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# Effects of landscape fragmentation on land loss

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ABSTRACT

Coastal Louisiana has been facing a serious land loss problem over the past several decades, and extensive research has been undertaken to address the problem. However, the importance of landscape fragmentation on land loss has seldom been examined. This paper evaluates the effects of landscape fragmentation on land loss in the Lower Mississippi River Basin region. The research hypothesis is that the higher the degree of fragmentation in a locality, the greater the amount of land loss in the next time period. We used Landsat-TM data with a pixel size of 30 m × 30 m in 1996 and 2010 and transformed the images into either land or water pixels. We then calculated the fractal dimension and Moran's *I* spatial autocorrelation statistics and used them to represent the degree of landscape fragmentation. Four sample box sizes, including sizes of 101 × 101, 71 × 71, 51 × 51, and 31 × 31 pixels, were used to detect if there is a relationship between fragmentation and land loss at different neighborhood (context) scales. For each box size, 100 samples were randomly selected. To isolate the fragmentation effect so that it can be better evaluated, we used only sample boxes with a 50% land-water ratio. Regression results between fragmentation and land loss show that the $R^2$ values for box sizes of 71 × 71, 51 × 51 and 31 × 31 were statistically significant (0.20, 0.45, 0.35; $p < 0.001$ for Moran's *I*) but not for the 101 × 101 box size. These results imply that land protection may be most effective by prioritizing areas with land patches that have the least fragmentation. Furthermore, the neighborhood scale at which the $R^2$ value is the highest indicates the scale at which the effects are most likely to be observed (51 × 51 box size, approximately 1.5 × 1.5 km$^2$, $R^2 = 0.45$), which suggests that future land loss modeling using this neighborhood scale would be most effective.

## 1. Introduction

As in most low-lying deltas in the world, coastal Louisiana is facing a severe land loss problem due to a combination of natural and human factors such as land subsidence, sea-level rise, and human alteration of the landscape. From 1932 to 2000, the coastal zone of southern Louisiana lost an estimated 4921 km$^2$ (1900 mile$^2$) of land to open water (Tibbetts, 2006). More recently, during the period of 1985–2010, coastal Louisiana lost about 42.9 km$^2$ (16.57 mile$^2$) of wetlands per year. If this trend persists, it would be equivalent to about losing the size of one football field per hour (Couvillion et al., 2016). Furthermore, it has been estimated that an additional 1800 km$^2$ will disappear by the year 2050 (Barras et al., 2003). Because of the land loss process, the coastal lands in the lower Mississippi Delta are subject to shoreline retreats (Twilley et al., 2016). This persistent land loss and shoreline retreat problem has already impacted the existing coastal infrastructure and human settlement, and it will continue in threatening the economic sustainability and population growth in the region (Cai et al., 2016; Qiang and Lam, 2015, 2016). Thus, determining which types of land pattern are prone to land loss will help coastal protection and restoration.

There have been many studies that examine the effects of natural factors and climate change on the disappearance of land, such as land subsidence, lack of river sediments, increases in storm magnitude and frequency, sea-level rise, and other climate change effects (Blum and Roberts, 2009; Zou et al., 2016). Studies that evaluate the effects of human activities such as canals and levees on land loss have also been conducted (Turner, 1987; Tweel and Turner, 2014). However, despite the substantial literature on the effects of habitat fragmentation on biodiversity (Fahrig, 2003; Villard and Metzger, 2014), literature that documents the relationship between landscape fragmentation and wetland loss is scanty. The degree of landscape fragmentation is an important attribute of land pattern; it has potential implications to land loss prevention and management. Thus, analysis of the effects of landscape fragmentation on land loss could provide valuable insights into the development of effective strategies for land restoration and protection.

This study examines how landscape fragmentation influences land

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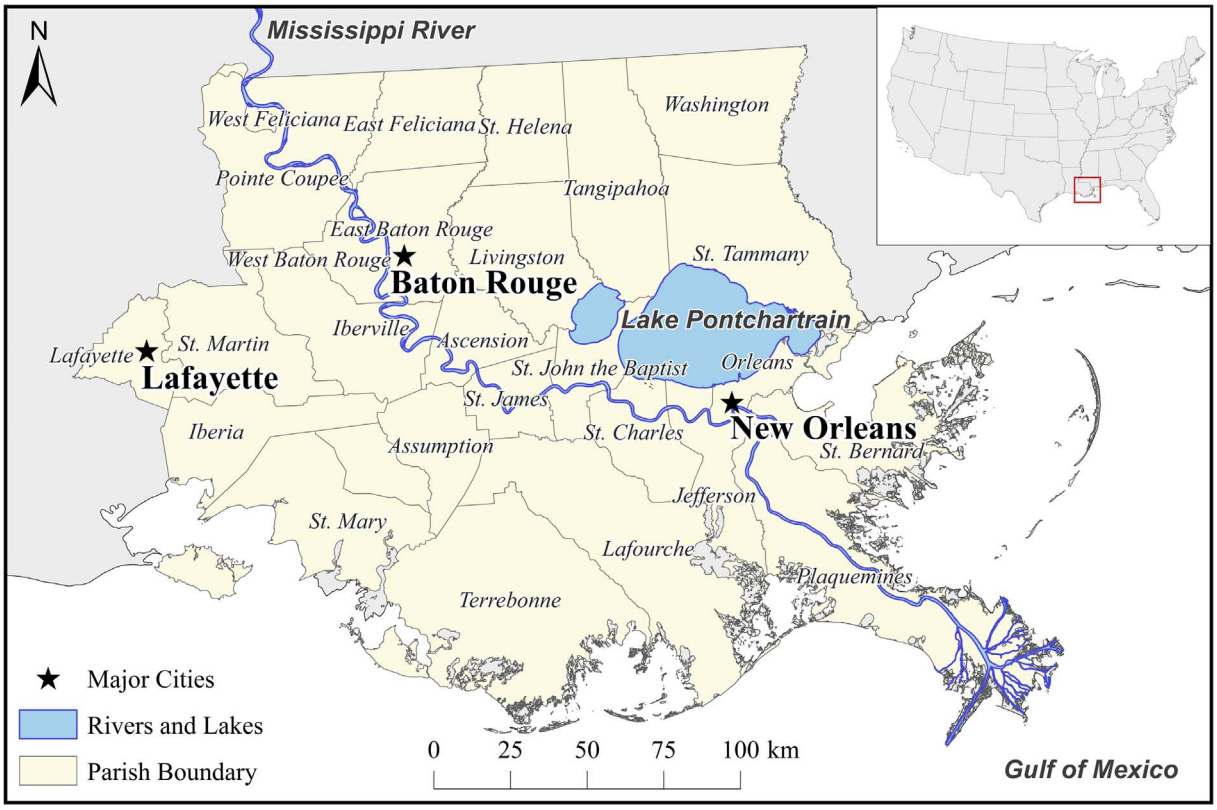


