

Hurricane Impacts on Gulf Coast Coastal Ecosystems: A Systematic Review of Socio-Ecological Vulnerability and Policy Responses in the Northern Gulf of Mexico

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Abstract

The northern Gulf of Mexico is vulnerable to hurricanes, with its wetlands, barrier islands, and estuaries providing vital storm protection and habitat for vulnerable local populations. Thus, following PRISMA guidelines with appropriate search strings, databases were searched for international publication relevant to the integrated hurricane-induced ecological changes with socio-economic vulnerability and coastal policy in this region. After screening 127 records, we reviewed 37 full-text articles and excluded 14 due to mismatches in population, exposure, or outcome, resulting in a qualitative synthesis of 23 articles. We extracted data on hurricane characteristics, locations, affected ecosystems, and documented impacts across ecological, social, and policy domains. The reviewed studies revealed critical shifts in geomorphology and hydrology (shoreline erosion, wetland accretion, and salinization) estuarine biogeochemistry (carbon/nutrient budgets, contaminant remobilisation), habitat structure, and socio-ecological policy dynamics (surge valuation, property buyouts, fishing sector). We confirmed that while wetlands and barrier islands diminish storm surges and wave action, their protective capacity is severely threatened by ongoing land loss, nutrient enrichment, and post-storm development. Ultimately, hurricane impacts cannot be separated from community vulnerabilities, and adaptation strategies must integrate ecosystem protection with equitable recovery policy.

INTRODUCTION

Hurricanes that impact the shoreline of the northern Gulf of Mexico are among the most economically and ecologically devastating natural hazards in North America. Louisiana, Texas, Mississippi, Alabama, and the Florida panhandle have been a test case for the extent of engineered flood protection and the potential of natural protection, given the low-lying geomorphology of the delta and barrier islands, the region's rapid relative sea-level rise, and its high coastal population density. Hurricanes Katrina (2005), Rita (2005), Ike (2008), Isaac (2012), and Harvey (2017) each in their own way changed the scientific and policy landscape of the role of coastal wetlands, barrier islands, and estuaries in buffering exposure to storm hazards and the effects of storms on the ecosystems on which coastal communities rely.

Coastal wetlands and barrier islands are often referred to as “natural infrastructure” because they buffer against waves and storm surge, trap sediment, and sustain habitat and fisheries productivity that support regional economies [1]. However, the northern Gulf of Mexico has experienced some of the highest rates of wetland loss in the world, resulting from subsidence, changes in river sediment, saltwater intrusion, and anthropogenic transformation of the coast, without the influence of, and in concert with, hurricane disturbance [2]. This is a double bind because the very ecosystems which are best suited to mitigate socio-economic vulnerability to hurricanes are themselves vulnerable to degradation from hurricanes and post-hurricane land use changes, as well as from wetland permitting decisions.

Hurricane effects on coastal systems have progressed significantly, yet are still splintered within and among disciplines and themes. Geomorphological research has focused on the effect of storms on the erosion of marshes and barrier islands, overwash, sediment transport, and shoreline migration [3, 4]. Concurrently, biogeochemical studies have recorded the effects of storms and floods on carbon and

nutrient transport and cycling in estuarine ecosystems, such as significant shifts in carbon dioxide fluxes and nutrient loads after large hurricanes [5, 6]. Economically, recent evidence shows that wetlands and other undeveloped coastal areas can help minimise flood damage, specifically that maintaining wetlands provides measurable benefits to flood-risk reduction [7, 8]. Policy design, local governance capacity and social equity are critical for disaster recovery and adaptation, as mechanisms like property buyouts, managed retreat, floodplain management and associated institutional constraints have been explored at the governance level [9, 10]. Despite these advances, these knowledge bases are often fragmented, with geomorphologists, biogeochemists, ecologists, economists, planning and policy scholars tackling various aspects of coastal hurricane risk and recovery. Such fragmentation can make it challenging to comprehend the interactions between physical ecosystem change, ecological and biogeochemical responses, economic effects, and governance responses throughout the recovery process. Meanwhile, this void is significant for both scientific and practical reasons. From a scientific perspective, Rudd et al. [11] reported that, the extent to which the protective ecosystem services provided by Gulf Coast wetlands and barrier islands are maintained in response to repeated hurricane disturbances is difficult to determine without a cross-disciplinary synthesis, and degradation of these services may be occurring without the knowledge of coastal risk reduction strategies. Meanwhile, Coastal management agencies, including the U.S. Army Corps of Engineers, state coastal master planners in Louisiana and Texas, are requesting billions of dollars to restore wetlands and barrier islands, partly because they are believed to mitigate flood risks and to benefit resilient communities [12, 13]. These benefits and their distribution, particularly among those who benefit and those who do not, should be systematically examined. Communities along the northern Gulf Coast are also socio-economically diverse, from larger metropolitan areas to smaller fishing communities and historically disadvantaged neighbourhoods, and hurricane recovery and adaptation policies (such as granting permits for wetlands, purchasing properties, and funding infrastructure) do not impact the whole community equally. Understanding the buffer capacity of ecosystems to hurricane impacts is thus both a socio-ecological question-"is there a buffer?"-and a socio-economic question-"a buffer for whom, at what socio-economic cost?" Therefore, this review systematically identifies, appraises, and synthesises peer-reviewed research to document the impacts of hurricane activity on coastal ecosystems, socio-ecological vulnerability, and policy responses to hurricane activity in the northern Gulf of Mexico. This review was informed by three research questions, using the PECO (Population, Exposure, Comparator, Outcome) framework, which was suitable for an exposure-based evidence base rather than a clinical-intervention evidence base.

RQ1: What are the ecological impacts and socio-economic disruptions caused by hurricanes in the Northern Gulf of Mexico?

RQ2: How do regional policies integrate ecosystem services into coastal disaster risk reduction?

