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ARTICLE

Prioritizing locations for the riparian establishment based on spatiotemporal change of riparian forest area at a watershed scale

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Abstract A majority of streams in Korea have been channelized and their adjacent flood plains have been converted for anthropogenic land use, especially in urbanized areas. Fortunately, recent elevated public recognition to the stream ecosystem has led to governmental efforts to conserve riparian areas. In this study, a simple method to prioritize locations for riparian establishment was developed at a watershed scale based on spatiotemporal change of riparian forest area. The developed method was applied for the Ansung and Sapkyo watersheds, which were under consideration for the stream riparian area establishment by the Korean Ministry of Environment. Two riparian forest indices, Riparian Forest Index (RFI) and Riparian Forest Change Index (RFCI) were developed to represent spatial and temporal change of watershed riparian forest, respectively. LANSAT satellite images with a 30 m × 30 m resolution were used to estimate the two riparian forest indices. A precautionary approach, which intends to preserve the existing riparian forests as much as possible, was applied by ranking sub-watersheds based on the two riparian forest indices to prioritize locations for the riparian establishment at a sub-watershed level. The results showed that overall urban land cover in riparian areas increased while forests and cropland decreased over the past 25 years. More importantly, riparian forest removal occurred more rapidly in the riparian area, which is one of the most important niches for riparian ecosystems, as compared to the entire watershed. Most riparian forests appeared to be located upstream of the watersheds, and thus it is important to develop management measures to preserve existing riparian forests from human activities. The developed approach could be a useful tool that can assist policy makers to prioritize locations for the riparian area establishment. However, this method has limitations of only considering riparian forest area and therefore, other aspects such as stream morphology as well as ecology needs to be incorporated into riparian area determination process as they become available in the future. In addition, considering that substantial portions of riparian areas have already been disturbed, the restoration aspect of the impaired riparian also needs to be investigated further.

Keywords Riparian forest · Land cover analysis · Prioritization · Riparian area establishment · Riparian index

Introduction

Urbanization with rapid economic growth over the last several decades has intensified urban land use for the ever-growing metropolises in Korea. Subsequently meandering streams were straightened by embanking and channelizing river systems, and natural flood plains were transformed for anthropogenic land use. During the course, the various environmental and ecological functions of the riparian areas including wildlife habitats, sediment and contaminants reduction, surface flow retention, and landscape improvement, were deteriorated (USDA Forest Service

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1998; Parkyn 2004). Fortunately, public concern about riparian area degradation has been elevated in Korea leading to the governmental efforts to restore or rehabilitate stream ecosystem. The Cheonggae stream restoration completed in 2005 gained enormous popularity and became a milestone of the Korean stream restoration project. Afterward, the Korean Ministry of Environment launched a River Ecological Restoration Project in 2005 planning invest approximately a billion dollar every year until 2015 for the ecological restoration of impaired streams mostly in urban areas (Korean Ministry of Environment 2007).

Gregory et al. (1991) outlined the important relations and dynamics riparian zone by defining it as the area of direct interaction between terrestrial and aquatic ecosystems. Riparian areas have been defined and named differently by individual researchers, and include terms such as riparian buffer, vegetated filter strip, vegetated wetland, riparian forest buffer, etc. (USDA Forest Service 1998). For the establishment of riparian areas, adjacent land use is of great importance among other factors including slope, stream order, vegetation type, hydrology, and soil (USDA Forest Service 1998; Wenger 1999; Hawes and Smith 2005). According to Alexander et al. (2007), headwater streams have profound influence on the biological integrity of entire river networks. Harding et al. (1998) found that past land use is a determinant of present species diversity in streams and conversion of forest to agriculture may result in reduction in biodiversity. Riparian vegetation serves many physical and biological functions such as sediment trap, flood control, nutrient uptake, and support for diverse community of species (Naiman et al. 1993; Lowrance et al. 1997). Especially when riparian zones are forested with trees, additional services including stream temperature moderation, carbon sequestration, structural habitat for amphibians, birds, mammals, and aquatic organisms (Bentrup 2008). As such, a riparian forest buffer provides an important habitat for riparian ecosystems, and is closely related with ecological stream integrity and high biodiversity.

Claggett et al. (2010) have developed a simple approach of estimating riparian forest cover change over large areas and implemented to a county area in Maryland from 1993/1994 to 2005 to evaluate the efficacy of riparian restoration efforts. To determine locations to establish riparian areas for water quality management, Randir et al. (2001) have developed a prioritization method at the watershed level by integrating geographic information, the relationship between land criteria and effects, and the travel-time of runoff water in Massachusetts, USA. Tomer et al. (2009) reported two landscape analysis techniques for identifying and mapping locations for agroforestry buffers to effectively improve water quality. One approach was to use soil survey information to rank soil map units, while another utilized topographic and streamflow information to identify locations for effective interception of water moving towards streams. However, most previous approaches have focused on water quality protection and thus little attempt has been run to prioritize locations for riparian area establishment from the riparian ecosystem conservation point of view.

