Restoration without borders:
An assessment of cumulative stressors to guide large-scale, integrated restoration of sea turtles in the Gulf of Mexico

Matt Love[1], Chris Robbins[1], Alexis Baldera[1], Scott Eastman[2], Alan Bolten[3], Robert Hardy[4], Richard Herren[5], Tasha Metz[6], Hannah B. Vander Zanden[2] and Bryan Wallace[7]

October 2017

Suggested citation**:** Love, M., Robbins, C., Baldera, A., Eastman, S., Bolten, A., Hardy, R., Herren, R., Metz., T., Vander Zanden, H. B., and Wallace, B. (2017). Restoration without borders: An assessment of cumulative stressors to guide large-scale, integrated restoration of sea turtles in the Gulf of Mexico. (unpublished)

Supplemental materials available upon request. Please contact the authors at gulf@oceanconservancy.org.

- Data sources
- Data Methods
- List of Adjusted Stressors
- List of Excluded Stressors

[1]Ocean Conservancy; [2]University of Florida; [3]Archie Carr Center for Sea Turtle Research, University of Florida; [4]Florida Fish and Wildlife Conservation Commission; [5]Sea Turtle Conservancy; [6]Texas A&M University Galveston; [7]Conservation Science Partners, Inc.

Executive Summary

Following the BP *Deepwater Horizon* oil disaster in 2010, restoration programs operating in the Gulf of Mexico have committed to addressing restoration needs based on a broader ecosystem perspective, rather than one at the individual species or habitat level, or at the state or federal agency jurisdictional level. Effective ecosystem-scale restoration requires an integration and prioritization of strategies across administrative boundaries based on highest need. In this proof-of-concept demonstration study, Ocean Conservancy proposes a method for undertaking a cumulative impacts assessment that can serve as the foundation for planning integrated restoration, prioritizing project and accounting for ecosystem-scale stressors. Cumulative stressor assessments can help decision-makers select individual restoration projects based on the presence or absence of threats within their own jurisdictions, while seeing how those actions fit within a larger restoration mosaic and contribute toward regionwide recovery goals. Given the finite funding for mitigating human impacts on wide-ranging species over the broad geography of the Gulf of Mexico, it will be critical to implement projects with the greatest potential for addressing the stressors of highest concern for target resources.

The two sea turtle species with the greatest documented injury from the BP oil disaster, Kemp's ridleys (*Lepidochely kempii*) and loggerheads (*Caretta caretta*), were used as the targets for this case study. The natural resource damage assessment estimated that up to 173,000 sea turtles were killed from the disaster, including turtles from all life stages. These species were ideal for this type of cumulative impact assessment given the previous quantification of mortality estimates from recognized threats in their respective federal recovery plans. Using the threats identified in each species' recovery plan and the quantified annual mortality estimates of each threat across all life stages, we mapped the distribution of 39 threats (termed "stressors" in this study) for the two species. This methodology for quantifying impact could be applied to other species or habitats of restoration concern to understand where ecological losses are greatest.

The results of our assessment found that the annual mortality estimate from the bottom trawl fishery was an order of magnitude greater than any other stressor and therefore dominated the distribution of in-water cumulative impacts. We recognize that since the recovery plans were completed turtle excluder device compliance rates and effectiveness have increased due to industry cooperation and increased law enforcement and gear monitoring. While the list of stressors mapped for this assessment was not exhaustive, a key takeaway in our assessment is that few areas exist in the terrestrial or marine environment where little to no impact is present for these species.

We took the results of the cumulative impacts assessment a step further by showing examples of restoration activities that could be implemented across the range of both species in various jurisdictions. Tracking restoration outcomes is important to know whether programmatic recovery goals are on track. This might be achieved by using a systemwide recovery ledger, showing which restoration actions could be strategically implemented to neutralize or mitigate stressors, as well as the best locations for these actions. We applied the ledger analogy to restoring Kemp's ridley and loggerhead sea turtles using a conceptual approach. The map-based stressors assessment in conjunction with a restoration ledger can be used to identify areas of greatest restoration need, guide cross-boundary prioritization of threats and implementation of an integrated portfolio of restoration actions, and help programs evaluate and improve outcomes through adaptive management.

Introduction

In the field of conservation, ecological restoration is evolving from a project- or species-specific process to one that is large-scale and integrated at the systems level, particularly in marine ecosystems (Wasson, 2015; L. B. Crowder, 2006). Under an ecosystem-based, or landscape-scale, restoration approach, the connectivity between terrestrial and aquatic systems in decision-making is given priority while the geopolitical borders spanning interconnected systems are de-emphasized. Longstanding regionwide restoration initiatives in the United States have adopted an ecosystem-based, “border-blind” approach, recognizing that the sources of environmental impairment are distributed across multiple jurisdictions, ecosystems or human communities and should be addressed through coordination to achieve systemwide recovery objectives (Salt et al., 2008; Nawi & Brandt, 2008; Doyle & Miralles-Wilhelm, 2008).

The Gulf of Mexico region is attempting the most ambitious ecosystem restoration effort ever undertaken in the wake of the BP oil disaster. The more than 15-year effort involves multiple state and federal jurisdictions and several sources of funding totaling $12 billion. Officials recognize that achieving effective, large-scale restoration for shared Gulf resources depends on strong intergovernmental coordination that leverages funding, maximizes synergies and avoids project conflicts (Gulf Coast Ecosystem Restoration Council, 2016; *Deepwater Horizon* Natural Resource Damage Assessment Trustees, 2016). Sea turtles injured by the BP oil disaster symbolize the importance of taking an ecosystemwide, integrated restoration approach because they cross multiple jurisdictions and face a gauntlet of natural and anthropogenic stressors during their complex life cycle.

Quantifying and mapping the intensity and distribution of stressor impacts on ecosystems or specific resources is increasingly used in planning of large-scale restoration (Halpern & Fujita, 2013). Cumulative stressor (impact) assessments are powerful visualization tools highlighting the presence or absence and severity of known or emerging stressors (Halpern et al*.,* 2008). In the context of restoration, this type of assessment can be used as a conceptual recovery ledger, in which ecosystem debt is incurred from the multiple stressors reducing sea turtle populations, and stressor mitigation actions are taken to reduce those debts. Decision-makers can use this information to tailor restoration strategies to specific areas or habitats of importance to prioritize mitigation measures. Areas of low or high stress can help shape appropriate actions, whether to protect areas of low stress from further harm or to restore areas or resources subject to higher levels of stress.

We undertook a geospatial assessment of cumulative impacts in the Gulf using Kemp’s ridley (*Lepidochelys kempii*) and loggerhead (*Caretta caretta*) sea turtles to demonstrate the application of this type of assessment in the context of restoring wide-ranging species of significant conservation concern. Loggerheads and Kemp’s ridleys had the highest estimates of sea turtle mortality from the BP oil disaster (*Deepwater Horizon* Natural Resource Damage Assessment Trustees, 2016). The *Deepwater Horizon* Natural Resource Damage Assessment Trustee Council has outlined a stressor-centric approach to coordinating and planning restoration through strategic frameworks (*Deepwater Horizon* Natural Resource Damage Assessment Trustees, 2017) that will guide the coordination of resource-level recovery across political boundaries. Indeed, Gulf sea turtle restoration has a long history of collaboration among governments, agencies, industries, nongovernmental groups and volunteers (Plotkin, 2016). In this assessment we use sea turtles as a case study to illustrate how information on the distribution and intensity of stressors can guide populationwide recovery efforts.

We believe a stressor-based methodology for coordinating, prioritizing and tracking resource-level actions can be useful to Gulf restoration programs committed to large-scale, holistic restoration as they seek to maximize ecosystem benefits and returns on investment.

Methods

We undertook this assessment based on the hypothesis that spatial orientation of stressors is critical for planning a suite of integrated restoration activities that will achieve recovery at the ecosystem scale. To illustrate the complex landscape of stressors impacting sea turtles throughout their life cycle we mapped the extent and intensity of each threat identified in recovery plans for these species (threat is the term used in each recovery plan, we use it here interchangeably with the concept of a stressor). We used the definitions and scope of stressors important to population viability of these two species provided by the U.S. federal and binational recovery plans (NMFS, 2011; NMFS, 2008). Each recovery plan represents the current assessment of best available knowledge on the impact of stressors to loggerheads and Kemp's ridleys within U.S. waters.

We applied the methodology pioneered by Halpern et al. (2008 & 2009) in earlier marine ecosystem impact assessment efforts to quantify the cumulative impact across the Gulf of Mexico. The study area covers the U.S. exclusive economic zone within the Gulf of Mexico, including state waters and inland bays and estuaries. The project area was subdivided into 1-square-kilometer grid cells, or spatial assessment units which represent the resolution for analysis of all data. Data sets with a native resolution finer or coarser than 1 square kilometer were aggregated to this scale. We used the open-source software EcoImpactMapper (Stock, 2016), which improves analysis efficiency and the data documentation process over previous methods that require coding to integrate new data with the analysis.