RQ3: What governance and institutional barriers hinder ecosystem-based adaptation in the region?

METHODOLOGY

Protocol and Reporting

This review was conducted and is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. A written a priori protocol specified the research questions, PECO elements, search strategy, eligibility criteria, and data extraction approach before screening began.

PECO Framework and Eligibility Criteria

Because this review addresses an environmental exposure and its ecological and policy consequences rather than a clinical intervention, eligibility was framed using the PECO rather than the PICO framework. Population was defined as coastal ecosystems (wetlands, marshes, estuaries, and barrier islands) and the human communities of the northern Gulf of Mexico coastal zone. Exposure was landfalling hurricanes, tropical storms, and associated storm surge [14, 15]. Comparator, where applicable, was pre-storm, non-hurricane, or undeveloped/less-developed reference conditions. Outcomes included ecological metrics (e.g., wetland accretion or loss, salinity, biogeochemical fluxes, habitat use) and socio-economic or policy metrics (e.g., flood damages avoided, wetland-permitting activity, buyout uptake, industry resilience, community recovery processes).

Studies were included if they (a) focused on the Northern Gulf of Mexico coastal zone (the U.S. Gulf Coast, encompassing Texas, Louisiana, Mississippi, Alabama, and the Florida Gulf coast); (b) addressed hurricane-related ecological impacts, coastal management, or adaptation policy; (c) were peer-reviewed journal articles or empirical policy reports published in English; and (d) were published in 2005 or later, capturing the post-Katrina era of accelerated policy attention, coastal restoration investment, and sea-level-rise-driven risk. Studies were excluded if they focused on non-Gulf regions (e.g., the Atlantic seaboard, the Caribbean, or the Asia-Pacific); consisted solely of meteorological or atmospheric modelling without ecological or policy linkage; were conference abstracts, editorials, book reviews, or grey literature without underlying data; or were published before 2005. This 2005 cutoff was chosen deliberately to capture the modern era of post-Katrina policy reform, accelerated relative sea-level rise, and large-scale coastal restoration planning in the region, rather than to exclude relevant earlier science.

Information Sources and Search Strategy

Two bibliographic databases, Web of Science and Scopus, were searched for peer-reviewed literature. The search string combined four concept blocks connected with Boolean AND, with terms within each block connected by OR: (1) Ecosystem terms ("coastal ecosystems," "wetlands," "marshes," "estuaries," "barrier islands"); (2) Hazard terms ("hurricane*", "tropical storm*", "storm surge*", "extreme weather"); (3) Region terms ("Gulf of Mexico," "Louisiana," "Texas," "Mississippi," "Florida Gulf coast"); and (4) Policy/management terms ("disaster risk reduction," "ecosystem-based adaptation," "coastal management," "policy," "governance"). The full Boolean string was: ("coastal ecosystems" OR wetlands OR

marshes OR estuaries OR "barrier islands") AND (hurricane* OR "tropical storm*" OR "storm surge*") AND ("Gulf of Mexico" OR Louisiana OR Texas OR Mississippi) AND ("disaster risk reduction" OR "ecosystem-based adaptation" OR "coastal management" OR policy OR governance).

Study Selection

The records were obtained from Web of Science (n = 79) and Scopus (n = 48), merged (n = 127), and deduplicated (35 were duplicates), resulting in a total of 92 unique records for title-and-abstract screening. 55 documents were deemed irrelevant to the scope, region, hazard and ecosystem/policy focus of the review. They were excluded at this stage, leaving 37 documents to be sought for full-text assessment. Of these, 14 were excluded at full text review: 4 because of wrong population (not the northern Gulf of Mexico coastal zone), 4 because of wrong exposure (not hurricane- or tropical-storm-related), and 6 because of wrong outcome (no ecological, socio-economic, and policy outcome reported) (Fig. 1).

Data Extraction

We used a structured extraction spreadsheet created using the export from the Covidence systematic-review platform to extract the lead author, year, hurricane event(s) or storm exposure examined, U.S. Gulf state (and specific location), ecosystem or system type, study design (e.g., field monitoring, remote sensing/geospatial analysis, modeling, survey or interview-based), and the main ecological, socio-economic, or policy findings for each included study. They were then coded thematically according to the three research questions posed in the review: ecological impacts, socio-ecological vulnerability, and policy responses, all of which overlapped.

Risk of Bias and Quality Appraisal

No single standardised risk-of-bias instrument was available to measure risk-of-bias across the entire evidence base, as included studies were conducted in different contexts (observational field monitoring, remote-sensing change detection, biogeochemical modelling, qualitative/survey-based social science). We therefore qualitatively rated each study in three categories: (1) the extent to which the hurricane event and its physical forcing (surge height, rainfall, wind field) were documented, (2) the extent to which ecological or socio-economic outcomes were documented with temporal replication (e.g., before and after the hurricane, or a suitable before-after comparison), and (3) the extent to which other stressors that could plausibly explain observed patterns were addressed (e.g., chronic subsidence, nutrient loading, prior development). The comparative designs in most studies were explicit before-and-after or impacted-versus-reference designs. They were rated as low to moderate risk of bias for the outcomes to which they applied, with a small number of studies using single post-storm snapshots with no explicit pre-storm baseline, a limitation identified in the synthesis below.

Data Synthesis

It was not appropriate to conduct a quantitative meta-analysis due to heterogeneity in outcomes, exposures, and study designs. Rather, the results were synthesised in a narrative and thematic manner within and across the three domains outlined above: ecological impacts, socio-ecological vulnerability, and policy responses, focusing on convergence, divergence across studies and geographic distributions (Louisiana, Texas, Mississippi, Alabama), and the specific hurricanes studied.

