Tab A, No 8(b)

Recommendations to the Gulf of Mexico Fishery Management Council:

Coordinating data and approaches to conduct a Kemp's ridley sea turtle stock assessment

Benny J. Gallaway (PI) and Nathan F. Putman (Co-PI)

LGL Ecological Research Associates Inc., Bryan, Texas

Chris Sasso and Paul M. Richards

NOAA Fisheries, Southeast Fisheries Science Center, Miami, Florida

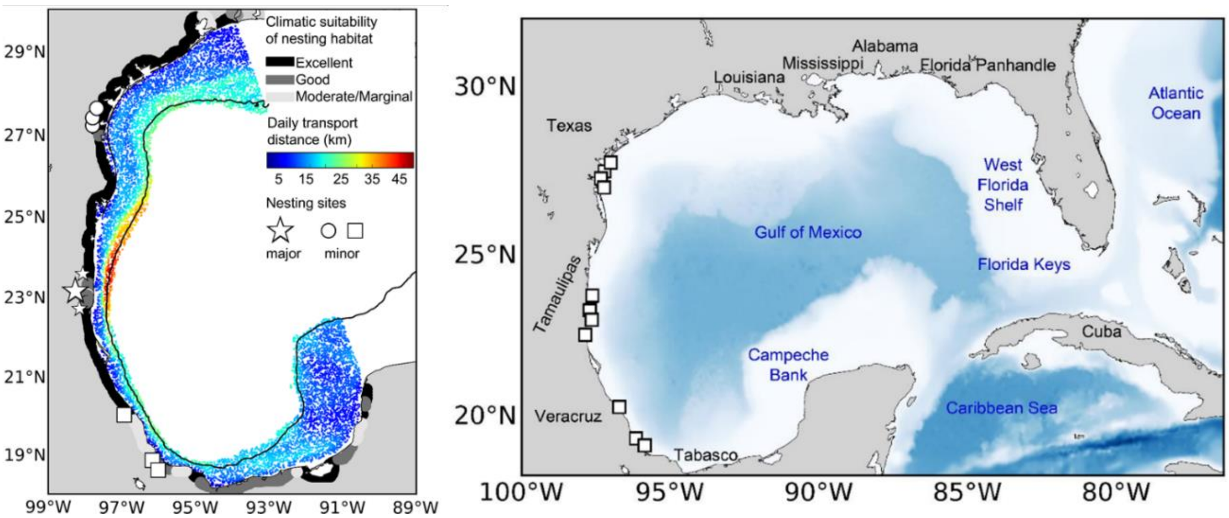
Charles Caillouet

Independent Researcher, Montgomery, Texas

Final Report Date: December 14, 2020

Introduction

Working to restore Kemp's ridley sea turtles (*Leipidochelys kempii*) is one of the key priorities for fisheries managers in the Gulf of Mexico. The reproductive grounds of Kemp's ridley are primarily along the beaches of the western Gulf. Upwards of 90% of the population nests in Tamaulipas, the remainder in Veracruz and Texas, with occasional nests recorded along the Campeche Bank and the southeastern U.S. (Fig. 1). While this restricted nesting range has allowed for intensive and focused conservation efforts it also makes this species of sea turtle particularly vulnerable to anthropogenic and natural perturbations.

