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Review and Meta-analyses

Effectiveness of stewardship and management strategies to conserve coastal bird populations in the northern Gulf of Mexico: a literature review

Eficacia de las estrategias de administración y gestión para conservar poblaciones de aves costeras en el norte del Golfo de México: una revisión bibliográfica

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ABSTRACT. Shorebirds, seabirds, and wading birds (hereafter coastal birds) have experienced considerable losses over the last century and require proactive conservation management to stabilize or grow populations. Habitat loss and/or degradation and human disturbance are among the most urgent threats faced by coastal bird populations. Identifying effective conservation management techniques to mitigate these threats is of great interest in the northern Gulf of Mexico (nGoM), a region that provides important habitat during the entire life cycle of resident birds and an essential breeding, wintering, and stopover site for migratory birds. A suite of 35 coastal birds have been identified as priority species for multi-scale conservation monitoring in this region by the Gulf of Mexico Avian Monitoring Network (GoMAMN). This review focuses on impacts of human disturbance and anthropogenic habitat loss and/or degradation on coastal birds and effectiveness of the management strategies implemented to mitigate them, with the goal of informing nGoM management. Our review found that human disturbance was best alleviated by simultaneously deploying complementary stewardship techniques (e.g., signs, fencing, steward patrols, education and community involvement, and beach closures to humans, dogs, and vehicles). However, the relative efficacy of each individual technique is unclear given that only 13% of human disturbance management studies and 38% of habitat management studies have been conducted in the nGoM region. Given the nature of coastal bird habitat and associated risks from sea level rise and human development, most habitat management studies encouraged strategic applications of beach renourishment, limitations on beach raking, as well as site- and species-specific restoration strategies. Studies demonstrated that successful management of coastal birds in the nGoM combined these approaches, employing complementary and adaptive strategies over extended periods.

RESUMEN. Las aves playeras, aves marinas y aves zancudas (en adelante, aves costeras) han sufrido pérdidas considerables durante el último siglo y requieren una gestión proactiva de conservación para estabilizar o hacer crecer las poblaciones. La pérdida y/o degradación del hábitat y la perturbación humana se encuentran entre las amenazas más urgentes que enfrentan las poblaciones de aves costeras. Identificar técnicas eficaces de gestión de la conservación para mitigar estas amenazas es de gran interés en el norte del Golfo de México (nGoM), una región que proporciona un hábitat importante durante todo el ciclo de vida de las aves residentes y un sitio esencial de reproducción, invernada y parada para aves migratorias. Un grupo de 35 aves costeras ha sido identificado como especies prioritarias para el monitoreo de la conservación a múltiples escalas en esta región por la Red de Monitoreo de Aves del Golfo de México (GoMAMN). Esta revisión se enfoca en los impactos de la perturbación humana y la pérdida y/o degradación antropogénica del hábitat sobre las aves costeras y la eficacia de las estrategias de gestión implementadas para mitigarlas, con el fin de informar el manejo en el nGoM. Nuestra revisión concluyó que las perturbaciones humanas se aliviaban mejor mediante la implementación simultánea de técnicas de gestión complementarias (e.g., señales, cercas, patrullas de vigilancia, educación y participación comunitaria, y cierres de playas para humanos, perros y vehículos). Sin embargo, la eficacia relativa de cada técnica individual no es clara dado que solo el 13% de los estudios de gestión de perturbaciones humanas y el 38% de los estudios de gestión del hábitat se han realizado en la región del nGoM. Dada la naturaleza del hábitat de las aves costeras y los riesgos asociados al aumento del nivel del mar y al desarrollo humano, la mayoría de los estudios de manejo del hábitat fomentaron aplicaciones estratégicas de regeneración de playas, limitaciones en el rastrillaje de playas, así como estrategias de restauración específicas para cada sitio y especie. Los estudios demostraron que el manejo exitoso de las aves costeras en el nGoM combinó estos enfoques, utilizando estrategias complementarias y adaptativas durante períodos prolongados.

Key Words: *coastal birds; Gulf of Mexico; habitat management; stewardship*

INTRODUCTION

Among the loss of 2.9 billion North American birds in the last half-century (Rosenberg et al. 2019), coastal birds, defined here as shorebird, seabird, and wading bird species that use beach habitats for part or all of their annual cycle, have experienced pronounced declines. Between 1970 and 2017, 50% of breeding and 68% of non-breeding coastal bird species have declined (Rosenberg et al. 2019), with North American shorebird

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populations declining at an accelerated rate (Smith et al. 2023). Globally, coastal birds are primarily threatened by habitat loss and/or degradation due to drivers including human disturbance, development, predation, collisions with anthropogenic structures and vehicles, and climate change (Rosenberg et al. 2019, Wilson et al. 2019).

The northern Gulf of Mexico (nGoM) provides breeding and foraging coastal habitats for diverse shorebirds, seabirds, and wading birds (Withers 2002, Burger 2018, Wilson et al. 2019). At least 395 bird species use the nGoM during some portion of their annual life cycle, of which 154 (39%) species are coastal birds, including 52 shorebirds, 77 seabirds, and 25 wading birds, and 241 species are terrestrial and wetland birds (Gallardo et al. 2009). The nGoM is a critical breeding region for vulnerable coastal Birds of Conservation Concern such as Black Skimmers (*Rynchops niger*), and Least Terns (*Sternula antillarum*; U.S. Fish and Wildlife Service 2021). Additionally, > 1 million shorebirds and wading birds use the nGoM coastline during migration and the stationary non-breeding season (Withers 2002), which includes the U.S. Endangered Species Act listed Piping Plover (*Charadrius melodus*) and Red Knot (*Calidris canutus*).

Given the nGoM's importance for coastal birds, the Gulf of Mexico Avian Monitoring Network (GoMAMN) was formed following the Deepwater Horizon oil spill. This collaborative organization is composed of scientists and resource managers who developed priority species lists and synthesized threats facing shorebirds, seabirds, and wading birds, among other avian taxa, in the region (Wilson et al. 2019, Fournier et al. 2023). GoMAMN identified human disturbance and habitat loss and/or degradation as the two greatest threats facing nGoM coastal birds, followed by predation and extreme weather events (Burger 2017, Burger 2018, Wilson et al. 2019). Consequently, they recommend effective stewardship, an umbrella term for a suite of management techniques to reduce the impacts of human disturbance, and habitat management, a set of techniques used to mitigate habitat loss and/or degradation, as essential tools for threat reduction within this key coastal region.

Human disturbance affects coastal birds throughout the annual cycle (Mengak and Dayer 2020) and is among the most pervasive and impactful threats in the nGoM (Brush et al. 2019), North America (Rosenberg et al. 2019), and globally (Croxall et al. 2012). With 40% of the U.S. population concentrated along coasts (Crossett et al. 2014), human activity increasingly overlaps with shoreline habitats (Neumann et al. 2015), making coastal birds vulnerable to reduced survival or productivity from human disturbances (e.g., walking, driving, or allowing unleashed dogs near breeding, roosting, or foraging birds; Gibson et al. 2018, Brush et al. 2019). Coastal areas, especially beaches, are intensively used for recreation across the nGoM, attracting millions of tourists and local residents each year (Table 1). This leads to extensive and intensive human disturbance from a wide variety of activities that impact coastal birds, including beach recreation, ecotourism, fishing, and even wildlife monitoring (Wilson et al. 2019, Mengak and Dayer 2020).

Habitat management is essential to conserve coastal birds regionally because the nGoM has experienced extensive shoreline habitat loss and/or degradation due to natural (e.g., erosion, submergence, sediment reduction, severe tropical storms), and human (e.g., coastal development, excavation, transportation, river modification, anthropogenic climate change) activities (Morton 2003, Mendelssohn et al. 2017). For example, Louisiana has lost nearly 4900 square kilometers of coast to erosion since 1932 (Barnes et al. 2015), and the Texas coast is eroding at an average rate of > 1.2 meters annually (Texas General Land Office 2023). Climate change further accelerates habitat loss (e.g., erosion, habitat alteration) through sea level rise and storm surges (Walter et al. 2013, Cope 2016, Von Holle et al. 2019), with sea levels predicted to rise 10–15 cm by 2050 and 0.8–3.9 m by 2150 (Sweet et al. 2022). The nGoM states are also highly developed, with nearly 20% of the U.S. population, over half of the country's petroleum and natural gas processing facilities (National Academies of Sciences, Engineering, and Medicine 2018), and 16% of the nation's armored coastline (Gittman et al. 2015). Undeveloped coastal areas are subject to extensive degradation from human disturbance, non-compatible beach management (e.g., beach raking, allowing dense vegetation growth, dredge and fill), and non-compatible freshwater management (e.g., changes in flowing freshwater, salinity, and plant community), pollutants, and industrial development (Bricker et al. 1999, Defeo et al. 2009, Ward and Tunnell 2017, Wilson et al. 2019).

In order to evaluate progress toward implementation of GoMAMN's priority actions to mitigate threats to coastal birds and identify gaps, we assessed the impacts of human disturbance and habitat loss and/or degradation on nGoM's coastal birds, and discussed the effectiveness of stewardship techniques and habitat management strategies developed to address these threats. Our effort is distinct from previous reviews of coastal bird management (e.g., Defeo et al. 2009, Lamb 2015) in that we take a broad view of multiple concurrent threats, management actions, and guilds to inform multi-species management, as well as focus on the nGoM region. To target species of greatest conservation concern, we focused our review on the 35 priority species identified by GoMAMN (Wilson et al. 2019; Table 2), as well as their congeners. We structure our review by guild, using the same species groupings as GoMAMN: seabirds, shorebirds, and wading birds (Wilson et al. 2019).

METHODS

Focal species and region

We focused on coastal birds of conservation concern in the nGoM because of the importance of this region for North American coastal bird populations (Withers 2002, Gallardo et al. 2009, Burger 2018, Remsen et al. 2019, Wilson et al. 2019). Specifically, we focused on 34 focal species representing a subset of the 10 shorebird (Charadriiformes), 15 seabird (Pelecaniformes, Suliformes, Procellariiformes, and Charadriiformes), and 10 wading bird species (Gruiformes and Ciconiiformes) GoMAMN identified as species of special concern throughout the region (Wilson et al. 2019; Table 2). We excluded pelagic-foraging seabirds that do not use terrestrial coastal habitats because these species face a unique set of threats in the offshore environment. Additionally, because of the limited availability of studies from the nGoM we also included literature on these species or their congeners that occurred outside of the nGoM to inform management of our focal species.

Table 1. Summary of visitation statistics for selected coastal areas across the northern Gulf of Mexico (nGoM).

State	Region	Year	Annual number of visitors	Citation
Alabama	nGoM	2021	8 million	Gulf Shores & Orange Beach Tourism 2022
Florida	Emerald Coast	2021	4.5 million	Florida Department of Environmental Protection 2022
Florida	Fort Myers Beach & Sanibel Island	2019	4.9 million	Downs et al. 2019
Louisiana	Grand Isle	2022	17,000	Louisiana House of Representatives 2023
Mississippi	nGoM	2022	14 million	Snyder 2023
Texas	Corpus Christi	2023	10 million	Meet Corpus Christi 2024
Texas	Galveston	2022	8 million	Visit Galveston 2023

Threats and threat management

Human-related disturbances to coastal birds were defined as activities that disturb normal avian behavior and increase energy expenditure during breeding, roosting, and/or foraging (Mengak and Dayer 2020). We considered habitat loss and/or degradation as anthropogenic or coupled natural and human-driven activities or events that removed or considerably reduced the quality of beach habitats used for breeding, roosting, or foraging, and could be mitigated through habitat management actions. As such we excluded threats such as water quality and oil spills that require non-habitat-based management. Our review consists of separate sections for these threats, each with an overview of threat impacts to shorebirds, seabirds, and wading birds. We then reviewed the suite of known stewardship and habitat management techniques used to address each threat and summarized impacts to multiple guilds concurrently.

Review methods

We located literature through Google Scholar, Wiley Online Library, BioOne, ResearchGate, Silverchair, JSTOR, Gale, and ScienceDirect. Literature searches used keywords containing each threat category and management strategy and coastal bird categories (i.e., "shorebirds," "seabirds," and "wading birds"), as well as all individual priority species (Table 2). Consequently, search terms included phrases such as "shorebird AND stewardship," "seabird AND habitat," and "'wading bird' AND degrad*." Publications were not filtered by geographic region. Lastly, we identified additional studies by reviewing literature cited in these papers.

RESULTS

Our literature search produced a total of 213 studies addressing the impacts of human disturbance and/or habitat loss and degradation on coastal birds (Appendix 1). Of these, over one-third (86, or 40%) assessed impacts of human disturbance and management actions to mitigate it (Table 3), whereas nearly two-thirds (131, or 61%) evaluated habitat loss and/or degradation and the associated management actions (Table 4), and four studies (2%) addressed both threats. The majority (66%) of human disturbance studies and nearly half (42%) of habitat loss and/or degradation studies solely evaluated the impacts of the threats on coastal birds without assessing the effects of management actions.

