

North Carolina's Final Coastal Frontier: Land Cover Change in the Inner Banks, 1996-2001

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North Carolina's coastal region has a long history of development that is most concentrated in oceanfront regions such as the Outer Banks and other barrier island beach communities. As land becomes scarce in oceanfront regions, interior coastal zones have the potential to act as outlets to absorb development pressure related to amenity, retirement, and working-age in-migrants. A recent news article published in 2006 claims that this process is already underway and that the interior coast is experiencing an inland "coastal boom". I define the Inner Banks as a new regional entity and examine the inland coastal boom theme by addressing two questions: (1) What are the patterns of net land cover change?, and (2) What are the most important types of land cover change?. Using 1996 and 2001 NOAA land cover data, I employ change analysis techniques involving analysis of the land cover transition matrix. Results indicate a small net gain in developed land area. However, of this gain, there is a strong signal of conversion from forest and scrub in 1996 to developed by 2001. Results are disaggregated from the entire Inner Banks region to the county level to map and report results which demonstrate substantial geographic variation with highest gains in developed area occurring in Carteret, Craven, Hertford, Chowan, and Pasquotank counties. If the Inner Banks is indeed North Carolina's final coastal frontier, then population growth and land development during the next decades have the potential to dramatically alter the region's land cover, ecosystems, economy, and cultural sense of place.

Introduction

A recent headline regarding land use and development in coastal North Carolina proclaimed that the "coastal boom moves inland" (Price 2006). The news article continued to describe a region undergoing tremendous change along the state's 3,000 miles (approximately 4,800 km) of estuarine waterfront. This inland coastal region historically has been lightly populated and economically lagging compared to neighboring barrier island oceanfront communities and large metropolitan areas located in the piedmont such as the Triangle (Raleigh, Durham, Chapel Hill), Triad (Greensboro, Winston-Salem, High Point), and metropolitan Charlotte. Intensive development has been present in North Carolina's barrier islands, including the Outer Banks, for decades

resulting in land scarcity and high property prices. The proclaimed inland coastal boom, though certainly of lower magnitude than Outer Banks development, arguably represents a new and final frontier of coastal development in North Carolina with potential impacts on the region's rich natural resource base, economy, and sense of place. The objective of this paper is to characterize land cover change for North Carolina's inland estuarine region, defined here as the "Inner Banks", over the years 1996 to 2001 thereby providing a baseline analysis of inland coastal change that can be tracked during subsequent years to help monitor the magnitude and effects of the "coastal boom".

Land use and land cover change research is

situated within the context of an emergent land change science that has matured as a fundamental element of global environmental change and sustainability science (Rindfuss et al. 2004). Geospatial information technology, GIS and remote sensing approaches underpin much of land change science. A common initial approach is to map land cover pattern at two or more time periods via classification of satellite imagery and to quantify net amounts and rates of change. The land cover transition matrix is the fundamental starting point that is used to identify patterns of net change. For example, what was the net gain or loss of developed, agriculture, forest, wetland or other land classes? Moving beyond net change, inspection of inter-category change (e.g. agriculture-to-developed, forest-to-wetland, etc.) can reveal more detailed information regarding specific from-to trajectories, or signals, of change. A danger with this approach is that researchers may fail to distinguish between random signals and the more important systematic signals of change that suggest key processes responsible for landscape dynamics. A methodological advance towards analysis of the transition matrix introduced by Pontius et al. (2004) and described in more detail below enables such discrimination (see also Braimoh 2006).

This paper introduces a regional definition of the Inner Banks and characterizes land cover change within the Inner Banks by analyzing a transition matrix derived from a multi-temporal land cover product obtained from NOAA and by employing a GIS-based methodology to answer the following research questions:

1. What was the net areal change for defined land cover classes in the Inner Banks during the period 1996-2001?
2. What were the most important systematic signals of conversion from non-developed to developed land?

Study Area

The study area is comprised of parts or the whole of 16 counties that border North Carolina's estuarine shoreline (Figure. 1) comprising the Inner Banks. Barrier island portions for 4 of the

16 counties, Carteret, Currituck, Dare, and Hyde, were excluded in order to focus analysis specifically on the interior coastal region. The non-profit corporation Foundation for Renewal of Eastern North Carolina (FoR ENC) is actively marketing and promoting this region as the "Inner Banks" through a recent branding campaign. As part of this campaign, FoR ENC markets an "IBX" window sticker and has produced promotional public service announcements and videos to promote the Inner Banks as a regional entity. Local communities are beginning to self-identify with the Inner Banks. For example, the town of Washington's web site encourages visitors to "Return to the Heart of the Inner Banks" (Washington Visitor Information, 2008).

In addition to regional branding, a goal of FoR ENC is to promote entrepreneurial and economic growth by highlighting the "creative economy" (Florida, 2002) and the attraction interior coastal amenities. Part of FoR ENC's mission statement states:

The Foundation of Renewal for Eastern North Carolina (FoR ENC) is a vehicle for change in one of America's most underserved regions, a non-profit "merchant bank" that trades in intellectual capital as much as in financial capital. FoR ENC is designed to serve as a catalyst for economic and entrepreneurial growth in Eastern North Carolina. FoR ENC blends the best practices of the for-profit and non-profit sectors to facilitate the process of renewing the economy across the region. This process includes identifying, developing, and energizing citizens and organizations across Eastern North Carolina and challenging our disparate parts to work as a whole to build a leadership base for the future of the region. (FoR ENC, 2008)

Preliminary data exploration and regional familiarity suggest that counties located north of the Albemarle Sound are functionally connected to the Virginia Beach-Norfolk-Newport News MSA located nearby in southeastern Virginia. This north-

