

1 **Characteristics of Deforestation in the Democratic People's Republic of Korea**
2 **(North Korea) between the 1980s and 2000s**

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ABSTRACT

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34 There has been a significant lack of land cover change studies in relation to deforestation in the
35 Democratic People's Republic of Korea (North Korea). The purpose of this study is to
36 characterise deforestation in North Korea through land cover change trajectory and spatial
37 analysis. We used three 30-m gridded land cover data sets for North Korea representing the
38 conditions of the late 1980s, 1990s, and 2000s, respectively, as well as a digital elevation model.
39 We examined the land cover trajectories during the two decades, i.e. which land cover became
40 which at the pixel level. In addition, we calculated topographic characteristics of deforested pixels.
41 Major findings from the study are summarised as follows: (1) net forest loss in North Korea
42 slowed since the 1990s, whereas land cover changes were active; (2) as a result of deforestation,
43 forest land cover became mostly agricultural and grassland; (3) expansion of agricultural land
44 cover continued during the time; and (4) elevation and slope of deforested areas decreased slightly
45 in the latter decade. The key contribution of the study is that it has demonstrated which land cover
46 became which at the 30-m pixel level, complementing existing studies that examined overall
47 forest stock in North Korea.

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49 **Keywords:** *Deforestation; North Korea; Forest; Land Cover; Spatial Distribution*

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INTRODUCTION

Land use/cover change results in significant consequences in the environment, in terms of climate (e.g. Findell et al. 2007), hydrology (e.g. Sajikumar & Remya 2015), and ecology (e.g. Parton et al. 2005), among others. Deforestation, which implies the long-term or permanent loss of forest cover and its transformation into another land cover, is one of the most widespread issues of land cover change. During the period 1990-2010, Africa and South America lost millions of hectare of forest per decade respectively, particularly in Brazil and Nigeria, by far exceeding other continents (FAO, 2010). Naturally, deforestation taking place in the Amazon or the tropics in general tends to have received most of the attention in recent decades, but deforestation is also of great concern in Asia, the most populous continent in the world (Zhao et al, 2006). This study presents results from an analysis of deforestation in the Democratic People's Republic of Korea (also known as North Korea).

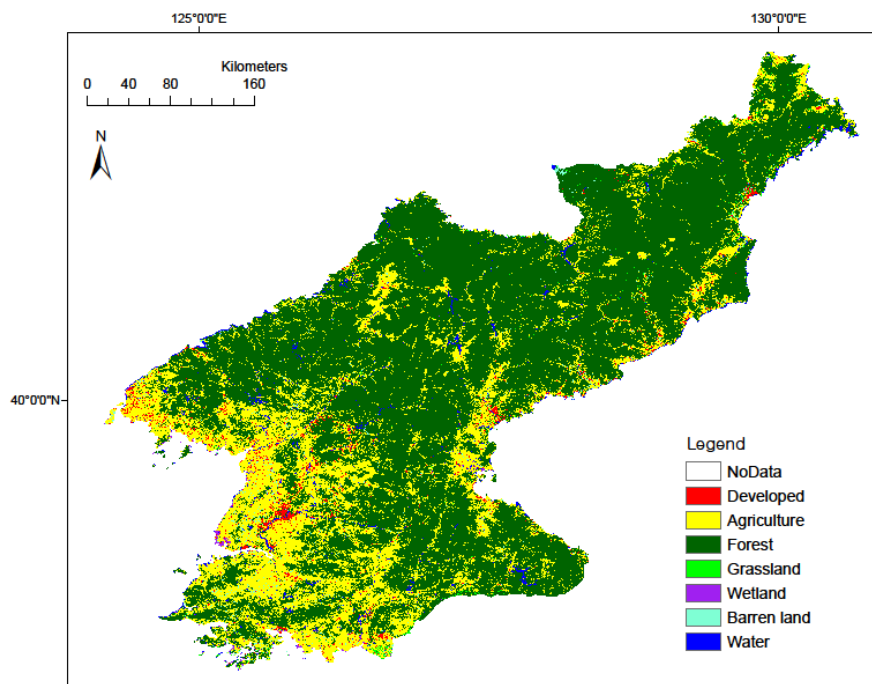
Deforestation in general has many direct and indirect causes. The overwhelming direct cause of deforestation is agriculture. Deforestation from subsistence and commercial farming is totaling about 70% of the total deforestation according to the United Nations Framework Convention on Climate Change (UNFCCC, 2007). The majority of studies of deforestation point out the expansion of agricultural practices as the major global cause (Debolini et al, 2013). Geist & Lambin (2002) found that agricultural expansion was by far the leading land use changes associated with nearly all tropical deforestation case. Demand for land for grazing is another important driving factor of deforestation in Latin America and Africa (FAO, 2012). Agricultural expansion and timber harvest were primary causes of large-scale deforestation in Asia (Zhao et al., 2006).