Shorebirds were the most studied guild, featured in 65% of studies solely focused on human disturbance impacts, 76% of studies focused on associated management actions, 49% of studies solely focused on habitat loss/degradation, and 68% evaluating habitat loss/degradation management. Seabirds were included in 39% of human disturbance impact studies (45% of management assessments) and 45% of habitat loss/degradation studies (41% of management assessments). Wading birds accounted for just 16% of human disturbance impact studies (10% of management assessments) and 25% of habitat loss/degradation studies (11% of management assessments). The nGoM was underrepresented in human disturbance literature, accounting for 21% of studies only focused on impact and 17% of management-related studies (Table 3). However, a larger proportion of habitat loss/degradation-focused studies occurred in the nGoM, where 36% assessed impacts alone and 37% evaluated associated management actions (Table 4).

Piping Plovers and Least Terns were the most frequently studied species, appearing in 17% and 16% of all studies, respectively (Table 5). Among studies evaluating the impacts of management actions to mitigate human disturbance, Piping Plovers (31%) and Least Terns (28%) were also most frequently studied. Human disturbance management impact studies most frequently used reproductive success as a response metric (55%), followed by abundance (38%) and habitat quality (28%). Piping Plovers (24%) and Least Terns (20%) were also most frequently used as focal species in habitat management studies. Habitat quality (57%) was most frequently used as a response metric in habitat management studies, followed by reproductive success (34%) and abundance (28%; Table 5).

Human disturbance impacts on coastal birds

Human disturbance results in lethal (e.g., trampling, nest or chick abandonment) and sublethal impacts (e.g., exposure to predators, reduced foraging), threatening reproductive success and adult survival (Gibson et al. 2018, Brush et al. 2019; Fig. 1). Lethal effects were more common during the breeding season, whereas sublethal effects occur year-round. Both lethal and sublethal impacts pose serious threats to coastal bird survival and productivity, and consequently populations (Fig. 1).

Lethal effects: breeding season

Beach driving, dogs, direct harassment, construction activity, general beachgoing, social events, recreational fishing, watersports, commercial fishing/aquaculture, and drones are considered the most harmful human disturbances for shorebirds (Mengak and Dayer 2020). Yet human disturbance impacts on shorebirds vary greatly by season, type of disturbance, and species. In the breeding season, human trampling and vehicles have direct lethal impacts to eggs, chicks, and breeding adults of coastal birds, including reduced nest success of Piping Plovers (Gaines and Ryan 1988) and Malaysian Plovers (*Anarhynchus peronii*; Yasué and Dearden 2006), and Black Skimmers (e.g.,

Table 2. Shorebird, seabird, and wading bird species of special concern to be prioritized for multi-scale monitoring throughout the northern Gulf of Mexico (nGoM). "Seasonal Presence (nGoM)" refers to the life stage (breeding or non-breeding) in which the species uses the nGoM. These species are of special concern because of threatened, endangered, or declining population status, or having a restricted range (Wilson et al. 2019).

Guild	Common name	Seasonal presence (nGoM)
Shorebirds	American Oystercatcher (*Haematopus palliatus*), Snowy Plover (*Anarhynchus nivosus*)	Year-round
	Wilson's Plover (*A. wilsonia*)	Breeding
	Piping Plover (*Charadrius melodus*), Long-billed Curlew (*Numenius americanus*), Marbled Godwit (*Limosa fedoa*), Red Knot (*Calidris canutus*), Dunlin (*C. alpina*), Buff-breasted Sandpiper (*C. subruficollis*), Western Sandpiper (*C. mauri*)	Non-breeding
Seabirds	Sooty Tern (*Onychoprion fuscatus*), Gull-billed Tern (*Gelochelidon nilotica*), Royal Tern (*Thalasseus maximus*), Sandwich Tern (*T. sandvicensis*), Black Skimmer (*Rynchops niger*), Black-capped Petrel (*Pterodroma hasitata*), Magnificent Frigatebird (*Fregata magnificens*), Brown Pelican (*Pelecanus occidentalis*)	Year-round
	Least Tern (*Sternula antillarum*), Sargasso Shearwater (*Puffinus lherminieri*)	Breeding
	Black Tern (*Chlidonias niger*), Common Loon (*Gavia immer*), Band-rumped Storm-Petrel (*Hydrobates castro*), Masked Booby (*Sula dactylatra*), Northern Gannet (*Morus bassanus*)	Non-breeding
Wading birds	Florida Sandhill Crane (*Antigone canadensis pratensis*), Mississippi Sandhill Crane (*A. canadensis pulla*), Wood Stork (*Mycteria americana*), Great Egret (*Ardea alba*), Little Blue Heron (*Egretta caerulea*), Tricolored Heron (*E. tricolor*), Reddish Egret (*E. rufescens*), White Ibis (*Eudocimus albus*), Roseate Spoonbill (*Platalea ajaja*)	Year-round
	Whooping Crane (*Grus americana*)	Non-breeding

Safina and Burger 1983). Human disturbance also increased chick mortality in Piping Plovers (Flemming et al. 1988, DeRose-Wilson et al. 2018, Stantial et al. 2021), herons (Burger et al. 1995), Sandhill Cranes (*Antigone canadensis*; Dwyer and Tanner 1992), and Wood Storks (*Mycteria americana*; Bouton et al. 2005). Beach vehicles have killed American Oystercatcher chicks (*Haematopus palliatus*; Davis et al. 2001), Snowy Plover chicks (*Anarhynchus nivosus*; Ruhlen et al. 2003), and adult and juvenile Piping Plovers (Melvin et al. 1994). Snowy Plover chick losses were three times greater during high-traffic weekends and holidays than weekdays (Ruhlen et al. 2003), and breeding Snowy Plovers (Pruner 2010) and American Oystercatchers (Virzi 2010) avoided heavily disturbed sites. Human disturbance caused colony failure and/or abandonment in Least Terns (Burger 1984) and Brown Pelicans (*Pelecanus occidentalis*; Anderson and Keith 1980), and caused nest abandonment (Maslo and Lockwood 2009). Research activities (e.g., banding) also increased nest desertion rates (Brubeck et al. 1981), although this was minimized by trapping fewer times per year closer to hatching dates (Nisbet 1981, Hill and Talent 1990).

Sublethal effects: breeding season

Human disturbance also had sublethal effects that were particularly detrimental during the energy-intensive reproductive period (Durkin and Cohen 2021) by increasing vigilance and flushing behaviors (Hill et al. 1997, Rogers et al. 2006, Burger et al. 2010), reducing chick growth in European Storm-petrel (*Hydrobates pelagicus*; Watson et al. 2021), and causing crowding that reduced seabird productivity and survival (Safina and Burger 1983, Eggert 2012). Disturbance reduced adult incubation, feeding, and/or brooding time (Teal 1965, Safina and Burger 1983, Yalden and Yalden 1990), where decreased incubation and chick brooding time increased heat stress and nest failure (Teal 1965, Safina and Burger 1983). Disturbances also decreased chick foraging and brooding times, and increased nest-fleeing, attenuating chick growth rates and/or overall survival (Flemming et al. 1988, Strauss 1990, Goldin and Regosin 1998, DeRose-Wilson et al. 2018, Stantial et al. 2021). Human disturbance also increased rates of self-inflicted egg destruction in gulls (Robert and Ralph 1975) and infanticide in Black Skimmers (Forys et al. 2022) and Heerman's Gulls (*Larus heermanni*; Anderson and Keith 1980). It has been suspected that increased flushing activity may leave nests exposed and vulnerable to higher predation rates (e.g., Ellison and Cleary 1978, Weston and Elgar 2007), though few studies could confirm this. Colonial seabirds and wading birds may adapt to disturbance (Nisbet 2000); for example, Black Skimmers on the Florida Gulf Coast flushed in response to natural disturbances (e.g., weather) more frequently than to human disturbance (Shope 2020), and White-fronted Plover (*Charadrius marginatus*) productivity was greater at disturbed sites, possibly because of reduced natural predators (Baudains and Lloyd 2007). However, chick habituation to human disturbance may increase predation rates via associated threats such as dogs (Baudains and Lloyd 2007). Some species have adapted to persistent human disturbance by using alternate nest sites, e.g., Least Terns nesting on gravel rooftops; however, gravel rooftop materials are increasingly being replaced with plastic, which is lower maintenance but less suitable for nesting (Krogh and Schweitzer 1999, Forys and Borboen-Abrams 2006).

Lethal and sublethal effects: nonbreeding season

Outside of the breeding season, shorebirds were generally less responsive to human disturbance (Yasué 2006, Hamza 2020) and were attracted to forage-related activities such as shell-fishing (Koch and Paton 2014), but human disturbance still reduced body condition and survival (Gibson et al. 2018). Human disturbance also impacted site selection, because migrating shorebirds delayed arrival and departed earlier (Fitzpatrick and Bouchez 1998) or abandoned sites altogether (Burger 1986) in response to human activity, particularly fast-moving activities such as running, biking, and dog-walking (Murchison et al. 2016, Hamza 2020). Shorebirds that remained in disturbed sites experienced negative sublethal effects (Gibson et al. 2018). Non-breeding season responses to existing disturbance or certain activities varied among species and disturbance types. Shorebirds, seabirds, and wading birds alike flushed when boats or jet skis approached from as far away as 46 m (Least Tern) to 156 m (Great Egret, *Ardea alba*; Rodgers and Schwikert 2002). Crested Terns (*Thalasseus*

Table 3. Number of peer-reviewed journal articles or reports related to the threats of human disturbance to focal coastal birds of the northern Gulf of Mexico (Table 2) or their congeners, and the impacts of management actions to mitigate those threats. Studies are categorized by the type of response metric: coastal bird abundance, reproductive success (i.e., productivity, nest success, and/or nesting behavior), and habitat quality (including habitat availability and/or foraging availability). Total number of studies are shown, with the number of those studies from the nGoM in parentheses. Note that some studies covered more than one guild and/or response metric and therefore the row and column sums may exceed the total number of studies shown in the right-most column and bottom row.

Management action	Abundance			Reproductive success			Habitat quality			Total studies
	Shorebirds	Seabirds	Wading birds	Shorebirds	Seabirds	Wading birds	Shorebirds	Seabirds	Wading birds	All guilds
None (threat impact only)	7 (2)	3 (1)	2 (1)	22 (3)	16 (6)	6 (1)	18 (3)	7 (5)	3 (3)	57 (12)
Fencing	3 (1)	3 (1)	0 (0)	6 (1)	6 (2)	2 (0)	2 (0)	1 (0)	1 (0)	14 (4)
Stewards	2 (1)	3 (1)	0 (0)	3 (0)	5 (1)	1 (0)	1 (1)	1 (1)	0 (0)	8 (3)
Signage and public education	5 (1)	5 (1)	0 (0)	4 (0)	4 (1)	1 (0)	2 (1)	1 (1)	0 (0)	15 (3)
Beach closures	6 (1)	2 (1)	0 (0)	6 (0)	3 (0)	1 (0)	5 (0)	0 (0)	0 (0)	12 (1)
Total studies	17 (3)	9 (2)	1 (1)	32 (4)	28 (8)	8 (1)	26 (4)	9 (6)	4 (3)	86 (17)

bergii) responded most strongly to motorized vehicles (Schlacher et al. 2013) whereas American Oystercatchers responded similarly to boating disturbance and predators (Peters and Otis 2005). Chronic disturbances (e.g., vehicles, fishing) also caused variable avoidance behaviors in wading birds; for example, Roseate Spoonbills (*Platalea ajaja*) were more sensitive to vehicles than were Little Blue Herons (*Egretta caerulea*), avoiding roads even with low activity (Klein et al. 1995). However, flushing may be indicative of a bird in good health, because birds at higher starvation risk flushed less frequently and at shorter distances (Stillman and Goss-Custard 2002). Although some foraging wading bird species may also avoid activities such as artisanal fishing resulting in non-lethal effects (Hamza 2020). Thus, although human disturbance had more intense and quantifiable lethal effects on coastal birds during the breeding season, the threat persists year-round.

Stewardship measures to mitigate human disturbance

Human disturbance impacts to coastal birds can be reduced by implementing one or more stewardship activities. Stewardship is an umbrella term that includes the use of signage, fencing, patrols by volunteer and/or professional "stewards" who speak to beachgoers near colonies, education and community involvement, and restrictions to human, vehicle, and dog access through permanent or temporary closures (Medeiros et al. 2007, Hevia and Bala 2018). Many managers use multiple stewardship techniques concurrently because a single action may be insufficient for reducing human disturbance (Hevia and Bala 2018, Darrah 2020, Comber et al. 2021).

Although coastal habitats can be protected (i.e., access restricted) to reduce disturbance, protection alone was often insufficient (Pouwels et al. 2017, Duckworth and Altwegg 2018). Active management, including stewardship techniques, was often necessary to prevent extirpation of birds and other wildlife (Bolam et al. 2021). On the nGoM and Atlantic coasts, populations of four species (Black Skimmer, Least Tern, Brown Pelican, and Piping Plover) grew 2–34 times faster in areas with active stewardship than in protected areas without known efforts to reduce human disturbance (Michel et al. 2021). Here, we review individual and combined stewardship technique effectiveness in mitigating human disturbance.

