Healthy Ecosystems Grants 2 Final Report

Project Title: Quantifying Environmental and Anthropogenic Drivers of Sea Turtle Distribution and Abundance in the Gulf of Mexico
Award Amount: $ 493,771
Awardee: University of Central Florida
Award Start Date: 12/04/15
Award End Date: 06/03/18
NAS Grant ID: 2000006434

Project Director: Kate Mansfield
Affiliation: Department of Biology, University of Central Florida

Project Key Personnel:
- Erin Seney, Department of Biology, University of Central Florida
- Nathan Putman, University of Miami Cooperative Institute for Marine and Atmospheric Studies

I. PROJECT SUMMARY (from proposal)

Understanding the mechanisms of biological connectivity throughout the Gulf of Mexico is essential for the management of ecosystems and protection of species. However, identifying to what extent the impacts of environmental and anthropogenic stressors occurring in one area are propagated throughout the Gulf via the dispersal and migration of marine organisms poses a significant challenge. Sea turtles are ideal organisms in which to build conceptual and quantitative frameworks to make progress in this area. These animals are distributed throughout the Gulf of Mexico, with nesting occurring along sandy beaches, hatchling turtles migrating offshore and dispersing into the deep Gulf, older juveniles recruiting to the continental shelf, and adults migrating between natal reproductive sites and distant nearshore foraging grounds. The fitness of turtles is an integration of these diverse marine environments, making them a particularly useful system in which to study how biological systems respond to variable environmental conditions. Likewise, ontogenetic habitat shifts across large geographic scales also make turtles susceptible to numerous anthropogenic interactions. Thus, sea turtles provide an important indication of how human activities influence the distribution and abundance of mobile marine species.

Datasets on the distribution and abundance of turtles across life-stages exist in various forms, many of which span multiple decades, but quantitative frameworks to integrate these data are limited. This project will quantify how spatial patterns in abundance vary over time, how different abundance and distribution measures are related, and how anthropogenic changes in the northern Gulf of Mexico and environmental variability have contributed to observed patterns. Additionally, the distribution and abundance of sea turtles will be mechanistically predicted through the novel use of ocean circulation models and satellite telemetry data. More than 400 tracks of sea turtles will be analyzed (including surface-pelagic stage juveniles, neritic juveniles, and mature females) to inform simulations of turtle movement within "hindcast" output of ocean circulation models. Simulations will span hatchling

dispersal through the homing migration of adults and will thus allow for the distributions of all life-stages of turtles to be predicted.

Modeled distributions will be compared to observations (e.g., survey, bycatch, strandings) for validation. The proposed work will produce spatially and temporally explicit estimates of how sea turtle distribution varies in response to environmental changes (at an individual and population level) and how changes in one location will likely impact other areas. Our methods will allow us to determine to what extent this connectivity is driven by ocean circulation processes compared to the behavior of turtles. These studies will "Advance understanding of environmental conditions, ecosystem services, and community health and well-being in the Gulf of Mexico" by providing unparalleled insight into how environmental conditions shape the spatial ecology of species of high-priority for recovery and provide Gulf-wide estimates of turtle distribution and movement that can be used in hypothesis testing for how anthropogenic impacts will effect turtles. Our analyses to mechanistically link spatiotemporal variation in environmental conditions relative to turtle abundance and distribution will fill the problematic gaps in current analytical techniques for predicting population trends in turtles.

II. PROJECT SUMMARY (from final report)

Sea turtles are flagship species for conservation in the Gulf of Mexico and globally. Knowledge of their distributions and status is of paramount importance for the management and recovery. The movements of turtles from nesting beaches to the open ocean to coastal waters makes them a particularly useful system in which to study how biological systems respond to large-scale variability in environmental conditions and provide an indication of how human activities influence the distribution and abundance of mobile marine species. We synthesized more than 30 years of data from strandings, bycatch, aerial surveys, nesting beach surveys, and satellite-tracking in the context of oceanographic conditions. We were thus able to describe long-term trends and patterns in sea turtle abundance for green, loggerhead, and Kemp's ridley sea turtles across the Gulf of Mexico. These data will be invaluable for contextualizing new data that are collected in the future campaigns to understand the Gulf of Mexico ecosystem.

