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CONNECTIVITY OF ATLANTIC AND GULF OF MEXICO WATERBIRD POPULATIONS

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Abstract.—The 2010 *Deepwater Horizon* (DWH) oil spill caused catastrophic damage to marine and terrestrial environments in and along the Gulf of Mexico. The DWH Natural Resource Damage Assessment (NRDA) estimated that 56,141–102,399 birds across 93 species were directly or indirectly injured, and breeding and foraging habitats suffered substantial damage. The 2016 DWH civil settlement allocated NRDA funds to Florida to replenish and protect DWH-injured bird species. Additional NRDA restoration funds were allocated Regionwide (i.e., all Gulf states) and to Open Ocean Restoration Areas. In addition, Florida was allocated funds through the National Fish and Wildlife Foundation's Gulf Environmental Benefit Fund (GEBF) to address DWH-injured living resources and habitats. NRDA and GEBF funds for bird restoration must be used in areas impacted by the DWH oil spill or in locations with clear connections to DWH-injured bird populations. We compiled and summarized literature and unpublished data to illustrate the coastal connectivity of 17 focal waterbird species between the Gulf of Mexico and the Atlantic Coast. We documented coastal connectivity for 13 of the 17 (76%) focal species. Rates of coastal connectivity derived from United States Geological Survey Bird Banding Lab data for populations anywhere on the United States Atlantic or Gulf coasts ranged by species from 0–22% of resighted individuals being observed on both coasts and ranged from 0–30% when restricted to coasts within Florida. The connectivity between the majority of Atlantic and Gulf coast focal populations is substantial, and the consideration of restoration projects on the Atlantic Coast should be determined on a case-by-case basis. Restoring living resources and breeding and foraging habitats along Florida's coastlines for the benefit of avian species that exhibit coastal connectivity will help create more resilient habitats for the benefit of at-risk species in the face of future catastrophes.

Key words: coastal birds, *Deepwater Horizon*, Florida, oil spill, restoration

In April 2010, the *Deepwater Horizon* (DWH) drilling platform experienced a catastrophic failure that resulted in the release of >130 million gallons of oil and other toxic chemicals into the Gulf of Mexico (hereafter, Gulf). Oil slicks eventually covered >43,000 km^2 of the Gulf's surface, and oil came ashore on >2,000 linear kilometers of coastline along all five United States Gulf states (DWH NRDA Trustees, 2016). The ecological and economic impacts of the spill were profound. For birds, the DWH Natural Resource Damage

Assessment (NRDA) estimated a loss of 56,141–102,399 individuals across 93 species, either via direct mortality or via a consequent loss of productivity, as well as substantial damage to breeding and foraging habitats (DWH NRDA Trustees, 2016).

In 2013, the National Fish and Wildlife Foundation's Gulf Environmental Benefit Fund (GEBF) was established as a result of the plea agreements resolving the criminal charges against British Exploration & Production Inc. (BP) and Transocean from the spill. The agreements directed a total of $2.544 billion to GEBF, with $356 million allocated for projects in Florida that "remedy harm to natural resources where there has been injury to, or destruction of, loss of, or loss of use of those resources" resulting from the spill. The 2016 civil settlement between the United States, Alabama, Florida, Louisiana, Mississippi, Texas, and BP resulted in a $20.8 billion settlement with ~$501.2 million in NRDA funds allocated to replenish and protect DWH-injured bird species. This included ~$680 million allocated to Florida to restore natural resources adversely affected by the spill (i.e., the Florida Restoration Area) and an additional ~$350 million and ~$1.24 billion for restoration of natural resources, primarily living coastal and marine resources, in the Regionwide and Open Ocean Restoration Areas, respectively, which could include activities in Florida. Funds specifically allocated to the Birds Restoration Type (i.e., projects that would replenish and protect DWH-impacted bird species) included ~$42.8 million in Florida, ~$72.2 million in the Regionwide Restoration Area, and $70 million in the Open Ocean Restoration Area (U.S. Department of Justice, 2016). NRDA and GEBF bird restoration projects must target DWH-injured bird populations or habitats, meaning that connectivity to Gulf populations must be demonstrated for projects outside of the Gulf.