Adopting the additive model developed from Halpern et al. (2008), we calculated a cumulative impact score I_c from all stressors using the following formula, where D_i is the log-transformed and normalized value of a stressor at location i, E_j is the expected presence or absence of the species at that location and μ_{ij} is the impact weight for the stressor on the species.

$$I_c = \sum_{j=1}^{n} \frac{1}{m} \sum_{i=1}^{m} D_i \times E_j \times \mu_{ij}$$

This impact score (I_c) represents the relative, combined ecological effect of every stressor for each discrete spatial unit of assessment in the Gulf of Mexico. The additive model assumes the increased ecological impact from each stressor is linear (Crain, 2008), meaning the total modeled effect of two or more stressors to the cumulative impact score are additive, increasing the impact score by the magnitude of the impact score of each individual stressor. While the interaction effects between different combinations of two or more stressors require further research to refine relationships between stressor combinations and how they impact species, this additive approach provides a reliable heuristic to a complex environment. This allows for a basic understanding of where stressors co-occur to create hot spots and how their combined impacts can be used to prioritize restoration actions.

The element of the model that quantifies the degree of impact from a stressor is the weighting factor, μ_{ij}, which is typically provided through expert elicitation. The second revision of both federal recovery plans for these species included quantification of estimated annual mortality for each threat at different life stages (i.e., nesting female, egg, hatchling, hatchling swim frenzy, juvenile and adult) (NMFS, 2011; NMFS, 2008). These estimates were used as the weighting factor, which we believe is an improvement over the typical expert elicitation approach because mortality estimates are based on quantified annual loss of turtles by life stage for each stressor, as opposed to expert opinion. The annual mortality for each life stage was adjusted by its reproductive value, which is an individual's potential for contributing offspring to future generations. The reproductive value differs by life stage, so the contribution value to the population for each life stage was converted to "relative reproductive values." Relative reproductive values (RRV) are based on the reproductive value of a nesting female, which equals 1. The summed annual mortality of a stressor in terms of RRV across life stages was used as the weighting factor, μ_{ij}, for each species and stressor combination.

In each recovery plan, annual mortality estimates were calculated over the entire population's range. However, the project area in this assessment is a subset of each species' range. Therefore, the weights for several terrestrial stressors had to be adjusted, because the primary extent of where their impact occurs lies outside the project area. For example, terrestrial predation of Kemp's ridley nests and hatchlings by native species is estimated to take the RRV equivalent of close to 3000 nesting females per year. A vast majority of this mortality occurs primarily in Mexico, where a majority of nesting occurs. Predation of Kemp's ridley nests in the U.S. is low not only due to lower nesting activity but also the use of nest corrals to protect all detected nests within Padre Island National Seashore. For the terrestrial stressors that differed in the project area relative to the full range of the population, we adjusted the annual mortality estimate by the proportion of nests inside and outside the project area. For Kemp's ridleys, we used the proportion of nests in Mexico and Texas over the five-year period of 2006 to 2010 to scale the weighting factor by nesting distribution within the project area. For loggerheads, a vast majority of nesting occurs in Florida, with a large proportion occurring in southeast Florida outside of the project area. We adjusted the annual mortality estimate by the proportion of nests in Florida between the Atlantic and Gulf of Mexico Index nesting beaches between 2012 and 2016 (Witherington et al., 2009). A list of adjusted stressors is available with the supplemental materials.

Calculation of impact is based on the species vulnerability to an activity through direct mortality, ancillary degradation to habitat or prey resources and sub-lethal impacts. Vulnerability is calculated as the combination of exposure and sensitivity. The element of sensitivity is provided by the weighting factor. The concept of exposure to a stressor depends on the extent of the stressor overlapping with the distribution of the species. Life stage distributions for each species are not currently available, although vessel and satellite data are beginning to fill these knowledge gaps (Hart et al., 2012; Mansfield et al., 2014; Shaver et al., 2013). All waters of the study area are potential habitat for one or more life stages of these two species. We assume distribution through time as a constant. This allows for the use of a general distribution of all life stages for both species combined, resulting in a ubiquitous area of probable occurrence across the U.S. waters of the Gulf of Mexico. The weighting factor is derived from the summation of impact across all life stages for each stressor. Therefore, specific distributions for each life stage are not required because they are included in the annual mortality estimate calculation. Due to the differential impacts of stressors on each species, loggerheads and Kemp's ridleys were analyzed separately.

Data on the species-specific impacts (weighting factor μ_{ij}) and geographic distribution of stressor intensity are required to model impacts. Impact and distribution information on each stressor was not available at the same degree of accuracy and resolution. In some cases, no data were available. Therefore estimates for annual mortality could not be quantified for every stressor. In each recovery plan, stressors with nonquantified annual mortality estimates fell into four categories: 1) no evidence of mortality based on best available information; 2) sublethal effects; 3) sublethal effects occur, and mortality has been documented, but data insufficient to assign an order of magnitude or 4) mortality documented or likely to occur, but data insufficient to assign an order of magnitude. We grouped the stressors into three general categories for analysis: 1) mapped and quantified, which indicates geographic and impact data were available in some form; 2) mapped but not quantified, indicating geographic data were present but information on impact was lacking or 3) not mapped but quantified, meaning geographic data were missing but impact information was available. It is important to consider all three categories when evaluating the cumulative impacts to these two sea turtle species.

Developing the spatial distribution of each stressor was the basis for quantifying cumulative impacts in the project area. A total of 63 discrete stressors were identified as relevant to influencing the status of at least one or both of the species. We compiled the best publicly available information representing activities related to the impacts of each stressor. Primary data sources included databases maintained by U.S. government agencies (e.g., Environmental Protection Agency, 2017; NOAA, 2017; Toft, 2013), universities (e.g., Western Carolina University, 2017), resource management agencies (e.g., Florida Fish and Wildlife Conservation Commission, 2017), or data products developed by government agencies for the purposes of managing regulated resource use activities (e.g., SoundMap Working Group, 2012). For a number of stressors, open source data from previous cumulative impact assessments (Halpern et al., 2008; Halpern et al., 2015) represented the best resource for mapping the distribution of particular stressors such as nutrient and organic pollutant loading from nonpoint source pollution in regional rivers and streams. Many terrestrial stressors are associated with human use activities or the degree of the human built infrastructure (NOAA, 2010). For those correlated with distribution of built infrastructure we used a human use impact index based on the degree of urbanization as a proxy for each related stressor.

For a subset of human use stressors without direct measures of activity, we developed proxies representing the reasonable distributions of where the use occurs. For example, data on fishing effort distribution by the oyster dredge fishery were not readily available. As such, we used the best available data on oyster reef distribution in states that allow use of this fishing gear (Anson, 2011).

As described in each recovery plan, it was not possible to calculate mortality estimates for every life stage exposed to all stressors due to data gaps. Briefly, if the stressor resulted in sublethal effects or sufficient data was not available to assign an order of magnitude to the estimate of annual mortality from that stressor, a quantified value was not possible. While there may be a summed adjusted mortality estimate across all life stages for a stressor, if the impact to any particular life stage was considered sublethal, that life stage impact was not quantified in the mortality estimate. The result is a reduction in the cumulative impact score from the absence of that particular stressor-life stage combination in the full assessment. Therefore it is important to recognize this cumulative impact assessment represents the minimum possible impact given existing information. A list of the stressors excluded from the spatial assessment is included with the supplemental materials. Future refinements to source data and appropriate proxies will improve the capabilities to represent a more complete picture of potential population sinks in the Gulf of Mexico.

Results

Within the recovery plans, a total of 51 stressors were assessed for Kemp's ridleys and 61 stressors for the northwest Atlantic population of loggerheads, which includes the Gulf of Mexico. The stressors represent a range of anthropogenic activities such as incidental catch in commercial and recreational fisheries and habitat impairment from pollution or coastal development. Sources of natural mortality such as predation or tropical storms were also included. We estimated mortality based on the quantified impacts for each stressor and represented spatially the activities underlying the impacts.

Spatial representations of 34 stressors (out of 51) impacting Kemp's ridleys and 36 (out of 61) for loggerheads were developed. Insufficient data prevented the calculation of annual mortality estimates for eight mapped Kemp's ridleys stressors and nine for loggerheads, as weighting factors are required for the impact model. Three Kemp's ridley and four loggerhead stressors represent sublethal impacts for which direct effects on the population are uncertain or not fully known. These mapped but nonquantified stressors are included in Figure 5, which illustrates the distribution of all mapped stressors combined. The remaining stressors with quantified mortality estimates, 23 for Kemp's ridleys and 23 for loggerheads, were mapped to illustrate the areas where the collective impacts of stressors are likely greatest for sea turtle populations in U.S. Gulf of Mexico waters.