RESULTS

Summary of the Included Studies

Twenty-three studies were identified (Table 1), including a large number of publications since 2014, after Hurricanes Katrina (2005), Ike (2008), Isaac (2012), and Harvey (2017). Louisiana was the most frequently studied state [16–24], followed by Texas [6, 26–34], with additional studies situated in Mississippi and Alabama [35–38] and one multi-state study of the recreational fishing industry across the five Gulf states [39]. Study designs included long-term field monitoring networks, sediment-core stratigraphy, satellite- and LiDAR-based remote sensing and geospatial change detection, biogeochemical mass-balance modelling, economic and financial-ratio analysis, and qualitative social science.

Table 1
Characteristics of included studies (n = 23)

S/N	Study	Hurricane Event(s)	Location	Ecosystem / Focus	Key Finding
1.	Barbier & Enchelmeyer (2014)	Hypothetical storm track, SE Louisiana	Louisiana	Coastal marsh / storm surge economics	Developed a methodology linking wetland and surge characteristics to expected reductions in property damage from hurricane flooding.
2.	Siverd et al. (2019)	Modeled storms, 1850–2110	Louisiana	Coastal landscape / storm surge hydrodynamics	Historical surge increases (0.26–0.41 m) driven by land/river management; future increases (0.55–0.75 m) dominated by relative sea-level rise.
3.	Hodge & Williams (2016)	Audrey (1957), Carla (1961), Rita (2005), Ike (2008)	Texas (McFaddin NWR)	Coastal marsh sedimentation	Hurricane overwash is the dominant nearshore marsh sediment source; contribution diminishes with distance inland.
4.	Keim et al. (2019)	Katrina (2005)	Louisiana (Bayou Sauvage)	Impounded coastal wetland / salinity	Elevated soil and pond salinity persisted 11 + years post-storm; full recovery estimated to take at least two decades.
5.	Highfield et al. (2018)	Ike (2008)	Texas (Galveston Island)	Estuarine/tidal wetlands / flood damage	Tidal wetlands reduced flood damage within about 500 ft of structures but damages increased at greater distances.
6.	Williams (2018)	Rita (2005), Ike (2008)	Texas (McFaddin NWR)	Foredune barriers / washover sedimentation	Higher, wider foredunes reduced washover

S/N	Study	Hurricane Event(s)	Location	Ecosystem / Focus	Key Finding
1.	Barbier & Enchelmeyer (2014)	Hypothetical storm track, SE Louisiana	Louisiana	Coastal marsh / storm surge economics	Developed a methodology linking wetland and surge characteristics to expected reductions in property damage from hurricane flooding.
					sediment volume by ~ 40% and inland extent by 505 m.
7.	Bianchette et al. (2016)	Isaac (2012)	Louisiana (CRMS network)	Wetland accretion	Accretion during Isaac (4.04 cm/yr) was 40–70% higher than pre-/post-storm rates; highest near the Mississippi River.
8.	Wang et al. (2020)	Severe weather / cold fronts	Louisiana (Calcasieu Lake Estuary)	Estuarine exchange flow / hydrodynamics	Along-channel transport strongly correlated with wind forcing, reversing direction with frontal passage.
9.	Törnqvist (2007)	Katrina (2005)	Louisiana (Mississippi Delta)	Delta geomorphology / policy	Framed Katrina as a predictable consequence of long-term wetland loss and policy neglect; drew comparison to the Dutch Delta Plan.
10.	Roy et al. (2014)	Katrina (2005)	Louisiana (Upper Pontchartrain Basin)	Societal phosphorus metabolism	Inorganic P fertilizer inputs fell 78% (2001-05 vs 2006-10), linked to fertilizer economics and Katrina-driven migration.
11.	Han & Schauwecker (2025)	Multiple, 1984–2015	Alabama/Mississippi (barrier islands)	Shoreline dynamics, developed vs. undeveloped	Developed Dauphin Island showed chronic erosion and bay-

S/N	Study	Hurricane Event(s)	Location	Ecosystem / Focus	Key Finding
1.	Barbier & Enchelmeyer (2014)	Hypothetical storm track, SE Louisiana	Louisiana	Coastal marsh / storm surge economics	Developed a methodology linking wetland and surge characteristics to expected reductions in property damage from hurricane flooding.
					side deposition; undeveloped islands retained greater geomorphic resilience.
12.	Mo et al. (2020)	Katrina (2005), Gustav (2008), Isaac (2012)	Louisiana (coast-wide)	Coastal marsh resilience / nutrients	Marshes generally recovered within 1–2 years, but the most severe damage occurred in nutrient-enriched Breton Sound.
13.	Hu et al. (2020)	Harvey (2017)	Texas (two subtropical estuaries)	Carbonate chemistry / CO ₂ flux	Eutrophic estuary showed large post-storm pCO ₂ and CO ₂ -flux increases; oligotrophic estuary showed little change.
14.	Rabien et al. (2015)	Ivan (2004), Katrina & Rita (2005)	Louisiana (Mississippi Delta shelf)	Foraminiferal paleo-signature	Hurricane-deposited sediment units are distinguishable from non-hurricane and flood units via foraminiferal assemblages.
15.	Yao et al. (2022)	Hydrologic extremes incl. hurricane flooding	Texas (four nwGOM estuaries)	Estuarine carbon budget	Tidal wetland lateral exchange supplied most organic/inorganic carbon loading; hurricane flooding raised CO ₂ efflux 2-10x.

