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Landscape characteristics of a stream and wetland mitigation banking program

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Abstract. In the United States, stream restoration is an increasing part of environmental and land management programs, particularly under the auspices of compensatory mitigation regulations. Markets and regulations surrounding stream mitigation are beginning to mirror those of the well-established wetland mitigation industry. Recent studies have shown that wetland mitigation programs commonly shift wetlands across space from urban to rural areas, thereby changing the functional characteristics and benefits of wetlands in the landscape. However, it is not yet known if stream mitigation mirrors this behavior, and if so, what effects this may have on landscape-scale ecological and hydrological processes. This project addresses three primary research questions. (1) What are the spatial relationships between stream and wetland impact and compensation sites as a result of regulations requiring stream and wetland mitigation in the State of North Carolina? (2) How do stream impacts come about due to the actions of different types of developers, and how do the characteristics of impacts sites compare with compensation sites? (3) To what extent does stream compensation relocate high-quality streams within the river network, and how does this affect localized (intrawatershed) loss or gain of aquatic resources? Using geospatial data collected from the North Carolina Division of Water Quality and the Army Corps of Engineers' Wilmington District, we analyzed the behavior of the North Carolina Ecosystem Enhancement Program in providing stream and wetland mitigation for the State of North Carolina. Our results suggest that this program provides mitigation (1) in different ways for different types of permittees; (2) at great distances (both Euclidean and within the stream network) from original impacts; (3) in significantly different places than impacts within watersheds; and (4) in many cases, in different watersheds from original impacts. Our analysis also reveals problems with regulator data collection, storage, and quality control. These results have significant implications given new federal requirements for ecological consistency within mitigation programs. Our results also indicate some of the landscape-scale implications of using market-based approaches to ecological restoration in general.

Key words: Ecosystem Enhancement Program; mitigation banking; Section 404 Clean Water Act; stream mitigation; watershed ecology; wetland mitigation.

Introduction

Ecosystem markets

Land use change throughout the United States has decreased the extent and quality of aquatic ecosystems (NRC 1992, 2001), with profound impacts on downstream receiving water bodies, including drinking water reservoirs and coastal ecosystems. These impacts have raised critical questions about the possibility of restoring damaged aquatic ecosystems (NRC 1992, Mosier et al. 2002, Bernhardt et al. 2005). The regulatory mechanisms for implementing ecosystem restoration vary greatly, but market-based approaches are increasingly preferred in the United States (Hough and Sudol 2008, Hough and Robertson 2009), particularly for restoration of aquatic ecosystems like wetlands and streams. The use of market mechanisms for regulating restoration programs introduces the potential for landscape and regional-level problems that have been largely ignored in the ecological literature, as most previous studies have focused largely on the ecological efficacy of specific restoration sites, i.e., whether restored sites are comparable to natural sites (NRC 2001). Because market mechanisms are now increasingly used in environmental conservation or restoration programs, it is important to document the landscape effects generated by these programs, and whether subtleties in the implementation of these programs may generate unexpected outcomes.

A growing literature highlights the potential for unintended consequences arising from poorly understood ecosystem service markets. For instance, recent

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studies show that wetland mitigation programs commonly promote shifts ("relocations") of wetlands across space, including movements from urban to rural areas, as well as between communities comprising vastly different ecological, social, and economic characteristics (King and Herbert 1997, Ruhl and Salzman 2006, BenDor et al. 2007). M. W. Doyle and A. J. Yates (*unpublished observations*) show that market mechanisms can, in certain circumstances, create economic incentives for many small restoration sites rather than fewer, large sites, which may affect the ecological effectiveness of these programs if project scale is correlated with ecological efficacy of restoration (as it often is under many mitigation programs [BenDor et al. 2008]). Also, Armsworth et al. (2006) show that land conservation purchases (as promoted in wetland and stream mitigation markets) can actually undermine conservation goals by creating economic incentives for land development in biologically valuable areas, or by accelerating the pace of land development. Finally, the air emissions literature suggests that market mechanisms can lead to the creation of pollution "hot spots," because pollution becomes concentrated and offsets become concentrated elsewhere on the landscape (Boyd et al. 2003). These previous studies show that markets can create landscape-level patterns of restoration sites that raise ecological concerns when numerous projects are accumulated over time and across the landscape. This stands as a new form of "cumulative effect," since these concerns may not be necessarily relevant at the scale of an individual project (BenDor 2009). As such, to evaluate the potential efficacy of ecological restoration programs, it is critical to move beyond studies of individual restoration sites to evaluate the ecological landscape produced by restoration programs as a whole (Palmer et al. 2005, Bernhardt et al. 2007). Unfortunately, data on landscape-scale environmental markets are rare, and rigorous spatial analysis of environmental trades is mostly nonexistent (BenDor et al. 2007). As ecosystem markets proliferate into diverse realms of environmental regulations, it is important to use available markets as test beds for potential unintended landscape consequences.

The goal of this paper is to address whether there have been cumulative landscape effects generated by a stream and wetland compensatory mitigation program (i.e., aquatic ecosystem market) and to understand if market or regulatory mechanisms are creating patterns that were unintended or unforeseen. We sought to quantify the spatial relationships between locations of stream impacts and stream restoration projects, and to determine whether there were systematic preferences for types of location for restoration that were attributable to markets (e.g., preferentially restoring smaller streams). We collected and organized geo-spatial data on stream and wetland sites for the entire state of North Carolina from the U.S. Army Corps of Engineers (Corps; impact permits) and the North Carolina Ecosystem Enhancement Program (EEP; mitigation permits). We used these data to analyze the EEP's compensatory stream and wetland mitigation programs across a range of land use metrics. We also performed a comprehensive spatial analysis on interwatershed compensation, localized net loss of wetland and stream sites, and the clustering behavior associated with impacts offset at distant compensation sites. We describe the policy and regulatory structures that create the ecosystem market, and the data sources we used along with the limitations and omissions of data. We then present the spatial analysis we used to describe industry and regulatory effects on the landscape. Finally, we provide an overview of the results, focusing our discussion on the potential ecological implications of the patterns observed.

Background

Stream and wetland restoration via mitigation

Government-led protection of aquatic ecosystems in the United States is primarily implemented as a permitting program under Section 404 of the Clean Water Act of 1977. Public or private developers who propose projects with certain types of harmful impacts to aquatic ecosystems must apply for a federal permit to impact these systems from the U.S. Army Corps of Engineers (hereafter, "Corps"). The Corps evaluates the project to assess the quantity of impacts from the proposed work, as well as whether the impacts will require any type of mitigation. To receive the permit for the proposed work, the developer is required to (1) avoid impacts, (2) minimize unavoidable impacts, and/or (3) compensate for unavoidable impacts through mitigation. Compensation is based on the premise that impacted ecosystems can be compensated by restored ecosystems elsewhere, a highly contentious assumption in the scientific community (Bedford 1996, Race and Fonseca 1996, Zedler 1996, NRC 2001). Much of compensatory mitigation is initiated in an attempt to prevent net losses of aquatic resources and associated functions across the United States. This effort was originally established through the widely supported "no net loss" policy recommended during the National Wetlands Policy Forum (1988). While compensatory mitigation is the key driver of wetland restoration in the United States, mitigation of stream damage is primarily practiced in North Carolina (Bernhardt et al. 2007, Sudduth et al. 2007). However, stream mitigation programs are now being promoted in many states (Lave et al. 2008).

Ecological restoration practices have matured during a period of expansion of market-oriented environmental regulation strategies (Salzman and Ruhl 2005, Lave et al. 2008, Hough and Robertson 2009). The combination of ecological restoration and market-oriented regulation created the mitigation banking industry. While wetland mitigation banking policies (and the industry) are being increasingly studied (NRC 2001, Robertson 2006), stream mitigation banking is mostly undocumented in

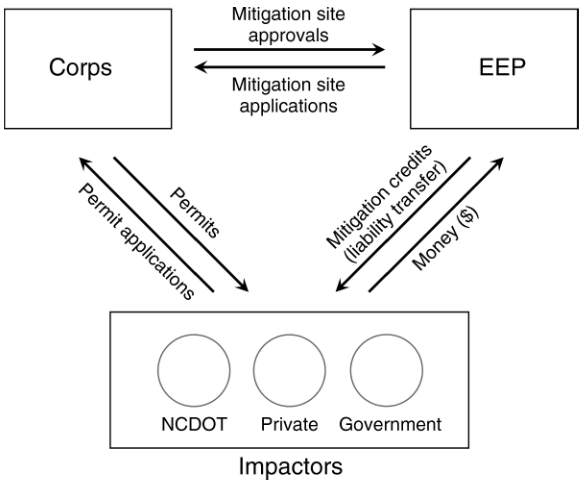

FIG. 1. Schematic of the relationship between the Corps (U.S. Army Corps of Engineers), EEP (North Carolina Ecosystem Enhancement Program), and impactors (permittees). The EEP first gets formal permission from the Corps to sell mitigation credits to impactors. When impactors apply to the Corps for permits, they may be given the option of transferring liability for compensation to the EEP. This occurs through the purchase of mitigation credits from the EEP.

the scientific literature, despite numerous stream mitigation programs throughout the United States (ELI 2006). Mitigation banking allows developers to mitigate or offset their impacts through the purchase of restoration credits, which are usually produced speculatively by for-profit companies (ELI 2006; hereafter we refer to these entities as "impactors" and "mitigators" to indicate those that are seeking credits to compensate for impacts, and those that are producing credits, respectively). Mitigators purchase degraded streams or wetlands and restore the ecosystem to generate restoration credits, which then must be certified by the Corps as well as state regulators. Mitigators often seek to produce credits in large quantities to meet the demands of numerous developers and to harness potential economies of scale, i.e., mitigation banks (BenDor and Brozovic 2007). As such, impacts at many different sites may be mitigated at a single bank site. The primary limitation to linking impacts to bank credits is the geographic service area, the area within which a bank's credits are available to mitigate impacts. Geographic service areas are often constrained by regulators to watersheds (e.g., 8-digit hydrologic unit code), or based on scales of government (e.g., county or state boundaries [Robertson 2006, BenDor and Brozovic 2007]).