Forest cover declined in Asia between 1990 and 2000 but increased later (FAO, 2010). There is also substantial regional variability in the forest cover change in Asia. For example, China's afforestation efforts greatly contributed to the forest cover increase after 2000, but South and Southeast Asian countries continued to lose net forest at high rates (FAO, 2010). Forest cover continued to decrease in North Korea (Engler et al, 2014). Deforestation accelerated in North Korea during the 1990s compared to the preceding decade not only in terms of quantity but also in shape (Kang & Choi, 2014). Deforestation in North Korea in recent decades has been receiving

112 1:50 000 scale so that 487 maps were produced to cover the entire North Korea for each term.

113 For the accuracy assessment, MoE derived samples from the center of the 1 minute grids
114 of each 1:50,000 digital map (15'×15') so that 225 samples were checked for each map. As
115 reference data, topographic maps for North Korea (1:50 000), military base maps (1:50 000) by
116 the Republic of Korea Army Mapping Agency, forest type maps, and vegetation maps were used.
117 According to the land cover map guideline by MoE (2013), the land cover data had more than 70%
118 accuracy for classification in the North Korean region. The land cover maps have seven land
119 cover classes: Water, Developed, Barren Land, Grassland, Wetland, Forest, and Agriculture
120 (upper cases were used in this document to represent land cover classes from the data sets). The
121 meaning of each class is presented in Table 1. Fig. 1 shows that Forest is the predominant land
122 cover, located mostly in eastern and northern parts of the country. Agricultural lands are
123 concentrated in western and coastal regions.

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125

126 **Fig. 1 Land cover of North Korea from the 2000 data set**

127

128 Land cover changes over time at each pixel were analyzed using a change trajectory
129 approach on ArcGIS 10[®]. Here the trajectory approach specifically means identifying the
130 succession of land cover over time at a particular location, as was conducted for gridded land

131 cover data sets by Feng & Liu (2014) and Wang et al. (2013). In the studies, the final resulting
 132 grids have cell values that indicate the land cover at each time represented by each input grid. In
 133 this study, it was implemented according to the following steps. First, for the most recent land
 134 cover data set (the 2000 data set), each land cover class was assigned a number from 1 to 7 as
 135 pixel attributes (Table 1). Second, for the 1990 data set, each land cover class was assigned a
 136 number from 10 to 70, with 10 corresponding to 1 and 70 to 7 in the 2000 data set respectively.
 137 Third, in the same way, each land cover class in the 1980 data set was assigned a number from
 138 100 to 700. Fourth, all three layers were overlaid and corresponding pixel values were added. The
 139 final three digit pixel values indicate the land cover change trajectory at the pixel. For example, a
 140 pixel value 342 means that the pixel was Forest in the 1980s, became Grassland in the 1990s, and
 141 then Agriculture in the 2000s. Two or three consecutive identical codes indicate no changes
 142 during the time spans. We acknowledge the land cover classification error, thus the results must
 143 be interpreted with caution. We generally neglect changes that occurred to small extents.

144 **Table 1. Land cover codes used for change trajectory analysis**

Land cover class (notes from MoE (2013))	1980	1990	2000
Developed (includes built-up areas such as residential, commercial, industrial, transportation)	100	10	1
Agriculture (includes crop fields, orchards, and dairy farms)	200	20	2
Forest (land where trees and shrubs grow collectively)	300	30	3
Grassland (land covered by herbaceous plants, including both natural and man-made grasslands)	400	40	4
Wetland (land that remains naturally saturated with water)	500	50	5
Barren land (bare ground without vegetation)	600	60	6
Water (includes lakes, reservoirs, and swamps)	700	70	7

145
 146 A Digital Elevation Model (DEM) was used to measure the elevation of the deforested
 147 areas. DEM data were downloaded from ASTER global DEM (GDEM) Web site (NASA, 2012).

148 The spatial resolution of GDEM data is 30m. The data sets were projected to a Universal
 149 Transverse Mercator (UTM) projection, JGD 2000 UTM Zone 52N (North Korea). Slope values
 150 were then calculated from the DEM.

151 The deforested areas were derived by partially implementing the change trajectory
 152 approach. For deforestation between the 1980s and 1990s (1980s-1990s), two grid layers were
 153 overlaid to add the values as in Table 1. Then only the pixels that were Forest in the 1980s and
 154 became something else in the 1990s were extracted and reclassified to the pixel value of 1.
 155 Deforestation between the 1990s and 2000s (1990s-2000s) was derived in the same manner. This
 156 data were used to calculate the elevation and slope of the deforested areas, taking the product of
 157 the DEM and slope layers with each of the reclassified deforestation grids.

