Double exposure and dynamic vulnerability: Assessing economic well-being, ecological change and the development of the oil and gas industry in coastal Louisiana

By

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ABSTRACT

The oil and gas industry has been a powerful driver of economic change in coastal Louisiana for the latter half of the 20th century and into the 21st. Yet, the overall impact of the industry on the economic well-being of host communities is varied, both spatially and temporally. While the majority of Louisiana's oil and gas production now occurs offshore, processing the extracted product is an energy-intensive undertaking requiring an expansive network of land-based infrastructure. Despite the positive economic aspects of this development, there are also potential negatives posed to coastal ecosystems and to communities located adjacent to oil and gas infrastructure. This research utilizes a double exposure framework to explore the relationship between oil and gas infrastructure development, fish and shellfish habitat, and economic well-being in Louisiana's coastal zone from 1950 to 2010. The approach followed four main steps: (1) Developing a hazardousness of place model to identify areas of magnified risk due to the combined hazards of multiple potential exposure sites related to the extraction and processing of crude oil and natural gas; (2) developing a model of ecological functioning to measure the ability of aquatic habitat to support key fish and shellfish species; (3) utilizing an integrated community economic well-being index to assess change on a decadal timescale; and (4) analyzing selected oil-dependent communities to illustrate how change processes occurring in different energy sectors result in differential outcomes. The results suggest that, for many communities, the dependence on the oil and gas industry has increased economic well-being but also increased sensitivity to natural and human-induced changes, including fluctuating economic conditions, environmental stress, coastal habitat destruction, and increasing social and economic pressures.

KEYWORDS: Offshore oil and gas, hazardousness of place, infrastructure, habitat suitability, historical geography.

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Coastal Louisiana supports nearly one-third of the crude oil and one-fifth of the natural gas produced in the United States (Laska *et al.* 2005). Although most of this production occurs within the Gulf of Mexico, the extraction and processing of the oil and gas requires an expansive network of onshore infrastructure to support the offshore industry such as platform fabrication, shipbuilding, and pipe-coating. Industries supported by oil and gas extraction include those that follow the production life-cycle of product produced from the onshore and offshore wells, and include gas-processing plants, refineries, and petrochemical plants as well as pipelines that transport the product to and from these facilities. As production shifted from onshore to offshore and into the deepwater Gulf of Mexico, an intensification of oil and gas development in Louisiana's coastal zone followed (Hemmerling et al. 2016). A common assumption is that the potential environmental threats posed by this industrial expansion will be accompanied by economic benefits to the host region (Freudenburg and Wilson 2002). Indeed, the development of this support network has fostered economic growth and generated employment opportunities for coastal residents along all sectors of the production chain (Scott 2014). Yet, populations living near oil and gas development often experience injustices based on social or economic status, rural condition, lack of political influence and inequitable siting processes and may bear greater vulnerability to risks associated with oil and gas development than the general population (McKenzie *et al.* 2016). Likewise, the growth and expansion of the oil and gas industry over this same time period has resulted in multiple ecological consequences to coastal ecosystems through each of the various stages of oil and gas development (Ko and Day 2004; Hemmerling *et al.* 2016).

The double exposure framework provides a means of examining how environmental and economic changes interact to spread risk and vulnerability over both space and time (Leichenko *et al.* 2010; Jeffers 2013). This framework recognizes that change occurs both simultaneously and sequentially, creating negative and positive outcomes for communities (Leichenko *et al.* 2010; O'Brien *et al.* 2004). As the 2010 Deepwater Horizon disaster highlighted, economic vulnerabilities may be intensified through double exposure when resource-dependent industries are geographically linked. In the immediate aftermath of the spill, for example, the U.S. government issued a six-month moratorium on deep-water drilling in the Gulf of Mexico. One study estimated that the moratorium would result in the loss of approximately 8,000 jobs and $487 million in lost wages to employees in oil and gas-related fields (Mason 2010). The short-term economic impact of the spill on fisheries was even more dramatic. The U.S. Bureau of Ocean Energy Management (BOEM) estimated the commercial fishing industry poten-

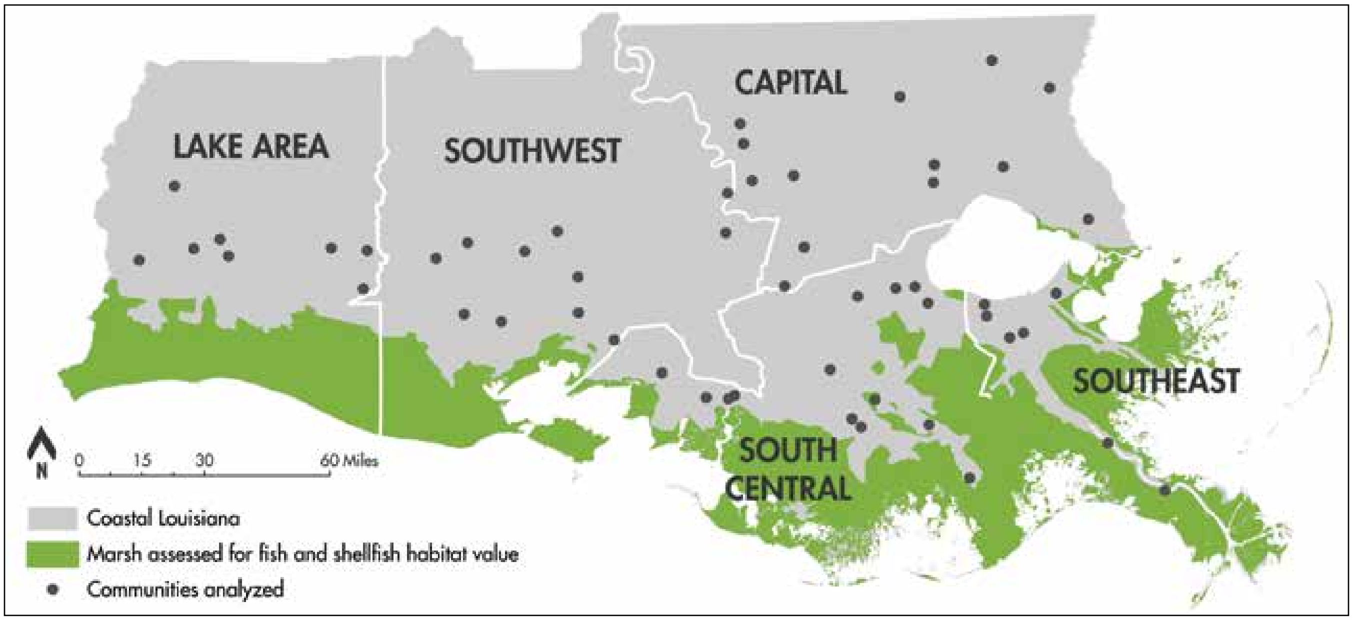

Figure 1. Map show the communities and extent of marsh area used in analyses, in coastal regions of Louisiana.