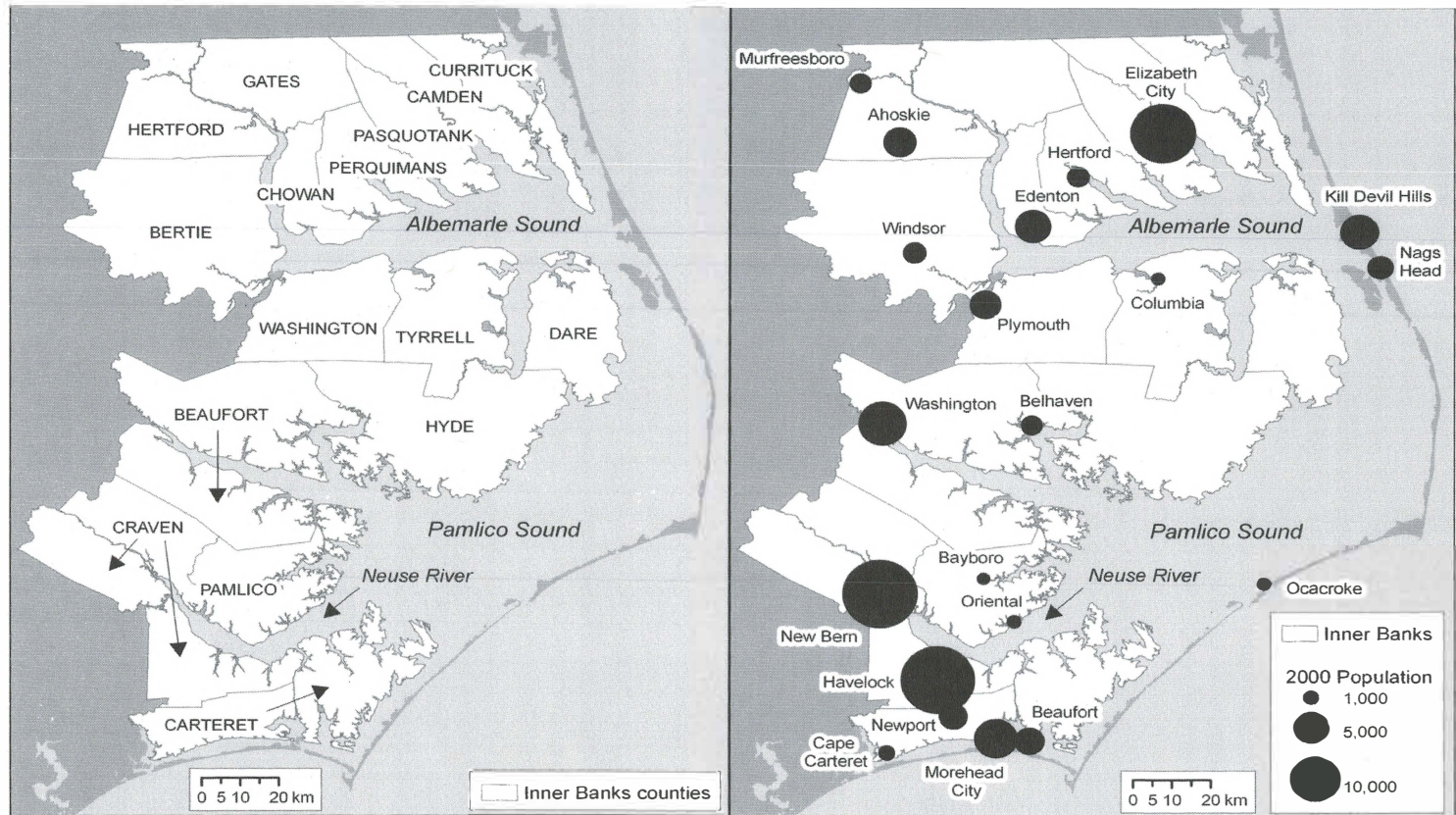


Figure 1. Inner Banks study area. Arrows by selected county names indicate county areal extents.

ern tier (Table 1) of the IBX is a destination for exurban working-age migrants who commute to the MSA and retirement age migrants from the MSA and elsewhere. Elizabeth City (Pasquotank County) is this tier's largest city. Population growth is exerting development pressure within these counties as land must be converted to accommodate new arrivals and as local governments work to provide required infrastructures and services. These pressures are evidenced by the fact that in 2007 Camden County enforced a temporary moratorium on new development due to exorbitant growth pressure. Also, during a field interview during the summer of 2006, the mayor of Hertford (Perquimans County) described challenges in regional planning related to in-migration specifically mentioning the large influx of "halfbacks" – a colloquial term for northeast retirement migrants who move initially to Florida and subsequently to North Carolina, or "halfway back". The apparent reason for such "halfback" moves is dissatisfaction with Florida as a residential location for selected retirement migrants. South of the Albemarle Sound, the central tier of the IBX borders the Albemarle and Pamlico sounds. This tier is the least populated, and counties include Washington, Tyrell, Hyde, the mainland portion of Dare, and the northern half of Beaufort. Washington (Beaufort County) is this tier's largest city. The southern tier borders the Neuse River and Pamlico Sound and counties consists of Craven, Pamlico, the mainland portion of Carteret, and the southern half of Beaufort. New Bern (Craven County) is its largest city, and its surrounding region is actively marketed and recognized as a retirement destination hotspot. Inland coastlines and waters act as amenity attractions. For example, Oriental (Pamlico County) is self-promoted as the "sailing capital of North Carolina" (Town of Oriental, 2008). The southern tier is also home to a substantial military population oriented towards Marine Corps Air Station Cherry Point in Craven County and Camp Lejeune (Marine Corps) in nearby Onslow County. Many Camp Lejeune personnel stationed in Onslow County locate residentially in the adjacent Carteret County.

Table 1 summarizes population growth patterns for 1990-2000 by regional tier and county. The

highest population and growth is in the southern tier followed closely by the northern tier. The central tier has a substantially smaller population and growth rate. Population growth for the entire state of North Carolina during the same period was 21.4%. Large portions of this state-wide growth are concentrated in the large metropolitan regions such as Charlotte and the Triangle. Inner Banks growth is geographically uneven among the three tiers and collectively is lower than growth for the state as a whole.

