OCS Study
BOEM 2023-073

Potential Lifecycle Impacts of Renewable Energy Construction and Operations on Endangered Sea Turtles with a Focus on the Northwest Atlantic

U.S. Department of the Interior
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Sterling, VA

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December 2023

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Prepared under BOEM Contract# 140M0121F0014

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Study concept, oversight, and funding were provided by the U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, under Contract Number 140M0121F0014. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of BOEM, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REPORT AVAILABILITY

CITATION

Reese A, Stolen M, Findlay CR, Smith J, Varghese H, Levenson J. 2022 Potential lifecycle impacts of renewable energy construction and operations on endangered sea turtles with a focus on the northwest Atlantic. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 129 p. Report No.: OCS Study BOEM 2023-073. Contract No.: 140M0121F0014.

ABOUT THE COVER

Cover photo: A leatherback hatchling makes it way to sea. © J. Levenson

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List of Abbreviations and Acronyms

ABR	Auditory Brainstem Response
AEP	auditory evoked potential
AMAPPS	Atlantic Marine Assessment Program for Protected Species
BOEM	Bureau of Ocean Energy Management
ESA	Endangered Species Act
GOM	Gulf of Mexico
HRG	high resolution geophysical
Hz	hertz
KDE	Kernel Density Estimation
kHz	kilohertz
MAB	Mid-Atlantic Bight
NOAA	National Oceanic and Atmospheric Administration
NWA	North West Atlantic
NWR	National Wildlife Refuge
OCS	Outer Continental Shelf
PTS	Permanent Threshold Shift
TTS	Temporary Threshold Shift
US	United States
WEA	Wind Energy Area

1. Introduction

The wind energy industry in the United States is experiencing rapid growth with current administration targets of 30 gigawatts by 2030. The US government is investing heavily and actively pursuing a national offshore wind strategy to reduce carbon emissions and create new jobs and (Gilman et al. 2016). Following the Energy Policy Act of 2005, the Department of the Interior announced in 2009 the final regulations for the Outer Continental Shelf (OCS) Renewable Energy Program in the Bureau of Ocean Energy Management (BOEM), which has the primary authority of developing the wind energy program. As a result, BOEM has identified wind energy areas (WEAs) offshore in the Atlantic, Gulf of Mexico (GOM), and the Pacific.

Wind energy installations are not without impact on the environment. The bases alter the seabed, and installation and decommissioning have the potential to affect a variety of protected species (Gill 2005; Inger et al. 2009; Boehlert and Gill 2010). Consequently, the location of WEAs and timing of their development necessitate detailed planning and mitigation to ensure protected species are safe at the individual and population level. Guidelines for reducing noise impacts on marine mammals were reviewed in 1998, initially via a panel convened by the National Oceanic and Atmospheric Administration (NOAA). This work resulted in Southall et al. (2007). NOAA convened work on sea turtles and fishes in 2004. After a series of panels and meetings, guidelines were published in Popper et al. (2014). Sea turtle research has fallen behind that of marine mammals because of the additional time that marine mammals have been under review and because of their biology; they generally are large and are identifiable through underwater vocalization. Nevertheless, investigations have identified potential impacts of marine noise on sea turtles, such as from the installation, use, and decommissioning of renewable energy infrastructure.

Turtles are long-lived and have life histories tied to coastal habitats for maturation and breeding. Five of the world's seven species of sea turtle occur in US Atlantic waters (Wallace et al. 2010). From most to least numerous, the turtle species are the loggerhead (*Caretta caretta*), green (*Chelonia mydas*) leatherback (*Dermochelys coriacea*), Kemp's ridley (*Lepidochelys kempii*), and hawksbill (*Eretmochelys coriacea*). Marine turtle distribution and abundance is not static. Thanks to conservation efforts, sea turtle metapopulations in the southeastern US are either fluctuating but stable, such as loggerheads (Ceriani et al. 2019), or increasing, such as green, hawksbill and leatherback turtles (Valdivia et al. 2019). Turtle species distributions vary seasonally, in line with fluctuations in sea temperatures (Palka et al. 2021). Sea temperature is a key driver of sea turtle distribution, and climate change can be expected to alter present-day turtle distributions, with likely seasonal expansion into previously thermally unsuitable areas.

This report briefly reviews the main potential impacts, both negative and positive, that marine renewable facilities may have on sea turtles at the individual and population level. We present a review of the distribution of turtles along the US East Coast, highlighting the nearshore areas of most importance in terms of the number of turtles that may be impacted, with species status considered. The report then reviews current knowledge on the sensory biology and behavioral response of turtles to underwater noise. For both turtle distribution and turtle behavior, the report critically assesses knowledge gaps and recommends actions to fill those gaps, which in turn will afford more rigorous science-led management options to minimize threats to these species listed under the US Endangered Species Act (ESA).

2. Anthropogenic Sound as a Potential Impact Factor or Sea Turtles

Anthropogenic (human-made) sound production has the potential to make an impact on sea turtles during all phases of WEA construction, operation, and decommissioning. This report does not intend to make accurate predictions of transmission and perception of underwater sound (and the likely impact on sea turtles) due to the complexity of that analysis. For a full explanation of types of anthropogenic sound and how they are measured, see Section 6 of Popper et al. (2014).

2.1. Current Soundscapes Experienced by Sea Turtles

Soundscapes are defined as *"ambient sound in terms of its spatial, temporal, and frequency attributes, and the types of sources contributing to the sound field"* (ISO 2017). Soundscapes are composed of naturally existing geophony (sounds from natural processes such as wind over water, waves, glacial calving to form icebergs, and underwater volcanoes) and biophony (sounds created by marine animals, such as whale songs and the sounds of urchins feeding on encrusting benthos). These soundscapes slowly and adapt with the marine ecosystems. However, new origins of sound from human activities (anthrophony) are increasingly altering marine soundscapes, and these sounds may have detrimental implications for marine life (Duarte et al. 2021).