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1.	Barbier & Enchelmeyer (2014)	Hypothetical storm track, SE Louisiana	Louisiana	Coastal marsh / storm surge economics	Developed a methodology linking wetland and surge characteristics to expected reductions in property damage from hurricane flooding.
16.	Reja et al. (2017)	Ike (2008)	Texas (upper coast)	Wetland permitting / CWA Section 404	Post-Ike permitting increased within the 100-year floodplain; continued net loss of palustrine wetlands in impacted counties.
17.	Dellapenna et al. (2020)	Harvey (2017)	Texas (Galveston Bay/San Jacinto Estuary)	Contaminant sediment remobilization	Erosion of ~ 48 cm of sediment mobilized an estimated 2 tons of legacy mercury into Galveston Bay.
18.	Ellis et al. (2011)	Multiple, 1974–2008	Alabama (Mobile Bay)	Land-use/land-cover change	LULC monitoring informed Mobile Bay National Estuary Program watershed management planning.
19.	Greenheck et al. (2025)	Hurricane-driven island degradation	Mississippi (Ship Island)	Barrier-island restoration / Gulf sturgeon habitat	Restoration shifted acoustically tracked sturgeon habitat use from Dog Keys Pass toward the restored Camille Cut area.

S/N	Study	Hurricane Event(s)	Location	Ecosystem / Focus	Key Finding
1.	Barbier & Enchelmeyer (2014)	Hypothetical storm track, SE Louisiana	Louisiana	Coastal marsh / storm surge economics	Developed a methodology linking wetland and surge characteristics to expected reductions in property damage from hurricane flooding.
20.	Savolainen et al. (2015)	Named storms, 2004–2008	Five U.S. Gulf states	Recreational for-hire fishing industry	Resilience depended on vessel size, homeport, and business structure; smaller, well-managed firms recovered best.
21.	Witmer & Roelke (2014)	Ike (2008)	Texas (two beaches)	Infaunal beach community recovery	Recovery occurred within 3–9 months absent vehicle traffic; recovery did not occur at a heavily driven beach.
22.	Matsushita et al. (2024)	Katrina (2005)	Louisiana (New Orleans)	Post-disaster recovery / placemaking	Citizen-driven placemaking helped displaced residents rebuild social capital over an extended recovery process.
23.	Atoba et al. (2021)	Harvey (2017)	Texas (upper coast)	Property buyouts / flood resilience	Incorporating ecological and proximity criteria into buyout targeting did not significantly reduce cost-effectiveness.

Ecological Impacts of Hurricanes on Coastal Ecosystems

Geomorphological and Sedimentary Change

Wetlands along the Gulf coast are both destructive and constructive to storm surge and overwash. Hurricane overwash from Hurricanes Rita (2005) and Ike (2008) was the primary source of nearshore marsh sedimentation over the last 20 years at McFaddin National Wildlife Refuge in southeastern Texas,

decreasing in importance with increasing distance inland, where floodwater deposition and organic deposition are most influential [26]. In keeping with this land building function, coast-wide monitoring efforts in Louisiana showed that vertical accretion rates during the period that included Hurricane Isaac (2012) averaged 4.04 cm/yr, an increase of about 40 percent from pre- and 70 percent from post-storm rates, and the highest rates near the Mississippi River and within approximately 70 km of the storm's track [20]. Another type of physical barrier that can limit the sediment supply to marshes is a paired transect study behind foredunes of varying height at the McFaddin refuge, where a high foredune (80 cm) caused a reduction in washover sediment volume by ~ 40 percent compared to a low foredune (40 cm), and a reduction in extent of deposit inland by 505 m, reflecting a direct trade-off between storm protection provided by the foredunes and the sediment subsidy to sustain marsh elevation [28]. Hydrodynamic modelling of the Louisiana coast from 1850 to 2110 showed that historical sea-level rise in storm surge height (0.26 to 0.41 m) across three coastal basins was due to local landscape management decisions. The projected sea-level rise in storm surge height (0.55 to 0.75 m) by 2110 was mostly influenced by relative sea-level rise rather than landscape configuration, suggesting diminishing returns in restored landscapes without addressing subsidence and eustatic rise [18]. Empirical evidence collected from developed (Dauphin Island) versus largely undeveloped (Petit Bois, Horn Island) barrier islands in Alabama and Mississippi over 1984–2015 indicates that shoreline hardening and development, in addition to hurricanes, influence long-term barrier-island trajectories [36].

Hydrology, Salinity and Nutrient Dynamic

This hydrological legacy of storm surge flooding may occur long after the storm itself. A legacy of the authors was that elevated soil and pond-sediment salinity was found to have persisted at an impounded levee-ridge forest at Bayou Sauvage, LA, for at least 11 years after Hurricane Katrina's storm surge, and recovery to pre-hurricane conditions was estimated to take at least 20 years, owing to slow salt flushing conditions at the impoundment [19]. Nutrient status also influences the resilience of marshes to storm impact: long-term satellite and field data from Louisiana revealed that recovery of biomass and areal extent after storms (Katrina, Gustav, and Isaac) typically occurred in 1–2 years, with the greatest and most persistent storm damage consistently occurring in marshes in the nutrient-rich Breton Sound basin, suggesting that chronic riverine nutrient loading may degrade marsh root structure and increase vulnerability to storm disturbance [23]. The societal-metabolism scale involved material flow analysis of phosphorus at the Upper Pontchartrain Basin, which quantified a 78 percent drop in inorganic fertilizer inputs from 2001–2005 to 2006–2010, due to both price shock for inorganic fertilizers and in-migration and decentralized settlement after Katrina, which reduced the amount of phosphorus recycled, and thus directly tied the demographic change caused by Katrina to the associated biogeochemical outcomes [22].