158 RESULTS AND DISCUSSION

159 *Magnitude of deforestation and other land cover change*

160 The results show a significant decrease in Forest between the 1980s and 1990s (Table
 161 2). The decrease is only 6%, but the areal extent is more than 5 000 km². During the same period,
 162 Developed increased by 44%, Agriculture 12%, and Grassland 24%. Agriculture increased by
 163 more than 2 600 km², which is more than half the size of deforestation. Between the 1990s and
 164 2000s, Forest barely changed in its areal extent, but Agriculture increased by 27% and Grassland
 165 decreased by 91%. It is interesting to note that Developed decreased by 5% during the 1990s-
 166 2000s. We speculate that it could be partly due to classification error but also conversion of
 167 abandoned built-up lands to other land covers. There are some conflicting reports regarding forest
 168 cover change in North Korea in the 2000s. Kang and Choi (2014) reported a large forest cover
 169 decrease between the 1990s and 2000s from 100-m-resolution land cover data sets, but Engler et
 170 al. (2014) reported little change in per-pixel tree cover percentage between the early and late
 171 2000s from MODIS (moderate-resolution imaging spectroradiometer) data. The per-pixel tree
 172 cover percentage decreased a lot between the early 1990s and the early 2000s (Engler et al. 2014).

173 **Table 2. Areal extent (in km²) of each land cover class calculated based on the number of**
 174 **pixels and the spatial resolution of the land cover datasets. Numbers in parentheses are**
 175 **percent changes from the previous dataset.**

Data set	1980	1990	2000
Land cover			

Developed	1 405	2 030 (44%)	1 933 (-5%)
Agriculture	21 318	23 965 (12%)	30 344 (27%)
Forest	91 874	86 565 (-6%)	86 428 (0%)
Grassland	5 027	6 238 (24%)	543 (-91%)
Wetland	447	359 (-20%)	275 (-23%)
Barren land	983	1 826 (86%)	1 207 (-34%)
Water	1 497	1 546 (3%)	1 826 (18%)

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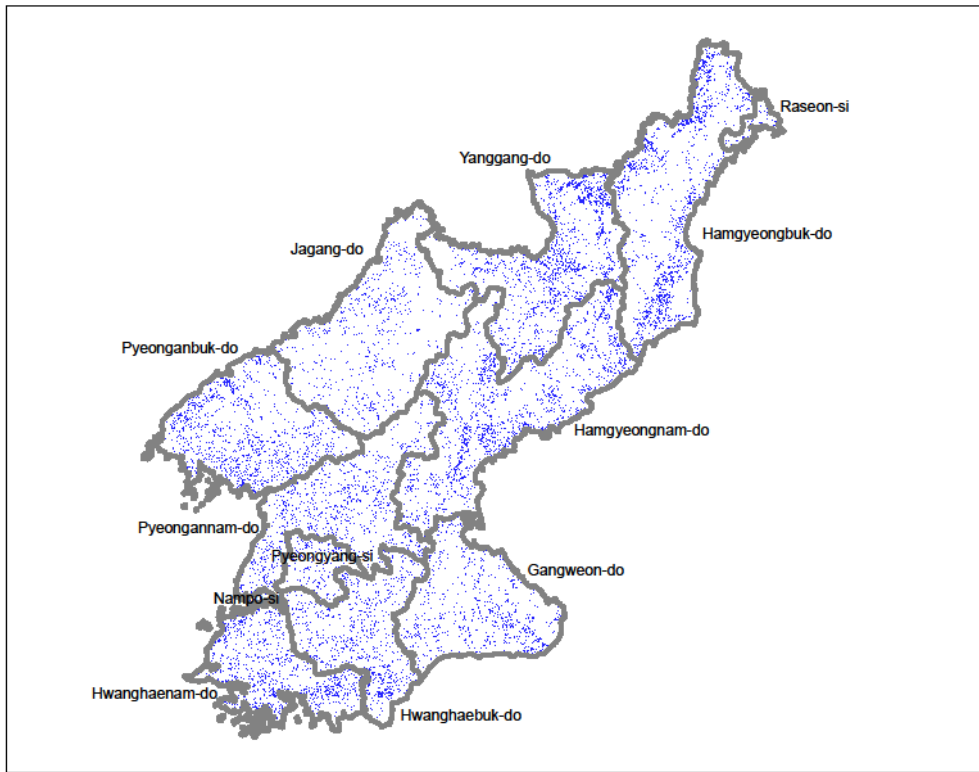
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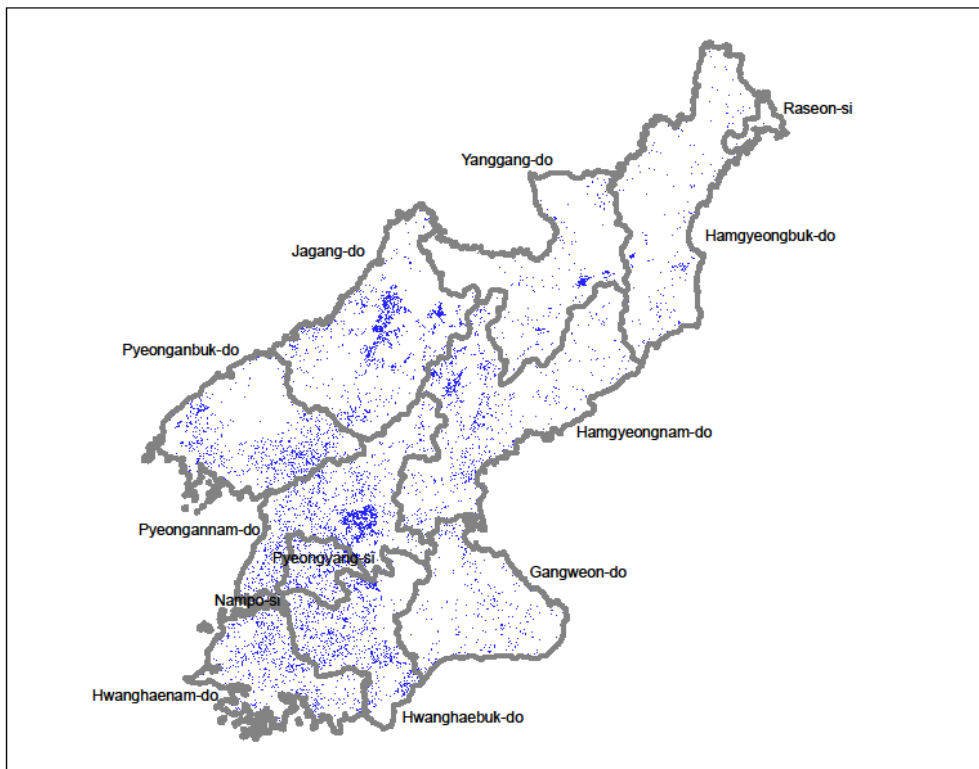
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Fig. 2 portrays the extent of deforested areas for each of the two decades overlaid by provincial boundaries. The upper panel shows the pixels that was Forest in the 1980 data and became something else in the 1990 data. The lower panel shows the pixels that was Forest in the 1990 data (regardless of whether they were Forest or something else in the 1980 data) and became something else in the 2000 data. Between the 1980s and 1990s, deforestation occurred in much of the country. On the other hand, deforestation during the 1990s-2000s appears to have concentrated in western provinces (*si* and *do*) such as Jagang-do, Pyeonganbuk-do, Pyeongannam-do and Pyeongyang-si. Pyeongyang (also known as Pyongyang) is the capital of and the largest city province in the country and deforestation is quite visible in and outside of Pyeongyang between the 1990s and 2000s. Jagang-do is a very remote and mountainous province, and deforestation was quite intensive in the middle of the province during the period. In both decades, deforestation was fairly widespread across the country, except in very inland areas (e.g. Yanggang-do) which are mostly high mountains and plateaus.

