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Inequity in ecosystem service delivery: socioeconomic gaps in the public-private conservation network

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ABSTRACT. Conservation areas, both public and private, are critical tools to protect biodiversity and deliver important ecosystem services (ES) to society. Although societal benefits from such ES are increasingly used to promote public support of conservation, the number of beneficiaries, their identity, and the magnitude of benefits are largely unknown for the vast majority of conservation areas in the United States public-private conservation network. The location of conservation areas in relation to people strongly influences the direction and magnitude of ES flows as well as the identity of beneficiaries. We analyzed benefit zones, the areas to which selected ES could be conveyed to beneficiaries, to assess who benefits from a typical conservation network. Better knowledge of ES flows and beneficiaries will help land conservationists make a stronger case for the broad collateral benefits of conservation and help to address issues of social-environmental justice. To evaluate who benefits the most from the current public-private conservation network, we delineated the benefit zones for local ES (within 16 km) that are conveyed along hydrological paths from public (federal and state) and private (easements) conservation lands in the states of North Carolina and Virginia, USA. We also discuss the challenges and demonstrate an approach for delineating nonhydrological benefits that are passively conveyed to beneficiaries. We mapped and compared the geographic distribution of benefit zones within and among conservation area types. We further compared beneficiary demographics across benefit zones of the conservation area types and found that hydrological benefit zones of federal protected areas encompass disproportionately fewer minority beneficiaries compared to statewide demographic patterns. In contrast, benefit zones of state protected areas and private easements encompassed a much greater proportion of minority beneficiaries (~22–25%). Benefit zones associated with private conservation lands included beneficiaries of significantly greater household income than benefit zones of other types of conservation areas. Our analysis of ES flows revealed significant socioeconomic gaps in how the current public-private conservation network benefits the public. These gaps warrant consideration in regional conservation plans and suggest that private conservation initiatives may be best suited for responding to the equity challenge. Enhancing the ecosystem benefits and the equity of benefit delivery from private conservation networks could build public and political support for long-term conservation strategies and ultimately enhance conservation efficacy.

Key Words: *benefit zone; GIS; human well-being; hydrological services; social-environmental justice*

INTRODUCTION

Conservation areas (CAs), both public and private, are critical tools to protect biodiversity and deliver important ecosystem services (ES) to surrounding stakeholders. Societal benefits from such ES are increasingly used to promote public support of conservation. However, the number of beneficiaries, their identity, and the magnitude of benefits are largely unknown for the vast majority of CAs. To date, ES assessments focusing on flow have largely sought to quantify the services conveyed (Costanza and Folke 1997, Loomis et al. 2000, Farber et al. 2002, Troy and Wilson 2006). Although quantifying capacity and the flow of services is important for ES accounting, it lends little to the understanding of how services are delivered across a landscape and who benefits from them. The lack of such an assessment hinders the ability to evaluate the equity of services and disservices from CAs and to make planning decisions that ensure environmental justice and sustainability.

The few ES assessments that have evaluated spatial patterns of service flows suggest that the extent and magnitude of services directly conveyed to beneficiaries vary greatly across landscapes (Koch et al. 2009, Martín-López et al. 2011, Bagstad et al. 2013, Cimon-Morin et al. 2013, Villamagna et al. 2013). Given the results of these assessments, we can assume that the services

provided by CAs vary in how and to whom they are conveyed. For example, CAs in low-density rural areas may provide fewer direct benefits to society from local services (e.g., erosion control) than CAs within a more densely populated area. Moreover, given socioeconomic and demographic patterns, we might also expect the racial and economic composition of the local beneficiaries to vary distinctly across areas, which raises the question of social and environmental equity among beneficiaries.

Concern over environmental equity, the equitable distribution of environmental benefits and costs, consistent with the equitable inclusion of stakeholders and consideration of their self-identities, histories, and traditions (Sikor 2013), and the U.S. social-environmental justice movement began in the early 1980s. The movement gained significant traction during the early 1990s with a disconcerting report by the U.S. Environmental Protection Agency (USEPA 1992) that found a strong correlation between the location of hazardous contaminant facilities and the composition of minority groups within the surrounding communities. This was followed by President Clinton's 1994 Executive Order requiring governmental agencies to address and ameliorate negative human health and environmental impacts on minority and low-income communities (Cutter 1995, Bullard and Johnson 2000). The social-environmental justice movement has

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continued since then, focusing largely on mitigating and preventing inequity in the distribution of risks related to pollution and natural resource management (Schroeder et al. 2008, Sikor and Stahl 2011; U.S. Environmental Protection Agency National Environmental Justice Advisory Council: https://www.epa.gov/environmentaljustice/national-environmental-justice-advisory-council). In the same vein, political ecologists have begun to emphasize the importance of distributional justice or the fair allocation of public spaces and the social-environmental benefits (i.e., ecosystem services) they provide (Low 2013, Kabisch and Haase 2014). The investigation of the distributional aspect of social-environmental justice has, to date, focused largely on urban green spaces and public areas (Heynen et al. 2006, Kabisch and Haase 2014). Much can be learned from these efforts and applied to land and natural resource conservation at the landscape scale.

With the emergence of ES as a metric for environmental condition at the human interface, we suggest that questions of social-environmental justice should expand to include the disproportionate distribution of benefits from public CAs. At present, few ES assessments have considered distributional justice among beneficiaries, making it difficult to integrate into landscape-scale conservation planning (Ernstson 2013, Lele 2013). ES convey critical life-sustaining and subsistence values to communities (Brown and Fagerholm 2015). Villamagna et al. (2015) make the case that these CAs, both public and privately managed, provide collateral ecosystem benefits; however, the question remains of to whom these benefits are conveyed. Extending the practice of social-environmental justice to include ES delivery suggests that the benefits from healthy ecosystems be shared equally among people and places. Spatial patterns of CA distributions embedded in a diverse socioeconomic and racial landscape raise the question: How equitable or just is the distribution of ES benefits from CAs?

To answer this important question, we believe a conscious spatial assessment of ES benefits from CAs is needed. Assessing the demographic (i.e., population density and race) and socioeconomic (i.e., household income) composition of beneficiaries will enable conservation planners and society as a whole to evaluate the equity of ES benefits and alter conservation programs accordingly to achieve greater social-environmental justice. Publically funded protected CAs (PPAs) are not uniformly distributed throughout the United States (Scott et al. 2001), and growth of the U.S. system of public lands has been fairly stagnant since the 1970s (Stein et al. 2007). Although President Obama has recently designated three new national monuments (Connolly 2016), his attempts to designate wilderness areas (e.g., H.R. 2406 amendment for the coastal plain within the Arctic National Wildlife Refuge) have been met by considerable opposition in Congress (DeMarban 2015). Thus, recent additions reflect presidential power and motivation rather than the bipartisan support in Congress otherwise needed to designate a new national park or wilderness area. Given the low potential of increased public land conservation in the eastern United States and recognition that private conservation easements (PCEs) have nearly equal capacity to provide collateral ecosystem benefits as PPAs (Villamagna et al. 2015), a comparative analysis of potential benefit delivery between PPAs and PCEs is warranted.