Florida's Atlantic Coast is home to many avian species affected by the DWH oil spill. Although connectivity between Atlantic and Gulf populations of coastal birds has been documented, data supporting that connectivity are scattered throughout the peer-reviewed literature, gray literature, and unpublished datasets. As such, the degree to which Florida's coastal populations are connected remains poorly articulated, which may limit the ability to secure funding for high-priority restoration projects on the Atlantic Coast. Here, we document the connectivity of Atlantic and Gulf populations of DWH-injured bird species. We prioritized bird species by identifying their threat status within Florida, spill-related injuries, and the potential for targeted restoration efforts. For each priority species, we compiled band-resighting data from the United States Geological Survey (USGS) Bird Banding Lab (BBL), internal sources, collaborative partners, and aggregated peer-reviewed and gray literature on dispersal and movement patterns documenting connectivity.

METHODS

Species prioritization.—We identified focal bird species by consulting the list of injured species provided in the *Deepwater Horizon* Oil Spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement (DWH NRDA Trustees, 2016). We chose 17 target species that were priorities in Florida (Table 1) rather than performing an exhaustive review of all 93 species. The criteria we used to determine whether a species was a priority were its conservation status in Florida, the estimated injury during the spill (we considered any species with <50 birds injured to have experienced limited injury), and our assessment of the likelihood of restoration activities targeting the species on the Atlantic Coast in Florida. For shorebirds: American Oystercatcher is listed as state-threatened, and it and Wilson's Plover are focal species of management and conservation efforts outlined in a DWH-funded recovery plan (Schulte 2016); the United States Fish and Wildlife Service lists Eastern Willet as a bird of conservation concern that breeds in Florida; Dunlin is a Species of Greatest Conservation Need (SGCN) in Florida's State Wildlife Action Plan (SWAP; FWC 2019) that experienced a moderate amount of injury. For seabirds: Black Skimmer and Least Tern are listed as state-threatened in Florida; Gull-billed Tern is a SGCN (FWC 2019); Black Tern, Common Tern, and Sandwich Tern are all Birds of Conservation Concern (USFWS 2008) with moderate or high levels of injury from the spill. We also included Royal Terns because of their high level of injury and known reliance on Florida's coastlines during breeding and migration. For wading birds: Roseate Spoonbill, Tricolored Heron, Little Blue Heron, and Reddish Egret are all listed as state-threatened; White Ibis and Brown Pelican were recently delisted and, as such, still have species action plans (FWC 2013a,b) and remain high priorities in Florida. We deemed the remaining species a lower priority and did not aggregate data for them.

Data collection.—We obtained band resight data from the BBL from August 1920 through February 2021 for 17 focal species (Table 1), which included all banded individuals reported as resighted, and the associated spatial data for those resights. We mapped banding and resight locations using the latitudinal and longitudinal coordinates provided. We selected observations from the United States Gulf and Atlantic coastlines based on a maritime boundary shapefile within ArcGIS. We sorted individual band identifications to determine if they were observed in the Gulf, the Atlantic, or both. We then further reduced observations to those that occurred along the Gulf and Atlantic coasts within Florida. The resulting dataset described the total number of resighted individuals by species and the proportion of those observed on both coasts.

We augmented the BBL data with supplementary band-resighting data we acquired from relevant Florida Fish and Wildlife Conservation Commission staff and additional partners who research the focal species. We also compiled peer-reviewed and gray literature on dispersal and movement patterns of the focal species that documented connectivity between the Atlantic and Gulf. Literature search words included names of the species in Table 1, and Atlantic, band return, coastal, connectivity, dispersal, Florida, Gulf of Mexico, movement, resights, seabird, shorebird, tracking, wading bird, and water bird. Peer-reviewed literature that analyzed movements of focal species through data collected from the BBL was excluded from our literature compilation to avoid double-counting band resights. Data were also obtained through Movebank.org, and each study's principal investigator permitted the use of data. We classified Movebank locations as coastal if they occurred on coastlines, in coastal waters, in tidal marshes, or <400m inland from a coastline.