The maximum cumulative impact scores provide a relative measure of the total potential annual loss of each species with the spatial distribution of higher scores representing areas of greatest concentration of known stress for each species. The maximum impact score for Kemp's ridleys was 2,811 across the project area. The maximum impact score for loggerheads was 12,103. Comparison of the relative maximums between the species indicates loggerheads are exposed to a greater absolute cumulative threat than Kemp's ridleys, not accounting for differences in conservation status. Since the scale of the weighting factor in the model is the same for both species (i.e., RRV of annual mortality), it is clear that the stressor impacts are theoretically higher for loggerheads than for Kemp's ridleys, in terms of turtle mortality in hotspots. The conservation status of each species needs to be included in an evaluation of potential mitigation measures based on comparison of relative impact scores. While the impact score for Kemp's ridleys is much lower than loggerheads, the effect of the assessed threats has a potential greater impact to Kemp's ridleys because they have a much smaller population. In the additive model, which uses overlapping geographies to show stressor area extent, the delineation of stressors must be accurate to avoid artificially inflating the cumulative impact scores due to geographic error. For example the highest-impact anthropogenic stressor for both species is the bottom trawl fishery (NMFS, 2008). The distribution of the fishing effort was derived from the GPS locations associated with the electronic logbook system used to manage the fishery (NMFS, 2017a), which provides highly accurate spatial locations of each fishing vessel at scales much less than the 1-square-kilometer resolution of the assessment grid. In contrast, other federally managed fisheries are only required to provide data at a much coarser 1-degree resolution (approximately 11,000 square kilometers) due to the proprietary nature of fishing activity and catch information, resulting in the spatial distribution of the fishing effort data covering an area larger than the area actually fished.

With the subset of stressors included in this analysis, one can still see there are few areas where species exposure to stressors is low. For both species, areas of high cumulative impact scores represent locations of significant human activity while areas of lowest impact tend to be far offshore or regions of low human activity. Areas of high relative impact span all habitats important to the life cycle of each population from terrestrial nesting beaches to developmental pelagic habitats and coastal foraging grounds of adults and subadults. Figures 1 and 2 illustrate the total area of impact from a subset of stressors to loggerheads along with the degree of impact to the population, adjusted for differences between the project area and the full range of the population.

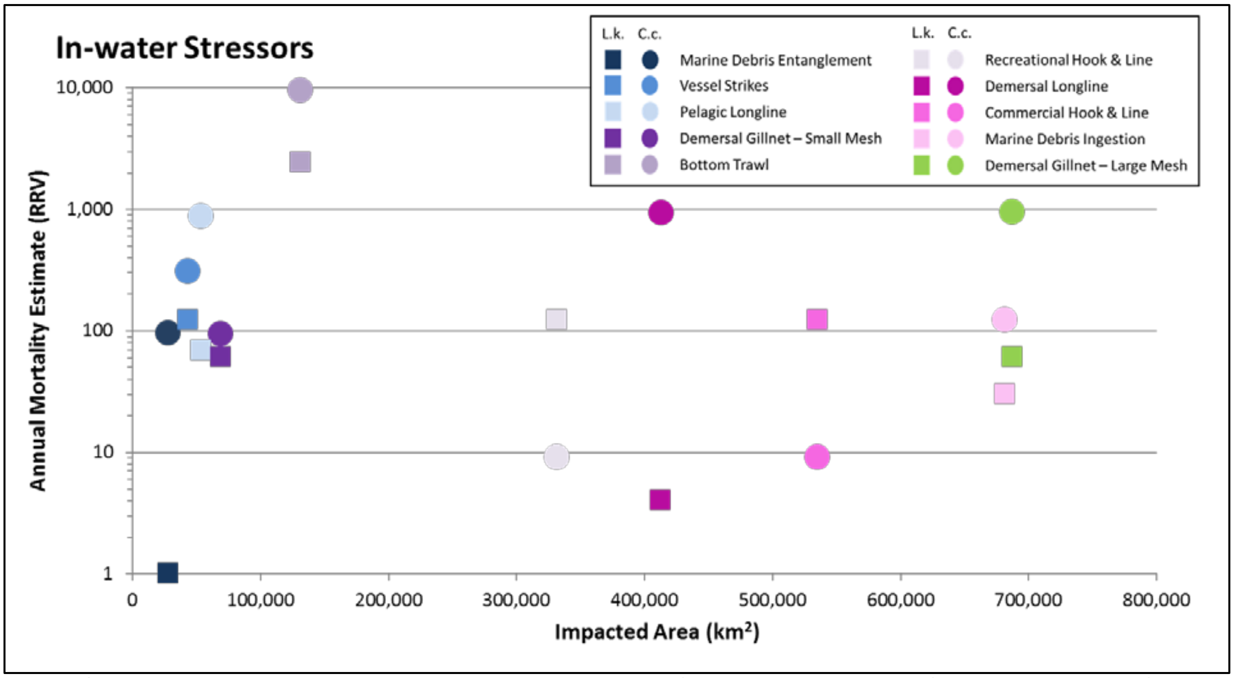

Figure 1. Annual mortality estimates (RRV) sorted by size of total impacted area for a select suite of in-water stressors. L.k. represents Kemp's ridleys (*Lepidochelys kempii*), and C.c. represents loggerheads (*Caretta caretta*).

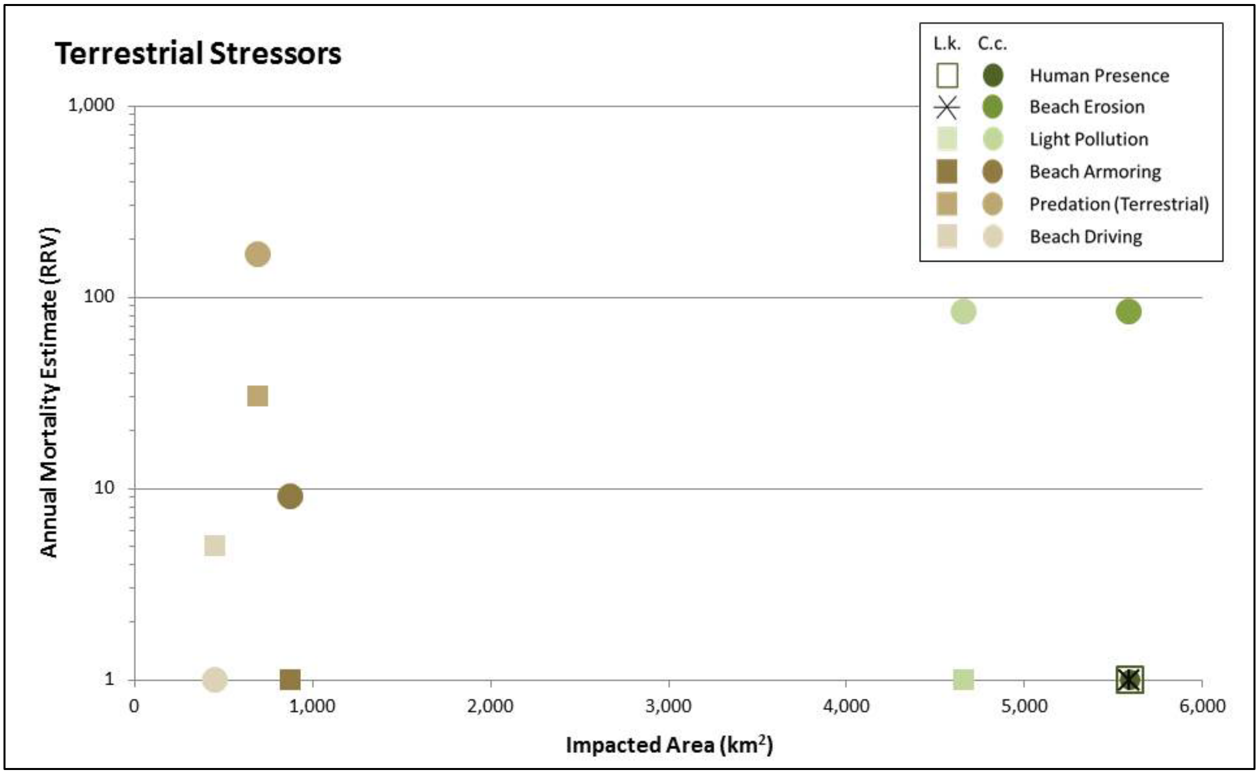

Figure 2. Annual mortality estimates (RRV) sorted by size of total impacted area for a select suite of terrestrial stressors to loggerheads.

Given the similarity of impact from quantified stressors for each species, the distribution of cumulative impact is relatively similar. For in-water stressors the bottom trawl fishery contributes the greatest impact to each population. The bottom trawl mortality estimate used in this analysis represents the level of mortality from this fishery at the time of recovery plan development in 2008 for Kemp's ridleys and in 2011 for loggerheads. The annual mortality estimate for this activity is an order of magnitude greater than all other quantified stressors in the recovery plan for both in-water and terrestrial stressors. Figures 3 and 4 show that the areas of greatest impact for both species occur around the Mississippi River Delta and extend through Louisiana nearshore waters west of the delta. There are other hotspots driven by this fishery around the Dry Tortugas and the shelf edge off the Texas coast. These areas represent locations of greatest relative vulnerability based on the assumption that each species is evenly distributed across the project area, and that the mortality estimate from the recovery plan represents the current level of mortality from this fishery.