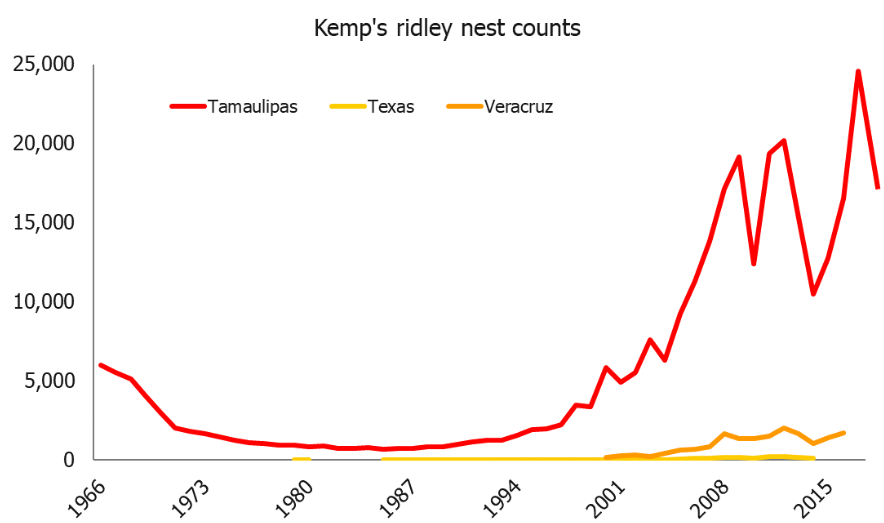


Maps showing the main nesting beaches of Kemp's ridley and their primary range (modified from Putman 2018; Putman et al. 2013).

The Kemp's ridley (Lepidochelys kempii) remains the most endangered sea turtle species, despite more than half a century of cumulative regulatory actions, conservation efforts, and research applied toward its recovery (Gallaway et al. 2016a, Caillouet et al., 2016). Beginning in 1966, Mexico's federal government began protecting Kemp's ridley nesting females, nests (i.e., clutches of eggs laid), and hatchlings released on the species' primary nesting beach near Rancho Nuevo on the Gulf of Mexico (GoM) coast of Tamaulipas, Mexico (Caillouet et al. 2016). Mexico's federal government also initiated annual counts of nests, eggs, and hatchlings released at Rancho Nuevo in 1966. The annual count of nests has served as an annual index of abundance of nesting females and is the primary way in which trends in the population are evaluated.

The binational recovery plan for Kemp's ridley turtles (National Marine Fisheries Service [NMFS] et al. 2011) estimated that this index was increasing exponentially at 19% per year in 2009. This high rate of increase likely resulted from cumulative beneficial effects of regulatory actions, conservation efforts, spatiotemporal closures to shrimp trawling, and diminishing shrimp trawling effort that, in combination, restored and increased annual inputs of hatchlings from the main nesting beaches and reduced at-sea mortality of neritic (i.e., post-pelagic) Kemp's ridleys (Gallaway et al. 2016; Caillouet et al. 2016). Natural factors, such as climate change or shifts in predator and/or prey populations, may also have contributed to the exponential increase (Heppell et al. 2007). Based on the simple concepts that population growth occurs when births (measured as annual hatchlings released, sexes combined) exceed deaths and that immigration and emigration can be ignored (Heppell et al. 2007), the pre-2010 exponential increase in the index could not have occurred unless additions of female hatchlings to the population overwhelmed all losses of females from natural and anthropogenic causes combined (Caillouet et al. 2016) or the number of nest per female increased and/or remigration intervals decreased. The latter scenarios could occur if increased productivity in foraging grounds resulted in increases in female body condition and energy available for reproductive effort, even if the adult female population was constant.

NMFS et al. (2011) predicted that by 2011, the Kemp's ridley population would become large enough to support 10,000 females nesting in a season (equivalent to 25,000 clutches divided by 2.5 clutches per nesting female), which is 1 of 2 criteria established for downlisting this species from endangered to threatened status. The other criterion for downlisting is a minimum annual release of 300,000 hatchlings from the index beach, which has been exceeded for more than a decade. However, instead of continuing to increase exponentially, the index dropped unexpectedly by more than a third in 2010 (Crowder & Heppell 2011; Gallaway et al. 2016a) and remained well below levels predicted by NMFS et al. (2011) through 2018 (Caillouet et al. 2018). The cause for the interruption of exponential growth has not been determined.



Kemp's ridley nest counts at major nesting beaches 1966-2018.

