1.3.8 Avian Sentinels of "One Health" for the Gulf of Mexico

M. A. Ottinger[1], J. K. S. Grace[2], T. Maness[3], and K. Dean[4]

[1]University of Houston; [2]Texas A&M University; [3]Louisiana Tech University; [4]University of Lethbridge

1.3.8.1 Abstract

The GOM is a complex ecosystem with a rich diversity of flora and fauna. The past few decades have brought dramatic changes to the GOM coastal ecosystem, with rising contamination from environmental chemicals associated with catastrophic events, including hurricanes and human-made crises. Assessing the impacts and interventions for future natural or human-made events remains challenging. The full implications of events such as Hurricane Harvey, which wreaked havoc in a region already heavily impacted by contamination from the DWH oil spill, are complex and ongoing. Understanding vulnerable areas associated with flooding and waterways are critical to maintain human health, wildlife populations, and the ecosystem. Coastal communities have been severely impacted by both natural and human-made events and their recovery relies on community and ecosystem resilience to achieve stability and nurture growth. Economic drivers and ecosystem attributes in these communities focus on fishing, oil, gas and chemical industries, ports, tourism and a range of other industries, as well as leisure activities that are fundamentally important for the health and well-being of individuals and the social and/or psychological health of human communities. Birds are important members of this ecosystem dynamic, not just for their roles in maintaining natural ecosystem balance, but also for providing direct benefits in the form of economically important leisure activities (e.g., hunting, birdwatching), and a more generalized sense of well-being for those who engage in "enjoyment of nature" activities. The concept of "One Health" articulates the close interrelationship between ecohealth and human health, particularly acknowledging not only the relationship of environment to human well-being, but also the critical co-dependence of the human population with our world. Birds provide sentinel wildlife species to assess "One Health" and the potential risk from exposure to environmental chemicals for individuals, species, and ultimately populations. Birds are often sensitive indicators of environmental damage, so understanding the health of GOM birds in relation to environmental stressors which include chemical contaminants, and the short- and long-term impacts of these stressors, can provide tremendous insight into the status of these key wildlife populations and a mirror into the "One Health" of the ecosystem. The GOM contains large numbers of resident and migratory bird species that rely heavily on the Central Flyway for spring and fall migrations. The quality of these habitats and resources has implications for human health and the economic well-being of coastal communities. This review will focus on the status of selected sentinel species of birds in the GOM, with attention to environmental challenges and impact for the "One Health" of wildlife and humans.

1.3.8.2 Introduction

The DWH oil spill, resulted in widespread contamination of GOM offshore and coastal regions. Data have been collected pertaining to wildlife impacts, and it is critical that these data be compiled, synthesized, and modeled to determine impact to, and resilience of, the ecosystem. Some studies have examined mechanisms and targets of the contaminants and potential risk to wildlife, providing valuable information regarding the potential for adverse outcomes from exposure in wildlife and potential for impacts to the ecosystem. Studies such as these are especially important because effects on wildlife health and the ecosystem are closely allied to that of human health and healthy communities. This concept of "One Health" is key to understanding the interrelationship between ecosystem health and that of associated human communities, such as coastal communities along the GOM, and for ascertaining potential risks to humans.

In addition to the dangers of contaminant exposure from oil and/or gas and other human industries, another critical factor to One Health of the ecosystem and human communities is natural disasters. The recent flooding from Hurricane Harvey extensively impacted the GOM and its coastal areas and may have had catastrophic ecosystem impacts. Moreover, inland regions can also be heavily impacted from such extreme rain events due to direct effects from runoff into rivers and associated flooding, as well as the accumulating volume of water carried downstream, changes in salinity and height of water tables, watercourse redirection, and soil erosion. Runoff from agricultural, residential, and industrial areas often carries substantial loads of environmental chemicals, which then travel through the environment and increase the risk of exposure to humans and wildlife. Additionally, there may be impacts due to spread of disease-causing bacteria and toxic algal blooms that not only affect health, but that can cause severe impacts on industries such as oyster production. These natural disasters set the context within which human-made impacts occur and are the background stressors for both wildlife and human populations, thereby impacting One Health of the ecosystem and associated communities. This review will consider the unique characteristics of avian species that make them important as sentinel species for the One Health of the GOM environment and provide an overview of the waterways and impacts of intermittent weather events affecting the region and the risk from environmental chemicals that are spread by natural and human-made events.