The sources of anthropogenic sound are broad and vary in frequency, amplitude, temporal structure, and duration (Southall et al. 2007). Anthropogenic sounds can typically be partitioned into impulsive or continuous (Southall et al. 2007; Popper et al. 2014). For example, transient sounds produced during impact pile driving for WEA construction can be defined as impulsive and are typically brief, repetitive, broadband (containing a wide range of frequencies), of high intensity, and with a relatively rapid rise time from minimal to maximal pressure (Southall et al. 2007; Popper et al. 2014). Conversely, shipping noise from the servicing of WEAs can be defined as continuous, be tonal (consisting of one or more frequencies, with or without harmonics) or broadband, and vary in intensity over time (Southall et al. 2007; Popper et al. 2014). In some instances, sounds cannot easily be partitioned into either category. Repetitive impulsive sounds can become 'smeared' with distance and reverberation, making them indistinguishable from continuous sounds (Hastie et al. 2019). These anthropogenic sounds may be incidental to activities, such as shipping or underwater construction, or purposeful, as in the case of operational sonar and seismic surveying.

To date, little is known about the soundscapes experienced by sea turtles in biologically important habitats used for resting, reproducing, and foraging, with only two published studies focusing on the sound sources and levels at known sea turtle foraging sites. In Fiji, the turtle habitats had negligible anthrophony, with most low frequency sounds originating from windy conditions and emissions from fish and crustaceans (Papale et al. 2020). In contrast, Samuel et al. (2005) showed that anthropogenic sound levels from boating and recreational activity during the high turtle activity season (between early July and September) in the Peconic Bay Estuary, Long Island, NY, were greater by over two orders of magnitude when compared to the periods with lowest human activity. The increasing and chronic exposure to anthropogenic sounds was suggested by authors to potentially affect sea turtle behavior and ecology. Consequently, the soundscapes and subsequent noise impacts presently experienced by sea turtles in biologically important habitats may be variable but in general are not well understood.

2.2. Potential Anthropogenic Noise and Other Impacts to Sea Turtles from Renewable Energy Developments

Marine anthropogenic noise may have individual- and population-level effects on marine wildlife (Duarte et al. 2021). Numerous reviews highlight behavioral, acoustic, and physiological responses of animals to these noise sources (Nowacek et al. 2007; Weilgart 2007; Popper and Hastings 2009; Slabbekoorn et al.

2016; Solan et al. 2016). Impacts from noise can include death or injury to individuals blast trauma, shifting auditory thresholds potentially affecting the ecology of the organisms, masking of signals that may be important to life history, and stimulating changes in spatial distribution or migratory pathways, which may impact the quality of forage habitat or increase their presence in 'riskier' areas (Popper et al. 2014). However, a recent review (Duarte et al. 2021) highlights the relative lack of attention given to some marine species—particularly fishes, invertebrates, and sea turtles—for which little is known about potential impacts from exposure to anthropogenic underwater noise. Consequently, the inclusion of these species is limited in reviews of impacts from noise, scientific assessments, and high-level policy documents.

For renewable energy development, different phases of development and the associated human noise-producing activities may affect the physiology and behavior of sea turtles in a variety of ways. In the initial phases of WEA development, surveying increases local boat traffic, raising underwater sound levels across a broad frequency spectrum, altering the local soundscapes experienced by sea turtles (Hildebrand 2009), and potentially masking acoustic communication between conspecifics (Popper et al. 2014). Further, this increase in vessel traffic may also increase the likelihood of turtle-vessel collisions. During surveying, high frequency sounds from high resolution geophysical (HRG) surveying techniques (i.e., boomers, sparkers, airguns, etc.) and the detonation of any unexploded ordnances within the WEA could affect sea turtle behavior and particularly their physiology (in the case of detonation of unexploded ordnances) if the turtles are within close proximity.

During the construction phase, increased boat traffic is expected to increase ambient sound levels and the potential for collisions. However, during the construction phase, HRG surveying noise would be replaced by loud impulsive noise from impact pile driving, which could result in physiological and/or behavior impacts or cause at least a short-term potential for displacement from established foraging areas or migratory routes. Other activities conducted during construction may also have some degree of physical environmental disruption or degradation, e.g., increased water turbidity. It is important to note that HRG surveys and impact pile driving both produce sounds with notable differences in temporal, spectral, and amplitude characteristics, which may result in differing potential noise impacts to sea turtles and require alternative mitigation strategies (Table 1).

Table 1. Comparison of the sounds produced by high resolution geophysical (HRG) surveying and impact pile driving operations, their potential noise impacts on sea turtles, and corresponding mitigation measures.

Activity	HRG	Impact Pile Driving
Location	Moving	Stationary
Entrapment	Possible in trailing lines, etc.	Improbable
Sound type	Extended series of sounds Varies from sequential frequency modulated chirps and continuous wave signals Peak energy from 400 Hz upwards as far as 20 to 400 kHz depending on equipment	Extended sequence of impact noises with 1 to 1.5 second intervals Predominant energy at frequencies of 500 Hz or less
Potential noise impacts	Potential (unproven) for barotrauma, physiological stress responses, auditory impairment, behavioral changes, displacement in individuals	Potential (unproven) for barotrauma, physiological stress responses, auditory impairment, behavioral changes, displacement in individuals
Impact mitigation	Vessel speed restrictions Real-time detection and action (shutdowns) Seasonal and area limitations	Sound attenuation (Bubble walls, Pile caps, etc.) Ramp-up procedures Real-time detection and action (shutdowns)

After construction is complete, service vessel activity would continue to elevate ambient sound levels and the risk of collision within WEAs. Near to wind turbines, operational low frequency sound likely would be constant (Tougaard et al. 2020). In addition to these potential noise impacts, electrical fields around underwater cables may negatively impact animals in close proximity, as sea turtles are known to have magnetoreception for orientation (Inger et al. 2009; Olssen et al. 2010; Dhanak et al. 2016; Levitt et al. 2021). The presence of the structures themselves may cause negative impacts due to altered habitats and currents or wake (Vanhellemont and Ruddick 2014; Paskyabi 2015; Segtnan and Christakos 2015) or positive impacts if they act as artificial reefs, refuges, or as new foraging grounds (Inger et al. 2009; Matley et al. 2021). Additionally, restricting access by non-authorized marine traffic to these areas would mean WEAs can act as *de facto* marine protected areas (Inger et al. 2009), the size of which may or may not have ecological significance to migratory animals, such as sea turtles.