The two most likely causes were hypothesized to be (1) the Deepwater Horizon (DWH) oil spill of 2010 and (2) the incidental capture of Kemp's ridley in shrimp trawls. These two hypotheses were put forward because (1) the DWH spill occurred across important foraging and migratory habitats of Kemp's ridley in the northern Gulf of Mexico and (2) bycatch in shrimp trawls has been identified as the greatest anthropogenic threat to Kemp's ridley by an order of magnitude. A stock assessment of Kemp's ridley that included shrimping effort in the U.S. Gulf of Mexico as the sole source of anthropogenic mortality indicated that it was not a major factor in changes in the nester index (Gallaway et al. 2016a). Whereas a similar analytical effort has not been undertaken to investigate the role of the oil spill, the Trustees concluded that DWH oil did not arrive on the continental shelf of the northern Gulf of Mexico until late May or early June 2010. By that time, adult Kemp's ridleys that were going to breed in 2010 would likely have already departed the northern Gulf of Mexico for breeding and nesting areas in the western Gulf. The lack of certainty on this point is frustrating from both a conservation and scientific perspective as it clearly indicates that our understanding of Kemp's ridley population dynamics - and even the present status of the species - is insufficient to effectively assess what management measures are needed to achieve recovery.

Given the present uncertainty in the drivers of Kemp's ridley population dynamics, assessing the status of the Kemp's ridley is especially important. While determining the cause of the departure from exponential growth in nest productivity that was apparent in 2010 may not be possible, a framework for quantifying Kemp's ridley abundance was developed and published (Gallaway et al. 2016a) and since that time considerable new information has come available that could contribute to a more robust update. Here, we identify the metrics and indices that could be included in a Kemp's ridley stock assessment within the coming year (2021).

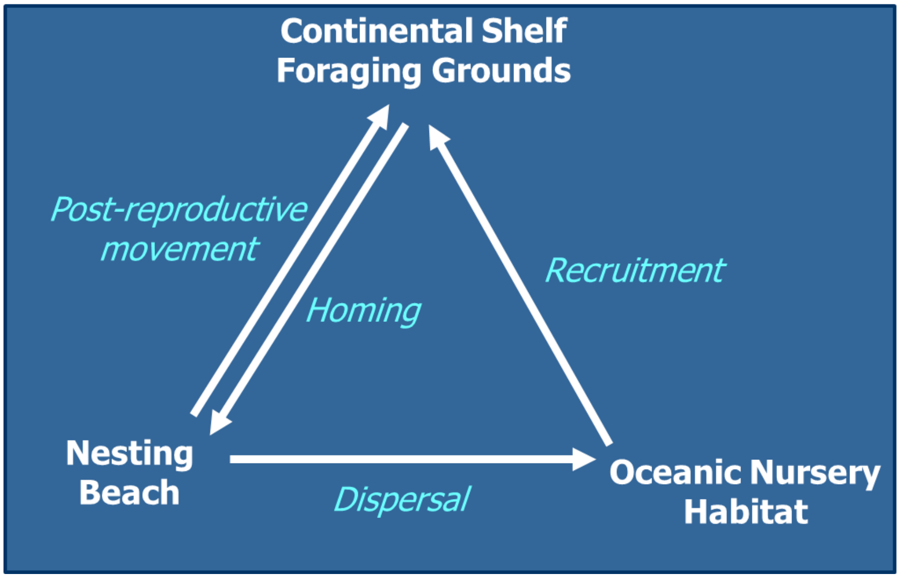
Key Aspects of Kemp's Ridley Biology

At a fundamental level, the status of a population can be determined by knowing:

1) reproductive output (+)
2) immigration (+)
3) natural mortality (-)
4) anthropogenic mortality (-)
5) emigration (-)

In some ways, this is fairly straightforward for Kemp's ridley, with the caveat that to use nesting data as the index information must also be available on clutch frequency (nests per female) and remigration intervals (years between nesting) (Esteban et al. 2017; Casale & Ceriani 2020). More than 90% of nesting occurs on monitored beaches in Tamaulipas where annual counts of nests and hatchlings released have been obtained since 1966. Kemp's ridley like other sea turtles tend to display fidelity to nesting sites and thus both immigration and emigration are likely sufficiently small that they can be ignored. Uncertainties are primarily associated with mortality rates (both natural and anthropogenic), age at which turtles begin reproduction, longevity, and sex ratio - each of which can be influenced by the complex life-history of sea turtles.

