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Analysis of factors contributing to abandoned residential developments using remote sensing and geographic information systems (GIS)

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Abstract New residential developments in the Southeastern United States peaked in early 2006, but since then declined leaving numerous residential developments stalled in various stages of construction. The status of 119 previously identified (2009) abandoned residential

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housing developments was reinvestigated in 2013 using the most current available high-resolution aerial photography with a randomly selected number of sites (40) in Greenville, Pickens and Spartanburg Counties in South Carolina. The original land cover before any housing developments was determined based on historical infrared aerial imagery (1999). Development sites were categorized based on the development status: no change, active development or completed development. Site locations were used to determine network distance to major cities and schools to determine if location is related to current development status. Historical aerial photos showed that the majority of land originally developed was forest land. Site visits indicated that 24 out of 40 sites previously identified as abandoned are in various stages of recent construction (three out of five in Pickens County, three out of 15 in Spartanburg County and 18 out of 20 in Greenville County). Of the 19 sites that were labeled as active through a field visit 15 were positively identified as active by using the aerial imagery. Sites with recent construction were closest to schools, but distance to urban centers was not a factor. This study suggests that proximity to schools may be a driving factor in restarting previously abandoned developments.

Keywords Aerial photos · Construction · Land classification · Real estate · Spatial patterns · Sprawl · Urban · Urban–rural interface

Introduction

In the past decades, the United States has experienced rapid population dispersal with more people moving away from the central city areas into the suburban and rural areas (Weisbrod et al. 1980). This population dispersal resulted in an economic decline of many central cities and the increase in costs of providing public services in the suburban areas (Weisbrod et al. 1980). This population change was accompanied by the conversion of forest and agricultural land to residential housing developments. The US experienced accelerated land development between 1982 and 2007 with a total of 16.2 million ha of newly developed land (U.S. Department of Agriculture and NRCS 2009). Prime farmland (5.7 million ha) was lost due to development (U.S. Department of Agriculture and NRCS 2009). Similarly, the Upstate region of South Carolina has experienced an unprecedented amount of population growth and consequent residential land development (Allen and Wyche 2008; South Carolina Budget and Control Board 2013; U.S. Department of Agriculture and NRCS 2009; Tables 1, 2 and 3), which is accompanied by a host of environmental issues (Goddard et al. 2008; Sciera et al. 2008). This residential development can be classified into the following types (York et al. 2011): exburbanization, the development of land outside the urban center (York and Munroe 2010); sprawl, expansion of auto-centered, low centered development (Irwin and Bockstael 2007; Heim 2001). All of these types of developments typically lead to the destruction of former forests, agricultural lands and landscape fragmentation (York et al. 2011). With the increase in developments in the Southeastern United States over the last decade many areas of forestland decreased in size, were fragmented or lost. This loss of forestland is not limited to South Carolina and has been observed across the Eastern United States (Zipperer et al. 2012). The issue of urbanization and loss and or fragmentation of forest land cover has become an important issue in the urban–rural interface across the United States.

Urban sprawl is often fueled by high-risk lending (Immergluck 2011). The US subprime crisis beginning in 2007 not only resulted in many foreclosures but also in abandoned residential developments (Immergluck 2011; Werts et al. 2013). Werts et al. (2013) identified 301 abandoned residential sites in 2009 with a total bare soil area of 2,378 ha in Greenville, Spartanburg, and Pickens counties in the Upstate South Carolina. A subset of these locations has

Table 1 Surface area of non-Federal and Federal land (owned by the U.S. Federal government) and water areas in South Carolina in thousands of hectares, with margins of error (USDA NRCS 2009)