Finally, after years of operation, decommissioning and removal of the infrastructure would generate more sound within WEAs, may cause at least a short-term potential for species displacement from established foraging areas or migratory routes, and may increase collision risk with vessel traffic.

A framework for studying the effects of offshore wind development on marine mammals and sea turtles has already been developed and published (Kraus et al. 2019). It highlights several core hypotheses for short- and long-term effects of these developments. Kraus et al. (2019) presents each hypothesis with its testability and potential study designs, with an emphasis on marine mammals, as well as developed assessment methods. Kraus et al. (2019) state that "…[*b*]ecause *sea turtles are acoustically non-detectable, disturbance studies of the effects on endangered sea turtles are likely to rely entirely upon changes in distribution and abundance, making visual surveys critical to assessments. Tagging studies may be possible as well, requiring captures and releases in the area."*

Table 2 presents an appraisal of activity and species independent multi-hypothesis framework, adapted to focus solely on sea turtles.

Table 2. Hypotheses for testing the effects of wind farms on sea turtles.

Short-term Effects of Wind Energy Development

Hypothesis	Importance	Testability	Assessment
Displacement hypothesis: Construction noise result in displacement of sea turtles away from activity locations.	High	High	There are several approaches to test this hypothesis, including aerial surveys and telemetry of individuals before, during, and after construction activities, then evaluating the distribution of animals under each of the conditions.
Behavior disruption hypothesis: Construction noise disrupt critical behaviors of sea turtles, such as feeding.	High	Low	Depth-sensing satellite tags deployed on resident turtles may measure changes in behavior when compared to turtles in equivalent control sites.
Physiological impact hypothesis: Construction noise cause elevated stress hormone levels in sea turtles.	High	Medium	Using concurrent acoustic measurements and capture-mark-recapture methods in the WEA and a control site, characterize the relationship between stress-related hormone levels and underwater noise from pile-driving and other activities.
Prey hypothesis: Construction activities and noise cause zooplankton to change their vertical distribution and or benthic mollusks change density or patch structure.	Low/Medium	Medium	Conduct benthos surveys to identify changes in prey abundance and hence forage quality caused by the development by identifying population structure, abundance, and distribution before, during, and after construction activities.

Long-term Effects of Wind Energy Development

Hypothesis	Importance	Testability	Assessment
Distribution change hypothesis: Wind turbine presence and operational low frequency noise either excludes or attracts sea turtles.	High	High	It will be critical to compare changes in turtle abundance and oceanographic conditions in the WEA to a nearby control area.
Long-term prey hypothesis: Wind turbine presence affects long-term feeding opportunities for sea turtles.	Low	High	The WEA structures will alter the sea floor environment and may change composition of benthos. By employing before and after studies or using a control site similar to the original WEA site condition, monitor prey abundance through benthos surveys and assess long-term feeding opportunities.
Ecosystem enhancement hypothesis: The development of artificial reefs on wind turbine foundations affects the regional ecosystem, potentially enhancing some characteristics of marine productivity.	Low	Medium	Conducting a study to assess sea turtles feeding on biofouling communities could be relatively simple and inexpensive using video cameras attached to foundations and monitoring the water around the legs.

Notes: Adapted from Kraus et al. (2019). *Hypothesis* characterizes the cause-and-effect aspect of WEA development. *Importance* indicates the severity of the impact highlighted by the hypothesis. *Testability* indicates how well the hypothesis can be tested to provide conclusive results. *Assessment* provides some indication of study designs that can be adopted to test the hypotheses.

It should be noted that this framework does not consider any direct mortality or injury to individual sea turtles, such as those caused by collisions between turtles and vessels, or entanglement or entrapment in the industrial equipment used in the process of surveying and developing a WEA.

To ensure the protection of sea turtles from the varied noise impacts listed above, several elements need to be in place. First, it is vital that we gain a clear understanding of the auditory sensitivity of sea turtles and the potential noise impacts different anthropogenic sounds may have on these species. Second, we need to understand the current seasonal distribution and abundance of sea turtles and changes that are likely to occur from predicted rising sea temperatures under different global warming scenarios. This information can be used to inform the potential for high-risk periods and assess whether current WEAs with limited use by sea turtles, which are at lower risk, may become more important areas for sea turtles in the future. Lastly, WEA sites need to be monitored throughout all development stages.

The following sections of this report primarily explore the first two of these three requirements by identifying gaps in our understanding and coalescing priority actions to address these gaps.

3. Hearing and Response to Sound in Turtles (Literature Review)

3.1. Ear Morphology and Hearing Capabilities of Turtles

Although all turtle species appear to have a typically reptilian ear, closer examination of the ear morphology of sea turtles indicate some slight differences from terrestrial and semi-aquatic turtles (Ridgway et al. 1969; Popper et al. 2014; Willis 2016). In sea turtles, the tympanic disk located on the surface of the head, within the air-filled middle ear, is backed by a thick layer of fatty connective tissue (Ridgway et al. 1969). The columella runs from the tympanic disk through connective tissue terminating on the columella footplate, which transfers the mechanical energy of sound to the inner ear. Mechanical stimulation causes the motion of fluid in the inner ear, which displaces hair cells, stimulating the auditory nerve (Willis 2016). It has been suggested that these adaptations may help sea turtles with deep diving abilities (Ridgway et al. 1969) or may be analogous to the lower jaw fat channels used by marine mammals to detect sound (Ketten et al. 1999). However, variation in this fatty tissue volume has been shown across species, within a single species, and within the same individual; consequently, the exact reasons for these variations in ear morphology remain unknown (Willis et al. 2016). The air-filled middle ear indicates that sea turtles likely detect sound pressure (Christensen-Dalsgaard et al. 2012), but whether sea turtles also detect sound via particle motion and how hearing changes with depth (when air within cavities becomes compressed) remain unknown.