From our earlier work, we believed that better information on sea turtle movement and behavior would allow for more robust predictions of species distributions. We have developed software that allows the complex movements of sea turtles (and other migratory species) to be elegantly modeled within an ocean circulation model. Previously such models were only appropriate for simulating the movement of planktonic and (mostly) passive organisms. This new software provides a valuable tool for understanding population connectivity, habitat selection, and mechanistically predicting the distribution of the numerous marine species that actively orient and swim.

III. PROJECT RESULTS

<u>Accomplishments</u>

Our aim was to assess sptatiotemporal variability in sea turtle distributions and abundance and to identify the environmental and anthropogenic drivers of these patterns. At the time of this report, our work has resulted in the 6 scientific articles (published or accepted for publication). We are finalizing an additional 7 manuscripts for submission.

<u>Scientific Articles</u>

1. Caillouet et al. (2016, Herpetological Conservation & Biology) provides recommendations to consider how spatiotemporal variability in environmental conditions and anthropogenic impacts could influence the potential for rehabilitated turtles that are released to contribute to population recovery.

2. Putman et al. (2016, Proceedings of the Royal Society - B) highlights the difficulty of inferring behavior from satellite-tracking data and describes more robust methods to derive the behavioral and environmental contributions to individual movements and population distribution in the marine environment.

3. Shamblin et al. (2017, Journal of Experimental Marine Biology & Ecology) uses ocean circulation models and mitogenomic data to assess the contributions of Atlantic basin green turtle rookeries to strandings in Texas. Contrary to prior expectations, show that the majority of turtles in this region originate from Mexico.

4. Caillouet et al. (2018, Chelonian Conservation & Biology) present a reanalysis of 50 years of nesting data in the Kemp's ridley sea turtle and show evidence for density dependent population growth beginning in 2004, well before the unexpected departure from exponential growth in 2010. We further show that nesting has reached an asymptote of ~25,000 nests per year, perhaps suggesting a drop in carrying capacity for this species in the Gulf of Mexico.

5. Gruss et al. (in press, Marine Ecology Progress Series) develop methods to allocate seasonal fluctuations of sea turtle and marine mammal biomass using statistical relationships between occurrence data and environmental conditions in the Gulf of Mexico.

6. Putman (accepted, Current Biology) summarizes major recent findings in the field of marine animal migration and recommends the prioritization of key data gaps in animal movement research that will open promising avenues to integrate individual movements with population-level and ecosystem processes.

<u>Manuscripts</u>

1. Sacco et al. (in manuscript, Target: Ecography) uses aerial survey, telemetry, bycatch, and strandings data to assess seasonal variability in green, loggerhead, Kemp's ridley and leatherback occurrence and abundance across the Gulf of Mexico following the DWH oil spill.

2. Putman et al. (in manuscript, Target: Nature or PNAS) use newly developed software to simulate the diverse movements of marine animals to explore the adaptiveness of stereotypical movement strategies across different regions, seasons, habitats, and swimming abilities. Across all conditions, directed orientation is shown to be more effective at increasing chlorophyll concentrations encountered (the base of the marine food-web) than passive drift, Levy walks, or Brownian motion.

3. Mansfield et al. (in manuscript, Target: Bulletin of Marine Science) synthesizes findings from recent sea turtle telemetry datasets obtained in the Gulf of Mexico to revise our understanding of ontogenetic habitat shifts in their early years.

4. Seney et al. (in manuscript, Target: Global Ecology & Biogeography or Diversity & Distributions) examine the environmental correlates of sea turtles strandings across a 35-year dataset. The directional components of wind stress allow for the development of a “correction factor” of stranding probability, which will allow sea turtle strandings to be used as a measure of in-water abundance.

5. Putman et al. (in prep, Target: Conservation Letters) demonstrates a relationship between time-lagged strandings of juvenile Kemp’s ridley and subsequent nesting output. The power-law relationships indicate standings can be used as a metric of juvenile recruitment and allow predictions of future nesting abundance (up to ~10 years).