tially lost as many as 9,315 jobs and a total of $952.9 million in sales in the first eight months after the spill (Carroll *et al.* 2016). It remains to be seen what the long-term impact of the Deepwater Horizon spill will be on the economic well-being of Louisiana's coastal communities, but it highlights the complexities and interdependencies that exist between oil and gas development, fisheries, and community well-being in Louisiana.

For this research, we adapt the double exposure framework to incorporate aspects of increasing oil and gas infrastructure development, shifting fish and shellfish habitat, and changes in economic well-being. Whereas double exposure research generally focuses on global issues such as climate change and economic globalization, this research looks at the localized, indirect impacts of these global processes. Coastal land loss and marsh fragmentation are directly impacted by sea level rise and climate change. Likewise, the oil and gas industry is affected by the boom-bust cycles associated with the expansion and contraction of global petroleum markets (Wallace et al. 2001). The impacts of these fluctuations often ripple through resource-dependent communities and are experienced at multiple scales, including the individual, household, and community.

In this paper, we conduct a cross-sectional analysis of economic well-being in 53 population centers in coastal Louisiana, ranging in size from small towns to large cities (Figure 1; Table 1). The research uses a selection of widely accepted and readily quantifiable measures of economic well-being, including income, unemployment, educational attainment, and poverty, to explore the relationship between well-being, oil and gas development, and ecosystem functioning. Our approach comprises four main steps: (1) Developing a hazardousness of place model to identify areas of magnified risk due to the combined hazards of multiple potential exposure sites related to the extraction and processing of crude oil and natural gas; (2) developing a model of ecological functioning to measure the ability of aquatic habitat to support key fish and shellfish species; (3) utilizing an integrated community-level economic well-being index to assess change on a decadal timescale; and (4) analyzing selected oil-dependent communities in coastal Louisiana to illustrate how change processes occurring in different energy sectors result in differential outcomes.

HAZARDOUSNESS OF PLACE AND THE SPATIAL EXPANSION OF THE OIL AND GAS INDUSTRY

The oil and gas industry in Louisiana has progressed through a number of historical stages as a combination of increasing demand and technological innovation has driven the shift from onshore production to nearshore and deep-water production. Initially, extraction focused on the deposits surrounding onshore salt domes north of the coastal wetlands where drillers found stable geologic foundations for the heavy oil-field apparatus (Davis 2010). By the 1930s, exploration and successful drilling had expanded throughout the coastal zone from Plaquemines to Calcasieu parishes. Economic impacts radiated outward from the rural fields, and towns like New Iberia, Lafayette, and Morgan City experienced considerable population growth and attracted outside investment in service industries such as drilling equipment, exploration, and related services (Brasseaux and Davis 2017; Pulsipher 2006; Austin *et al.* 2008a). In 1947, just south of Morgan City, Kerr McGee drilled the first offshore well out of sight of land, allowing for an expansion of offshore oil and gas development.

The success of exploratory operations in south Louisiana led to increasing well outputs throughout the twentieth century until 1969, when oil production peaked in Louisiana and reserves began to decline. Demand for petroleum and petroleum products, however, continued to increase and producers began drilling in areas previously considered economically infeasible, moving from the coastal marshes further offshore (Davis and Place 1983; Priest 2009). As production shifted, onshore industries evolved to support offshore extraction. Ship-building firms manufactured specialized craft for the industry. Pilots, divers, and other specialists as well as manual laborers all found a demand for their skills offshore. Additionally, restaurants, realtors, and other businesses benefitted from the influx of out-of-state companies and their workers.

The expansion of offshore production sustained regional economies and drove

Table 1.
Study area communities considered by socioeconomic well-being analysis.

Community name		
Abbeville[2]	Gretna[2]	Patterson[2]
Amite[3]	Hammond[2]	Plaquemine[2]
Baker[2]	Harahan[2]	Ponchatoula[2]
Baton Rouge[2]	Houma[2]	Port Allen[2]
Bayou Cane[1]	Jeanerette[2]	Port Sulphur[1]
Berwick[3]	Jennings[2]	Raceland[1]
Bogalusa[2]	Kaplan[2]	Rayne[2]
Breaux Bridge[2]	Kenner[2]	Reserve[1]
Buras-Triumph[1]	Lafayette[2]	Slidell[2]
Covington[2]	Lake Arthur[3]	St. Martinville[2]
Crowley[2]	Lake Charles[2]	Sulphur[2]
Denham Springs[2]	Laplace[1]	Thibodaux[2]
DeQuincy[2]	Larose[1]	Vinton[3]
Donaldsonville[2]	Lutcher[3]	Welsh[3]
Franklin[2]	Morgan[2]	Westlake[2]
Franklinton[3]	New Iberia[2]	Westwego[2]
Golden Meadow[3]	New Orleans[2]	Zachary[2]
Gonzales[2]	Norco[1]	

1) Classified as a Census Designated Place (CDP) by the U.S. Census Bureau.
2) Classified as a city by the U.S. Census Bureau.
3) Classified as a town by the U.S. Census Bureau.

urban growth throughout the coastal zone. Morgan City, for example, developed into a hub for the offshore industry through the growth of platform fabrication, ship building, and related service industries. New Iberia and Houma also grew during the boom years of the 1960s and 1970s (Austin et al. 2008b). Lafayette developed into a major center for oil and gas service companies. These communities saw energy-related employment rise in importance and shape their economies despite their physical distance from the extraction sites. As oil and gas production peaked, population and industrial growth placed heavy demands on communities in terms of housing, public utilities, medical services, and public safety. During downturns, these communities struggled to sustain the level of services they put in place during boom years (Coelho 2006).