Year	Federal land	Water areas	Non-Federal land			Total surface area
			Developed	Rural	Total	
1982	417.7	296.9	550.1	6788.2	7338.3	8069.1
	–	–	±77.8	±77.1	±18.5	–
1987	416.5	317.3	617.2	6718.2	7335.4	8069.1
	–	–	±91.3	±90.5	±18.3	–
1992	419.3	318.5	708.1	6623.3	7331.3	8069.1
	–	–	±101.6	±101.0	±18.8	–
1997	419.3	320.2	856.9	6472.7	7332.4	8069.1
	–	–	±111.5	±112.6	±19.6	–
2002	419.3	325.1	990.3	6334.4	7324.7	8069.1
	–	–	±102.0	±105.1	±18.6	–
2007	419.3	328.4	1081.6	6239.8	7321.4	8069.1
	–	–	±112.9	±114.6	±19.3	–

been used as a benchmark for this study. Werts et al. (2013) demonstrated residential developments often lack adequate soil erosion controls that can result in sediment pollution of streams, so there was likely an environmental impact in addition to the economic impact from these events.

Since residential development and abandonment appear to be cyclical, it is important to understand the factors contributing to abandoned residential developments. Previous research indicated that consumer housing and location preferences were important factors that help explain urban/suburban development patterns (Weisbrod et al. 1980). These housing and location preferences can be influenced by a consumer's age, income, race and these preferences may include: residential density, size, quality, condition, price of housing, and the level of public services (e.g. schools, police, fire, health services, and recreational opportunities) (Weisbrod et al. 1980). Studies by Mayo (1973); Lerman et al. (1977) and Pollakowski (1975)

Table 2 Land cover/use of non-Federal (land not owned by the U.S. Federal government) rural land in South Carolina in thousands of hectares, with margins of error (USDA NRCS 2009)

Year	Cropland	CRP land	Pasture land	Forest land	Other rural land	Total rural land
1982	1438.5		474.8	4587.4	287.5	6788.2
	±124.2	–	±119.6	±164.6	±72.0	±77.1
1987	1333.9	39.5	464.7	4588.7	291.3	6718.2
	±121.2	–	±110.2	±158.3	±78.1	±90.5
1992	1195.1	106.9	465.3	4562.0	293.9	6623.3
	±109.5	–	±108.1	±163.8	±81.0	±101.0
1997	1040.3	106.0	469.8	4550.4	306.1	6472.7
	±103.8	–	±99.8	±176.8	±79.4	±112.6
2002	981.4	75.4	431.1	4536.0	310.5	6334.4
	±102.2	–	±133.6	±169.9	±85.6	±105.1
2007	902.5	69.0	433.1	4519.5	315.7	6239.8
	±176.1	–	±190.9	±243.9	±87.0	±114.6

Table 3 Prime farmland (land with best combination of physical and chemical characteristics for agricultural production) in South Carolina in thousands of hectares, with margins of error (USDA NRCS 2009)

Year	Cropland	CRP land	Pasture land	Forest land	Other rural land	Total rural land
1982	672.1		150.4	542.1	24.0	1388.6
	±95.5	–	±54.7	±90.4	±12.3	±152.5
1987	626.2	21.2	150.9	549.6	25.1	1372.9
	±97.4	–	±55.4	±86.3	±14.7	±153.4
1992	562.0	53.3	158.5	550.9	26.3	1351.0
	±94.0	–	±57.6	±90.0	±15.0	±151.4
1997	503.6	50.7	163.6	561.4	34.3	1313.5
	±89.3	–	±50.6	±176.8	±21.5	±146.9
2002	489.2	42.1	139.1	580.5	34.5	1285.4
	±98.7	–	±65.2	±154.9	±12.1	±159.9
2007	451.3	38.6	141.8	596.9	38.2	1266.8
	±128.2	–	±98.8	±165.7	±21.1	±155.5

found that the levels of public service were less important for most households compared to transportation accessibility for work. Pijanowski et al. (2002) used neural networks and GIS to forecast land use changes in Michigan's Grand Traverse Bay watershed and found that residential development was greatly influenced by the watershed view quality. Schlossberg et al. (2006) reported that communities across the US have been shifting away from small neighborhood schools to larger schools in the suburbs. Hansen and Winther (2007) examined how accessibility (potential of opportunities for interaction) and availability of vacant land can be used for the metropolitan planning purposes.

