

Spatio-Temporal Dynamic of Land Use and Land Cover in Andit Tid Watershed, Wet Frost/Afro-Alpine Highland of Ethiopia

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Abstract: Spatial and temporal dynamics of land use/land covers (LULC) are the results of human activities and population growth. The LULC change is caused by both, natural and anthropogenic factors. The objective of this study was to detect LULC changes in Andit Tid watershed. The study has used ArcGIS 10.5 and Landsat images of 1984, 1996, 2008, and 2017 to see LULC changes of Andit Tid watershed. The result indicated that the plantation forest and cultivated land have been increased by 41.94 ha and 33.39 ha, respectively from 1984 to 2017 due to the population increase and improper agricultural activity. On the other hand, the bushland and grassland coverage has been decreased by -7.29 and -67.95 ha, between the study periods respectively. This shows the tempo-spatial dynamic conditions of LULC change in the study watershed. The change of LULC was related mainly to anthropogenic factors such rapid population growth which consequence high demand land for cultivation practices, settlement and grazing land. Thus, attention must give to increase of intensified agricultural activities that increase land productivity to satisfy the ever-increasing demand of cultivated land of high population in the study watershed. A further search on the impact of these LULC changes on the livelihood and ecosystem services is recommended.

Keywords: *Andit Tid watershed, Land use/land cover, Population increase, Landsat images and Plantation forest.*

1. Introduction

Land is the foundation of almost all resources used by humans but human activity affects the planet on a scale so vast it can be easily seen from space. As a result, more than 50% of the world's land area has been significantly converted to human-dominated land uses [1]. LULC change is a complex phenomenon that directly and indirectly is influenced by multiple socioeconomic and biophysical driving forces. The major driving factor includes population growth, cropland expansion, and overgrazing [2, 3]. The most notable effects of LULC changes are severe soil erosion and land degradation. These are the main reasons for the decline of agricultural production, the disappearance of multipurpose indigenous tree species, diminishing of grazing lands, and reduction in the abundance of medicinal plant species [1, 4].

LULC changes have also led to the declining of forest cover, water bodies and wetland areas whereas the increasing of cultivated and built-up areas largely driven by population growth and economic development [5-10]. In Ethiopia, extensive conversion of vegetation cover and expansion of farmlands along with the ecological vulnerability (the ability of systems to absorb changes of state variables, driving variables, and parameters) lands have implications for large-scale Geo-ecological fragmentation and land degradation [11].

In relation to this, in the highlands of Ethiopia, LULC change is mainly caused by agricultural expansion, government land policy, overgrazing, population pressure, investments and social unrest [12] led to severe land degradation, biodiversity loss, deforestation, soil erosion, and soil fertility loss [13]. In most cases of LULC change, croplands increase at the expense of forest, woodland, and grasslands. For example, in the Central Rift Valley of Ethiopia the area covered with forest, woodlands, grasslands, and water has declined from 10, 33, 30, and 16% to 4, 18, 17, and 13% of the total respectively. While the area cover for cropland increased from 11 to 47% [12, 14].

Likewise, in the Northeastern highlands of Ethiopia, the forest lands declined from 4% in 1973 to 0.2% in 2015. The total forest lands cleared between 1973 and 2015 amounts to 552 ha. This is 95% of the forest cover that existed in 1973. Similarly, shrublands declined from 28% in 1973 to 25% in 2015. Meanwhile, croplands and rural settlements increased from 39 % in 1973 to 44% in 1986 and 54% in 2015 [3]. In contrast, [15] reported that forest cover increases at a rate of 11 ha per annum from 1957 to 1998 in Chemoga Watershed, Blue Nile Basin, Ethiopia. Due to rapid population growth, and expansion of agricultural and plantation forests, the Ethiopian highland has been severely degraded over the last three decades.

Andit Tid watershed is one of the catchments of the Soil Conservation Research Program (SCRIP) of the Amhara Regional Agricultural Research Institute (ARARI) in the Ethiopian highlands. It began in 1982 by the Institute of Geography of the University of Bern (Switzerland) in the Ethiopian highlands. The watershed lacks a complete picture of LULC's change from its establishment to the present day. Therefore, understanding LULC dynamics over time can help in projecting future changes in LULC and instigate more appropriate policy interventions for achieving better land management. Such an analysis that produces accurate information on land cover is also required for both scientific. Since the LULC changes affect the land productivity and livelihood status of the community, the present study focused on identifying the changes in LULC change in Andit Tid watershed during the years 1985, 1996, 2008 and 2017.