1.3.8.3 The Gulf of Mexico and Associated Waterways

The Mississippi River, originating in Minnesota and terminating in Louisiana is a major contributor of fresh water to the GOM, bringing with it dissolved and particulate materials (Figure 43). Of particular interest is the diversity of land use along the Mississippi–Atchafalaya River Basin. By the time the river reaches the GOM, it has collected runoff from urban and agricultural lands, creating a mixture of environmental chemicals with those already present in the GOM. Thus, it is critical to consider any exposures to mixtures of chemicals, aknowledging that there may be synergistic interactions resulting in additive adverse effects and increased risk to exposed populations. More local to the GOM, the Brazos River stretches more than 800 miles through agricultural and urban regions, with a basin having a large catchment area. The Brazos runs through Waco, Texas and traverses further through farmlands and varied landscapes on its way south to Houston and ultimately to the GOM near Freeport. During Hurricane Harvey and other widespread rain events, heavy rainfall contributed to a dramatic increase in the volume of water and debris from the upper regions of the river that were carried downstream. This greatly exacerbated the flooding in southern regions, especially as the river passed through the Houston area and south to the GOM. In addition to the Brazos River, Buffalo Bayou flows from Katy to Houston and ultimately through the Houston Ship Channel to the GOM, and also contributes large volumes of water and debris.

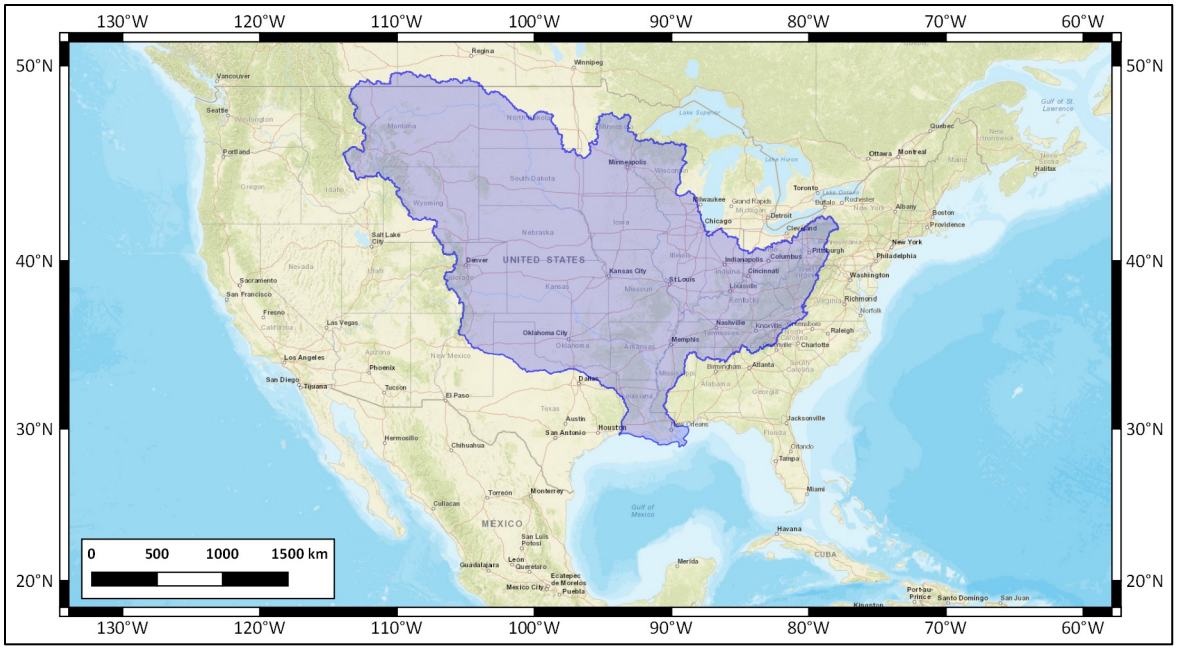

Figure 43. Mississippi River drainage basin.
Mississippi River drainage basin highlighted in blue. Drainage basin shapefile from USGS ScienceBase and basemap from ESRI Basemap layers collection. Figure prepared by M. Besonen.