It is well established that sound plays an important role in the livelihood of many marine species, such as cetaceans, which use sound extensively to communicate and sense their environment (Richardson et al. 1995). In contrast, far less is known about the importance of sound to sea turtles at different life-history stages. Studies have indicated that freshwater and sea turtle species can detect and produce sound in both air and underwater (Bartol et al. 1999; Barton and Ketten 2006; Christensen-Dalsgaard et al. 2012; Martin et al. 2012; Piniak 2012; Ferrara et al. 2013; Ferrara et al. 2014a, 2014b; Piniak et al. 2016; Ferrara et al. 2019; Monteiro et al. 2019; Charrier et al. 2022). However, it is believed that these species are less sensitive to airborne sounds than other reptiles (Wever 1978). Sounds produced by turtles at different life-history stages have been suggested to be used for a range of biological purposes including communication between conspecifics (Charrier et al. 2022), reproduction (Galeotti et al. 2005; Giles et al. 2009), hatching synchronization and nest emergence (McKenna et al. 2019), and auditory scene analysis (Popper et al. 2014); therefore, sound likely plays an important role in the livelihood of sea turtles.

To determine the susceptibility of sea turtles to anthropogenic noise impacts, it is necessary to understand their hearing capabilities to ascertain which sound sources are likely to be of concern for these species. As is evident from above, the auditory capabilities of sea turtles have to some degree been assessed through two main research avenues:

1) **Electrophysiological studies** record auditory evoked potentials (AEP), i.e., recording nerve response to a sound stimulus. In essence, AEPs are recorded by insertion of needle electrodes sub-dermally at the top of the head (recording electrode) and intramuscularly in the deltoid muscle of the neck (reference electrode); a ground electrode is also inserted in a muscle for measurements in air or in seawater for underwater tests (Piniak 2012). The studies investigate nerve responses (spikes in nervous system activity) to sound stimuli at various levels and frequencies.
2) **Behavioral studies** test sound stimuli, i.e., an animal is recorded as physically reacting to sound. These studies are more complicated to perform as they require significant training of subject animals. For example, a turtle is trained to place its head in a hoop to start the trial and then swim to specific areas of a pool and bite on a plastic tube to confirm its response (Bartol and Bartol 2011).

Through systematic use of either of these two experimental techniques, auditory thresholds at different sound frequencies are constructed, generally from around 50 Hz through to 1 kHz or more. This analysis produces an audiogram that displays sensitivity to sound at different frequencies with frequency across the x-axis and threshold level (presented as a sound pressure level with the unit of dB re 1 µPa RMS) on the y-axis. See example audiogram for multiple turtle species presented in Figure 1. In this figure, the lower the value on the y-axis, the more sensitive the animal is to that frequency of sound.

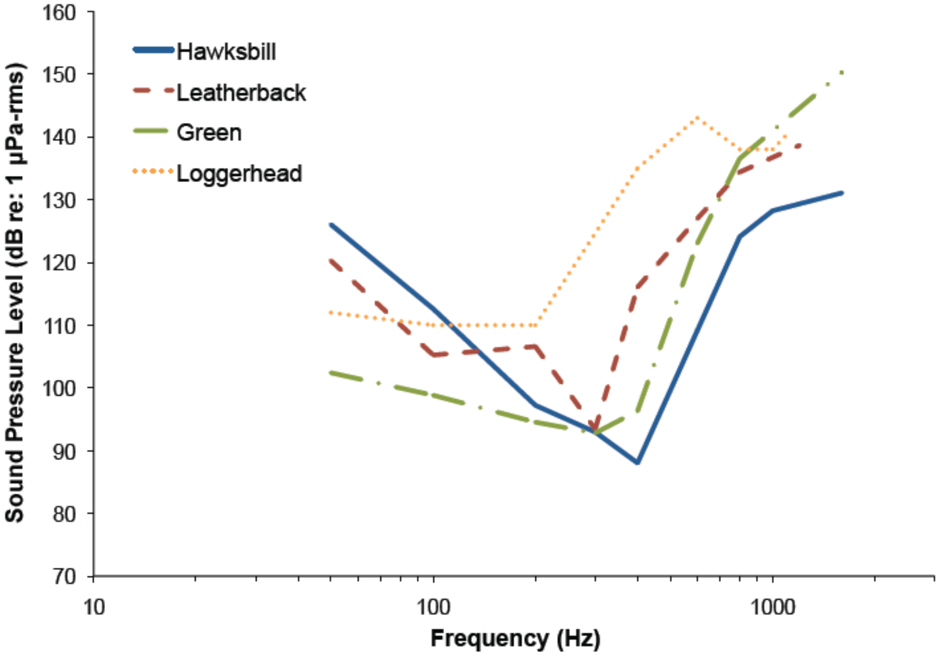

Figure 1. Fully submerged underwater sound pressure audiograms for juvenile green (*Chelonia mydas*), hatching leatherback (*Dermochelys coriacea*), hatchling hawksbill (*Eretmochelys imbricata*), and adult loggerhead (*Caretta caretta*) sea turtles.

These data were determined by recording auditory evoked potential responses to tonal stimuli. Note, the x-axis is on a log scale. Source: Piniak (2012).