Fencing

Fencing reduces disturbance by symbolically or physically barring human activities. Fencing reduced flushing behavior in multiple species (Ikuta and Blumstein 2003), increased fledging success in heronries (Carlson and McLean 1996), and improved productivity and initial nesting success in shorebirds (e.g., Piping Plovers; McIntyre et al. 2010). Fencing also reduced predation stimulated by human activity, such as ghost crabs (subfamily Ocypodinae) that prey on Snowy Plover chicks when adults flush from human disturbance and make conspicuous displays (Pruner 2010). Fencing effectiveness varies with disturbance rate and concurrent stewardship strategies. For example, fences improved Black Skimmer hatching and fledging success in areas with daily disturbance, but lowered fledging success with weekly disturbance (Safina and Burger 1983), suggesting that fencing benefits chicks only when disturbance is high. Least Tern nest daily survival rates improved when fencing was paired with signs and steward patrols in the nGoM (Darrah 2020), and populations increased when fencing was paired with habitat manipulation, predator protection, and decoy attraction (Burger 1989). However, Least Terns were still impacted by human disturbance at sites where people continuously walked along the fenceline (Jefferson et al. 2022). Symbolic fencing paired with closures reduced disturbance and restored coastal bird foraging habitat in the Atlantic (Kelly 2014).

Overall, fencing improved reproductive success (e.g., hatching, fledgling, nest daily survival) across all three guilds, and was frequently paired with other stewardship measures (e.g., signage, closures, steward patrols). Additionally, fencing reduced disturbance and potentially human-associated predation in shorebirds, and increased seabird populations when paired with additional management techniques. The positive or ineffective impact of fencing on seabird productivity was measured in the nGoM (Pruner 2010, Darrah 2020, Jefferson et al. 2022), but no other studies quantified productivity in other guilds or abundance in any guild in the region.

Stewards

Volunteer stewards and/or law enforcement near beach nesting bird colonies can discourage disturbance and may improve future visitor behavior through education. Typically, steward patrols are

Table 4. Number of peer-reviewed journal articles or reports related to the threats of habitat loss and/or degradation to focal coastal birds of the northern Gulf of Mexico (Table 2) or their congeners, and the impacts of management actions to mitigate those threats. Studies are categorized by the type of response metric: coastal bird abundance, reproductive success (i.e., productivity, nest success, and/or nesting behavior), and habitat quality (including habitat availability and/or foraging availability). Total number of studies are shown, with the number of those studies from the nGoM in parentheses. Note that some studies covered more than one guild and/or response metric and therefore the row sums may exceed the total number of studies shown in the right-most column and bottom row.

Management action	Abundance			Reproductive success			Habitat quality			Total studies
	Shorebirds	Seabirds	Wading birds	Shorebirds	Seabirds	Wading birds	Shorebirds	Seabirds	Wading birds	All guilds
None (threat impact only)	9 (2)	5 (1)	3 (1)	13 (4)	8 (5)	5 (5)	6 (2)	14 (6)	7 (5)	55 (20)
Vegetation management and wetland creation	8 (2)	5 (1)	1 (1)	6 (1)	3 (0)	0 (0)	2 (1)	4 (2)	0 (0)	18 (5)
Beach nourishment	4 (0)	2 (0)	0 (0)	1 (0)	1 (0)	0 (0)	10 (4)	4 (3)	0 (0)	18 (7)
Dredge spoil island creation	3 (0)	0 (0)	1 (0)	3 (0)	0 (0)	1 (0)	4 (2)	9 (4)	4 (3)	18 (8)
Reducing beach raking	1 (0)	0 (0)	0 (0)	2 (1)	1 (1)	0 (0)	9 (5)	7 (6)	1 (1)	12 (7)
Predation management	6 (0)	0 (0)	1 (1)	13 (1)	2 (2)	0 (0)	0 (0)	0 (0)	0 (0)	16 (3)
Total studies	26 (4)	11 (2)	6 (3)	35 (6)	13 (7)	6 (5)	30 (14)	37 (20)	12 (9)	131 (48)

combined with other stewardship techniques such as signage and/or fencing. Pairing steward patrols with other stewardship techniques has improved tern daily nest survival rates in the nGoM (Darrah 2020) and nest success elsewhere (Medeiros et al. 2007). In herons, this combined approach likely prevented detrimental impacts as a comparatively unpatrolled heronry suffered 15–28% nest losses after a single human disturbance event (Burger et al. 1995). The Australian "Plover Watch" volunteer program combined ranger patrols with signs, fencing, closures, and other educational campaigns and improved reproductive success of Hooded Plovers (*Thinornis cucullatus*; Dowling and Weston 1999). However, major downsides to this approach include the labor-intensive requirements and difficulty obtaining enough resources to maintain a constant, widespread patrol (Dowling and Weston 1999).

Steward patrols improved productivity across all three guilds. However, most steward patrols were paired with other stewardship measures (e.g., signage, fencing, closures), making it difficult to assess the effectiveness of this technique independently. Positive impacts of steward patrols on seabird productivity were measured in the nGoM in one study (Darrah 2020), but did not assess impacts on wading birds.

Signs and public education

Signage near beach-nesting colonies can provide education and a symbolic barrier to visitors (Medeiros et al. 2007). Many programs used signage campaigns to engage the public (e.g., having students create signs) while encouraging beachgoers to avoid disturbing nesting colonies. Examples of these programs include Audubon South Carolina's "Let 'em Rest, Let 'em Nest" program (Audubon South Carolina 2024), Audubon New York's "Be a Good Egg" (Comber and Dayer 2019), and Audubon-led "#ShareTheShore" campaigns (e.g., Audubon New York 2021). Signs may indirectly increase coastal bird population size and productivity via reduced human disturbance, but their effectiveness is variable. Signs are also often used with other stewardship techniques, making their impact difficult to isolate. For example, signage paired with other stewardship efforts increased Atlantic coast Piping Plover, Least Tern, and American Oystercatcher abundance (Hecker 2008, Mass Audubon 2023) and productivity (Mass Audubon 2023), as well as nesting success of Little Terns (*Sternula albifrons*; Medeiros et al. 2007). In the nGoM, Least Tern nest daily survival rates increased with a combination of signs, stewards, and fencing (Darrah 2020).

The effects of signs on human behavior often did not extend beyond where they were physically posted (Comber et al. 2021) and were sometimes insufficient to limit human disturbance (Hevia and Bala 2018). Effectiveness of signage also depends on the match between sign type and audience (Comber et al. 2021). For example, signs that explained potential sanctions were more effective for people with a high sense of social responsibility (Gramann et al. 1995), but these were not always successful (Rimmer et al. 2013). Another study found that signs with narratives were more effective than normative messaging (i.e., signaling social norms) at changing behavior, but visitors still recreated within Snowy Plover habitat (Schoenleber et al. 2022). Additional recommendations to improve messaging and public reception included use of consistent wording, messaging in multiple languages, leveraging social norms, offering alternative pathways if possible, and emphasizing legal consequences if enforced (Comber and Dayer 2019). However, we found few studies of the most effective sign designs and placement, and stewardship efforts could benefit from a more thorough investigation (Ballantyne and Hughes 2006).

Other forms of public education used in stewardship included media coverage, pamphlets, and posters (Burger 1989, Dowling and Weston 1999, Medeiros et al. 2007). These strategies were sometimes combined with outreach campaigns, such as community-based social marketing (CBSM) that uses psychology and marketing to develop campaigns promoting a behavior change (Comber et al. 2021, Comber and Dayer 2024). In more isolated locations where enforcement strategies (e.g., signs, fences, stewards) are ineffective, strategies may include designing education and outreach around mindfulness (Laycock 2023). Education and outreach effectiveness depends on how well it considers messaging, local social environment (e.g., culture, beach use perceptions), and site-specific threats. Human perceptions and behavior were influenced by communication type (e.g., social marketing, signage, community involvement; Hecker 2008,

Table 5. Summary table of the number of studies in which northern Gulf of Mexico focal coastal bird species (n = 34) were shown to be impacted by the threats of human disturbance and habitat loss and degradation and/or management actions to mitigate them. For each focal species the number of studies documenting the species' response to both threats as well as management actions taken to minimize the impact of the threats of human disturbance (FEN = fencing, STE = stewards, SPE = signage and public education, CLO = closure) and habitat loss and degradation (VMW = vegetation management and wetland creation, BN = beach nourishment, DSI = dredge spoil islands, RBR = reducing beach raking, and PM = predation management) are shown. The number of studies that occurred within the nGoM is shown in parentheses. See Table 2 for species' scientific names.

		Human disturbance					Habitat loss and degradation						
Group	Species	Impact only	FEN	STE	SPE	CLO	Impact only	VMW	BN	DSI	RBR	PM	Total
Shorebirds	American Oystercatcher	5 (1)	1 (0)	1 (0)	3 (0)	0 (0)	4 (2)	0 (0)	3 (2)	4 (2)	0 (0)	0 (0)	19 (7)
	Snowy Plover	3 (1)	1 (1)	1 (1)	2 (1)	1 (0)	4 (2)	5 (0)	3 (2)	0 (0)	4 (2)	3 (1)	19 (8)
	Wilson's Plover	0 (0)	0 (0)	0 (0)	2 (0)	0 (0)	5 (2)	1 (1)	4 (1)	0 (0)	1 (1)	1 (1)	13 (5)
	Piping Plover	9 (0)	4 (1)	3 (1)	6 (1)	5 (1)	2 (0)	3 (0)	7 (3)	2 (0)	3 (1)	6 (0)	36 (5)
	Long-billed Curlew	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)
	Marbled Godwit	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Red Knot	6 (0)	0 (0)	0 (0)	0 (0)	2 (0)	0 (0)	0 (0)	2 (1)	0 (0)	1 (1)	0 (0)	11 (2)
	Dunlin	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Buff-breasted Sandpiper	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Western Sandpiper	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	2 (0)
Seabirds	Sooty Tern	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (1)
	Least Tern	5 (4)	5 (3)	5 (3)	6 (3)	2 (1)	8 (3)	1 (0)	4 (2)	5 (1)	3 (3)	3 (2)	34 (17)
	Gull-billed Tern	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0)
	Black Tern	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Royal Tern	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	3 (2)
	Sandwich Tern	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (1)	0 (0)	0 (0)	2 (1)	0 (0)	0 (0)	5 (2)
	Black Skimmer	5 (4)	3 (1)	2 (1)	4 (1)	3 (1)	3 (0)	0 (0)	2 (1)	4 (2)	1 (1)	0 (0)	19 (8)
	Common Loon	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Band-rumped Storm-Petrel	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Black-capped Petrel	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Sargasso Shearwater	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)
	Magnificent Frigatebird	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Masked Booby	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Northern Gannet	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Brown Pelican	4 (3)	1 (1)	1 (1)	3 (1)	1 (1)	1 (0)	2 (2)	1 (0)	1 (1)	0 (0)	0 (0)	12 (7)
Wading birds	Sandhill Crane (Florida, Mississippi)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (2)
	Whooping Crane	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Wood Stork	2 (1)	0 (0)	0 (0)	0 (0)	0 (0)	2 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (2)
	Great Egret	1 (1)	1 (0)	0 (0)	0 (0)	0 (0)	2 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (2)
	Little Blue Heron	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)
	Tricolored Heron	2 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	3 (2)
	Reddish Egret	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	0 (0)	2 (2)	1 (1)	1 (1)	6 (6)
	White Ibis	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	2 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (2)
	Roseate Spoonbill	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	1 (1)	0 (0)	2 (2)	0 (0)	0 (0)	5 (5)