Kemp's ridley undertake ontogenetic migrations, a common life-history trait in marine animals, whereby an initial dispersive-pelagic oceanic stage (lasting 1-3 years) is followed by recruitment to coastal habitats and seasonal migrations by older juveniles. After a decade or more, Kemp's ridley mature and undertake both seasonal and reproductive migrations. While this life-history strategy allows animals to match environmental conditions with stage-specific physiological requirements, these transitions greatly complicate determining the effectiveness of (and thus prioritizing) management actions. Turtles that occur in different locations are likely to have different growth rates, probabilities of survival, age attaining maturity, and exposure to anthropogenic threats. Thus, accounting for spatiotemporal variability in Kemp's ridley distribution and abundance by life-stage may be important to assessing the status of the species.



Schematic of the ontogenetic movements of Kemp's ridley sea turtles.

Elements of the Gallaway et al. (2016a) Kemp's Ridley Stock Assessment

Annual number of nests: combined for 3 index beaches in Tamaulipas (1966-2012)

Annual number of hatchlings: combined for 3 index beaches in Tamaulipas (1966-2012), separated by coral or in situ

Mark-recapture growth increment: Data from CMTTP ~223 records (1980-2012)

Strandings length frequency: 5,953 records across the northern Gulf of Mexico (1980-2012)

Shrimping effort: effort (days fished) across 4 spatial zones (approximately WFL, AL-MS, LA, TX) and 3 depth zones (0-10 fm, 10-30 fm, 30+ fm) in the Gulf of Mexico

Habitat weight: based on expert opinion, the relative importance of each shrimping zone to mature females was determined.

Clutch frequency: numbers of nests laid per season

Remigration interval: years between nesting

Observed proportion of strandings

Proportion of Mature females of age *a*

Number of nests per adult female in the population: quotient of annual number of nests per adult female divided by the remigration interval

Proportion of coral hatchlings that are female

Proportion of *in situ* hatchlings that are female

Natural mortality

Shrimp trawl mortality

Shrimp trawl catchability: partitioned into ages 2-4 (0.2, SD = 0.04) and 5+ (0.155, SD = 0.014)

TED effect multiplier: starts in 1990 to influence catchability (0.233, SD = 0.069)

Other proxies, indices, and factors to include that may provide information on Kemp's ridley vital rates

Fishing Effort in U.S. waters: While shrimping effort has historically been considered to be the most important factor influencing anthropogenic mortality of Kemp's ridley, recent analyses indicate that the other fisheries may pose a similar or greater threat (Putman et al., in review). Spatiotemporal variation in fishing effort can be obtained for the U.S. Gulf of Mexico through the NMFS Self-Reported Commercial Coastal Logbook and NMFS Marine Recreational Information Program (MRIP). Data for fisheries managed independently by U.S. states are available through each state's Department of Natural Resources, Fisheries & Wildlife, or equivalent and are also pertinent to include.

Bycatch / Catchability / Discard Mortality: Estimating the susceptibility of Kemp's ridley to fishing mortality by age (size) and gear type is also and important step. Data is available from NMFS Observer Program records for commercial fisheries. Data mining from the published literature would likewise supplement this dataset for commercial and recreational fisheries.

Indirect anthropogenic /natural mortality: While fisheries mortality is often the focus of management efforts, indirect mortality may also result from boat strikes; entanglement in derelict gear, small artificial reefs, and marine debris. In particular boat strikes have been shown to be a relatively large source of morality along the coast of Florida (Foley et al. 2019). Similarly, other issues such as Harmful Algal Blooms (e.g., red tides) and cold stunning events can be problematic. Directly accounting for these sources of mortality may also be informative.

Anthropogenic rescue and rehabilitation: Considerable effort is placed on rescuing stranded and debilitated sea turtles and rehabilitating them. How these efforts contribute to population recovery may be useful to determine, especially to help gauge how these efforts compare to other conservation measures.