Estuarine Biogeochemistry

Hurricanes create unique signatures in the carbon and carbonate chemistry of estuaries, but these responses depend strongly on the watershed. In the northwestern Gulf, the Mission-Aransas estuary, a relatively undeveloped, oligotrophic ecosystem, suffered comparatively small increases in CO₂ partial

pressure and flux after Hurricane Harvey, even though the storm's eye sank into the Gulf of Mexico. In contrast, the relatively more developed and eutrophic Guadalupe-San Antonio estuary, which the storm's centre did not directly hit, experienced large increases in CO₂ partial pressure and flux and also a brief period of low dissolved oxygen, indicating that the carbon response to hurricane flooding is more a function of watershed land use than storm intensity [29]. The northwestern Gulf 4-year, 4-estuary carbon mass-balance indicated that lateral exchange from tidal wetlands accounted for a large percentage of the total organic carbon loading (86.5 per cent). The total dissolved inorganic carbon loading (62.7 per cent), and hurricane-induced flooding led to an increase in CO₂ efflux by two to ten times for brief periods, highlighting the disproportionately large, though short-lived, biogeochemical impact of storms in these systems [30]. The exchange flows over the shallow tidal channel of Calcasieu Pass during extreme weather conditions were also strongly correlated with wind forcing, and along-channel exchange flow directionality changes as fronts pass, which are processes of relevance to the propagation of storm surge and related water-quality signals into and out of estuaries [35].

Contaminant Remobilization

Legacy contaminants may also be mobilised from the sediments of urban estuaries during flooding associated with hurricanes. The authors estimate that the sediment eroded from the San Jacinto Estuary and lower Buffalo Bayou by the flood waters of Hurricane Harvey carried an estimated 16.4 million tons into Galveston Bay from an archive of sediments dating back a century or more, and that slow-moving hurricanes able to cause extreme rainfall will inundate other estuaries overlaid with human habitation in the future, causing to be remobilized similar legacy contaminant loads.

Paleo-Environmental and Habitat/Species Responses

The foraminifera assemblages identified in the shelf sediments off the Mississippi Delta were found to be systematically different between storm (hurricane) deposits, non-hurricane deposits, and a river-flood deposit, with rare marsh taxa and high abundance of coastal-taxa in the storm deposits representing a significant seaward transport of shelf and marsh material by storm events that could be used as a proxy tool to reconstruct storm frequency and provenance in the past [24]. Overall, habitat use on the restored Ship Island, MS, shifted from the previously used Dog Keys Pass to areas north of the restored pass. Critical foraging habitat use in the restored habitat was associated with hurricane-driven degradation of the previously used habitat, demonstrating that barrier-island restoration can reshape, but not eliminate, critical foraging habitat use by this federally threatened species [38]. On the community level, monthly monitoring of two Texas beaches, one with relatively little vehicle traffic and one with continued heavy vehicle traffic, before and after Hurricane Ike, showed that recovery was underway at the former beach in 3 to 9 months, indicating that the storm itself was not the deterrent to recovery, but continued vehicle activity [33].

Socio-ecological Vulnerability

Several studies measured the socio-economic impacts of ecological changes. Barbier and Enchelmeyer showed how to economically value storm-surge protection from Gulf Coast wetlands along a storm track

through southeast Louisiana, including New Orleans [17]. They presented a strong set of evidence to support restoration investments. An observation-based study conducted in parallel on Galveston Island revealed that structures up to approximately 500 ft from the edge of tidal wetlands benefited from reduced flood damage due to Hurricane Ike, but increased damage occurred beyond this distance, highlighting the spatially variable nature of the flood damage reduction benefit provided by tidal wetlands and the importance of how restoration and zoning decisions are targeted [27]. Personal vulnerability to livelihood losses was measured in an analysis of the Gulf recreational for-hire fishing industry, which found that the ability of individual firms to withstand losses was dependent on their vessel size, homeport and business model, and thus that industry-wide resilience will depend on port infrastructure modernisation and functioning insurance markets, not individual firm-level resilience [39]. At the community level, Katrina was seen as a 'predictable outcome' of the failure to address the vulnerability of coastal ecosystems and wetlands, and of 'policy neglect' in the Mississippi Delta for decades. The scale of this vulnerability was compared to that of the Netherlands in 1953, when a community-wide perspective on geoscience led to Katrina being seen as a foreseeable result of decades of coastal erosion, loss of wetlands, and unaddressed policy neglect within the Delta [21]. Citizen-driven "placemaking," a collective process for rebuilding social capital and shared space in a longer-term recovery process, was shown to support residents in managing the extended social disconnection and uncertainty experienced due to displacement, highlighting that socio-ecological vulnerability is a lived social process that remains long after the physical hazard has passed [25].

These findings show that the effectiveness of institutional, economic, and community-level responses also shape socio-ecological vulnerability, and the policy responses identified across the reviewed studies are outlined in Table 2.

Policy Responses and their Effectiveness

Table 2
Summary of policy responses and reported outcomes

S/N	Policy Response	Aim	Reported Outcome / Effectiveness
1.	Wetland economic valuation (Barbier & Enchelmeyer, 2014)	Restoration investment justification via surge-protection value	Provides an evidentiary basis for restoration spending; benefit is track- and site-specific, limiting generalization.
2.	CWA Section 404 wetland permitting (Reja et al., 2017)	Regulate wetland alteration in floodplains after storms	Permitting increased in the floodplain post-Ike; net wetland loss continued, suggesting weak protective effect as implemented.
3.	Property buyout programs (Atoba et al., 2021)	Acquire flood-damaged properties, incorporating ecological criteria	Ecological/proximity criteria added with no significant loss of cost-effectiveness; a replicable model for equity-conscious buyouts.
4.	Barrier-island restoration (Greenheck et al., 2025)	Rebuild degraded barrier-island habitat (Ship Island)	Restored habitat use by a federally threatened species (Gulf sturgeon), though use patterns shifted rather than simply increased.
5.	Watershed/land-use management planning (Ellis et al., 2011)	Use LULC monitoring to guide Mobile Bay Estuary Program planning	Operationalized remote-sensing data into conservation decision-making, but effectiveness in reducing storm exposure not directly measured.
6.	Coastal defense engineering (foredunes/barriers) (Williams, 2018)	Reduce storm surge and overwash reaching infrastructure	Reduces washover sediment reaching marshes by ~ 40%, trading off marsh sediment supply against infrastructure protection.
7.	Citizen-driven placemaking (Matsushita et al., 2024)	Informal, community-led response filling gaps in institutional recovery support	Effective at rebuilding social capital, but represents a substitute for, not a replacement of, institutional recovery policy.
8.	Industry/insurance policy context (Savolainen et al., 2015)	Market-based resilience via insurance and port infrastructure	Resilience concentrated in better-capitalized firms; policy implication is need for improved port facilities and insurance access.
9.	Delta-scale flood defense planning (Törnqvist, 2007)	Comparison to Dutch Delta Plan-style comprehensive coastal defense	Highlights political-will gap in U.S. Gulf Coast planning relative to comprehensive delta protection models.