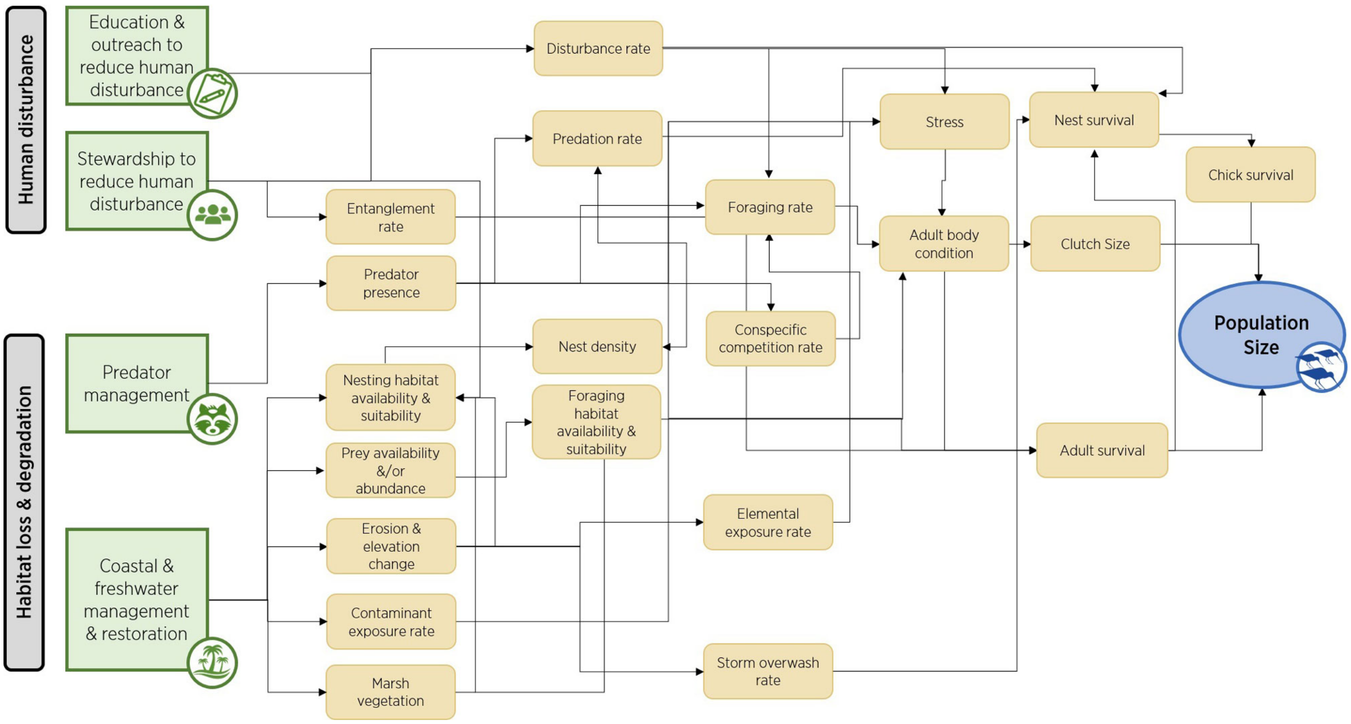
Burger et al. 2021, Comber et al. 2021, Schillerstrom 2021), beachgoer familiarity with the shoreline (Schillerstrom 2021), collaborating interest groups (e.g., birdwatchers, fishermen, recreationists; Burger et al. 2021), demographics (e.g., age, gender; Burger et al. 2021, Burger et al. 2023), and socioeconomics (Corre et al. 2013). On the Atlantic coast, for example, fishermen and recreationists had higher ratings of steward importance than visitors interested in shorebirds and/or crabs (Burger et al. 2021), and those with greater existing familiarity with the beach had more of a positive impact on giving shorebirds space than education-related efforts (Schillerstrom 2021). To incorporate these different perspectives of human behavior and effectively implement education-based changes, several studies encouraged involving a diverse local community representation in education development and stewardship planning, as well as soliciting feedback for improvement over time (Hecker 2008, Corre et al. 2013). Education was also an important contributor to successful coastal bird stewardship programs, because it was included in most multi-stewardship efforts where beach nesting bird populations or productivity improved (Burger 1989, Dowling and Weston 1999, Medeiros et al. 2007, Hecker 2008, Hevia and Bala 2018). However, education and outreach campaigns' isolated impact on bird populations and/or productivity is difficult to ascertain and not completely understood.

Public education, when paired with other stewardship techniques (e.g., fencing, stewards, closures) improved productivity and/or beach nesting populations in shorebirds (Dowling and Weston 1999, Hecker 2008, Hevia and Bala 2018) and seabirds (Burger 1989, Medeiros et al. 2007). Signage was found in one study to improve productivity in wading birds (Burger et al. 1995). Few education-related studies took place in the nGoM, finding improved productivity in Least Terns when signs were combined with stewards providing education and fencing (Darrah 2020).

Beach closures

Permanent and/or temporary beach closures successfully limited major sources of human disturbance in multiple management programs. Reduced human disturbance from closures supported

Fig. 1. Influence diagram showing the relationships between management actions (green boxes) related to human disturbance (top) and habitat loss and/or degradation (bottom), intermediate processes (yellow boxes), and population size for beach-nesting and -foraging coastal birds in the northern Gulf of Mexico.



increased nest density, hatching success, and fledging success of Black Skimmers (Safina and Burger 1983), high fledgling success and increased abundance of Snowy Plovers (Lafferty et al. 2006), and increased multiple shorebird species populations (Comber et al. 2021, Lewis et al. 2022). Restricting off-road vehicle use improved Piping Plover breeding pair abundance, productivity, and habitat (MacIvor 1990; Goldin 1990, *unpublished data*). Vehicle restrictions also significantly increased Piping Plover, American Oystercatcher, and Least Tern abundance when paired with signs, habitat management, and predator exclosures (Hecker 2008). Prevention and/or restricted access of dogs to beaches significantly increased Hooded Plover nesting success relative to beaches with no dog restrictions (Dowling and Weston 1999). Temporary closures of a New Jersey beach to recreationists, largely anglers, joggers, dog walkers, and drivers, allowed Red Knots to spread out across the beach, rather than concentrating in a small relatively undisturbed area (Burger and Niles 2013a).

Local community support for beach closures varied, even when closures were temporary. Although birdwatchers and, in some cases, anglers in New Jersey tended to support and be compliant with temporary closures, joggers and dog walkers were less supportive, occasionally non-compliant, and feared closure expansion (Burger and Niles 2013a, b). Involving diverse collaborators early in the process and understanding and addressing concerns by beach recreationist type increased compliance and, consequently, success of beach closures in protecting birds (Burger and Niles 2013b). Additionally, providing consistent temporary closure status messaging and optimizing closed protected areas for roosting and nesting birds while granting recreationists alternative access helped ensure beach closure success (Burger and Niles 2013b).

Closures (e.g., vehicle restrictions, dog restrictions, temporary closures) also improved shorebird and seabird abundances when paired with signs, habitat management, and predator exclosures. Additionally, closures improved productivity, increased habitat size, reduced disturbance, and restored foraging habitat for shorebirds. Comparatively little is known about the efficacy of closures in protecting wading birds, and no studies were found in nGoM.

Summary of stewardship measures to mitigate human disturbance effects on multiple guilds in the nGoM

When managing human disturbance, a combination of signage, fencing, and stewards may be most effective, with positive impacts on reproductive success across all three guilds, and abundance in at least shorebirds and seabirds. The addition of closures may also improve abundance, reduce disturbance, and restore foraging habitat for shorebirds, but currently less is known for seabirds and wading birds. Within the nGoM specifically, the effects of volunteer stewardship, fencing, and fencing paired with signs and steward patrols positively impacted reproductive success and reduced human-stimulated predation of shorebirds (Pruner 2010, Darrah 2020). However, little is known for wading birds in this region, and we did not identify any nGoM studies that measured impacts of closures on productivity, or of any management practice on abundance of any coastal bird guild.

Habitat loss and degradation impacts on coastal birds

Coastal development impacts

Shoreline habitat loss and degradation from natural and anthropogenic causes, as well as feedback among these drivers, has both displaced coastal birds from breeding and stopover habitat and reduced population and health metrics (e.g., nest success, survival, body condition) of birds that persist (Galbraith et al. 2014, Von Holle et al. 2019, Vitale et al. 2021). Loss and/or degradation of coastal breeding, migratory, and wintering habitat due to development is one of the largest contributors to population declines of Least Terns (Burger 1984, 1989, Zambrano et al. 1997, Devries and Forys 2004) and other shorebirds (Galbraith et al. 2002, 2014, Zöckler et al. 2003, Thomas et al. 2006, Aharon-Rotman et al. 2016, Ruthberg-Campagna 2021), especially on bottleneck migratory routes (Studds et al. 2017). Coastal development also increased foraging effort and overall energy requirements in seabirds (Kavelaars et al. 2020) and consequently threatened populations (Hunter et al. 2006, Jodice et al. 2019). The extent of impact varied among seabird species in response to degree of site fidelity (Mackin 2016) and adaptability (Jodice et al. 2007, Lopes et al. 2015), but obligate beach-nesters (e.g., Laridae) were particularly vulnerable (Hunter et al. 2006).

Even where coastal habitat remains, development increased other threats such as beach erosion, monocultural vegetation, and consequently increased shorebird nest storm surge loss and predation rates (Yasué and Dearden 2006) and exacerbated impacts of erosion and sea level rise on wading birds (Hunter et al. 2006, Wilson et al. 2019, Collins et al. 2021). Many seabirds accepted novel habitats such as dredge-spoil islands (e.g., Guilfoyle et al. 2024) and rooftops (e.g., Devries and Forys 2004), though suitable rooftop availability declined, and future availability is uncertain (Jiménez et al. 2023). Moreover, long-term development-related disturbance suppressed shorebird abundance and richness more than acute events (e.g., red tides and storms; Ruthberg-Campagna 2021).

Beach management impacts

Incompatible anthropogenic beach management also impacted birds on less-developed shorelines. Beach raking or grooming is commonly used to make beaches more aesthetically pleasing and accessible to recreationists (Defeo et al. 2009) and address excessive algal blooms (Lapointe and Bedford 2007). However, raking exacerbated erosion (Williams et al. 2008), and caused lethal (e.g., collisions, running over nests) and sublethal (e.g., flushing, habitat removal, productivity) effects on shorebirds (Schultz Schiro et al. 2017). Beach grooming also significantly decreased prey availability for shorebirds by removing beach wrack and associated invertebrates (Lleywellyn and Shackley 1996, Dugan et al. 2003). Shorebirds especially rely on beach wrack for foraging (Lott et al. 2009), such as Snowy Plovers in California (Dugan et al. 2003), Atlantic and nGoM Piping Plovers (Nordstrom et al. 2000, Darrah et al. 2021), and nGoM Red Knots and Semipalmated Sandpipers (*Calidris pusilla*; Darrah et al. 2021). In Pensacola, Florida, *Sargassum* wrack was used by 11 out of 22 shorebird species for foraging, resting, and hiding (Schultz Schiro et al. 2017). Consequently, beach grooming increased shorebird mortality rates, especially during migration (Goss-Custard et al. 1995)

Vegetation management impacts

Vegetation control that fails to consider habitat preferences of coastal birds and their predators—which varies among bird species (DeRose-Wilson et al. 2013, Page et al. 2023, Zdravkovic et al. 2023), predator identity, and egg crypsis (Lauro and Nol 1995)—often had lethal and sublethal effects on coastal birds. Increased vegetation density was associated with higher nest predation rates in Wilson's (*Anarhynchus wilsonia*), Piping, and Snowy Plovers (Page et al. 1985, Powell and Collier 2000, Murphy et al. 2003, Hood and Dinsmore 2007), higher predation rates on adult and young Least Terns (Burger 1989) and Wood Storks (Rodgers 1987), and reduced habitat quality for Least and Royal Terns (*Thalasseus maximus*; Soots and Parnell 1975, Jackson and Jackson 1985, Emslie et al. 2009). However, dense vegetation also benefited breeding shorebirds and seabirds by providing camouflage from aerial predators (Burger 1987, Saliva and Burger 1989, Corbat 1990), reducing heat stress (Borboroglu and Yorio 2007), and protecting nests from erosion and storms (Burger and Lesser 1978, Burger and Gochfeld 1990, Raynor et al. 2012). Consequently, Brown Pelicans preferred breeding sites with dense vegetation (Walter et al. 2013), and Sandwich (*Thalasseus sandvicensis*) and Common Tern (*Sterna hirundo*) and Black Skimmer productivity increased with vegetation density (Burger and Lesser 1978, Burger and Gochfeld 1990, Raynor et al. 2012). Yet in other studies, vegetation density did not affect shorebird nesting success (Corbat 1990, DeRose-Wilson et al. 2013, Zdravkovic 2013).

Invasive plants introduced for aesthetics or dune management also degraded breeding habitat and reduced shorebird populations (Zarnetske et al. 2010, Dinsmore et al. 2014). Breeding seabirds were also threatened by invasive plant encroachment as well as succession, lack of fire suppression, or conversely vegetative loss (Nesbitt and Hatchitt 2008, Billodeaux et al. 2010). These effects varied depending on habitat characteristics, local predator type, other hazards (e.g., erosion and storm surges), and nesting ecology (Kotliar and Burger 1986, Brinker et al. 2007, Walter et al. 2013, Lamb 2015, Cope 2016).