**Fig. 1.** The study area — the Lower Mississippi River Basin.
(Source: Cai et al., 2016).

loss. The research hypothesis is that the higher the degree of landscape fragmentation in a locality, the greater the amount of land loss in the next time period. In addition, since most spatial relationships change with scale and context (Lam and Quattrochi, 1992; Lam, 2004; Kwan, 2012; Quattrochi et al., 2017), the study will examine how the relationship between landscape fragmentation and land loss changes with different neighborhood sizes (i.e., context or scale effects). The study area is the Lower Mississippi River Basin (LMRB) region, which is located in southeastern Louisiana, USA, and includes the parishes (i.e., counties) from north of Lake Pontchartrain to the coast (Fig. 1). The southern, coastal portion of the study region has been suffering huge land loss over the past several decades, and the problem has been a great concern to governmental agencies at all levels and the local communities. Studies of the land loss factors such as fragmentation are important to the planning and development of the region. In this study, we used Landsat-5 TM data with a pixel size of 30 m × 30 m in 1996 and 2010 to evaluate the land loss problem between the two dates. To better evaluate the fragmentation effects at different neighborhood scales, we extracted samples of four different box sizes (31 × 31, 51 × 51, 71 × 71, and 101 × 101 pixels) with a constant 50% land-water ratio. Fractal dimension and Moran's *I* spatial autocorrelation statistic were then calculated to represent the degree of fragmentation (Quattrochi and Goodchild, 1997; Quattrochi et al., 1997; Lam et al., 1998, 2002). Correlation and regression analyses between the fragmentation indices in 1996 and the land loss percentage in 2010 were conducted to test the hypothesis.

### 1.1. Overview of land loss and fragmentation

Land loss refers to the process of complete erosion or losses of beaches and coastal wetlands to water. Land loss is a major environmental problem currently faced by a number of countries, and the Mississippi Delta in coastal Louisiana is a prominent example. In 2000, Louisiana had > 4 million acres of wetlands, representing 40% of the nation's total (Penland et al., 2000). The coastal lands in Louisiana were once the most diverse and productive ecosystems in the U.S., but these have been experiencing rapid degradation and fragmentation.

Coastal land loss in Louisiana is caused by both human activities and natural processes (Hitch et al., 2011). The natural processes include coastal erosion, subsidence, and sea-level rise, and the human processes include building dams and levees which have led to substantial reduction of sediments to replenish the land (Scaife et al., 1983). In addition, certain human activities related to water transportation and navigation, such as boat wakes, canals, and pipelines, alter the water circulation and can lead to land loss (Faulkner, 2004). Another cause of coastal land loss is the creation of coastal structures including seawalls and groins (Van Dijk, 2003). Also the discharge of pollutants and the burning of vegetation will destroy the soil structure and lead to fragmentation and land loss (Allison et al., 2014). Furthermore, sea level rise poses a serious threat to land submergence and land loss. Pachauri et al. (2014) estimated a global rise of around 1.8 mm in the sea level every year, which would lead to a large amount of low-lying coastal lands to be submerged.

The relationship between landscape fragmentation and coastal land loss is both intuitive and intriguing, and the underlying process could be very complex depending on the configuration of the marsh land. Researchers have suggested that coastal marsh collapse is affected by two key processes operating in opposite direction: the vertical sediment deposition and the horizontal wave erosion (Fagherazzi et al., 2013; Mariotti and Fagherazzi, 2013; Tonelli et al., 2010). Sediment discharge by a river or other means will increase marsh land, whereas marsh land is decreased by erosion by waves along the edges. Fragmentation of marsh land will tend to increase the length of the edge of marsh land, thus increasing the likelihood of marsh collapse. Other researchers have added that fragmentation of the marsh land will cause an increase in isolation of some of the patches of land and reduction in the size of the

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