Analysis.—We created tabular summaries of observed dispersal or movement patterns between Atlantic and Gulf populations of focal species from BBL data, partner-collected data, and data in the peer-reviewed and gray literature.

Table 1. Focal species, listing status, and estimated injury from the Deep Water Horizon oil spill. The Status column refers to species that are listed as state-threatened in Florida, Species of Greatest Conservation Need by Florida Fish and Wildlife Conservation Commission (SGCN – FWC), and Birds of Conservation Concern by the United States Fish and Wildlife Service (BCC – USFWS).

Guild	Species	Status	Estimated Injury
Shorebirds	American Oystercatcher (*Haematopus palliatus*)	State-threatened	82-125
	Wilson's Plover (*Anarhynchus wilsonia)*	SGCN - FWC	17-28
	Dunlin (*Calidris alpina*)	SGCN - FWC	92-311
	Eastern Willet (*Tringa semipalmata*)	BCC-USFWS	77-122
Seabirds	Black Skimmer (*Rynchops niger*)	State-threatened	1,591-2,663
	Least Tern (*Sternula antillarum*)	State-threatened	747-1,214
	Black Tern (*Childonias niger*)	BCC-USFWS	796-1,066
	Common Tern (*Sterna hirundo*)	BCC-USFWS	277-546
	Gull-billed Tern (*Gelochelidon nilotica*)	SGCN-FWC	28-44
	Royal Tern (*Thalasseus maximus*)		2,940-5,058
	Sandwich Tern (*Thalasseus sandvicensis*)	BCC-USFWS	693-1,092
Pelicans & Wading Birds	Brown Pelican (*Pelecanus occidentalis*)	SGCN; recently delisted	12,720-27,613
	Roseate Spoonbill (*Platalea ajaja*)	State-threatened	268-458
	Tricolored Heron (*Egretta tricolor*)	State-threatened	282-429
	Little Blue Heron (*Egretta caerulea*)	State-threatened	31-47
	Reddish Egret (*Egretta rufescens*)	State-threatened	25-39
	White Ibis (*Eudocimus albus*)	SGCN; recently delisted	621-1,891

Results

Data obtained through the BBL and 22 additional sources provided band-resight and movement data for all 17 focal species (Table 2). BBL data provided information for 129,556 individuals that were banded and then resighted on the Gulf or Atlantic Coast within the United States; 6,585 (5.1%) of these individuals across 13 species were resighted on the Gulf and Atlantic coasts. The proportion of resighted birds that were observed and reported to the BBL on both coasts by species ranged from 0% (Wilson's Plover, Eastern Willet, Black Tern, Gull-billed Tern) to 22% for the Royal Tern (Table 2). BBL data indicated that 3,141 individuals across 14 species were banded and resighted on the Gulf or Atlantic coasts within Florida, and 274 (8.7%) across 9 species were observed on both coasts of Florida, including six state-threatened species (Table 2).

We obtained supplementary band-resight data from nine peer-reviewed papers and five working groups or banding professionals (Table 2). Species that showed a greater connectivity level when compared to BBL data included American Oystercatcher, Black Skimmer, and Wilson's Plover. The percentage of individuals resighted on the Gulf and Atlantic coasts ranged widely (0-63%), in part because of significant variation in either resight effort or reported resight effort. As such, these data should be interpreted as documenting evidence of connectivity rather than rates of connectivity. Finally, we gathered eight sources that provided records of movement data from GPS or VHF tracking devices for seven focal species, including three listed as state-threatened species. We compiled information for 662 individuals tracked by tagging devices along the Gulf or along the Atlantic Coast within the United States, 6 (1%) of which were observed on both the Gulf and Atlantic coasts, including 5 within Florida (Table 2).