The recovery plan mortality estimates used in our analysis do not reflect improved compliance with turtle excluder devices (TEDs) and lower sea turtle capture rates documented in the otter trawl shrimp fishery from 2014-2016 (NMFS, 2017b). Improved TED compliance can be attributed to enhanced gear monitoring efforts, industry assistance and law enforcement actions (M. Barnette, personal communication, September 5, 2017). For example, Texas Parks and Wildlife and NOAA checked approximately 100 TEDs during recent enforcement exercises and reported no TED violations (Texas Parks and Wildlife Department, 2017), possibly due to enhanced patrols funded through BP oil disaster restoration. Currently, TEDs are not required on inshore skimmer trawls, but

NOAA is considering approval of draft rules requiring TEDs in this fleet. In recognition of the impact of this gear type on sea turtle populations, a restoration project targeting TEDs on skimmer trawls in Mississippi waters was awarded in 2016 and will be managed by the Mississippi Department of Environmental Quality in collaboration with the National Fish and Wildlife Federation. If improved TED compliance and effectiveness in the otter trawl fishery continues and is sustainable, sea turtle mortality estimates may need to be recalculated to reflect fewer fatal interactions with this fleet. In addition, sea turtle mortality estimates could further change if TEDs are ultimately required and enforced in skimmer trawls.

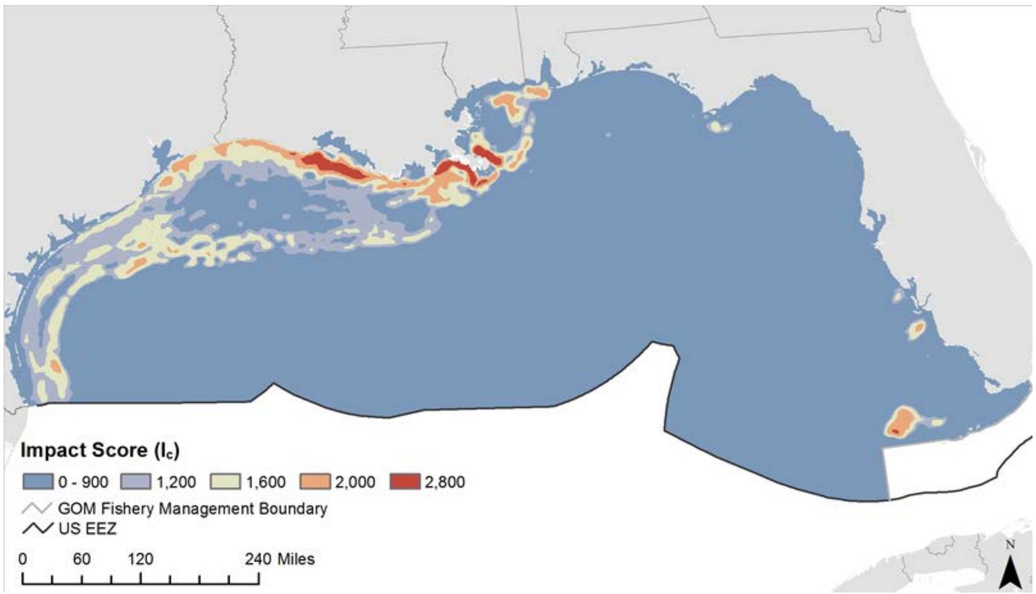

Figure 3. Cumulative impact scores for Kemp's ridleys. Scores were binned using the "natural breaks" algorithm in ArcGIS and rounded to nearest hundred value.

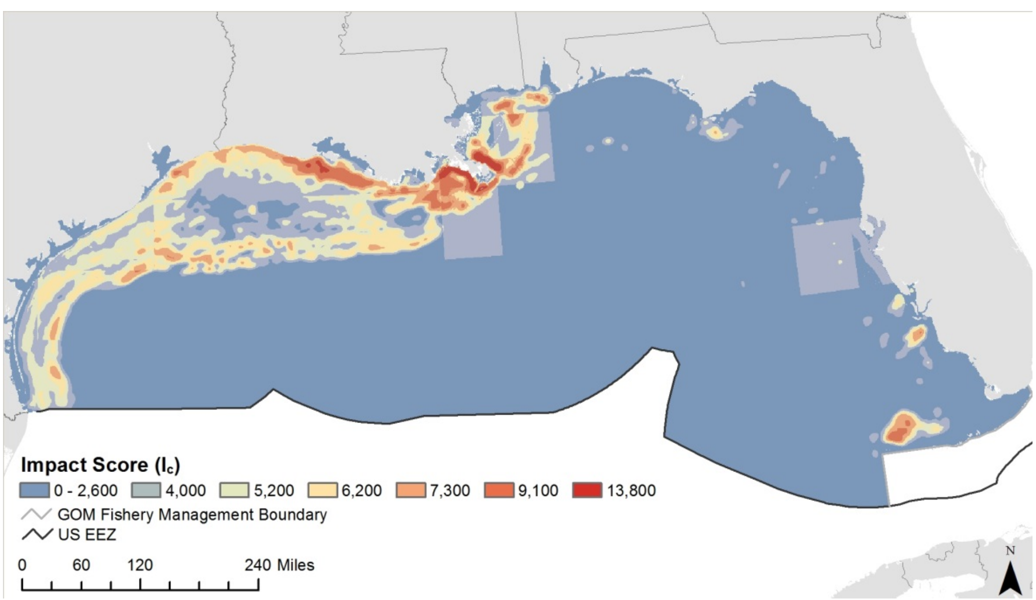

Figure 4. Cumulative impact scores for loggerheads. Scores were binned using the "natural breaks" algorithm in ArcGIS and rounded to the nearest hundred value.

Additional in-water stressors of high impact are associated with bycatch from other fisheries and vessel strikes. Data for fisheries with significant bycatch include pelagic longline, demersal longline and demersal gillnets (NMFS, 2003b), which are represented at much coarser resolutions than the bottom trawl fishery, represented by the rectangular impact areas in Figure 4. Demersal longline and large mesh gillnets are estimated to kill approximately 2,000 loggerhead turtles and fewer than 100 Kemp's ridleys every year (NMFS, 2008; NMFS, 2011), with small mesh gillnets killing fewer than 200 of both species combined (NMFS, 2008). Demersal longline effort occurs Gulf-wide on continental shelf and slope waters, while the small mesh gillnet fishery is concentrated off the coast of Tampa and southwest Florida. The pelagic longline fishery, and potentially its impacts, is underrepresented as the data provided for this fishing gear type only included the coastal logbook survey vessels. The full distribution effort of the pelagic longline fishery in waters of the continental shelf and slope of the northern Gulf are not represented. Yellowfin tuna and swordfish are the target species for the pelagic longline fishery with major home ports located in Panama City, Florida; Destin, Florida; Dulac, Louisiana and Venice, Louisiana (NMFS, 2004).Therefore, it is important to recognize that more complete fishing data are needed to improve the fishery's estimated impacts on both populations.

Two stressors are associated with recreational fishing: recreational hook and line, and vessel strikes. Anglers fishing from piers, boats and beaches fall into recreational hook and line, while vessel strikes is a broader category that includes propeller and collision injuries from boats and ships. Annual mortality estimates in the recreational hook and line fishery is 122 individuals for Kemp's ridleys and nine for loggerheads. Vessel strikes represent mortality and sublethal impacts from a boat striking a turtle while it is on or near the surface of the water. The annual mortality estimated from vessel strikes is 122 for Kemp's ridleys and 308 for loggerheads (NMFS, 2008; NMFS et al., 2011). The impact generated from the model is a function of boat traffic derived from the number of access points (boat ramps and marinas) weighted by the amount of development (a proxy for population of boaters) within a 10-kilometer radius of each access point. We believe this provides a reasonable basis for estimating where the strikes would be most common. We estimate this stressor to be highest in southwest Florida from Tampa Bay to Fort Myers, with other hotspots near Destin, Florida and Galveston Bay, Texas.

Unlike commercial fisheries, no comparable fisheries observer program exists for the recreational fishery, and, as such, data on sea turtle encounters in that sector are not independently collected. Estimates were based on strandings data and voluntary reports of incidentally hooked animals. Recreational fishing effort has generally increased in the Gulf since the early 2000s, so the number of interactions and mortalities is potentially higher than reflected in the data used for this analysis. For example, since 2010, an increasing number of sea turtle interactions with recreational anglers has been reported in some states, particularly in the northern Gulf, where juvenile Kemp's ridleys develop and forage (Coleman et al., 2016). In addition, the number of angling days has increased every year since 2010, though this trend could be related to cheaper fuel and could be temporary if fuel prices increase (Karnauskas et al., 2017). Therefore, the mortality estimates for recreational hook and line are likely conservative and warrant further analysis.