This study examines potential factors influencing the development of previously abandoned residential housing construction sites. Specific objectives of this study were to analyze factors contributing to the status of abandoned residential developments in Upstate South Carolina to help understand the motivations for these changes.

Methods

Study area

The study area is located in Pickens, Greenville, and Spartanburg counties in Upstate South Carolina in the Southeastern United States, which is characterized by a humid subtropical climate with topography ranging from gently rolling hills and pasture land to mountainous terrain in the northern areas (Fig. 1).

Historical land cover evaluation

Historical digital orthophoto quarter quadrangles (DOQQ) (1999) of Greenville, Pickens, and Spartanburg Counties were obtained from the South Carolina Department of Natural Resources (SCDNR) GIS Clearinghouse. Each DOQQ is a three band, infrared aerial image with an approximate 1 m resolution. ArcGIS 10.1 was used to classify DOQQ imagery using a supervised Maximum Likelihood Classification independently for each quadrangle. Four different land cover categories (Table 4) were used (Fields, Deciduous, Conifers, and Urban)

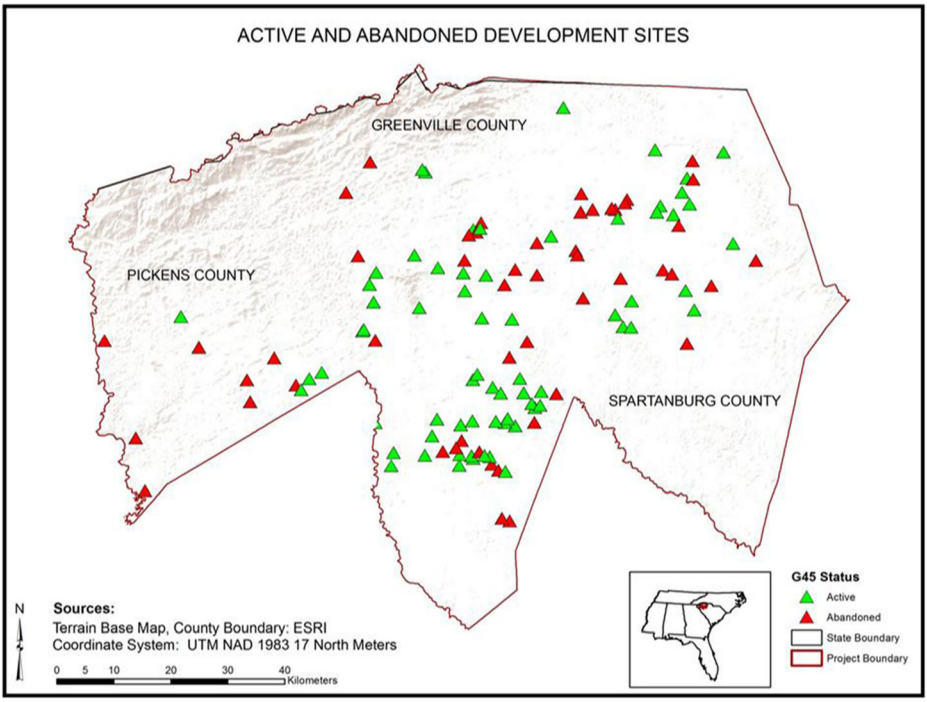

Fig. 1 Spatial distribution of 119 development sites (active or abandoned) classified using remote sensing. County boundaries dissolved to display spatial extent of project area

to allow for the evaluation of the amount of agricultural and forest lands lost as a result of residential development sites. Within this process a minimum of ten training samples per land cover category were defined and used to create a signature file that was used to classify each image. Each classified layer was evaluated to assure the classified image represented visible land cover with an estimated producer's accuracy of greater than 90 %. This verification of the classification of each aerial photo quadrangle was possible both because each individual photo was classified and since land cover types could easily be determined using the high-resolution nature of the aerial photos.