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193 **Fig. 2** Areas where deforestation occurred during the 1980s-1990s (upper panel) and the

194 **1990s-2000s (lower panel) respectively**

195

196 This rapid decrease in Forest during the 1980s-2000s is alarming but not surprising,
197 given the literature which stated increasing dependence on these resources due to natural disasters
198 and flooding (UNEP, 2003; Myeong & Hong, 2009). The significant increase in Agriculture also
199 closely agrees with these works, which noted the natural disasters that caused destruction of
200 previous agricultural land and more clear-cutting of forests, as well as food shortages in the
201 country.

202 Economically, North Korea continued a negative economic growth since 1991 and the
203 total food supply was reduced (Table 3). It caused a lot of people to starve to death since the mid-
204 1990s (Kim, 2009). Since 1994, food imports to North Korea were also rapidly reduced for two
205 reasons. Domestically there was a lack of foreign currency due to economic deterioration and the
206 lack of substitute exports. Internationally, China reduced the grain exports from northeastern
207 China in the mid-1990s because of the food shortage caused by flooding in southern China (Kim
208 & Park, 1995). In addition, when droughts and floods ruined harvests in the 1990s, a famine was
209 touched off and claimed numerous lives. Villagers desperately scoured forests for food and fuel
210 (Stone, 2012).

211

212 **Table 3. Grain production and gross domestic product (GDP) growth rate during the 1990s**
213 **in North Korea (Lee, 2008)**

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Grain Production (ton)	443	427	388	413	345	369	349	389	422	359
GDP Growth Rate (%)	-3.5	-6.0	-4.2	-2.1	-4.1	-3.6	-6.3	-1.1	6.2	1.3

214

215 ***Land cover change trajectories regarding forest***

216 The entire land cover change matrices are presented in Tables 4 and 5. Table 4 shows
217 how each of the seven land cover classes in the 1980s (rows) changed by the 1990s (columns)
218 both in terms area (km²) and percentage. Pixels of Agriculture remained mostly Agriculture
219 (66.1%) and 17% of it became Forest and 12% became Grassland by the 1990s. Forest did not

220 change much in terms of percentage, with 87.9% of Forest pixels remaining Forest and 7.2% of
 221 it becoming Agriculture in the 1990s. However, the absolute size of the Forest-to-Agriculture
 222 conversion is quite large (6 602 km²), almost half that of Agriculture-to-Agriculture and larger
 223 than any other entry in the table. It is also much larger than the Agriculture-to-Forest conversion
 224 (3 630 km²). We also note that the Grassland-to-Agriculture conversion (2 172 km²) is much
 225 larger than the Agriculture-to-Grassland conversion (1 541 km²).