2. Materials and Methods

2.1. Study Area

Andit Tid watershed is located at about 190 km North-East of Addis Ababa at the top of the eastern escarpment of the Ethiopian central highlands on the way to Dessie between coordinates of 39°43'E and 9°48'N (Figure 1). Administratively, Andit Tid watershed laid within the North Shewa Zone of the Amahara National Regional State. Elevation of the watershed ranges from 3022 to 3468 m a.s.l. The watershed receives a mean annual rainfall of 1651 mm. The minimum and maximum temperature of the area is 7°C and 17°C, respectively. It has a bimodal rainfall regime with one dryer month (June) between Belg (first, short rainy season) and Kiremt (second, main rainy season). The watershed has wet frost highland agroclimatic zones. Major soil groups in the study area are Humic Andosols which cover most of the cultivated land and the area under heather tree and Lithosols in some steep concave slope areas of the watershed.

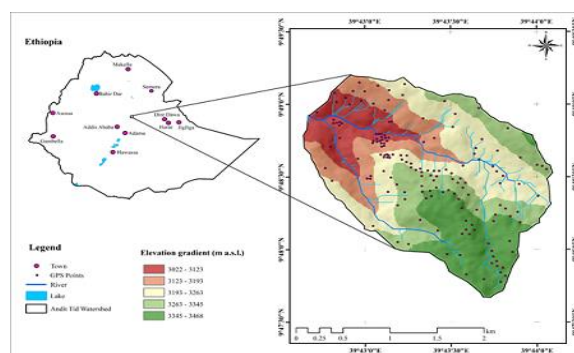


Figure 1.
Location of Andit Tid watershed.

2.2. Data Sources

Four Level 1 Landsat scenes of 1984, 1996, 2008, and 2017 with less than 10% cloud cover were downloaded from the U.S Geological Survey (USGS) earth explorer in Geo TIFF format. The imagery utilized was acquired during the dry season (December, January, and February) of the year in the study area (Table 1). LULC dynamics of Andit Tid watershed were analyzed for the last 33 years.

Table 1.

Remote sensing images used in the study.

PACECRAFT	Sensor Type	Acquisition Date	Resolution	Path/Raw	Source
LANDSAT 5	MSS	2-Jan-1985	60 m * 60 m	168/053	USGS
LANDSAT 5	TM	18-Dec-1996	30 m * 30 m	168/053	USGS
LANDSAT 7	ETM+	14-Mar-2008	30 m * 30 m	168/053	USGS
LANDSAT 8	OLI & TIRS	18-Jan-2017	30 m * 30 m	168/053	USGS

Note: MSS=Multispectral Scanner, TM = Landsat Thematic Mapper, ETM+ = Enhanced Thematic Mapper OLI = Operational Land Imager, and TIRS Thermal Infrared Sensor.

2.3. Landsat Imagery Pre-Processing

The Level 1 products were originally corrected for geometric and terrain distortion by the image provider using ground control points and the digital elevation model (DEM) [16, 17]. Landsat images were pre-processed using ArcGIS 10.5 software by applying the basic image pre-processing techniques such as geo-referencing, mosaicking, and sub-setting of the image based on Area of Interest (AOI). All images were geo-referenced into the same map projection of World Geodetic System (WGS) 1984 Zone 37 N. To classify LULC types, a false-color grid composite image was developed. The major land class units used in the land cover analysis are shown in (Table 2).

Table 2.

Descriptions of land use and land cover classes in the study area.

Land cover type	Description
Plantation Forest	Area covered with tree plantations (dominantly with eucalyptus trees) on hillsides, mountains and, degraded areas
Bushland	Areas dominantly covered by a heather tree (<i>Erica arborea</i> and <i>Hypericum</i> sps), mixed with some shrub trees and less than 50% herbaceous and grass cover
Open grassland	Area dominantly covered by grasses with only a few widely scattered shrubs and trees and are openly grazed by domestic animals.
Cultivated land	Areas prepared for growing crops including areas under cultivation, fallow land, and land under preparation

2.4. Land Use/ Land Cover Classification

Training samples were selected based on the information obtained from ground truth data acquired through field surveys. For past years, ground control points were obtained from topographic maps and discussion with elders. As a rule of thumb, a minimum of 40 training samples (ten times of the sum of all LULC classes) was chosen for each class [18]. The Hybrid method, combining unsupervised and pixel-based supervised image classification with maximum likelihood algorithm was used. Supervised image classification is a recommended classification approach to yield good results when satisfactory training data and detailed information about the study area are available.