Based on the available data from auditory sensitivity studies of sea turtle hearing, these species appear to hear sounds below 1,000 Hz and have their most sensitive hearing at lower frequencies (i.e., 100–600 Hz) (Ridgway et al. 1969; Martin et al. 2012; Piniak 2012). Some studies with loggerhead turtles have shown that behavioral tests are more sensitive than electrophysiological ones (Bartol and Bartol 2011; Martin et al. 2012). However, behavioral studies assessing auditory capabilities of sea turtles generally align with results from electrophysiological ones (Martin et al. 2012). Consequently, electrophysiological tests are suitable, especially in cases when there is no time to train turtles to respond to auditory stimuli.

Nonetheless, it is important to highlight the limitations of both AEP and behavioral studies. For example, both assessments require turtles to be housed in dedicated research facilities and tested under controlled conditions, and although some studies have attempted to examined turtle behavioral responses to sound in more natural conditions, these studies have focused on identifying sound as a deterrent (O'Hara and Wilcox 1990; McCauley et al. 2000) or recording turtles' reactions to non-experimental sound (Weir 2007; DeRuiter and Larbi Doukara 2012) rather than making direct measurements of hearing sensitivity. Auditory sensitivity studies often are limited by local ambient sound levels during assessments; experience potential perturbations in the sound field resulting from testing tank wall and air interfaces (Parvulescu 1964; Gray et al. 2016; Rogers et al. 2016); and limited to higher frequency sounds due to the inability for commonly used transducers to produce sufficiently high levels of sound at low frequencies underwater (Houser et al. 2017).

Table 3 presents the limited number of publications relating to the topic of sea turtle auditory capabilities reviewed species by species and their findings.

Table 3. Hearing capabilities in sea turtles, by species.

Species	Medium of the Emitted Stimulus	Life Stage	Hearing Range (in Hertz) and Associated Decibel Value in Brackets	Highest Sensitivity (in Hertz) and Associated Decibel Value in Brackets	Procedure*	Reference
Loggerhead	underwater	post-hatchling	50 (124) to 1,100 (134)	200 (116)	Auditory evoked potentials	Bartol and Bartol 2011; Lavender et al. 2014
Loggerhead	underwater	post-hatchling	50 (101) to 800 (116)	200 (85)	Behavioral	Bartol and Bartol 2011; Lavender et al. 2014
Loggerhead	underwater	juvenile	50 (117) to 1,100 (140)	50 (117), 100 (118), and 400 (118)	Auditory evoked potentials	Bartol and Bartol 2011; Lavender et al. 2014
Loggerhead	underwater	juvenile	50 (103) to 1,000 (102)	800 (76)	Behavioral	Bartol and Bartol 2011; Lavender et al. 2014
Loggerhead	underwater	adult	100 (112) to 1,131 (141)	200 (110) and 400 (110)	Auditory evoked potentials	Martin et al. 2012
Loggerhead	underwater	adult	50 (110) to 800 (148)	100 (98)	Behavioral	Martin et al. 2012
Loggerhead	aerial	post-hatchling	100 (92) to 900 (94)	500 (81) and 600 (84)	Auditory evoked potentials	Ketten and Bartol 2006
Loggerhead	aerial	juvenile	100 (97) to 800 (122)	600 (94) and 700 (96)	Auditory evoked potentials	Bartol and Ketten 2006
Loggerhead	aerial	juvenile	100 (87) to 700 (98)	100 (87), 400 (87), and 500 (86)	Auditory evoked potentials	Ketten and Bartol 2006
Loggerhead	vibrational	juvenile	250 (-30 dB re: 1g rms) to 1,000 (-10 dB re: 1g rms)	250 (-30 dB re: 1g rms)	Auditory evoked potentials	Bartol et al. 1999
Loggerhead	underwater	n/a	35 to 1,000	n/a	Behavioral	Lenhardt 2002
Loggerhead	underwater	n/a	100 to 1,000 (tested)	400-500 (106 dB SPL re 1 μm)	Auditory evoked potentials	Lenhardt 2002
Green	underwater	juvenile	50 (95) to 1,600 (157)	200 (87), 300 (85), and 400 (88)	Auditory evoked potentials	Piniak et al. 2016
Green	aerial	juvenile	50 (18 dB re: 1 dyne/cm^2) to 2,000 (39 dB re: 1 dyne/cm^2)	400 (-35 dB re: 1 dyne/cm^2)	Cochlear response potentials	Ridgway et al. 1969
Green	aerial	juvenile	100 (101) to 800 (119)	600 (94) and 700 (96)	Auditory evoked potentials	Ketten and Bartol 2006

Species	Medium of the Emitted Stimulus	Life Stage	Hearing Range (in Hertz) and Associated Decibel Value in Brackets	Highest Sensitivity (in Hertz) and Associated Decibel Value in Brackets	Procedure*	Reference
Green	aerial	juvenile	50 (80 dB re: 20 µPa-rms) to 800 (78 dB re: 20 µPa-rms)	400 (44 dB re: 20 µPa-rms)	Auditory evoked potentials	Piniak et al. 2016
Green	aerial	subadult	100 (93) to 500 (108)	300 (83)	Auditory evoked potentials	Bartol and Ketten 2006
Green	aerial	subadult	100 (96) to 500 (106)	200 (93) and 400 (91)	Auditory evoked potentials	Ketten and Bartol 2006
Green	vibrational	juvenile	30 (18 dB re: 1 dyne/cm^2) – 700 (21 dB re: 1 dyne/cm^2)	300 (-11 dB re: 1 dyne/cm^2) and 500 (-12 dB re: 1 dyne/cm^2)	Cochlear response potentials	Ridgway et al. 1969
Kemp's ridley	aerial	juvenile	100 (110) to 500 (113)	100 (110), 200 (110). and 500 (113)	Auditory evoked potentials	Ketten and Bartol 2006
Kemp's ridley	aerial	juvenile	100 (104) to 500 (115)	100 (104) and 200 (106)	Auditory evoked potentials	Bartol and Ketten 2006
Leatherback	underwater	hatchling	50 to 1,200	300 (84)	Auditory evoked potentials	Piniak 2012; Piniak et al. 2012a
Leatherback	aerial	hatchling	50 to 1,600	300 (62 dB re: 20 µPa-rms)	Auditory evoked potentials	Piniak 2012; Piniak et al. 2012a
Hawksbill	underwater	hatchling	50 – 1,600	400 (84)	Auditory evoked potentials	Piniak 2012
Hawksbill	aerial	hatchling	50 – 1,600	300 (51 dB re: 20 µPa-rms)	Auditory evoked potentials	Piniak 2012