Ecologically, the Inner Banks forms the core of the Albemarle-Pamlico Estuary System, the second largest estuary system in the US after the Chesapeake Bay. It provides habitat for the largest population of black bear within North Carolina and the recently reintroduced red wolf. It is a major habitat for waterfowl and migrating birds. The annual bird migration is an important tourist attraction of the region. Much of the region is characterized by large low-lying areas (< 2 m elevation) with gentle slopes, low-gradient streams, and poorly drained soils (Moorhead and Brinson, 1995). In terms of area, wetlands is the largest land cover class and predominates in the eastern IBX and riparian zones, followed in magnitude by forest which is more prevalent in the west (Figures 2 & 3). While humans historically have made substantial modifications (naval stores industry, drainage projects, agriculture), the region houses a rich natural resource base whose environmental amenities act as an attraction for in-migrants, second home owners, and tourists. The developed built environment forms a small percentage of the IBX landscape (Figure 4) which has its highest levels in the southern Inner Banks associated with cities such as New Bern, Havelock, Morehead City, and Beaufort.

Data and Methods

NOAA's Coastal Change and Analysis Program (C-CAP) is a nationally standardized database of land cover and land change information, developed using Landsat remotely sensed imagery (NOAA, 1995). Gridded land cover data (30 m resolution) were extracted from the 1996 and 2001 C-CAP land cover products (NOAA Coastal Services

Table 1. Population change, 1990-2000.

County	1990	2000	% change
Northern Tier	125,455	135,518	8.0
Bertie	20,388	20,044	-1.7
Camden	5,904	6,885	16.6
Chowan	13,506	14,526	7.5
Currituck*	12,290	16,152	31.4
Gates	9,305	10,113	8.7
Hertford	22,317	21,533	-3.5
Pasquotank	31,298	34,897	11.5
Perquimans	10,447	11,368	8.9
Central Tier	45,881	69,069	4.8
Beaufort**	42,283	44,958	6.3
Dare*	1,024	1,182	15.4
Hyde	4,721	5,057	7.1
Tyrrell	3,856	4,149	7.6
Washington	13,997	13,723	-2.0
Southern Tier	135,796	151,516	11.6
Carteret*	42,811	47,146	10.1
Craven	81,613	91,436	12.0
Pamlico	11,372	12,934	13.7

Source: US Census, 1990 and 2000.

* Barrier island population excluded.

** Beaufort County counted entirely as Central Tier.

Center, 2007). Generalization of C-CAP's original classification scheme yielded the following land cover classes used for analysis: developed, agriculture, forest, scrub, wetlands, and other. The "other" class consisted largely of large inland lakes (e.g. Lake Mattamuskeet). The "scrub" class is defined as areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation and includes tree shrubs, young trees in early successional stage, or trees stunted from environmental conditions. A raster combine function was then applied to the two generalized land cover grids to create a single "change" grid representing, on a per pixel basis, land cover categories for both dates with which patterns of change can be analyzed.

Analysis of change was conducted initially through construction of a traditional transition matrix (Table 2). Interpretation of the matrix is straightforward with elements c_{ij} (i does not equal j) indicating proportions (percents) of the landscape transitioning from class i to class j , for example a change from forest (i) to developed (j) denoted by c_{ij} . More simply, the ij notation refers to a specific from-to land cover change magnitude reported as the percent of the total landscape area. Elements of the main diagonal, c_{ii} , indicate proportions of land classes that did not change, or *persistence*. Total percentages per class in 1996 and 2001 are indicated in the Total 1996 column and Total 2001 row respectively. Total losses per class in 1996 and gains per class in 2001 are indicated in the Loss column and Gain row respectively.

Following Pontius et al. (2004), identification of systematic inter-category transitions requires computing both expected gains and losses for each class pair assuming a random process of gain and loss. Expected gain for class pair i and j is defined as:

$$g_{ij} = (c_{+j} - c_{ij}) \left(\frac{c_{i+}}{100 - c_{j+}} \right), \forall i \neq j$$

This formulation assumes that the amount of class j gain from a specified class i and the study area's proportion of class i during 1996 are empirically given. The empirically observed gain is then distributed to come from the other j categories ac-