The objectives of this study were (1) to investigate and compare the spatiotemporal change of riparian forest, (2) develop appropriate indices to represent spatiotemporal changes of riparian forest area, and (3) to prioritize sub-watersheds for the establishment of riparian areas using the developed riparian forest indices. The developed method was applied for the Ansung and Sapkyo watersheds to determine priorities at a small watershed scale. These two watersheds were chosen since these two were under consideration for the stream riparian area establishment by the Korean Ministry of Environment.

Materials and method

Information on the study watershed

The two watersheds of Ansung and Sapkyo were selected in this study. These two study watersheds are located in the midwest coastal region of the Korean peninsula and have experienced rapid urbanization for the past several decades. This required government to develop measures to conserve the riparian buffer areas. Thus, the Korean Ministry of Environment has launched a study in 2008 to develop an effective way to establish riparian area, which provided a primary motive for this study.

Estuarine dike reservoirs were constructed downstream of both the study watersheds in the early 1970s. Streamside buffer area conservation was important in this region for riparian ecosystem as well as reservoir water quality protection. The size of each watershed is 1,655.7 and 1,649.9 km^2 for the Ansung and Sapkyo watersheds, respectively. The study watersheds were further divided into sub-watersheds based on the confluences of major streams. Accordingly, the Ansung watershed is composed of 18 sub-watersheds while the Sapkyo watershed includes 16 sub-watersheds as shown in Fig. 1.

The two watersheds are adjacent north to south and have very similar climatic characteristics (Table 1). Annual mean precipitation over the study region is approximately 1,250 mm, which is also similar with the annual mean precipitation of the Korean peninsula. The watershed outlets are located adjacently at the southwest corner in the Ansung watershed and at the north part of the Sapkyo watershed (see Fig. 1). The Ansung watershed has been intensely urbanized, particularly in the northern part; where the Suwon Metropolitan area is located. In contrast,