Table 4 Land cover classification types and definitions

Land cover classification	Characteristics
Fields	Any open area that does not include impervious surfaces or water. Examples: cultivated crops, fallow fields, grasslands, bare ground.
Deciduous	Forested areas that are predominantly deciduous trees. These are indicated on imagery as leaf off areas.
Conifers	Forested areas that are predominantly evergreen trees. These are indicated on imagery as leaf on areas.
Urban	All areas that have commercial/residential buildings, pavement, and manmade impervious surfaces.

Evaluation of previously identified abandoned developments using aerial photography

Two different sources of aerial imagery were used to evaluate the development status of the abandoned residential development sites identified in 2009 (Werts et al. 2013). Werts et al. (2013) used a combination of remote sensing and field visits to pinpoint the location of abandoned residential housing developments in the Upstate of South Carolina, USA. The World Imagery Service from ESRI (1 meter resolution) contained aerial photo imagery from 2011 (ESRI 2013), while the Google 45 imagery used in this study was acquired in 2012 and represents high resolution oblique aerial imagery taken at a 45° angle allowing for increased viewing detail because of its resolution and perspective (Table 5). For this study, the most important attributes of these aerial photo sources are the acquisition timing, so future reference to these sources will be listed as either 2011 (ESRI World Imagery Service) or 2012 (Google 45) aerial imagery.

Original site locations (Fig. 1) were examined using ArcGIS 10.1. Each development location was geocoded and both the 2011 and 2012 high resolution aerial photography was used to examine the development status and to classify developments based upon activity level. The imagery was used to note the number of visible houses and then compared with the original abandoned development data from 2009 (Werts et al. 2013) to determine if the development was active or abandoned. If houses existed in previous years, a site was determined to be active if: 1) additional houses appeared in subsequent years or 2) the presence of other activities, such as road construction, utility placement, etc. was completed or in progress.

Random selection of sites for field visits

A stratified random sample was used to select 40 sites for field verification visits from the 119 abandoned development sites used in this study. This sample represented all three counties in the study area (Table 6). Field verification was performed to compare how the analysis using high resolution aerial photos compared with actual activity on a subset of the sites. Upon each site visit, characteristics of the site were noted and the site was classified as either as having recent or ongoing development activity or as being abandoned. A digital camera with built in global positioning system (GPS) capabilities was used to document site s level. Evaluation of sediment control structures and ground cover was also conducted, because the presence of these items is closely correlated to active site development.

Table 5 Data sources and descriptions

Data layer*	Source	Resolution/Scale	Year
Imagery			
World imagery service	ESRI	1 m	2011
Google 45	Google, Inc.	N/A	2012
Infrared digital ortho photo quads (DOQQ)	SCDNR	1 m	1999
Vector data layers			
Streams	SCDNR	–	2001
Watersheds	NHDplus	–	
Census blocks	US Census bureau	–	2011
Roads	ESRI	–	2012

Table 6 Field verification of the current construction status of previously identified abandoned developments

County	2013 Site visit inventory	2013 Site visit construction status
Pickens	5	3 recent construction
Greenville	20	18 recent construction
Spartanburg	15	3 recent construction
Total	40	24 recent construction

Evaluation of spatial relationships and demographic characteristics

Road network analysis (ArcGIS 10.1 Network Analyst Extension) was used to determine proximities of developments to the nearest urban center and schools. Network analysis represents a true distance to urban centers/schools along existing roads, compared to a linear distance calculation. Population density data from the 2010 census were determined for a 1 km buffer around each development location to determine if the resumption of active development was related to the existing housing density. With little building activity in 2010, it was assumed that the census data represented existing population density, compared with 2012 imagery which showed a potential restart of development. Statistical comparison, using unpaired t-tests, was used to determine if there was a difference between newly active and abandoned development sites and the distance to urban centers/schools and existing population densities.