Notes: Extracted from Papale et al. (2020) and expanded. Unless otherwise stated, the intensity is expressed as dB re: 1 µPa.

* Auditory evoked potentials are electric responses generated by the brain in response to the acoustic stimulation of the nervous system, whereby electrodes are used to detect voltages. No useable data are available from an additional study on juvenile green turtles in Malaysia (Yudhana et al. 2010).

3.1.1. Loggerhead Turtle

The loggerhead turtle is the most comprehensively studied species, with auditory capabilities tested on post-hatchling, juvenile, and adult life stages both in water and in air. With some variation between individual and per study, peak sensitivity underwater generally lies between 100–400 Hz and peak aerial sensitivity lies between 400–600 Hz (Martin et al. 2012). One exceptional behavioral study indicated peak sensitivity of a juvenile turtle underwater at 800 Hz (Bartol and Bartol 2011; Lavender et al. 2014).

3.1.2. Green Turtle

The green turtle was probably the first species of turtle to be tested and the study by Ridgway et al. (1969) using both air measurements and mechanical stimulation revealed maximum sensitivity to sound in the region of 300–400 Hz. Subsequent work by others has produced similar results (Bartol and Ketten 2006; Piniak 2012; Piniak et al. 2012b; Piniak et al. 2016). Bartol and Ketten (2006) obtained peak sensitivity for juvenile green turtles, in air, at slightly higher frequencies, between 600 and 700 Hz.

3.1.3. Leatherback Turtle

Auditory capabilities of leatherback turtles have only been tested for hatchlings. Auditory responses were obtained from 50 to over 1,000 Hz and peak sensitivity measured at 300 Hz, both in air and underwater (Piniak 2012; Piniak et al. 2012a).

3.1.4. Kemp's Ridley Turtle

Only juvenile Kemp's ridley turtles have been assessed. In air they have limited auditory capabilities in the range of 100 to 500 Hz, peaking in sensitivity in the lower frequencies (1002–00 Hz) (Bartol and Ketten 2006; Ketten and Bartol 2006)

3.1.5. Hawksbill Turtle

As with leatherback turtles, the auditory capabilities of hawksbill turtles been assessed in air and in water but only with hatchlings. They were found to be sensitive to a relatively wide range of frequencies from 50–1,600 Hz, with sensitivity peaking around 300–400 Hz (Piniak 2012).

3.2. Behavioral, Acoustic, and Physiological Responses to Anthropogenic Noise

Exposure to anthropogenic noise may have detrimental implications for sea turtles by altering biologically important behaviors (i.e., foraging, resting, and reproducing), displacing individuals, masking acoustic cues, and altering their physiology; these impacts may affect individual fitness and, if experienced repeatedly or chronically, may have consequences for sea turtle populations (Popper et al. 2014; Duarte et al. 2021). Below we highlight what is known about the behavioral, acoustic, and physiological responses of sea turtles during exposure to anthropogenic noise.

3.2.1. Behavioral Responses

Several publications cover sea turtles' immediate behavioral responses to anthropogenic noise. These publications predominantly focus on responses to seismic airgun sounds and their use as a potential deterrent (O'Hara and Wilcox 1990; Moein et al. 1994; McCauley et al. 2000; Lenhardt 2002; Weir 2007; Southwood et al. 2008; DeRuiter and Larbi Doukara 2012). In these studies, caged and free-swimming sea turtles are reported as reacting to the sounds by initiating a startle dive (Weir 2007; DeRuiter and Larbi Doukara 2012), rising to the surface, and altering swimming patterns (McCauley et al. 2000). In other studies, sea turtles avoided the airgun source initially, but authors suggested that animals potentially habituated to the source over time (Moein et al. 1994). Consequently, although some behavioral response may be observed in response to anthropogenic noises, findings are variable and inconclusive.

In addition to changing behavior, exposure to anthropogenic noise may result in the displacement of individuals from important habitats used for foraging, resting, and reproducing. However, to date, no studies have directly assessed the potential for displacement of sea turtles following exposure to anthropogenic noise. Nonetheless, Weir (2007) notes that fewer sea turtles were seen at the surface when airguns were firing compared to when they were silent, suggesting displacement may occur. Many of these studies used a small number of captive or caged individuals, and it is important to consider that these results may not be directly applicable to the responses of free-living animals exposed to anthropogenic noises due to subtle differences in the environmental settings (Popper et al. 2014). Further, behavioral responses to anthropogenic noise are known to vary with context, species, sex, age, size, motivation (feeding, mating, and movement around the home range, etc.) (Popper et al. 2014).

3.2.2. Acoustic Responses (Masking)

If noise contains sufficient energy inside the detectable frequency region of a sound of interest, occurs at the same time, and is beyond the critical ratio,[1] then the sound may become inaudible or difficult to detect by the receiver in an effect termed 'masking' (Clark et al. 2009; Erbe et al. 2016). Masking is of concern as it may limit communication between conspecifics and/or the detection of predators, which may have direct fitness consequences for sea turtles. Data on hearing for all vertebrates indicates that the degree of masking is related to the amplitude and frequency of the masking noise (Popper et al. 2014). Presently, there is a complete lack of data on the potential for masking in sea turtles from exposure to anthropogenic noise, although it is expected to occur under certain circumstances (Popper et al. 2014). Current sound exposure guidelines for sea turtles considers masking to occur when the signal-to-noise ratio is reduced by more than 6 dB (Popper et al. 2014).