2.5. Post Classification

Ground truth points (reference point) were collected to assess the accuracy of the classified LULC classes. A confusion matrix (overall accuracy, producer's accuracy, and user's accuracy) were derived from the reference data and used for accuracy assessment. Confusion matrix which is a cross-tabulation of the class labels allocated by the classified map and reference data [19], is the most popular method of accuracy assessment [18]. After the classification and calculation of the area in hectares, a comparison of the LULC statistics within and between classes and years was performed.

2.6. Change Dictation

Post-classification comparison change detection was made to determine the change in LULC between two independently classified maps from images of two different dates. The rate of land cover change was calculated for the three periods from 1984 – 1996, 1996 – 2007, and 2007–2017 using the following formula:

$$\text{Rate of land cover changes (\% yr}^{-1}\text{)} = \frac{(B-A)}{t} \times 100 \quad [\text{equation 1}]$$

Where A = previous land covers area (ha); B = recent land cover area (ha); t = number of years between A and B.

The LULC change (%) was calculated using the following formula:

$$\text{LULC change (\%)} = \frac{\text{Area}_{\text{final year}} - \text{Area}_{\text{initial year}}}{\text{Area}_{\text{initial year}}} \times 100 \quad [\text{equation2}]$$

Transition matrix was computed for all identified land cover classes using overlay functions in ArcGIS 10.5 software and Pivot Table function in Microsoft Excel 2019 to analyze LULC trajectory (transitions matrix).

3. Results

3.1. Accuracy Assessment of Land Use/ Land Covers Change

The least level of accuracy was calculated to be 85.35% for the 2008 LULC map (**Table 3**), which could be considered to be an excellent result. Accuracy assessment is used to check the quality of classified images based on the reference data used for the classification. It is an important measurement used to assess how accurately the classified image is in a match with the referenced data. The accuracy assessment involves an error matrix that was built from two datasets that are the remotely sensed classified map and reference data (Google earth, previous imagery, or collected data from the field) used for the classification. Kappa within error matrix is always used to determine the error encounter during the classification of satellite images and the classified map will be considered as excellent if the Kappa coefficient (K) greater than 0.77. The most significant accuracy assessment measurements are user, producer, and overall accuracy.

All accuracy assessment measurements indicated that the classified image exactly fits with the reference data. The overall accuracies for the LULC map of Andit Tid watershed in 1984, 1996, 2008, and 2017 were 93.3, 94.34, 85.35, and 98.11%, respectively. It is computed by dividing the total correctly classified number of pixels (i.e., summation of the diagonal) by the total number of pixels in the matrix (total). Producer's accuracy, referees to the probability of reference pixels being classified correctly that were 97.50, 100, 84.62, and 95.24% for 1984, 1996, 2008,

and 2017 LULC map, respectively. User's accuracy refers to the probability that the pixel's in the classified map represent that class on the ground that was 92.86, 93.02, 89.19, and 100% for 1984, 1996, 2008, and 2017 LULC map, respectively. Grassland was largely misclassified in the 2008 LULC map that is 76.19% as compared to the other land use types (**Table 3**).

3.2. Land Use and Land Cover

Regarding the LULC classification map of 1984, the watershed was covered with zero plantation forest, while bushland, grassland, and cultivated land have covered 52.2, 183.6, 227.52 hectares respectively (**Table 4 and Figure 2**). By the year 1996, the plantation forest cover has become 9.63 hectares and continues to increase by 15.3 and 41.94 hectares by the year 2008 and 2017, respectively. In the same year, the coverage of bushland, grassland, and cultivated land were 73.35, 134.19, and 246.24, respectively.