Table 7 Digital ortho quarter quad (DOQQ) land classification results

Land classes	Total (ha)	Total (%)
Greenville county		
Fields	397.96	33
Evergreen	266.98	22
Deciduous	385.91	32
Urban	171.89	14
Total	1222.74	100
Pickens county		
Fields	13.55	22
Evergreen	22.08	36
Deciduous	24.10	40
Urban	1.15	2
Total	60.89	100
Spartanburg county		
Fields	113.54	25
Evergreen	134.51	30
Deciduous	129.76	29
Urban	70.39	16
Total	448.19	100

Results

Land cover analysis

Table 7 shows the results from the land cover classification for the development locations for each of the three counties. The totals reflect the amount of area within each of the 119 developments and the land cover inside each development prior to construction. The majority of the sites were in forestland and/or agriculture in 1999. Using the four land classes, the 488 ha comprising the 119 sites was 28 % fields, 34 % evergreen forest, 31 % deciduous forest, and 7 % urban.

Aerial photography

Sites were classified as either abandoned or active using 2011 and 2012 aerial imagery. Overall, 56.7 % of the sites considered likely transitioned from abandoned (in 2009) to active (in 2012) based on this analysis. Several sites (8 %) classified as abandoned using 2011 imagery subsequently became active based on the 2012 imagery, while a similar percent (8 %) of sites showed new building activity by 2011 that was unchanged in 2012. Sites that remained unchanged