The North Carolina Ecosystem Enhancement Program

In order for development activities to occur, entrepreneurial mitigation banks must actively produce stream or wetland restoration credits of sufficient quantity and in appropriate locations to keep ahead of development activities. If there are no credits available in an area, then impacts cannot be permitted for lack of compensation, unless regulators allow permittees to perform compensation themselves (which is increasingly frowned upon by regulators [Hough and Sudol 2008]). In North Carolina, the largest single impactor of streams and wetlands is the North Carolina Department of Transportation (NCDOT). During the mid-1990s, NCDOT experienced project delays because of the lack of availability of compensation credits (Dye Management Group 2007). In response to this, the state created the North Carolina Wetlands Restoration Program (WRP) in 1996, a state-administered wetlands and stream mitigation program. This program was refined and reformulated into the North Carolina Ecosystem Enhancement Program (EEP) in 2003. In the early period of the EEP, there were several "transition years" during which some of the current regulations were relaxed. For instance, high-quality preservation sites could be used to offset distant impacts, because many restoration sites were not available. In addition, while current Corps regulations require EEP compensation to be within the same 8-digit HUC (Hydrologic Unit Code) watershed as the impact; during the transition years this was not required.

The EEP was intended to use the projected NCDOT construction activities as a plan from which to proactively develop mitigation credits well ahead of time in the needed geographic areas. Because of the availability of credits, EEP-generated mitigation credits were also used by private developers. However, EEP credits in the past have been under priced. Templeton et al. (2008) conducted an economic study of EEP projects for >58 215 m of stream restoration and showed that while the EEP collected fees of ~\$232 per linear foot (1 foot = 0.3048 m) of stream mitigation (\$761/m), the inflation-adjusted expense was \$242 per linear foot (\$794/m), without considering full monitoring expenses. This gives the EEP a competitive advantage over private mitigation bankers. Thus, within North Carolina, all impactors (NCDOT, private entities, and non-NCDOT government agencies) primarily trade with the EEP (Fig. 1).

Impacts and compensation measurement

In North Carolina, impacts and compensation credits are evaluated based on several geomorphic and ecological criteria, but are quantified and inventoried as stream or wetland mitigation units (SMUs/WMUs), which are based on resource quality of both impact and compensation site, type of impact/compensation, and the length of impacted/restored streams or area of impacted/restored wetlands. SMUs/WMUs are the commodities traded in this ecosystem service market, where one SMU is defined as one linear foot of stream (i.e., one credit; 0.30 m), and one WMU is one acre (credit; 0.41 ha) of wetland. (We state values in English units because that is how they are conveyed in state and federal policy.) Because of the difference between natural ecosystems and restored ecosystems, regulators overseeing compen-

TABLE 1. Differences in definitions, requirements, and ratios associated with compensation methods in North Carolina.

Activity	Definition and specific actions	Compensation ratio
Stream restoration	Converting unstable, altered, or degraded stream to natural stable condition. Involves restoration of dimension, pattern, and profile based on reference reach information.	1:1
Wetland restoration	The manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural or historic functions to a former or degraded wetland. Reestablishment of wetland and/or other aquatic resource characteristics and function(s) at a site where they have ceased to exist, or exist in a substantially degraded state.	1:1
Stream enhancement level I	Rehabilitation to improve water quality or ecological function; may include in-stream or stream bank activities, but in total fall short of restoring one or more geomorphic variables. Involves improvement of dimension and profile based on reference reach information.	1.5:1
Wetland enhancement	Increasing one or more of the functions of an existing wetland by manipulation of vegetation or hydrology. Activities conducted in existing wetlands or other aquatic resources that increase one or more aquatic functions.	2:1
Stream enhancement level II	Rehabilitation that augments channel stability, water quality, and stream ecology, but falls short of restoring both dimension and profile. Involves bank stabilization, livestock exclusion, or reconnecting channel to floodplain.	2.5:1
Wetland creation	Establishment of a wetland or other aquatic resource where one did not formerly exist. The construction of a wetland in an area where wetlands did not exist in the recent past.	3:1
Stream preservation	Protection of ecologically important streams including upland buffers and both sides of channel. Involves purchase of land or establishment of easement.	5:1
Wetland preservation	Protection of ecologically important wetlands or other aquatic resources. Involves protection of existing habitat conditions, through purchase of land or establishment of easement.	5:1

Notes: The compensation ratio describes the length (linear m) of stream and area (ha) of wetlands that must be restored for each linear m/ha of stream or wetland destroyed. Under the North Carolina stream mitigation guidance, "dimension" refers to cross-section, "pattern" to planform (sinuosity), and profile to slope (Corps 2003). Thus, "Enhancement level I" requires that channel cross-section and slope be manipulated at the project site, whereas "Restoration" requires the additional manipulation of planform. Enhancement of wetlands results in a gain of some wetland functions but does not result in a gain of wetland area.

satory mitigation will often require a trading ratio (also known as a "compensation ratio") based on the quality of the impacted stream and the type of compensation performed by the mitigator: for example, 200 m of impacted stream may result in 400 m of required stream compensation.

Under regulations governing the EEP, a fraction of compensation credits must come from stream/wetland restoration, with the rest being derived from "enhancement" or "preservation" credits (EEP 2004). Table 1 presents the differences in definitions, requirements, and ratios associated with these compensation methods. The problem is the extent to which hydrology, geomorphology, aquatic habitat, and vegetation of the stream channel and flood-prone areas are restored and evaluated in North Carolina. Stream "enhancement" refers to less extensive restoration activities, including stream bank stabilization and re-vegetation, and typically does not involve channel realignment. Similarly, wetland enhancement involves manipulation of hydrology or vegetation that results in net increase of wetland function, but not wetland areas (i.e., manipulation at an existing wetland site). Preservation of streams and wetlands refers to the direct purchase of stream and riparian property or of permanent conservation easements precluding development in the riparian area. These latter two sources of mitigation credits generate less SMUs/WMUs than complete restoration (Corps 2003). Our goal in this analysis was to evaluate the landscape-level implications of wetland and stream transactions as permitted by the Corps and fulfilled by the EEP. This evaluation involved collecting highly disaggregated, spatially explicit data on the locations, types, and extent of wetland and stream impacts throughout the State of North Carolina.

Data

The Corps commonly collects information on impact sites, including their location during the permitting process. In our case, additional Corps-permitted impact permit data were also available from the North Carolina Division of Water Quality (DWQ), while mitigation data were available from the EEP (Appendix A). We used available data for wetland and stream mitigation sites managed by the EEP, including the credit and debit ledger for both the private (also includes non-NCDOT government agencies) and NCDOT mitigation programs (which are legally maintained as separate entities). When compensation is required, the wetland and stream mitigation process can typically be represented as a transaction between impacted resources and their offsets at compensation sites. While impacts and compensation sites can hold a number of relationships, these transactions can typically be broken into one-to-one relationships, where an individual impact is offset at a single compensation site.

The EEP ledger maintains records linking impacts mitigated through the EEP to the specific sites used as compensation, and includes information on size and type of impact, type of impact permittee, and amount and type of mitigation credits debited from each mitigation site. Because stream and wetland impacts and restoration are coupled, wetland data were intermixed with stream data, thus facilitating our construction of a joint database. We should note here that while the EEP can link impacts directly to compensation sites, it does not consider this connection to be permanent. Rather, it considers its total amount of available credits (stream or wetland) in a watershed to be fungible in compensating for any individual impact. This is relatively unique to mitigation programs nationwide, where Corps districts are required (often for legal purposes) to track individual transactions between impacts and compensatory mitigation sites. Transactions involving private mitigation banks were relatively infrequent (and minimal; only a handful occur each year), and data were not uniformly available, so we only used EEP data. The EEP categorizes compensation among cold, cool, and warm streams, and wetlands into riparian and nonriparian areas. As we will show, our data set contains only a subset of the impacts for which the EEP provides compensation.