6. Putman et al. (in prep, Target: Current Biology or Proceedings of the Royal Society –B) quantify differences in sea turtle swimming behavior among species, life-stages and habitats in the Gulf of Mexico from an 18-year tracking dataset.

7. Putman et al. (in prep, Target: Global Ecology & Biogeography or Diversity & Distributions) predicts annual variability in oceanic stage sea turtle distribution and abundance across the Gulf of Mexico. Predicted distributions are based on simulating hatchling transport from major green, loggerhead, and Kemp’s ridley nesting beaches from 1993-2017 weighted by annual variation in nest counts.

Implications

Each of the publications have important implications to science and society (see above). In combination, however, they represent a valuable framework that offers a holistic view of a key group of species in the Gulf of Mexico ecosystem. Sea turtles are late-maturing, long-lived, highly migratory organisms. This synthesis approach drives home the need to take a broader look beyond the nesting beach when assessing sea turtle population trends. Sea turtles live at least as long as humans and occupy oceanic, coastal, and shoreline habitats and serve as indicators of ecological health of the oceans and coastal habitats that many humans rely on for recreation and livelihoods. The work provides a multi-decade historical benchmark by which future sea turtle research in the Gulf of Mexico can be compared. For other regions and for other species, it outlines a valuable way forward to understand the mechanisms the drive species distributions and abundance. These data will allow researchers and managers to understand whether increased sea turtle observations are the results of changes in habitat availability, reproductive output, or factors that influence detectability. In our group's own work, these data are particularly useful as we being to incorporate genetics (including sequencing markers to infer stock of origin and gene expression/transcriptome work to explore gene-environment interactions) and disease ecology into our in-water data collection and modeling projects. Additionally, development of novel software to simulate the swimming and diving behavior movements of diverse marine animals will allow questions to be addressed that were previously impossible. This software can be applied across all life-stages of sea turtles and from marine species as diverse as pelagic algae to whales.

Unexpected Results

In designing software that could simulate the diverse movements of marine animals we decided to turn to mathematical abstractions that describe animal movement that have broad applicability across taxa and environments. One of the main areas of present investigation is on a class of random walks in which the direction for a given time-step is determined by a power-law probability density function:

f(x) = Cx^-μ

Where f(x) represents the number of steps falling within a given directional bin (x), C is a parameter for unit bin for the power-law compliance, and μ (an exponent) represents the "steepness" of the right tail part of the distribution. When μ approaches 1, movement trajectories become straighter ("directed") because the probability of selecting the same directional bin each timestep increases. As μ approaches 3, movement trajectories become more like classic Brownian motion ("random") because the probability of selecting the same directional bin each timestep is less likely. When μ is ~2, movements are characterized by clusters of random movements with occasional periods of directed movements ("Levy walk").

Theoretical studies indicate that the Levy walk (μ =2) is an optimal search strategy for foraging in environments where prey are patchily distributed and limited information is available on where prey are likely to occur. Numerous studies appear to show broad support for the occurrence of Levy walks. The trajectories of animals ranging from monkeys to mollusks have been described as fitting a heavy-tailed, power-law function with exponents ~2. Likewise, evidence for Levy walks have been described in animals traversing petri dishes and ocean basins. However, like many of the efforts to mathematically describe animal movement (e.g., state-space models), surprisingly little consideration is given to the influence of direct environmental forcing on the movements of animals by either proponents or skeptics. This is a fundamental oversight given that much of the empirical evidence for Levy walks is obtained from animals moving through flow fields (either atmospheric winds or ocean currents).