Discussion

Populations along the Gulf and Atlantic coasts exhibited at least some level of connectivity for 13 of 17 (76%) focal species in this study. BBL data indicated that connectivity between coastlines was relatively high, particularly for Black Skimmer, Royal Tern, Roseate Spoonbill, and Sandwich Tern (Table 2) and was somewhat lower but still notable for American Oystercatcher, Brown Pelican, and Dunlin (Table 2). Data from supplementary sources also provided evidence of coastal connectivity for American Oystercatcher, Black Skimmer, Sandwich Tern, and Wilson's Plover.

Within Florida, coastal connectivity was notable for some of the most imperiled species (American Oystercatcher, 9%; Black Skimmer, 9%; Least Tern, 11%; Roseate Spoonbill, 12%; Tricolored

Table 2. Summary of mark-resight and telemetry data that describe coastal connectivity between the U.S. Gulf of Mexico and Atlantic coasts, and the Florida Gulf of Mexico and Atlantic Coasts. The "# of resighted individuals" metric refers to birds that are associated with at least one, band-resight or telemetry movement data.

	Entire Atlantic Coast and Gulf Coast			Florida's Atlantic and Gulf Coast				
Species	# of resighted individuals	# observed on both coasts	%	# of re-sighted individuals	# observed on both coasts	%	Data type	Data source
American Oystercatcher	846	56	7%	35	3	9%	BBL	1
	5157	585	11%	1599	63	4%	Other:banding	2
	55	41	74%	55	3	5%	Other:banding	3
Wilson's Plover	66	0	0%	12	0	0%	BBL	1
	271	5	2%	269	3	1%	Other:banding	4
Dunlin	73	3	4%	3	0	0%	BBL	1
Eastern Willet	25	0	0%	0	0	0%	BBL	1
Black Skimmer	2131	279	13%	184	16	9%	BBL	1
	133	51	38%	133	3	2%	Other:banding	3
	2	0	0%	0	0	0%	Telemetry	5
	93	27	29%	93	6	6%	Other:banding	6
Least Tern	553	4	1%	35	4	11%	BBL	1
	4	0	0%	4	0	0%	Other:banding	3
	75	0	0%	6	0	0%	Other:banding	7
Black Tern	6	0	0%	0	0	0%	BBL	1
Common Tern	84277	15	0%	0	0	0%	BBL	1
	4	2	50%	4	0	0%	Other:banding	3
	266	0	0%	0	0	0%	Telemetry	8

Data sources: [1]Breeding Bird Lab; [2]American Oystercatcher Working Group; [3]Florida Banded Bird Resightings 2021 (Facebook Group); [4]Florida Fish and Wildlife Conservation Commission; [5]Rolland et al. 2019; [6]Audubon North Carolina, National Audubon Society; [7]USGS Northern Prairie Wildlife Research Center; [8]Loring et al. 2019; [9]Bard et al. 2001; [10]Golden et al. 2002; [11]Van Velzen 1971; [12]Rolland et al. 2020; [13]Movebank.org; [14]Longstreet 1944; [15]Schreiber 1976; [16]Poli 2015; [17]Mason 1945; [18]Walter et al. 2014; [19]Robertson et al. 1983; [20]Dusi 1967; [21]Koczur et al. 2018; [22]Geary et al. 2015; [23]Lamb et al. 2018.

Table 2. (Continued) Summary of mark-resight and telemetry data that describe coastal connectivity between the U.S. Gulf of Mexico and Atlantic coasts, and the Florida Gulf of Mexico and Atlantic Coasts. The "# of resighted individuals" metric refers to birds that are associated with at least one, band-resight or telemetry movement data.