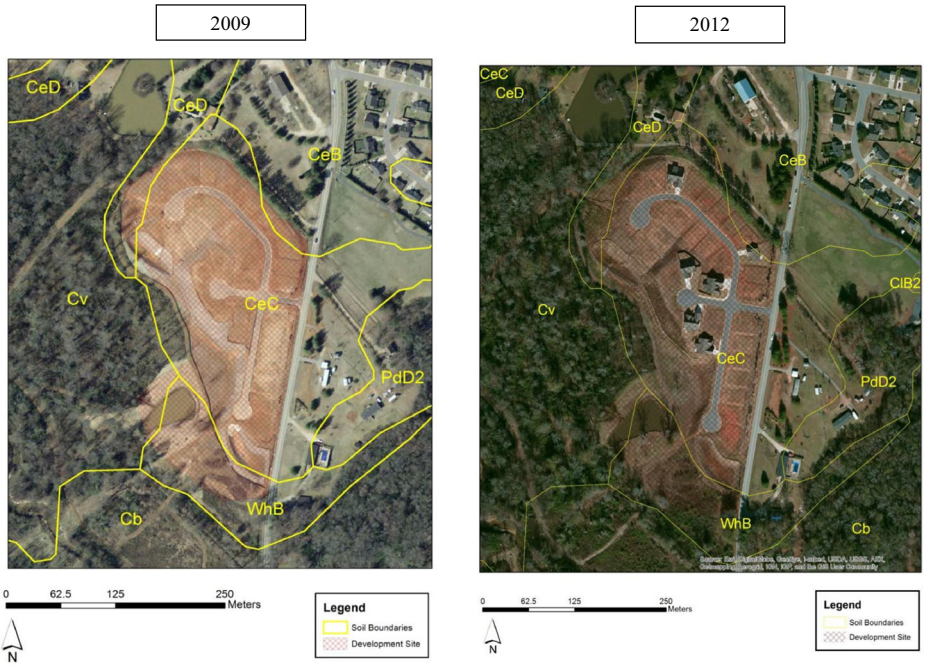

Fig. 2 Temporal comparison of typical residential development in 2009 and 2013 (Source: Greenville County GIS Department). Soil data from SSURGO data (Soil Survey Staff 2009): *CeB*, Cecil sandy loam (Fine, kaolinitic, thermic Typic Kanhapludults), 2–6 % slope; *CeD*, Cecil sandy loam (Fine, kaolinitic, thermic Typic Kanhapludults), 10–15 % slope; *Cv*, Chewacla (Fine-loamy, mixed, active, thermic Fluvaquentic Dystrudepts); *Cb*, Cartecay and Toccoa (Coarse-loamy, mixed, semiactive, nonacid, thermic Aquic Udifluvents); *CeC*, Cecil sandy loam (Fine, kaolinitic, thermic Typic Kanhapludults), 6–10 % slope; *ClB2*, Cecil clay loam (Fine, kaolinitic, thermic Typic Kanhapludults), 2–6 % slope; *PdD2*, Pacolet clay loam (Fine, kaolinitic, thermic Typic Kanhapludults), 10–15 % slope; *WhB*, Wickham sandy loam (Fine-loamy, mixed, semiactive, thermic Typic Hapludults), 2–6 % slope

between 2011 and 2012 imagery may represent sites that were initially classified as abandoned, but had subsequent (typically limited) housing construction between 2009 and 2011.

Field visit analysis

Onsite inspections were conducted for 40 of the 119 development sites a year after (2013) the most recent aerial imagery available for this study (2012). From the initial imagery classification, 21 sites were considered abandoned and field verification found 11 were correctly classified (errors are likely because development restarted between the date of image acquisition and field visit). During imagery classification, 19 sites were classified as active and field visits found that 15 of those sites were correctly classified. Field site inspection found that the majority of the sites in Greenville County were either fully developed or had active construction. Spartanburg County had 15 active sites showing various stages of construction (Table 6). In Pickens County, three of the five sites showed activity. Field visit analysis resulted in verification of aerial photographic analysis to show development status (active, abandoned). There were a significant number of imagery classified abandoned sites that were found to be in an active state, but this was likely not because of errors in photo evaluation, but because of recent field changes based on the dates of the aerial photography.

Spatial relationship analysis

The development sites were divided into four categories for analysis based on the development status and year of aerial imagery used: 2011 imagery- active, 2011 imagery- abandoned, 2012 imagery- active and 2012 imagery- abandoned. This allowed for temporal comparisons to be made to assess changes over time with spatial relationships. Abandoned sites on average were larger in spatial extent when compared to active sites while 2012 imagery active sites were larger than those found based on 2011 imagery. Active sites identified with 2012 imagery were statistically more likely to be in areas of higher 2010 census based population density ($p<0.0428$, GraphPad and Inc 2013). Proximity to schools (average distance to school =2.6 km for active, 3.8 km for abandoned; Fig. 4) was statistically significant when comparing active vs. abandoned for both imagery dates ($p<0.0002$, GraphPad and Inc 2013). School type (i.e. high school, middle school, elementary school or private school) was not a factor in development status when looking at distances to closest school. There was no overall statistical significance when comparing the network road distance from active/abandoned developments to urban centers (Fig. 4). Interestingly, there was a significant difference between development status for the sites located around the Greenville city urban center ($p<0.0067$, GraphPad and Inc 2013), but this relationship did not hold for the Pickens and Spartanburg centers.

Discussion

Aerial photography has long been used to identify land cover change (Fensham and Fairfax 2002), however the increasing availability of multiple georeferenced aerial photos for numerous dates over the same spatial area provides an opportunity to examine the impact and status of land cover change. The advantage of using aerial photos compared with lower resolution satellite image analysis is that the land cover can be identified with a high degree of certainty with the human eye because of their high spatial resolution. Overall, 65 % of the development sites were forest land prior to development based on an analysis of 1999 aerial photos (Table 7), so the development boom and subsequent abandonment likely impacted overall forest cover in

the upstate of South Carolina. This likely permanent loss of forest and some agriculture lands was similarly found by Zipperer et al. (2012) for regions of Maryland, U.SA. In contrast, land conversions in this area from forest to farm during the 1920's in the upstate of South Carolina largely reverted to forest after soil productivity declined (Richter and Markewitz 2001).