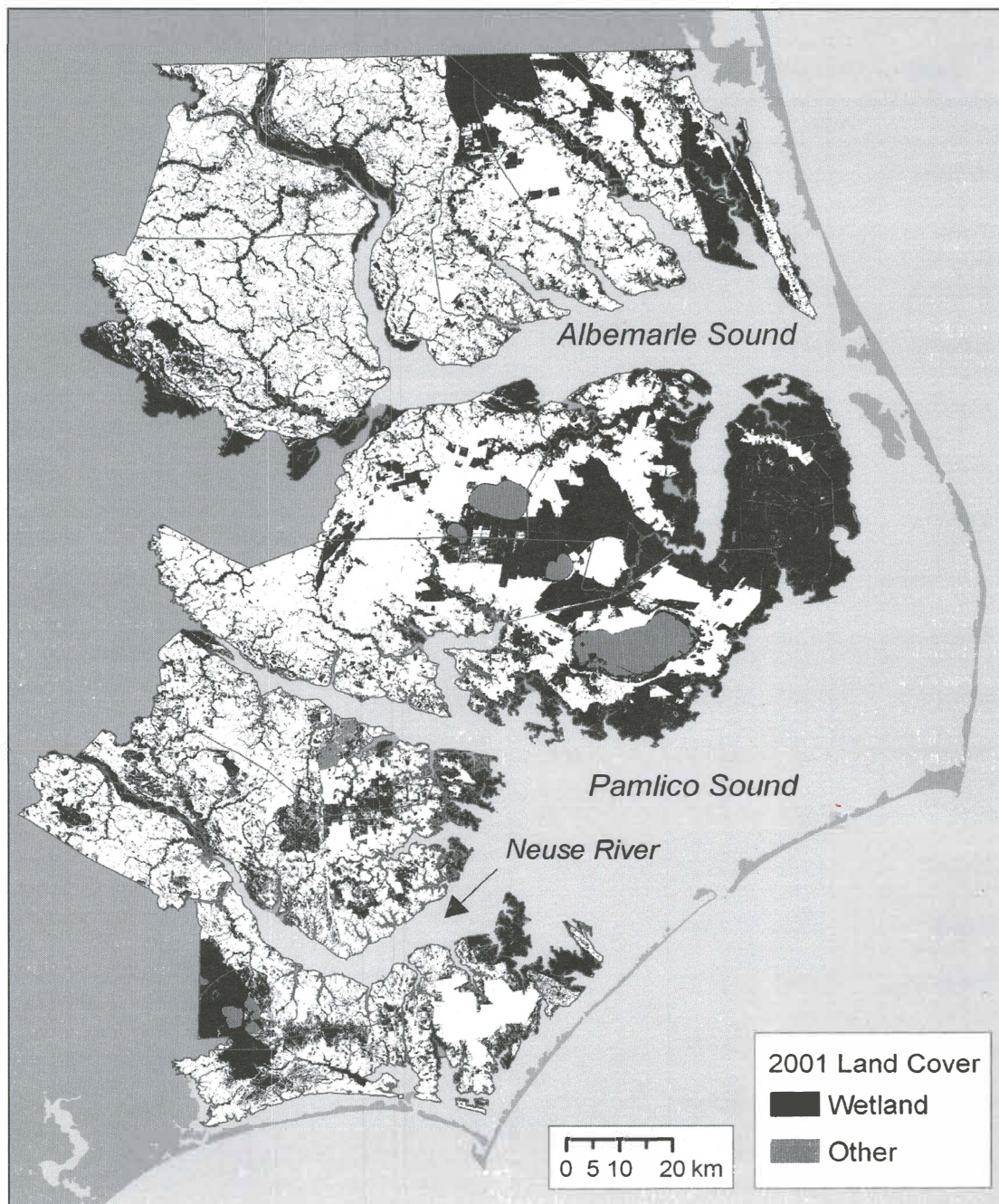


Figure 2. 2001 land cover: wetland and other. Source: derived from NOAA-CCAP.

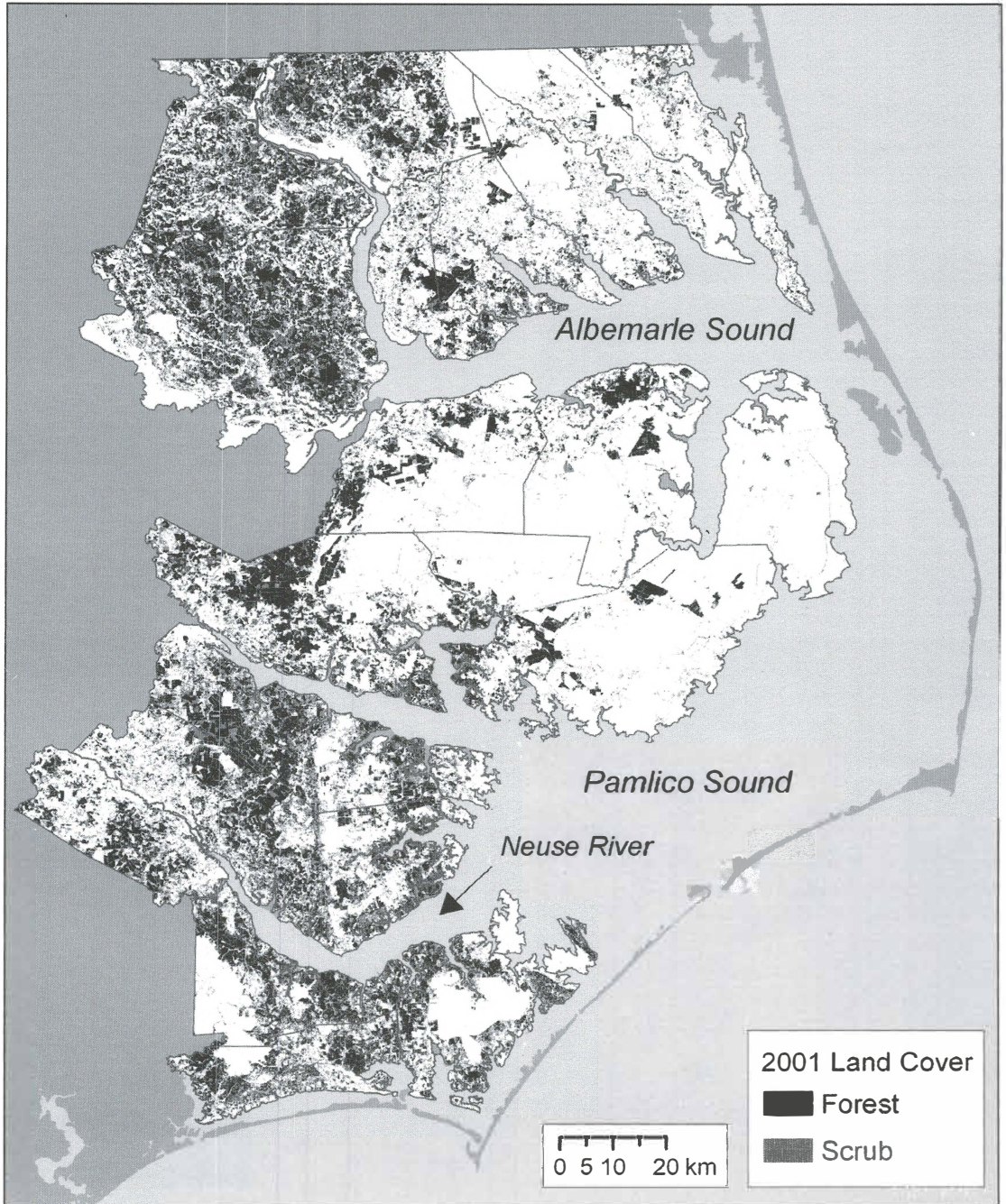


Figure 3. 2001 land cover: forest and scrub. Source: derived from NOAA-CCAP.