An important step toward incorporating equity concerns into ES analyses is to develop an objective, repeatable technique for characterizing the pathways of ES flows from CAs and the identities of potential beneficiaries. Given the complex nature of human interactions with the environment and use of services, we suggest that delineating the geographic benefit zone, the area in which services are conveyed to beneficiaries, is a helpful first step to quantifying ES flow. However, the geographic delineation of benefit zones differs by how ES are conveyed to beneficiaries (Johnson et al. 2012, Villamagna et al. 2013), more so than the category (e.g., regulating vs. cultural) to which the services are assigned by foundational studies, including the Millennium Ecosystem Assessment (2005). This benefit flow-centric perspective of ES is novel, but it is much needed for a robust assessment of ecosystem benefits. Therefore, delineating the geographic benefit zone requires the identification of local services and an understanding of how the service is generated and delivered to people.

Unlike global services such as carbon sequestration and climate regulation, some services are passively conveyed to local users (e.g., air quality, aesthetics). These services convey nonrival benefits (Fisher et al. 2009) that are provided to nearby populations at no cost. In contrast, services such as surface water regulation and water quality regulation are hydrological in nature, which means in the absence of technology and transport, these services only convey benefits to beneficiaries downstream of the service-providing area. These hydrological services are the critical foundation for the provision of many other socially valuable services, including drinking water, biodiversity support, and water-based recreation. Other services (e.g., recreation, wildlife watching, timber harvest, food production) may require time or monetary investment to travel to or from the service-providing area. The role of transportation networks (i.e., water, rail, road) in the distribution of benefits from these nonhydrological services may create far-reaching spatial disconnects between the service-providing area and the benefit zone; thus, the benefit zones for such services are likely to be diffuse and patchy.

Although geographic distributions of CAs have been evaluated with regard to biodiversity protection (Merelender et al. 2004), few studies have considered the demographic and socioeconomic characteristics of areas surrounding CAs in the USA. Here, we map the flow of societal benefits generated through public and private conservation and explore how private conservation can extend natural service benefits to communities currently underserved by publicly conserved land. By delineating benefit zones and analyzing the potential beneficiaries within, we can assess social-environmental justice in ES terms, compare the geography and extent of benefit zones among PPAs and PCEs, and identify gaps in the present conservation network that may be filled by new private CAs. To advance progress toward the inclusion of ES in the practice of social-environmental justice, our objectives were: (1) to develop a simple and repeatable GIS-based technique for mapping the pathways of ES flows, (2) to delineate location-based benefit zones for PPAs and PCAs, and (3) to evaluate and compare the socioeconomic and demographic composition of potential beneficiaries within the benefit zones of federal and state PPAs to those of PCEs. Building on the work of Villamagna et al. (2015), we focused on the states of Virginia and North Carolina, USA to demonstrate the method; however, the approach is applicable worldwide, where data are available.

Our study will help draw attention to issues of social-environmental justice with respect to ES (Ernstson 2013, Lele 2013, Sikor 2013) and elucidate the value of PCEs as an ES conservation strategy.

METHODS

Assessing the socioeconomic characteristics of potential beneficiaries from ES generated within PPAs and PCEs requires a geoprocessing model that will first delineate the geographic benefit zones for each CA individually and then summarize spatially explicit demographic data within each CA's benefit zone. Given the overlapping nature of benefit zones, we developed an iterative model using Model Builder for ArcDesktop 10.0 (ESRI 2012). Mapping the geographic benefit zones for CAs requires data regarding the spatial location and size of CAs; information about the managing agency and gap protection status, which provides a measure of protection and management intent given to each CA (USGS 2012); as well as elevation data.

Using the aforementioned GIS model, we delineated benefit zones for all conservation areas, public and private, that held a gap protection status of 1 and 2. A gap protection status of 1 denotes permanent protection from land conversion and maintenance of a natural disturbance regime. A gap protection status of 2 denotes land protected from conversion, but with allowed uses or management practices that may "degrade the quality of existing natural communities, including suppression of natural disturbance" (USGS 2012). Villamagna et al. (2015) provide a discussion of data sources and constraints, and the U.S. Geological Survey provides further detail on gap status codes (USGS; http://gapanalysis.usgs.gov/blog/iucn-definitions/).

Mapping conservation areas

The focal CAs for this analysis are those used by Villamagna et al. (2015) to evaluate ES capacity within public and private CAs of Virginia and North Carolina. Conservation easement records and geographic boundaries were derived from the National Conservation Easement Database (NCED; http://nced.conservationregistry.org/) that provided information regarding the holders of the easement, the landowner type, the purpose of the easement, and the location. We further constrained our analysis to include only easements with environment-related purposes, including "environmental systems," "recreation and education," "open space forest," and "open space farm." We included easements held by nongovernmental organizations (NGOs), municipalities, state governments, and the federal government.

State and federal PPA records and geographic boundaries were downloaded from the USGS National Inventory Protected Areas Database (PAD-US; USGS 2012). This database provides extensive information about each protected area, including land owner, management type, purpose, and gap status. We excluded federal PPAs that were classified as memorial parkways, national battlefields, national monuments, and several other classes for which the primary motivation for protection was not environmental conservation. Although many of these public lands contribute a diversity of services to local beneficiaries, we decided to assess CAs that focus on land conservation for ecological purposes. Similar assessments of cultural and heritage sites are currently being pursued as a follow-up to this study.

Easements managed by state and federal agencies were excluded from the PAD-US data set to avoid overlap with NCED records.

Mapping ecosystem service flow

Patterns of ES flow vary with the type of service and the surrounding landscape. In the absence of technology or transport, services associated with hydrological functions (hereafter hydrological services) will only be experienced by people downstream. We define hydrological services as those for which the benefits are conveyed to people who access downstream areas and resources (e.g., water purification). These services can include regulating, cultural, and provisioning services associated with or affected by capacity and stress upland. In contrast, nonhydrological services may be conveyed to people near the source of the service or to people farther away by means of a transportation network that links them to the service (see Fig. 4 in Villamagna et al. 2013). Nonhydrological services may include local regulating (e.g., air quality), cultural (e.g., scenic views), and provisioning services (e.g., wild food). Herein, we describe methods and challenges of mapping the potential flow of benefits from local hydrological services and characterize the potential population of beneficiaries within these benefit zones (Appendix 2, panel B). We provide an analogous discussion and demonstration of mapping nonhydrological services in the accompanying Appendices.

Hydrological services

The attenuation of hydrological ecosystem services is largely unknown and, where investigated, is highly variable and sometimes nonlinear (Koch et al. 2009). The distance over which benefits may be conveyed varies among services as well as naturally with topography (e.g., slope) and with the assistance of human-built infrastructure. One example is the extensive aqueduct system that carries drinking water from the Catskill-Delaware and Croton drinking water supply watersheds to New York City (Mehaffey et al. 2005). An ES framework coming out of South East Queensland, Australia provides an excellent overview of the directional biases associated with ES delivery (http://www.ecosystemservicesseq.com.au/ecosystem-services.html); however, there are no well-defined thresholds for evaluating the flow of benefits at a regional scale such as the bistate focus of this analysis. Therefore, we have adopted a 16 km downstream radius from each CA. Although arbitrary for hydrological services, we offer this radius as an analytical starting point for comparison to an analogous approach for nonhydrological aquatic services such as freshwater recreational fishing. As noted by Villamagna et al. (2014), research has suggested that freshwater anglers are 1.8-times more likely to fish within 16 km of their homes than areas between 18 and 160 km away (Hunt and Hutt 2010). This suggests that most beneficiaries of recreational fishing, a cultural ES, likely live within 16 km of a CA that hosts a fishing spot. A demonstration of a fixed-distance omnidirectional approach for delineating nonhydrological benefit zones within 16 km of CAs is discussed in greater depth in Appendix 2, with supplemental tables and figures provided in Appendices 3–5.

