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# Declining human population but increasing residential development around protected areas in Puerto Rico

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ABSTRACT

Increasing residential development around protected areas is a major threat for protected areas worldwide, and human population growth is often the most important cause. However, population is decreasing in many regions as a result of socio-economic changes, and it is unclear how residential development around protected areas is affected in these situations. We investigated whether decreasing human population alleviates pressures from residential development around protected areas, using Puerto Rico—an island with declining population—as a case study. We calculated population and housing changes from the 2000 to 2010 census around 124 protected areas, using buffers of different sizes. We found that the number of houses around protected areas continued to increase while population declined both around protected areas and island-wide. A total of 32,300 new houses were constructed within only 1 km from protected areas, while population declined by 28,868 within the same area. At the same time, 90% of protected areas showed increases in housing in the surrounding lands, 47% showed population declines, and 40% showed population increases, revealing strong spatial variations. Our results highlight that residential development remains an important component of lands surrounding protected areas in Puerto Rico, but the spatial variations in population and housing changes indicate that management actions in response to housing effects may need to be individually targeted. More broadly, our findings reinforce the awareness that residential development effects on protected areas are most likely widespread and common in many socioeconomic and demographic settings.

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## 1. Introduction

Establishing protected areas is a widespread conservation strategy, designed to reduce habitat loss due to land use, and to stem biodiversity loss across the world. However, many protected areas fail to achieve these goals due to unmanaged or ineffective management of land use on adjacent lands (DeFries et al., 2005). Lands around protected areas are important to ensure connectivity and species movement, and when land use intensity is low in these lands they contribute to the effective size of the protected area (Hansen and DeFries, 2007). Habitat loss and degradation around protected areas, on the other hand, increase the isolation of a protected area and the magnitude of human effects (Barber et al., 2011; Mcdonald et al., 2009), ultimately altering the conservation value of the protected area (Wood et al., 2015). Understanding land use and human population changes around protected areas is therefore key for protected area management and biodiversity conservation in general (DeFries et al., 2007; Joppa et al., 2009).

The process of urban expansion and residential development accompanied by human population growth near protected areas throughout the world represent a growing pressure (Güneralp et al., 2013; Pejchar et al., 2015; Spear et al., 2013). Indeed, population growth is the most important driver of land development, together with an increase of per capita Growth Domestic Product (Güneralp and Seto, 2013; Seto et al., 2011; Wade and Theobald, 2010) that promote amenity migration and the development of second homes near protected areas in highly-developed countries (Hansen et al., 2002; Leroux and Kerr, 2013). By 2030, urban areas and residential developments are predicted to expand around most protected areas in some regions in Europe (Brambilla and Ronchi, 2016), and in Asia (Mcdonald et al., 2008), while from 1940 to 2030 1 million new housing units are projected to be constructed within 1-km from protected areas boundaries in the conterminous United States (Radeloff et al., 2010). Residential development is also expanding in many Pacific and Caribbean Islands (Stein et al., 2014).

However, while total human population is expected to expand in the next decades, many places of the world are projected to see declines in population, with unclear effects on land change, protected areas and biodiversity conservation. For example, between 2015 and 2050,

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human population is projected to decrease in 48 countries across the world including in regions with the highest population densities such as China and Europe (e.g., Spain, Greece, Germany, Portugal (United Nations, 2015a). Decline in fertility, aging populations, and outmigration are among the most important drivers of populations decline in these countries. Similarly, several islands in the Caribbean (e.g., Cuba, Jamaica, Puerto Rico) are projected to undergo population decline during the same period (United Nations, 2015a). Further, regions within countries are also exhibiting population declines despite net population increases at the national level. For example, the state of Michigan in the United States showed a recent population decline of 0.6% of its population over the last census decade (2000 − 2010) losing 54,804 people even though the US population increased by 9.7% (Mackun and Wilson, 2011). Domestic outmigration due to economic crisis and unemployment explained population decline in this state (Farley, 2010), but the potential consequences of these population declines on protected areas is unknown, adding uncertainty to management planning.

Understanding changes in residential development around protected areas in places with population declines can help in anticipating potential opportunities for conservation and restoration, as well as to better understand the link between changes in population, housing, and protected areas. Questions on whether decreasing human population alleviates pressures from residential development around protected areas, or whether housing expansion is a widespread problem, are critical considering the high urbanization rates globally (United Nations, 2015b) and future prospects for population declines in some countries and regions (United Nations, 2015a). However, our knowledge on these topics is limited.

Our goal was to understand how residential development around protected areas has changed in response to the recent human population decline, using Puerto Rico as a test case. The island of Puerto Rico, in the Caribbean, supports a high human population density, is rich in endemic species (Gould et al., 2008) and is considered a biodiversity hotspots (Myers et al., 2000). It has seen an abrupt population decline over the last decade as a result of outmigration due to an economic crisis and aging population. Specifically, our objectives were: 1) to quantify total change in housing and population around the protected areas network and compare these changes with the island as a whole, and 2) assess variability by analyzing spatial patterns of housing and population change around individual protected areas across the island.