1.3.8.4 Industry along the GOM

A large concentration of oil and gas industry exists throughout the GOM involving all aspects of the industry from oil and gas exploration through to petroleum refineries and natural gas processing plants. A large concentration of oil and gas industry along the coast and in the GOM was in the path of Hurricane Harvey. Further, shipping and trade is concentrated in the ports of Galveston, Houston, and others in Texas and Louisiana. The DWH oil spill resulted in widespread contamination of coastal regions, including those containing oil and gas processing plants. In addition, Houston is known as the energy capital of the United States because it is home to many energy-related industries beyond refineries. A myriad of manufacturing and chemical production facilities associated with oil and gas are also located here. Further, energy-related manufacturing is concentrated in areas that would feel the impact and disruption of hurricanes and hurricane-related flooding. This has numerous implications for both the economy and human condition as well as for the ecosystem. For example, if the supply of electricity is interrupted and control and failsafe devices fail, resulting fires could release hazardous chemicals into the air/water or onto land, potentially impacting the health of humans, wildlife, and ecosystems. Although the examples given are more focused on Houston and the area associated with the Houston Ship Channel, a similar concentration of the chemical industry is also found on the Louisiana coast and at its ports as well as west to Corpus Christi, Texas. Taken together, the high concentration of oil, gas, and chemical industries in the northwestern GOM, in combination with an extreme natural event such as a hurricane, can pose a significant risk to the ecosystem and human health. A consequence of the extensive industrialization, trade, and commercialization is environmental chemical contamination. The US Environmental Protection Agency in collaboration with the National Institutes of Environmental Health Sciences (NIEHS) provides national and regional maps of identified sites of concentrated environmental chemicals (TOXMAP).

1.3.8.5 Status of Birds in the GOM

The entire coastal region of the GOM is populated by hundreds of resident and migratory bird species. According to the Texas Parks and Wildlife Department, 98.5% of the 338 species of birds considered to be Nearctic-Neotropical migrants can be observed in Texas (Online FAQ. Just over over half of the 600+ species recorded in Texas are migratory birds utilizing the Central Flyway (Figure 44, green shading). In addition, other routes utilized by migratory birds may cross over the GOM. Stopover sites along Gulf coastal areas are critical for migratory birds to successfully reach their wintering or breeding grounds. The Smithsonian's Migratory Bird Center has been tracking migrants traversing the Gulf Coast using banding, stable isotopes and tracking techniques to study long-distance migrants (. In addition, there are historical and current records through the work of agencies, interest groups, and foundations. These records in combination with the North American Bird Banding Laboratory provide an extensive and detailed resource that encompass historical and current data that will be described.