By the year 2008, the extent of bushland increased to 76.41 hectares from 52.2 hectares in 1984. In the same year the coverage of grassland and cultivated land were 131.94, and 239.76 hectares, respectively. By the recent year 2017 LULC type the cultivated land has been increased to 260.91 hectares from 227.52 hectares in 1984 or 239.76 hectares in 2008. The extent of grassland coverage has been decreased continuously from 1984 to 2017, whereas the plantation forest and cultivated land have increased. The long-term LULC change from 1984 to 2017 indicated that the plantation forest and cultivated land have been increased by 41.94 ha and 33.39 ha respectively. On the other hand, the bushland and grassland coverage has been decreased by -7.29 and -67.95 ha, respectively.

Table 3.

Accuracy assessment (%) for the LULC maps of the different periods (1984, 1996, 2008, and 2017).

LULC types	1984		1996		2008		2017	
	Producer Accuracy	User Accuracy	Producer Accuracy	User Accuracy	Producer Accuracy	User Accuracy	Producer Accuracy	User Accuracy
Plantation Forest	-	-	90	100	87.18	97.14	100	97.4359
Bush land	90	100	92.31	92.31	87.5	81.4	97.5	97.5
Grass land	92.5	88.1	95	92.68	82.05	76.19	100	97.5
Cultivated Land	97.5	92.86	100	93.02	84.62	89.19	95.24	100
Overall Accuracy	93.33	-	94.34	-	85.35	-	98.11	-

Table 4.

Land use/ land cover change between 1984 and 2017 at Andit Tid Watershed.

LULC type	LULC (ha)				LULC change (ha) 1984-2017			
	1984	1996	2008	2017	1984-1996	1996-2008	2008-2017	1984-2017
Plantation Forest	0	9.63	15.3	41.94	9.63	5.67	26.64	41.94
Bush land	52.2	73.35	76.41	44.91	21.15	3.06	-31.5	-7.29
Grass land	183.6	134.19	131.94	115.65	-49.41	-2.25	-16.29	-67.95
Cultivated Land	227.52	246.24	239.76	260.91	18.72	-6.48	21.15	33.39
Total	463.32	463.41	463.41	463.41	-	-	-	-

Cultivated land was the most dominant land cover class in Andit Tid watershed and has been continuously increasing due to the growth of the population. The bushland coverage that was developed in the southern part of the year 2008 has been completely disappeared in 2017 besides the shrinking of large bushland in the southeastern part of the watershed. The plantation forest started to develop in 1996 in the northwest part of the watershed and continuously expand its extent in all directions up to 2017. Due to the expansion of plantation forest and cultivated land through time since 1984, the bushland has become almost disappearing, except a little bit in the central part of the watershed.

The rates of change in LULC are shown in **Table 5**. It is noticed that the plantation forest and cultivated land increase in coverage, but the change rate was slow during the year 1996-2008 which showed a decrease in the rate of change of cultivated land (-0.54 ha yr⁻¹), and slow for plantation forest (0.47 ha yr⁻¹). During the year 1984-1996, the grassland change rate was quite fast (-4.12 ha yr⁻¹) as compared to other years. The change rate of plantation forest and cultivated land area was noticed increasing continuously during 2008-2017 with a net rate of change of 2.96 and 2.35 ha yr⁻¹ respectively. Grassland indicated a

decreasing rate of change for the whole study period, whereas the plantation forest showed an increasing rate of change for the whole study period.

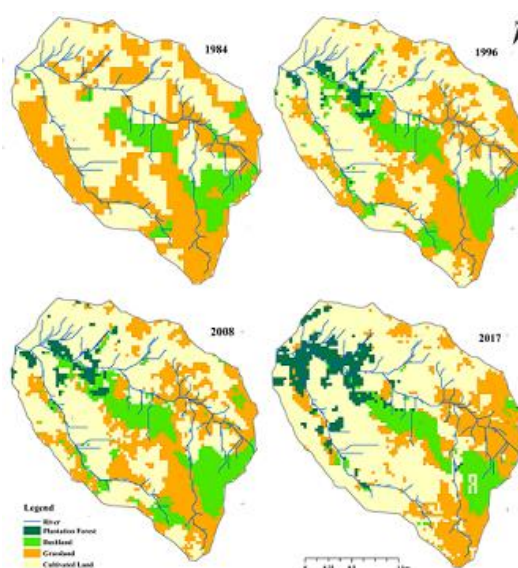


Figure 2.
LULC change map of Andit Tid watershed between 1984 and 2017.