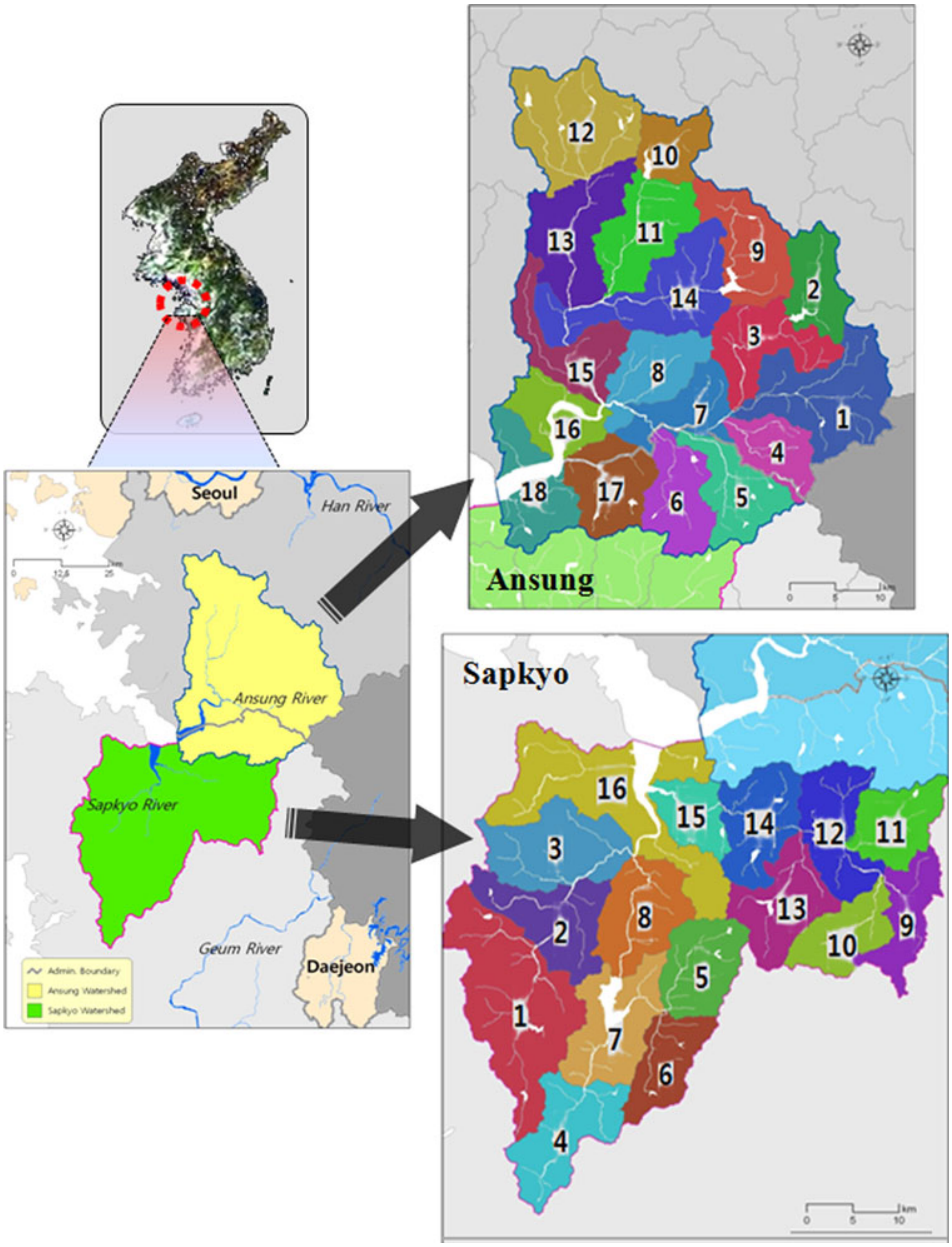

Fig. 1 Maps of the study watersheds and their sub-watersheds

Table 1 Mean climatic data for the study watersheds from 1971 to 2007 (KMA 2008)

Watershed	Temperature (°C)			Precipitation (mm)	Mean evaporation (mm)	Wind speed (m/s)	Relative humidity (%)	Sun radiation (h)	Atmospheric pressure (hPa)
	Mean	Max	Min						
Ansung	11.8	17.1	7.1	1,275.3	1,103.0	1.6	70.6	6.1	1,016.8
Sapkyo	11.6	17.5	6.3	1,242.0	1,047.8	1.5	72.7	7.0	1,016.9

urbanization in the Sapkyo watershed has occurred sporadically and agricultural paddy fields are located in the downstream area; which is the northern part of the watershed.

Landcover analysis within the riparian buffer

Land cover data at a resolution of 30 m × 30 m from LANDSAT satellite images were obtained from the Water

Management Information System (WAMIS) of the Korean government and utilized for the riparian land cover analyses. The WAMIS provides the land cover data at 5-year intervals from 1975 up until 2000 online. Land cover was classified into seven categories, i.e., urban areas, forests, water bodies, wetlands, grassland, fallow, and cropland areas. For this study, urban areas, forests, and cropland were emphasized in the analysis since forests are natural while the other two are anthropogenic.

A stream order map (STOM) and a national/local stream map (NLSM) were obtained from WAMIS and used for the riparian buffer analyses. The STOM was generated based on a 1:25,000 scale map using the Horton-Strahler classification method (Knighton 1998; Zhang et al. 2007). This method is one of the most popular stream classification methods and involves three major principles: (1) the tributary which originates at a source and has no tributary is designated as stream order one, (2) the junction of two streams with same order u is designated as stream order $u + 1$, and (3) the junction of two streams with unequal u and v is designated as steam order max (u, v) (Zhang et al. 2007).

National and local streams refer to streams designated by the Korean River Law. National streams are managed central government in Korea and their stream orders are mostly greater than 4. Local streams are administrated by local government and their orders are mostly less than 4. The streams topologies in the STOM and NLSM are line and polygon, respectively. This is because the STOM was delineated from a map, while the NLSM was generated from satellite images which allow for drawing a water body into a polygon. The orders of the national and local streams in the NLSM were mostly greater than 5, which appeared to be located relatively downstream and composed of less than 10% of the total streams length.

The two stream maps needed to be merged for the riparian buffer analysis. The STOM was overlaid onto the NLSM and the superposed part of the STOM was removed (see the schematics in Fig. 2). Since most national and local streams are downstream, the remaining STOM can be considered as headwater streams. The widths of the headwater streams were assumed to be 3, 5, 8, and 12 m for the stream orders of 1, 2, 3, and 4, correspondently. The widths were somewhat arbitrarily determined to be less than 15 m, which was the average width of the streams measured randomly on the NLSM map. The buffered STOM and NLSM with the same topology of a polygon were consolidated into a stream map. The riparian buffers were generated with the buffer widths of 30, 60, 90, 120, and 150 m in which land cover compositions were analyzed spatiotemporally.

Definition of two forest area indices

Two indices were defined based on the riparian forest area to evaluate the riparian status. This is based on the fact that the larger the riparian forest is, the more likely it is that the riparian ecosystem will be healthy and, therefore, the riparian forest may be a good proxy indicator of riparian integrity. Accordingly measures to preserve the healthier riparian area, that is, the larger riparian forests, need to be implemented. Riparian forest areas within the riparian buffer width of 150 m were utilized to estimate both the riparian indices.

The first index was the Riparian Forest Index (RFI), which is defined as the ratio of riparian forest area to total riparian area at a sub-watershed scale.

$$\mathrm{RFI} = \frac{\text{Forest area}}{\text{Total riparian area}} \tag{1}$$

The greater the value of the RFI means the healthier the riparian area and implies a higher priority in the riparian area establishment from the viewpoint of riparian preservation.

The second index defined was the Riparian Forest Change Index (RFCI), which takes into account the land cover changes over 25 years from 1975 to 2000. This index reflects the vulnerability of riparian forests to being converted for other anthropogenic purposes, such as urban areas or croplands, into the prioritization process. The RFCI is formulated as follows:

$$\mathrm{RFCI} = \frac{\text{Change in forest area over 25 years}}{\text{Forest area in 1975}} \tag{2}$$

where the forest area change is the forest area of 1975 subtracted by that of 2000. Although riparian forest data are available every 5 years since 1975 to 2000, the overall change of forest area for the study period was considered into the RFCI calculation. This was because the riparian forest areas in most sub-watersheds were changed in a linear manner. Thus, overall change was thought to be an appropriate representative of riparian forest change.