226 **Table 4. Land cover change matrix between the 1980 and 1990 data sets. Integer entries are the**
 227 **area (in km²) of corresponding changes and percentage entries are with respect to the sum on each**
 228 **row. Rows are for the 1980 data and columns are the 1990 data. For example, 87.9% of Forest (80**
 229 **741 km²) in the 1980 data remained Forest in the 1990 data while 7.2% (6 602 km²) of it became**
 230 **Agriculture.**

1990 data \ 1980 data	Developed	Agriculture	Forest	Grassland	Wetland	Barren land	Water	Sum
Developed	741 52.8%	387 27.6%	106 7.6%	88 6.3%	13 0.9%	47 3.3%	20 1.4%	1 403 100%
Agriculture	859 4.0%	14 093 66.1%	3 630 17.0%	1 541 7.2%	46 0.2%	968 4.5%	168 0.8%	21 305 100%
Forest	246 0.3%	6 602 7.2%	80 741 87.9%	3 771 4.1%	26 0.0%	369 0.4%	107 0.1%	91 861 100%
Grassland	91 1.8%	2 172 43.2%	1 864 37.1%	692 13.8%	10 0.2%	166 3.3%	29 0.6%	5 025 100%
Wetland	24 5.5%	106 23.8%	29 6.6%	22 4.9%	186 41.9%	21 4.7%	56 12.7%	445 100%
Barren land	41 4.2%	478 48.7%	119 12.2%	80 8.1%	7 0.7%	205 20.9%	51 5.2%	980 100%
Water	27 1.8%	123 8.2%	69 4.6%	43 2.9%	69 4.7%	48 3.3%	1,109 74.5%	1 489 100%

231

232 Table 5 is the change matrix between the 1990s and 2000s. The Forest-to-Agriculture
 233 conversion took place over an area of 7 196 km², increasing by 9% of the same change between
 234 the 1980s and 1990s. It is worth noting that conversion to Forest occurred to a large extent as well.
 235 The Agriculture-to-Forest conversion occurred over an area of 3 462 km² and the Grassland-to-
 236 Forest conversion over 3 575 km². The Grassland-to-Agriculture and Forest-to-Agriculture
 237 conversions occurred a lot as well, over areas of 2 205 km² and 7 196 km², respectively.
 238 Examination of the maps reveals that the Agriculture-to-Forest conversion spreads out across the
 239 country, but the Grassland-to-Forest conversion particularly concentrates in Yanggang-do, one of
 240 the most remote and densely forested areas.

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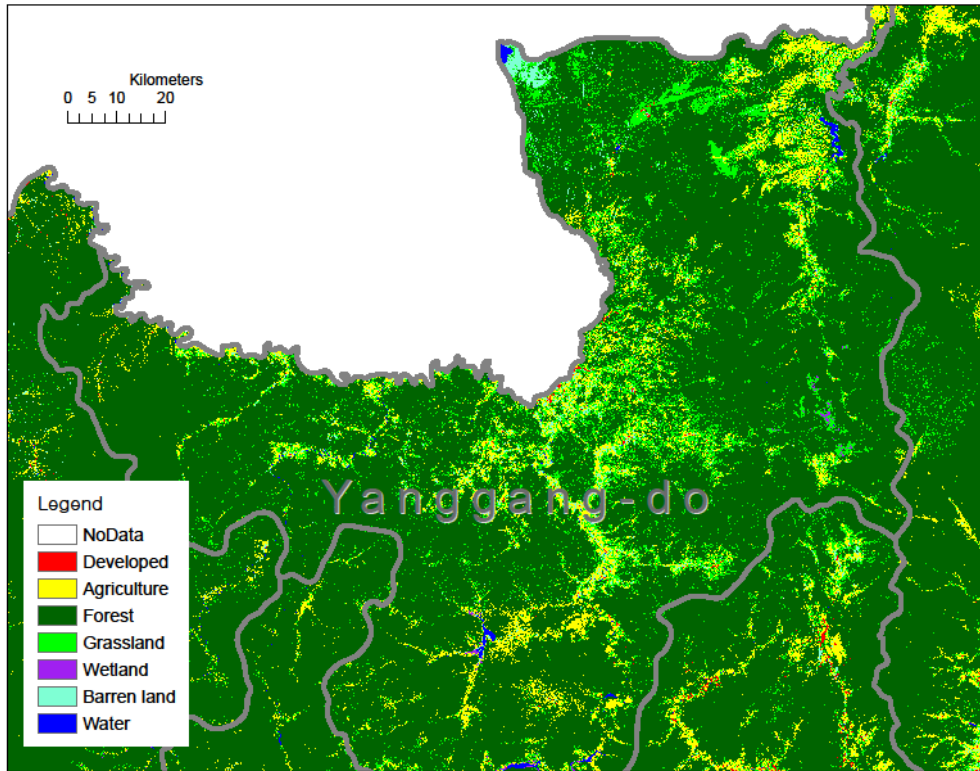
242 **Table 5. Same as Table 4 but for the 1990 and 2000 data sets**