3.2.3. Physiological Responses

To date, nothing is known about the potential for sea turtles to experience auditory impairment from exposure to anthropogenic underwater noise. Auditory impairment can be described as either a temporary threshold shift (TTS) or a permanent threshold shift (PTS), depending on the potential for auditory recovery post-exposure (Popper et al. 2014), and represents a change in an animals' ability to hear, whereby they become less sensitive at one or more frequencies because of the exposure (Popper et al. 2014; Houser et al. 2017). A reduction in hearing sensitivity from exposure to anthropogenic noise may have ecological consequences for sea turtles if sound is used for acoustic communication between conspecifics or predator detection. In certain circumstances, TTS and potentially PTS may occur in sea turtles, as it does for most other vertebrates where auditory impairment has been investigated (Popper et al. 2014). Current sound exposure guidelines for sea turtles defines TTS as occurring when the hearing threshold is reduced by 6 dB or more in terms of sound pressure or particle motion (Popper et al. 2014).

Little is known about the potential for physiological injury and subsequent mortality in sea turtles following exposure to high amplitude noise. Preliminary studies by Ketten et al. (2005) noted that fresh sea turtle cadavers appeared highly resistant to internal trauma following a high-level explosive event. However, Klima et al. (1988) and Gitschlag and Herczeg (1994) found that explosive removal of offshore oil and gas structures in the GOM resulted in injury and death of a small number of sea turtles, which they attributed to barotrauma. Near to high amplitude noise, such as from explosive events, sea turtles may be subject to physiological injury or mortality.

A review of literature on physiological stress in sea turtles revealed very few published studies. To date, no research has been published on potential stress responses in sea turtles to elevated environmental noise. The most common way to assess stress in reptiles has been to measure corticosterone (the primary hormone produced in response to stressful stimuli) levels in blood, together with other hematological metrics (Aguirre et al. 1995; Martínez Silvestre 2014; Hunt et al. 2020). For example, a short-term stress response has been observed in Kemp's ridley sea turtles following ground transport for rehabilitation (Hunt et al. 2016) and in green turtles afflicted with fibropapillomatosis (Aguirre et al. 1995), as indicated through elevated levels of corticosterone and other hematological or enzymatic responses. Other physiological impacts of chronic stress include immunosuppression, which can make individuals more prone to infections and disease (Milton and Lutz 2003). Consequently, chronic exposure to anthropogenic noise may result in increased stress responses in sea turtles which could have direct fitness consequences for individuals.

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[1] The critical ratio is the difference between the sound pressure level of a pure tone just audible in the presence of continuous noise of constant spectral density and the sound pressure spectrum for that noise expressed in decibels (Clark et al. 2009; Erbe et al. 2016).

3.3. Summary of Understanding

Research on sea turtle auditory capabilities has progressed little, if at all, since the seminal work of Piniak (2012). Table 3 summarizes current knowledge. Hearing sensitivity generally has been determined through detection of AEPs. Where comparative studies exist, turtle behavioral responses are elicited at lower sound thresholds than for AEPs; however, results from these two measures generally appear to align (Martin et al. 2012). Turtles detect low frequency sounds (50–2,000 Hz) in air and water with peak sensitivity in the 100–600 Hz range (Martin et al. 2012; Piniak 2012).

Few data exist on the behavioral, acoustic, or physiological response of sea turtles from exposure to anthropogenic noise. Studies of behavioral responses indicate mixed results and varying degrees of response from not well controlled experimental or wild situations, limiting our ability to draw conclusions. Further, our understanding of the acoustic (i.e., masking) and physiological effects (e.g., TTS, PTS, physiological injury, and elevated stress hormones) of anthropogenic noise exposure on sea turtles is limited or lacking.

3.4. Gaps in Understanding

There are three thematic gaps in our empirical understanding of hearing and responses to anthropogenic noise in sea turtles. The first gap is the lack of hearing sensitivity information for different species and life-history stages. Data are completely lacking for olive ridley and flatback sea turtles (neither of which currently occur in the North West Atlantic [NWA]). Different life-stage and age-class data gaps exist for species already partially studied, such as any life stage other than hatchling for leatherback and hawksbill sea turtles, and adult Kemp's ridley and green turtles. Acquiring this knowledge would aid our understanding of how sound may be perceived by animals throughout their life cycle and broaden our understanding of species that may be impacted by WEAs within and outside of the NWA.

The second gap in our understanding of sea turtle hearing is of the functional morphology of the sea turtle ear. By acquiring this information on a per species basis, we would be able to better understand the mechanism(s) by which sea turtles detect and use sound (i.e., acoustic pressure or particle motion). This information should then be verified using specific tests, such as AEP or behavioral studies under appropriate scientific conditions (Piniak et al. 2012b).

Finally, there is also a critical need to investigate the behavioral, acoustic, and physiological effects of anthropogenic sound on sea turtles. These results would help to determine what levels of sound (as perceived by turtles), which may lead to behavioral changes, TTS or PTS, auditory masking, and the fitness impacts from stress responses to noise. Existing studies are flawed due to poor experimental design, making them unrelatable to 'wild' conditions or insufficient due to small sample sizes and contradictory results. Addressing these gaps in our understanding is critical for the conservation and protection of these endangered species.

3.5. Recommended Priorities for Knowledge Acquisition

Several documents cover prioritization of knowledge acquisition relating to turtle hearing and the effects of anthropogenic sound (Piniak 2012; Popper et al. 2014; Nelms et al. 2016; Elliott et al. 2019; Gitschlag et al. 2021). We highlight these studies in the discussion below and include additional recommendations for knowledge acquisition.