We were particularly interested in the spatial effects of ecosystem markets. The EEP data did not contain geospatial information on the locations of stream or wetland impacts mitigated by the EEP. Rather, we obtained permit data from the Wilmington Corps District detailing these locations, and matched them to the EEP restoration sites. These data included construction project descriptions, type of project permittee (DOT, Private entity [i.e., private developer], non-DOT government agency), permit type (individual, nationwide, or regional general permit), impact hectares (wetlands) and linear meters (stream). In order to tie the impact and restoration locations to stream networks, stream impact and compensation site points were snapped to the 1:24,000 National Center for Geographic Information Analysis (NCGIA) hydrography data set (NCGIA and NCDWQ 2007), as well as the National Hydrography Dataset (NHD+; USEPA 2008) in order to increase confidence in their locations in/adjacent to stream channels. Although the NCGIA hydrography data are significantly more detailed, the NHD+ contains verified stream order and linkage data and lends more confidence to our drainage area analysis. Impact and compensation data points were snapped (moved to the nearest stream channel) using the Hawths Tools extension for ArcGIS 9.2 (Beyer 2004, ESRI 2008). Snapping data points known to be along the NHD+ and NCGIA hydrography data set ($n = 408$ stream sites) was based on our suspicions about the spatial accuracy of Corps and EEP site data (BenDor et al. 2007: Appendix 1, for a discussion). Compensation sites snapped to the NHD+ were relocated a median distance of just over 41.5 m, while impact sites were moved just over 55.2 m, while sites snapped to the NCGIA dataset were relocated median distances of 66.4 and 10.1 m, respectively.

Methods

We developed summary statistics for the behavior of the EEP program by separating permitted impacts by impactor type (DOT, Private, non-DOT government) and compensation by impactor and physical type (restoration, enhancement, or preservation). We disaggregated data to better understand the compensation ratio required by regulators in various instances and across geographies. A central premise of mitigation banking is that the compensation should occur as close as possible to the impact in order to reduce the potential for pollution or impact hot spots, and recent federal regulations have required that compensation occur within the same watershed as the impact (watershed units of concern are left to individual Corps districts to define; 73 Fed. Reg. 70, 19593–19705, [April 10, 2008]). To examine any spatial effects, we analyzed the relationship between impact and compensation sites through spatial analysis of our data using a geographic information system (GIS). We analyzed the distance between impact and compensation sites through a series of t tests based on permittee type in order to determine agents predicating the largest "movement" of quality wetlands and stream sites across the landscape. We examined the movement distance using both Euclidean distance, but more importantly, the river network distance between impact and compensation sites, which provides a more ecologically and water-quality-relevant measure of spatial proximity.

We then assessed the extent to which impact events were adequately offset geographically, with compensation comparing impacts and mitigation credits by watershed (8-digit HUC) to assess the net loss or net gain within that watershed. By summing the preservation, enhancement (levels I and II), and restoration performed as weighted by the credit ratios that each provide (Table 1), we created an "adjusted ratio" that accounts for the credit granted to each compensation method by regulators in determining if a project has provided enough compensation (see ratios for stream and wetland compensation in *Background*). This analysis does not address whether the loss of ecosystem functions at impact sites is ever fully compensated by functions gained at restored sites, a subject critical, but beyond our data or the analysis available here.

We continued our spatial analysis of these data by using global and local cluster analyses to search for clusters of impact sites that had similar relocation distances between impact and compensation sites, thus indicating the potential for localized net loss or gain of wetlands and streams. Clusters were defined as sites located in proximity to one another (as defined by a spatial neighborhood, which we defined as the 10 nearest neighboring sites) that have similar values of an attribute (such as relocation distance; see BenDor et al. [2007] for more information). Cluster analyses are measures of spatial autocorrelation, which is the spatial association of objects based on a given attribute (Rogerson 2001). While global spatial autocorrelation measures the extent to which objects in an entire landscape cluster together, measures of local spatial autocorrelation determine the precise locations of actual clusters formed by objects in space. Global spatial autocorrelation is often measured using Moran's I, and is characterized on a scale similar to Pearson's correlation coefficient (−1 to +1), where −1 denotes complete spatial dissociation (a black and white checkerboard pattern), and +1 denotes complete spatial association (all white on the left, and all black on the right side of the board).

We focused our attention on an important measure of local spatial autocorrelation (localized clustering), performing a Local Indicator of Spatial Association (LISA) analysis (Anselin 1995, Brody and Highfield 2005) to determine areas within the region containing clusters of impact sites with high or low stream and wetland relocation distances. By doing this, we located areas that may continue to be susceptible to high relocation distances due to off-site compensation activities in the future. We also used this analysis to determine the effects of bank proximity on the location and size of clusters mitigated at high distances. Finally, we compared the drainage areas between impacts and compensation stream sites to test for systematic trends in movement of compensation sites up or downstream within a watershed, as well as the displacement distance within the stream network.

Results

Descriptive analysis: impacts and mitigation

Electronic data received from the different agencies were inconsistent and often either incomplete or nonexistent. According to EEP records, between 1996 and 2007 there were 15 875 m of impacted streams and 23.7 ha of impacted wetlands (riparian and nonriparian). In contrast, according to Corps records, there were 10 618 m of impacted streams and 234.0 ha of impacted wetlands (Appendix B). The magnitude of this discrepancy is likely the result of major data quality and database management problems. Here, missing data either occurred as missing permit records (nonexistent records) or as missing or incorrect entry of data into individual permit records (indicating low levels of data quality control). For simplicity, we present the results of analyzing the EEP data only (summary of Corps data are available in Appendix B).

There were 839 transactions (defined above) between 607 impact sites and 170 EEP compensation sites (Appendix A). Of these impact-compensation transactions, 431 were performed for regulated wetlands, while 408 were performed for streams. While the compensation sites were spread throughout the state, impact sites were concentrated in the rapidly developing urban areas (Appendix C). Our data set recorded "impact events" as independently recorded actions degrading aquatic resources. We recorded a total of 537 impact events, resulting in 607 impacts, because some events impacted both streams and wetlands. Of the permitted impacts, private entities accounted for 72% (n = 386) of independent impact events, non-NCDOT government agencies for 11% (59), and NCDOT for 17% (92). However, while private impacts were more numerous, NCDOT impacts were generally larger (medians: 0.76 wetland hectares and 228.9 linear stream meters) than non-NCDOT government (medians: 0.09 ha and 70.7 m) and private entities (medians: 0.09 ha and 80.47 m; all $P < 0.05$).

Compensation data contained within the EEP ledger were substantially more complete than impact data. We recorded 170 compensation sites providing compensation for impacts through 839 individual transactions (an impact linked to its corresponding compensation), which were made up of 528 private transactions, 221 by the DOT, and 90 by non-DOT government agencies. The NCDOT impacts required larger stream restoration and enhancement sites (often at a higher compensation ratio), as well as larger riparian restoration and preservation sites than both government and private permittees (all $P < 0.05$; Appendix D). NCDOT impacts were also compensated for by larger riparian enhancement and preservation projects, which were larger than either private and government projects (both $P < 0.04$). No differences were detected between the sizes of mitigation efforts by private and non-NCDOT government entities. Stream restoration was far more prevalent than enhancement or preservation (Fig. 2, Table 2). In a similar manner to nonriparian wetlands, restoration was the dominant compensation method, but for riparian wetlands, preservation was more common than restoration and enhancement. Between permittee types, the NCDOT used stream restoration significantly more than other government agencies ($P < 0.006$), and nonriparian wetland restoration significantly more than private entities ($P < 0.04$). The use of riparian and nonriparian wetland creation was rare by all permittee types.

Transactions distances

Mitigation transactions traded streams and wetlands by an average Euclidean distance of 54.7 km between impact sites and compensation sites, as shown by the Euclidean transaction lines in Appendix E (cf. Appendix B). The distance between impact and compensation sites varied substantially by impactor, as the average NCDOT displacement distance (63.3 km) was significantly larger than that associated with private (51.7 km; $P < 0.02$) or government (51.3 km; $P < 0.04$) transactions. The average displacement distance of

