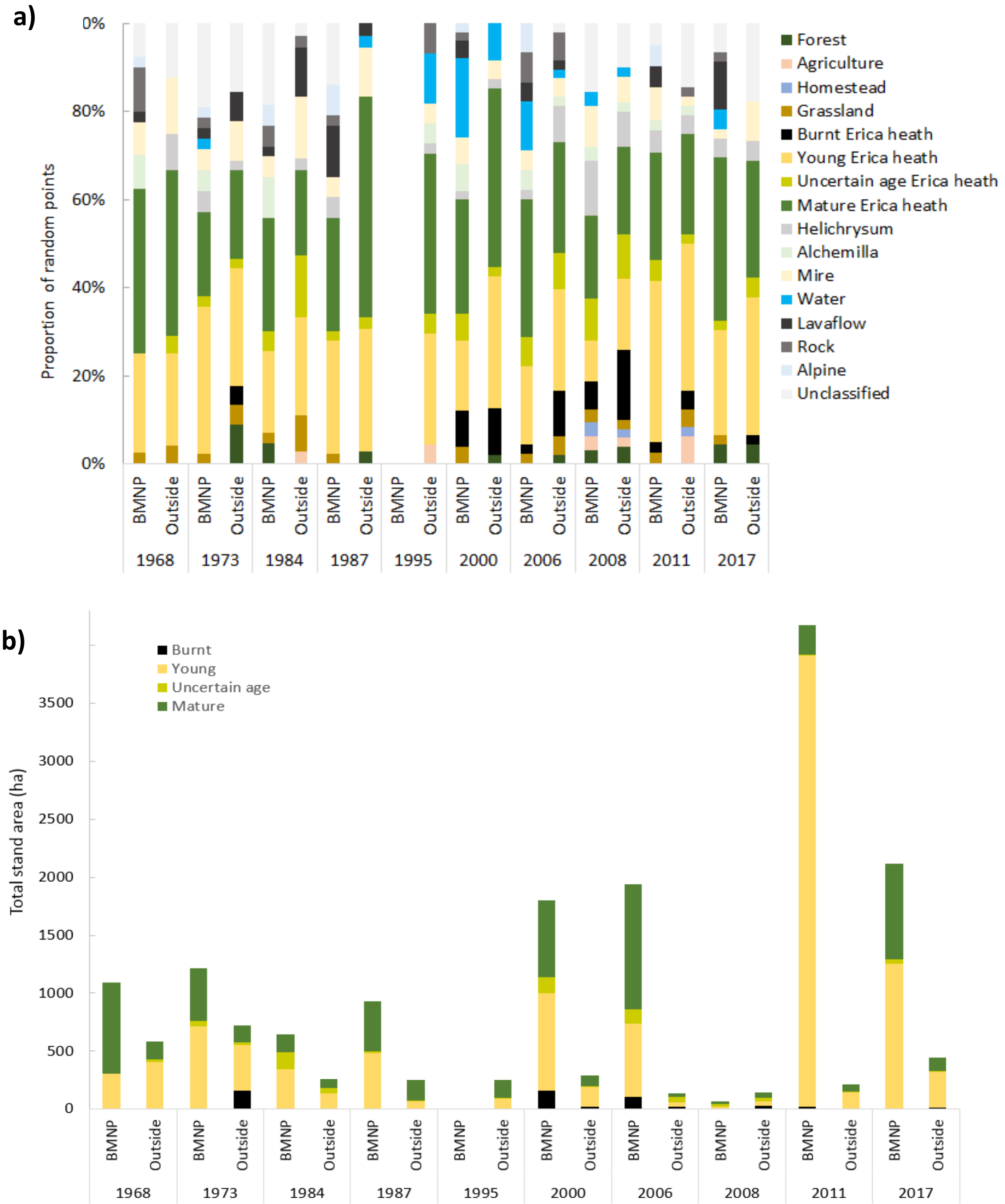

Figure A1.1 a) Proportion of sample points which fell on all identified types of land covers in the studied zone between 3500-3900 m.a.sl. **b)** Summed area cover for all delineated heathland patches each year for burnt, young and mature stands, and stands with uncertain age (intermediate colour, likely 4-year old stands or flat land with sparse lignotubers).