To delineate the hydrological benefit zone and identify potential beneficiaries, we developed a GIS model that identifies the flow path of water for up to 16 km from each CA. This iterative model depends on elevation data (USGS 2009) and uses the Spatial Analysis Toolbox (ESRI 2011). For CAs closer than 16 km to the

Table 1. Estimates of hydrological ecosystem service beneficiaries from state, federal, and easement conservation areas (mean ± standard deviation). Mean beneficiary density was highest within easement benefit zones (~28 beneficiaries/km²), followed by federal PPAs (~19 beneficiaries/km²), and state PPAs (~4 beneficiaries/km²). Least-square means were used to test for differences among conservation area types; the same lowercase letter following the estmates indicate nonsignificant differences based on Bonferroni confidence limits. *P* values are provided above each comparison. The analogous state-level metrics for North Carolina and Virginia (U.S. Census Bureau 2013*a,b*) are provided for comparison.

Beneficiary	Benefit zone (km²)	Mean beneficiary population	Proportion White (%)	Proportion Black (%)	Proportion other race (%)	Proportion Hispanic (%)	Median income (USD)
P	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.012
State	1085 ± 1 a	19,863 ± 1 a	73.9 ± 1.01 a	19.2 ± 1.05 a	4.1 ± 1.03 a	3.2 ± 1.04 a	43,066 ± 1 a
Federal	1588 ± 1.1 b	30,598 ± 1 b	89.2 ± 1.02 b	6.5 ± 1.07 b	2.5 ± 1.04 b	1.7 ± 1.05 b	44,064 ± 1 ab
Easement	828 ± 1.1 c	23,370 ± 1 c	72.4 ± 1.02 a	17.7 ± 1.08 a	4.6 ± 1.05 a	3.4 ± 1.06 a	47,863 ± 1 b
North Carolina	125,920	9,535,483	68	21	3	8	46,450
Virginia	102,279	8,001,024	69	19	6	8	63,636

coast or a surface water shoreline, the flow path was shorter. We delineated benefit zones by intersecting census tract spatial data with the flow path from each CA. Although census tracts are administrative boundaries that do not necessarily coincide with natural water flows, they provide the finest resolution of population data available for the region. CAs for which a flow path could not be mapped were excluded from the analysis; this included CAs that were too small in area to be recognized by our GIS model (i.e., < 900 m²). We compared the racial composition and median household income of beneficiaries within hydrological service benefit zones among the different CA types, as well as to analogous statistics at the bistate scale to evaluate social-environmental equity between beneficiaries and nonbeneficiaries.

Demographic analysis of hydrological services
We used the 2010 U.S. Censuses of North Carolina and Virginia to summarize the number of potential beneficiaries affected by each CA and then compared the mean number of beneficiaries among CA types. We used generalized linear models in SAS 9.3 (SAS Institute, Cary, North Carolina, USA) to test for differences in total beneficiaries; beneficiary density (population per area); proportion of Caucasian beneficiaries; proportion of Black or African-American beneficiaries (U.S. Census Bureau 2010); proportion of beneficiaries from other non-Black or non-African-American, non-Caucasian races; proportion of Hispanic beneficiaries (may be of any race); and median household income among the three types of CAs. The underlying distributions of demographic data were variable. To avoid incorporating statistical bias by assuming distribution homogeneity among all data sets, we used the dispersion parameter approach for selecting a distribution described by Anderson (2008) and reported the results in Appendix 1 (Table A1). With generalized linear models, we tested least-square means among CA types and demographic metrics using Bonferroni-adjusted confidence limits.

In addition to the population and income summaries for each CA type, we also calculated the frequency of service benefit flows for each census tract by counting the number of benefit zones that overlapped each tract; these counts were made for each CA type and all types together. Benefit zones were equally weighted and summarized by census tract using Cell Statistics in ArcGIS 10.0 Spatial Analyst toolbox (ESRI 2012). This provided a spatial representation of the distribution and accumulation of benefit zones attributed to PCEs and PPAs.

RESULTS

Geographic patterns of conservation areas
Clear size and geographic patterns were detected from mapping CAs throughout North Carolina and Virginia. Federal (*N* = 628) and state protected areas (*N* = 493) with a gap status of 1 or 2 were on average significantly larger than conservation easements (*N* = 230; Table 1). In general, the number lands with gap status of 2 far exceeded the number lands with gap status of 1 for all CA types. Federal PPAs are largely found in the Appalachian, Ridge and Valley, and Coastal Plain provinces, whereas state PPAs are widely distributed throughout Virginia, with larger parcels in the Appalachian, Ridge and Valley, and Coastal Plain provinces, but less common in North Carolina. Conservation easements are more common in Virginia but are substantially larger in North Carolina, where they are mostly located in the mountainous west and coastal plain (Fig. 1). Few CAs occurred near the large population centers of Charlotte, Winston-Salem, Greensboro, Durham, Raleigh, Greenville, and Rocky Mount in North Carolina, or Richmond in Virginia.

Fig. 1. Location and size of conservation easements and federal and state protected areas (PPAs) that have a gap status of 1, 2, or unknown (easements only) in North Carolina and Virginia, USA. Symbol size corresponds to the relative area of the conservation area.
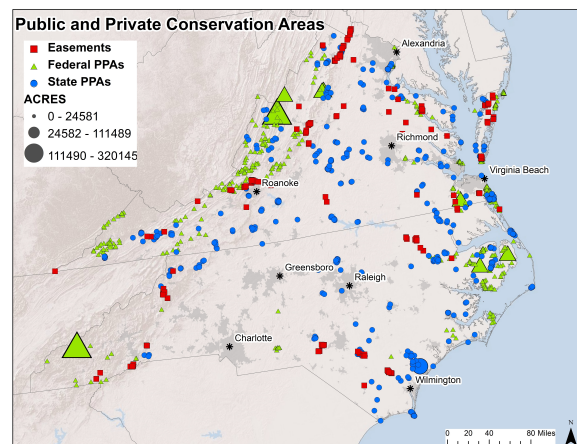
Table 2. A proportional comparison of the population outside and inside hydrological benefit zones and among state and federal protected areas and private conservation easements. Percentages are calculated based on the total combined population of North Carolina and Virginia, and proportion median income is reported as the proportion greater or less than the mean of North Carolina and Virginia's median household incomes (U.S. Census Bureau 2013*a,b*).