The RFCI can take a positive or negative value depending on whether the riparian forest area increases or decreases. The greater RFCI value indicates the greater increase or the smaller decrease in riparian forest areas for positive or negative values, respectively. Therefore, a watershed with a greater RFCI value implies that the riparian forest area was less disturbed by human activities and accordingly less urgent for the riparian preservation as compared to those with rapid decrease, i.e., smaller RFCI values. Since the urbanization process has been underway in both watersheds, riparian forest areas also would have been decreased over the time and thus negative RFCI values are expected.

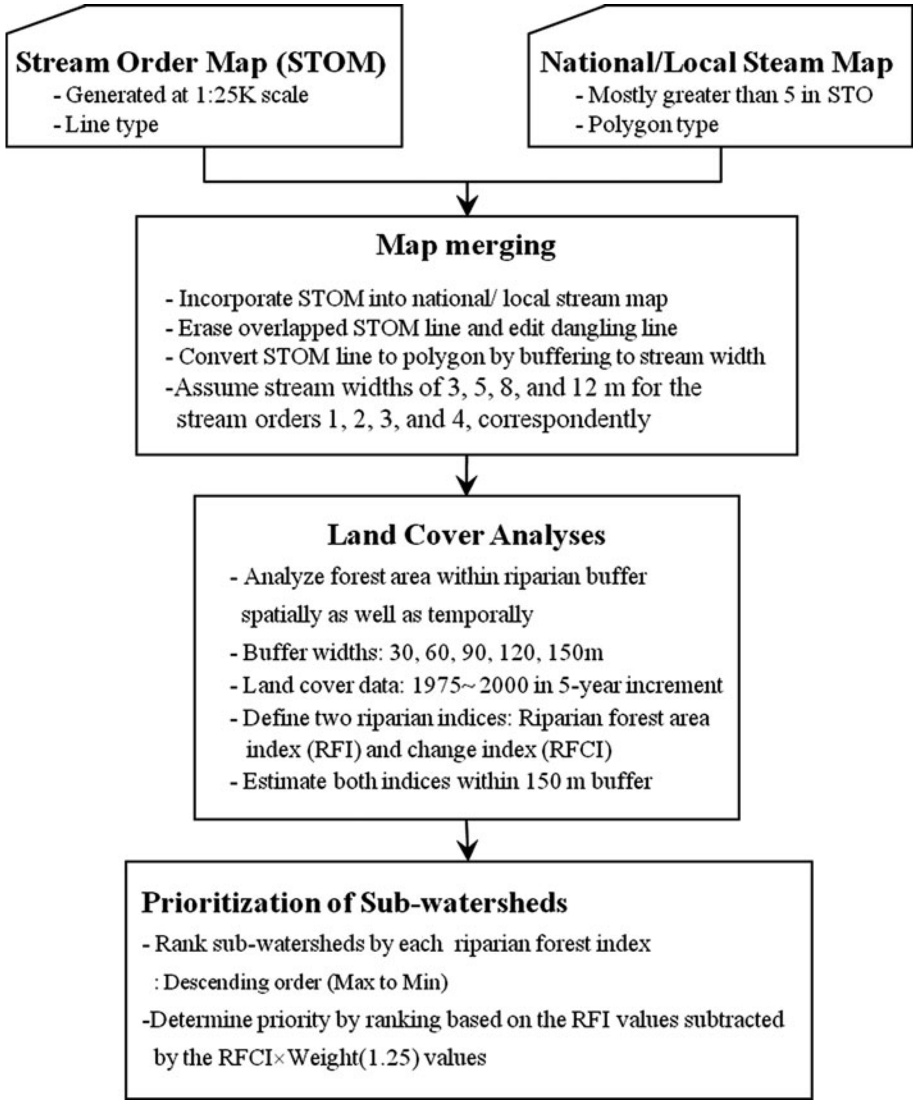

Fig. 2 Schematics of the prioritization process at a sub-watershed scale

Prioritization of sub-watersheds for riparian forest conservation

The baseline of determining priority for riparian forest establishment was to preserve current riparian forest areas as much as possible from being converted for other anthropogenic land uses. To realize this rule, two approaches based on riparian forest indices were applied: a static approach which takes into account the latest riparian status using the RFIs and a dynamic approach which considers the historical change in riparian forest areas using the RFCIs.

The two riparian forest indices, that is, the RFI and RFCI were estimated for each sub-watershed of the Ansung and Sapkyo watersheds. The two riparian indices have different implications from the viewpoint of riparian preservation. The greater RFI values mean the greater presence of riparian forests in the riparian area and thus higher priority for riparian preservation. In contrast, the larger RFCI values indicate forest area increase or slower forest disappearance from the riparian area, and accordingly lower priority.