Table A1.4 Number of homesteads located within 500 m from delineated *Erica* stands inside and outside Bale Mountains National Park (BMNP).

Number of homesteads	1968	2017
BMNP above treeline	0	5
BMNP below treeline	0	0
Outside above treeline	2	11
Outside below treeline	0	1

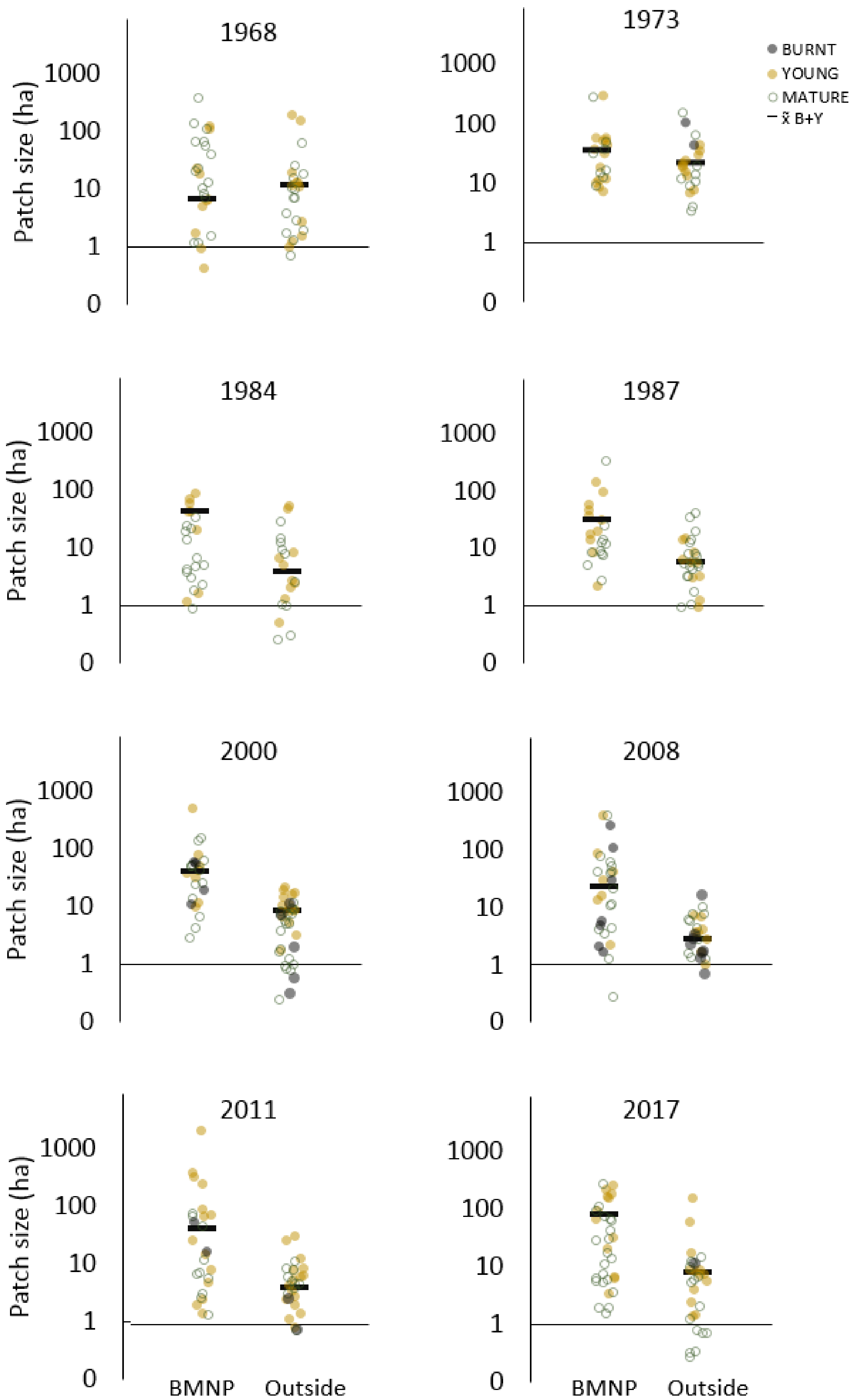

Figure A1.2. Patch sizes of burnt (grey dots), young (yellow dots) and mature stands (green circles), and the median of burnt + young stands (black line) (for 8 selected years) 1968 -2017. Inside Bale Mountains National Park (BMNP) and outside. Mature stands show similar size distributions as young stands