Benefit zone	Proportion of total population (%)	Proportion White (%)	Proportion Black (%)	Proportion other race (%)	Proportion Hispanic (%)	Proportion area (%)	Proportion median income (%)
Outside	77	51	17	4	7	42	+6
Within	23	18	4	< 1	1	58	−4
State	49	34	10	2	4	48	+7
Federal	37	24	8	2	3	38	+17
Easement	19	15	3	< 1	1	20	−2

Benefit zones and beneficiaries

Generally, the size of a CA's hydrological benefit zone is related to the size of the CA itself and its location within the watershed. For example, upper watershed CAs might affect more census tracts downstream because of the highly branched nature of small stream networks and the size of downstream census tracts. Benefit zones of federal PPAs were significantly larger than those of other CAs, with easements having the smallest benefit zone. However, the size of the benefit zone alone does not determine its potential effect on beneficiaries. Proximity to dense population centers greatly influences the potential flow of service benefits.

From a distribution perspective, the benefit zones of state PPAs in both states were more evenly distributed than those of federal PPAs and rarely overlapped with those of federal PPAs. Likewise, PCE benefit zones rarely overlapped with those of PPAs. By examining the spatial patterns of benefit zone overlap for each CA type individually and combined, we identified areas of high service flow potential (Fig. 2) as well as gaps, i.e., areas that do not accrue benefits due to the lack of CAs.

Hydrological benefit zones

The overlap of benefit zones for hydrological services varied considerably across CA types. We found greater overlap in benefit zones within federal PPAs than within state PPAs or easements (Fig. 2). The greatest accumulation of federal benefit zones was along the Atlantic coast and in the Ridge and Valley province north of Roanoke, but combined, the zones covered nearly 40% of the combined land area of both states (Table 2). The benefit zones of state PPAs (Fig. 2A) were relatively unclustered, extending throughout most of the two states except in central and southwest North Carolina. When considered together, the benefit zones of state PPAs covered nearly half the land area of both states combined, and 48% of the total population resides within these benefit zones (Table 2). The scattered easement benefit zones collectively covered nearly 20% of the total land area of North Carolina and Virginia (Fig. 2C), with fewer clusters than state or federal zones; Virginia had nominally more clusters and more broadly distributed benefit zones than North Carolina.

Although easements are on average smaller in area than state and federal PPAs, the number of beneficiaries within the benefit zones of easements are greater than those within benefit zones of state PPAs and similar to those within benefit zones of federal PPAs (Table 1; analogous results for the nonhydrological demonstration

are reported in Appendix 1, Table A2). As a result, easements provided hydrological services to a significantly higher density of beneficiaries than did public PPAs. The size of a benefit zone is influenced by the location (e.g., elevation) of the CA within the watershed and the size of intersecting census tracts, which are smaller in higher density areas. Likewise, beneficiaries are limited to downslope areas, so CAs located on the coast lack localized beneficiaries.

The mean proportion of Caucasian beneficiaries from federal PPAs was approximately 20% greater than the proportional abundance in the bistate region and significantly greater than the proportion within the benefit zones of state PPAs and PCEs. The hydrological benefit zones of state PPAs and easements encompassed a greater proportion of non-Caucasian beneficiaries than did those of federal PPAs (Table 1); on average, only 6.5% of the population within hydrological benefit zones in the bistate region are Black or African-American. On average, < 5% of the beneficiaries in benefit zones of all CA types were of Hispanic origin, which is lower than the proportion reported for North Carolina and Virginia overall (8%; U.S. Census 2013*a,b*). Overall, people of color seem to be underserved by hydrological benefits conveyed from CAs, particularly from federal PPAs. The racial composition of beneficiaries in hydrological benefit zones was similar to that in nonhydrological benefit zones (Appendix 4), but the total number of beneficiaries was substantially greater (Appendix 1, Table A2).

Household-level income of hydrological beneficiaries also varied significantly among CA types (Table 1). Median household income, on average, was greater among beneficiaries from easements than beneficiaries from federal or state PPAs; incomes of beneficiaries from federal and state PPAs were similar. State and federal PPAs on average provided hydrological services to beneficiaries making below the median household income of Virginia (USD $63,636) and above that of North Carolina (USD $46,450). Although individual easements were significantly smaller than state or federal PPAs, median household income within their hydrological benefit zones was consistently high throughout the study area, with higher incomes in northern and central Virginia than in North Carolina (Fig. 3). Mean household income of beneficiaries within hydrological zones was slightly higher than median income in North Carolina, but much lower (approximately USD $15,000–$20,000 less) than the equivalent measure in Virginia (U.S. Census Bureau 2013*a,b*). Overall, it

Fig. 2. Maps illustrating the benefit zones attributed to hydrological ecosystem services from state PPAs (A), federal PPAs (B), and conservation easements (C). Colors illustrate the number of overlapping benefit zones.
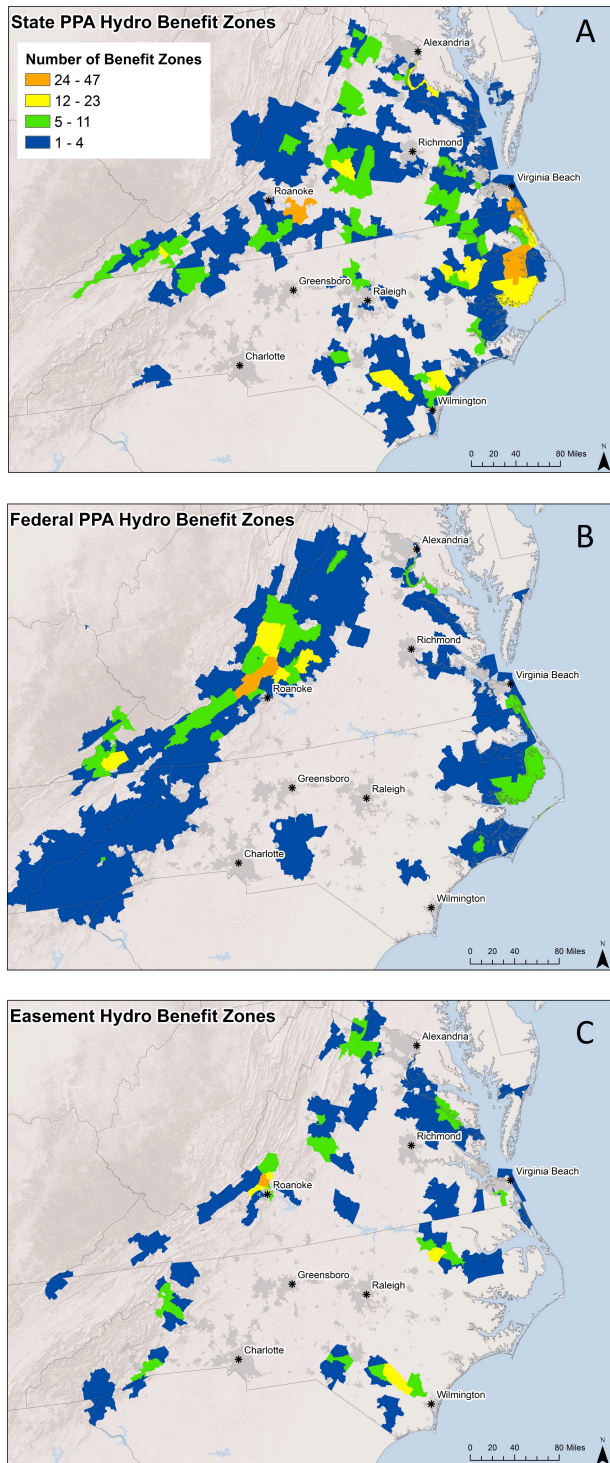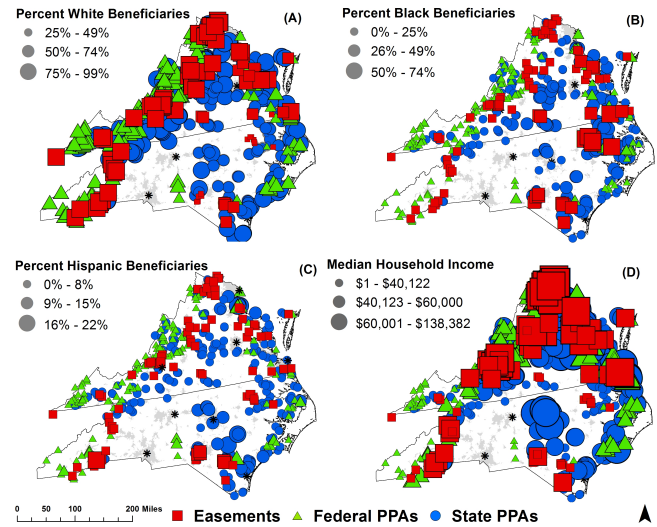