As a first step towards addressing this issue, we performed numerical experiments to assess the effectiveness of different movement strategies for encountering foraging opportunities in a realistic marine environment. We used the surface layer of the Hybrid Coordinate Ocean Model (HYCOM), a high- resolution, eddy-resolving ocean circulation model. This model depicts, fronts, filaments, and mesoscale processes that are relevant to the movement of marine organisms. We used two different configurations of HYCOM, one for the Gulf of Mexico (0.04° grid resolution, 3 hourly timestep) and one for the Global ocean (0.08° grid resolution, daily timestep). Overlaid on the ocean velocity fields were satellite-based observations of chlorophyll concentration that corresponded to the same temporal period as the ocean currents. Chlorophyll corresponds to primary production, the base of the ocean food-web. Areas with high chlorophyll concentration would likely allow provide a greater opportunity for efficient foraging than areas with lower concentrations.

Across this backdrop, we simulated four different types of movement using a power-law probability density function (equation 1), a simple way to approximate types of movement that are observed in animals. For simplicity we examined four movement scenarios: passive drift, random (i.e., Brownian) orientation ($\mu=2.9$), Levy orientation ($\mu=2.0$), and directed orientation ($\mu=1.1$) (Figure 1). For passive drift, particle movement was determined only by the velocity of the ocean currents encountered. For the other strategies, swimming speeds of 0.02 m/s, 0.20 m/s and 2.00 m/s were applied to the particle trajectories. This range of speeds brackets the physiological capacity of the broad diversity of marine taxa, ranging from larval fishes and invertebrates (0.02 m/s) to tunas and whales (2.00 m/s)

Virtual particles were released at identical places and times (the first day of June 2009, September 2009, December 2009, and March 2010) within the ocean circulation models. Particles were tracked for 60 days in Gulf of Mexico HYCOM and 30 days in Global HYCOM. At midnight each day the particle location was recorded along with the corresponding value of chlorophyll concentration. From each release point and date we determined which of the four movement strategies resulted in the highest mean daily chlorophyll values over the particles track duration.

We found that across all seasons, whether released in the deep ocean (>200m depth) or over the continental shelf (<200 m), and irrespective of swim speeds, particles that were programmed with directed orientation consistently encountered higher chlorophyll concentrations than those that adopted Levy walks, Brownian walks, or drifted passively. These findings are in stark contrast to previous work that indicated Levy walks as the most effective foraging strategy in low-information environments. Our work indicates that even if animals are choosing random directions (i.e., not moving toward a particular target), maintaining a heading is more adaptive than more frequent changes in direction or simply drifting. We speculate that the turbulent nature of ocean currents introduces sufficient variability in an animal’s trajectory that its track becomes similar to a terrestrial animal undertaking a Levy walk.

Our findings suggest that for most marine species, directed orientation is more effective at encountering high chlorophyll concentrations than either Levy or random (Brownian) orientation. This finding, combined with previous results showing that turning imposes higher energetic costs on organisms, suggests that natural selection would tend to favor directed orientation in the marine environment. As such, sensory abilities to select and maintain a heading would be highly beneficial. Indeed, there is a growing indication that numerous and diverse marine species possess a "map" and "compass" sense based on geomagnetic cues. These results have been obtained in life-stages with relatively limited swimming abilities (e.g., hatchling sea turtles, stream-stage juvenile salmon, and glass eels). Our results here indicate that directed orientation, even at seemingly trivial speeds, is the most reliable way to increase foraging opportunities.

Our study indicates that understanding the adaptiveness of movements in the marine environment requires explicitly considering the role of ocean currents. Levy movements have been argued to be a scale-invariant optimal strategy for foraging. Our results suggest that the directional flow of ocean currents strongly limits the generality of this theory. At the fastest swimming speeds modeled (where ocean currents play less of a role in net movement) Levy orientation begins to perform somewhat better (though still lags directed orientation). An area worth further investigation is whether the combination of directed orientation and turbulent ocean flows generates net movement of organisms that is Levy-like.
Indeed, this is the most likely explanation for studies to-date that have shown "Levy-like" movements in tracked animals, given that those studies did not take into account the role ocean currents had on shaping the tracks that were analyzed. Indeed, when analyses are performed to assess the role of oceanic currents on the tracks of animals, in many cases directed orientation is detected.