## 2. Methodology

### 2.1. Study area, and recent population and housing changes

Puerto Rico occupies 8937 km$^2$, supports 3.7 million people, and is one of the most urbanized islands in the Caribbean Archipelago (Lugo et al., 2012a). It includes three inhabited islands: the main island (with 99.7% of the population), Vieques and Culebra (with 0.3% of the population), as well as several non-inhabited islands, islets, and cays. Puerto Rico is a mountainous island with 55% forest cover (USDA, 2017), heavily urbanized coastal areas, and relatively low-density development in the uplands (Helmer et al., 2008; Kennaway and Helmer, 2007; Parés-Ramos et al., 2008). The island is part of the Caribbean Islands Global Biodiversity Hotspot (Birdlife International, 2010), it supports different forest types (subtropical dry, moist, wet, and rain forests), as well as many endemic and endangered species.

The population of Puerto Rico decreased by ~83,000 people, or 2%, from the year 2000 (pop. 3,808,610) to 2010 (pop. 3,725,789). During that time period there were 218,472 new housing units built, representing an overall growth in new housing of 15%, or 9% growth of new occupied housing (115,206), and 66% growth of new vacant housing (103,264) (US Census Bureau, 2015; Fig. 1a). The main cause of the population decline was the economic crisis beginning in the mid-2000s with a local debt crisis and worsening with the 2008 recession. These events caused rapid outmigration of Puerto Ricans to the mainland United States (Pew Research Center, 2015; Abel and Deitz, 2014). As a result, Puerto Rico was placed among the top 10 countries with the biggest population decline rate in 2014 (Statista, 2016), and this depopulation trend is projected to continue thru 2050 (US Census Bureau, 2016). Nevertheless, residential development in Puerto Rico continued to rise, as it has done for the past 60 years, always exceeding population growth (Fig. 1a). Housing projections for 2030 suggest that the number of houses in the island will continue to increase (Stein et al., 2014).

### 2.2. Protected areas data

The island has a large network of protected areas and we focused our analysis on those terrestrial protected areas (n = 124), which as of September 2015 occupied 8% (709 km$^2$) of the land surface (Fig. 1b), and excluded marine protected areas, protected areas that are cays or islets, and marine extensions of coastal protected areas (Caribbean Landscape Conservation Cooperative, 2015). Terrestrial protected areas in Puerto Rico are typically small, range from less than 1 km$^2$ to 115 km$^2$ (mean = 6 km$^2$) and include public and privately-owned land (e.g., State Forests and Natural Reserves, US Forest Service National Forest, US Fish and Wildlife Service Refuges, NGOs). About 71% (500 km$^2$) of the protected areas occur in the interior mountains and hills, and 29% (209 km$^2$) in the coastal plains.

### 2.3. Census data

To evaluate changes in population and housing units we used population and housing data for the years 2000 and 2010 from the US Census at the level of census block, which is the smallest census unit (US Census Bureau, 2015). A housing unit is a living quarter in which the occupant or occupants live separately from any other individuals in the building and have direct access to their living quarters from outside the building or through a common hall, and includes permanent residences, seasonal houses and vacant units (US Census Bureau, 2015). Thus, apartments and multifamily units in a single structure are counted as multiple housing units. A major challenge for direct comparisons of census datasets from different years is the potential changes in the number and boundaries of the census blocks between years (Logan et al., 2014). In Puerto Rico there were ~55,000 census blocks in 2000 but ~76,000 census blocks in 2010. To overcome this limitation we used an algorithm to allocate 2000 housing and population data to 2010 blocks and adjust those blocks for the protected area's boundaries (Radeloff et al., 2010; Syphard et al., 2009) using the 2000–2010 census blocks and Block Relationship File provided by the US Census Bureau, and our protected areas layer.

### 2.4. Analysis

To quantify changes in people and housing units around protected areas, we used buffers of different sizes around protected areas. Measuring changes in land use/land cover at different distances to protected areas is a common approach to quantify the strength of the interactions between protected areas and external pressures in surrounding lands (Hamilton et al., 2013; Leroux and Kerr, 2013; Ye et al., 2015). Land use activities at shorter distances are expected to have a larger effect on protected areas than if the same activity occurs further away (Mcdonald et al., 2009). For the purpose of this study we used distances of 0.5, 1, 1.5 and 2 km of the boundary of the protected areas, which were large enough to include multiple census blocks, representing 8%, 15%, 23%, and 31% of the island's land surface, respectively. We decided our buffers based on the size of the island and to align with previous research for comparison of results (Radeloff et al., 2010). For each protected area and buffer zone, we extracted the number of housing units and population in 2000 and 2010 from the census based on the