2000 data \ 1990 data	Developed	Agriculture	Forest	Grassland	Wetland	Barren land	Water	Sum
Developed	1 019 50.2%	724 35.7%	169 8.3%	15 0.7%	10 0.5%	58 2.8%	35 1.7%	2 029 100%
Agriculture	571 2.4%	19 097 79.7%	3 462 14.4%	147 0.6%	36 0.2%	397 1.7%	251 1.0%	23 961 100%
Forest	125 0.1%	7 196 8.3%	78 865 91.1%	129 0.1%	10 0.0%	107 0.1%	128 0.1%	86 559 100%
Grassland	105 1.7%	2 205 35.4%	3 575 57.3%	235 3.8%	5 0.1%	54 0.9%	58 0.9%	6 236 100%
Wetland	13 3.7%	97 27.3%	23 6.5%	1 0.3%	180 50.6%	8 2.1%	34 9.4%	356 100%
Barren land	82 4.5%	893 48.9%	220 12.0%	13 0.7%	8 0.5%	545 29.8%	64 3.5%	1 825 100%
Water	15 1.0%	114 7.4%	101 6.5%	4 0.2%	23 1.5%	37 2.4%	1 245 80.9%	1 539 100%

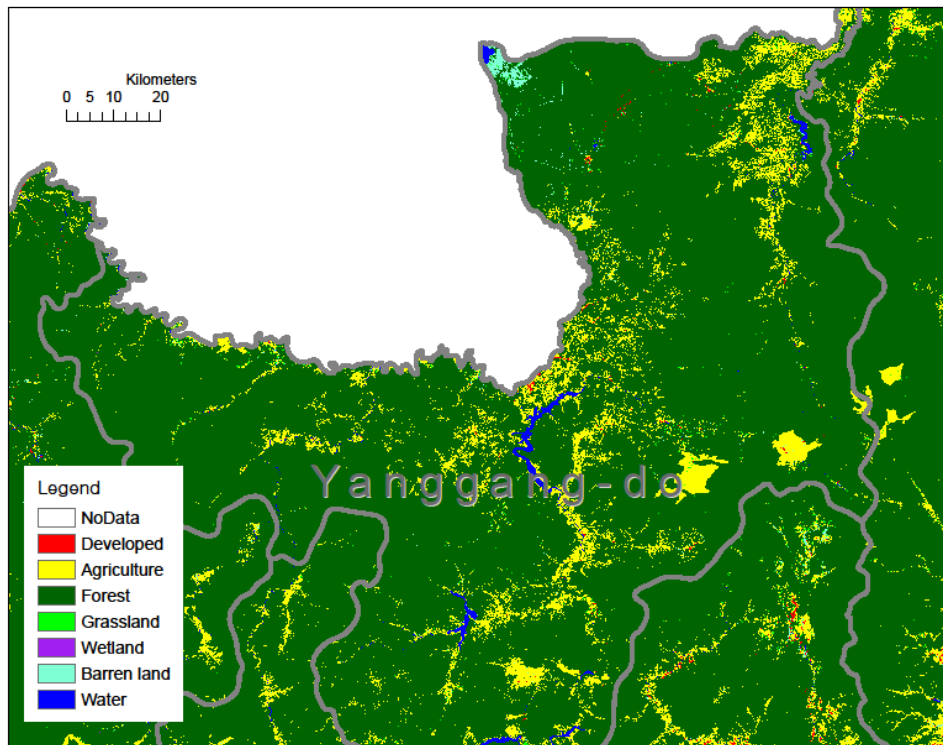
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244 Fig. 3 illustrates the Grassland-to-Forest conversion in Yanggang-do during the 1990s-
 245 2000s. In the 1990s, Grassland was quite widespread, located mostly between Agriculture and
 246 Forest (Fig. 3 upper panel). In the 2000 data (Fig. 3 lower panel), much of the Grassland appears
 247 as Forest or Agriculture. Between the 1980s and 1990s, many Forest pixels became Grassland or
 248 Agriculture (not shown). Here an overarching phenomenon is the expansion of Agriculture. The