Recruitment dynamics: It has long been noted that hatchling production does not linearly predict the time-lagged amount of subsequent nesting. This is likely because of temporal variation in the survivorship of different cohorts and productivity of foraging grounds (which possibly influences remigration interval and total hatchling output per female). With an index of coastal recruitment, it may be possible to better account for natural variation in survival during the pelagic-stage. This would allow both more accurate time-lagged predictions of nesting and a better assessment of anthropogenic drivers of mortality (by reducing uncertainty in natural mortality). Predictions of coastal recruitment of young turtles to different areas in the Gulf of Mexico and Atlantic could be obtained using a combination of ocean circulation particle-tracking simulations and stranding data for smaller (<40 cm SCL) Kemp's ridley (e.g., Putman et al. 2020a, 2020b).

Growth rates: Several new papers have been published estimating growth rates and diet of Kemp's ridley in different habitats (Avens et al. 2020, Ramirez et al. 2020a, 2020b; Lamont & Johnson 2020). Updating the stock assessment to reflect these newly available data will be useful.

Clutch frequency and remigration interval: A newly available tagging database has been curated by LGL researchers that has come from the index beaches in Tamaulipas. From this we can better estimate clutch frequency and remigration interval, two factors that otherwise confound using nest counts as a direct proxy for female abundance.

Prey availability: Kemp's ridley are carnivorous and known to feed on crustaceans such as blue crabs (*Calinectes sapidus*). An index of prey abundance (e.g., indices of blue crab abundance, CPUE data by state) relative to the distribution of Kemp's ridley may be informative as to their potential for growth, survivorship, and age to maturity – especially in the context of density-dependent processes (see below).

Density dependence: There are strong indications that the Kemp's ridley nesting index shows signs of density dependence. For many years, Kemp's ridley population dynamics were independent of density (from prior to monitoring began in 1966 through the early 2000s). However, logistic models suggest that density dependence began prior to the apparent drop in 2010 (Caillouet et al. 2018). Density dependence means that growth rates and survivorship are likely to decrease as more turtles are produced owing to intraspecific competition for resources and as the population moves closer to carrying capacity. Explicitly accounting for this possibility in demographic models is important.

Spatiotemporal variation in Kemp's ridley distribution: Determining changes in the distribution of Kemp's ridley across their range is an important aspect of weighting other indices (fishing effort, prey abundance, etc.) associated with growth and survivorship. Such data can be obtained through aerial survey, satellite-tracking, and stranding data which can be synthesized using habitat and movement models. When possible, such spatial data should be weighted by nesting population size (e.g., telemetry studies of post-nesting females).

Kemp's ridley in Mexico's waters: Obtaining fishing effort data for Mexico is likely to be extremely important to understanding anthropogenic pressures on Kemp's ridley (Cuevas et al. 2018). This will require coordination with scientific colleagues and managers between the U.S. and Mexico (e.g., Cuevas et al. 2020). At a minimum, some assessment of what proportion of each Kemp's ridley life-stage occurs in Mexico is needed to help determine how major this gap of information might be.

Kemp's ridley in Atlantic waters: The fate of Kemp's ridley that enter the Atlantic Ocean is uncertain. There are reasons to believe that growth is reduced in the Atlantic and perhaps few turtle survive to return to the Gulf of Mexico. What proportion return to the Gulf to nest is important to consider in terms of prioritizing conservation efforts. For detailed discussion see Caillouet & Gallaway (2020).

Changes in nest monitoring effort / approaches: It may be useful to determine what changes (if any) have occurred to monitor the Kemp's ridley index beaches, particularly whether biases or increased variation may contribute to apparent variability in abundance. It is conceivable that with time counting efforts have improved and *fewer* turtles are missed. Alternatively, as the number of turtles has increased it may be more difficult to count all of them and *more* turtles are missed. Discussions with those generating the nesting data would likely be informative and could be accounted for in the stock assessment model.

Changes in hatchling sex-ratios: The sex of sea turtles is shaped in part by environmental conditions during incubation (temperature and humidity) (Wyenken & Lolavar 2015). Assessing changes in the incubation conditions of turtles may allow for a more precise estimate of the number of female hatchlings produced that will (eventually) contribute as female nesters. For instance, if sex-ratios skew to be more male than usual (e.g., more turtles nest earlier in the year when it is cooler or in high humidity environments) (Lolavar & Wyneken 2017), the number of hatchlings that could later contribute to nesting will be reduced.