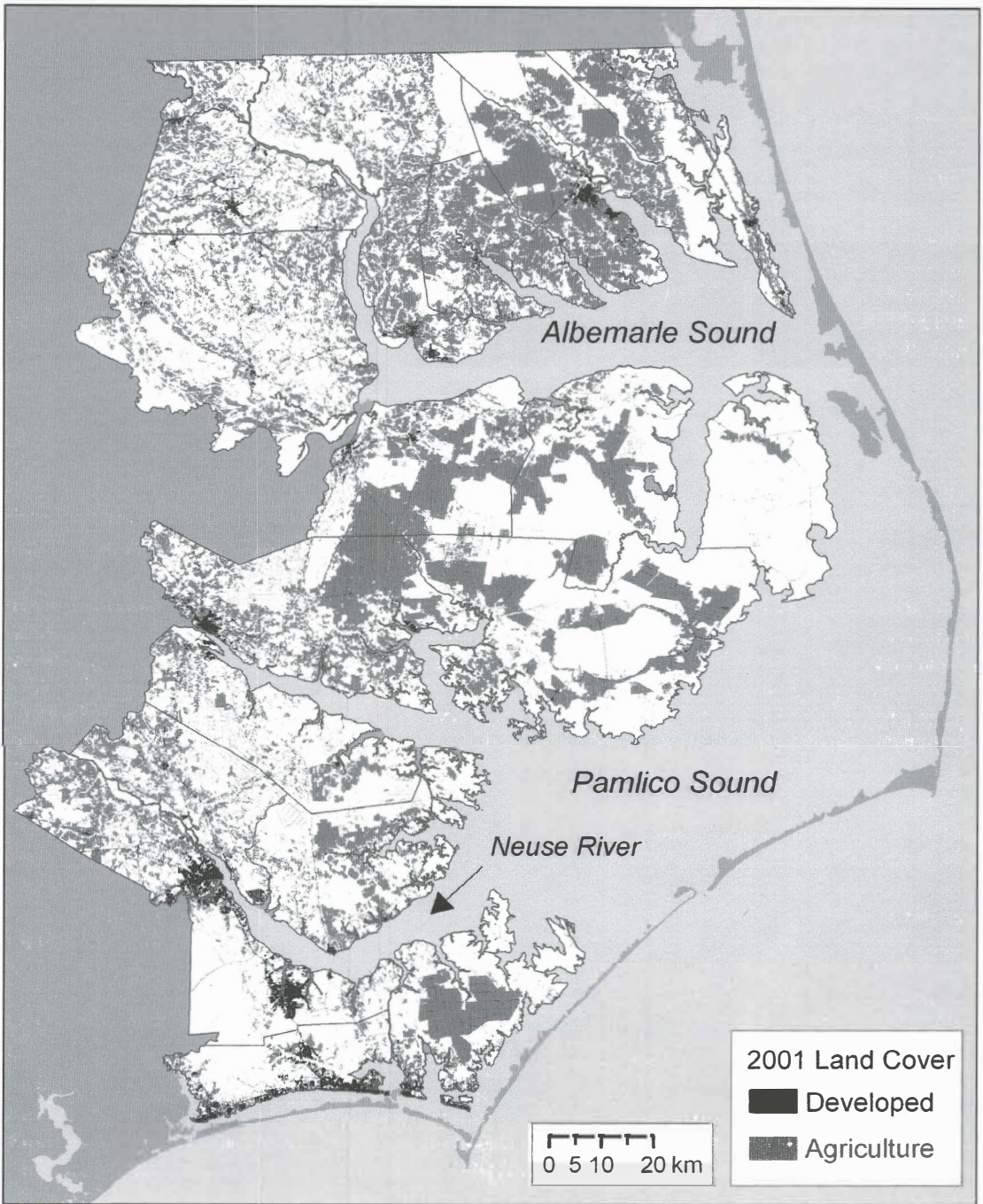


Figure 4. 2001 land cover: developed and agriculture. Source: derived from NOAA-CCAP.

cording to their relative proportions in 1996. This represents a random process of gain by ensuring that, for a gaining class, gains from other classes are proportional to how the other classes populated the study area in 1996. For diagonal entries, expected gain is set equal to observed gain in order to hold persistence constant and thereby examine off-diagonal transitions given the observed level of persistence.

In a similar fashion, expected loss under a random process for class pair ij is defined as:

$$l_{ij} = (c_{i+} - c_{ii}) \left(\frac{c_{+j}}{100 - c_{+i}} \right) \forall i \neq j$$

This assumes that the loss of each class is given. The observed loss is then distributed among the other categories according to their relative proportions in 2001.

Given the focus on change for the "developed" land class, subsequent analysis focuses largely on this single category. Additionally, since there was no loss of land identified as developed in 1996 (i.e. the developed class only experienced gains from other classes) analysis was further limited mainly to inspection of gains in development from 1996 to 2001.

For each from-to transition, the difference between the empirically observed gain and the expected gain under a random process are calculated via simple subtraction and is defined as observed gain minus expected gain. An interpretation is that a large positive deviation between observed gain and expected gain indicates a systematic propensity for class i (e.g. developed) to gain from class j (i.e. one of the previously non-developed classes). A large negative deviation indicates a systematic propensity for class i to avoid gaining from class j . Caution should be taken when comparing the raw magnitudes of deviations due to the fact that larger areal classes in 1996 would be expected under a random process of change to have larger deviations due simply to the fact of their larger areal size. For example, if forest area is five times larger than scrub area in 1996, then under a random process the expected gain in developed from forest should be five times larger than the expected gain in developed from scrub. This

can result in a larger raw deviation for the forest-to-developed class pair due solely to forest's originally large areal size in 1996. To enable valid comparison, a final step normalizes the deviations of the empirically observed gain from the expected gain by dividing by the expected gain to create a normalized deviation ratio which is defined as $(c_{ij} - g_{ij})/g_{ij}$. As a hypothetical example, if the observed gain in developed from forest (c_{ij}) is 0.10% and the expected gain (g_{ij}) is 0.05%, then the deviation ratio is: $(0.10 - 0.05) / 0.05 = 1.00$. An interpretation is that developed gained 100% more from forest than would be expected randomly – or the developed class gained two times more from the forest class than expected. If the observed gain in developed from forest (c_{ij}) is 0.05% and the expected gain (g_{ij}) is 0.10%, then the deviation ratio is: $(0.05 - 0.10) / 0.10 = -0.50$. In this case the developed class gained 50% less from the forest class than would be expected randomly, or half as much as expected.