249 Forest-to-Grassland conversion during the 1980s-1990s was probably due to efforts to obtain
250 firewood or to cultivate. During the 1990s-2000s, it seems Grassland changed to Agriculture or
251 vegetation continued to grow over Grassland, resulting in being classified as Forest.
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255

256 **Fig. 3 Land cover over Yanggang-do from the 1990 data set (upper panel) and 2000 data set**
 257 **(lower panel) respectively**

258

259 Table 6 shows land cover changes from Forest to other classes. Between the 1980s and
 260 1990s, deforestation resulted mostly in Agriculture and Grassland. Of the Forest pixels that did
 261 not change during the 1980s-1990s, 5 033 km² of them changed to another land cover between
 262 the 1990s and the 2000s, almost exclusively to Agriculture. The conversion to Agriculture
 263 decreased in absolute terms, but it remained the most predominant conversion. On the other hand,
 264 the conversion to Grassland decreased dramatically. As found in Table 2, Grassland overall
 265 decreased substantially during the 1990s-2000s whereas Agriculture increased by 27%. The fact
 266 that about 60% of deforestation between the 1980s and 1990s resulted in Agriculture coincides
 267 with the massive food shortage during the 1990s. The large conversion from Forest to Grassland
 268 during the time is probably because trees were cut for firewood or conversion to agriculture is left
 269 incomplete. The Forest-to-Agriculture conversion continued during the 1990s-2000s but more
 270 slowly.

271

272 **Table 6. Areal extent (in km²) of land cover changes from Forest to each of non-forest land**
 273 **cover classes. The second column shows the changes from Forest to non-forest cells during**

274 the 1980s-1990s. The third column shows the changes from Forest that did not change
 275 during the 1980s-1990s but changed during the 1990s-2000s.

Change from Forest to	Time	80-90	90-00
Developed		246	39
Agriculture		6 602	4 780
Grassland		3770	94
Wetland		26	4
Barren land		369	47
Water		107	70
Total		11 120	5 033

276

277 Table 7 shows land cover changes that eventually resulted in Forest between the 1980s
 278 and 2000s. The overall size of forest cover as a result of land cover change is 10 706 km²,
 279 approximately double the size of the overall forest cover decrease (5 446 km² from Table 2) during
 280 the same period. Grassland, Forest, and Agriculture are the most important sources of conversion
 281 to Forest. Here conversion from Forest to Forest means ‘Forest-something else-Forest’
 282 conversions. When Forest turned to something else in the 1990s, it mostly turned to Grassland
 283 and Agriculture. Conversion to Forest from other land covers is quite negligible.

284

285 **Table 7. Land cover changes from non-forest to Forest (km²) during 1980s-2000s. The**
 286 **change from Forest to Forest indicates that Forest became non-forest and became Forest**
 287 **again.**

To Forest from	
Developed	121
Agriculture	3 342
Forest	4 879
Grassland	2 050
Wetland	44

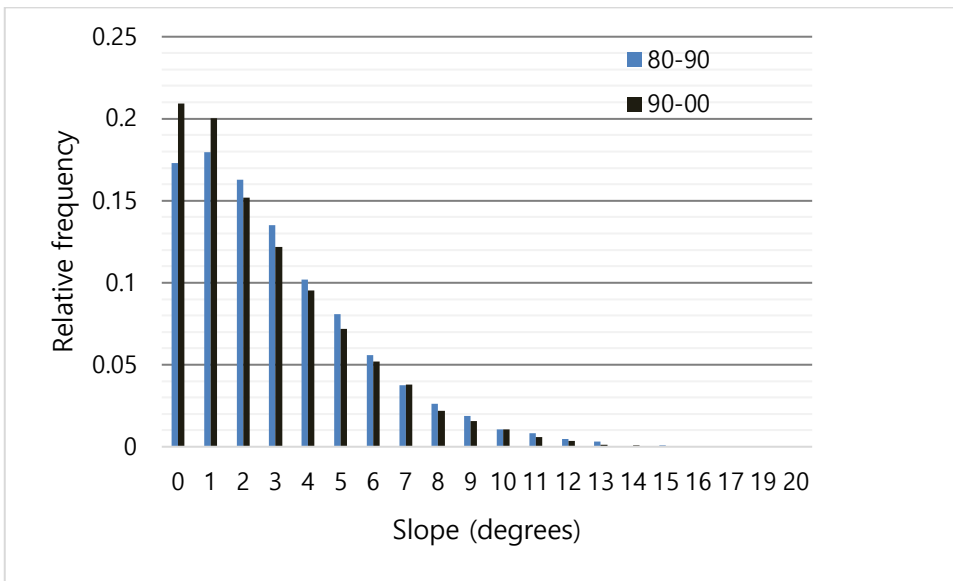
Barren land	155
Water	115
Total	10 706

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290 ***Slope and elevation in deforested areas***

291 The maximum slope in the deforested areas during the 1990s-2000s was 17.3°,
 292 decreasing from 20.2° during the 1980s-1990s. On average, slope slightly decreased from 3.52°
 293 to 3.24°, which is not statistically significant. The distribution of deforested areas by slope is
 294 portrayed in Fig. 4 as relative frequency. The distribution by slope is somewhat different between
 295 the two periods. During the latter decade, deforestation occurred in areas of slightly gentler slope
 296 than the earlier decade. It coincides with the large size of deforestation in western provinces where
 297 most of the plains are located.