Fig. 3. Proportional representation of White (A), Black (B), and Hispanic (C) beneficiaries, and mean household income (D) within the hydrological benefit zones of conservation areas.

seems that CAs are not disproportionately benefiting the rich within North Carolina or Virginia.

Comparisons between populations living inside and outside hydrological benefit zones revealed that 77% of the bistate population lives outside of these zones (Table 2): 66% Caucasian, 22% Black or African-American, and 4% of Hispanic origin. These statistics support our earlier conclusion that the benefit zones of the conservation network examined include a slightly greater proportion of Caucasian beneficiaries than expected based on racial composition at the bistate scale. We found median household income of areas within hydrological benefit zones to be 4% lower, and those areas outside hydrological benefit zones to be 6% higher than the bistate average, suggesting that households at or below the median income of the bistate region are being served by hydrological services from a CA network. Analogous results for the nonhydrological demonstration can be found in Appendix 1, Tables A2 and A3 and Appendices 4 and 5.

DISCUSSION
We used an innovative GIS-based technique to map pathways of ES flows from public and private conservation areas in Virginia and North Carolina. We next discuss the distributional patterns of benefit zones and opportunities for enhancing social-environmental justice associated with ES and CAs.

Environmental equity of ecosystem services
CAs provide benefits to people near and far by protecting ES directly and indirectly related to the primary purpose of CAs (Villamagna et al. 2015). Although it is important to consider the conservation function of public and private CAs, it is as instructive to consider the landscape in which they are embedded and the collateral societal benefits that may be conveyed (Merenlender et al. 2004). Our estimates suggest that nearly 10 million people live within a 16 km downstream hydrological radius of CAs in North Carolina and Virginia. Collectively, the

16-km CA hydrological benefit zones cover 63% of the bistate region, making it clear that the conservation network has the potential to affect more than just the people who visit the PPA or live in the PCE.

Issues of environmental equity occur when environmental degradation disproportionately affects a group of people or places (Cutter 1995). However, we suggest that environmental equity is also contingent on equitable distribution of benefits from environmental conservation. This is especially the case in areas where land conservation provides collateral benefits that may increase the ecological resilience of nearby and downstream communities to climate and land-use change (Villamagna et al. 2015). We considered race and median household income to be two of the most important indicators of environmental equity (Cutter 1995) and took several important steps toward better understanding how the existing network of public and private CAs in North Carolina and Virginia are conveying ecosystem service benefits to society. When compared to the racial composition of North Carolina and Virginia, we found that the hydrological service benefit zones of state PPAs and easements comprised slightly fewer Black or African-American and Hispanic beneficiaries (between 1 and 4%) than expected based on statewide demographic composition. However, federal PPAs disproportionately benefit Caucasian beneficiaries in terms of hydrological services; Black or African-American and Hispanic populations were substantially underrepresented (Table 2). Collectively, our results suggest that the public-private conservation network of this bistate region services people from varying socioeconomic conditions, but that more could be done to level the playing field in terms of the racial composition of beneficiaries.

The hydrological benefit zones of the current conservation network within the bistate region include a disproportionately greater proportion of Caucasian beneficiaries (Table 2). The disparity in racial proportions downslope of PPAs suggests the need for an introspective examination of current conservation patterns as well as future conservation plans. For example, studies are needed to understand how overlapping benefit zones collectively affect the residents within them. If benefits from multiple CAs are multiplicative (i.e., human well-being is increased in areas of overlapping benefit zones), the observed disparity may decrease, indicating greater overall environmental equity within the conservation network. Furthermore, this analysis assumes that the benefits conveyed to beneficiaries are constant throughout the benefit zone; however, it is more likely that service benefits attenuate with distance from the CA (Johnson et al. 2012). More research is needed to evaluate the spatial distribution of ecosystem service flows and how benefits change over space and time.

Although beyond the scope of our study, we suspect that the greater proportion of Caucasian beneficiaries within federal PPA benefit zones may be a side effect of historic settlement patterns and more recent urbanization. The dominant race in western North Carolina and Virginia has been Caucasian since the mid-20th century, but prior to that, there was significant racial diversity, especially including Black or African-American and Caucasian and Indian populations (Price 1953, Stuckert 1987). This information suggests that the conservation network may

have once been more socially equitable. Even though the current pattern was unintentional and the motivation for federal PPAs has traditionally prioritized ecosystem and landscape protection and not the services they provide beyond management boundaries, the need to consider equity remains. Shifts in spatial demography such as those within North Carolina and Virginia (Barcus 2007) are occurring across much of the United States. This suggests the need for a national-level assessment of environmental equity within the conservation network and, where needed, steps to enhance equity. Within North Carolina and Virginia, this may mean increasing CAs near and upland of underrepresented populations, many of which are close to urban centers and far from most federal PPAs.

Establishing new conservation areas
Our analysis provides a snapshot of who benefits from public and private land conservation approaches and may help inform future conservation planning. Based on the benefit accumulation maps, there is an apparent need to establish CAs that provide ES protection in much of North Carolina and in parts of southern Virginia. However, given the current political climate and patterns of residential development in the southeast United States (Stein et al. 2007), the establishment of new federally protected areas is unlikely. Thus, an extension of the ES benefit network to counter the observed skewing of ES benefits to Caucasian beneficiaries will likely come from alternative efforts, i.e., mainly state or private conservation initiatives.