In the early 1980s, there was a global oil glut and coastal Louisiana suffered a dramatic bust. The Houma metropolitan area lost nearly a quarter of all jobs from 1982 to 1987. With the drop in oil-related employment, there was an outward migration that continued into the 1990s as the industry shifted many of its activities to Houston and many higher-paying technical positions left the state (McGuire 2006). The number of service industries similarly dropped and state revenue suffered as severance tax income declined (Pulsipher 2006). Personal incomes flattened out during the 1980s as the region searched for alternatives to oil.

Following the oil bust, technological advances and the increased price of oil made it more economically feasible to drill on the Outer Continental Shelf (OCS) and the deep-water Gulf of Mexico. These developments allowed for a tremendous expansion of the offshore-based industry in coastal Louisiana. Onshore industries developed to support offshore extraction and renewed the importance of oil to the region's economy. This shift in production also prompted several adjustments in the industry. The town of Venice, which was a key embarkation point for nearshore rigs in the 1970s, has lost most of its oilfield service capacity to Port Fourchon, an offshore service base with no permanent population. The fixed platforms used in the 1960s and 1970s were replaced by mobile deep-water drilling platforms resulting in fewer total drilling platforms, and some fabrication shifted to out-of-state locations. Morgan City now hosts a much-diminished platform fabrication industry. Furthermore, because OCS drilling took place beyond the state's territorial waters and thus did not pay severance tax, the state did not experience a comparable influx of revenue.

Still, with the expansion of oil production into the OCS, jobs in the industry have increased and local services experienced renewed activity. By the late 1990s, employment in almost all oil-related sectors was higher than in 1980 just before the oil bust (McGuire 2006). Oil prices began to climb in the early 21st century and stimulated additional expansion of OCS activity, contributing spillover economic effects to coastal parishes in Louisiana. After several strong years, the BP spill disrupted mineral-related activity briefly in 2010, but the industry remains a prominent part of the economy.

Over the course of its history in Louisiana, oil and gas development has fostered economic growth and provided employment opportunities for many coastal residents. While the majority of Louisiana's production now occurs offshore, processing the extracted oil and gas is an energy-intensive undertaking requiring an expansive network of land-based infrastructure. Despite the positive aspects of this development, there are also potential negatives posed to coastal ecosystems and to communities located adjacent to oil and gas infrastructure. As with many industrial processes, there is a potential for release of air and water pollutants, physical and public safety hazards, and a range of psychosocial stressors resulting from the noise, odor and light pollution produced (Adgate *et al.* 2014). To assess some of these potential risks, we developed a hazardousness of place model that combines proximity- and risk-based methods (Hemmerling and Colten 2004; Hemmerling 2007). To model the impacts of these industries, detailed infrastructure locations were derived from secondary data sources and permit records available from the U.S. Environmental Protection Agency (USEPA) and broken down by North American Industry Classification System (NAICS) code. As the hazard analysis conducted is based on physical proximity, the locational accuracy of identified infrastructure is an important antecedent to modeling efforts. The footprint of each facility was verified using the most recent United States Geological Survey (USGS) Digital Orthophoto Quarter Quads. Infrastructure dating was accomplished using a combination of web resources, historical business directories, satellite imagery, historical pipeline maps, and historical USGS topographic maps.

After being geolocated and dated, each infrastructure element was assigned an

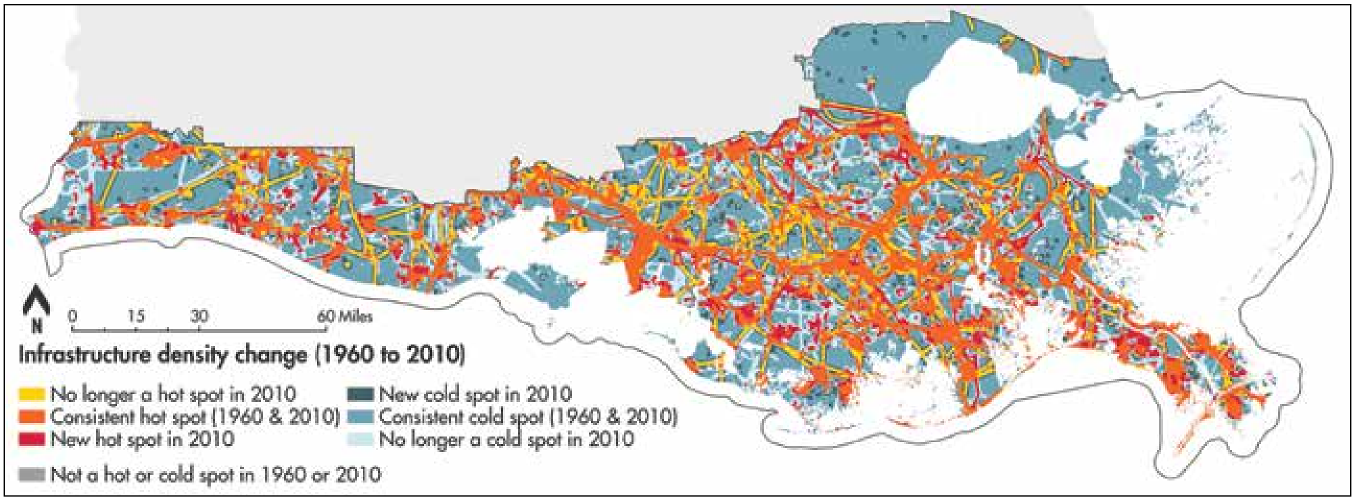

Figure 2. Map shows change in hot spots and cold spots of hazards-weighted infrastructure density in coastal Louisiana from 1960 to 2010. Hot spots indicate areas of significantly high infrastructure density clustered with similar areas of high infrastructure density, while cold spots are areas that have a significantly low level of infrastructure density surrounded by areas with similarly low infrastructure density.