Terrestrial stressors impact nesting females, the incubating eggs and emerging hatchlings. On U.S. beaches, estimates of mortality from terrestrial stressors are an order of magnitude lower than fishery bycatch-induced mortality. Given the magnitude of impact from the in-water stressors, the combined terrestrial stressors are not visible on the map due to the full scale range. However, mortality from nest predation on Mexican beaches, where a vast majority of Kemp's ridleys nest, is estimated to be as high as bottom trawl fishing in U.S. waters. The difference in scale of impact from in-water to terrestrial stressors give the impression on the map that that there is little impact to terrestrial life stages when compared on the same scale as in-water threats. However it is important to recognize that terrestrial habitats are critical for the life cycle of sea turtles. While direct mortality estimates may not result in a high impact score for each stressor, a reduction in reproduction from reduced habitat availability by degradation from stressors does reduce the overall viability of these populations.

The primary stressors modeled in this assessment, in terms of annual mortality estimates, are beach erosion, light pollution and predation. The first two result in mortality from loss of nests with the eroding beach and disorientation of emerging hatchlings as they seek the brightest horizon on their way to the sea. Light pollution occurs in areas of greatest development around southwest Florida from Tampa Bay to Fort Myers, an area from Panama City, Florida to the Louisiana-Mississippi state line, and areas of Galveston and Corpus Christi, Texas. Beach erosion is greatest around St. George Island, Florida, parts of the Alabama and Mississippi coasts, and the Galveston and South Padre Island areas on the Texas coast. Predation, from native and exotic predators, is the loss of primarily the egg and hatchling life stages as they incubate in the nest or make their way to the sea. The distribution of native species predation is modeled using the distribution of the coyote and red fox. Other primary predators such as ghost crabs, raccoons and grey foxes were not included due to the lack of data on their distribution. Areas of greatest predation risk, assumed here to be where the two predators overlap in distribution, are the northern Gulf from St. George Island, Florida to the Louisiana-Mississippi state line; and areas of the central Texas coast between Galveston and Corpus Christi.

The Gulf-wide scale used to map stressors is too large to show the relatively narrow strip of impacted nesting habitat which is typically less than 200 meters wide. To fully characterize the impacts to this habitat, the scale of the assessment units would need to be reduced to better match the scale of the habitat.

The areas of lowest relative cumulative impact are in coastal waters off the Florida Panhandle where the bottom trawl fishery is not active. Additionally, this area is also devoid of petroleum industry activity. This likely reduces the exposure to other stressors like potential oil and toxin spills from transport between industrial facilities. This area is important for consideration by the restoration community, because it is more efficient to preserve an area in good condition through conservation measures and prevent decline of ecosystem services than to remediate an area in poor condition (Benayas et al., 2009; Possingham et al., 2015). Various protections already exist in this region, from the permanent pelagic longline exclusion zones of the DeSoto Canyon area to the numerous aquatic preserves protecting the extensive seagrass beds. The stressors ranking the highest in this region are related to recreational activities such as the hook and line fishery and vessel strikes. In contrast, terrestrial stressors tend to be higher in Florida than other Gulf states due to the degree of development occurring along the beaches used by nesting sea turtles. In Texas, Padre Island National Seashore represents the opposite extreme with low impacts to sea turtle nesting beaches.

While interpreting the spatial patterns of the quantified stressors, it is important to recognize the suite of stressors absent from the analysis, i.e., the nonquantified or sublethal effects (a complete list is available with the supplemental materials) and the changes to sea turtle habitat and ecosystem functions forecasted to occur from climate change. Figure 5 illustrates the presence of all stressors to both species, quantified and nonquantified, regardless of impact. The recovery plan expert working groups for both species suggested that nonquantified threats could possibly have a collectively greater impact than all quantified stressors combined. For example, loss of suitable habitat for foraging and nesting creates a long-term deficit for population viability that may last indefinitely. The mapped stressors that represent sublethal or nonquantified impacts for Kemp's ridleys are primarily in marine waters located off the coast of Louisiana near the mouth of the Mississippi River and extending west to Galveston, Texas. This area represents the primary extent of annual hypoxic zones, oil and gas infrastructure, and hotspots for oil spills. The loggerhead sublethal or nonquantified stressors with spatial data represent shore-based stressors that include beach nourishment, erosion and beach debris. Climate change-induced impacts are likely to reduce the availability of nesting habitat and alter the ecosystem functions that support healthy sea turtle populations (Fuentes et al., 2010). While we are able to develop spatial distributions or use model derivatives to understand the extent of sublethal or nonquantified stressors, we still do not have a science-based evaluation of their collective impacts to these species.

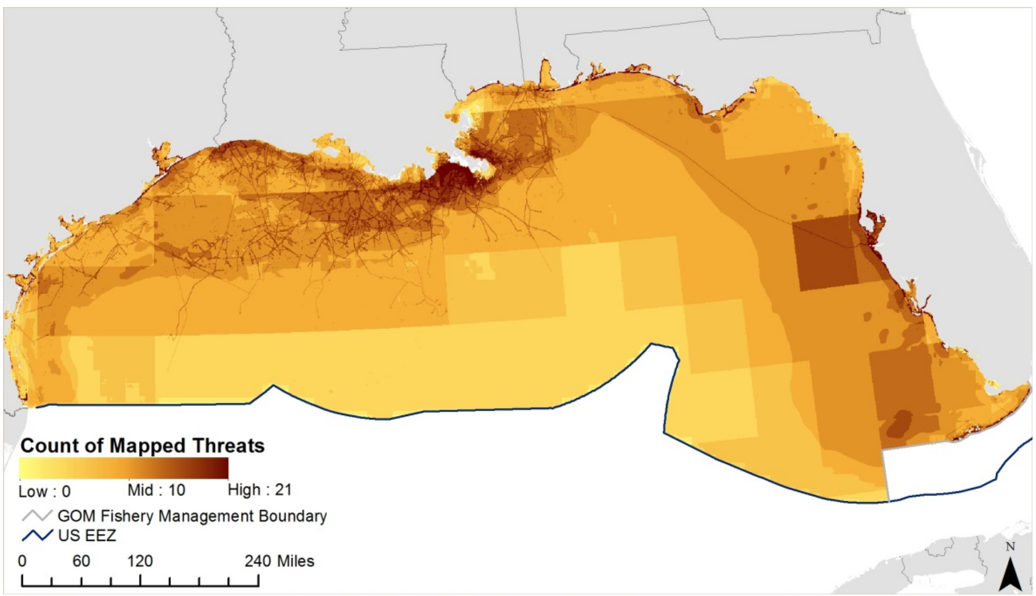

Figure 5. The sum presence of all mapped stressors (quantified and nonquantified) for both species (n = 21).

Discussion

Restoring the Gulf of Mexico ecosystem in response to the BP oil disaster will be a multi-decadal endeavor. This is particularly the case for long-lived species such as sea turtles that can take up to a decade or more to reach the reproductive life stage, making it difficult to detect changes in populations as they respond to restoration actions (NAS, 2016). In as large and dynamic a marine ecosystem as the Gulf of Mexico, effective restoration requires coordination across the multitude of jurisdictions best positioned to address barriers to recovery. The results of the cumulative stressors assessment reveal a) the distribution of threats to Kemp's ridley and loggerhead sea turtles across jurisdictions and b) the individual and collective impact of each threat across each jurisdiction. Ultimately, restoration decision-makers need to apply these results in ways that maximize the population-level benefits of individual agency actions.

Prioritizing decisions with a finite amount of funding is one of the many challenges of restoration. Ranking stressors from greatest to lowest impact and showing the distribution of those stressors can help clarify the types of actions that would best address the various threats. For example, the most significant threats to Kemp's ridleys in terms of mortality are predation, concentrated in the primary nesting grounds in Mexico (not mapped), and bottom trawling. The latter is a Gulf-wide issue, although the northern Gulf and areas of the continental shelf near southwest Florida are of greatest concern due to the historical bottom trawling effort and density of foraging sea turtles in these areas (Hart et al., 2012; Shaver et al., 2013). Bottom trawling is also the cause of greatest mortality for loggerhead sea turtles, followed by demersal gillnets and legal harvest of sea turtles from Caribbean and Atlantic waters (not mapped). Improved compliance with TEDs in the Gulf of Mexico otter trawl fishery in recent years due in part to industry assistance and increased enforcement has resulted in greater TED effectiveness and in lower Kemp's ridley and loggerhead capture rates. Aside from the primary drivers of mortality, sublethal stressors such as marine debris and shoreline hardening are also of concern, but additional information is needed to assess their population-level effects that in turn will help decision-makers prioritize restoration actions and meet restoration and recovery goals.

Protecting Kemp's ridley eggs from predators to increase hatchling emergence and survival on Mexican nesting beaches would help mitigate a significant source of mortality. Similarly, reducing incidental bycatch and mortality in the bottom trawl fishery across U.S. jurisdictions by enhancing observer programs and identifying bycatch hot spots, combined with state enforcement enhancement or temporal or spatial management developed in cooperation with industry, would be beneficial for both species. These actions, taken from official restoration or recovery planning documents, are meant to be illustrative of an integrated, regionwide approach to restoration and do not represent the full suite of actions needed to meet recovery goals.