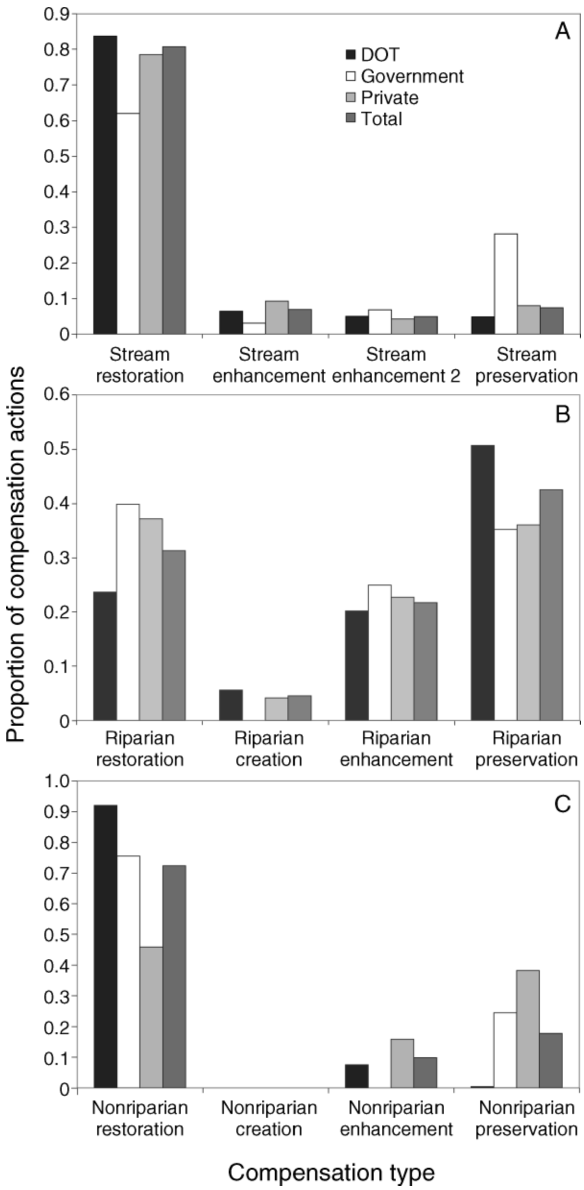

FIG. 2. The relative use of compensation methods is shown for streams and wetlands (riparian and nonriparian). Both stream and nonriparian compensation efforts heavily favor restoration over enhancement, creation, or preservation. DOT stands for Department of Transportation.

streams through the channel network was 177 ± 173 km (mean ± SD; median = 111 km), with maximum values of >1330 km, and a minimum of 2.4 km (Fig. 3).

Interwatershed compensation

Localized net losses of streams (Fig. 4A) appeared within three watersheds, each of which had few (if any) stream compensation sites. Most other watersheds experienced gains due to current compensation practices (i.e., high trading ratios). Riparian wetlands (Fig. 4B) were lost within four geographically disparate watersheds, although the maximum net loss in a watershed was found to be only 0.24 ha. Nonriparian wetlands (Fig. 4C), however, experienced a much more common rate of localized net loss, with losses appearing in eight watersheds in the piedmont and coastal plain regions of the eastern portion of the state, although again, these losses were fairly small (<0.49 ha/watershed). Overall, the EEP mitigation programs seem to generate small localized net losses of streams in certain instances, while contributing to a substantial overall net gain of >67.9 km of stream, 130.9 ha of riparian wetlands, and 142.2 ha of nonriparian wetlands.

Spatial analysis: clustering behavior

Spatial clustering of high and low displacement distances between impact and compensation sites was significant, as measured by Moran's I (0.1507, pseudo-$P < 0.001$ after 999 permutations [Anselin 2007]), indicating that the transaction distances associated with compensation were not randomly distributed. A more localized analysis (LISA) showed six major clusters of transaction distances (Appendix F). Impacts to wetlands on the Outer Banks, a string of barrier islands circling Albemarle-Pamlico Sound, were preferentially mitigated at two sites on the other side of the estuary. These impacts totaled 0.12 ha of riparian wetlands and 1.54 ha of nonriparian wetlands. The other clusters centered on the five fastest growing metropolitan regions within the state: Wilmington, Raleigh/Durham, Winston-Salem/Greensboro, Charlotte, and Asheville (Appendix F). Clustering in Wilmington, Charlotte, and Asheville primarily consisted of groups of impacts that were near compensation sites. Conversely, impacts throughout the Outer Banks and Winston-Salem tend to have significantly higher displacement distances than other impacts throughout the region.

Spatial analysis: interwatershed mitigation

Out of 839 mitigation transactions, 194 (23.1%) impacts were offset into different 8-digit watersheds, 752 (89.6%) into different 11-digit watersheds (subwatersheds within 8-digit watershed), and 816 (97.2%) into different 14-digit watersheds (subwatersheds within 11-digit watershed). The NCDOT impacts were offset at compensation sites located outside of the 8-digit watershed 28% of the time, which was higher than that for other government agencies (21%) or private impactors (21%). Of the impacts that were mitigated outside their 8-digit HUC watershed, average Euclidean transaction distances for NCDOT, non-NCDOT government, and private entities were 121.11 km, 79.32 km, and 70.80 km, respectively.

Spatial analysis: movement within stream network

In order to determine potential shifts between the relative stream order associated with impact and compensation sites, we compared the flow accumulation as calculated in the NHD+ at each site. Compensation

TABLE 2. Summary statistics of EEP (Ecosystem Enhancement Program) wetland and stream compensation by compensation method.

Treatment	N	Mean	SD	Median	Minimum	Maximum
Stream (linear meters)						
Restoration	355	90.2	221.4	550.7	4.7	8086.5
Enhancement	47	121.9	143.6	126.3	13.7	609.6
Enhancement 2	22	164.3	218.5	245.3	14.2	1030.2
Preservation	14	217.9	515.3	586.3	9.1	1850.1
Wetland (hectares)						
Riparian						
Restoration	190	0.1	0.3	0.5	0	5.0
Creation	3	3.6	2.4	1.9	0.3	3.7
Enhancement	65	0.3	0.5	0.7	0	4.3
Preservation	62	0.5	1.1	2.0	0	13.1
Nonriparian						
Restoration	150	0.1	0.4	1.9	0	19.7
Creation	0	…	…	…	…	…
Enhancement	17	0.2	0.6	0.1	0	3.6
Preservation	23	0.2	0.7	1.1	0	3.1

Notes: Stream and wetland compensation is broken down by compensation method. Stream restoration involves channel realignment and recontouring, stabilization, and revegetation of stream banks and flood-prone areas. "Stream enhancement I" involves stream bank recontouring, stabilization, and revegetation, and stream enhancement II involves only stream bank stabilization and revegetation (EEP 2004). Riparian and nonriparian wetland compensation involves restoration, creation, enhancement, and preservation. N represents the number of impacts utilizing each compensation method, and size statistics are given for each compensation method. Mitigation credit ratios were determined by Corps (2003).

sites were farther upstream than impact sites. Impact sites drained, on average, 144 km^2 compared to 43 km^2 at compensation sites ($P < 0.0001$, $n = 408$). However, there were very different trends based on impactor type. Compensation sites for NCDOT impacts were slightly larger than impact sites (60 km^2 vs. 57 km^2, $P < 0.001$, $n = 129$), while compensation sites used for private impacts drained substantially and significantly less than impact sites (36 km^2 vs. 202 km^2, $P < 0.01$, $n = 226$). Although compensation sites appeared to drain less than government impact sites, 21 km^2 vs. 119 km^2 ($n = 43$), the difference was statistically insignificant.

Discussion

Policy implementation

Ecological restoration of wetlands is largely accomplished under the auspices of compensatory mitigation. Current practices in North Carolina indicate that stream restoration could follow this trend. This approach has landscape impacts that are poorly understood. Moreover, the future implementation of many mitigation programs is the subject of debate in light of new federal regulations covering compensatory mitigation (hereafter referred to as "New Federal Rule," 73 Fed. Reg. 70, 19593–19705, [10 April 2008]; [Hough and Sudol 2008]). Our results point to a number of systematic, landscape-wide effects of the EEP, which has been described as a potential model for compensatory mitigation programs in other states (Shabman and Scodari 2004). Most importantly, our results indicate that compensation performed under the EEP complies with the broadest goal of wetlands and stream regulation: permitted aquatic resource impacts have led to virtually no net loss of streams or wetlands at the 8-digit watershed scale (Fig. 4). However, although our depiction of the distribution of net losses in Fig. 4 shows only minor localized losses; this assumes that all wetland/stream compensation is performed perfectly and establishes full ecological function (at least enough to compensate for the remnant functions existing in impacted resources), an assumption we return to below. Moreover, this conclusion contrasts the behavior observed in areas such as Chicago (BenDor et al. 2007), where mitigation programs have led to substantial net gains in all watersheds (net gains averaging over 49 ha of wetlands

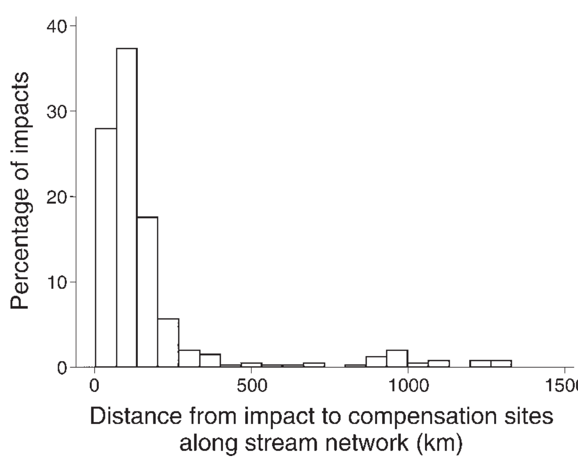

FIG. 3. Distribution of network distances between impact and compensation sites as calculated through the NHD (National Hydrography Dataset) stream network.