intensity value, influence distance, and a distance decay function based on analysis of USEPA toxic release data. Intensity value was based upon an historical review of toxic releases associated with each relevant NAICS code and chemical toxicity measures developed by the Indiana Pollution Prevention and Safe Materials Institute. To assess influence distance, researchers created a number of proximity-based buffers that are dependent on the specific hazard associated with each activity (Hemmerling and Colten 2004; Hemmerling 2007). Using USEPA's Risk Management Program computer modeling software (RMP*Comp), a worst-case release scenario and offsite consequence analysis was performed for each facility to determine the endpoint distance of a hypothetical release (U.S. Environmental Protection Agency 2017). The U.S. Department of Transportation guidelines also establish default isolation zones for hazardous releases that was used to create site specific buffers around facilities with fugitive release that may not be modeled in RMP*Comp. Using a concave decay rate, residents living closer to a hazardous facility were assumed to experience impacts that decrease dramatically as one approaches the endpoint distance threshold. Finally, a composite model of potential risk was developed using an arithmetic overlay incorporating all risk elements into a single overarching hazardscape (Hemmerling and Colten 2004). Using the Protected Area Tools toolbox developed by The Nature Conservancy (Schill and Raber 2012), an environmental risk surface was developed on a decadal time step and the resultant hazards value was used to classify each location in coastal Louisiana by a weighted hazardousness of place rating.

Examination of the hazardscape reveals that oil- and gas-related infrastructure density rapidly expanded between 1960 and 2010, reflecting the shift from predominantly onshore and nearshore extraction to offshore and deep-water extraction (Figure 2). While the density of oil-related industrial infrastructure increased in all regions of the Louisiana coast over the study period, the rates of increase varied, with the greatest rates of increase occurring in the South Central and Southeast regions, indicated by a significant interaction term, $p = <0.05$. Both the total density of infrastructure and the rate of growth of oil- and gas-related infrastructure was lowest in the Capital region, which includes the north shore of Lake Pontchartrain, home to many affluent residential suburbs of New Orleans.

HISTORICAL CHANGES IN ECOLOGICAL FUNCTIONING: FISH AND SHELLFISH

Coastal Louisiana contains approximately 37% of all estuarine marshes in the contiguous United States, which provide valuable ecosystem services including water regulation, recreation, fisheries production, carbon sequestration, wave attenuation, and surge reduction (Visser *et al.* 2012; Batker *et al.* 2014). Much of this habitat is at risk due to a combination of sea level rise, subsidence, saltwater intrusion, and reduced sediment inflow (Day *et al.* 2000; Scavia *et al.* 2002; Day *et al.* 2011). Between 1932 and 2010, coastal Louisiana lost over 4,800 km^2 of wetlands and is predicted to lose a further 2,118 to 4,677 km^2 over the next 50 years (Couvillion *et al.* 2011; LA CPRA 2012; Couvillion and Beck 2013). This high rate of marsh loss is not spatially uniform, involving changes in the structure, configuration, and spatial distribution of the vegetation (Reed *et al.* 2007). Habitat fragmentation — the breaking apart of continuous habitat into smaller patches — directly impacts species utilizing the habitat (Lindenmayer and Fischer 2013). Responses to fragmentation vary by species as some may linearly increase or decrease while others exhibit more complex patterns (Bennett and Saunders 2010).

Despite extensive wetland loss, fishery yields in Louisiana have remained relatively stable since the 1950s (Chesney *et al.* 2000; Cowan *et al.* 2014). One reason for this is that the process of wetland loss starts with increased marsh fragmentation which provides increased access to habitat for fish and shellfish (Browder *et al.* 1985). However, fragmentation also increases the rate of land loss, suggesting that this increased access to habitat is transitory (Couvillion *et al.* 2016). For this research, the ability of the ecosystem to support fish and shellfish species was assessed by examining the ratio of land to water over time, a key component of marsh fragmentation (Jerabek *et al.* 2017). Aerial photographs from 1956 and Landsat imagery from the 1970s to 2010 were used to derive the data. These maps were classified into land and water at a 30m resolution as described by Couvil-

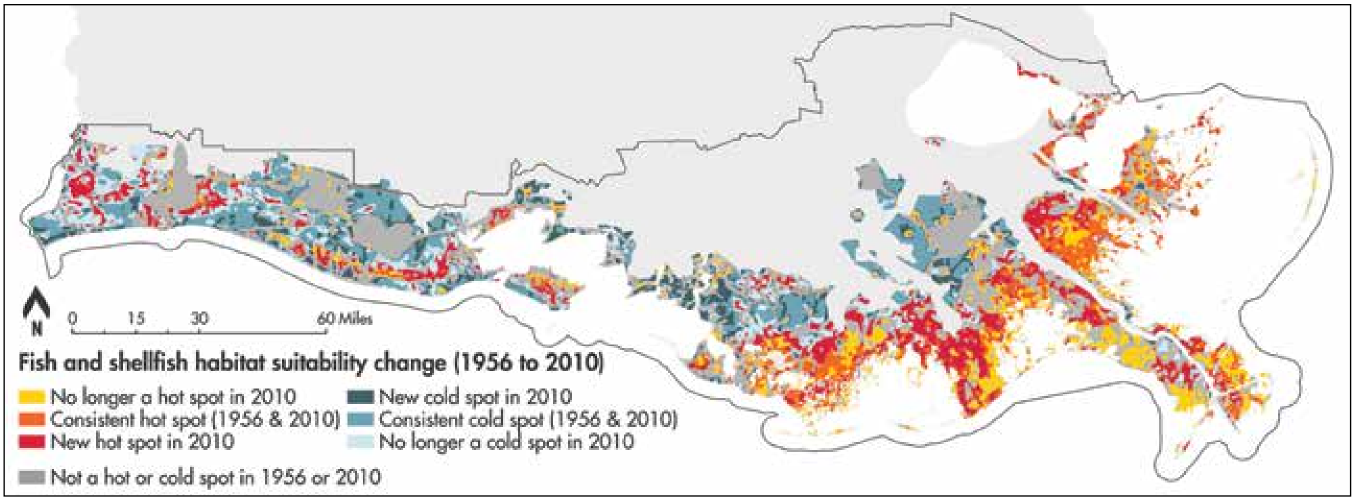

Figure 3. Map shows change in hot spots and cold spots of habitat suitability for fish and shellfish species in coastal Louisiana, comparing 1956 and 2010 (Adapted from Couvillion *et al.* 2011). Hot spots indicate significant peak intensities of suitable habitat scores surrounded by other highly suitable habitat while cold spots are areas that possess the low-quality habitat surrounded by similarly low-quality habitat.