The first step is to look within the existing conservation network for opportunities to enhance existing protection, rather than create new areas. Our analysis indicated a substantial number of easements throughout underrepresented areas that had a gap status of 3 or 4, which were excluded from the analysis. This status indicates that the land is not protected from potentially degrading land-use practices. Of the easement records in the NCED data set at the time of our analysis, 96% held a gap status of 3 or 4, neither of which are considered by the International Union for the Conservation of Nature to be an area "recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (http://gapanalysis.usgs.gov/blog/iucn-definitions/). Increasing the protection status of these lands or allocating more land to conservation easements could be stimulated by increasing public outreach and education and creating incentive programs. This would increase awareness regarding the private landowner benefits of putting land into environmentally minded easements and reducing the private cost of easements by creating legal agreements that enable the private landowner to continue to gain financial benefits from land in addition to tax benefits. However, easements alone may not be the answer. It takes land ownership and above-subsistence income for a property owner to consider putting land into easement. Thus, by the nature of the institutions guiding private land conservation (e.g., land trusts), PCEs may be limited to areas of affluence and are therefore naturally constrained to benefiting others of a similar socioeconomic status. This raises important questions. Should environmental equity be considered a virtue of private land conservation? Do private land trusts and conservation planners have a social responsibility to prioritize land protection in areas with a greater proportion of minority (i.e., non-Caucasian) beneficiaries with below-median household income,

or should federal and state conservation agencies be held accountable? If the latter, how can social-environmental justice be ensured when the growth of public land conservation is stagnating? According to Merenlender et al. (2004), social equity is a key element to sustainability and therefore should be examined in relation to private land conservation, but what this means in practice remains unclear.

If ES equity is deemed desirable, the most effective strategy for creating a more racially and socioeconomically diverse conservation landscape may be for state conservation agencies to partner with land trusts and private landowners. Given a new focus on ecosystem services, agencies not traditionally engaged in conservation may be enticed to join partnerships. For example, state agencies of environmental quality, housing, and urban development, as well as health and human services might be interested if the social benefits from private land conservation were promoted more explicitly. These partnerships could enhance equity among participants in the planning and management process, and in doing so, enhance environmental justice within the ES framework (Sikor 2013). Likewise, the approach to defining benefit zones may help conservation-minded agencies, NGOs (e.g., The Nature Conservancy), and land trusts prioritize land conservation efforts, facilitate the planning process, and maximize the societal benefits from private land conservation.

Whether by fee-simple acquisition or easement contracts, state land and easement managers (e.g., land trusts) could seek to establish new easements in relatively affluent areas surrounded by or upstream of less affluent and racially diverse areas to enhance social equality with respect to the flow of ES. Based on our assessment, efforts could be made to enhance protection of ES upstream of areas with a greater proportion of minority beneficiaries. For owners of smaller land parcels more common in suburban and rural areas, easements may not be feasible or financially wise. In these areas, greater financial incentives could be offered to land owners in densely populated areas such that several small land owners set aside a portion of their land toward a collective easement in which the collective benefits may outweigh the individual landowner's cost. This process could follow the approach of community forest cooperatives (Barten et al. 2001). By doing so, land conservation would provide benefits to a higher density and, presumably, greater diversity of beneficiaries.

Protecting services directly

Given the public and private constraints of ES protection by means of land conservation strategies such as PPAs and PCEs, a more direct ES protection approach may be needed in the United States. Payment for ecosystem services (PES) programs may offer a more direct market-based approach to protecting services in areas where demand and the societal return on investment is high. Although PES programs are just taking root in the United States (Mercer et al. 2011), they have gained significant traction in Europe and partnering nations worldwide by means of "The Economics of Ecosystems and Biodiversity" program (Wunder et al. 2008, Cassola 2010). PES programs are structured by considering demand for services and identifying areas that can foster the provision of these services. To increase the potential success of the program, the locations of ES supply and demand should be clearly defined. PES programs in target areas (e.g., high

human density, minority communities) could strategize by applying the methods described here to map the benefit zones of potential easements and evaluate the potential beneficiaries from these PCEs. The potential beneficiaries could then be assessed for their willingness to pay to conserve the service. Using a reciprocal approach, one could first identify the areas where ES are needed (i.e., geography of demand) and then map potential areas where easement enhancement or creation should be prioritized.

CONCLUSION

Since the early 1990s, considerable emphasis has been placed on environmental equity, largely focusing on the equitable distribution of risks related to pollution and natural resource management (USEPA 1992, Schroeder et al. 2008, Sikor and Stahl 2011; U.S. Environmental Protection Agency National Environmental Justice Advisory Council: https://www.epa.gov/environmentaljustice/national-environmental-justice-advisory-council). Concurrently, ecosystem services have emerged as a helpful currency for evaluating ecosystem effects on human well-being, yet little effort has been made to merge these distinct but related fields. To enhance the ability to quantify, map, and ultimately make ES information more accessible and useful to decision makers, we must acknowledge the dynamic processes by which ES are produced and how ES benefits are conveyed to people (Carpenter et al. 2009, Chan et al. 2012, Johnson et al. 2012, Bagstad et al. 2013). We suggest that defining the geographic benefit zones of ES flows is an important first step to evaluating the distribution of benefits across a socially, economically, and ecologically diverse landscape, and one that can guide future conservation efforts and help address equity concerns. Conservation actions involve trade-offs among ES and among stakeholders, any of which can be highly contentious. Regardless of the location of CAs, they impose costs, especially opportunity costs. Examining the potential benefit zones of future conservation areas and comparing the socioeconomic composition of beneficiaries within these areas is of the utmost importance to ensure sustainability and social-environmental justice.

Responses to this article can be read online at:
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Appendix 1:

Supplemental Table 1: Underlying distributions assumed for variables in general linear models used to analyze benefit zone and beneficiaries among conservation area types.

Variables	Hydrologic
Percentage White beneficiaries	Lognormal (0.02)
Percentage Black beneficiaries	Exponential (0.85)
Percentage other beneficiaries	Lognormal (0.11)
Percentage Hispanic beneficiaries	Lognormal (0.17)
Median income	Lognormal (0.06)
Benefit zone area	Exponential (0.91)
Total beneficiary density (units?)	Exponential (0.76)
Total beneficiaries	Exponential (0.84)

Non-hydrologic services

Potential local beneficiaries of non-hydrologic services include people living within a close proximity to the service-providing area, in this case the CA. Little is known about the flow of services across landscapes, but presumably the flow distance is different depending on the service. For example, research has suggested that freshwater anglers were 1.8 times more likely to fish within 10 miles of their homes than areas between 11 and 100 miles (Hunt and Hutt 2010). This suggests that most beneficiaries of a recreational fishing, a cultural ES, likely live within 10 miles of a CA that hosts a fishing spot. For other services, like scenic views, topography and the built environment play influencing roles in the distance benefits of scenery extend. Research focused on each of these local non-hydrologic benefits is needed to better describe the attenuation of services to beneficiaries over space and time. For some services like recreational fishing or hunting, a fixed-distance approach for delineating benefit zones may be adequate. For services like air quality or scenic views, a more complex modeling approach is needed (e.g. Schirpke et al. 2013). ArcGIS provides a viewshed tool that can accomplish this task, but requires information about the landscape itself, which is beyond the scope of this paper. An ES framework coming out of South East Queensland (AU) provides an excellent overview of the directional biases associated with ES delivery (http://www.ecosystemservicesseq.com.au/ecosystem-services.html). We demonstrate a fixed-distance omni-directional approach for delineating non-hydrologic benefit zones within 10 miles of CAs. A conceptualization of this approach and that for the hydrologic service analysis is provided in Supplemental Figure 1 (Appendix 2). Results from a beneficiary analysis analogous to that of the hydrologic benefit zones are provided in Supplemental Tables 2 and 3 (below) and Supplemental Figures 2 and 4 (Appendices 3 -5).