Some of the integrated studies included in this analysis explored the impacts of formal policy instruments on, and, in some instances, the undermining of, the support base for coastal disaster risk reduction, i.e., ecosystem services. Analysis of permitting activity for the Clean Water Act Section 404 wetlands program following Hurricane Ike along the upper Texas coast showed that the number of permits was higher within the 100-year floodplain in impacted counties compared to control counties. In contrast, the number of palustrine wetlands continued to decline. Existing regulatory permitting

processes have the potential to inadvertently exacerbate wetland loss, thereby increasing future exposure to hurricanes [31]. A multi-criteria spatial framework for selecting properties for post-flood buyout after Hurricane Harvey on the upper Texas coast further revealed that explicitly considering the ecological and proximity criteria in addition to the cost-effectiveness criteria did not significantly diminish the economic efficiency of the buyout program in economic terms, indicating that there was no substantial equity-efficiency trade-off when considering the cost of the buyout program to incorporate ecological values into the process of acquiring properties for disaster recovery [34]. This Land-use and Land-cover Change (LUCC) analysis was carried out as a pilot project of the Gulf of Mexico Alliance (GMA) and was used to help inform watershed management planning by the Mobile Bay National Estuary Program (MBNEP) and to help operationalise remote-sensing-based monitoring of urbanisation and wetland loss directly into coastal management decisions [37]. A species- and habitat-focused restoration policy, such as restoring barrier-island habitat at Ship Island, Mississippi, between 2017 and 2020 due to degradation from hurricanes, has a long-term ecological accountability requirement for post-project monitoring, in this case an acoustic tracking array, that is increasingly required of large-scale engineered restoration projects [38].

DISCUSSION

Summary of main findings

The purpose of this systematic review was to compile 23 studies published from 2007 to 2025 that examined the impacts of hurricanes on coastal ecosystems and their socio-ecological and policy aspects in the northern Gulf of Mexico. Three broad trends have emerged. First, hurricanes have both a destructive and constructive impact on the barrier islands and wetlands of the Gulf coast: storm overwash and sediment deposition during a storm can build marsh elevations to counteract relative sea level rise (RSLR) [26, 20], but the same storms can also erode shorelines, elevate soil salinity for years after the storm, and interact with chronic nutrient enrichment and subsidence to leave some marshes structurally weaker after each subsequent storm [19, 23, 18]. Second, socio-economic dimensions to this ecological change are significant and unevenly distributed: while wetlands can clearly mitigate flood damages and storm-surge risk within certain spatial and configurational limits [17, 27], the industries and communities most vulnerable to healthy coastal ecosystems, ranging from for-hire fishing fleets to historically disinvested urban neighborhoods, are also most exposed to the immediate hazard of the event and to the much longer social process of recovery [39, 25]. Third, policy and governance decisions, from permitting to buyout targeting to barrier-island restoration, are not inherently neutral with respect to ecological outcomes, and can either further exacerbate wetland loss, as in the case of permitting after Ike [31], or include ecological value in recovery decisions at little to no extra cost, as in the case of buyouts relating to Harvey [34].

A holistic socio-ecological vulnerability approach

The conceptual framework (Fig. 2) that emerges from these studies suggests that hurricane forcing influences coastal ecosystems, resulting in ecological impacts (wetland and barrier-island change, altered salinity and biogeochemistry, contaminant remobilization, habitat disruption, etc.) that, in turn,

affect socio-ecological vulnerability (exposure of property, livelihoods, and social networks to residual flood and economic risk) and are in some ways, for better or worse, mediated by policy responses (restoration, permitting, buyouts, placemaking, and governance). Critically, this is not a one-way street: policy responses can also affect future ecological exposure, such as increased wetland loss due to permitting after a storm or increased chronic shoreline erosion due to barrier-island development prior to the next storm [31, 36]. This feedback loop helps illustrate the importance of restoring or protecting ecosystems alongside surrounding socio-ecological factors, including permitting, insurance, and land use, if such restoration efforts are to be successful and sustainable in reducing socio-ecological vulnerability along this coast.

The effectiveness and inequities of the policy

The picture of policy effectiveness is mixed, and it is not all positive. On the other hand, the cost of the buyout in Harvey illustrates that ecological considerations need not result in a significant cost penalty to cost-effectiveness; a rare empirical effort to demonstrate that equity- and ecology-focused redesign of a disaster program need not compromise cost-effectiveness [34]. However, the post-Ike permitting analysis implies that, left unchallenged, the existing regulatory framework passively encourages the loss of those wetlands that are needed to protect future generations, a structural disconnect between the goals of coastal management and the incentives within regular permitting processes. The post-Ike permitting analysis, on the other hand, suggests that if permitting processes are not deliberately reformed, they can passively reinforce the loss of the very wetlands they are supposed to safeguard in the future [31]. Although the inequity of recovery is visible in this literature, it has not yet been quantified. Only one study directly engaged with the lived experience of recovery inequity, describing how citizen-driven placemaking served as a substitute for some institutional support to help displaced New Orleans residents rebuild social connections after Katrina [25]. Only one examined differential resilience within an economic sector, which found that smaller, well-capitalised recreational fishing operations recovered more quickly than others [39]. One important characteristic of the northern Gulf of Mexico's hurricane recovery that is not documented in the 23 studies reviewed is the absence of specific, quantitative analyses of race, income, and/or tenure differences in the outcomes of hurricane recovery efforts. This is an important gap in the ecologically and policy-focused literature that was reviewed by the search strategy used for this report.