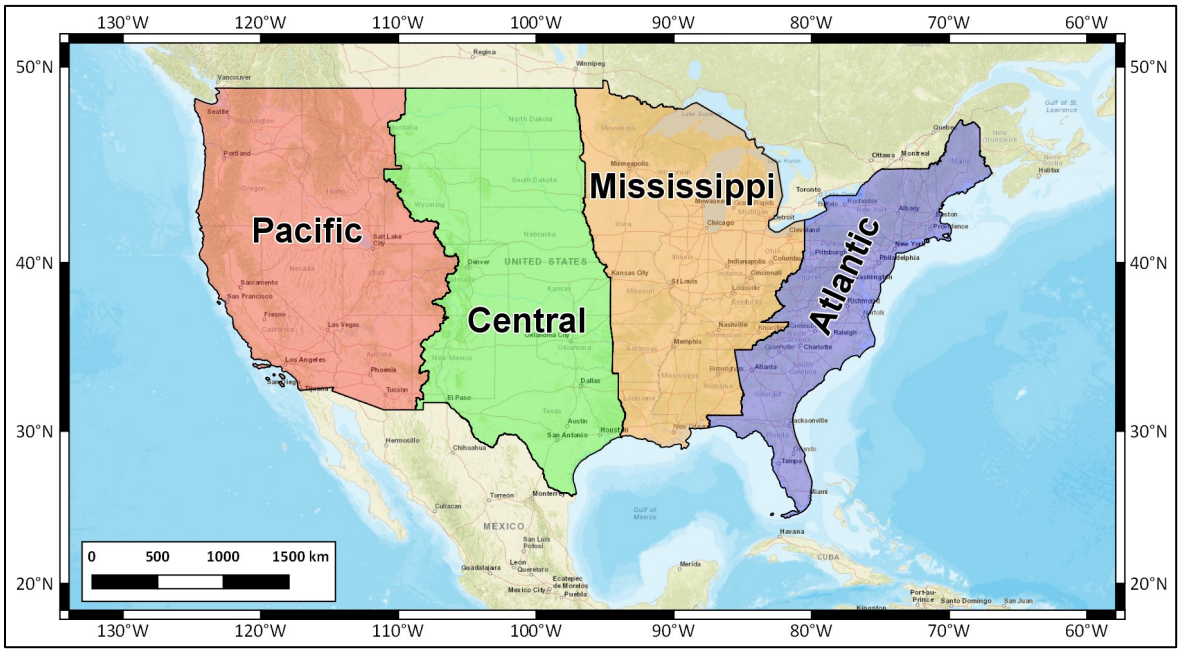

Figure 44. Migratory waterfowl flyway boundaries.
This figure shows migratory waterfowl flyways (red-Pacific, green-Central, orange-Mississippi, blue-Atlantic) over the continental United States. Shapefile for flyways is from the US Fish and Wildlife Service.) and basemap is from the ESRI Basemap layers collection. Figure prepared by M. Besonen.

A large database of Central Flyway migratory bird data is available through the North American Bird Banding Laboratory that is a partnership between the US Geological Survey (USGS) and the Canadian Wildlife Service (CWS). This partnership was initiated in 1909 and formalized in 1920; information from banding permits, sightings of banded birds, and reports of deceased individuals provide long-term data with individual records on longevity and seasonal locations. The National Audubon Society has 188 years of Christmas Bird Counts with more than 22 million birds counted. The Gulf of Mexico Avian Monitoring Network (GoMAMN) also has a considerable amount of retrospective and current data on migratory and resident avian populations. These long-term monitoring projects provide large and robust

pre-existing datasets that have enormous potential for modeling purposes. Integrating these data with health-related assessments provides valuable insights into short- and long-term impacts of habitat restoration on ecosystem and human health. The northern GOM is critical habitat for migratory and resident species; managers must have more information to assess the impact of habitat restoration on bird populations and health.

Habitat availability and loss due to weather events or urbanization presents major challenges for birds that reside in or migrate through the GOM (Burger 2017). It is important that dynamic changes occurring in coastal regions are integrated into risk assessment models. This includes climate change, anthropogenic activities associated with industry, urbanization, and commercialization, and other sources of contamination (e.g., oil spills), as well as natural events (e.g., tropical systems and other extreme weather events). This is especially true for endangered birds in the region, such as the whooping crane (*Grus americana*), for which the impacts of climate and habitat changes need to be considered in the context of species restoration programs. The International Crane Foundation in Baraboo, Wisconsin and Patuxent Wildlife Research Center in Laurel, Maryland have been the sites of captive breeding colonies, and these organizations support and carry out monitoring and reestablishment programs. Wild populations migrate over 2,400 miles from their breeding grounds in the wetlands of Wood Buffalo National Park in northern Canada to Aransas National Wildlife Refuge in Texas. According to the *US Fish and Wildlife Service News*, birds arrive to the Aransas National Wildlife Refuge wintering grounds by mid-December and are being monitored. A relatively low proportion of potential crane wintering habitat is protected on federal or state lands, with most habitat found on private lands. This illustrates the main issue of habitat protection for this species, and the need for rigorous but flexible management programs that include partnerships between government agencies, non-governmental agencies, businesses, and private citizens.