Supplemental Table 2: Mean (± standard deviation) estimates of non-hydrologic (non-hydro) ecosystem service beneficiaries from state, federal and easement conservation areas. Least-square means were used to test for differences among conservation area types; the same superscript letter following the mean and standard deviation values indicate non-significant differences based on Bonferroni confidence limits. P-values are provided above each comparison. The analogous state-level metrics for North Carolina and Virginia, according to 2010 Census, are provided for comparison.

|	Benefit Zone (km^2)	Mean Beneficiary Population	Percent of White	Percent of Black	Percent of Other	Percent of Hispanic	Median Income
Non-Hydro	<.0001	0.853	<.0001	<.0001	<.0001	<.0001	0.036
State	941 ± 1 ^{a}	4035 ± 1 ^{a}	73.9 ± 1.01 ^{a}	19.5 ± 1.01 ^{a}	4.1 ± 1.03 ^{a}	3.2 ± 1.03 ^{a}	$42020 ± 1 ^{a}
Federal	1391 ± 1.1 ^{b}	3902 ± 1 ^{a}	89.6 ± 1.02 ^{b}	6.2 ± 1.03 ^{b}	2.5 ± 1.04 ^{b}	1.7 ± 1.05 ^{b}	$43491 ± 1 ^{ab}
Easement	869 ± 1.1 ^{a}	4113 ± 1 ^{a}	74.2 ± 1.02 ^{a}	17.1 ± 1.02 ^{c}	4.2 ± 1.04 ^{a}	3.0 ± 1.05 ^{a}	$51875 ± 1 ^{b}
North Carolina	125920	9535483	68	21	3	8	$46450
Virginia	102279	8001024	69	19	6	8	$63636

Supplemental Table 3: A proportional comparison of the population outside and inside non-hydrologic (non-hydro) benefit zones among state, federal protected areas and private conservation easements. Percentages are calculated based on the total combined population of North Carolina and Virginia and percent median income is reported as the percent greater or less than the mean of North Carolina and Virginia's median household incomes reported in the 2010 US census.

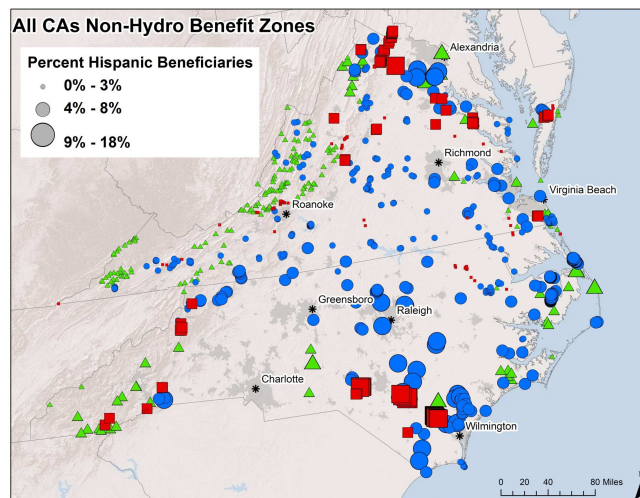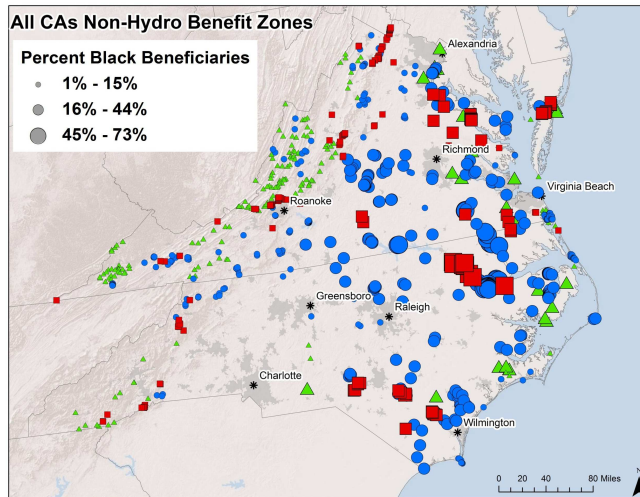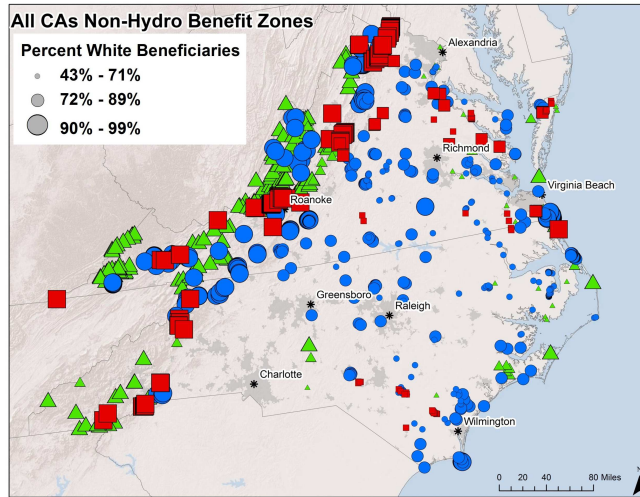|	Percent of Total Population	Percent White	Percent Black	Percent Other	Percent Hispanic	Percent Area	Percent Median Income
Outside Non-hydro	47%	31%	10%	3%	4%	37%	-3%
Inside Non-Hydro	53%	36%	11%	2%	4%	63%	+10%
State	14%	11%	3%	< 1%	1%	41%	-5%
Federal	9%	7%	1%	< 1%	< 1%	30%	-7%
Easement	6%	5%	1%	< 1%	< 1%	18%	-2%