Results

Land cover percentages and net change were extracted from the computed transition matrix (Table 3). Wetlands, agriculture, and forest were the largest classes for both years. Developed land increased from 2.42% to 2.55% of the study area for a net change of 0.13 percentage points – a net change that was the second smallest in raw magnitude. Note however, that a simple focus on raw net change may mask important systematic patterns of change that more detailed analysis of the transition matrix is designed to capture as described above in the methods. Mindful of this caveat, the two largest net changes were for forest (-1.65) and scrub (1.24). It is likely that this represents a transition between these two classes with selected forest sites being cleared since 1996 and appearing as scrub in the 2001 classification. Additionally, given the originally large areas of agriculture and forest in 1996, their raw net changes, while large compared to net change for developed area, most likely indicates fairly stable land cover proportions for agriculture and forest. Focusing on the developed class, a summary of net

Table 2. Derivation of a land cover transition matrix (percents).

2001							
1996	2001	Developed	Agriculture	Forest	Scrub	Wetland	Other
Developed	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{16}	c_{1+}
Agriculture	c_{21}	c_{22}	c_{23}	c_{24}	c_{25}	c_{26}	c_{2+}
Forest	c_{31}	c_{32}	c_{33}	c_{34}	c_{35}	c_{36}	c_{3+}
Scrub	c_{41}	c_{42}	c_{43}	c_{44}	c_{45}	c_{46}	c_{4+}
Wetland	c_{51}	c_{52}	c_{53}	c_{54}	c_{55}	c_{56}	c_{5+}
Other	c_{61}	c_{62}	c_{63}	c_{64}	c_{65}	c_{66}	c_{6+}
Total 2001	c_{+1}	c_{+2}	c_{+3}	c_{+4}	c_{+5}	c_{+6}	100
Gain	$c_{+1} - c_{11}$	$c_{+2} - c_{22}$	$c_{+3} - c_{33}$	$c_{+4} - c_{44}$	$c_{+5} - c_{55}$	$c_{+6} - c_{66}$	c_{+6}
							$c_{1+} - c_{11}$
							$c_{2+} - c_{22}$
							$c_{3+} - c_{33}$
							$c_{4+} - c_{44}$
							$c_{5+} - c_{55}$
							$c_{6+} - c_{66}$

change by county (Figure. 5) reveals geographic variation with northern and southern tier counties experiencing the largest net gains of developed area in terms of percentage point gains.

The empirical transition matrix reports percents of from-to change for every class pair (Table 4). To focus analysis on growth of developed land area, the full matrix was subsetting to include only transitions involving conversion of non-developed classes to the developed class and was expanded to also report: expected gain, deviations between observed and expected gain, and the normalized deviation ratio (Table 5). Recall that there were no instances of the developed class converting to the agriculture, forest, scrub, wetland, or other classes. For empirically observed gain, the developed class gained the most from forest followed by gains from agriculture, scrub, and wetland. However, inspection of the normalized deviation ratios reveals that the strongest positive signal of change was for scrub-to-developed followed by forest-to-developed. Thus, there was a systematic propensity for scrub and forested land to convert to developed. Agriculture-to-developed had a negative ratio indicating a systematic propensity for developed to avoid gaining from agriculture even though this transition had the second highest empirically observed magnitude. There was an even stronger propensity for developed to avoid gaining from wetland as is evident from the fact that the wetland-to-developed transition had the largest negative ratio.

Results for the entire IBX region presented above were disaggregated and mapped at the county level in order to describe geographic patterns of changes. A threshold deviation ratio of 0.20 was employed to identify counties depicted with thick boundaries that exhibited a systematic propensity for developed area to gain from agriculture, forest, and scrub. Systematic transitions from agriculture-to-developed were clearly concentrated in the northern tier counties (Figure 6a). Transitions from forest-to-developed occurred widely throughout the IBX region in all three tiers (Figure 6b). Transitions from scrub-to-developed were present in only the central and southern tiers (Figure 6c). Every county had a negative ratio for the wetlands-to-developed transi-

tion indicating the aforementioned avoidance of gain in developed from wetlands. To highlight the strength of this avoidance, a threshold deviation of -0.90 was employed (i.e. counties with a ratio less than or equal to -0.90). Results show that northern tier counties had the strongest tendency to avoid conversion of wetlands to developed (Figure 6d).

Discussion

Transition matrix analysis techniques provided answers to two main research questions. Focusing on change for developed land area, developed area grew from 2.42% to 2.55% of the Inner Banks study area over the period 1996-2001 for a net change of 0.13 points. While this net change was lower than net change for most other classes, transition matrix analysis involving calculations of expected change under a random process revealed more nuanced information pointing to systematic signals of conversion. Deviations ratios showed that the major processes of conversion involved shifts from forest and scrub to developed. While conversion from agriculture to developed had the second highest magnitude, its negative deviation ratio suggests that this type of transition was not as important as conversion from forest or scrub. However, a caveat is that land classified as scrub in 1996 may in fact have been old agricultural land that was not being cultivated and consequently appeared as scrub in the NOAA C-CAP land cover product. For example, tobacco farms that have been taken out of production may undergo vegetative succession and eventually be sold to developers for conversion to residential development by 2001. Thus, agricultural conversion may play a more prominent role in land cover change for the Inner Banks than suggested by a simple focus on transition matrix results. Geographically, conversion from agriculture was more pronounced in the northern tier, conversion from forest was distributed among all three tiers, and conversion from scrub was more pronounced in the central and southern tiers.

The vast majority of land cover (95%) experienced no change during the 1996-2001 period. This study period may slightly precede or represent the early beginnings of the inland "coastal boom" re-

Table 3. Land cover percents and net change.