Another critically endangered bird is the Attwater prairie chicken (*Tympanuchus cupido attwateri*), for which the US Fish and Wildlife Service has led the breeding and restoration program in partnership with the Houston Zoo and NASA Johnson Space Center. Captive-reared chicks have been released into a protected habitat at the Attwater Prairie Chicken National Wildlife Refuge and are monitored. According to the latest reports, Hurricane Harvey significantly decreased the resident population. However, there was hope that the 49 birds that were released in late fall 2017 would successfully reestablish the breeding population. In the cases of the whooping crane and Attwater prairie chicken, enormous effort has been directed to saving these endangered species. However, the number of bird species joining the ranks of threatened and endangered species continues to rise and will likely accelerate as climate- and weather-related events, coupled with anthropogenic factors impact habitat and adversely affect health, fitness, and longevity of the birds residing there.

1.3.8.6 Unique Characteristics of Birds and Their Role as Sentinels of "One Health"

Diverse life history strategies, and unique physiological and endocrine characteristics differentiate birds from mammals and other vertebrate classes and make them important sentinel species for monitoring environmental health. Birds reproductive strategies fall into two general categories: altricial and precocial. Altricial species include songbirds, which are helpless when hatched and require parental care until they fledge. Most waterfowl, wildfowl, and shorebirds are precocial species, with chicks that are well developed and mobile when they hatch, can feed and forage on their own, but need some parental care, especially protection. Sexual differentiation of reproductive function and the song system occur pre- and posthatch in altricial species (Adkins-Regan et al., 1990), whereas precocial chicks complete sexual differentiation prehatch. Evidence for differential risk to altricial and precocial birds from environmental chemical exposure is increasing, with precocial birds primarily impacted by exposure during embryonic development and altricial birds remaining more vulnerable throughout their lives. However, exposure to environmental chemicals, especially to endocrine disrupting chemicals *in ovo*, can be extremely damaging to individuals from both groups (Ottinger and Dean 2011). As in mammals, sexual differentiation of reproductive and metabolic endocrine function occurs in the embryo and posthatch stages of development

and relies on exposure to gonadal steroids. However, in birds, males are the homogametic sex (ZZ) and females are heterogametic sex (ZW).

Birds also have unique physiological and endocrine characteristics that allow them to migrate great distances and survive under extremely variable and sometimes extreme conditions (Gill 1995; Ricklefs 2010). Birds have a higher metabolic rate and body temperature (105 °F) than mammals, both of which may result in accelerated toxicokinetics when exposed to environmental contaminants. Birds that are apex predators, such as osprey (*Pandion haliaetus*), may ingest and feed their chicks prey containing environmental contaminants (Lazarus et al., 2016) resulting in bioaccumulation and biomagnification. Further, lipophilic compounds (i.e., those stored in fat cells), which include many environmental contaminants, become part of an individual's body burden and may pose a high risk in migratory birds during periods of rapid accumulation (i.e., increased food intakebefore migration) and migration-associated energy drain and mobilization of lipid stores. Thyroid hormone is critical for premigratory fattening and is impacted by exposure to polychlorinated biphenyls (PCBs) and other chemicals that affect the thyroid hormone system (Ottinger and Dean 2011). These rapid shifts in metabolic processes make migratory birds excellent models for understanding the potentially detrimental effects of environmental stressors, contaminants, and disease on human and ecosystem health.

Though it would be predicted that their high body temperature and metabolic rate would result in a shorter lifespan, many birds, including hummingbirds, parrots, and seabirds, exhibit remarkably long lifespans (Ottinger et al. 1995; Nisbet et al. 1999; Holmes and Ottinger 2006; Ottinger and Lavoie 2007). This longevity lends itself to comparisons with human longevity and potential effects of environmental stressors. Typically, long-lived birds have adaptions such as apparent resistance to oxidative damage (Ogburn et al., 2001). Long-lived birds usually don't breed until later in life, unlike short-lived species, and generally produce relatively few (1–2) chicks per year. As such, exposure to environmental contaminants that promote oxidative damage may have adverse effects even in long-lived birds, because the increased damage would weaken overall health and potentially shorten lifespan. Because these birds produce a relatively low number of chicks annually, impaired reproduction and attenuated lifespan have the potential for long-term risk to the population.