To consider both static and dynamic approaches collectively into the sub-watershed prioritization process, the two riparian indices were combined by subtracting the weighted RFCI value from the RFI value for each sub-watershed. An arbitrary factor of 1.25 was multiplied to the FRCI value as the weight on the forest dynamic aspect to emphasize more urgency to stop or reduce the disappearance of riparian forest area. This is because more rapid removal of riparian forest was thought to deserve more attention when it comes to riparian forest reservation. This abides by the baseline of the maximum preservation rule of the existing riparian area as described previously.

Then the sub-watersheds were ranked by the subtracted values for each study watershed, i.e., Ansung and Sapkyo independently. Thus, the larger the riparian forest area (the greater RFI values) and the more rapid the forest reduction rate (the smaller RFCI values), the riparian area of the sub-watershed should be established with a higher priority. The ranking of the subtracted values became the priority for the riparian area establishment.

Results and discussion

Land cover composition of each sub-watershed

Fractional composition of land cover for each sub-watershed was estimated using the latest land cover data in 2000. As presented in Fig. 3, the three major land cover types are urban areas, forests, and cropland. Urban fractions of the sub-watersheds are overall greater in the Ansung watershed than the Sapkyo watershed. This probably reflects the fact that the northern part of the Ansung watershed is highly urbanized where the Suwon metropolitan area is located (sub-watershed ID 12). Cropland fractions appeared to be similar for both study watersheds, while forests occupy more fractions in the Sapkyo watershed than the Ansung watershed. The sub-watersheds in which cropland areas take up a substantial portion are mostly located downstream of the Ansung (sub-watersheds 7, 8, 15, 16, and 17) and Sapkyo streams (sub-watersheds 2, 3, 15, and 16). The overall fractions of urban areas, forests, and cropland to the entire watershed were 11, 36, and 40% for the Ansung watershed and 6, 44, and 40% for the Sapkyo watershed, respectively.

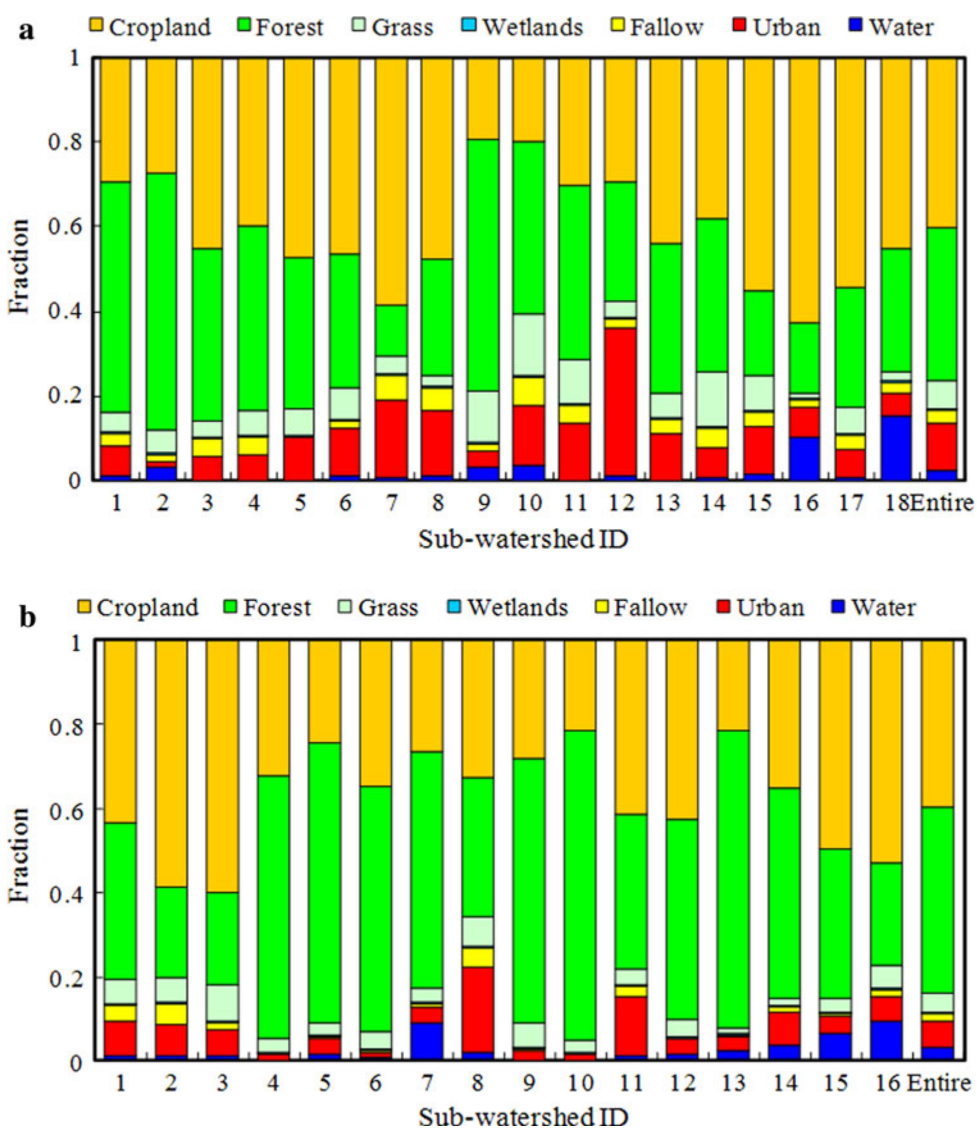

Fig. 3 Land cover composition of each sub-watershed in 2000 for **a** the Ansung and **b** Sapkyo watersheds