Ecological patterns and evolutionary processes are driven by the movements of organisms. Thus, our understanding of fundamental aspects of biology (e.g., species distributions, population dynamics, colonization, speciation, and extinction) are strongly shaped by how we depict organismal movement. Our findings provide important insight into a fundamental aspect of marine ecology. This work questions long-held assumptions about the adaptiveness of different movement strategies and offers a new paradigm for understanding the drivers of movement in marine ecosystems.

Project Relevance

The following audiences would be most interested in the results of this project:

- Researchers
- Educators
- State Government Officials
- Federal Government Officials
- Non-Profit Private Sector
- For-Profit Private Sector

The results of our project are of interest to any Gulf of Mexico stakeholders that are impacted by regulations surrounding the protection and management of sea turtles (e.g., fisheries, oil & gas industry, state and federal managers, etc.). The broad historical context for sea turtle distribution and abundance in the Gulf of Mexico will allow for more robust planning of ways to minimize negative anthropogenic interactions with turtles. Likewise, the findings open up new questions as to how best to manage these species given their responses to environmental changes. For instance, under the Endangered Species Act, Critical Habitat has not yet been designated for green turtles and Kemp's ridleys. Kemp's ridleys in particular spend a large portion of their lives exclusively within the Gulf of Mexico. Our data and resulting products will better inform federal managers and stock assessments for these protected species. The datasets we generated will be available to other researchers to build upon and contextualize their new observations. Finally, the charismatic sea turtles are ambassadors of marine science that educators can use to teach students about marine ecology.

Education and Training

Number of students, postdoctoral scholars, or educational components involved in the project:

- Undergraduate students: 0
- Graduate students: 4
- Postdoctoral scholars: 0
- Other educational components: 2

Other education components of this project included presentations at scientific conferences and workshops and invited outreach and public talks. Presentations related to the project were given by the PIs and two PhD students at the Rita Levi-Montaicini Lecture and Workshop on Navigation (dei Lincei Rome, Italy, April 2017), 37th Annual International Sea Turtle Symposium (Las Vegas, NV, April 2017), 6th International Bio-Logging Science Symposium (Konstanz, Germany, September 2017), 1st ICARUS User Workshop (Konstanz, Germany, September 2017), 2018 Southeast Regional Sea Turtle Meeting (Myrtle Beach, SC, February 2018), 28th Annual International Sea Turtle Symposium (Kobe, Japan, February 2018), American Fisheries Society – Oregon Chapter Annual Meeting (Eugene, OR, March 2018), and the U.S. Regional Association of the International Association for Landscape Ecology 2018 Annual Meeting (Chicago, IL, April 2018). Public outreach and invited talks included presentations by Drs. Mansfield (UCF) and Putman (consultant/subcontractor) at Dartmouth College (September 2016), The Lodge, Little St. Simons Island (August 2017), Palm Beach UCF Alumni Chapter (July 2017), Inaugural Florida Marine Science Symposium (October 2017), and Texas A&M University (February 2018). Additional details on conference presentations and public talks are listed in Sections 5 and 7 of this report, respectively.

IV. DATA AND INFORMATION PRODUCTS

This project produced data and information products of the following types:

- Data
- Scholarly publications, reports or monographs, workshop summaries or conference proceedings
- Models or simulations
- Software packages or digital tools, or other interactive media

DATA

See attached Data Report.

Relationships Between Data Sets:

These data sets represent different methods for assessing sea turtle distribution and abundance. Some are opportunistic observations (e.g., strandings and bycatch) others are surveys (e.g., aerial surveys of in-water abundance, nesting beach surveys or reproductive output). Others data sets are the environmental conditions associated with observations that are used to extrapolate sea turtle distribution beyond the studied area. A final type of data set is modeled juvenile sea turtle distributions using information on nesting site locations and ocean currents. Together, these data sets provide a unique and holistic picture of how multiple species of sea turtles are distributed in the Gulf of Mexico and the environmental conditions that shape those patterns.

Other Activities to Make Data Discoverable:

All data mentioned in the data table will form the basis of a peer-reviewed publication and thus will be made widely known to other researchers, managers, and the public. Tabular data will be made available as Supplemental Information, housed on the journal website. Upon publication, gridded and geospatial data will be housed in Dryad (https://datadryad.org/).