Class	% 1996	% 2001	Net Change
Developed	2.42	2.55	0.13
Agriculture	29.47	29.97	0.51
Forest	23.03	21.38	-1.65
Scrub	5.72	6.96	1.24
Wetland	36.77	36.51	-0.26
Other	2.59	2.62	0.04

ported in the Raleigh News & Observer (Price 2006). In fact, it would be surprising to find high levels of change over such a short period for a largely undeveloped, geographically remote, and lightly populated region like the Inner Banks. It is indeed common in land change research to find high levels of persistence. Persistence levels in Wear and Bolstad (1998) and Pontius et al. (2004) for five different study regions ranged from 69% to 90%, although these studies ranged over 20 year periods. Despite the low quantities of change, the methods employed here enabled nuanced identification of systematic signals of change focusing specifically on conversion to developed land.

The idea of "inland boom" warrants further comparative research with other coastal or inland regions to place these rates in context. Certainly rates for high growth metropolitan regions experiencing suburbanization will outpace rates for the Inner Banks, a relatively undeveloped region. However, this does not diminish the fact that systematic land cover change occurred during 1996-2001 as revealed in this baseline analysis. Results warrant continued monitoring of the Inner Banks during the present decade for which media coverage and anecdotal evidence is suggesting more dramatic transitions. If the Inner Banks is indeed North Carolina's final coastal frontier, then population growth and land

development during the next decades have the potential to dramatically alter the region's land cover, ecosystems, economy, and cultural sense of place.

Another interior coastal region of North Carolina that is experiencing change is Brunswick County which is located in the southern part of the Wilmington metropolitan area and is adjacent to the Myrtle Beach metropolitan area in South Carolina. Similar to the Outer Banks, the barrier island portion of Brunswick County is highly developed. Retirees have been particularly attracted to this region due to various environmental amenities as well as cultural and economic amenities associated with the neighboring metropolitan centers. In fact, some observers have referred to the region using the moniker "Retirement Alley." Interior land area within the county acts as a spatial outlet to absorb in-migration and development pressure. Land transition in Brunswick County is further along than transitions in most of the Inner Banks; however, there are likely similarities among many of the driving processes. Thus, sustained monitoring and comparative research of both the Inner Banks and other interior coastal regions such as Brunswick County that may be at different historical stages of development is likely to yield rich insights regarding patterns, processes, and consequences of coastal land cover change.

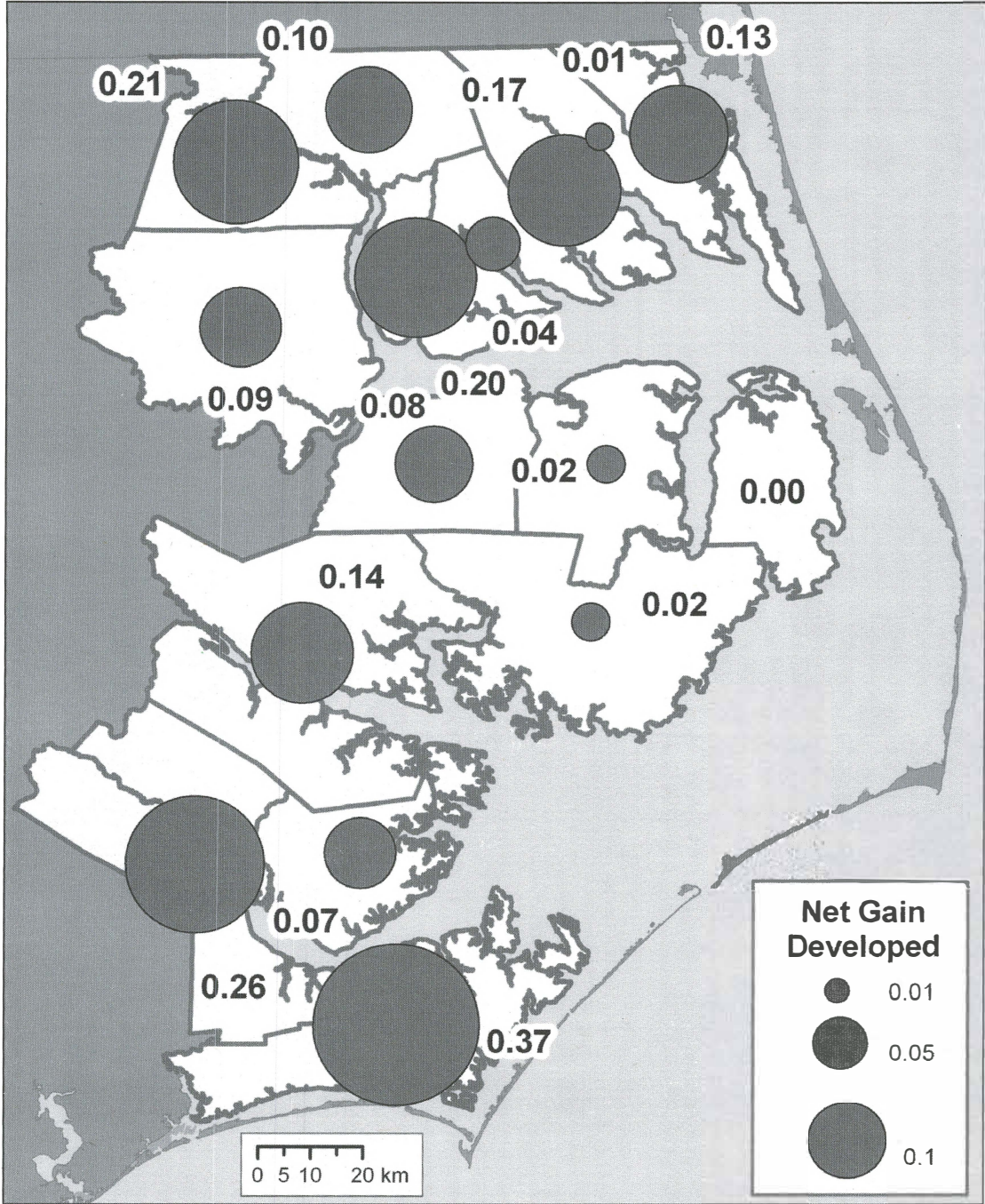


Figure 5. Net gain in developed land area by county, 1996-2001.