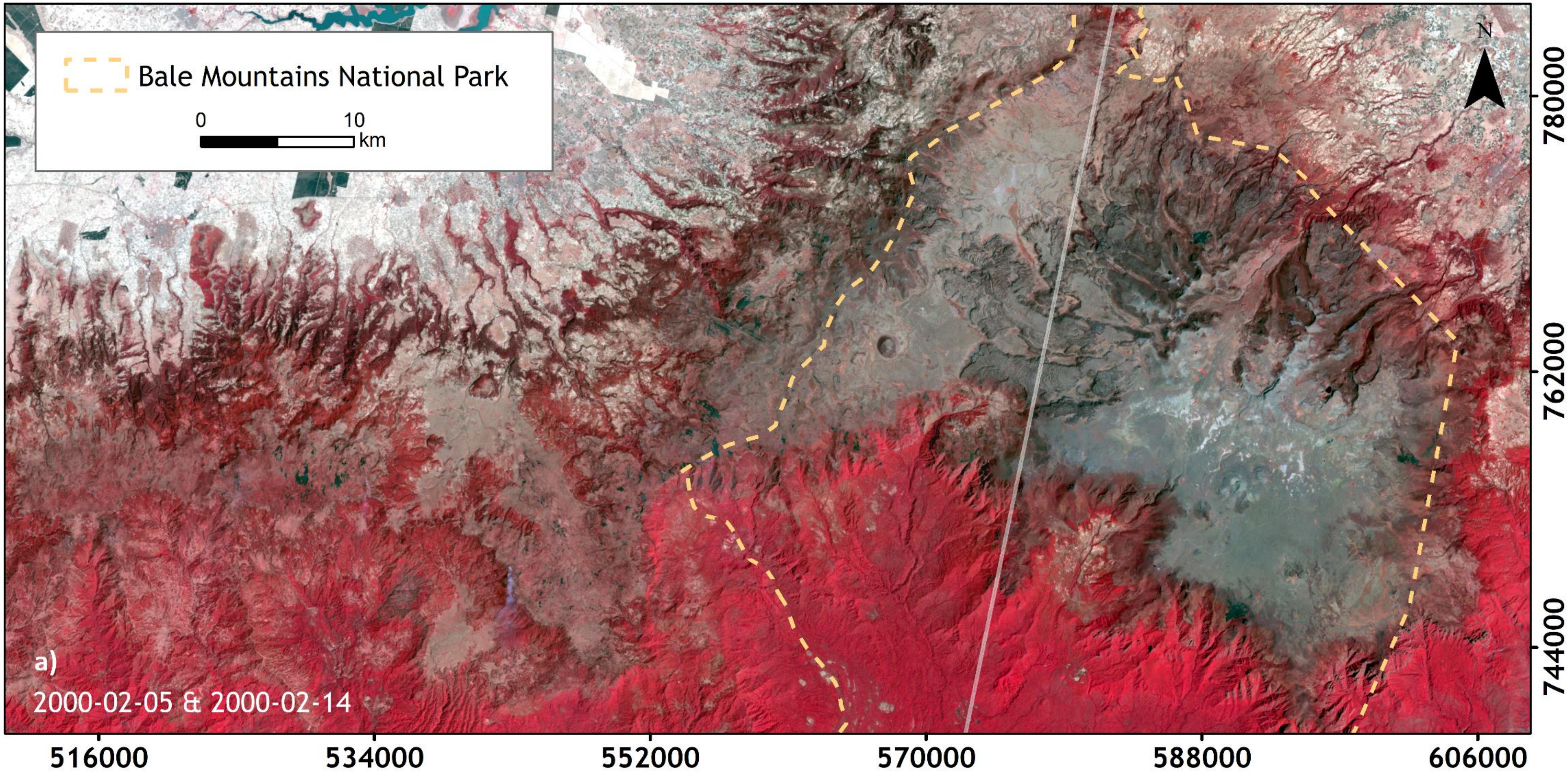

Figure A1.3 a) Bale Mountains image from drought year 1999/2000. Two tiled Landsat images from 5th (left) and 14th (right) from February 2000, with the BMNP border superimposed. The heathland zone appears grey-red (a patchwork of grass-dominated stands and *Erica*-dominated stands). A blue smoke from an active heathland fire is visible ~10 km west of the western park border, in the lower half of the image. Black patches are stands which had burnt during the first half of the dry season 1999/2000, not including late-season fires in March-April. Large black burns are visible on the western ridge outside the park, just along the western park border, and inside the park, on the eastern slope, ~10 km SE of Rira and along the Harenna escarpment, one large black patch can be seen in the complex lava-flow terrain north of Sanetti plateau. Many, mostly small, burnt patches are visible outside the park.