Table 5.
Rate of land use/ land cover change at Andit Tid watershed since 1984. **Note:** LULC = land use and land cover.

LULC types	Rate of LULC change ha yr ⁻¹			
	1984-1996	1996-2008	2008-2017	1984-2017
Plantation forest	0.8	0.47	2.96	1.27
Bushland	1.76	0.26	-3.5	-0.22
Grassland	-4.12	-0.19	-1.81	-2.06
Cultivated land	1.56	-0.54	2.35	1.01

3.3. Land Use and Land Cover Transition Matrix

The transition matrix **Table 6** showed the conversion of one land cover class to another in different years. An area of 183.6 ha of grassland cover has been converted to plantation forest, bushland, or cultivated land area during 1984-1996, resulting in a net increase of 10.80, 20.52, 14.76 ha for plantation forest, bushland, and cultivated land area respectively. Area of 76.41 ha of bushland and 131.94 ha coverage of grassland have been converted to either plantation forest or cultivated land area during 2008-2017, resulting in a net increase of 26.64 ha of plantation forest and 21.15 ha of cultivated land. Between the years 1996 and 2008 there have been net gains of plantation forest (5.67 ha) and bushland (3.06 ha), whereas there was a decrease in the grassland by -2.25 ha and cultivated land by -6.48 ha. The increase of plantation forest in recent years (2017) mainly comes from grassland cover that extends up to 183.6 ha during 1984 and 134.19 ha during 1996.

4. Discussion

The major LULC categories identified are plantation forest, bushland, grassland, and cultivated land. Over the two decades and from other studies [20], similar trends of LULC changed at different rates of conversion were shown in all cover types. The plantation forest and cultivated land were dynamic in their changes. The cultivated land coverage increased from 1984 (227.52 ha) to (246.24 ha) in 1996 then decreased to (239.76 ha) in 2008 and again increased to 260.91 ha in 2017. The increment of cultivated land could be related to a high population demand for different cultivation practices, similarly, the grassland has decreased because of it. Andit Tid watershed is one of the most known cereals production areas in the country [21].

Table 6.
LULC Transition Matrix between 1984 - 1996, 1996-2008, and 2008-2017 at Andit Tid watershed.

LULC Type		LULC of 1996				Loss
		Plantation Forest	Bushland	Grassland	Cultivated Land	
LULC of 1984	Plantation Forest	0	0	0	0	0
	Bushland	1.08	39.96	9	1.44	51.48
	Grassland	3.6	14.4	95.04	64.08	177.12
	Cultivated Land	6.12	17.64	27	175.68	226.44
	Gain	10.8	72	131.04	241.2	455.04
	Net gain	10.8	20.52	-46.08	14.76	
	Net Persistence Ratio	0	0.51	-0.48	0.08	
LULC of 2008						
LULC of 1996	Plantation Forest	9.27	0.36			9.63
	Bushland	3.15	68.85	0.18	1.17	73.35
	Grassland	0.63	6.93	124.65	1.98	134.19
	Cultivated Land	2.25	0.27	7.11	236.61	246.24

	Gain	15.3	76.41	131.94	239.76	463.41
	Net gain	5.67	3.06	-2.25	-6.48	
	Net Persistence Ratio	0.61	0.04	-0.02	-0.03	
LULC of 2017						
LULC of 2008	Plantation Forest	11.7	0.45	0.09	3.06	15.3
	Bushland	5.22	39.15	13.95	18.09	76.41
	Grassland	2.43	4.41	67.41	57.69	131.94
	Cultivated Land	22.59	0.9	34.2	182.07	239.76
	Gain	41.94	44.91	115.65	260.91	463.41
	Net gain	26.64	-31.5	-16.29	21.15	
	Net Persistence Ratio	2.28	-0.8	-0.24	0.12	

Note: LULC = land use and land cover.

However, the increase in population imposes greater pressure on the land and other natural resources in the watershed, which results in the degradation of the resources in quality and quantity. Population growth tends to cause the conversion of natural landscapes into use for the needs of the community resulting in changes in the land use pattern [22]. The population growth was very rapid and within this time in the watershed, there was a very rapid LULC change [23]. Similarly, according to Nurelegn and Amare [24] in the Ribb River watershed, there was the continued expansion of cultivated land and settlement over the years which has brought a significant decrease in water bodies, forests, and bush LULC classes.