Impacts of coupled natural and anthropogenic processes

Anthropogenic climate change-driven sea level rise was implicated in loss and/or degradation of coastal bird habitats (Hunter et al. 2006, Reynolds et al. 2015, Jodice et al. 2019, Von Holle et al. 2019). Some coastal birds, including nGoM Snowy Plovers and Atlantic American Oystercatchers, selectively nested in lower areas exposed to frequent storm surges (Convertino et al. 2011, Sterling 2017). Sea level rise, erosion, and habitat loss following storm surges drove Atlantic seabird population declines (Erwin et al. 2011), substantial nesting habitat loss in the nGoM (Walter et al. 2013, Cope 2016), breeding site abandonment (Walter et al. 2013), and increased nest storm surge loss risk, threatening up to 70% of seabird breeding habitat (Von Holle et al. 2019). Habitat losses from sea level rise and erosion were in turn exacerbated by both natural and anthropogenic processes, including existing and expanding coastline development (Hunter et al. 2006, Wilson et al. 2019, Collins et al. 2021), beach driving (Houser et al. 2013), and subsidence (Sweet et al. 2022). Management to mitigate natural processes such as erosion and sea level rise also impacted coastal bird populations. The installation of "hard" structures (e.g., bulkheads, seawalls, shore-perpendicular groin structures, and jetties) to protect erosion-prone beaches displaced and sometimes removed entire intertidal zones used for foraging (Farrell et al. 2016). This led to reduced breeding shorebird diversity (Dugan et al. 2011) and American Oystercatcher abundance in Florida (Hodgson et al. 2008, Farrell et al. 2016) but not Louisiana (Zenzal et al. 2023). Erosion control measures that impacted beach structure and waterflow also reduced wading bird food supply (Ruetz et al. 2005, Herring et al. 2010, Beerens et al. 2015), thus decreasing productivity (Lorenz et al. 2009, Herring et al. 2010).

Predation impacts

Finally, above and beyond the impacts of vegetation on predation rates, reviewed above, human-adapted coastal bird predators (e.g., raccoons [*Procyon lotor*], coyotes [*Canis latrans*], and domestic, semi-feral, and feral cats [*Felis catus*]) are more abundant near settlements (Davis et al. 2001, Cove et al. 2018). Nests and chicks are threatened by other major predators as well including (but not limited to) American Crows (*Corvus brachyrhynchos*; Rimmer and Deblinger 1992, Nesbitt and Badger 1995, Pearson and Colwell 2014), gulls, a variety of mammals, (Rimmer and Deblinger 1992), and ghost crabs (*Ocypode quadrata*; Sabine et al. 2006). Predators may consume eggs, chicks, and adult birds, reducing survival at all life stages (Jenks-Jay 1982, Murphy et al. 2003, Engeman et al. 2010, St Clair et al. 2010, Wilson et al. 2019) and causing nest failure, including of Snowy Plovers (Pearson et al. 2016), Piping Plovers (Patterson et al. 1991) and American Oystercatchers (Davis et al. 2001, Sabine et al. 2006, Jodice et al. 2014). Moreover, mammalian predator presence may increase flushing distances and consequently energetic costs and predation risk of nesting shorebirds, as observed in Two-banded Plovers (*Anarhynchus falklandicus*; St Clair et al. 2010).

Management actions to mitigate habitat loss and/or degradation

Restoration through vegetation management and wetland creation

Coastal bird habitat restoration plans often focused on maintaining a suitable balance of open habitat, vegetation, and wrack materials, especially for shorebirds. Vegetation management effectively maintained or enhanced shorebird and seabird population size and productivity in the nGoM and beyond (Jackson and Jackson 1985, Burger 1989, Samways et al. 2010, Gamblin et al. 2023, Johnston et al. 2023). Reducing beach grass plantings and adding dredged materials also increased Atlantic Piping Plover breeding populations (U.S. Fish and Wildlife Service 1996, Hecker 2008). In the Pacific, Snowy Plover populations increased following invasive beachgrass removal (Zarnetske et al. 2010), as well as vegetation management paired with reduced beach raking (Johnston et al. 2023). Vegetation management in the form of marsh terracing effectively slowed erosion, vegetation loss, and flooding, and increased waterbird density by 3.8 times and richness by 1.4 times in Louisiana (O'Connell and Nyman 2010) and increased availability of habitat and prey in the nGoM (Brusati et al. 2001). Vegetated wetland creation increased populations of all three guilds (O'Connell and Nyman 2010), along with food provisioning for shorebirds and wading birds (Brusati et al. 2001).

Vegetation management effectiveness in the nGoM was influenced by predation rates, flooding, and timing of nest initiation, and was augmented when additional stewardship strategies are used in tandem (Visser et al. 2005, Walter et al. 2013). Vegetation management strategies also need to maintain native species; for example, invasive plant removal increased Snowy Plover nest success and recruitment (Powell and Collier 2000, Dinsmore et al. 2014, Leja 2015) and wildlife diversity and abundance (Russell et al. 2009) outside the nGoM, whereas native vegetation was beneficial for sheltering chicks (Powell and Collier 2000).

Restoration through beach nourishment

Beach nourishment, the application of dredge spoils to extend and elevate beaches, addresses shoreline losses due to sea level and increasing storm intensity and frequency in the nGoM without hardening and exacerbating erosion as seawalls and groins do, maintaining recreational access and providing some ecological benefits (Bush et al. 2004, Peterson and Bishop 2005, Farrell et al. 2016). When used strategically, nourishment increased coastal bird habitat extent by reducing vegetation (Farrell et al. 2016), improving foraging habitat and food provisioning (Smith et al. 2020), and reducing threat of nest loss to storm surges (Lankford et al. 2018). The addition of dredged material in the Atlantic increased Piping Plover abundance (Hecker 2008) and Red Knot prey abundance (e.g., horseshoe crab [*Limulus polyphemus*] eggs) through high coarse grain application (Smith et al. 2020). Increasing beach height benefited species that prefer nesting at higher elevations and move upslope (Zinsser et al. 2017), such as Wilson's Plover in the Atlantic (DeRose-Wilson et al. 2013, Sterling 2017, Zinsser et al. 2017) and Least Terns (Gochfeld 1983, Mazzocchi and Forys 2005), Brown Pelicans (Visser et al. 2005), and Black Skimmers (Owen and Pierce 2013) in the nGoM by reducing erosion and nest storm surge loss, managing over-vegetation, and controlling predation intensity (Owen and Pierce 2013). Renourished beaches were used by breeding and wintering Snowy Plovers and wintering Piping Plovers in southwest Florida (Lott 2009). Least Terns, specifically, were attracted to nGoM sites with added shell material to dredged islands and successfully reproduced (Mallach and Leberg 1999).

However, when applied without consideration of beach-nesting birds, application of dredged materials disturbed foraging and nesting shorebirds including Snowy and Piping Plovers and reduced prey availability (Peterson and Manning 2001, Speybroeck et al. 2006), and if left unmaintained converted to unsuitable upland habitat (Drake et al. 2001). Similarly, nourishment facilitated access for terrestrial coastal bird predators (Guilfoyle et al. 2006, Lankford et al. 2018).

Restoration through dredge spoil habitat creation

New islands and sandbars created by dredge spoil supported all guilds of coastal birds. In Mississippi, numbers of Wilson's Plovers nesting on New Round Island (a dredge spoil island) increased following vegetation regrowth (Gamblin et al. 2023). Similarly, Florida's dredge spoil Barge Canal Islands supported 11% of Florida's population of American Oystercatchers in 2019 (Selman and Davis 2015). Dredge spoil islands in the Atlantic supported larger American Oystercatcher breeding populations than nearby barrier islands because of lower predation and disturbance rates (McGowan et al. 2005, Virzi et al. 2016), and supported wintering Piping Plovers (Cohen et al. 2008). Piping

Plovers also had higher nest success on engineered Missouri River sandbars for the first few years, until nesting density increased and vegetation encroached (Catlin et al. 2015), and created habitat was essential to the species' metapopulation persistence in the region (Catlin et al. 2016). Seabirds also benefited from the habitat created by dredge-spoil islands, including Black Skimmers, Brown Pelicans, and Least, Royal, and Sandwich Terns across the nGoM (Jackson and Jackson 1985, Gore 1991, Owen and Pierce 2013, Hackney et al. 2016) and Atlantic coastlines (Erwin 1977, Burger 1984, Kotliar and Burger 1986, Erwin et al. 2003, 2007). Wading birds including Tricolored (*Egretta tricolor*) and Little Blue Herons, and Reddish *(E. rufescens),* Snowy (*E. thula*), and Western Cattle-Egrets *(Ardea ibis*), and Roseate Spoonbills benefited from dredge spoil islands in the Laguna Madre of Texas (Smith 2002). Reddish Egret conservation plans in Texas call for dredge spoil islands where breeding habitat is limited or of low quality (Krainyk et al. 2020), and 11 species of wading birds in Louisiana use dredge spoil islands or open depositional areas during the breeding season (Guilfoyle et al. 2024).

The benefits of dredge spoil islands may not persist long term without habitat and predation management. Climatic events (e.g., flooding, droughts) and predation rates threatened nest survival of ibis and heron colonies on Atlantic dredge spoil islands without ongoing management, which may result in colony abandonment (Post 1990). Increased erosion rates due to oyster reef declines in the nGoM shrunk both natural and dredge spoil islands, generating ecological traps (Vitale et al. 2021). To preserve dredge-spoil islands for breeding birds facing substantial erosion risk in the nGoM (Hackney et al. 2016), islands' dunes and beaches could be nourished and managed for protective breakwaters, mindful of down-shore erosional shadow (Visser et al. 2005, Walter et al. 2013).

Beach raking

Reducing beach raking and increasing coastline wrack has become an important management tool for increasing shorebird, seabird, and wading bird prey availability in the nGoM (Williams et al. 2008, Lott et al. 2009, Darrah et al. 2021). Cessation of beach grooming restored dune habitat in the Pacific and increased abundance of roosting shorebirds and breeding Snowy Plover (Johnston et al. 2023). In terms of prey availability, increasing the amount of wrack present improved Atlantic Piping Plover fledgling output (McIntyre and Heath 2011), though entirely ceasing beach raking was often infeasible, especially during algal blooms (Lapointe and Bedford 2007). Closing off raking near breeding colonies and setting a 10-day recovery minimum prior to fall migrant arrival reduced food resource losses in Texas (Engelhard and Withers 1997). However, shorebirds, seabirds (e.g., Least Tern, Caspian Tern [*Hydroprogne caspia*]), and wading birds (e.g., Reddish Egret) in the nGoM primarily rely on fresh wrack deposits, such that beach raking targeting old *Sargassum* wrack did not have adverse impacts (Williams et al. 2008). Moreover, moderately cleaned beaches had comparable biodiversity and community structure as natural beaches unlike intensively cleaned shorelines with reduced wildlife abundance (e.g., Baltic Sea; Malm et al. 2004). Finally, signs and stewards successfully improved public perception of beach wrack in the nGoM, reducing aesthetic concerns of tourists and improving habitat for multiple shorebird and seabird species (Feagin et al. 2014, Schultz Schiro et al. 2017).

Predation management

Predation management benefited coastal birds by mitigating the impacts of increased predation pressure on human-developed and -managed coastlines. The Atlantic Flyway Shorebird Initiative (Hunt et al. 2019) found trapping and shooting were effective techniques for decreasing predator abundance/occupancy and increasing shorebird hatching, fledging, adult survival, population size, and recolonization. In the nGoM, predator removal successfully controlled Reddish Egret predators (e.g., feral hogs [*Sus scrofa*] and coyotes) on islands (Wilson et al. 2012). Among nonlethal techniques, predator exclusion and harassment were considered the most successful (Hunt et al. 2019). Overall, proactive management during the early, pre-hatch nesting period was more effective than reactive management (Struthers and Ryan 2005, Cohen et al. 2009), though less is known specifically in the nGoM.

Predation management may interact with other management activities to strengthen or weaken their effects (Hecker 2008). For example, shorebird nest exclosures largely had a positive impact on productivity across many species such as Piping, Wilson's, Snowy Plovers, and other shorebirds (e.g., Isaksson et al. 2007, Smith et al. 2011, Pearson et al. 2016, Hunt et al. 2019, Darrah et al. 2020, Anteau et al. 2022), though some studies found no productivity gains (e.g., Burns et al. 2013). Moreover, in the Atlantic, nest exclosures increased nest abandonment and lowered survival, because local predators learned to take advantage of exclosures targeting chicks and incubating adults (e.g., Niehaus et al. 2004, Isaksson et al. 2007, McIntyre et al. 2010, Burns et al. 2013). Similarly, Least Tern shelters helped chicks avoid extreme heat and aerial predators such as Northern Harriers [*Circus hudsonius*] in the Atlantic (Jenks-Jay 1982) but also attracted unwanted vandalism and human disturbance to nests (Maguire et al. 2011). Many predation management strategies exist (e.g., removal, exclusion, habitat management, nest exclosures, chick shelters) and chosen implementation considerations include local characteristics such as the target species, predator type(s), habitat, and ecology.

Summary of management actions to mitigate habitat loss and/or degradation effects on multiple guilds in the nGoM

Across the nGoM and beyond, habitat loss and degradation were most frequently and effectively managed using vegetation management, beach nourishment, and reduced beach raking to maintain wrack. Habitat creation through dredge spoil islands and wetland restoration either improved or were critical in supporting healthy populations across all three guilds, whereas beach nourishment and reducing beach raking benefited populations, productivity, and/or habitat in shorebirds, seabirds, and wading birds. Habitat loss and degradation mitigation practices were reported as most effective when managers assessed species- and site-specific factors such as coastal bird habitat requirements and preferences, impact on predator and prey communities, interaction with human disturbance, and public perceptions.