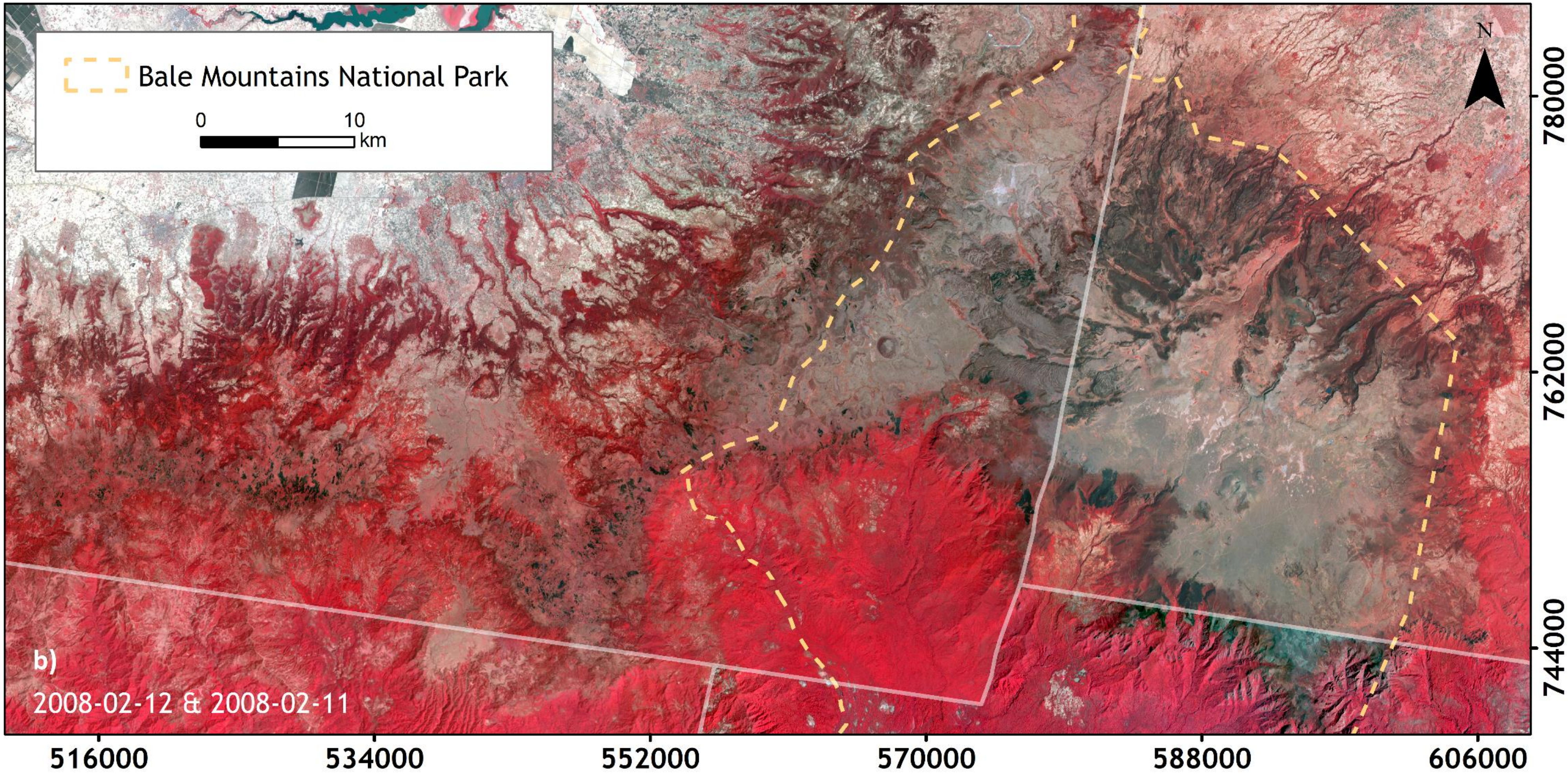

Figure A1.3 b) Bale Mountains image from drought year 2007/2008; two tiled SPOT images from 11th (left) and 12th (right) of February 2008. Large (~30–290 ha) black burns are visible along the Harenna escarpment in the park. Many small burnt patches are visible outside the park.