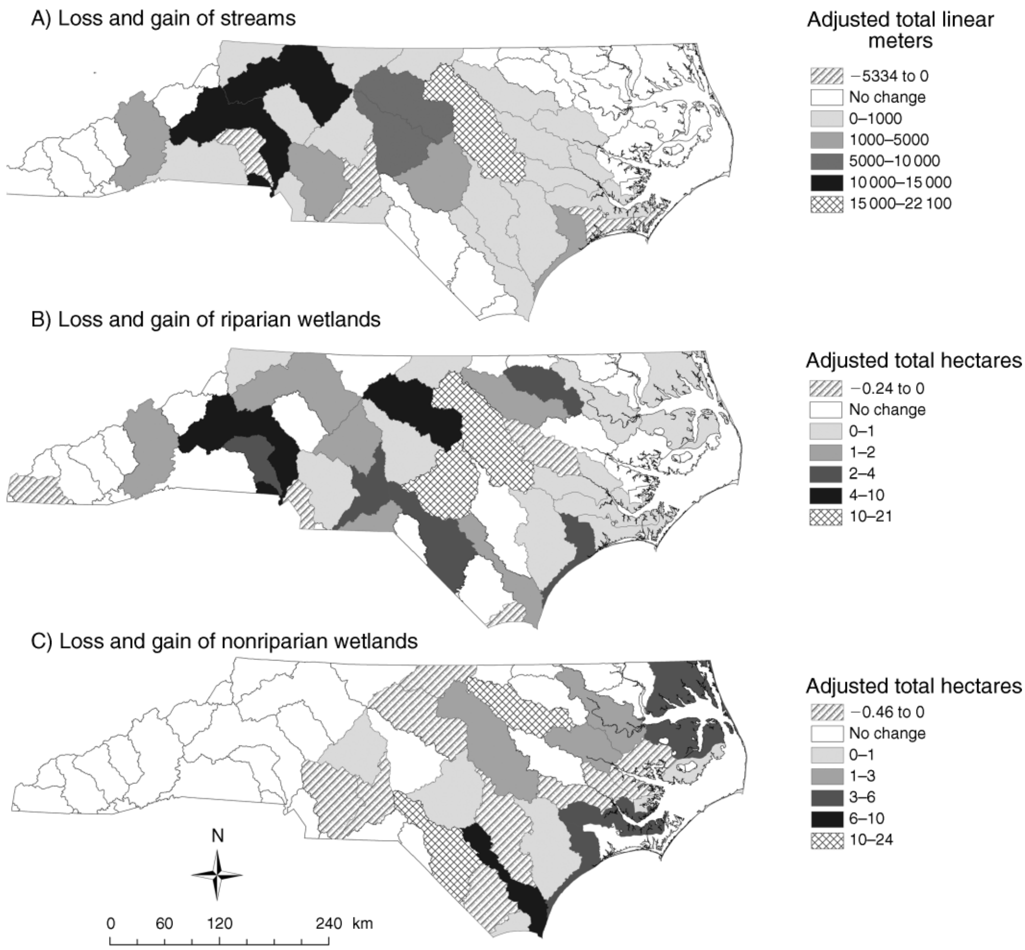

FIG. 4. Stream and wetland resource change by HUC (Hydrologic Unit Code): (A) net stream loss and gain; (B) net riparian wetland loss and gain; (C) net nonriparian wetland loss and gain.

were seen throughout Chicago watersheds, with nearly 183 ha of wetlands gained in the rapidly urbanizing Des Plaines River watershed).

There are other aspects of the EEP mitigation program and its effect on the ecological landscape that are less obvious, but equally important. Permitted impacts on streams tend to be comparatively more substantial than wetland impacts while being nearly as common, indicating that stream compensation issues are becoming increasingly important in North Carolina. While science, economics, and policies for wetlands have received considerable research attention in the past decade (NRC 2001), a similar concerted research thrust is needed to address the severe dearth of knowledge surrounding stream restoration and mitigation (Bernhardt et al. 2005, Lave et al. 2008). Stream mitigation falls under the New Federal Rule (§332.3[e][3]) as a "difficult-to-replace" resource. As a result, lessons learned through studying mitigation of wetlands, and the way wetland markets operate, will clearly provide the foundation for future stream mitigation research. Other results indicate that there were important logistical shortcomings in this program. Missing or incomplete Corps data (and a lack of redundancy of this information in EEP data) on extent and type of impacts limited our ability to understand the behavior of impactors, particularly with regard to their compliance with permit conditions. The common (BenDor et al. 2007: Appendix 1) inability of regulators to capture, verify, or maintain accurate databases of their actions (and those of their permittees) is a major impediment to understanding the landscape-level operation of their programs. Moreover, maintaining such accurate and usable databases is now required by the New Federal Rule (e.g., §332.8[h][3][ii]). We used the EEP database because it was substantially more complete than other comparable databases, yet there were clearly substantial data consistency problems (Appendix B: Compare data from Corps with data from EEP). It remains to be seen how quality control of data will factor into the implementation of this regulation. It is important to note as well that the data used here were collected before the New Federal Rule went into effect. It should also be noted that the unique model used by the EEP for tracking impact and compensation transactions complicates evaluation of their programs. The EEP does not consider impact compensation transactions to be permanent, but rather considers compensation credits to be fungible between similar sites within a watershed. In this situation, we could see many potential problems forming, including problems legally defending that compensation was performed "in-kind" (e.g., the proper stream/wetland type) at the correct site. These and other problems have plagued programs with similar models (called "in-lieu fee" programs) around the nation (Urban et al. 1999, ELI 2002).

The incentives created via stated mitigation trading ratios (Table 1) are critical to understanding the long-term impact of mitigation practices on ecology of aquatic resources. Mitigators benefit the most through stream restoration rather than enhancement, and this is evidenced in the frequency of restoration projects compared to other types of stream mitigation (Fig. 2). The ecological implications of this are mixed: restoration has profound environmental consequences (e.g., mobilization of floodplain sediment during realignment, deforestation of riparian corridor), but uncertain ecological benefits (Bernhardt et al. 2005). Indeed, it is unclear whether the ecological gains of stream restoration are substantially greater than those via enhancement. Yet it is clear from our data that there is a preference by the mitigation community for restoration, likely in response to the economic incentive of the credit ratios. The widespread usage of riparian wetland preservation causes concern, particularly since preservation does not serve as an offset for wetland losses and can create the potential for future localized hydrological and ecological problems. While there were very little watershed-level net losses of streams or wetlands, our findings indicate that streams and wetlands were displaced across substantial Euclidean, stream network, and interwatershed distances (Appendix F; Figs. 3 and 4). When compared to other mitigation programs where data are available (Chicago data averaged 21.7 km [BenDor et al. 2007]), these distances are extraordinarily large (many 8-digit watersheds in North Carolina average 60 km wide and 100 km long). When we measure stream displacement distances as they occur through the stream network, these distances become even larger. This movement between watersheds lies in contrast to the New Federal Rule, which stipulates that compensation be located within the same watershed as the impact site (§332.3[b][1]). However, the Rule is intentionally vague about what scale of watershed is appropriate (e.g., 8-digit vs. 14-digit HUC). Furthermore, when we consider the EEP's self-imposed constraint that transactions remain entirely within 8-digit watersheds (a constraint it has not always complied with, particularly in the early, transition years of the program), this large distance becomes less understandable.

Perhaps the most surprising finding was the significant differences between permittee types in this regard, particularly the abnormally high distances associated with NCDOT impacts. The EEP was originally created to implement compensation for NCDOT impacts. As such, the EEP takes short-term (5-year) planning input for NCDOT impacts, giving them advanced information on the types and locations of future impacts. The fact that preplanned impacts led to the highest levels of spatial displacement (and the highest rate of interwatershed compensation, nearly 30%), could at least partially be the result of early agreements allowing NCDOT impacts to be compensated for with distant preservation sites left over from previous mitigation programs. Clustering of stream and wetland impacts based on their displacement distances reveals areas where aquatic resources are relocated across great distances. Most of these clusters are located in rapidly developing, sprawling urban areas where compensation sites could only be placed on extremely expensive (and sometimes highly disturbed) land, thereby precluding their establishment. Additionally, areas of concern include clustering of impacts on the Outer Banks region of the State. The Outer Banks are a chain of hurricane-prone, highly erodible barrier islands that extend along much of the North Carolina coastline. Impacts on these islands were preferentially mitigated in two areas, near the estuaries of the Chowan and Tar Rivers across the Albemarle-Pamlico Sound. This behavior has enormous implications for the sustainability of this island chain, and indicates a weakness of the mitigation approach. It also has implications for implementation of the New Federal Rule, particularly provisions pertaining to the allowable mitigation bank service area associated with coastal impacts, as coastal wetlands and streams would fall under the "difficult to replace" impact category (73 Fed. Reg. 70, 19596).

Ecological implications

There are numerous implications for the ecology of the landscape that could arise because of both the actual mitigation policies, and the implementation of these policies in North Carolina. While we can document the spatial and landscape patterns emerging, the fundamental ecology needed to address their clear implications is often lacking, requiring some process-based speculation. Even if we assume that restored sites are ecologically equivalent to natural, undisturbed sites, the results of our spatial analyses indicate that there will still be important ecological changes that occur simply because of the changing spatial configuration of these ecosystems. The primary ecologically relevant signatures of the mitigation program in North Carolina that we observed are (1) defragmentation, (2) movement upstream in the watersheds, and (3) loss of place-specific functions.