lion *et al.* (2011). An independent dataset delineating marsh zones was obtained for the following years: 1949 (O'Neil 1949), 1968 (Chabreck *et al.* 1968), 1978 (Chabreck and Linscombe 1978), 1988 (Chabreck and Linscombe 1988), 1997 (Chabreck and Linscombe 1997), 2001 (Linscombe and Chabreck 2001), 2007 (Sasser *et al.* 2008) and 2013 (Sasser *et al.* 2014). Marsh classification was based on plant species abundance and composition from aerial surveys (Sasser *et al.* 2008). Only those areas consistently surveyed across all time periods were used in this analysis.

The ability of coastal habitat to support key fish and shellfish species was assessed using a simplified trapezoid habitat suitability index (HSI) curve that defines areas with 25%-80% marsh as most suitable for juvenile fish and shellfish (Minello and Rozas 2002; Baltz 2012). The HSI was scaled from 0 to 1, with 1 being defined as the most suitable and 0 least suitable. The index was modified so that the HSI score for open water was increased as more recent findings have shown that open water has more value than originally believed for juvenile nekton species in coastal Louisiana (Rozas and Minello 2015; Hijuelos *et al.* 2016). An earlier version of this index was applied to juvenile nekton species in marsh landscapes at 500m resolution (Baltz 2012). However, given the 30m resolution of the input dataset, a 480m resolution was used. The percent of marsh and water within each grid cell was calculated and used to generate a value for each year of the analysis.

The Getis-Ord Gi* statistic, a measure of spatial autocorrelation, was used to identify areas of peak and low suitability relative to the coastwide mean for each year. Hot spots indicate significant peak intensities of suitable habitat scores surrounded by other highly suitable habitat while cold spots are areas that possess the low-quality habitat surrounded by similarly low-quality habitat. A 700m Euclidian distance band was applied to the test statistic to ensure each cell had one neighbor to test for spatial autocorrelation.

Coastwide analysis shows that, despite increasing marsh fragmentation and a rapid decline in total wetland area since 1956, the amount of quality habitat for fish and shellfish increased through 2000, then significantly declined by 2010 (Figure 3). The period from 2000 to 2010 included several major hurricanes, the Deepwater Horizon oil spill, and a number of high Mississippi River flow events, but may also indicate declining resilience of the coast to maintain suitable habitat for fish and shellfish. Estimated habitat quality for fish and shellfish varied across Louisiana's coastal zone. Saline and brackish marshes showed the highest suitability, while fresh and intermediate marshes had the lowest. Loss of hot spots between 1956 and 2010 throughout the Mississippi River Delta reflects the conversion of marsh habitat to open water during that period. As coastal marshes have fragmented and then become open water over the last six decades, hot spots for fish and shellfish habitat have shifted northward.

NATURAL RESOURCE DEPENDENCE AND ECONOMIC WELL-BEING

Over 41% of all Louisiana workers reside in the coastal parishes — the greatest proportion of all Gulf of Mexico states (National Ocean Economics Program 2018). A large portion of these workers are employed in coastal economy sectors, including oil and gas production, fisheries, marine construction, shipbuilding, tourism, and marine transportation (Kildow *et al.* 2014). The development of the offshore industry involves several interconnected coastal economy sectors and has had a tremendous impact on the economic landscape of coastal Louisiana throughout the 20th century and into the 21st. In total, the oil and gas industry directly employs nearly 65,000 workers throughout Louisiana. Additionally, for every new job created in the oil and gas industry, there are 3.4 additional jobs created in in other sectors of the economy (Scott 2014).

While the overall importance of Louisiana's oil and gas development as an economic engine for the state is well documented, the degree to which this development results in enhanced well-being is subject to debate. Despite the fact that oil and gas extraction wages are 2½ times higher than the average wage earned by a Louisiana worker (Scott 2014), research has shown that, over time, the coastal parishes don't seem to be any worse off or any better off than the rest of the state in terms of personal income growth (Pulsipher 2008; Scott