Recommended stock assessment modeling approach

In the 2012/2013 efforts to produce a stock assessment model for the Kemp's ridley the broad participation of scientists from the state/federal government, academia, and the private sector was prioritized to assure consensus from all stakeholders. Given the significant investment of that work, the framework developed (Gallaway et al. 2016a) and its implementation in several other studies (e.g., Gallaway et al. 2016b, Bevan et al. 2016; Kocmoud et al. 2019, Griffin et al. 2019) we suggest that this approach be adopted again.

To this end, we suggest that a series of range-finding analyses be conducted using the matrix model described in Kocmoud et al. (2019). The benefit of this is that sensitivity analyses can be performed on each model parameter extremely quickly. With this step, it will be possible to examine the sensitivity of the stock assessment model to the newly included environmental and demographic parameters (some of which may have wide confidence intervals) as well as other vital rates. After this initial assessment, the AD Model Builder program applied by Gallaway et al. (2016a) could be used to run the most pertinent scenarios given the identified influences of habitat weighting (as discussed above to track spatiotemporal variation in turtle distributions), prey abundance, and factors influencing natural and anthropogenic mortality.

References

Avens, Larisa, Matthew D. Ramirez, April G. Hall, Melissa L. Snover, Heather L. Haas, Matthew H. Godfrey, Lisa R. Goshe, Melissa Cook, and Selina S. Heppell. "Regional differences in Kemp's ridley sea turtle growth trajectories and expected age at maturation." *Marine Ecology Progress Series* 654 (2020): 143-161.

Bevan, E., Wibbels, T., Najera, B.M.Z., Sarti, L., Martinez, F.I., Cuevas, J.M., Gallaway, B.J., Pena, L.J. and Burchfield, P.M., 2016. Estimating the historic size and current status of the Kemp's ridley sea turtle (Lepidochelys kempii) population. *Ecosphere*, *7*(3), p.e01244.

Caillouet Jr, C.W., Raborn, S.W., Shaver, D.J., Putman, N.F., Gallaway, B.J. and Mansfield, K.L., 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*(1), pp.123-133.

Caillouet, C.W. and Gallaway, B.J. 2020. Kemp's ridley sea turtle emigration and immigrations between the Gulf of Mexico and North Atlantic Ocean should not be ignored in age-structured population modeling. *Marine Turtle Newsletter*, *161*, pp. 9-14.

Caillouet, C.W., Gallaway, B.J. and Putman, N.F., 2016. Kemp's ridley sea turtle saga and setback: novel analyses of cumulative hatchlings released and time-lagged annual nests in Tamaulipas, Mexico. *Chelonian Conservation and Biology*, *15*(1), pp.115-131.

Casale, P. and Ceriani, S.A., 2020. Sea turtle populations are overestimated worldwide from remigration intervals: correction for bias. *Endangered Species Research*, *41*, pp.141-151.

Crowder, L. and Heppell, S., 2011. The decline and rise of a sea turtle: how Kemp's ridleys are recovering in the Gulf of Mexico. *Solutions*, *2*(1), pp.67-73.

Cuevas, E., Guzmán-Hernández, V., Uribe-Martínez, A., Raymundo-Sánchez, A. and Herrera-Pavon, R., 2018. Identification of potential sea turtle bycatch hotspots using a spatially explicit approach in the Yucatan Peninsula, Mexico. *Chelonian conservation and biology*, *17*(1), pp.78-93.

Cuevas, E., Putman, N.F., Uribe-Martínez, A., López-Castro, M.C., Guzmán-Hernández, V., Gallegos-Fernández, S.A., Liceaga-Correa, M.D.L.Á., Trujillo-Córdova, J.A., González-Díaz-Mirón, R.D.J., Negrete-Phillipe, A. and Acosta-Sánchez, H.H., 2020. First spatial distribution analysis of male sea turtles in the southern Gulf of Mexico. *Frontiers in Marine Science*, *7*, p.962.