INFORMATION PRODUCTS

See attached Information Products Report.

Citations for Project Publications, Reports and Monographs, and Workshop and Conference Proceedings:

Published papers

Putman, N., R. Lumpkin, A. Sacco, K. Mansfield. 2016. Passive drift or active swimming in marine organisms? Proceedings of the Royal Society B. 283 20161689; DOI: 10.1098/rspb.2016.1689.

Caillouet, C.W., N.F. Putman, D.J. Shaver, R.A. Valverde, E.E. Seney, K.J. Lohmann, K.L. Mansfield, B.J. Gallaway, J.P. Flanagan, M.H. Godfrey. 2016. A call for evaluation of the contribution made by rescue, resuscitation, rehabilitation, and release translocations to Kemp's ridley sea turtle (Lepidochelys kempii) population recovery. Herpetological Conservation and Biology. 11:486–496.

Shamblin, B.M., P.H. Dutton, D.A. Bagley, N.F. Putman, K.L. Mansfield, L.M. Ehrhart, L.J. Pena, C.J. Narin. 2017. Mexican origins for the Texas green turtle foraging aggregation: a cautionary tale of incomplete baselines and poor marker resolution. Journal of Experimental Marine Biology and Ecology. 488: 111-120, https://doi.org/10.1016/j.jembe.2016.11.009.

Caillouet, C.W., S. W. Raborn, D.J. Shaver, N.F. Putman, B.J. Gallaway, K.L. Mansfield. 2018. Did declining carrying capacity for the Kemp's ridley sea turtle population within the Gulf of Mexico contribute to the nesting setback in 2010−2017? Chelonian Conservation and Biology. 17:123-133.

Accepted/In Press papers:

Gruss, A., M. Drexler, C. Ainsworth, J. Roberts, R. Carmichael, N. Putman, P. Richards, E. Chancellor, E. Babcock, M. Love. In press. Improving the spatial allocation of marine mammal and sea turtle biomasses in spatially-explicit ecosystem models. Marine Ecology Progress Series.

Putman, N. Accpeted. Marine migration. Current Biology.

Manuscripts in preparation:

Sacco, A, N. Putman, L Garrison, C. Sasso, P. Richards, E. Seney, K. Mansfield. Sea turtle distribution and habitat selection in the Gulf of Mexico following the Deepwater Horizon oil spill. Target: Ecography.

Putman, N., P. Verley, E. Seney, K. Mansfield. Directed orientation is more adaptive than Levy and Brownian movement in the marine environment. Target: Nature or PNAS.

Mansfield, K., K. Phillips, E. Seney, N. Putman. Rethinking early sea turtle ontogeny, a Gulf of Mexico case study. Target: Bulletin of Marine Science.

Seney, E., N. Putman, M. Cook, A. Foley, D. Shaver, W. Teas, M. Tumlin, K. Mansfield, Katherine. Linkages among spatiotemporal distributions, population dynamics, and environmental factors in a 35-year sea turtle strandings dataset. Target: Global Ecology & Biogeogrpahy or Diversity & Distributions.

Putman, N., E. Seney, W. Teas, A. Foley, D. Shaver, M. Cook, M. Tumlin, C. Caillouet, B. Gallaway, S. Raborn, K. Mansfield. Annual variation in juvenile Kemp's ridley strandings provides insight into future nesting abundance. Target: Conservation Letters

Putman, N., K. Mansfield, E. Seney, P. Verley, and others. Quantifying differences in sea turtle swimming behavior among species, life-stages, and habitats in the Gulf of Mexico. Target: Current Biology or Proceedings of the Royal Society –B.

Putman, N., K. Mansfield, E. Seney, P. Verley, and others. Predicting the distribution and abundance of Kemp's ridley, green, and loggerhead oceanic-stage sea turtles across the Gulf of Mexico. Target: Global Ecology & Biogeogrpahy or Diversity & Distributions.