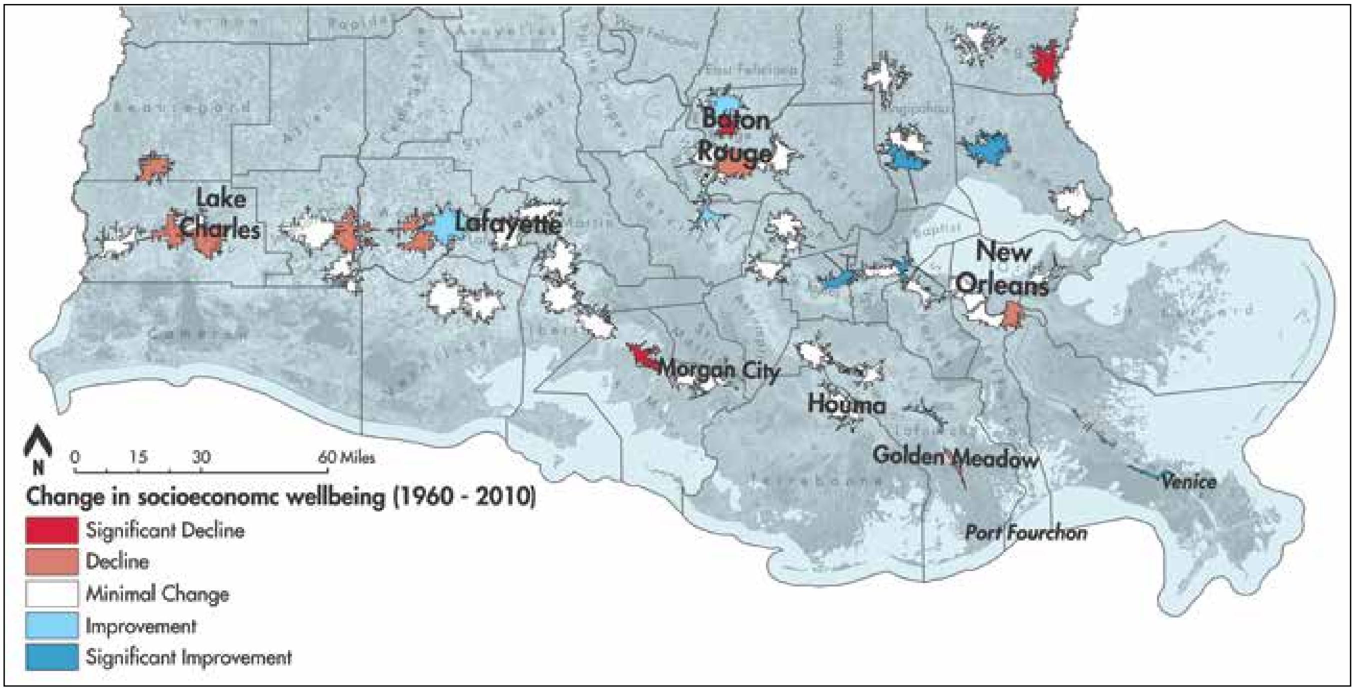

Figure 4. Map shows change in integrated economic well-being for communities in coastal Louisiana between 1960 and 2010.

2014). While aggregate income levels within the Louisiana coastal zone may not correlate to either oil and gas intensity or industrial composition, oil and gas development has often been shown to provide a temporary source of economic stability and growth for coastal communities (Pulsipher 2008). Over the long term, this economic stability and growth depends upon how well communities are able to expand beyond their dependence on oil and gas. Research suggests that the degree to which oil and gas extraction and processing becomes linked to subsequent economic development and infrastructure is the key to fostering community well-being, as long as this development is relatively independent of the parent resource industry (Stedman *et al.* 2004).

Without this independence, oil and gas shocks will reverberate through the linked industries, potentially exacerbating rather than counterbalancing shifts in well-being (Freudenburg and Gramling 1998). Overdependence on natural resource employment results in higher levels of economic instability and social vulnerability. This vulnerability has been tied to multiple diverse stressors, including shifts in resource demand resulting from economic or policy changes, industry fluctuations, weather and climatic change, shifts in technology and automation of processes, and shift of control from local to extra-local corporations (Matarrita-Cascante and Trejos 2013). For this reason, the level of natural resource dependence is often seen as an important determinant of a community's economic well-being and social vulnerability to the impacts of land loss, sea level rise, and tropical storm events. In resource-dependent communities, for example, disruption of livelihoods can result from the loss of land and animals for farmers, or boats and nets for fishers (Wisner *et al.* 2004). In the case of petroleum extraction, damage to infrastructure and the time needed to bring operations back online following storm events may place heightened economic strains on oil- and gas-dependent communities. This has implications during hazards events, where delays in evacuation to protect assets present health and safety issues, and during recovery, when the potential loss of property and assets may result in livelihood deterioration (Hemmerling and Hijuelos 2016). In addition, the inherent hazards associated with the infrastructure, such as the release of hazardous materials, can delay or prevent recovery.

To assess historical changes in the economic well-being of coastal Louisiana, we utilized a series of profile indicators to construct a timeline of change in economic well-being at the community level. Profile indicators are static, descriptive indicators that describe a situation at a given point in time. Such indicators are explicitly quantitative and generally derived from a top-down approach and are generally collected rigorously, scrutinized by experts, and assessed for relevance using statistical tools (Reed *et al.* 2006). Profile indicators, when examined across regions or over time, can be used to identify trends in the data that might be missed at the observational level. The data used in this study are from the U.S. Census Bureau and include the decennial census and the American Community Survey, an ongoing sample survey consisting of multiple years of data.

The units of analysis consist of 53 incorporated and unincorporated places located within a 30-minute drive time from the Louisiana coastal zone (Figure 1; Table 1). This time corresponds approximately to the average time Louisiana residents spend commuting from their home to their place of employment according to the U.S. Census. While smaller geographical units such as the census block and tract have been consistently available since the 1990 census, prior censuses only assessed sub-state level populations at the place and county levels. Of these, the place is the smallest unit for which a wide range of demographic and economic data has been consistently measured and reported. Place boundaries may be either legally or statistically derived based upon whether the community is officially incorporated or unincorporated, respectively. The 53 communities utilized here are those for which the U.S. Census Bureau has a continuous data record from 1960 to 2010.