	Entire Atlantic Coast and Gulf Coast			Florida's Atlantic and Gulf Coast				
Species	# of resighted individuals	# observed on both coasts	%	# of re-sighted individuals	# observed on both coasts	%	Data type	Data source
Gull-billed Tern	36	0	0%	9	0	0%	BBL	1
Royal Tern	19625	4248	22%	162	49	30%	BBL	1
	96	95	99%	96	0	0%	Other:banding	3
	82	0	0%	82	0	0%	Other:banding	9
	6	0	0%	6	0	0%	Other:banding	10
	21	9	43%	16	9	56%	Other:banding	11
	6	0	0%	0	0	0%	Telemetry	12
Sandwich Tern	1303	242	19%	2	0	0%	BBL	1
	13	5	38%	13	1	8%	Other:banding	3
Brown Pelican	19877	1717	9%	2594	188	7%	BBL	1
	9	1	11%	9	0	0%	Other:banding	3
	227	0	0%	0	0	0%	Telemetry	13
	228	13	6%	228	12	5%	Other:banding	14
	1084	0	0%	0	0	0%	Other:banding	15
	30	2	7%	14	2	14%	Telemetry	16
	389	20	5%	389	19	5%	Other:banding	17
	66	0	0%	0	0	0%	Other:banding	18

Data sources: [1]Breeding Bird Lab; [2]American Oystercatcher Working Group; [3]Florida Banded Bird Resightings 2021 (Facebook Group); [4]Florida Fish and Wildlife Conservation Commission; [5]Rolland et al. 2019; [6]Audubon North Carolina, National Audubon Society; [7]USGS Northern Prairie Wildlife Research Center; [8]Loring et al. 2019; [9]Bard et al. 2001; [10]Golden et al. 2002; [11]Van Velzen 1971; [12]Rolland et al. 2020; [13]Movebank.org; [14]Longstreet 1944; [15]Schreiber 1976; [16]Poli 2015; [17]Mason 1945; [18]Walter et al. 2014; [19]Robertson et al. 1983; [20]Dusi 1967; [21]Koczur et al. 2018; [22]Geary et al. 2015; [23]Lamb et al. 2018.

Table 2. (Continued) Summary of mark-resight and telemetry data that describe coastal connectivity between the U.S. Gulf of Mexico and Atlantic coasts, and the Florida Gulf of Mexico and Atlantic Coasts. The "# of resighted individuals" metric refers to birds that are associated with at least, one band-resight or telemetry movement data.

	Entire Atlantic Coast and Gulf Coast			Florida's Atlantic and Gulf Coast				
Species	# of resighted individuals	# observed on both coasts	%	# of re-sighted individuals	# observed on both coasts	%	Data type	Data source
Roseate Spoonbill	83	8	10%	66	8	12%	BBL	1
	20	1	5%	20	1	5%	Telemetry	13
	8	0	0%	8	0	0%	Other:banding	19
Tricolored Heron	224	4	2%	16	3	19%	BBL	1
Little Blue Heron	204	2	1%	8	0	0%	BBL	1
	18	1	6%	2	1	50%	Other:banding	20
Reddish Egret	88	2	2%	7	2	29%	BBL	1
	35	0	0%	5	0	0%	Telemetry	21
	25	0	0%	0	0	0%	Telemetry	22
	3	0	0%	0	0	0%	Telemetry	23
White Ibis	139	5	4%	8	1	13%	BBL	1
	48[a]	3	6%	48	2	4%	Other:banding	13

Data sources: [1]Breeding Bird Lab; [2]American Oystercatcher Working Group; [3]Florida Banded Bird Resightings 2021 (Facebook Group); [4]Florida Fish and Wildlife Conservation Commission; [5]Rolland et al. 2019; [6]Audubon North Carolina, National Audubon Society; [7]USGS Northern Prairie Wildlife Research Center; [8]Loring et al. 2019; [9]Bard et al. 2001; [10]Golden et al. 2002; [11]Van Velzen 1971; [12]Rolland et al. 2020; [13]Movebank.org; [14]Longstreet 1944; [15]Schreiber 1976; [16]Poli 2015; [17]Mason 1945; [18]Walter et al. 2014; [19]Robertson et al. 1983; [20]Dusi 1967; [21]Koczur et al. 2018; [22]Geary et al. 2015; [23]Lamb et al. 2018.