APPENDIX 2. Benefit zones are mapped for non-hydrologic services (A) by delineating a 10-mile (16.09 km) radius-circular buffer around each conservation area and identifying the full and partial census tracts within that buffer. Only the area within the benefit zone (blue) is included in the assessment of population, demography, and household income. Benefit zones for hydrologic services (B) are delineated by mapping the potential flow path of surface water from the conservation area downstream for up to 10 miles. Census tracts that are intersected by the flow path are fully included in the hydrologic benefit zone.
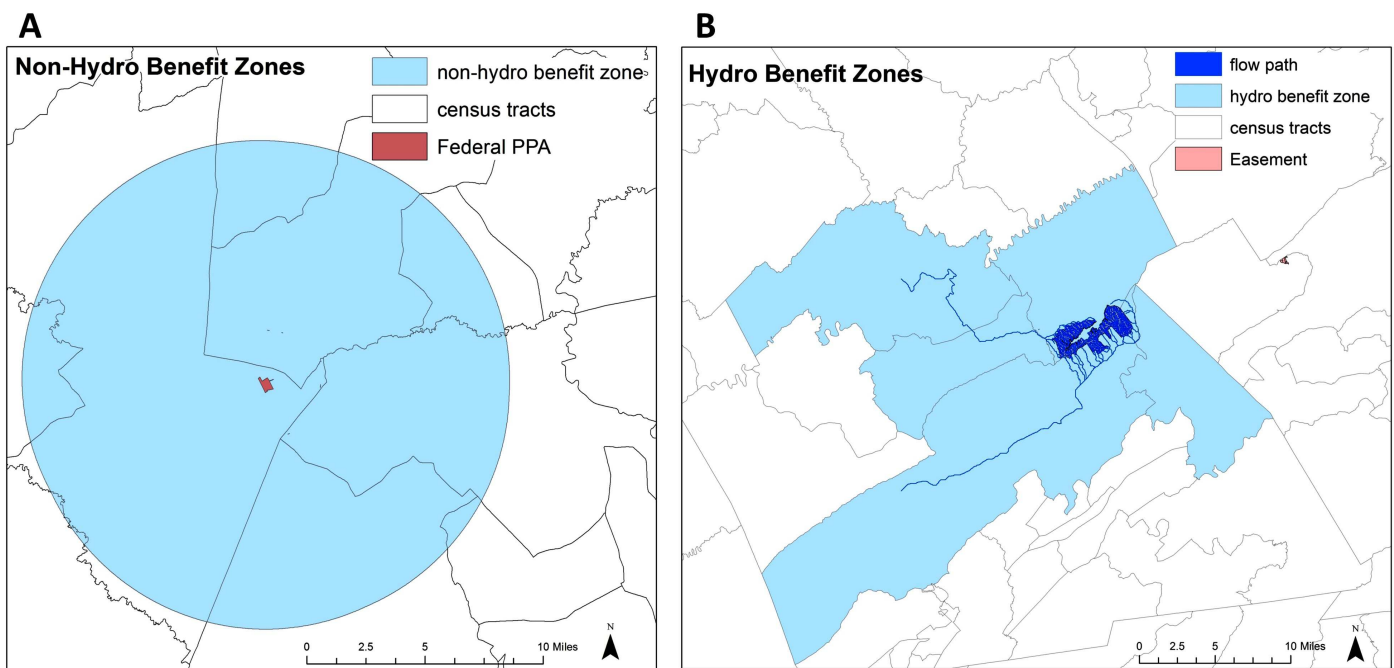
APPENDIX 3. Maps illustrating the benefit zones attributed to A) non-hydrologic ecosystem services from state public protected areas (PPAs), B) non-hydrologic ecosystem services from federal PPAs, C) non-hydrologic ecosystem services from conservation easements.
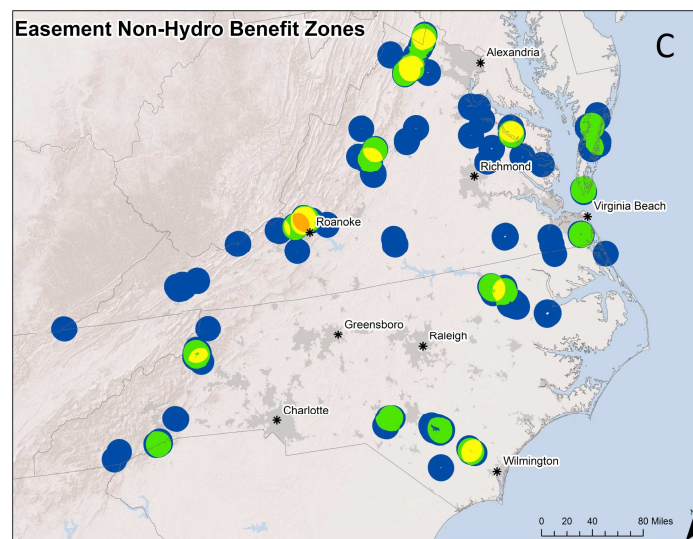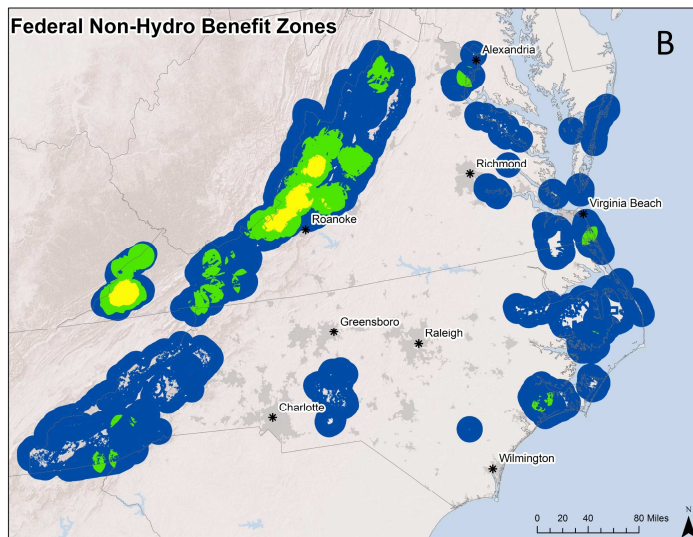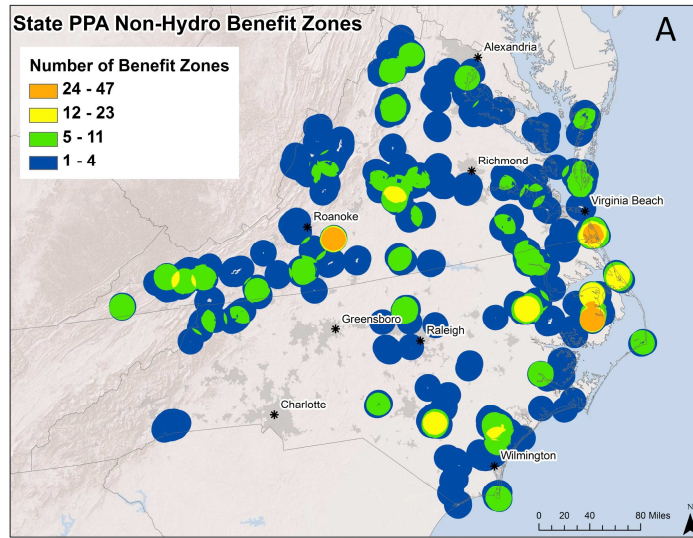
APPENDIX 4. Proportional representation of (A) White, (B) Black, and (C) Hispanic beneficiaries within the non-hydrologic benefit zones of conservation easements (square), federal public protected areas (PPAS; triangle), and state PPAs (circle).

APPENDIX 5. Proportional representation of mean household income within the non-hydrologic benefit zones of conservation easements (square), federal public protected areas (PPAS; triangle), and state PPAs (circle).

Median Household Income
Non-Hydro Benefit Zones

- Easements
- Federal PPAs
- State PPAs

Median Household Income
- $1.00 - $40,122.00
- $40,122.01 - $60,000.00
- $60,000.01 - $138,382.00

Alexandria
Richmond
Virginia Beach
Roanoke
Greensboro
Raleigh
Charlotte
Wilmington

0 20 40   80 Miles