The availability of high resolution oblique and vertical aerial photography provides new opportunities to not only classify land cover, but to infer land use because of the resolution of the photography. Many of the new sources of publically available aerial photos (e.g. Google and Bing) cannot be used directly within or classified by GIS software, however it is possible to perform detailed site evaluations through visual inspection because of their high resolution. More than 50 % of the previously identified abandoned residential housing developments converted from abandoned to active status between 2009 and 2012 as determined by interpretation of these high resolution aerial images (Fig. 2). Field verification which occurred in 2013 showed that while 78 % of the sites identified as being in an active development phase were still active, 48 % of the aerial photo identified abandoned sites had evidence of activity during the field visit. This disconnect between aerial classification and field classification results was surprising considering the high resolution nature of the images and is likely because of the time difference between the aerial photos and field visits. This shows that having recent aerial imagery is critical when there are rapid changes on the ground, regardless of the clarity provided by high resolution and oblique imagery.

Spatial analysis provides context to help understand factors related to the development status of these residential housing developments. Conversion from abandoned to active status was statistically more likely to occur in areas of higher population density (1 km area around the development as determined by 2010 census data). This comparison is valid because there

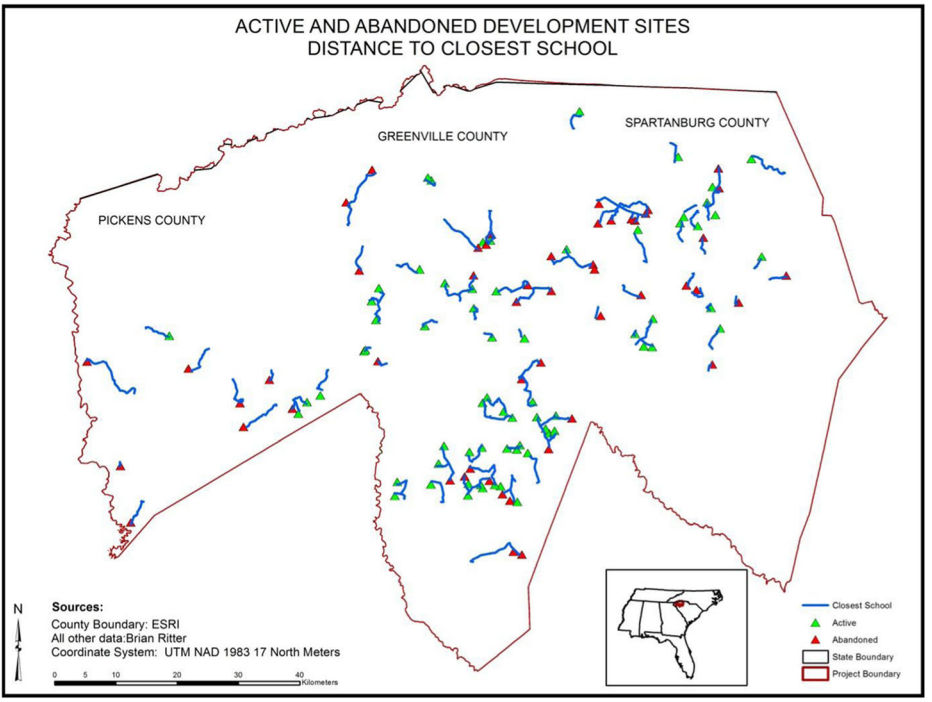

Fig. 3 Spatial relationship of developments to schools

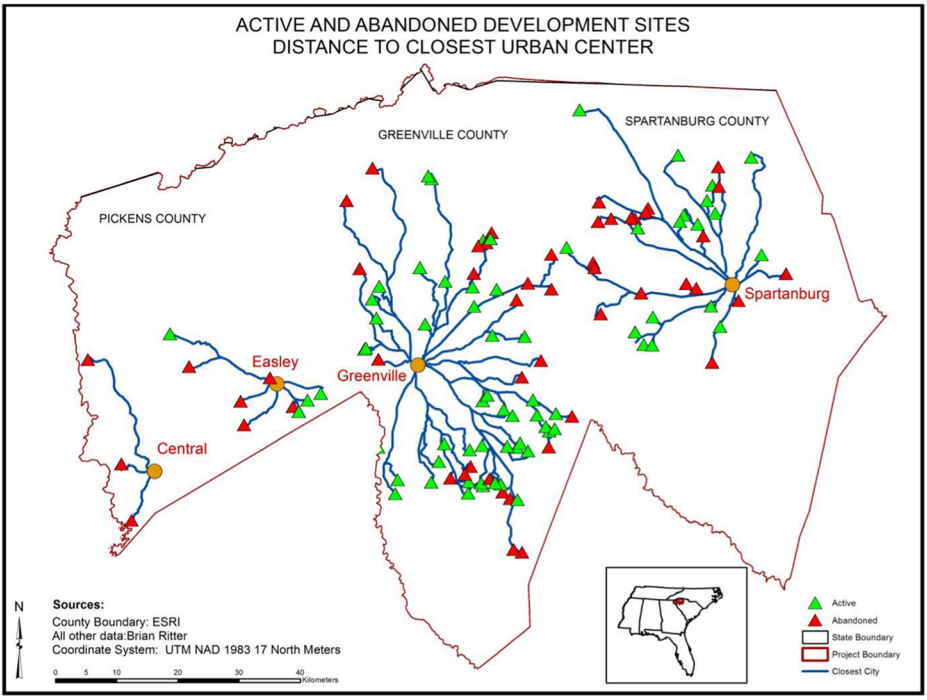

Fig. 4 Spatial relationship of developments to urban centers

was little residential housing development in this area in 2010, so the results likely indicate that rural areas were slower to go from active to abandoned between 2009 and 2012. Road network analyses revealed that there was a statistically significant difference between active and abandoned sites and distance to school regardless of school type (charter, vocational, elementary, middle, and high; Fig. 3), which indicates that developments were more likely to go from abandoned to active status if they were near a school. Overall, there was no statistical difference between distance to urban centers and whether a development became active, but there was a relationship for the developments around the Greenville urban center that is evident in Fig. 4.