Table A1.5 Livelihood parameters (average(range)) for respondents divided per wealth group, age group (young: 20-30, mid-age: 31-49, old: >50 years old), residency inside vs. outside BMNP, and on the northern vs. southern aspects of the mountain, respectively. Responses to questions were entered into a spreadsheet with demographic and livelihood data and patterns in replies were sought based on these groupings.

	(average (range)) Wealth group*			Age group			Residency		Aspect of mountain	
	Poor	Middle	Rich	Young	Mid-age	Old	outside	inside	North	South
# respondents	14	18	9	10	24	7	21	20	20	21
# schoolyears	2(0-4)	4(2-6)	3(0-7)	5(4-6)	3(0-7)	0(0-0)	3(0-7)	2(0-5)	3(0-7)	2(0-4)
# wives	1(1-1)	1(0-2)	2(1-3)	1(0-1)	1(1-2)	2(1-3)	2(1-3)	1(0-2)	1(0-2)	2(1-3)
# children	5(1-11)	7(0-21)	10(4-17)	2(0-5)	8(1-17)	14(5-21)	9(1-21)	6(0-12)	5(0-11)	9(4-21)
# cows	6(0-15)	9(0-25)	22(9-30)	7(0-10)	15(2-30)	13(7-25)	14(3-30)	10(0-25)	9(0-30)	14(0-30)
# sheep	7(0-15)	8(0-25)	17(0-30)	5(0-15)	11(0-30)	11(0-25)	13(0-30)	8(0-25)	7(0-10)	12(0-20)
# goats	0(0-2)	3(0-20)	3(0-20)	3(0-15)	1(0-20)	6(0-20)	5(0-20)	2(0-3)	0(0-3)	4(0-20)
# horses	3(0-5)	2(0-10)	7(2-10)	1(0-3)	4(0-10)	4(0-10)	4(0-10)	3(0-9)	2(0-5)	5(0-10)
# donkeys		0.4(0-3)	0.3(0-2)		0.3(0-2)	0.6(0-3)	0.2(0-2)	0.4(0-3)	1(0-3)	0(0-1)
dist. to heath (m)	850	750	600	850	1000	400	800	850	(50-2000)	(300-3000)
% Income from: livestock	35(10-60)	51(10-60)	58(10-90)	39(10-60)	51(10-90)	52(30-60)	47(10-90)	55(10-60)	47(10-80)	58(20-90)
-“- crops	53(30-75)	38(0-60)	40(0-60)	46(9-75)	43(0-65)	42(0-60)	38(0-75)	48(15-65)	40(0-75)	43(0-60)
-“- honey	9(0-20)	4(0-20)	3(0-10)	7(0-20)	7(0-20)	2(0-8)	4(0-20)	6(0-20)	1(0-5)	9(0-20)
-“- tourism	1(0-5)	12(0-75)	23(0-50)	2(0-5)	21(0-75)	4(0-10)	6(0-40)	19(0-75)	16(0-75)	7(0-50)
-“- bamboo		4(0-30)	10(0-40)	10(0-30)	4(0-40)	1(0-5)	8(0-40)		1(0-5)	10(0-40)
-“- timber	3(0-10)			3(0-10)			3(0-10)		3(0-10)	
-“- forest protection		1(0-10)			1(0-10)		1(0-10)			1(0-10)

*Wealth groups based mainly on numbers of livestock and horses (for old respondents: also number of wives/homesteads, numbers of children, and social status during Imperial time (Tesfaye et al. 2012).) Respondents not separated per gender since it is summed household estimations

Appendix 1 – background, supporting parts of methods and results to: *Change in heathland fire sizes inside vs. outside the Bale Mountains National Park, Ethiopia, over 50 years of fire-exclusion policy: Lessons for REDD*

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