This threatens both the local highland users through a reduction in soil productivity and lowlands through sedimentation. The study by Yitafere [25] from the analysis of satellite images (between 1985 and 2001) has also found that in the Lake Tana basin croplands have increased to about 4.2% in 15 years (between 1985/86 and 2001/03), which largely occurred at the expense of grassland and shrubland. As Yitafere [25] indicated land use/ land cover in the upstream of Ribb and adjoining watersheds are being degraded contributing to the flood hazard prevailing in the area. Since the Ribb Watershed has been subjected to prolonged use for agriculture without conserving natural resources, forest degradation, loss of biodiversity, shortage of fuelwood, and forage trees are vegetation-related problems existing in the area [26].

There was a demand for agriculture and settlement lands for the increasing population and obtaining fuelwood from open access woodlands. This has led to the expansion of agriculture and settlement lands by clearing bushlands and grasslands (Table 4). This implies that population growth in Andit Tid watershed was one of the causes of conversion of bushland and grassland into farm and cultivated lands within the stated periods and its final consequence is the disturbance of the ecosystems of the watershed. Also, in most East African countries, areas under canopy cover were converted into grazing land, farmland, or charcoal production [21].

Similar studies by Luca [27] in West Bengal revealed that area under dense forests decreased from 58% in 1990 to 33% in 2000 but increased to 39% in 2005, whereas open forest has increased from 10% in 1990 to 22% in 2000 but again decreased to 7% in 2005. The LULC change analysis of Andit Tid watershed indicated that plantation forest coverage has been increased continuously from 1984 (zero ha) up to 2017 (41.94 ha), whereas the grassland coverage has been decreased continuously from 1984 (183.6 ha) up to 2017 (115.65 ha). Bushland coverage increased continuously from 1984 (52.2 ha) up to 2008 (76.41 ha) and then decreased from 2008 to 2017 (44.91 ha). Due to the Andit Tid watershed development and rehabilitation for a long time by different organizations, the plantation forest has been increased. Expansion of plantation forestry both industrial and non-industrial on currently uncultivated and sloping lands is one strategy to overcome land degradation on the Ethiopian highland [28].

Moreover, Ethiopia has been a global leader in landscape restoration, including a recently launched, massive tree-planting campaign. Coupled with a renewed effort to protect remaining standing forests (and other ecosystems of value), this will provide immediate benefits to rural land users. In this study, grassland has been decreased significantly and continuously from 1984 to 2017 that could decrease the role of such land-use types to ecosystem services such as carbon stock and sequestration [29].

The land is very much intertwined with human culture and identity in the watershed. It is also the main asset that farmers have to accumulate wealth. Accordingly, the size of the land that they own and the level of security they have in their holdings affect a household's income, and their incentive to work and to invest in it [30]. From the researcher's personal experience and observation and discussion with the community in the area, farmers did not have enough land and they have not practiced the use of chemical fertilizers because of the high cost. Instead, they try to expand their plot by clearing bushland and grasslands near their plot of farmlands [21]. The farmers, because of lack of land, plow steep slopes with no more products. Their farming system has been the most ancient type and has no attached technique for managing soil loss. Thus, for the land to be secured and used in a long and sustainable manner the landholding system should be private. However, the landholding system in the study area in particular and in the country, in general, has been in the hands of the government for a long time. Indeed, the change was related mainly to anthropogenic factors.

5. Conclusion

The main characteristics of the LULC changes observed in Andit Tid watershed imply a reduction in the total amount of bushland and grassland and a significant increase in cultivation and plantation forests. This shows the dynamic conditions of land cover change in the study area. The demand for agriculture and settlement for increasing population and expansion of agriculture led to the clearing of bush and grasslands in Andit Tid watershed. These changes continuously alter the spatial patterns of the landscape and greatly modify the entire landscape of the watershed. As the area needs urgent action, sustainable land management approaches should be integrated with the traditional farming and non-farming uses of land in the watershed. Combining practical action with research can help a practice to be supported with scientific evidence.

Acknowledgments

Debre Birhan University, Ethiopia is duly acknowledged for financing this study.

Data Availability

The data used to support the finding and conclusion of this study are included within the manuscript.

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