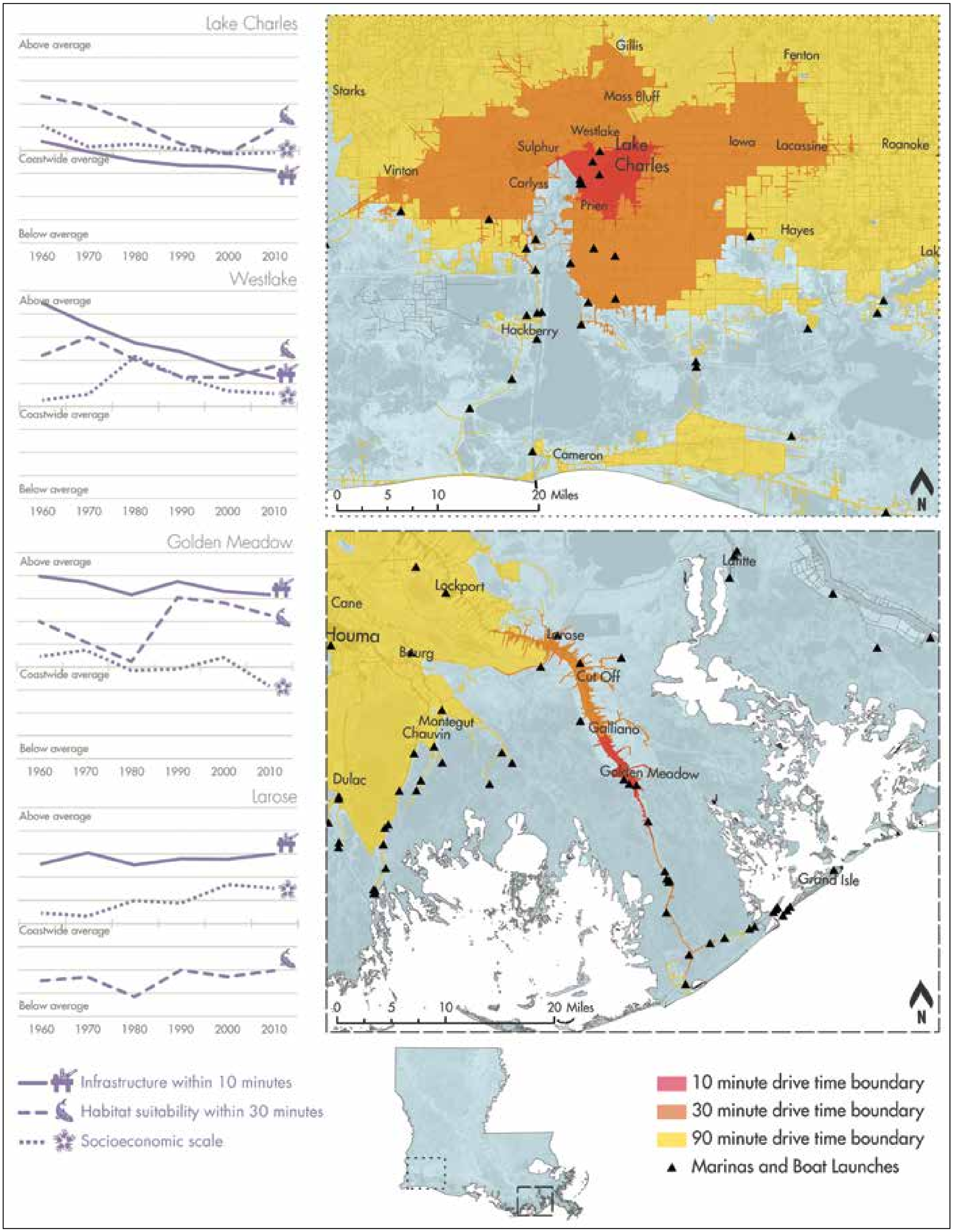

Figure 5. Graphic shows infrastructure density, habitat value for fish and shellfish, and economic well-being for communities in (A) Calcasieu Parish and (B) Lafourche Parish. Drive-time buffers used for community proximity analyses of (A) Lake Charles and (B) Golden Meadow are shown.

The economic status of each community in the study area was analyzed using census datasets that are closely correlated with income. Adapting methods developed by the U.S. Forest Service, an economic well-being index was derived which incorporates four primary categories of data that are consistently available in each decennial census: poverty, unemployment, home ownership, and educational attainment (Doak and Kusel 1996; Hemmerling *et al.* 2016). The primary assumptions behind the selection of these variables are that higher levels of home ownership, education, and employment indicate higher levels of economic well-being and that higher levels of poverty indicate lower levels of economic well-being (Doak and Kusel 1996). These individual variables were standardized and combined, with each category weighted equally, into a single additive index able to characterize changes in the economic status of coastal communities from one decadal census to another (Hemmerling *et al.* 2016). This index was developed for each decennial census from 1960 through 2010 and assessed against levels of oil and gas development and distance to quality fish and shellfish habitat.

Examination of the integrated index found that economic well-being has remained fairly constant through time on a coastwide basis, although regional- and community-scale differences are apparent (Figure 4). A Pearson product-moment correlation coefficient was computed to assess the relationship between economic well-being, oil and gas development, and fish and shellfish habitat for each decadal timestep. This relationship was assessed at various scales, from the community itself (10-minute drive time), commuting distance (30-minute drive time), and travel for recreation (90-minute drive time). Economic well-being was positively correlated with increasing distance from the coast, $R = 0.256$, $n = 186$, $p = <0.05$. Communities that had a higher density of oil and gas infrastructure within a 10-minute drive time had higher levels of economic well-being, $R = 0.161$, $n = 186$, $p = <0.05$, as did those that had a higher density of suitable fish and shellfish habitat within a 30-minute commuting time, $R = 0.234$, $n = 186$, $p = <0.05$. When we only look at the 30 communities closest to the coast, this correlation increased markedly, indicating that communities closer to the coast have a tighter relationship between resource-dependence, ecological value and economic well-being, particularly levels of employment.

CASE STUDIES IN ECONOMIC SECTOR SPECIALIZATION IN COASTAL LOUISIANA: CALCASIEU AND LAFOURCHE PARISHES

While the economic importance of the oil and gas industry to the state of Louisiana cannot be understated, this analysis reveals that there are significant differences in levels of economic well-being experienced by resource-dependent communities over time. This is due in part to the fact that the oil and gas industry is comprised of workers from various employment sectors, including those who work offshore and shift workers in refineries, fabrication yards, and onshore service and supply bases. Still others are temporary, seasonal, part-time, and contract workers, whose employment fluctuates based on wider economic conditions. Further, responses to industry cycles, corporate restructuring, and work organization differ considerably among each of these different sectors of the oil industry and these responses contribute in turn to differing economic impacts felt by workers and families within these sectors (Austin *et al.* 2002). This analysis reveals that, despite an overall strong correlation between economic well-being and oil industry development at the coastwide scale, trends within individual communities are highly variable. To explore this variability, this research will explore two communities with strong ties to the oil and gas industry; Golden Meadow, in lower Lafourche Parish, which is strongly tied to the offshore oil industry and Lake Charles, in Calcasieu Parish, an important petroleum refining center (Figure 4). Both Golden Meadow and Lake Charles have experienced an overall decline in economic well-being, yet this decline, based in part on sectoral specialization, is qualitatively different in each community.