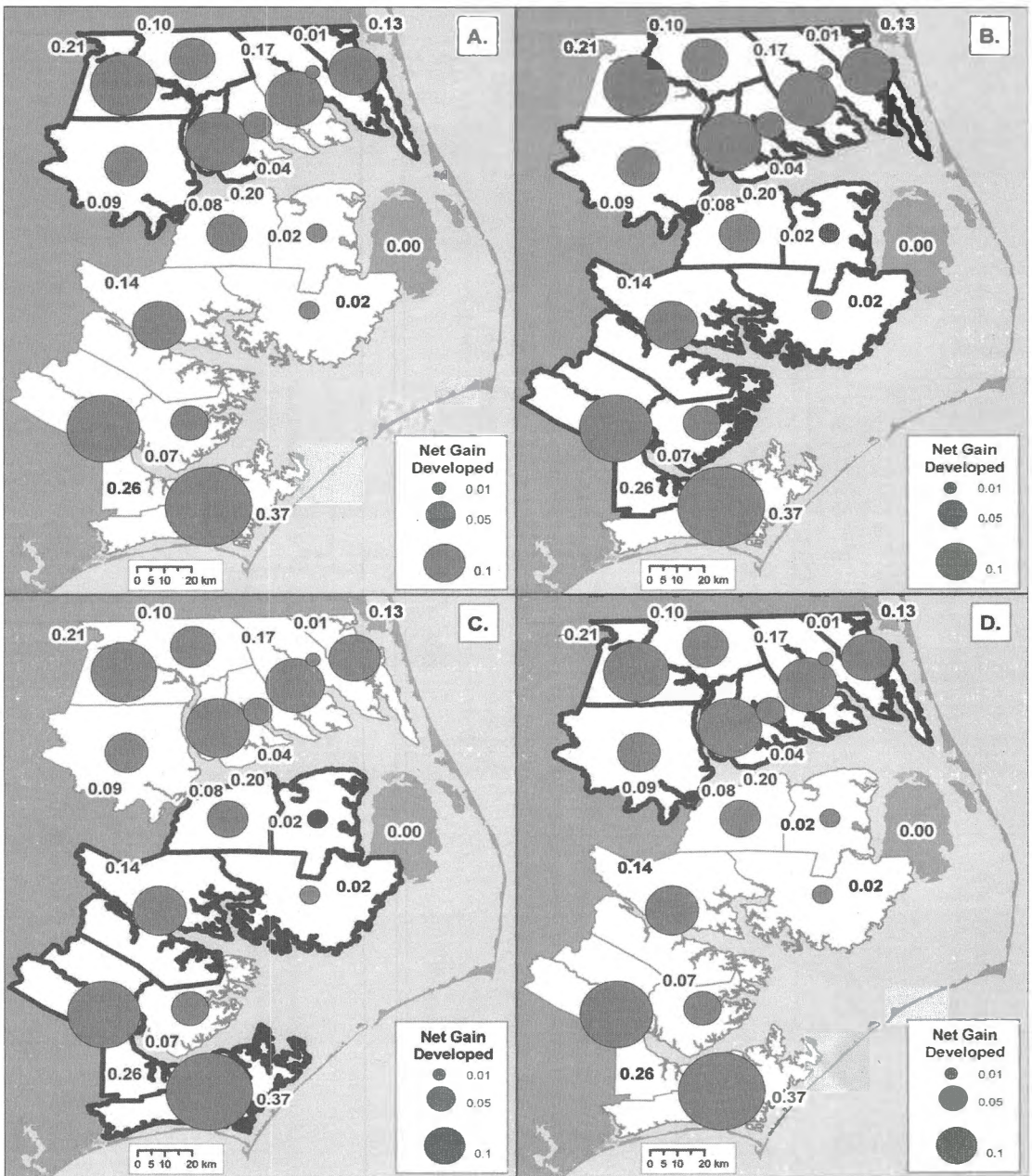


Figure 6. Net percentage point gain in developed land area (graduated symbols) by county and systematic and cover transitions (thick black boundaries): (a) agriculture-to-developed, (b) forest-to-developed, (c) scrub-to-developed, (d) wetland-to-developed (systematic avoidance of change).

Table 4. Empirical land cover transition matrix (percents).

	2001	Developed	Agriculture	Forest	Scrub	Wetland	Other	Total 1996	Loss
1996									
Developed		2.42	0.00	0.00	0.00	0.00	0.00	2.42	0.00
Agriculture		0.03	28.52	0.08	0.51	0.31	0.02	29.47	0.95
Forest		0.06	0.96	20.64	1.23	0.13	0.02	23.03	2.39
Scrub		0.02	0.12	0.56	4.94	0.07	0.01	5.72	0.79
Wetland		0.02	0.36	0.10	0.28	35.98	0.03	36.77	0.79
Other		0.00	0.01	0.00	0.01	0.02	2.54	2.59	0.05
Total 2001		2.55	29.97	21.38	6.96	36.51	2.62	100.00	
Gain		0.13	1.45	0.75	2.03	0.53	0.08		

Table 5. Expanded land cover transition matrix for conversion from non-developed to developed (conversion from Other to Developed omitted).

	2001	
1996	Developed	
Agriculture	0.03	Observed Gain
	0.04	Expected Gain
	-0.01	Deviation
	-0.17	Deviation Ratio
Forest	0.06	Observed Gain
	0.03	Expected Gain
	0.03	Deviation
	0.89	Deviation Ratio
Scrub	0.02	Observed Gain
	0.01	Expected Gain
	0.01	Deviation
	1.21	Deviation Ratio
Wetland	0.02	Observed Gain
	0.05	Expected Gain
	-0.03	Deviation
	-0.58	Deviation Ratio

Acknowledgements

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