Gulf restoration decision-makers are taking important steps to implement ecosystem-based restoration across geopolitical borders. An example of this approach is one that the Regionwide Trustee Implementation Group is executing on behalf of the *Deepwater Horizon* Natural Resource Assessment Trustee Council. The Regionwide TIG created strategic frameworks to promote the coordination of projects for wide-ranging injured natural resources, including sea turtles, marine mammals, birds and oysters. Under these frameworks, a portfolio of restoration activities will be implemented across all five Gulf states and in nearshore and offshore waters of the Gulf to maximize benefits. In another example, the Trustee Council initiated a Gulf-wide sea turtle restoration project aimed at improving sea turtle survival during key life stages by addressing the most serious threats. Activities implemented with BP oil disaster funding are noted in Tables 1 and 2.

We believe that mapping stressors and their cumulative impacts adds a useful visual dimension to planning, prioritizing and coordinating restoration activities at an ecosystem scale. In some cases, it might be a better use of restoration funding to protect areas of relatively low stress, preventing sea turtle nesting or foraging grounds from additional impairment. Protecting intact, functional habitat is often more time- and cost-effective than restoring degraded habitat to regain the same level of ecosystem services (Benayas et al., 2009; Possingham et al., 2015). This strategy might be appropriate to blunt the impacts of projected sea level rise. Regardless, cumulative stressor assessments can help decision-makers select individual restoration projects based on the presence or absence of threats within their own jurisdictions, while understanding how those actions fit within a larger restoration mosaic and contribute toward regionwide recovery goals.

The Gulf restoration programs will want to know where and how their individual investments are collectively addressing threats and achieving recovery objectives. This might be achieved by using a systemwide recovery ledger, showing where restoration actions, and which ones, could be strategically implemented to neutralize or mitigate stressors. We applied the ledger analogy to restoring Kemp's ridley and loggerhead sea turtles using a conceptual approach (see Tables 1 and 2). In this approach, we showed the stressors of greatest concern in relation to the affected sea turtle life stages and each geographic area where those threats have been documented. One or more example restoration activities are provided for each stressor. We identified the geography in which the activity is currently underway with BP oil disaster funding or where that activity is potentially needed to address the relevant stressor.

The cumulative stressors assessment shows where the combined threats might result in the heaviest impacts relative to sea turtle abundance and where restoration actions are urgently needed to reverse declines and accelerate recovery. A restoration ledger complements the assessment by showing the distribution of threats and their relative impacts across geographies and which restoration actions are underway or still needed to meet programmatic recovery goals. As efforts successfully ameliorate the threats of greatest concern, these can be downgraded on the ledger, while other threats of lower but ongoing concern are elevated. In future iterations of the restoration ledger, as stressors are reduced, the estimated rangewide mortality would also decrease. Mortality reductions could also be tracked and quantified for each geographic area in the ledger or an accompanying table. A robust monitoring program with standard metrics for monitoring project-level success, combined with population or resource-level assessments, would inform whether restoration activities have achieved improvements in resource status through stressor abatement (Baldera et al., 2017).

Future research to better refine our understanding of sea turtle distributions, the distribution of stressors and the associated level of activity for each stressor would allow restoration planners and resource managers the ability to prioritize specific actions that would provide the greatest benefit to sea turtle population recovery. For example, fishery time-area closures, which could greatly reduce sea turtle bycatch, require reliable information on the timing and distribution of turtles in an area to have the greatest recovery outcomes. Scientifically rigorous estimates of population-level impacts resulting from threats enable resource managers to make informed restoration decisions and to more accurately track restoration outcomes.

Initiatives are underway to develop more comprehensive life history distributions for many species in the Gulf of Mexico based on data from research and monitoring programs (Arnaud et al., 2017). This comprehensive monitoring information has not previously been quantified at the Gulf-wide scale. By synthesizing the best available comprehensive data for target species and ecosystems in the Gulf, a foundation of information is available for more empirical risk assessments applicable to broader groups of marine resources and ecosystems. With an improved understanding of the overlap between human activities and the distribution and abundance of resources targeted for restoration, managers can develop geographically targeted strategies. Developing a Gulf-wide impact index can help in this regard. By integrating an ecosystem perspective with the distribution of stressors and a better understanding of resource condition, ecosystem models can provide a process to evaluate restoration actions. This type of assessment for planning and tracking management actions can be a valuable scientific tool for other important marine species and ecosystems targeted for restoration.

Conclusion

Kemp's ridley and loggerhead sea turtles were ideal natural resources for this assessment because the mortality estimates associated with their threats had largely been quantified by experts during recovery planning. We recognize that threat quantification is not an insignificant undertaking and might not be feasible for all focal natural resources. Even qualitative stressor assessments can put restoration priorities and actions into clearer perspective. However, a growing number of comprehensive, long-term ecosystem monitoring efforts in the Gulf, or syntheses derived from those datasets, will increasingly enable scientists to conduct empirically based and spatially explicit cumulative impact assessments on living marine resources. These will in turn aid decision-making in restoration and natural resource management.

We are encouraged to see restoration programs take steps toward coordinating and integrating restoration activities and approach restoration as an ecosystem-wide endeavor. We believe cumulative stressor assessments and restoration ledgers accounting for stressors (costs) and restoration efforts (gains) are tools that programs can use to plan and prioritize activities, evaluate restoration progress and improve results through adaptive management.

Table 1. A conceptual approach to restoring Kemp's ridley sea turtles by addressing the stressors of greatest concern across relevant jurisdictions using BP oil disaster funding

Stressor	Est. rangewide mortality[1]	Affected life stages	Examples of activities addressing stressors and supporting recovery[2]	TX	LA	MS	AL	FL	Open Ocean	Outside U.S. Gulf (stressors not mapped)
Predation (terrestrial)	2970 (Mexico) 30 (Texas)		Maintain and reinforce habitat protection on nesting beaches	●						Mexico ●
			Maintain hatchling production/survival at levels to achieve recovery goals	●						Mexico ●
Bottom trawl	2436		Temporal and spatial fishery management to reduce sea turtle bycatch in Gulf commercial fisheries	●[3]	○	○	○	○	(EEZ off TX)[4] ●	
			Expand existing or develop new observer programs and enhance analytical capacity within the program to improve bycatch estimates, identify hot spots	●	●	●	●	●	●	
			Enhance state enforcement efforts to improve compliance with existing sea turtle conservation requirements	●	○	○	○	○	○	
Vessel strikes	122		Develop a comprehensive GIS database to assess vessel interactions and identify hot spots	○	○	○	○	○		
			Support or enhance stranding network response and rehabilitation capacity	●	●	●	●	●	●	
			Boater education in areas of high vessel traffic and sea turtle abundance	○	○	○	○	●		
Recreational hook & line	122		Increase monitoring of angler/sea turtle interactions		○	○	○	○	○	
			Engage angler community on best practices for reducing harm to sea turtles during interactions		○	○	○	○	○	
Commercial hook & line (incl. demersal)	122		Pilot new technologies for monitoring and estimating bycatch			○	○	○	○	Mexican shark fishery ○
			Research and implement new technologies for reducing bycatch			○	○	○	○	Mexican shark fishery ○
Top-/mid-water trawl	122		Require TEDs or equally effective bycatch reduction measures							Mid-Atlantic ○
			Distribute turtle excluder devices & provide hands-on training							Mid-Atlantic ○
Demersal gillnet (small & large mesh)	122		Reduce mortality and ensure enforcement of existing fisheries regulations	○	○	○	○	Small only ○	Small only ○	
Cold stunning	92		Support or enhance stranding network response and rehabilitation capacity	●	●	●	●	●		NE U.S.[5] ○
Pelagic longline	69		Implement monitoring to improve bycatch estimates and measures to reduce bycatch[6]	○	○	○	○	○	●	Mexico ○

Key

Generalized life histories	
Terrestrial zone (nesting adult, hatchling stage)	
Oceanic zone juvenile (foraging in offshore surface waters, algal mats)	
Neritic zone juvenile (foraging in coastal waters)	
Oceanic zone adult (foraging offshore)	
Neritic zone adult (foraging, mating in coastal waters)	
Adapted from NMFS (2011)	

BP oil disaster-funded activity underway ● Potential need for additional oil disaster-funded activities ○ Stressor present and quantified

[1]Stressors having a "Total Estimated Adjusted Annual Mortality" (i.e., adult female equivalent) of 50 or higher were included. This subset of stressors accounts for more than 95 percent of total estimated annual mortality.
[2]Examples are for illustrative purposes and do not represent a complete set of recovery actions. Adapted from the following unless otherwise noted: (NMFS, 2011; *Deepwater Horizon* Natural Resource Damage Assessment Trustees, 2016; *Deepwater Horizon* Natural Resource Damage Assessment Trustees, 2017)
[3]Not a BP oil disaster-funded activity. The purpose of the Texas May-July shrimp fishery closure (in effect since 1981) is to allow shrimp growth, but the closure also benefits and protects nesting female sea turtles swimming in the area during the same period.
[4]implemented by the National Marine Fisheries Service to complement and support compliance with the Texas shrimp fishery closure.
[5]Primarily Cape Cod and Long Island Sound.
[6]The Pelagic Longline Bycatch Reduction Project is underway regionwide and open to fishermen based in all Gulf states; however, the fishery and associated bycatch occurs mostly in the open ocean outside state territorial waters.