1.3.8.7 Ecosystem Restoration and Risk of Adverse Effects from Chemical Exposure

Ecosystem restoration along the Gulf Coast demands accountability for the effectiveness of restoration methods. A primary goal of restoration is more resilient wildlife populations, which can be indicated by increased survival rates and reproductive success. Long-term monitoring of these life history variables is time- and cost-intensive and often provides endpoints without identifying the processes that caused the result, particularly in cases where population recovery is poor. Consequently, few restoration efforts can be reliably assessed, which limits our ability to improve restoration methods. Use of metrics related to physiological health can take less time and often cost less than long-term monitoring while providing a better assessment of the status of a population. Yet for birds, little is known about which health metrics are most appropriate, informative, cost-effective, and convenient for practitioners to assess. Identifying ecologically-important avian health parameters using both large-scale retrospective and fine-scale, species-level approaches are needed. Given the unique characteristics of birds, it is critical to define pertinent metrics to assess the health of individuals and potential risk to populations. Potential overall measures are listed below to provide a general assessment of individual health and fitness.

- Survival and lifespan
- Reproduction and/or viability of young
- Growth rate (important for survival after fledging [Maness and Anderson 2013])
- Health (blood measures, lesions, feather and body condition, parasite load)
- Reproductive axis and other physiological mechanisms
- Neuroendocrine and molecular endocrine regulators

- Behavior (reproductive, stress, health indicators)
- Gonadal steroids, stress hormones
- Immune function and oxidative damage
- Physiological function (thyroid, adrenal)
- Neuroendocrine and/or regulatory status
- Organ systems and pathology

Recent publications provide more specific information on the adverse impacts of exposure to the oil released from the DWH oil spill. Studies of laughing gulls (*Leucophaeus atricilla*) and double-crested cormorants (*Phalacocorx auritus*) showed increased oxidative damage and deleterious effects on cardiac tissue and mortality of some birds (Horak et al. 2017; Pritsos et al. 2017; Harr et al., 2017). Homing pigeons (*Columba livia domestica*) showed altered flight paths after light oiling, suggesting impaired navigational capabilities and flight ability (Pérez et al. 2017). Western sandpipers (*Calidris mauri*) exposed to dietary oil showed reduced blood- and liver-related responses and histological indicators of a stress-related adrenal response (Bursian et al. 2017). Furthermore, there were behavioral impacts on takeoff and flight maintenance in western sandpipers following exposure to small amounts of external oiling (Maggini et al. 2017).

1.3.8.8 Summary

Habitat for birds that reside in or migrate through the GOM is decreasing due to industry, port and trade expansion, and urbanization. It is critical to protect the breeding and wintering grounds of these birds as the effects of climate change progress. Moreover, extreme weather events exacerbate the challenges faced by birds, especially those dependent on finding sufficient food resources to refuel during their migration. In addition to these challenges, there is growing concern for the effects of environmental contaminants and their potential adverse effects on birds, particularly those that are lethal to a subset of individuals or that more widely impair reproductive or metabolic endocrine function and/or depress immune function. It is critical to have reliable assessment tools so that managers can accurately evaluate risk to individuals and populations. Moreover, birds have unique characteristics that make them useful sentinels of ecosystem health. They are indicators of the health of the environment and, because of the close interrelationship with human coastal communities, they provide awareness and understanding of the status of One Health for the GOM.

1.3.8.9 References

Adkins-Regan E, Abdelnabi M, Mobarak M, Ottinger MA. 1990. Sex steroid levels in developing and adult male and female zebra finches (*Poephila guttata*). General Comparative Endocrinology. 78(1): 93-109.

Burger J. 2017. Avian resources of the northern Gulf of Mexico. In: Ward C, editor. Habitats and biota of the Gulf of Mexico: before the Deepwater Horizon oil spill. Volume 2. Fish resources, fisheries, sea turtles, avian resources, marine mammals, diseases and mortalities. New York (NY): Springer. p. 1352–1488.