Within the riparian buffer width of 150 m, respective fractions of urban areas, forests, and cropland areas were 10, 31, and 46% for the Ansung watershed and 5, 46, and 39% for the Sapkyo watershed, respectively. Overall fractional trends of riparian land use were similar with those for entire watersheds. Forested portions of the riparian area decreased by about 5%, and cropland portions increased by about 6% as compared with fractions for the entire Ansung watershed. The fractions of riparian land cover for the Sapkyo watershed were similar with those of the entire watershed. This implies that the Ansung riparian areas were more disturbed by anthropogenic activities than the Sapkyo watershed.

Temporal changes in riparian land cover

Historical changes in riparian land cover were investigated every 5 years over a 25-year period from 1975 to 2000 within each riparian buffer width of 30, 60, 90, 120, and 150 m. Both study watersheds showed increases in urban area and decreases in forest and cropland areas. As shown in Fig. 4, the area changes increase almost linearly with the increase of the riparian buffer width.

The Ansung watershed experienced a more rapid land cover change, particularly in urban areas, than the Sapkyo watershed. A riparian area of 82.5 km^2 within the 150 m buffer width was urbanized over the 25-year period in the Ansung watershed while 43.5 km^2 was converted to urban areas in the Sapkyo watershed. These areas are equivalent to 5.0 and 2.6% of the respective watershed areas, which indicates that almost twice the urbanization occurred in the Ansung watershed than the Sapkyo watershed.

The greatest absolute change in land cover area occurred in riparian forests, which are known to be one of the most important niches for riparian ecosystems, and are assumed to be an indirect indicator of riparian health in this study. Forest areas of 90.2 km^2 (5.5%) and 74.2 km^2 (4.4%) disappeared from the 150 m riparian buffer over the last 25 years for the Ansung and Sapkyo watersheds, respectively. In fact, most riparian forests are located upstream of the watersheds (see Fig. 3), i.e., sub-watersheds 1, 2, 9, and 10 for the Ansung watershed, and 4, 5, 6, 9, 19, and 13 for the Sapkyo watershed. This finding, therefore, indicates that the riparian areas adjacent to headwater streams have decreased steadily over the decades primarily due to human activities, such as urbanization and agriculture. Thus, some management measures need to be developed to preserve the riparian areas near headwater streams. Cropland decreases within the 150 m buffer was similar for both watersheds, at approximately 35 km^2, and accounted for about 2.1% for each watershed.

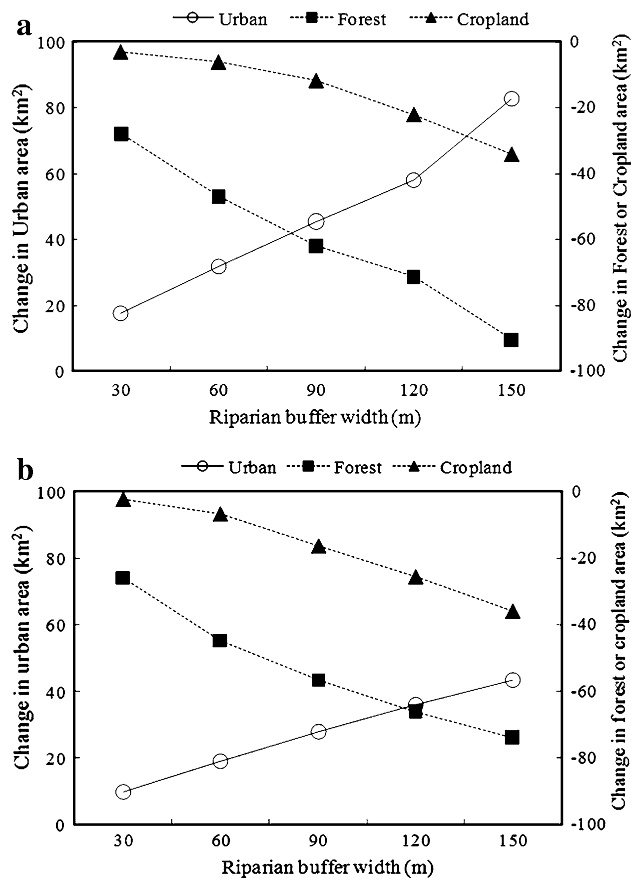

Fig. 4 Land cover changes in riparian area over the 25 years from 1975 to 2000 for **a** the Ansung and **b** the Sapkyo watersheds. The positive values in the primary *y*-axis indicate the area increases in urban land cover (*open circle*) over the period, while negative values in the secondary *y*-axis represent the area decreases in forest (*filled square*) and cropland (*filled triangle*) land covers

Prioritization of sub-watersheds for the establishment of Riparian areas

Riparian land cover within the buffer width of 150 m was analyzed spatiotemporally and utilized for the sub-watershed prioritization process. The reason why 150 m was chosen was that this distance is similar with the minimum average habitat radius of wild amphibians, which is an important resident in the riparian area (Semlitsch and Bodie 2003). The riparian width of 150 m also covers the required distance for the stream water quality protection by trapping non-point pollutants (Wegner 1999).