Esteban, N., Mortimer, J.A. and Hays, G.C., 2017. How numbers of nesting sea turtles can be overestimated by nearly a factor of two. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1849), p.20162581.

Gallaway, B.J., Gazey, W.J., Caillouet Jr, C.W., Plotkin, P.T., Abreu Grobois, F.A., Amos, A.F., Burchfield, P.M., Carthy, R.R., Castro Martínez, M.A., Cole, J.G. Coleman, A.T., et al. 2016a. Development of a Kemp's ridley sea turtle stock assessment model. *Gulf of Mexico Science*, *33*(2), p.3.

Gallaway, B.J., Gazey, W.J., Wibbels, T., Bevan, E., Shaver, D.J. and George, J., 2016b. Evaluation of the status of the Kemp's ridley sea turtle after the 2010 Deepwater Horizon oil spill. *Gulf of Mexico Science*, *33*(2), p.6.

Griffin, L.P., Griffin, C.R., Finn, J.T., Prescott, R.L., Faherty, M., Still, B.M. and Danylchuk, A.J., 2019. 0Warming seas increase cold-stunning events for Kemp's ridley sea turtles in the northwest Atlantic. *PloS one*, *14*(1), p.e0211503.

Heppell, S.S., Burchfield, P.M. and Pena, L.J., 2007. Kemp's ridley recovery: how far have we come, and where are we headed. *Biology and Conservation of Ridley Sea Turtles*, pp.325-335.

Kocmoud, A.R., Wang, H.H., Grant, W.E. and Gallaway, B.J., 2019. Population dynamics of the endangered Kemp's ridley sea turtle following the 2010 oil spill in the Gulf of Mexico: Simulation of potential cause-effect relationships. *Ecological Modelling*, *392*, pp.159-178.

Lamont, M.M. and Johnson, D., 2020. Growth rates for immature Kemp's ridley sea turtles from a foraging area in the northern Gulf of Mexico. *Marine Ecology Progress Series*, *652*, pp.145-155.

Lolavar, A. and Wyneken, J., 2017. Experimental assessment of the effects of moisture on loggerhead sea turtle hatchling sex ratios. *Zoology*, *123*, pp.64-70.

National Marine Fisheries Service (NMFS), US Fish and Wildlife Service (USFWS), and Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT). 2011. Bi-national recovery plan for the Kemp's Ridley sea turtle (*Lepidochelys kempii*). Second revision. Silver Spring, MD: National Marine Fisheries Service, 177 pp.

Putman, N.F., Hawkins, J. and Gallaway, B.J., 2020b. Managing fisheries in a world with more sea turtles. *Proceedings of the Royal Society B*, *287*(1930), p.20200220.

Putman, N.F., Seney, E.E., Verley, P., Shaver, D.J., López-Castro, M.C., Cook, M., Guzmán, V., Brost, B., Ceriani, S.A., Mirón, R.D.J.G.D., Peña, L.J., et al. 2020a. Predicted distributions and abundances of the sea turtle 'lost years' in the western North Atlantic Ocean. *Ecography*, *43*(4), pp.506-517.

Ramirez, M.D., Avens, L., Goshe, L.R., Snover, M.L., Cook, M. and Heppell, S.S., 2020b. Regional Variation in Kemp's Ridley Sea Turtle Diet Composition and Its Potential Relationship With Somatic Growth. *Frontiers in Marine Science*, *7*, p.253.

Ramirez, M.D., Avens, L., Goshe, L.R., Snover, M.L., Cook, M., Haas, H.L. and Heppell, S.S., 2020a. Regional environmental drivers of Kemp's ridley sea turtle somatic growth variation. *Marine Biology*, *167*(10), pp.1-20.

Wyneken, J. and Lolavar, A., 2015. Loggerhead sea turtle environmental sex determination: implications of moisture and temperature for climate change based predictions for species survival. *Journal of Experimental Zoology Part B: Molecular and Developmental Evolution*, *324*(3), pp.295-314.