However, information surrounding the impacts of habitat management practices on coastal birds in the nGoM was often limited. We found no studies documenting beach nourishment benefits for wading birds in the nGoM or beyond, nor studies assessing impacts of nourishment or dredge spoil islands on coastal bird abundance or productivity. In the nGoM, the positive impacts of vegetation management on abundance and productivity were measured for shorebirds, but not for seabirds or wading birds, though the impact of wetland creation on abundance and creating important habitat was measured across all three guilds. Predation management impacts were also evaluated for all three guilds, though most studies, particularly on the impacts of nest exclosures, whose effects varied regionally, were from outside the nGoM. We also found no studies evaluating impacts of raking management on coastal bird abundance or productivity in the nGoM. Overall, most studies evaluating the impacts of habitat restoration focused on the breeding season.

CONCLUSIONS

Although coastal bird populations face many threats across the nGoM and beyond, human disturbance and habitat loss and/or degradation both have among the largest negative impacts and are feasible to address through on-the-ground management. Effective, scientifically based threat mitigation supports nGoM resident and migratory bird species that rely on the remaining coastal habitat in the region. Here, we reviewed the literature on management effectiveness to mitigate these threats with an eye toward identifying research gaps and informing multi-guild management across the nGoM. We acknowledge the likely publication bias toward studies with positive results as opposed to neutral or negative outcomes, though negative and neutral outcomes were reported. Yet we found that although stewardship (e.g., fencing, patrols, education) and habitat management techniques have demonstrably improved coastal bird abundance, productivity, and/or habitat in the nGoM and elsewhere, considerable research gaps exist.

Notably, few studies have measured abundance or productivity responses to stewardship actions that reduce human disturbance for any of the three coastal bird guilds (shorebirds, seabirds, and wading birds). Although rarely assessed robustly, all five broad stewardship techniques aimed at reducing human disturbance (i.e., signage, fencing, stewards, education, closures) contributed to improved productivity, population size, or both across all three guilds because the majority of studies evaluating stewardship impacts (76%) focused on a single guild (shorebirds), and only 17% of the studies of human disturbance management efficacy were conducted in the nGoM. Considerable gaps remain in terms of stewardship impacts on abundance, impacts on productivity for other focal species in the nGoM (especially wading birds), and studies measuring the impact of beach closures.

Similarly, the three primary habitat management techniques (i.e., vegetation management and wetland creation, beach nourishment and dredge-spoil island creation, and reduced or managed beach raking) benefited all three coastal bird guilds when implemented appropriately. Vegetation management effectiveness depended on local forces (e.g., predation, flooding, species requirements, nest timing) and required on-going maintenance such as vegetation removal to sustain long-term positive impacts, whereas beach nourishment depended on whether its application disturbed birds, reduced prey abundance, or increased predator access. This line of research was better represented in the nGoM compared to stewardship (37% of the total studies) and all three guilds were more evenly represented, though there were still fewer studies on wading birds (11%) than shorebirds (68%) or seabirds (41%).

There is no one-size-fits-all approach to address human disturbance and habitat loss across multiple guilds. Although most studies documenting beneficial impacts of threat mitigation focused on shorebirds, in most cases these best management and stewardship practices can also be applied across guilds if local factors (e.g., species-specific habitat preferences, local stressors, types of human disturbance) are accounted for (e.g., Burger et al. 1995, 2021). Our review found that the most effective management plans for increasing population sizes and productivity of coastal birds have used a suite of simultaneous stewardship efforts across large regions (e.g., Burger 1989, Dowling and Weston 1999, Cohen et al. 2009, McIntyre et al. 2010, Catlin et al. 2015, Darrah 2020). Furthermore, our review found that management actions were more effective when applied over long periods of time and paired with monitoring in an adaptive management framework to maintain positive impacts and respond to environmental changes (e.g., Burger 1989, Russell et al. 2009, Engeman et al. 2010, Leja 2015). Implementing these strategies requires substantial investment and could be supported by expanding existing volunteer stewardship programs similar to those run by conservation groups and state organizations across the nGoM. Ultimately, strategically employing simultaneous complementary techniques that take into account site and species-specific characteristics described in this review may effectively recover coastal bird populations along the nGoM and beyond.

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Data Availability:

Data/code sharing is not applicable to this article because no data/code were analyzed in this study.

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Appendix 1. Summary table of all reference studies (n = 214) evaluating the response of focal or non-focal species to human disturbance and habitat loss and/or degradation. The study location, whether nGoM focal species were impacted, whether the study was only focused on the impact of human disturbance and habitat loss and/or degradation ("Impact Only"), or evaluated management strategies, bird response to threat and directionality if applicable (Positive, Negative, or Neutral), bird group affected and whether they are focal or non-focal (F = Focal, NF = Non-focal), focal species, and other species impacted if reported are included for each citation. Primary human disturbance management categories include fencing, stewards, closures, and signage, public education (grouped). Primary habitat loss and/or degradation management categories include beach nourishment, dredge spoil islands, reduced beach raking, predation management, and vegetation management, wetland creation (grouped). Response categories include abundance, reproductive success, and habitat quality. Bird groups follow GoMAMN guild categories: shorebirds, seabirds, and wading birds.

Citation	Study Location	nGoM Focal Species Impacted	Human Disturbance	Habitat Loss and Degradation	Bird Response to Threat	Bird Group Affected (F = Focal, NF = Non-focal)	Focal Species Impacted	Other Species Impacted
Aharon-Rotman et al. 2016	Australia			Impact Only	Habitat Quality (Positive)	Shorebirds (NF)		Ruddy Turnstone
Anderson and Keith 1980	Baja	Yes	Impact Only		Reproductive Success	Seabirds (F)	Brown Pelican	

Anteau et al. 2022	Great Plains	Yes		Predation Management	Reproductive Success (Positive)	Shorebirds (F)	Piping Plover
Baudains and Lloyd 2007	South Africa		Impact Only		Reproductive Success	Shorebirds (NF)	
Beerens et al. 2015	Everglades	Yes		Impact Only	Habitat Quality (Positive)	Wading Birds (F)	Great Egret, White Ibis, Wood Stork
Billodeaux et al. 2010	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Wading Birds (F)	Sandhill Crane
Bolam et al. 2021	Global		Impact Only		Abundance	Shorebirds (NF), Seabirds (NF), Wading Birds (NF)	
Borboroglu and Yorio 2007	South America			Impact Only	Habitat Quality (Positive)	Seabirds (NF)	
Bouton et al. 2005	Brazil	Yes	Impact Only		Reproductive Success	Wading Birds (F)	Wood Stork

Brinker et al. 2007	Atlantic	Yes		Impact Only	Reproductive Success (Positive)	Seabirds (F, NF)	Black Skimmer, Brown Pelican, GullNegativebilled Tern, Least Tern, Royal Tern, Sandwich Tern	
Brubeck et al. 1981	nGoM	Yes	Impact Only		Reproductive Success	Seabirds (F)	Least Tern	
Brusati et al. 2001	nGoM	Yes		Vegetation Management or Wetland Creation	Habitat Quality (Positive)	Shorebirds (F, NF)	LongNegativebilled Curlew	
Brush et al. 2019	nGoM	Yes	Impact Only		Abundance, Reproductive Success, Habitat Quality	Shorebirds (F, NF)	Shorebirds (collectively)	Shorebirds (collectively)
Burger 1984	Atlantic	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Seabirds (F)	Least Tern	
Burger 1986	Atlantic	Yes	Impact Only		Habitat Quality	Shorebirds (F, NF)	Shorebirds (collectively)	Shorebirds (collectively)
Burger 1987	Atlantic	Yes		Impact Only	Abundance (Positive)	Shorebirds (F)	Piping Plover	

Burger 1989	Atlantic	Yes	Fencing, Stewards	Vegetation Management or Wetland Creation	Abundance (Positive), Reproductive Success (Positive)	Seabirds (F)	Least Tern	
Burger and Gochfeld 1990	Range wide	Yes		Impact Only	Reproductive Success (Positive)	Seabirds (F)	Black Skimmer	
Burger and Lesser 1978	Atlantic			Impact Only	Reproductive Success (Positive)	Seabirds (NF)		Common Tern
Burger and Niles 2013a	Atlantic	Yes	Closures		Habitat Quality (Positive)	Shorebirds (F)	Red Knot	
Burger and Niles 2013b	Atlantic	Yes	Closures		Habitat Quality (Positive)	Shorebirds (F)	Red Knot	

Burger et al. 1995	Atlantic	Yes	Fencing, Stewards, Signage, Public Education, Closures		Reproductive Success (Positive)	Shorebirds (F, NF), Seabirds (F, NF), Wading Birds (F, NF)	Black Skimmer, Least Tern, Piping Plover, egrets (collectively), herons (collectively), ibises (collectively), shorebirds (collectively), terns (collectively)	Egrets (collectively), herons (collectively), ibises (collectively), shorebirds (collectively), terns (collectively)
Burger et al. 2010	Atlantic	Yes	Impact Only		Reproductive Success	Seabirds (F)	Black Skimmer	
Burger et al. 2021	Atlantic	Yes	Impact Only		Abundance	Shorebirds (F)	Red Knot	
Burger et al. 2023	Atlantic	Yes	Impact Only		Habitat Quality	Shorebirds (F)	Red Knot	
Burns et al. 2013	Atlantic			Predation Management	Abundance (Positive), Reproductive Success (Positive)	Shorebirds (NF)		

Carlson and McLean 1996	Midwest		Fencing		Reproductive Success (Positive)	Wading Birds (NF)		Great Blue Heron
Catlin et al. 2015	Inland	Yes		Dredge Spoil Islands	Abundance (Positive), Reproductive Success (Positive), Habitat Quality (Positive)	Shorebirds (F)	Piping Plover	
Catlin et al. 2016	Inland	Yes		Dredge Spoil Islands	Abundance (Positive), Reproductive Success (Positive), Habitat Quality (Positive)	Shorebirds (F)	Piping Plover	
Cohen et al. 2008	Atlantic	Yes		Beach Nourishment	Habitat Quality (Positive)	Shorebirds (F)	Piping Plover	
Cohen et al. 2009	Atlantic	Yes		Predation Management	Reproductive Success (Positive)	Shorebirds (F)	Piping Plover	
Collins et al. 2021	nGoM	Yes		Impact Only	Habitat Quality (Positive)	Wading Birds (F)	Reddish Egret	

Comber and Dayer 2019	Atlantic	Yes	Signage, Public Education		Abundance (Positive)	Shorebirds (F), Seabirds (F)	American Oystercatcher, Black Skimmer, Brown Pelican, Least Tern, Piping Plover, Wilson’s Plover
Comber and Dayer 2024	Atlantic	Yes	Signage, Public Education			Shorebirds (F, NF)	Shorebirds (collectively)
Comber et al. 2021	Atlantic	Yes	Signage, Public Education		Abundance (Positive)	Shorebirds (F), Seabirds (F)	American Oystercatcher, Black Skimmer, Brown Pelican, Least Tern, Piping Plover, Wilson’s Plover
Convertino et al. 2011	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F)	Snowy Plover
Cope 2016	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Seabirds (F)	Sooty Tern

Corbat 1990	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F), Seabirds (F)	American Oystercatcher, Least Tern, Wilson's Plover
Corre et al. 2013	France		Signage, Public Education				
Croxall et al. 2012	Global		Impact Only		Abundance, Reproductive Success, Habitat Quality	Seabirds (NF)	
Darrah 2020	nGoM	Yes	Fencing, Stewards, Signage, Public Education		Reproductive Success (Positive)	Seabirds (F)	Least Tern
Darrah et al. 2021	nGoM	Yes		Reducing Beach Raking	Habitat Quality (Positive)	Shorebirds (F, NF), Seabirds (F, NF)	Piping Plover, Red Knot, seabirds (collectively), shorebirds (collectively)
Davis et al. 2001	Atlantic	Yes	Impact Only		Reproductive Success	Shorebirds (F)	American Oystercatcher

Defeo et al. 2009	Global			Impact Only	Habitat Quality (Positive)	Shorebirds (NF), Seabirds (NF), Wading Birds (NF)		
DeRose-Wilson et al. 2013	Atlantic	Yes		Beach Nourishment	Habitat Quality (Positive)	Shorebirds (F)	Wilson's Plover	
DeRose-Wilson et al. 2018	Atlantic	Yes	Impact Only		Reproductive Success	Shorebirds (F)	Piping Plover	
Devries and Forys 2004	nGoM	Yes		Impact Only	Habitat Quality (Positive)	Seabirds (F)	Least Tern	
Dinsmore et al. 2014	Oregon	Yes		Vegetation Management or Wetland Creation	Reproductive Success (Positive)	Shorebirds (F)	Western Snowy Plover	
Dowling and Weston 1999	Australia		Fencing, Stewards, Signage, Public Education, Closures		Reproductive Success (Positive)	Shorebirds (NF)		Hooded Plover
Drake et al. 2001	nGoM	Yes		Beach Nourishment	Habitat Quality (Positive)	Shorebirds (F)	Piping Plover	