Presentations at scientific meetings (international, national, regional; *denotes student presenter):

Putman, N.F. Magnetic maps as a unifying explanation for long-distance navigation in marine animals. Invited speaker. Rita Levi-Montaicini Lecture and Workshop on Navigation, hosted by the European Brain Research Institute & Accademia Nazionale dei Lincei Rome, Italy (April 2017).

Sacco A.E., N.F. Putman, L.P. Garrison, E.E. Seney, K.L. Mansfield. April 2017. Sea turtle distribution and habitat selection in the Gulf of Mexico following the Deepwater Horizon oil spill. Oral presentation. 37th Annual International Sea Turtle Symposium. Las Vegas, NV (April 2017).

Phillips, K.F., and K. L. Mansfield. Combining satellite tracking and genetics to characterize oceanic juvenile sea turtle habitat use. Poster presentation. 6th International Bio-Logging Science Symposium. Konstanz, Germany (September 2017).

Mansfield, K.L. Satellite tracking oceanic stage sea turtles. 1st ICARUS User Workshop. Invited presentation. Konstanz, Germany (September 2017).

Sacco, A.E., Putman, N. F., Garrison, L.P., Sasso, C.R., Seney, E.E., Mansfield K.L. Sea turtle distribution and habitat selection in the Gulf of Mexico following the Deepwater Horizon oil spill. University of Central Florida Graduate Fellows Symposium. Orlando, FL. (November 2017).

Seney E.E., N.F. Putman, M. Cook, A.M. Foley, D.J. Shaver, W.G. Teas, M.C. Tumlin, K.L. Mansfield. Linkages among spatiotemporal distributions, population dynamics, and environmental factors in a 35-year sea turtle strandings dataset. Oral presentation. 2018 Southeast Regional Sea Turtle Meeting, Myrtle Beach, SC (February 2018).

Phillips, K.F., and K.L. Mansfield. Genetic composition and tracked movements of oceanic-stage green turtles in the Gulf of Mexico. Poster presentation. 38th International Symposium on Sea Turtle Biology and Conservation, Kobe, Japan (February 2018).

Putman, N.F. The role of magnetic maps in marine migration. Oral presentation. American Fisheries Society – Oregon Chapter annual meeting, Eugene, OR (March 2018).

Sacco A.E., N.F. Putman, L.P. Garrison, C.L. Sasso, E.E. Seney, K.L. Mansfield. Oral presentation. Sea turtle abundance, distribution, and habitat selection in the Gulf of Mexico following the Deepwater Horizon oil spill. U.S. Regional Association of the International Association for Landscape Ecology Annual Meeting. Chicago, IL (April 2018).

Additional Documentation About Information Production:
A manuscript is in preparation by P. Verley, the developer of Ichthyop particle-tracking software (www.ichthyop.org) and a sub-contract on this award, to describe the new modifications of this

software that allow the diverse movements of marine migrants to be simulated in ocean circulation model output.

Websites and Data Portals:

- www.ichthyop.org

Other Activities to Ensure Access to Information Products:
All information products mentioned in this report are peer-reviewed publication and thus will be made widely known to other researchers, managers, and the public. The modeling software developed to simulate marine animal migrations will be added to the existing website for this tool (http://www.ichthyop.org/). This website allows free downloads of this software and permissions to modify the code as desired. We are also working with colleagues at the University of Miami (at no cost to the project) to make a freely-available and user-friendly way to analyze the outputs of this tool.

V. PUBLIC INTEREST AND COMMUNICATIONS

Most Unique or Innovative Aspect of the Project

During tests of the new movement software we discovered that directed swimming (even if the direction was chosen at random) resulted in increased foraging opportunities (measured by average chlorophyll concentration encountered) compared to other behavior that had previously been shown to be "optimal" foraging strategies for maximizing prey encounters. The apparent reason for the disagreement between our study and others is that our study included the influence of ocean circulation processes on net movement. When other researchers have examined the adaptiveness of different movement strategies the implicit assumption is that ocean currents do not contribute much to the effectiveness of various search behavior (even when considering marine taxa). In those cases, a strategy known as a "Levy walk" (randomly oriented short steps interspersed with occasional long steps) is shown to be most effective when prey is patchily distributed. When prey is common, "Brownian movements" (just randomly oriented short steps) is most effective. In contrast, our results show that irrespective of swim speed or prey availability, directed swimming (even if the initial direction chosen is random) results in a better foraging outcome than Levy walks, Brownian movements, or passive drift. This finding fundamentally changes how we understand the selective pressures acting on movement and migration in the marine environment. If animals are (almost) always benefited by maintaining directed orientation long-distance movements and migration may be easily selected for in marine populations.