Table 2. A conceptual approach to restoring loggerhead sea turtles[1] by addressing the stressors of greatest concern across relevant jurisdictions using BP oil disaster funding

Stressor	Est. rangewide mortality[2]	Affected life stages	Examples of activities addressing stressors and supporting recovery[3]	TX	LA	MS	AL	FL	Open Ocean	Outside U.S. Gulf (stressors not mapped)
Bottom trawl	9417		Expand existing or develop new observer programs and enhance analytical capacity within the program to improve bycatch estimates, identify hot spots	●	●	●	●	●	●	
			Enhance state enforcement efforts to improve compliance with existing sea turtle conservation requirements [4]	●	○	○	○	○		
Demersal Gillnet (large & small mesh)	1,036		Implement measures to minimize bycatch in large mesh gillnet fisheries	○	○	○	○	Small only ○	Small only ○	
Legal harvest	943		Work with foreign nations to quantify and eliminate commercial and subsistence harvest							Caribbean and Atlantic ○
Demersal longline	942		Increase observer coverage in federally permitted shrimp fishery to improve estimates of interactions	○				○	○	
Pelagic longline	872		Pilot new technologies and fishing practices to reduce bycatch	○	○	○	○	○	○	○
			Pilot new longline gear types to minimize loggerhead interactions and post-interaction mortality[5]	○	○	○	○	○	●	○
Vessel strikes	308		Develop a comprehensive GIS database to assess vessel interactions and identify hot spots			○	○	●		
			Develop and implement a strategy to reduce vessel/sea turtle interactions			○	○	○		
Marine debris[6]	217		Enhance marine debris cleanup programs in coastal waters, with emphasis on piers and artificial reefs	○	○	○	○	●	○	
Predation[7] (terrestrial & marine)	167		Reduce nest predations, particularly mammalian predation	●	○	○	○	○		
			Site artificial reefs a minimum distance from shore where nearshore areas are mostly sandy and free of structure[8]	○	○	○	○	○		
Beach armoring	123		Remove failed/ineffective erosion control structures			○	○	○		
			Maintain or acquire nesting beaches and adjacent uplands to be held in public trust			○	○	○		
Illegal harvest	107		Assist foreign countries with enforcement of national regulations and enhance capacity in key areas							Caribbean and Atlantic ○
Dredge fishery	94		Characterize, quantify and minimize bycatch	○	○	○	○			○
Light pollution	84		Minimize sources and effects of light pollution on hatchling and nesting females			○	●	●		
Beach erosion	83		Ensure beach sand placement projects are compatible with nesting requirements and do not degrade habitat	○	○			○		

Key

Generalized life histories	
Terrestrial zone (nesting adult, hatchling stage)	
Neritic zone hatchling (hatchling swim frenzy to offshore waters)	
Oceanic zone juvenile (foraging mostly <5m with dives to 200m in offshore waters)	
Neritic zone juvenile (foraging in continental shelf, estuarine waters)	
Oceanic zone adult (foraging in oceanic habitats)	
Neritic zone adult (foraging in continental shelf waters)	
Adapted from NMFS (2011)	

BP oil disaster-funded activity underway ● Potential need for additional oil disaster-funded activities ○ Stressor present and quantified

[1]Northern Gulf of Mexico Recovery Unit only.
[2]Threats having a "Total Estimated Adjusted Annual Mortality" (i.e., adult female equivalent) of 50 or higher were included. This subset of threats accounts for more than 95 percent of total estimated annual mortality.
[3]Examples are for illustrative purposes and do not represent a complete set of recovery actions. Adapted from the following unless otherwise noted: (NMFS, 2011; Natural Resource Trustees, 2016; and Natural Resource Trustees, 2017)
[4]Adult female loggerheads from AL and FL beaches forage in shrimp trawling areas to a higher degree than previously believed (Hart et al., 2014).
[5]The Pelagic Longline Bycatch Reduction Project is underway regionwide and open to fishermen based in all Gulf states; however, the fishery and associated bycatch occurs mostly in the open ocean outside state territorial waters.
[6]Includes entanglement and ingestion.
[7]Includes total predation by native and exotic species in both the terrestrial and marine environments, plus other undefined sources of egg stage mortality.
[8]Barnette, 2017

Acknowledgements

This study was generously supported and refined by technical advisors who provided guidance and recommendations on the ecology and conservation of sea turtles in the Gulf of Mexico. Advisors that are not listed as co-authors are Raymond Carthy, University of Florida and U.S. Geological Society Fish and Wildlife Research Unit; Marco Garcia Cruz, Instituto Venezolano de Investigaciones Cientificas; and Tomo Hirama, Florida Fish and Wildlife Conservation Commission.

Assessing impacts to sea turtles requires the use of many external data sources to represent the spatial distribution of each stressor. Identification of stressor data sources were greatly aided by the support of Scott Eastman, Ph.D. student at the University of Florida. Many individuals were invaluable in providing datasets that could be used to map stressor distributions, including Alice Bard, Florida State Parks; Harry Blanchet, Louisiana Department of Wildlife and Fisheries; Jorge Brenner, The Nature Conservancy; Beth Brost, Florida Fish and Wildlife Conservation Commission; Timo Franz, Dumpark Creative Industries; John Froeschke, Gulf of Mexico Fisheries Management Council; Jason Gedamke, National Oceanic and Atmospheric Administration, David Gloeckner, National Oceanic and Atmospheric Administration; Rachel Gittman, Northeastern University; Jonathan Gorham, Inwater Research Group, Inc.; John Hak, NatureServe; Robert Hardy, Florida Fish and Wildlife Conservation Commission; Rick Hart, National Oceanic and Atmospheric Administration; Tim Haverland, National Oceanic and Atmospheric Administration; Doug Helton, National Oceanic and Atmospheric Administration; Nate Herold, National Oceanic and Atmospheric Administration; Tomo Hirama, Florida Fish and Wildlife Conservation Commission; Keith Kolasa, Hernando County Florida; Laurent Lebreton, The Modeling House; Mary Orms, U.S. Fish and Wildlife Service; David Pike, Rhodes College; Todd Phillips; Pamela Plotkin, Texas A&M University; Bonnie Ponwith, National Oceanic and Atmospheric Administration; Nathan Putman, National Oceanic and Atmospheric Administration; Jeff Rester, Gulf States Marine Fisheries Commission; Erin Seney, University of Central Florida; Nicole Smith, Louisiana Department of Wildlife and Fisheries; Patrick Smith, Lake Pontchatrain Basin Foundation; Sigrid Smith, Delaware State University; Tom Strange, Covington Civil and Environmental; Blair Tirpak, U.S. Geological Survey; and Beth Wrege, National Oceanic and Atmospheric Administration.

References

Anson, K., Arnold, W., Banks, P., Berrigan, M., Pollack, J., Randall, B., & Reed, D. (2011). *Eastern oyster*. In *Gulf of Mexico data atlas*. Stennis Space Center, MS: National Centers for Environmental Information. Retrieved from http://gulfatlas.noaa.gov

Baldera, A., Hanson, D., & Kraft, B. (2017). Tracking success: Selecting project-level monitoring indicators to meet programmatic restoration needs in the Gulf of Mexico. (unpublished)

Barnette, M. C. (2017). *Potential impacts of artificial reef development on sea turtle conservation in Florida*. NOAA Technical Memorandum NMFS-SER-5. U.S Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. St. Petersburg, FL: Southeast Regional Office.

Benayas, J. M. R., Newton, A. C., Diaz, A., & Bullock, J. M. (2009). Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. *Science*, *325*: 1121-1124.

Crain, C. M., Kroeker, K., & Halpern, B. S. (2008). Interactive and cumulative effects of multiple human stressors in marine systems. *Ecology Letters*, *11*(12), 1304-1315.

Crowder, L. B., Osherenko, G., Young, O. R., Airamé, S., Norse, E. A., Baron, N., Day, J. C., Douvere, F., Ehler, C. N., Halpern, B. S., Langdon, S. J., McLeod, K. L., Ogden, J. C., Peach, R. E., Rosenberg, A. A., & Wilson, J. A. (2006). Sustainability. Resolving mismatches in U.S. ocean governance. *Science, 313*(5787), 617-618.