Dugan et al. 2003	California	Yes		Reducing Beach Raking	Habitat Quality (Positive)	Shorebirds (F)	Western Snowy Plover	Black-bellied Plover	Negative
Dugan et al. 2011	Global			Impact Only	Abundance (Positive)	Shorebirds (NF)			
Durkin and Cohen 2021	nGoM	Yes	Impact Only		Reproductive Success	Shorebirds (F)	Snowy Plover		
Dwyer and Tanner 1992	Atlantic	Yes	Impact Only		Reproductive Success	Wading Birds (F)	Florida Sandhill Crane		
Eggert 2012	nGoM, Atlantic	Yes	Impact Only		Reproductive Success	Seabirds (F)	Black Skimmer, Brown Pelican		
Ellison and Cleary 1978	Atlantic		Impact Only		Reproductive Success	Seabirds (NF)		Double-crested Cormorant	Negative
Emslie et al. 2009	Atlantic	Yes		Impact Only	Habitat Quality (Positive)	Seabirds (F)	Least Tern, Royal Tern		
Engelhard and Withers 1997	nGoM			Reducing Beach Raking	Habitat Quality (Positive)	Shorebirds (NF), Seabirds (NF)			
Engeman et al. 2010	nGoM	Yes		Reducing Beach Raking, Predation Management	Reproductive Success (Positive)	Shorebirds (F), Seabirds (F)	Least Tern, Snowy Plover, Wilson's Plover		

Erwin 1977	Atlantic	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Seabirds (F)	Black Skimmer
Erwin et al. 2003	Atlantic	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Seabirds (F)	Black Skimmer, Least Tern, Royal Tern, Sandwich Tern
Erwin et al. 2007	Atlantic	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Seabirds (F), Wading Birds (NF)	Least Tern
Erwin et al. 2011	Atlantic	Yes		Impact Only	Abundance (Positive)	Seabirds (F), Wading Birds (F, NF)	Black Skimmer, Least Tern, egrets (collectively), herons (collectively)
Farrell et al. 2016	nGoM	Yes		Beach Nourishment	Habitat Quality (Positive)	Shorebirds (F)	American Oystercatcher
Feagin et al. 2014	nGoM			Reducing Beach Raking	Habitat Quality (Positive)	Shorebirds (NF), Seabirds (NF)	
Fitzpatrick and Bouchez 1998	Europe		Impact Only		Habitat Quality	Shorebirds (NF)	

Flemming et al. 1988	Atlantic	Yes	Impact Only		Reproductive Success	Shorebirds (F)	Piping Plover
Florida Shorebird Alliance 2012	nGoM	Yes		Reducing Beach Raking	Habitat Quality (Positive)	Seabirds (F)	Black Skimmer
Forys and Borboen-Abrams 2006	nGoM	Yes	Impact Only		Habitat Quality	Seabirds (F)	Least Tern
Forys et al. 2022	nGoM	Yes	Impact Only		Reproductive Success	Seabirds (F)	Black Skimmer
Gaines and Ryan 1988	North Dakota	Yes	Impact Only		Reproductive Success	Shorebirds (F)	Piping Plover
Galbraith et al. 2002	Pacific, Atlantic	Yes		Impact Only	Abundance (Positive)	Shorebirds (F, NF)	Shorebirds (collectively)
Galbraith et al. 2014	North America	Yes		Impact Only	Abundance (Positive)	Shorebirds (F, NF)	Shorebirds (collectively)
Gamblin et al. 2022	nGoM	Yes		Vegetation Management or Wetland Creation	Abundance (Positive), Reproductive Success (Positive)	Shorebirds (F)	Wilson’s Plover

Gibson et al. 2018	Atlantic	Yes	Impact Only		Abundance, Reproductive Success, Habitat Quality	Shorebirds (F)	Piping Plover
Gochfeld 1983	Atlantic	Yes		Beach Nourishment	Habitat Quality (Positive)	Seabirds (F)	Least Tern
Goldin 1990	Atlantic	Yes	Closures		Abundance (Positive), Reproductive Success (Positive), Habitat Quality (Positive)	Shorebirds (F)	Piping Plover
Goldin and Regosin 1998	Atlantic	Yes	Impact Only		Reproductive Success, Habitat Quality	Shorebirds (F)	Piping Plover
Gore 1991	nGoM	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Seabirds (F)	Black Skimmer
Goss-Custard et al. 1995	Europe			Impact Only	Abundance (Positive)	Shorebirds (NF)	

Guilfoyle et al. 2006	Atlantic	Yes		Beach Nourishment	Abundance (Negative)	Shorebirds (F), Seabirds (F)	American Oystercatcher, Black Skimmer, Brown Pelican, Least Tern, Piping Plover, Snowy Plover, Wilson's Plover	
Guilfoyle et al. 2024	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F, NF), Seabirds (F, NF), Wading Birds (F, NF)	Seabirds (collectively), shorebirds (collectively), wading birds (collectively)	Seabirds (collectively), shorebirds (collectively), wading birds (collectively)
Hackney et al. 2016	nGoM	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Seabirds (F, NF), Wading Birds (F, NF)	Brown Pelican, Roseate Spoonbill, Royal Tern, Sandwich Tern	Forster's Tern, Laughing Gull, Snowy Egret
Hamza 2020	Europe		Impact Only		Habitat Quality	Shorebirds (NF)		

Hecker 2008	Atlantic	Yes	Signage, Public Education, Closures	Vegetation Management or Wetland Creation, Beach Nourishment	Abundance (Positive), Reproductive Success (Positive)	Shorebirds (F), Seabirds (F)	Piping Plover		
Herring et al. 2010	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Wading Birds (F)	Great Egret, White Ibis		
Hevia and Bala 2018	Patagonia		Fencing, Signage, Public Education		Reproductive Success (Neutral)	Shorebirds (NF)		Two banded Plover	Negative
Hill and Talent 1990	Inland	Yes	Impact Only		Reproductive Success	Shorebirds (F), Seabirds (F)	Least Tern, Snowy Plover		
Hill et al. 1997	United Kingdom		Impact Only		Reproductive Success	Shorebirds (NF), Seabirds (NF), Wading Birds (NF)			
Hodgson et al. 2008	nGoM	Yes		Impact Only	Abundance (Positive)	Shorebirds (F)	American Oystercatcher		
Hood and Dinsmore 2007	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F)	Snowy Plover, Wilson's Plover		

Hunt et al. 2019	Atlantic	Yes		Predation Management	Reproductive Success (Positive)	Shorebirds (F)	Piping Plover, Snowy Plover	
Hunter et al. 2006	nGoM, Atlantic	Yes		Impact Only	Habitat Quality (Positive)	Shorebirds (F, NF), Seabirds (F, NF), Wading Birds (F, NF)	Seabirds (collectively), shorebirds (collectively), wading birds (collectively)	Seabirds (collectively), shorebirds (collectively), wading birds (collectively)
Ikuta and Blumstein 2003	California	Yes	Fencing		Habitat Quality (Positive)	Shorebirds (F, NF), Seabirds (NF), Wading Birds (F, NF)	Great Egret, Western Sandpiper	BlackNegativebellied Plover, BlackNegativenecked Stilt, Great Blue Heron, Greater Yellowlegs, Least Sandpiper, RingNegativebilled Gull, Snowy Egret, Willet

Isaksson et al. 2007	Europe			Predation Management	Abundance (Positive), Reproductive Success (Positive)	Shorebirds (NF)	
Jackson and Jackson 1985	nGoM	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Seabirds (F)	Least Tern
Jefferson et al. 2022	nGoM	Yes	Fencing		Reproductive Success (Neutral)	Seabirds (F)	Least Tern
Jenks-Jay 1982	Atlantic	Yes		Predation Management	Reproductive Success (Positive)	Shorebirds (F)	Least Tern
Jiménez et al. 2023	nGoM	Yes		Impact Only	Habitat Quality (Positive)	Seabirds (F)	Least Tern
Jodice et al. 2007	Atlantic	Yes		Impact Only	Abundance (Positive)	Seabirds (F, NF)	Seabirds (collectively)
Jodice et al. 2014	Atlantic	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F)	American Oystercatcher

Jodice et al. 2019	nGoM	Yes		Impact Only	Abundance (Positive), Reproductive Success (Positive), Habitat Quality (Positive)	Seabirds (F, NF)	Seabirds (collectively)
Johnston et al. 2023	Pacific	Yes		Vegetation Management or Wetland Creation, Reducing Beach Raking	Abundance (Positive), Habitat Quality (Positive)	Shore birds (F)	Snowy Plover
Kavelaars et al. 2020	Netherlands			Impact Only	Habitat Quality (Positive)	Seabirds (NF)	
Kelly 2014	Atlantic	Yes	Fencing, Closures		Habitat Quality (Positive)	Shore birds (F, NF)	Shorebirds (collectively)
Klein et al. 1995	nGoM	Yes	Impact Only		Habitat Quality	Seabirds (F), Wading Birds (F, NF)	Brown Pelican, egrets (collectively), herons (collectively)
Koch and Paton 2014	Atlantic	Yes	Impact Only		Habitat Quality	Shore birds (F)	American Oystercatcher, Red Knot

Kotliar and Burger 1986	Atlantic	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Seabirds (F)	Least Tern	
Krainyk et al. 2020	nGoM	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Wading Birds (F)	Reddish Egret	
Krogh and Schweitzer 1999	nGoM	Yes	Impact Only		Reproductive Success	Seabirds (F)	Least Tern	
Lafferty et al.2006	Pacific	Yes	Closures		Abundance (Positive), Reproductive Success (Positive)	Shorebirds (F)	Snowy Plover	
Lamb 2015	North Atlantic	Yes		Vegetation Management or Wetland Creation	Habitat Quality (Positive)	Seabirds (F, NF)	Terns (collectively)	Terns (collectively)
Lankford et al. 2018	nGoM	Yes		Predation Management	Reproductive Success (Positive)	Seabirds (F)	Least Tern	
Lauro and Nol 1995	Australia			Impact Only	Reproductive Success (Positive)	Shorebirds (NF)		
Laycock 2023	nGoM	Yes	Impact Only		Habitat Quality	Seabirds (F)	Black Skimmer	

Leja 2015	California	Yes		Vegetation Management or Wetland Creation	Reproductive Success (Positive)	Shorebirds (F)	Western Snowy Plover	
Lewis et al. 2022	South Africa		Closures		Abundance (Positive)	Shorebirds (NF)		Shorebirds (collectively)
Lleywellyn and Shackley 1996	United Kingdom			Impact Only	Habitat Quality (Positive)	Shorebirds (NF)		
Lopes et al. 2015	Portugal			Impact Only	Habitat Quality (Positive)	Seabirds (NF)		
Lorenz et al. 2009	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Wading Birds (F)	Roseate Spoonbill	
Lott 2009	nGoM	Yes		Beach Nourishment	Habitat Quality (Positive)	Shorebirds (F)	Piping Plover, Snowy Plover	
Lott et al. 2009	nGoM	Yes		Impact Only	Habitat Quality (Positive)	Shorebirds (F, NF), Seabirds (F, NF), Wading Birds (F, NF)	Seabirds (collectively), shorebirds (collectively), wading birds (collectively)	Seabirds (collectively), shorebirds (collectively), wading birds (collectively)

MacIvor 1990	Atlantic	Yes	Closures		Abundance (Positive), Reproductive Success (Positive), Habitat Quality (Positive)	Shorebirds (F)	Piping Plover	
Mackin 2016	Caribbean	Yes		Impact Only	Abundance (Positive)	Seabirds (F)	Sargasso Shearwater	
Maguire et al. 2011	Europe			Predation Management	Reproductive Success (Positive)	Shorebirds (NF)		
Mallach and Leberg 1999	nGoM	Yes		Beach Nourishment	Habitat Quality (Positive)	Seabirds (F)	Least Tern	
Malm et al. 2004	Baltic Sea			Reducing Beach Raking	Habitat Quality (Positive)	Shorebirds (NF), Seabirds (NF)		
Maslo and Lockwood 2009	Atlantic	Yes	Impact Only		Reproductive Success	Shorebirds (F)	Piping Plover	
Mass Audubon 2023	Atlantic	Yes	Fencing, Stewards, Signage, Public Education		Abundance (Positive), Reproductive Success (Positive)	Shorebirds (F), Seabirds (F)	American Oystercatcher, Piping Plover	Roseate Tern