Most Exciting or Surprising Thing Learned During the Project

Perhaps the most exciting thing we have learned from this project is that we can make fairly robust predictions of nest abundance in Kemp's ridley sea turtles (R-squared values ~0.74) from strandings data of juveniles obtained in the previous 7-13 years. The relationship is positive and follows a power function; more strandings predict more future nests, but there seems to be an asymptote. This result has three important implications: (1) Kemp's ridley strandings can be used as index of recruitment from the oceanic-stage into coastal life-stages, (2) the power function relationship between strandings and future nests suggests density dependence, more turtles recruiting result in more turtles nesting, but eventually this tapers off, and (3) we can set expectations up to a decade into the future as to what the likely reproductive output of Kemp's ridley will be to help guide and prioritize management decisions.

Most Important Outcome or Benefit of Project

The most important benefits of our project is increasing opportunities for understanding movements of oceanic sea turtles (i.e., integration of behavior) and better understanding of environmental factors that can be used to predict spatiotemporal distribution of sea turtles. The datasets we have generated will be directly applicable to all future sea turtle research undertaken in the Gulf of Mexico. We provide valuable historical context and a benchmark upon which new research can build. The research will be useful to a variety of stakeholders including fisheries managers, protected resource managers, scientific researchers, and the oil and gas industry, among others. Essentially any group that needs to make spatially explicit predictions of turtle occurrence in the Gulf of Mexico will be benefited by our work. A secondary benefit is the modeling software we have developed that allows the diverse movements of marine migrants to be simulated. We anticipate this software being useful to researchers studying the movements of taxa ranging from algae to jellyfish to red snapper to sea turtles to whales.

Communications, Outreach, and Dissemination Activities of Project

We will work with UCF to generate press releases for future high-impact publications resulting from this award, and we will promote all publications on the UCF Marine Turtle Research Group's Facebook page (https://www.facebook.com/ucfmtrg/) and Dr. Mansfield's lab Twitter page (@UCFTurtleLab). The following press release was issued by UCF regarding the initial award: https://today.ucf.edu/ucf-lands-grant-to- study-sea-turtles-life-cycle-post-deepwater-horizon-explosion/. This press release was picked up by state and local news organizations including: http://spacecoastdaily.com/2015/12/ucf-lands-grant-to-study-sea- turtles-life-cycle-post-deepwater-horizon-explosion/.

In addition to conference presentations listed earlier in this report, invited outreach and public talks related to the project included:
Dartmouth College, Department of Biology: Environmental variability and the movement ecology of marine organisms. N. F. Putman invited seminar, Hanover, New Hampshire (September 2016).

The Lodge, Little St. Simons Island: Tracking Atlantic sea turtles—from eggs to adulthood. K. L. Mansfield, invited guest and speaker for evening naturalist program. Little St. Simon Island, GA (August 2017).

Palm Beach UCF Alumni Chapter: The UCF Marine Turtle Research Group: a whole life cycle approach to sea turtle conservation. K. L. Mansfield invited guest and speaker at the annual Palm beach Alumni Chapter turtle walk at the Loggerhead Marinelife Center. Juno Beach, FL (July 2017).

Inaugural Florida Marine Science Symposium: Connecting technology, oceanography, and manicurists to understand the sea turtle “lost years”. K. L. Mansfield invited presenter. St. Petersburg, FL (October 2017).

Texas A&M University, Oceanography Department: Ocean circulation, geomagnetism, and sensory biology as drivers of ecological patterns in marine animals. N. F. Putman invited seminar (February 2018).