For each of the two riparian forest indices, the sub-watersheds were ranked separately for each study watershed and summarized in Table 2. The priority of riparian preservation was determined by ranking the RFI values subtracted by the RFCI × 1.25 values (the (c) column in Table 2). Figure 5 clearly shows the relationships of the preservation priorities in association with the RFI and RFCI indices. The higher priority for preservation is

Table 2 Prioritization of sub-watersheds for the establishment of riparian area

Sub-watershed ID	Ansung watershed				Sapkyo watershed			
	RFI (a)	RFCI (b)	((a) − (b) × 1.25) (c)	Priority (ranking of (c))	RFI (a)	RFCI (b)	((a) − (b) × 1.25) (c)	Priority (ranking of (c))
1	0.457	−0.102	0.585	2	0.355	−0.137	0.526	8
2	0.456	−0.046	0.514	4	0.380	−0.042	0.432	10
3	0.287	−0.025	0.318	13	0.301	−0.161	0.502	9
4	0.331	−0.071	0.421	8	0.531	−0.073	0.622	6
5	0.297	−0.080	0.397	9	0.601	−0.128	0.761	2
6	0.260	0.013	0.244	17	0.486	−0.171	0.700	3
7	0.110	−0.111	0.249	16	0.506	−0.057	0.577	7
8	0.193	−0.050	0.255	15	0.476	0.120	0.326	15
9	0.480	−0.133	0.645	1	0.561	−0.084	0.666	5
10	0.287	−0.188	0.523	3	0.677	−0.080	0.778	1
11	0.365	−0.001	0.366	10	0.338	−0.014	0.355	13
12	0.294	−0.110	0.432	5	0.404	0.058	0.331	14
13	0.310	−0.092	0.424	7	0.641	−0.027	0.675	4
14	0.295	−0.104	0.425	6	0.491	0.083	0.387	11
15	0.187	−0.117	0.334	11	0.358	0.063	0.279	16
16	0.118	−0.089	0.230	18	0.289	−0.075	0.383	12
17	0.239	−0.047	0.298	14				
18	0.236	−0.067	0.320	12				

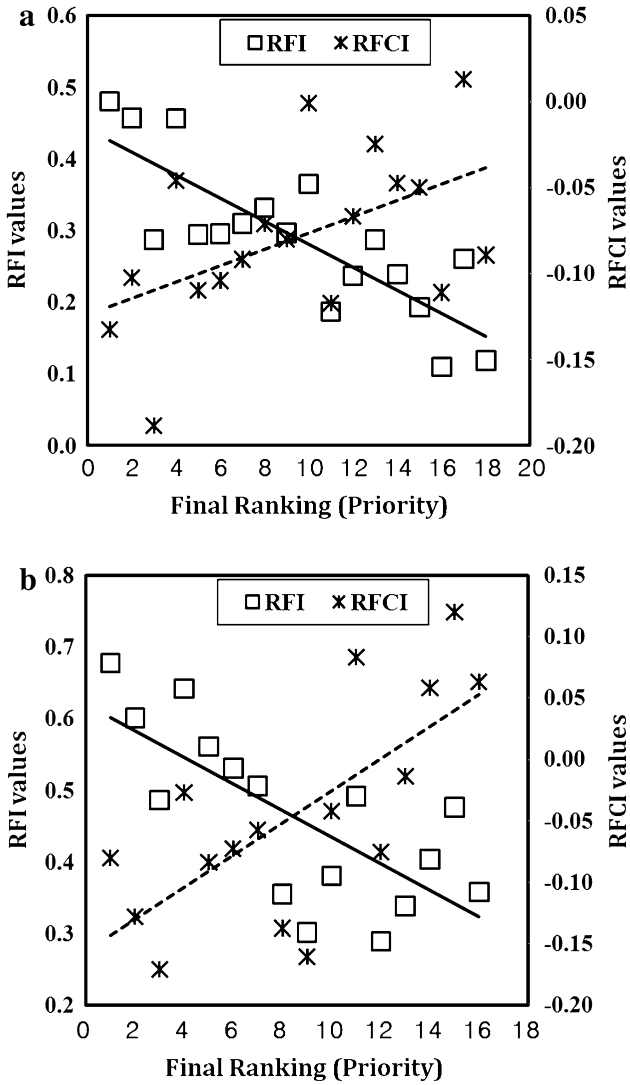

Fig. 5 Riparian preservation priorities versus the RFI and RFCI indices for **a** Ansung and **b** Sapkyo watershed. The RFI and RFCI stand for the Riparian Forest Index and Riparian Forest Change Index, respectively. The *solid* and *dotted lines* represent overall relationships of the RFI and RFCI indices against the final rankings. In other words, the greater RFI values or the smaller RFCI values tend to be related the higher priorities for riparian area establishment

positively related to the RFI values while negatively related to the RFCI values. In other words, more forest areas existed (greater RFI values) and more rapidly disappeared (smaller RFCI values), the higher priority for the riparian preservation.