Climate change Adaptation implications

From this synthesis, three implications for coastal managers and policymakers are clear. To begin, restoration investments should be driven by the spatial and configurational thresholds at which wetlands offer measurable flood-damage reduction [27], rather than simply by the concept of “more wetland,” regardless of spatial proximity to at-risk structures. Second, relative sea-level rise will be the primary driver of projected future increases in storm surge in Louisiana, so restoration and green infrastructure should complement, and not replace, structural adaptation and managed retreat where appropriate, particularly through ecologically informed buyout programs [34]. Third, regulatory reform of post-storm wetland permitting is a relatively low-cost, high-leverage effort: Regulation of permitting processes,

shown to have the largest influence on continued wetland loss after Hurricane Ike [31], may be most cost effective in protecting future wetland protective capacity than restoration alone after a storm.

CONCLUSION

The impacts of hurricanes on northern Gulf of Mexico coastal ecosystems such as marsh accretion, barrier-island erosion, estuarine biogeochemical disruption and contaminant remobilization, are closely linked to the socio-economic vulnerability of coastal communities and to policy instruments that regulate coastal land, water, and property. To the specific research questions of the review, the following results were found: Hurricane-induced ecological impacts are both constructive (deposition, marsh building) and destructive (erosion, long-term salinization, contaminant release) and both have measurable consequences on socio-economic impacts, though in spatially-varying ways (flood damages, livelihood loss, social displacement); although there are some ecologically-informed examples of buyout design, most of the existing regional policies do not incorporate ecosystem services into Disaster Risk Management (DRM), and routine permitting processes may passively erode future protective capacity; and on multi-decadal time scales, the relative sea-level rise outweighed the benefits of restoration, and there was almost no quantitative consideration in the ecological and policy literature searched of distributional and equity outcomes of recovery. We recommend that coastal management agencies explicitly consider ecological and equity outcomes when making wetland-permitting decisions after a hurricane, as was done during the buyout for Hurricane Harvey, as part of future systematic reviews;) require scientific criteria and ecological and equity indicators as a standard component of future disaster recovery acquisition programs; fund research and monitoring that explicitly links ecological restoration results to science-based assessments of socio-economic and equity impacts so that future systematic reviews can not only determine whether Gulf Coast ecosystems are being restored, but whether they are being restored in a manner that reduces vulnerability to the most exposed community; and consider ecological and equity outcomes as a necessary component of future systematic reviews.

Declarations

Ethical Approval and Accordance Statement: This study was a systematic review and did not include human participants, individual-level data, or biological materials. Ethical approval from an institutional review board or ethics committee was therefore not required.

Consent to Participate:

Not applicable.

Consent to Publish declaration: Not applicable

Clinical trial number

Not applicable

Disclosure statement There are no competing interests to report.

Artificial Intelligence

Generative AI was not used in the research and preparation of this manuscript.

Authors' Contribution

OGI conceptualized the study, developed the methodology, coordinated progress on the project, and ensured alignment with journal guidelines. KO drafted the results section, reviewed and edited the manuscript. PDA drafted the discussion and conclusions sections. KE drafted the abstract, introduction, and validated PRISMA results.

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Author Contribution

OGI conceptualized the study, developed the methodology, coordinated progress on the project, and ensured alignment with journal guidelines. KO drafted the results section, reviewed and edited the manuscript. PDA drafted the discussion and conclusions sections. KE drafted the abstract, introduction, and validated PRISMA results.