Conclusion

This study revisited previously identified abandoned residential housing developments in Greenville, Pickens and Spartanburg Counties in South Carolina using high-resolution aerial photography with a randomly selected subset of field visits. Historical aerial photos showed that the majority of land originally developed was primarily forest land with some agricultural land. Site visits found the majority of locations previously identified as abandoned were in various stages of construction. Aerial photo analysis showed a lower level of conversion from abandoned to active construction site, which was attributed to the time lag between the acquisition of the aerial imagery and the field visits. The difference between aerial photo interpretation and field visit result represent an error, but likely not an error in aerial photo interpretation, but a problem caused by a rapidly changing development status on the ground.

Sites with recent construction were closest to schools, but distance to urban centers was only a factor near the city of Greenville. This study suggests that proximity to schools and population density may be a driving factor in restarting previously abandoned developments, while the importance of distance to urban centers other researchers have found (Weisbrod et al. 1980), may influence the development decision, but are not always a driving force. Insights from this study provide a spatial temporal methodology to evaluate development across the urban/rural interface. With ever increasing sources of high resolution aerial imagery, the currency of imagery should improve which should reduce the errors associated with this type of aerial photo interpretation. Large numbers of previously abandoned housing developments are likely changing from inactive to active status throughout the United States as the economy improves, and it is important to try to understand the factors driving this redevelopment.

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