The shift to offshore extraction did not result in the construction of new large refining centers as existing facilities expanded capacity as offshore extraction increased. The refineries and liquefied natural gas facilities in Calcasieu Parish, for example, increased capacity to process the increasing amounts of crude brought onshore. Despite the presence of a large petroleum refining cluster that expanded and densified, economic well-being has declined in many communities in Calcasieu Parish (Figure 5A). This decline is related to increasing poverty levels and lower home-ownership rates, suggesting that economic benefits of industrial expansion are limited to a segment of the population (Hemmerling *et al.* 2016). These economic stressors are offset by higher educational attainment levels, particularly in urban communities such as Lake Charles and Westlake, suggesting that industrial expansion may produce indirect socioeconomic benefits for these communities. Economic well-being in Lake Charles decreased slightly since 1960 as increasing levels of poverty and dropping levels of home ownership are offset by high levels of educational attainment and the high level of taxes paid by the petroleum extracting, refining, and pipeline industries in Calcasieu Parish. These results are very similar to those found in neighboring Westlake. Over 55% of the Westlake's coastal employment consists of petroleum refining and manufacturing. With the expansion of offshore oil and gas production, Westlake experienced an uptick in economic well-being from 1960 to 1980, followed by a readjustment and decline to levels slightly higher than those found in 1960. Despite above average levels of unemployment, Westlake tends to have relatively high levels of educational attainment and home ownership along with low poverty levels.

Conversely, resource-dependent communities that support the offshore industry tend to have relatively low levels of poverty and unemployment, although they often have lower levels of educational attainment, as many residents choose to work the oil fields at the expense of completing school (Hemmerling *et al.* 2016). Lafourche Parish, for example, is home to Port Fourchon, the principal land-based supply center for the majority of the offshore oil and gas activity occurring in the Gulf of Mexico (Figure 5B). According to the Greater Lafourche Port Commission (2019), over 90% of the Gulf of Mexico's deep-water production is serviced at Port Fourchon and over 250 companies currently utilize the port as a base of operations. Communities along Bayou Lafourche such as Golden Meadow and Larose are home to many workers employed at the port, on the rigs, in shipbuilding, and in marine transportation. These communities have relatively high levels of home ownership and low levels of educational attainment. Golden Meadow has a much smaller manufacturing base than other communities located further up Bayou Lafourche and is heavily dependent on oilfield work and water transportation. This has led to employment levels only slightly higher than that of other coastal communities but also higher levels of poverty. Between 2000 and 2010, Golden Meadow experienced a drop in economic well-being, due to the combination of Hurricane Katrina, the Deepwater Horizon disaster, and the collapse of oil prices. Larose, however, located at the junction of Bayou Lafourche and the Gulf Intracoastal Waterway, is home to more coastal economy-based industries and several large shipyards that employ a large number of residents, which correlates with lower levels of poverty. Despite the fact that education attainment levels have remained significantly below the coastwide average, high levels of employment have led to an overall increase in economic well-being, as poverty levels have fallen and homeownership rates have increased.

Both Calcasieu Parish and Lafourche Parish are key locations in Louisiana's coastal oil and gas industry and will continue to play an important role in the future. A number of recent economic expansions highlight the growing influence of industry in these two locations. An uptick demand for liquefied natural gas has resulted in $56.1 billion in new industrial construction starts across Calcasieu Parish (Calcasieu Parish School Board 2018). Similarly, the construction of a new bulkhead project in Port Fourchon will open up nearly 1/3-mile of additional waterfront property for prospective tenants to operate from (Greater Lafourche Port Commission 2019). While this research broadly suggests that individuals living in nearby communities should experience an increase in economic well-being as a result of these developments, the interconnectedness of inherent economic well-being and social vulnerability factors at the local level suggest that this conclusion may not be that simple. As these two case studies underscore, changes in economic well-being within individual communities can often change from one census decadal period to the next, often for vastly different reasons. While these industrial expansions are expected to provide new jobs and bring additional tax revenues to each parish, it remains to be seen precisely how these benefits will impact community-level economic well-being in the future.

CONCLUSION

In many ways, communities in coastal Louisiana can be considered prototypical social-ecological systems, with a large proportion of coastal residents highly dependent upon both renewable and nonrenewable resources for their economic well-being and resilience (Hemmerling 2018). The oil and gas industry, in particular, has been a powerful driver of economic change in coastal Louisiana for the latter half of the twentieth century and into the twenty-first. Yet, the overall impact of the industry on the economic well-being of host communities has been shown to be varied, both spatially and temporally. For many communities, an overdependence on oil and gas has made them extremely sensitive to natural and human-induced changes, including environmental stress, climate change impacts, coastal habitat destruction, fluctuating global economic pressures, and increasing social and economic pressures. Similarly, communities whose economies are strongly tied to fisheries have proven to be just as vulnerable to these stressors, perhaps even more so over the long term.

The sensitivity of many of Louisiana's coastal communities to environmental change has, in many cases, resulted in a coincident decrease in economic well-being, highlighting the double-edged sword of natural resource dependence. As complex social-ecological systems, coastal Louisiana's resource-dependent communities are inherently highly dynamic, with internal vulnerabilities constantly shifting through time due to any number of outside shocks and stresses. Understanding how historical shocks and stresses have shaped present day social and ecological landscapes is vital to planning and managing efforts designed to enhance community and regional resilience. Without this historical understanding, planners cannot fully anticipate the impacts of individual and double exposure threats, respond to these threats, recover from hazard events, or reduce community vulnerabilities (Colten *et al.* 2008; Hemmerling 2018). There is no doubt that the long-term economic well-being of coastal Louisiana's communities will continue to be dependent on the region's abundant natural resources. Those communities that have seen the greatest increase in economic well-being have been those best able to use the coastal economy as a springboard from which to grow and diversify their economic base. Yet, as the 2010 Deepwater Horizon disaster highlighted, the economic vulnerability of coastal communities may be intensified through the double exposure of geographically linked industries. The double exposure framework utilized in this research highlights the complex interdependencies that exist between industrial development, ecological health, and economic well-being. Understanding these interdependencies is vital to planning for the long-term sustainability of Louisiana's coastal communities and the economies that support them.

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