First, our results clearly showed a spatial defragmentation of streams and wetlands, as numerous small impacts were mitigated by fewer, large sites. (Appendix

F: Note many arrows originating at diffuse locations but pointing to same location.) The advantages and disadvantages of Single Large or Several Small (SLOSS) habitat or restoration sites across the landscape are not at all clear (Cedfeldt et al. 2000), and this extends beyond the better known question of SLOSS for habitat conservation reserves (Schwartz 1999). For instance, small and often isolated wetlands can provide network habitat for birds (Semlitsch 2000). Also, smaller, fragmented, headwater wetlands can provide increased nutrient retention (Carleton et al. 2001). However, large wetlands and/or streams provide wildlife habitat potential that are not possible with small, isolated ecosystems (Schwartz 1999), and higher retention of nutrients in streams is accomplished at exponentially increasing levels with increasing lengths of stream (Doyle et al. 2003). Complicating this problem is the high level of disturbance present in the urban ecological context of aquatic resource impacts. This context makes large-scale wetland or stream restoration difficult, particularly in areas under hydrologic stress. As well, M. W. Doyle and A. J. Yates, (*unpublished observations*) show that market-based approaches to regulation create incentives for participants to restore smaller sites rather than larger sites. In all, more fully explicating the relative benefits of small or large restoration sites, as well as understanding their regulatory importance, is one of the critical ecological research contributions needed in the realm of ecosystem markets and environmental restoration.

Second, our results also showed the existence of a preference to restore streams and wetlands farther upstream in the watershed than the impacts for which they compensate. Logistically and economically, this was not surprising: smaller sites are relatively easier and cheaper to restore, and it is unclear whether it is possible to restore the functions of large rivers (Gore and Shields 1995). There are important ecological implications of this movement, but like the SLOSS issue, the science is unclear. Smaller streams may have high nutrient retention rates (Alexander et al. 2000), but small channels carry less total load, and thus the cumulative load retained is highest for larger channels within river networks (Ensign and Doyle 2006, Mulholland et al. 2008). Also, larger streams are the corridors through which a greater portion of organisms migrate or nutrients and sediment are transported. Regardless, the ecosystem functions of downstream streams and wetlands are likely to be distinct from those upstream, and so functional replacement will be lost through such market-induced pressures for upstream restoration sites.

Third, our results show that the ecosystem migration can be driven by land use changes at the local to regional scale. In the past, migration has also been directed away from population centers, particularly as sprawling urban development patterns convert wetlands and natural stream corridors into urban land uses. As a result, mitigation programs facilitate the loss of wetlands and streams in urban and suburban fringes through the gain of restored wetlands in outer rural areas (King and Herbert 1997, Robertson 2006, Ruhl and Salzman 2006, BenDor et al. 2007). In North Carolina, the potential for this behavior is particularly high, as the Winston-Salem and the Raleigh-Durham metropolitan regions have been measured as two of the fastest sprawling (spatially expanding) regions in the nation (Ewing et al. 2002). Here, the landscape benefits of functional equivalence are lost when aquatic resources are relocated to remote rural areas that have a low proportion of impervious or agricultural areas upstream. These sites are likely to have much smaller potential impact on nutrient retention and stormwater runoff storage than wetlands prevalent in rapidly developing suburban areas. This is a prime example of the place-specific functions performed by many wetland and stream systems.

A pressing concern we raise with regard to recent federal and state regulations centers on the extent to which mitigation programs should allow aquatic resources (and their functions, benefits, and values) to be relocated away from the site of impact. This is an especially important issue for areas such as the Outer Banks (or along the American Gulf Coast from Alabama to Texas), where vulnerable wetlands and streams serve an important role in anchoring barrier islands or protecting against storm surges due to frequent hurricane activity. Here, the offset of impacts (relocation) to inland estuaries, as we observed, does not support the same ecological communities, produce the same ecological functions, or generate the same ecological values as impacted wetlands. Thus, there are place-specific functions that are lost through these mitigation programs.

Conclusions

Ecological restoration associated with compensatory mitigation is now a significant management practice, and an increasingly significant industry. Current regulations promote markets in order to reduce ecological losses associated with mitigation. However, coupled markets for land and ecosystem services create a tension in which restoration timing, proximity, and quality cannot ordinarily be mutually attained without significant advance planning (Fig. 5). The application of market-like practices to ecological management programs raises concerns that may not be apparent on a case-by-case evaluation of impact and restoration sites, as has been the focus of many previous studies. The meager literature that has detailed transaction-level operation of markets for stream or wetland mitigation credits has shown that these markets produce specific side-effect behaviors, including induced movement of aquatic resources across space and time (Robertson 2006, Ruhl and Salzman 2006, BenDor et al. 2007, BenDor 2009), change in size (Robertson and Hayden 2008), and defragmentation (Semlitsch 2000). In compensatory mitigation programs, there are distinct trade-offs, such as ecological quality, temporal quality, and

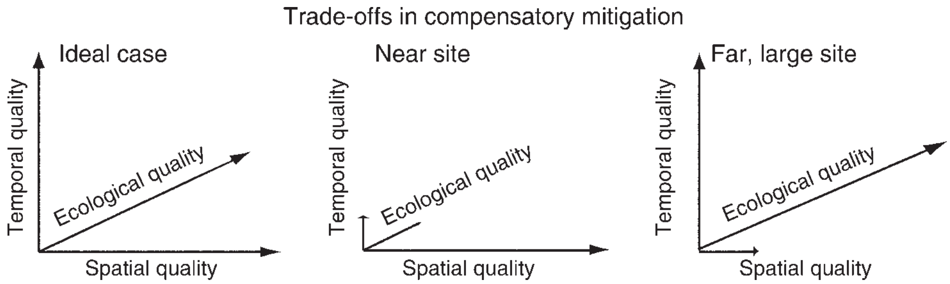

FIG. 5. Conceptual model of trade-offs in compensatory mitigation programs between spatial proximity, timing, and quality of restoration. Ideal case: All characteristics of restoration project are high, indicating a site close to impacts, restoration completed prior to impacts, with demonstrable ecological benefits. Near site: Typical project to date; located in relatively close proximity; restoration not completed at time of impacts; only minimal indicator data collected to show success of project. Far, large site: Large site with demonstrated ecological benefits beyond surrogate metrics alone; completed prior to impacts including rigorous data for monitoring; located farther away from impact site. Temporal quality: Timing of restoration relative to impacts; high temporal quality indicates that restoration and monitoring were completed in advance of impacts; low temporal quality is associated with restoration completed after impacts. Spatial quality: Location of restoration relative to impacts; high spatial quality is associated with restoration sites in close proximity and landscape position to impacts; low spatial quality is associated with distant mitigation sites, or sites that are out of the watershed. Ecological quality: Amount of demonstrable physical, biological, and chemical benefits at the restoration site; high ecological quality is associated with actual measurements of functional improvements (e.g., community composition, nutrient retention, sediment load reductions); low ecological quality is associated with no functional improvements, no direct monitoring, or reliance on surrogate variables.

spatial quality. Ecological quality refers to the ecosystem functions sought by restoration projects, which generally include improvements in physical, chemical, or biological integrity, such as retention of floods and nutrients, or increases in biodiversity. Most important, high ecological quality in a compensatory mitigation sense would be associated with a restoration site in which functional improvements have been rigorously documented via empirical measurements, rather than relying on surrogate or indicator variables. Indeed, the New Federal Rule is moving in the direction of requiring more empirically grounded metrics of ecological quality.

Regardless of site characteristics, site location is also important in considering compensatory mitigation at entire landscape scales. Thus, compensatory mitigation sites must also be thought of as having "spatial quality." Restoration sites that are located in close proximity to impact sites could be considered to be of higher spatial quality than those that are far away (or are in another watershed), since they are likely to exhibit similar functions and provide similar services as nearby wetlands (Brinson and Rheinhardt 1996). Geographic service areas are a policy instrument used to ensure some minimal level of spatial quality of compensation sites within a program, although this requirement has obviously changed through time for the EEP. Finally, and less well understood, is the issue of time of restoration relative to the time of the impacts, or "temporal quality." In order to prevent net loss of ecosystem functions, the overarching goal of most compensatory mitigation programs, restoration sites must be completed and functioning before impacts occur. (This is one of the original arguments for mitigation banking [Corps and EPA 1995].) However, given the time required for a restoration site to recover ecological functions, this sequence can be problematic. At a minimum, achieving higher temporal quality would require that sites are completed and monitored prior to being used for impact compensation. The worst case scenario, in terms of temporal quality, occurs when impacts take place prior to initiating compensating restoration projects. It is important to note that even if a restoration site is an excellent ecologically functioning site near the impact site, if it is completed several years after the impacts, then there is a long time window during which there is a temporary "debit" of functioning ecosystems (BenDor 2009).