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Figures

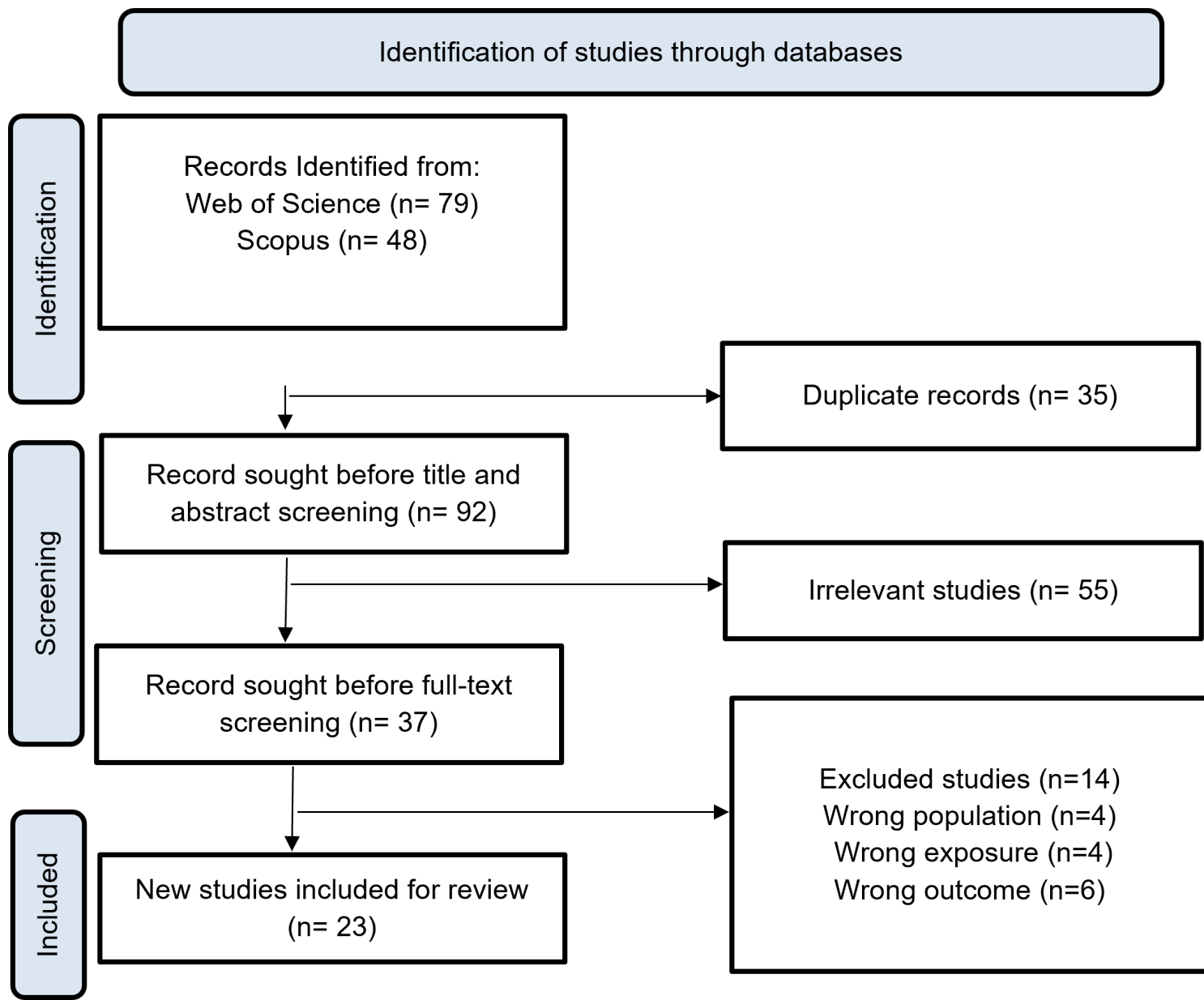


Figure 1

PRISMA Flow diagram of information search for the systematic review

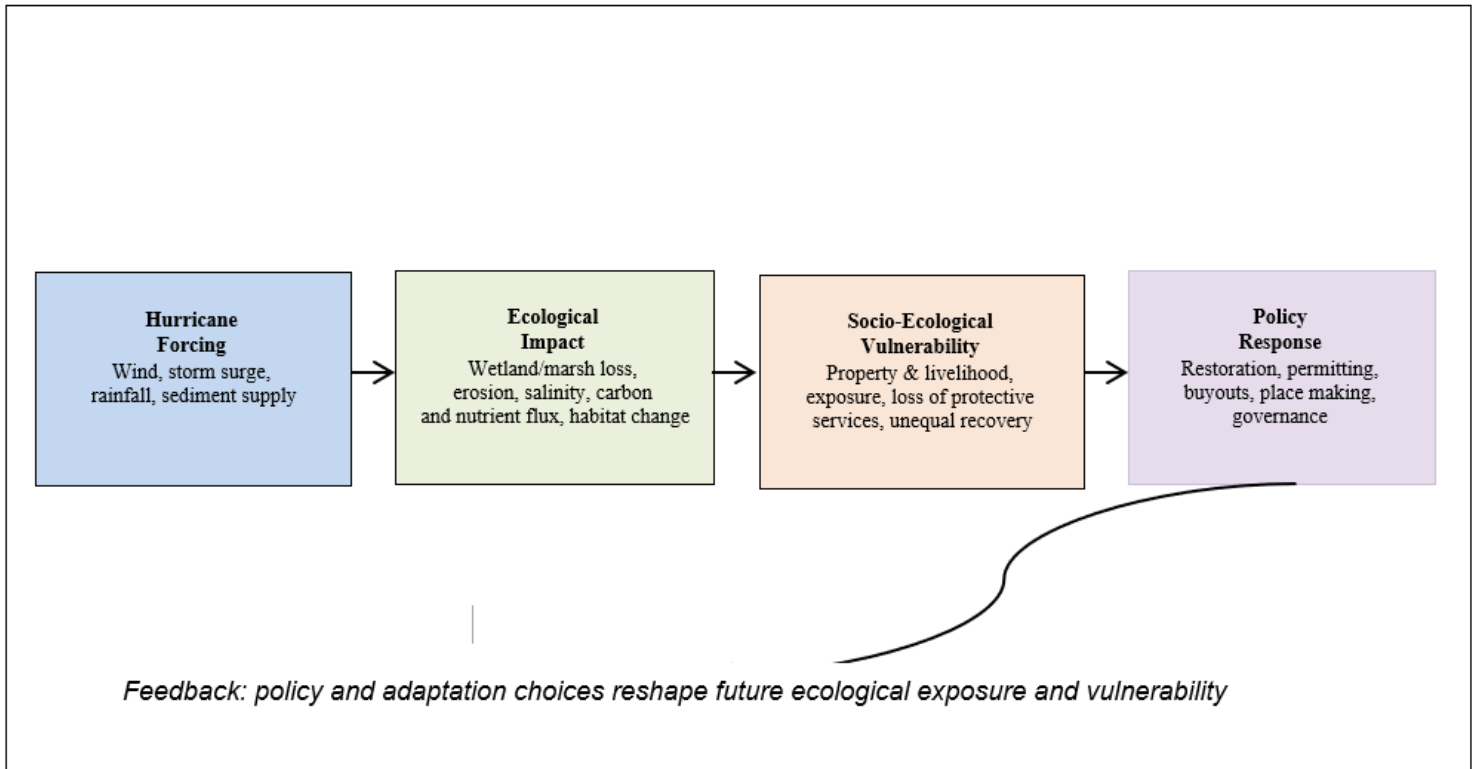


Figure 2

Conceptual framework linking hurricane forcing, ecological impact, socio-ecological vulnerability, and policy response, with feedback from policy to future ecological exposure