Deepwater Horizon Natural Resource Damage Assessment Trustees. (2016). Deepwater Horizon *oil spill: Final programmatic damage assessment and restoration plan and final programmatic environmental impact statement.* Retrieved from *http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan*

Deepwater Horizon Natural Resource Damage Assessment Trustees. (2017). Deepwater Horizon *oil spill Natural Resource Damage Assessment: Strategic framework for sea turtle restoration activities*. Retrieved from http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan

Doyle, M., & Miralles-Wilhelm, F. (2008). The culture of collaboration in the Chesapeake Bay program. In M. Doyle & C. A. Drew (Eds.), *Large-Scale Ecosystem Restoration: Five Cases Studies from the United States* (pp. 191-218). Washington, DC: Island Press, 2008.

Environmental Protection Agency. (2017). *Facility Registry Service (combined)*[Comma Separated Value]. Retrieved from https://www.epa.gov/enviro/epa-state-combined-csv-download-files.

Florida Fish and Wildlife Conservation Commission. (2017). *Statewide atlas of nesting occurrence and density (2011-2015)*[Shapefile]. Retrieved from http://ocean.floridamarine.org/SeaTurtle/nesting/FlexViewer/

Fuentes, M. M. P. B., Limpus, C. J., & Hamann, M. (2010). Vulnerability of sea turtle nesting grounds to climate change. *Global Change Biology*, *17*(1), 140-153.

Grüss, A., Thorson, J. T., Babcock, E. A., & Tarnecki, J. H. (2017). Producing distribution maps for informing ecosystem-based fisheries management using a comprehensive survey database and spatio-temporal models. *ICES Journal of Marine Science*, fsx120.

Gulf Coast Ecosystem Restoration Council. (2016). *Comprehensive plan update: Restoring the Gulf Coast's ecosystem and economy*. Retrieved from https://restorethegulf.gov/sites/default/files/CO-PL_20161208_CompPlanUpdate_English.pdf

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., Bruno, J. F., Casey, K. S., Ebert, C., Fox, H. E., Fujita, R., Heinemann, D., Lenihan, H. S., Madin, E. M. P., Perry, M. T., Selig, E. R., Spalding, M., Steneck, R., & Watson, R., (2008). A global map of human impact on marine ecosystems. *Science, 319*(5865), 948-952.

Halpern, B. S., Kappel, C. V., Selkoe, K. A., Micheli, F., Ebert, C. M., Kontgis, C., Crain, C. M., Martone, R. G., Shearer, C. and Teck, S. J. (2009). Mapping cumulative human impacts to California Current marine ecosystems. *Conservation Letters, 2*(2009), 138-148.

Halpern, B. S., & Fujita, R. (2013). Assumptions, challenges, and future directions in cumulative impact analysis. *Ecosphere*, *4*(10), 131.

Halpern, B. S, Frazier, M., Potapenko, J. Casey, K. S., Koenig, K., Longo, C., Lowndes, J. S., Rockwood, R. C., Selig, E. R., Selkoe, K. A., Walbridge, S. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nature Communications*, *6*, 7615.

Hart, K. M., Lamont, M. M., Fujisaki, I., Tucker, A. D., & Carthy, R. R. (2012). Common coastal foraging areas for loggerheads in the Gulf of Mexico: Opportunities for marine conservation. *Biological Conservation*, *145*(1), 185-194.

Karnauskas, M., Kelble, C. R., Regan, S., Quenée, C., Allee, R., Jepson, M., Freitag, A., Craig, J. K., Carollo, C., Barbero, L., Trifonova, N., Hanisko, D., & Zapfe, G. (2017). *2017 Ecosystem status report update for the Gulf of Mexico*. NOAA Technical Memorandum NMFS-SEFSC-706, U.S Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Miami, FL: Southeast Fisheries Science Center.

Mansfield, K. L., Wyneken, J., Porter, W. P., & Luo, J. (2014). First satellite tracks of neonate sea turtles redefine the "lost years" oceanic niche. *Proceedings of the Royal Society B: Biological Sciences, 281*(1781), 20133039-20133039.

National Academy of Sciences. (2016). *Effective monitoring to evaluate ecological restoration in the Gulf of Mexico*. Washington, DC: National Academies Press.

National Marine Fisheries Service (NMFS). (2004). Final Supplemental Environmental Impact Statement,
Reduction of Sea Turtle Bycatch and Bycatch Mortality in the Atlantic Pelagic Longline. Silver Spring, MD: Author.

National Marine Fisheries Service (NMFS). (2003b). *Biological opinion on the continued operation of Atlantic shark fisheries (commercial shark bottom longline and drift gillnet fisheries and recreational shark fisheries) under the fishery management plan for Atlantic tunas, swordfish, and sharks (HMS FMP) and the proposed rule for draft amendment 1 to the HMS FMP, July 2003*. St. Petersburg, FL: Author.

National Marine Fisheries Service (NMFS). (2008). *Recovery plan for the northwest Atlantic population of the loggerhead sea turtle (*Caretta caretta*), Second revision.* Silver Spring, MD: Author.

National Marine Fisheries Service (NMFS). (2017a). *Gulf of Mexico cellular electronic logbook program shrimp trawl start locations, 2007-2016*. Galveston, TX: Author.

National Marine Fisheries Service (NMFS). (2017b). Monthly southeastern shrimp otter trawl fleet TED Inspections. Retrieved from http://sero.nmfs.noaa.gov/protected_resources/sea_turtle_protection_and_shrimp_fisheries/documents/southeastern_shrimp_otter_ted_inspections__compliance__sea_turtle_capture_rates__and_ted_effectiveness_april_2014-december_2016.pdf

National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service, & Secretaría de Medio Ambiente y Recursos Naturales. (2011). *Bi-national recovery plan for the Kemp's ridley sea turtle (*Lepidochelys kempii*), Second revision*. Silver Spring, MD: Author.

National Oceanic and Atmospheric Administration (NOAA). (2010). *Coastal change analysis program high resolution land cover and change, Alabama, Florida, Louisiana, Mississippi & Texas*. Retrieved from https://coast.noaa.gov/ccapftp/

National Oceanic and Atmospheric Administration (NOAA). (2017). *Phytoplankton monitoring network (2006-2017)*[Shapefile]. Retrieved from https://www.ncddc.noaa.gov/website/PMN/viewer.htm

Nawi, D., & Brandt, A.W. The California Bay-Delta: The challenges of collaboration. In M. Doyle & C. A. Drew (Eds.), *Large-Scale Ecosystem Restoration: Five Cases Studies from the United States* (pp. 130-162). Washington, DC: Island Press, 2008.

Plotkin, P. (2016). Introduction to the special issue on the Kemp's ridley sea turtle. *Gulf of Mexico Science*, *33*(2), 127.

Possingham, H. P., Bode, M., & Klein, C. (2015). Optimal conservation outcomes require both restoration and protection. *PLoS Biology*, *13*(1), e1002052.

Salt, T. R., Langton, S., & Doyle, M. The challenges of restoring the Everglades system. In M. Doyle & C. A. Drew (Eds.), *Large-Scale Ecosystem Restoration: Five Cases Studies from the United States* (pp. 20-48). Washington, DC: Island Press, 2008.

Shaver, D. J., Hart, K. M., Fujisaki, I., Rubio, C., Sartain, A. R., Peňa, J., Burchfield, P. M., Gamez, D. G., & Ortiz, J. (2013). Foraging area fidelity for Kemp's ridleys in the Gulf of Mexico. *Ecology and Evolution*, *3*(7), 2002-2012.

SoundMap Working Group & Heat Light and Sound Research, Inc. (2012). *Average annual ambient noise modeling methodology summed outputs with airguns.* [Data file - Single Frequency 200Hz at 5 m Depth].

Stock, A. (2016). Open source software for mapping human impacts on marine ecosystems with an additive model. *Journal of Open Research Software, 4*(e21), 1-7.

Texas Parks and Wildlife Department. (2017). *JEA Presentation 2017*. [Presentation] Gulf of Mexico

Fishery Management Council, San Antonio, TX. Retrieved from http://gulfcouncil.org/wp-content/uploads/A-8-REVISED-TPWD%E2%80%93-JEA-Presentation-2017.pdf

Toft, T. (2013). Recreational facilities - Marinas and boat ramps (U.S. only), In *Gulf of Mexico data atlas* [Internet]. Stennis Space Center, MS: National Centers for Environmental Information. Retrieved from: https://gulfatlas.noaa.gov/

Wasson, K., Suarez, B., Akhavan, A., McCarthy, E., Kildow, J., Johnson, K., Fountain, M. C., Woolfok, A., Silberstein, M., Pendleton, L., & Feliz, D. (2015). Lessons learned from an ecosystem-based management approach to restoration of a California estuary. *Marine Policy*, *58*, 60-70.

Western Carolina University. (2017). *Beach nourishment database (2017)* [Shapefile]. Retrieved from http://beachnourishment.wcu.edu/

Witherington, B., Kubilis, P., Brost, B. & Meylan, A. (2009). Decreasing annual nest counts in a globally important loggerhead sea turtle population. *Ecological Applications*, *19*, 30-54.