Bursian SJ, Dean KM, Harr KE, Kennedy L, Link JE, Maggini I, Pritsos C, Pritsos KL, Schmidt RE, Guglielmo CG. 2017. Effect of oral exposure to artificially weathered Deepwater Horizon crude oil on blood chemistries, hepatic antioxidant enzyme activities, organ weights and histopathology in western sandpipers (*Calidris mauri*). Ecotoxicology and Environmental Safety. 146:91–97.

Gill FB. 1995. Ornithology, 2nd ed. New York (NY): W.H. Freeman.

Holmes DJ, Ottinger MA. 2006. Domestic and wild bird models for the study of aging. In: Conn PM, editor. Handbook of *Models for Human Aging*. Amsterdam: Elsevier. p. 351–366.

Harr, KE, Rishniw M, Rupp TL, Cacela D, Dean, KM, Dorr BS, Hanson-Dorr KC, Healy K, Horak K, Link JE, et al. 2017. Dermal exposure to weathered MC252 crude oil results in echocardiographically identifiable systolic myocardial dysfunction in double crested cormorants (*Phalacrocorax auritus*). Ecotoxicology and Environmetal Safety. 146: 76–82.

Horak KE, Bursian SJ, Ellis CK, Dean KM, Link JE, Hanson-Dorr KC, Cunningham FL, Harr KE, Pritsos CA, Pritsos KL et al. 2017. Toxic effects of orally ingested oil from the Deepwater Horizon spill on laughing gulls. Ecotoxicology and Environmental Safety. 146: 83–90.

Lazarus RS, Rattner BA, McGowan PC, Hale RC, Karouna-Renier NK, Erickson RA, Ottinger MA. 2016. Chesapeake Bay fish-osprey (*Pandion haliaetus*) food chain: evaluation of contaminant exposure and genetic damage. Environmental Toxicology and Chemistry. 35: 1560–1575.

Maggini I, Kennedy LV, Elliott KH, Dean KM, MacCurdy R, Macmillan A, Pritsos CA, Guglielmo CG. 2017. Trouble on takeoff: crude oil on feathers reduces escape performance of shorebirds. Ecotoxicology and Environmental Safety. 141:171–177.

Maness, TJ and Anderson, DJ. 2013. Predictors of juvenile survival in birds. Ornithological Monographs. 78(1):1–55.

Nisbet ICT, Finch CE, Thompson N, Russek-Cohen E, Proudman JA, Ottinger MA. 1999. Endocrine patterns during aging in the common tern (*Sterna hirundo*). General Comparative Endocrinology. 114: 279–286.

Ogburn CE, Martin GM, Ottinger MA, Holmes DJ, Carlberg K, Austad SN. 2001. Exceptional cellular resistance to oxidative damage in long-lived birds requires active gene expression. Journal Gerontology: Biological Sciences. 11: B468–B474.

Ottinger MA, Dean KM. 2011. Neuroendocrine impacts of endocrine disrupting chemicals in birds: life stage and species sensitivities. Journal of Toxicology and Environmental Health, Part B Critical Review. 14(5-7): 413–422.

Ottinger MA, Lavoie E. 2007. Neuroendocrine and immune characteristics of aging in avian species. Cytogenetic Genome Research. 117(1-4): 352–357.

Ottinger MA, Nisbet ICT, Finch CE. 1995. Aging and reproduction: comparative endocrinology of the common tern and Japanese quail. American Zoologist. 35: 299–306.

Pérez CR, Moye JK, Cacela D, Dean KM, Pritsos CA. 2017. Homing pigeons externally exposed to Deepwater Horizon crude oil change flight performance and behavior. Environmental Pollution 230: 530–539.

Pritsos KL, Pérez CR, Muthumalage T, Dean KM, Cacela D, Hanson-Dorr KC, Cunningham FL, Bursian SJ, Link JE, Shriner SA, Horak KE, Pritsos CA. 2017. Dietary intake of Deepwater Horizon oil-injected live food fish by double-crested cormorants resulted in oxidative stress. Ecotoxicology and Environmental Safety. 146: 62–67.

Ricklefs RE. 2010. Life-history connections to rates of aging in terrestrial vertebrates. Proceedings of the National Academy of Science. 107: 10314–10319.