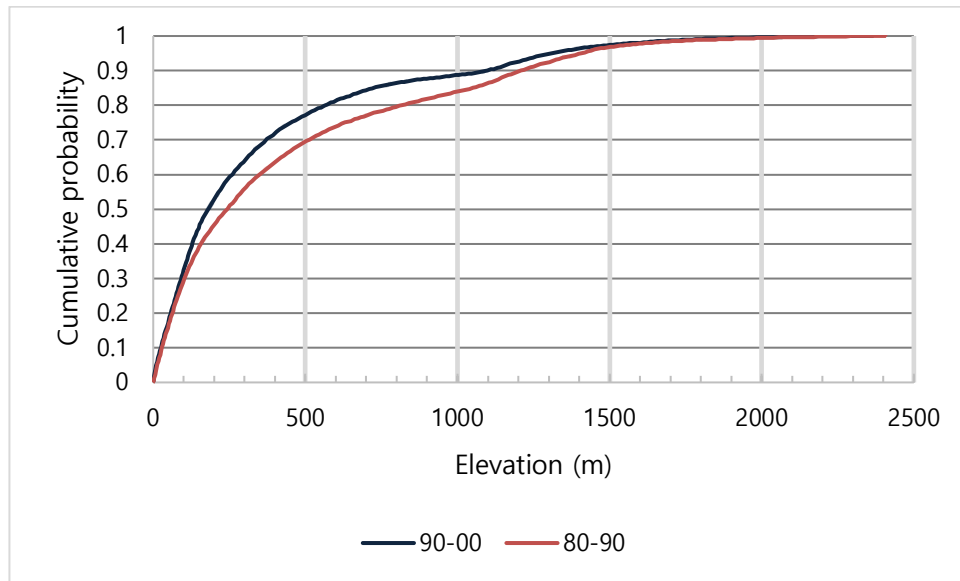
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299 **Fig. 4 Relative frequency of deforested areas by slope for the 1980s-1990s (left bars) and**
 300 **1990s-2000s (right bars) periods**

301

302 The maximum elevation of deforested areas slightly decreased from 2 415 m for the
 303 1980s-1990s to 2 367 m for the 1990s-2000s. The mean elevation shows a somewhat large
 304 decrease, from 434 m for the 1980s-1990s to 354 m for the 1990s-2000s. The distribution of
 305 deforested areas by elevation is portrayed in Fig. 5 as cumulative probability. Unlike slope,

306 elevation has far too many unique values, thus we decided to show as cumulative probability. The
307 figure shows a noticeable difference for the elevation range of 200-1 500 m, reflecting the
308 decrease in the mean elevations of deforested areas. For example, during the 1980s-1990s, about
309 80% of deforestation occurred under 800 m, but during the 1990s-2000s, the proportion was
310 almost 90%. The decrease in the mean elevation may mean that deforestation is more active at
311 the lower elevation areas, which may be near urban areas or agricultural fields.



312

313 **Fig. 5 Cumulative probability of deforested areas by elevation for the 1980s-1990s and the**
314 **1990s-2000s periods**

315

316 CONCLUSIONS

317 Much of previous work in deforestation has mainly focused on issues related to tropical
318 deforestation, and studies regarding North Korea have been sporadic. Especially, North Korea is
319 a unique area of interest in relation to deforestation because of natural disasters, imprudent
320 policies, and striving for self-reliance, requiring enormous demand for forest resources. This
321 study attempted to examine the deforestation in terms of land cover change trajectory and its
322 spatial characteristics between the 1980s and the 2000s using three land cover data sets
323 representing each decade. The results are summarised as follows: (1) net forest loss in North
324 Korea slowed since the 1990s, whereas land cover changes were active; (2) as a result of
325 deforestation, forest land cover became mostly agricultural and grass lands; (3) expansion of

326 agricultural land cover continued during the time; and (4) deforestation appears to have occurred
327 more frequently in areas of slightly lower elevation and gentler slope during the 1990s-2000s than
328 the earlier decade. The key contribution of the study is that it has demonstrated which land cover
329 class became which at the pixel level, complementing existing studies that examined overall forest
330 stock in North Korea. The finding that deforestation mostly resulted in Agriculture and Grassland
331 corroborates the existing explanation for deforestation, food and fuel shortage.

332

333 Acknowledgment

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