Overall, the RFI value, 0.46 on average, for the Sapkyo watershed was significantly greater than 0.29 for the Ansung watershed (P value < 0.0001). This probably reflects the fact that the Ansung watershed is more urbanized as compared to the Sapkyo watershed. However, the average FRCI values were -0.08 and -0.05 for the Ansung and Sapkyo watershed, respectively, and were not significantly different (P value $= 0.172$). This indicates the riparian forest areas for both the watersheds have decreased similarly over the study period.

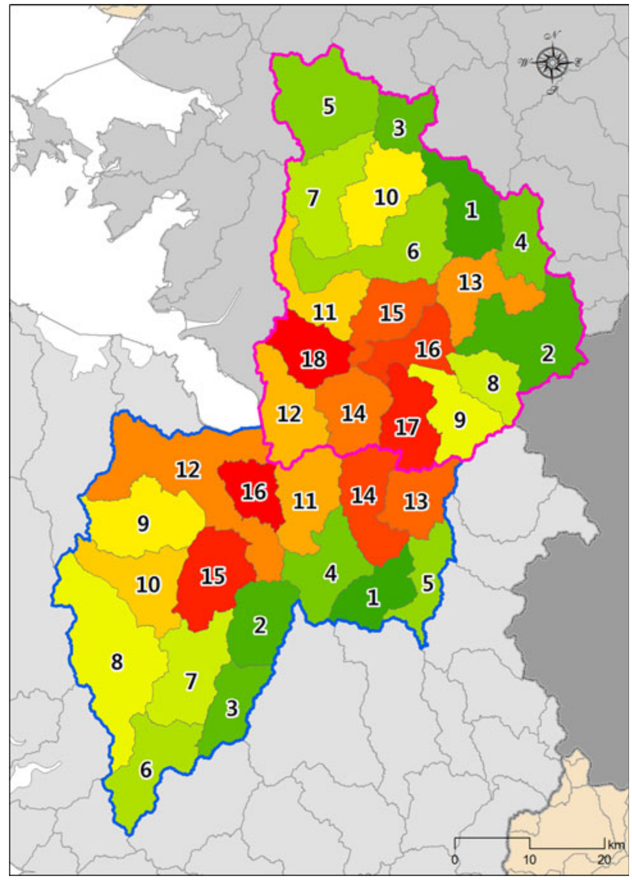

Fig. 6 Graphical presentation of sub-watershed priorities for the establishment of riparian area. The *digits* on the map represent the priority ranking for each study watershed separately. The priority rankings are also presented in color descending from *green* to *yellow* to *orange* to *red*

The sub-watershed IDs, for the five highest priorities in the order, were 9, 1, 10, 2 and 12, and 10, 5, 6, 13, and 9 for the Ansung and Sapkyo watersheds, respectively. Most high priority sub-watersheds were upstream watersheds which are located adjacent to headwater streams (Fig. 6). In contrast, downstream sub-watersheds, where a majority of cropland is located, scored lower in priority. This is because this study primarily emphasized the riparian forest to determine priority for the riparian establishment. Therefore, another approach based on the viewpoint of riparian restoration needs to be developed and incorporated into the prioritization process in the future.

Conclusions

In this study, land cover in the riparian buffer was investigated spatiotemporally and a precautionary approach for riparian forest preservation using riparian forest areas was developed to prioritize locations for the riparian establishment at a watershed scale. Overall, urban land cover in the riparian areas increased, while forest and cropland decreased. The absolute land cover change, mostly decreases, in riparian area was the greatest for riparian forest, which is one of the most important niches for riparian ecosystems. Considering that most riparian forests are located upstream of the watersheds, the reduction in riparian forest implies riparian impairment nearby headwater streams and highlights the necessity of appropriate upstream management for watershed riparian forest conservation. A precautionary approach, which emphasizes the preservation of current forest as much as possible, was developed in this study and applied for the study watersheds prioritization. This approach could be a simple tool to assist policy makers in prioritizing locations at a watershed level for the riparian area establishment from a preservation point of view. The proposed simple method in this study has limitation of only taking into account spatiotemporal change riparian forest cover for riparian area establishment. Other aspects such as stream morphological and ecological aspects need to be incorporated into riparian area determination as they become available in the future. In addition, considering substantial portions of riparian areas already being impaired in Korea, the restoration aspect of the impaired riparian needs to be investigated further and incorporated into the prioritization procedure.

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