Heron, 19%; Reddish Egret, 29%), although a large dataset from the American Oystercatcher Working Group suggested a somewhat lower level of connectivity (4%) for American Oystercatchers. We caution against treating any percentage presented here as a true rate of coastal connectivity and would instead suggest considering these percentages as minima for two reasons. First, coastal connectivity rates for birds derived from band-resight data are biased low to an unknown but potentially substantial extent because the dataset relies, in part, on individual bands to be resighted and reported. Although extensive band-resight information is collected by shorebird program staff, conservation partners, and the public, resight data may not be reported to BBL and instead remain in databases within shorebird programs. Second, many individuals reported to the BBL, American Oystercatcher Working Group, and other datasets were most likely banded as chicks, and the mortality risk for very young individuals is generally very high for bird species (Cox et al. 2014, Koczur et al. 2014), which suggests that many banded birds died before they had an opportunity be resighted. The combination of these factors results in datasets where recorded resights could be at or below the true number of birds using both coasts, and the number of banded birds could match or exceed those that had an opportunity to use both coasts.

Royal Terns exhibited the highest apparent level of connectivity between the Atlantic and Gulf coasts, with 22% of individuals reported to the BBL being observed on both coastlines. Royal Terns breed and were banded along coastlines from Virginia through the southeast and along the Gulf in the United States (Buckley et al. 2021). Their breeding range and migratory route through Florida may strongly impact their relatively high rate of observed coastal connectivity. Based on BBL band-resights, 100% of Royal Terns observed on both of Florida's coastlines were banded in Florida, suggesting that Royal Terns have strong coastal connectivity within the state.

Although coastal connectivity was high for Royal Terns, connectivity for other tern species was relatively low or non-existent. Species-specific breeding ranges and migratory pathways may influence the likelihood that a species demonstrates coastal connectivity between the Atlantic and Gulf. For example, the coastal connectivity rate for Common Terns is effectively 0%, with only 15 out of 84,277 individuals from BBL data observed in both the Atlantic and Gulf and zero individuals observed on both coasts within Florida. The southern extent of the breeding range for Common Terns is northern South Carolina along the Atlantic Coast, and Common Terns migrate to Central and South America for the winter (Arnold et al. 2020). During the winter, Common Terns are rare along the southern Atlantic and Gulf coastlines (Arnold et al. 2020). Life history details such as these may help explain why

some species have higher rates of coastal connectivity than others. However, we acknowledge that some of the variation among species may be a consequence of differing study objectives (i.e., some banding studies may include concerted resighting efforts), species-specific band observability, or other factors, and suggest that a cautious interpretation of interspecific differences is warranted.

Allocation of restoration funding often reflects a complex interplay between factors related to species abundance and restoration targets (e.g., where restoration will benefit birds, how many birds will be affected, where restoration can be reasonably implemented, what are its impacts on nontarget species), social factors (e.g., whether restoration is compatible with the interests of other stakeholders), and funding rules or constraints. Restoration on Florida's Atlantic Coast is of interest to conservation practitioners because of the abundance of critically important sites for birds (e.g., Florida's largest Reddish Egret colony is on the Atlantic Coast; Cox et al. 2019). Dispersing restoration efforts throughout the state can effectively safeguard imperiled species by mitigating risks to wildlife associated with stressors such as hurricanes and oil spills. Moreover, broadening the scope of restoration efforts may enhance the potential of achieving statewide population targets. The data summarized here indicate that connectivity between some Atlantic and Gulf coast bird populations may be substantial and that consideration of restoration projects on Florida's Atlantic Coast through DWH settlement funds may be warranted.

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