The federal and state policies for compensatory mitigation have placed alternating emphasis on ecological, spatial, and temporal quality, and these different emphases must in turn interact with market dynamics that drive mitigation banking. The New Federal Rule emphasizes spatial quality by encouraging compensation sites to be within the same watershed as impacts (§230.93[b][1]). The Rule does this by suggesting a more rigorously defined geographic service area, the area within which restoration can compensate for impacts. However, small geographic service areas result in "thin" markets, where insufficient demand potential for mitigation credits (due to uncertainty about the number of potential buyers) fails to provide the incentive for mitigation bankers to speculatively purchase and restore an ecosystem. Larger geographic service areas thicken the market, but increase the potential distance between impacts and mitigation projects. Moreover, it is possible that large geographic service areas provide an incentive for investment in large restoration sites, as the thick market increases the potential to sell large quantities of credits over time. If large restoration sites have greater potential to provide greater ecosystem services than small sites, a realistic assumption, then large geographic service areas may be a policy change needed to provide incentives for investment in large restoration sites. Large restoration sites also potentially provide greater quantities of credits in advance of impacts in the future. In terms of Fig. 5, by reducing the emphasis on spatial quality, it may be possible to increase both ecological and temporal quality of compensatory mitigation sites and transactions.

Guidance on these trade-offs is quite mixed from both the scientific and policy communities: the NRC (2001) review of compensatory mitigation of wetlands throughout the United States noted that compensatory mitigation should consider landscape position and take a watershed approach. Yet the NRC also argued that restoration sites should be established prior to granting impact permits. Current regulations have sought to avoid the proximity problem by creating programs that allow compensation to occur after impacts. In North Carolina, the stated focus of the EEP has centered on ensuring proximity of compensation to impact sites, and while the EEP makes great efforts to provide advance compensation, their guidelines do allow postimpact compensation. This approach, which is common to many programs around the United States, known as "in-lieu fee" programs (Wilkinson 2009), assumes that at the landscape and programmatic scale, spatial quality should supersede temporal quality; sacrificing the benefits of advance timing of compensation is presumably made up by the advantages of geographic proximity.

Our study shows that while the landscape effects of compensatory mitigation programs on streams and wetlands can be substantial, they can often go unseen when viewed on a case-by-case basis. The drivers of these landscape effects are both ecological and economic, and moving forward with science and policy requires a more coupled approach that includes considerations of how policies will drive market forces, which could in turn drive restoration site location, thus driving potential ecological restoration success at broad spatial scales. Determining the extent to which spatial proximity, timing, and compensation project size affect project ecological quality is a critical question that will only be answered through a combination of case studies and landscape-scale analysis of mitigation programs.

Acknowledgments

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APPENDIX A

The data sources and data collection process (*Ecological Archives* A019-086-A1).

APPENDIX B

Summary of impact data by permittee type (*Ecological Archives* A019-086-A2).

APPENDIX C

Map of impact and Ecosystem Enhancement Program compensation sites in North Carolina (*Ecological Archives* A019-086-A3).

APPENDIX D

Summary statistics of Ecosystem Enhancement Program wetland and stream compensation by permittee (*Ecological Archives* A019-086-A4).

APPENDIX E

Map showing transactions between impact and compensation sites (*Ecological Archives* A019-086-A5).

APPENDIX F

Results of LISA (Local Indicator of Spatial Association) analysis (*Ecological Archives* A019-086-A6).

APPENDICES

APPENDIX A. The data sources and data collection process.

Data source	Description/coverage	Data elements included	Time period	Cleaned data
Army Corps of Engineers (Corps) Wilmington District	Regulatory Analysis and Management Systems (RAMS): all federally permitted impact sites	Impacts: type, location, permittee name, date permit granted	1990–2006	527 – matched with EEP mitigated impact sites
	NC Division of Water Quality (DWQ) Basin-wide Information Management System (BIMS): contains additional information on water quality certifications for many Corps Section 404 permits	Impacts: type, location, permittee name, date permit granted	1985–2008	80 – matched with EEP mitigated sites (of those not matched with Corps data)
North Carolina Ecosystem Enhancement Program (EEP)	Mitigation debit ledger for NC Department of Transportation (NCDOT) and non-NCDOT mitigation programs	Impacts: EEP mitigated impact permit IDs, mitigation requirements	1996–2007	607 – matched to Corps and DWQ permit information with coordinates (sum of two rows above)
		Compensation sites: Name, type, size and location of compensation sites created and managed by the EEP	1998–2007	170 – with coordinates, compensation type, and size or length data
		Transactions: Compensation site name and credit amount/type utilized to mitigate each impact (total EEP mitigation transactions)	1996–2007	839 – impacts matched spatially to EEP compensation sites
Final dataset			1998–2007	607 impact sites (with 408 stream and 431 wetland impacts) 170 compensation sites 839 total transactions

Data were collected from a variety of sources. Corps data were used to gather geo-spatial information on the location and size of Corps-permitted impacts. However, missing data and data inconsistencies led us to use Division of Water Quality (DWQ) data (containing the same information) as a check on Corps data and source for additional information on Section 404 permit impacts. NC Ecosystem Enhancement Program (EEP) data contained information on compensation sites and their locations.

APPENDIX B. Summary of impact data by permittee type.

	N	Mean	Std. dev	Median	Min.	Max.	Sum
NC Department of Transportation (NCDOT) (n_{stream}=62, $n_{wetland}$=56)							
EEP stream (m)	1	98.5	98.5	.	98.5	98.5	98.5
Corps stream (m)	23	87.8	158.4	150.0	14.6	529.7	3644.2
EEP riparian (ha)	4	0.1	0.1	<0.1	<0.1	0.2	0.4
EEP non-riparian (ha)	0	.	.	.	.	.	.
Corps wetland (ha)	41	0.3	5.0	21.1	0	133.7	203.5
Government (Non-NCDOT) (n_{stream}=323 $n_{wetland}$=33)							
EEP stream	13	80.5	104.2	68.2	41.8	238.4	1354.2
Corps stream	20	71.9	89.0	89.1	6.1	399.3	1779.7
EEP riparian	8	0.1	0.1	0.1	<0.1	0.2	0.9
EEP non-riparian	8	0.1	0.1	0.0	<0.1	0.2	0.8
Corps wetland	25	0.1	0.4	0.9	<0.1	3.3	10.9
Private (n_{stream}=190, $n_{wetland}$=234)							
EEP stream	73	79.2	125.5	167.0	2.7	940.3	9165.3
Corps stream	81	79.2	129.0	284.3	6.1	2438.4	10451.3
EEP riparian	75	0.1	0.2	0.4	0	2.8	12.8
EEP non-riparian	95	<0.1	0.1	0.1	0	0.6	8.9
Corps wetland	186	0.1	0.1	0.1	0	1.1	20.1
Total (n_{stream}=284, $n_{wetland}$=323)							
EEP stream	124	78.9	128.0	241.3	6.1	2438.4	15875.2
Corps stream	87	80.5	122.0	155.1	2.7	940.3	10618.0
EEP riparian	87	0.1	0.2	0.3	0	2.8	14.1
EEP non-riparian	103	<0.1	0.1	0.1	0	0.6	9.6
Corps wetland	252	0.1	0.9	8.6	0	133.7	234.6

This table, and each corresponding observation count (*N*), represent data for impacts that were fully recorded in EEP (North Carolina Ecosystem Enhancement Program) and Army Corps records. Values for EEP stream impacts are the sum of recorded warm, cool, and cold stream impacts defined by summer maximum temperature thresholds and geographic location (EEP 2004). EEP wetlands information is separated into values for riparian and non-riparian wetland impacts.

APPENDIX D. Summary statistics of EEP wetland and stream compensation by permittee.

	N	Mean	Std. dev	Median	Min.	Max.
DOT (*n*=221)						
Streams (m)	186	1003.3	532.5	14.6	1306.9	8212.5
Riparian wetlands (Ha)	145	0.6	0.4	0	0.9	4.9
Non-riparian wetlands (Ha)	54	1.3	0.2	0	4.4	23.2
Total stream mitigation Requirements (m)	186	1874.2	1065.0	29.3	2584.0	16425.1
Total wetland mitigation Requirements (Ha)	150	2.2	0.7	0	6.1	50.9
Distance displacement (km)	221	63.3	65.4	44.6	2.0	445.2
Government (*n*=90)						
Streams	45	92.5	66.1	20.6	82.2	442.9
Riparian wetlands	44	0.2	0.1	0	0.1	0.7
Non-riparian wetlands	19	0.3	0.1	0	0.5	2.0
Total stream mitigation Requirements	46	158.0	113.7	41.1	164.5	885.7
Total wetland mitigation Requirements	60	0.4	0.2	0	0.6	4.0
Distance displacement	90	51.4	35.7	47.5	1.4	183.1
Private (*n*=528)						
Streams	267	76.7	59.1	2.7	69.0	472.4
Riparian wetlands	187	0.2	0.1	0	0.4	2.8
Non-riparian wetlands	160	0.1	0	0	0.2	0.6
Total Stream mitigation Requirements	267	127.6	90.8	5.5	107.5	944.9
Total wetland mitigation Requirements	339	0.3	0.2	0	0.6	5.0
Distance displacement	528	51.7	35.7	48.4	2.9	296.8
Total (*n*=839)						
Streams	498	424.3	83.1	2.7	916.1	8212.5
Riparian wetlands	376	0.4	0.2	0	0.6	4.9
Non-riparian wetlands	233	0.4	0.1	0	2.1	23.2
Total stream mitigation Requirements	499	781.4	145.1	5.5	1788.9	16425.1
Total wetland mitigation Requirements	549	0.9	0.2	0	3.3	50.9
Distance displacement	839	54.7	45.7	48.2	1.4	445.2

The observation count in each row (*n*) represents the number of compensation actions that involved either streams or riparian/non-riparian wetlands (or sometimes a combination of streams and wetlands). Values for EEP (North Carolina Ecosystem Enhancement Program) stream mitigation are the sum of recorded warm, cool, and cold stream impacts. Total stream and wetland mitigation requirements are the total (simple sum of linear meters or hectares) restoration, creation, enhancement, and preservation required by regulators.