Mazzocchi and Forys 2005	nGoM	Yes		Beach Nourishment	Habitat Quality (Positive)	Seabirds (F)	Least Tern	
McGowan et al. 2005	Atlantic	Yes		Dredge Spoil Islands	Abundance (Positive)	Shorebirds (F)	American Oystercatcher	
McIntyre and Heath 2011	Atlantic	Yes		Reducing Beach Raking	Reproductive Success (Positive)	Shorebirds (F)	Piping Plover	
McIntyre et al. 2010	Atlantic	Yes	Fencing	Vegetation Management or Wetland Creation, Predation Management	Abundance (Positive), Reproductive Success (Positive)	Shorebirds (F)	Piping Plover	
Medeiros et al. 2007	Portugal		Stewards, Signage, Public Education		Reproductive Success (Positive)	Seabirds (NF)		Little Tern
Melvin et al. 1994	Atlantic	Yes	Impact Only		Abundance, Reproductive Success	Shorebirds (F)	Piping Plover	
Mengak and Dayer 2020	Atlantic	Yes	Impact Only		Abundance, Reproductive Success, Habitat Quality	Shorebirds (F, NF)	Shorebirds (collectively)	Shorebirds (collectively)

Michel et al. 2021	nGoM, Atlantic	Yes	Fencing, Stewards, Signage, Public Education, Closures		Abundance (Positive)	Shorebirds (F), Seabirds (F)	Black Skimmer, Brown Pelican, Least Tern, Piping Plover	
Murchison et al. 2016	Pacific	Yes	Impact Only		Habitat Quality	Shorebirds (F)	Red Knot	
Murphy et al. 2003	Great Plains	Yes		Predation Management	Abundance (Positive)	Shorebirds (F)	Piping Plover	
Nesbitt and Hatchitt 2008	nGoM, Atlantic	Yes		Impact Only	Abundance (Positive), Habitat Quality (Positive)	Wading Birds (F)	Sandhill Crane	
Niehaus et al. 2004	Pacific	Yes		Predation Management	Abundance (Positive), Reproductive Success (Positive)	Shorebirds (F)	Western Sandpiper	
Nisbet 1981	Atlantic	Yes	Impact Only		Reproductive Success	Seabirds (F, NF)		Common Tern, Roseate Tern
Nisbet 2000	Global		Impact Only		Reproductive Success	Seabirds (NF), Wading Birds		

						(NF)		
Nordstrom et al. 2000	Atlantic	Yes		Reducing Beach Raking	Habitat Quality (Positive)	Shorebirds (F)	Piping Plover	
O’Connell and Nyman 2010	nGoM	Yes		Vegetation Management or Wetland Creation	Abundance (Positive)	Shorebirds (F, NF), Seabirds (F, NF), Wading Birds (F, NF)	Roseate Spoonbill, egrets (collectively), herons (collectively), plovers (collectively), terns (collectively)	Egrets (collectively), herons (collectively), plovers (collectively), terns (collectively)
Owen and Pierce 2013	nGoM	Yes		Beach Nourishment, Dredge Spoil Islands	Habitat Quality (Positive)	Seabirds (F)	Black Skimmer	
Page et al. 1985	Pacific	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F)	Snowy Plover	
Page et al. 2023	Global	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F)	Snowy Plover	
Patterson et al. 1991	Atlantic	Yes		Impact Only	Reproductive Success (Positiv	Shorebirds (F)	Piping Plover	

					e)			
Pearson et al. 2016	Pacific	Yes		Predation Management	Reproductive Success (Positive)	Shorebirds (F)	Snowy Plover	
Peters and Otis 2005	Atlantic	Yes	Impact Only		Habitat Quality	Shorebirds (F)	American Oystercatcher	
Peterson and Bishop 2005	Global			Beach Nourishment	Habitat Quality (Positive)	Shorebirds (NF)		
Peterson and Manning 2001	Atlantic	Yes		Beach Nourishment	Abundance (Negative)	Shorebirds (F, NF)	Shorebirds (collectively)	Shorebirds (collectively)
Post 1990	Atlantic	Yes		Dredge Spoil Islands	Abundance (Negative), Reproductive Success (Negative)	Wading Birds (F, NF)	Herons (collectively), ibises (collectively)	Herons (collectively), ibises (collectively)
Powell and Collier 2000	California	Yes		Vegetation Management or Wetland Creation	Reproductive Success (Positive)	Shorebirds (F)	Western Snowy Plover	
Pruner 2010	nGoM	Yes	Fencing		Reproductive Success (Positive)	Shorebirds (F)	Snowy Plover	

Raynor et al. 2012	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Seabirds (F)	Sandwich Tern	Roseate Tern
Reynolds et al. 2015	Pacific			Impact Only	Habitat Quality (Positive)	Seabirds (NF)		
Rimmer et al. 2013	Australia		Signage, Public Education			Shorebirds (NF)		Hooded Plover
Robert and Ralph 1975	Pacific		Impact Only		Reproductive Success	Seabirds (NF)		
Rodgers 1987	nGoM	Yes		Impact Only	Reproductive Success (Positive)	Wading Birds (F)	Wood Stork	

Rodgers and Schwikert 2002	nGoM, Atlantic	Yes	Impact Only		Habitat Quality	Shore birds (F, NF), Seabirds (F, NF), Wading Birds (F, NF)	American Oystercatcher, Brown Pelican, Great Egret, Least Tern, Little Blue Heron, Reddish Egret, Roseate Spoonbill, Royal Tern, Tricolored Heron, White Ibis, Wood Stork	Seabirds (collectively), shorebirds (collectively), wading birds (collectively)
Rogers et al. 2006	Australia	Yes	Impact Only		Habitat Quality	Shore birds (F)	Red Knot	
Ruetz et al. 2005	nGoM	Yes		Impact Only	Habitat Quality (Positive)	Seabirds (F, NF), Wading Birds (F, NF)	Seabirds (collectively), wading birds (collectively)	Seabirds (collectively), wading birds (collectively)
Ruhlen et al. 2003	California	Yes	Impact Only		Reproductive Success	Shore birds (F)	Snowy Plover	

Russell et al. 2009	California			Vegetation Management or Wetland Creation	Abundance (Positive)	Shorebirds (NF), Seabirds (NF)		
Ruthbert-Campagna 2021	nGoM	Yes		Impact Only	Abundance (Positive)	Shorebirds (F, NF)	Shorebirds (collectively)	Shorebirds (collectively)
Sabine et al. 2006	Atlantic	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F)	American Oystercatcher	
Safina and Burger 1983	Atlantic	Yes	Fencing, Closures		Reproductive Success (Positive)	Seabirds (F)	Black Skimmer	
Saliva and Burger 1989	Caribbean	Yes		Vegetation Management or Wetland Creation	Habitat Quality (Positive)	Seabirds (F)	Sooty Tern	
Samways et al. 2010	Seychelles	Yes		Vegetation Management or Wetland Creation	Abundance (Positive), Reproductive Success (Positive)	Seabirds (F)	Sooty Tern	
Schillerstrom 2021	Atlantic	Yes	Impact Only		Habitat Quality	Shorebirds (F)	Red Knot	
Schlacher et al. 2013	Australia		Impact Only		Habitat Quality	Seabirds (NF)		

Schoenleber et al. 2022	Pacific	Yes	Signage, Public Education		Habitat Quality (Positive)	Shorebirds (F)	Snowy Plover	
Schultz Schiro et al. 2017	nGoM	Yes	Stewards, Signage, Public Education	Reducing Beach Raking	Habitat Quality (Positive)	Shorebirds (F), Seabirds (F)	Least Tern, Snowy Plover	BlackNegativebellied Plover, Sanderling, Ruddy Turnstone, Willet
Selman and Davis 2015	nGoM	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Shorebirds (F)	American Oystercatcher	
Shope 2020	nGoM	Yes	Impact Only		Reproductive Success	Seabirds (F)	Black Skimmer	
Smith 2002	nGoM	Yes		Dredge Spoil Islands	Habitat Quality (Positive)	Wading Birds (F, NF)	Reddish Egret, Roseate Spoonbill, Tricolored Heron, egrets (collectively), herons (collectively)	Egrets (collectively), herons (collectively)
Smith et al. 2011	Global			Predation Management	Reproductive Success (Positive)	Shorebirds (NF)		
Smith et al. 2020	Atlantic	Yes		Beach Nourishment	Habitat Quality (Positive)	Shorebirds (F)	Red Knot	

Soots and Parnell 1975	Atlantic	Yes		Impact Only	Habitat Quality (Positive)	Seabirds (F)	Least Tern, Royal Tern	
Speybroeck et al. 2006	Global			Beach Nourishment	Habitat Quality (Positive)	Shorebirds (NF)		
St. Clair et al. 2010	Argentina		Impact Only		Reproductive Success	Shorebirds (NF)		
Stantial et al. 2021	Atlantic	Yes	Impact Only		Reproductive Success	Shorebirds (F)	Piping Plover	
Sterling 2017	Atlantic	Yes		Impact Only	Reproductive Success (Positive), Habitat Quality (Positive)	Shorebirds (F)	Wilson’s Plover	
Stillman and Goss-Custard 2002	Europe		Impact Only		Habitat Quality	Shorebirds (NF)		
Strauss 1990	Atlantic	Yes	Impact Only		Reproductive Success	Shorebirds (F)	Piping Plover	
Struthers and Ryan 2005	Great Lakes	Yes		Predation Management	Reproductive Success (Positive)	Shorebirds (F)	Piping Plover	
Studds et al. 2017	Asia			Impact Only	Abundance (Positive)	Shorebirds (NF)		
Teal 1965	Atlantic	Yes	Impact Only		Reproductive Success	Wading Birds (F,	Tricolored Heron	Snowy Egret

						NF)		
Thomas et al. 2006	North America	Yes		Impact Only	Abundance (Positive)	Shorebirds (F, NF)	Shorebirds (collectively)	Shorebirds (collectively)
U.S. Fish and Wildlife Service 1996	Atlantic	Yes		Vegetation Management or Wetland Creation, Beach Nourishment	Abundance (Positive)	Shorebirds (F)	Piping Plover	
Virzi 2010	Atlantic	Yes	Impact Only		Habitat Quality	Shorebirds (F)	American Oystercatcher	
Virzi et al. 2016	Atlantic	Yes		Dredge Spoil Islands	Reproductive Success (Positive)	Shorebirds (F)	American Oystercatcher	
Visser et al. 2005	nGoM	Yes		Vegetation Management or Wetland Creation	Habitat Quality (Positive)	Seabirds (F)	Brown Pelican	
Vitale et al. 2021	nGoM	Yes		Dredge Spoil Islands	Habitat Quality (Negative)	Shorebirds (F)	American Oystercatcher	
Von Holle et al. 2019	Atlantic	Yes		Impact Only	Habitat Quality (Positive)	Seabirds (F)	GullNegativebilled Tern, Sandwich Tern	

Walter et al. 2013	nGoM	Yes		Vegetation Management or Wetland Creation	Habitat Quality (Positive)	Seabirds (F)	Brown Pelican	
Watson et al. 2021	Europe		Impact Only		Reproductive Success	Seabirds (NF)		
Weston and Elgar 2007	Australia		Impact Only		Reproductive Success	Shorebirds (NF)		Hooded Plover
Williams et al. 2008	nGoM	Yes		Reducing Beach Raking	Habitat Quality (Positive)	Shorebirds (NF), Seabirds (F, NF), Wading Birds (F)	Least Tern, Reddish Egret	Caspian Tern, Laughing Gull, Willet
Wilson et al. 2012	nGoM	Yes		Predation Management	Abundance (Positive)	Wading Birds (F)	Reddish Egret	
Wilson et al. 2019	nGoM	Yes	Impact Only		Abundance, Reproductive Success, Habitat Quality	Shorebirds (F, NF), Seabirds (F, NF), Wading Birds (F, NF)	Seabirds (collectively), shorebirds (collectively), wading birds (collectively)	Seabirds (collectively), shorebirds (collectively), wading birds (collectively)
Yalden and Yalden 1990	United Kingdom		Impact Only		Reproductive Success	Shorebirds (NF)		

Yasué 2006	British Columbia		Impact Only		Habitat Quality	Shorebirds (NF)	
Yasué and Dearden 2006	Malaysia		Impact Only		Reproductive Success	Shorebirds (NF)	
Zambrano et al. 1997	Atlantic	Yes		Impact Only	Abundance (Positive)	Seabirds (F)	Least Tern
Zarnetske et al. 2010	Pacific	Yes		Vegetation Management or Wetland Creation	Abundance (Positive)	Shorebirds (F)	Snowy Plover
Zdravkovic 2013	Atlantic	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F)	Wilson's Plover
Zdravkovic et al. 2023	Atlantic	Yes		Impact Only	Reproductive Success (Positive)	Shorebirds (F)	Wilson's Plover
Zenzal et al. 2023	nGoM	Yes		Beach Nourishment	Habitat Quality (Neutral)	Shorebirds (F)	American Oystercatcher, Piping Plover, Red Knot, Snowy Plover, Wilson's Plover
Zinsser et al. 2017	Atlantic	Yes		Beach Nourishment	Habitat Quality (Positive)	Shorebirds (F)	Wilson’s Plover

Zöckler et al. 2003	Global	Impact Only	Abundance (Positive)	Wading Birds (NF)