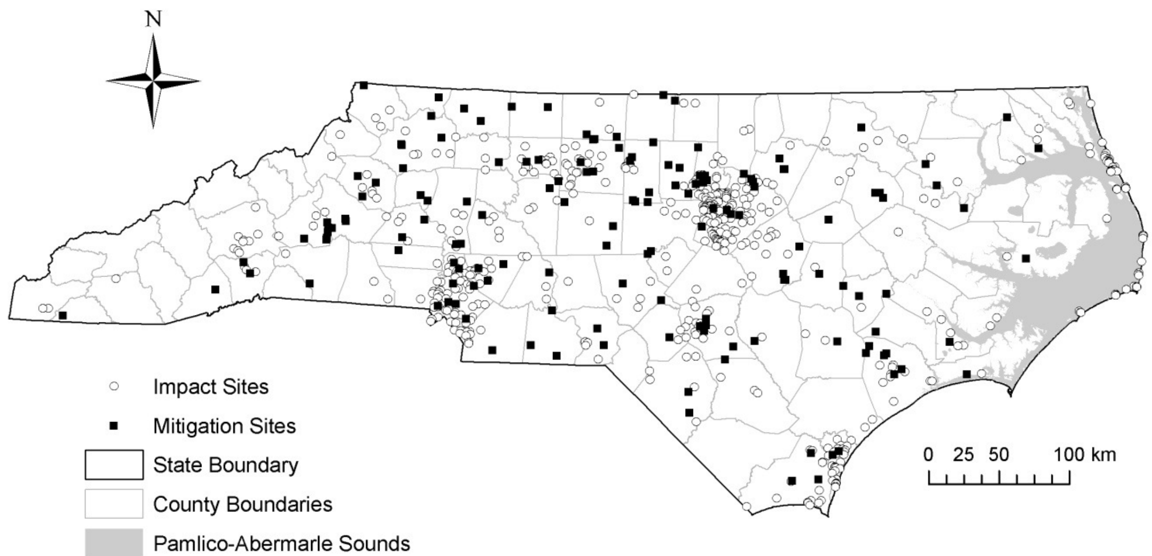
APPENDIX FIGURE CAPTIONS

APPENDIX C. Map of impact and EEP compensation sites in North Carolina.

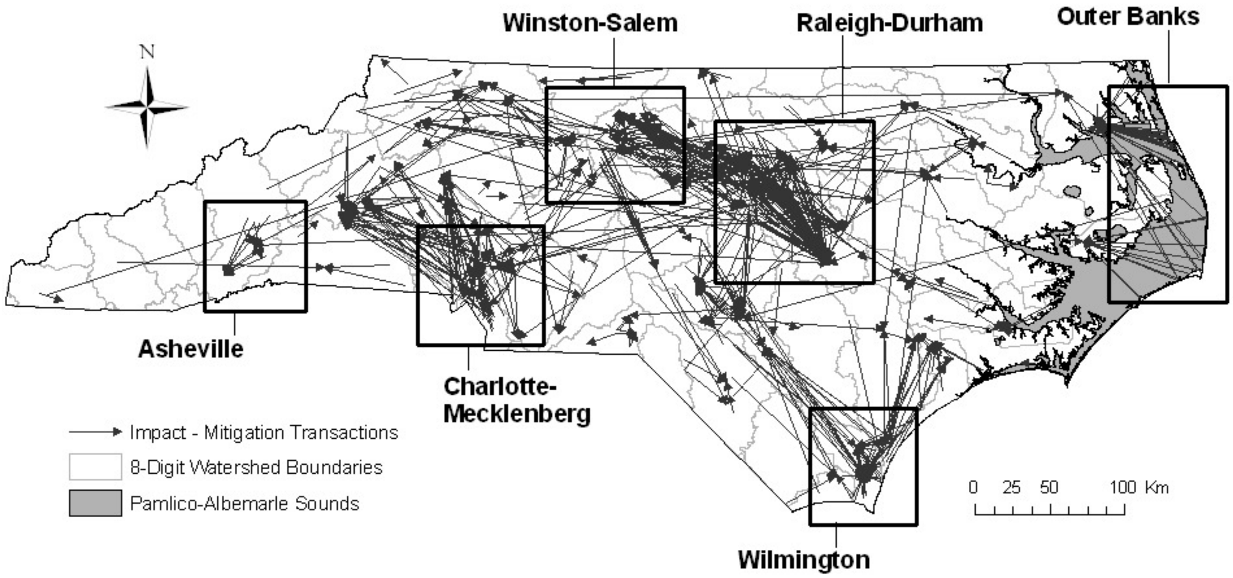
APPENDIX E. Map showing transactions between impact (arrows) and compensation sites (arrowheads). Impact clusters (arrow ends) are seen in the growing metropolitan areas in the state.

APPENDIX F. LISA (Local Indicator of Spatial Association) analysis measures the association of impact sites with other nearby points in terms of similarities in their displacement distances. Here, ‘nearby points’ are measured as the 10-nearest neighbors. We show areas where the LISA analysis determined observations to be part of either high-high clusters (black dots), in which an impact with a high displacement distance is surrounded by other points with high displacement distances, or low-low clusters (black stars), in which low distance points are surrounded by other low distance points. Note the high level of impacts clustered by displacement distance located in the same urbanizing areas as shown in Appendix Fig. 2.

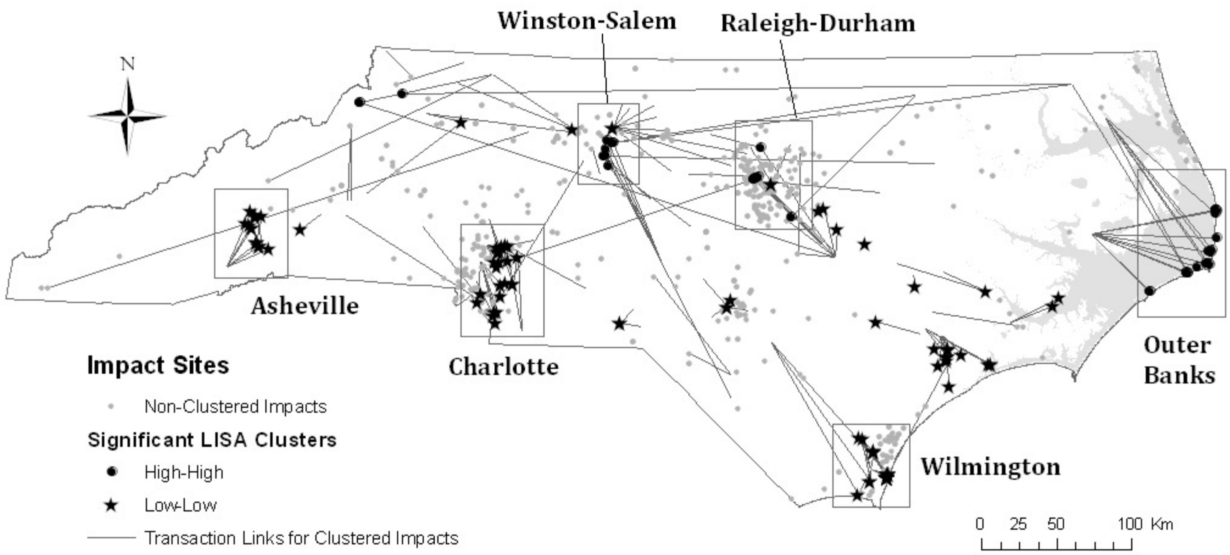
Appendix C


N
Impact Sites
Mitigation Sites
State Boundary
County Boundaries
Pamlico-Abermarle Sounds
0 25 50 100 km

Appendix E


Winston-Salem
Raleigh-Durham
Outer Banks
N
Asheville
Charlotte-
Mecklenberg
Wilmington
Impact - Mitigation Transactions
8-Digit Watershed Boundaries
Pamlico-Albemarle Sounds
0 25 50 100 Km

Appendix F


Winston-Salem
Raleigh-Durham
N
Asheville
Charlotte
Outer Banks
Wilmington
Impact Sites
Non-Clustered Impacts
Significant LISA Clusters
High-High
Low-Low
Transaction Links for Clustered Impacts
0 25 50 100 Km