The highest priority is to examine physiological, acoustic, and behavioral responses of sea turtles to various anthropogenic sounds. As suggested above, studies should determine if sea turtles experience masking in response to anthropogenic noise, which will be better informed by studies assessing the auditory capabilities of sea turtles. The potential for and levels that may cause TTS following exposure to noise in sea turtles could be assessed using experimental noise exposure studies; in these studies, noises of different frequencies, amplitudes, temporal structures, and durations are played to captive sea turtles, followed by AEP or behavioral measurements of their hearing thresholds. This approach would be similar to the types of studies used to assess the potential for TTS in cetaceans (see Finneran 2015; Southall et al. 2007, 2019). The physiological effect of exposure to noise should also be tested via evidence of hormonal stress responses from exposure to noise in turtles.

The recommendation is to conduct studies of stress response in sea turtles proximate to WEA development. The groundwork for assessing physiological stress in turtles proximate to WEA developments has been laid. Baseline biochemical characteristics of sea turtle blood have been established for some species in some locations (see Snoddy et al. 2009; Flint 2013 and references therein). The importance of rapid sampling has been shown in studies of loggerheads (Flower et al. 2015) to avoid capture stress affecting sample results. Further, experiments on wild sea turtle behavioral responses to anthropogenic stressors, such as seismic airgun surveys, HRG surveys, impact pile driving and shipping noise, could be used to better inform current (i.e., look-outs onboard vessels, changes in temporal and spatial sound areas) (Blackstock et al. 2017) and future mitigation and management approaches for WEAs, to pursue adaptive management approach and make these approaches more rigorously defensible.

Improving scientific understanding of sea turtle hearing and functional morphology is also important. The determination of underwater audiograms for all species and all life stages, from hatchling to mature adult, would provide insights into the auditory capabilities of turtles and help inform what measures need to be put in place to protect turtles from loud sounds, i.e., whether one size would fit all or each species and age class would require its own set of limits. Better understanding of the morphology of turtle ears, which are known to have air spaces, and their sensitivity to acoustic pressure or particle motion would improve our knowledge on the susceptibility of the ear to damage and how hearing sensitivity may vary with depth.

4. Distribution (Residency and Migratory) of Sea Turtles Along East Coast US

The following review covers the species of sea turtles in the NWA and GOM contiguous area. Overall turtle abundance in the region reflects the size of the breeding populations seasonally utilizing the sandy coasts to lay their eggs. Therefore, we first present this data, followed by a review of seasonal abundance and distribution of all life stages of sea turtles in the region.

The Kemp's ridley (*Lepidochelys kempii*) has a very high proportion of its global population present in these waters, especially the northern GOM, where it breeds. They are also known to be present in the Chesapeake Bay area, where several have been tracked (DiMatteo et al. 2021). Although impacts at WEA sites in the NWA would affect individual turtles of this species, impacts on the general population is unknown, as the NWA is considered a population sink for this species, with minimal numbers of turtles returning to the GOM to breed (Caillouet Jr. and Gallaway 2020). Consequently, this review covers five species of sea turtle: the loggerhead, green, leatherback, hawksbill, and Kemp's ridley.

4.1. Nesting Distribution per Species with Timing and Population Sizes

In general, adult sea turtles aggregate off the nesting beaches at least one month before nesting, with males departing the area during the early part of the nesting season. A female's nesting season may last 1 to 3 months, depending on the individual and the species, during which time she deposits three to seven clutches of eggs at approximately 2-week intervals. After depositing the final clutch for the year, they will migrate to seasonal or year-round 'feeding' habitats, which may be several hundreds of kilometers away from the nesting area. Consequently, there is a great seasonal influx of adult turtles into nearshore habitats, followed by the mass transit from the beach to oceanic waters of hundreds of thousands of newly hatched turtles (Miller 1997).

Most sea turtles nesting on the eastern US seaboard do so in the state of Florida, with nest numbers decreasing northwards (Figure 2). Nesting populations and the relative distribution of the five subject species of sea turtle are presented below in order of greatest nesting abundance to least.

4.1.1. Loggerhead Turtle

Loggerhead is the most numerous nesting species of turtle on the US East Coast. The nesting metapopulation has been divided by geographical region. The northern region from Georgia to Maryland received around 6,400 nests/year (Shamblin et al. 2017), Peninsular Florida received around 70,000 nests (Ceriani et al. 2019), and the Dry Tortugas received a modest ~340 nests (Ceriani et al. 2019). However, the Florida Statewide Nesting Beach Survey Program indicates around 90,000–120,000 nests were made per year in the years 2016–2020 (FWC 2023). An additional 1,100 clutches are laid each year in the northern GOM (Ceriani et al. 2019).

Loggerhead nesting occurs from late April to early September in Florida (Witherington et al. 2006), with later start and shorter seasons in more northern states, such as from late May to the end of July in Virginia (Cross et al. 2001). Consequently, there is a seasonal abundance of breeding adult loggerhead turtles along the US coast from at least April to September and passage of tens of thousands of hatchling turtles through September and into October. One summer abundance estimation predicted upwards of 800,000 loggerhead turtles (juvenile and adult) present along the NWA continental shelf (NEFSC and SEFSC 2011).

Outside of the breeding season, many loggerheads, both juveniles and adults, still inhabit neritic waters along the eastern US seaboard. However, a seasonal north-south shift in turtles to warmer waters in the winter has been well documented for North Carolina loggerheads that initially migrate north after breeding (Hawkes et al. 2007; McNeill et al. 2020); however, this shift does not mean the region is devoid of turtles in the winter. Patel et al. (2021) tracked 196 juvenile and adult loggerheads from the Mid-Atlantic Bight (MAB) between 2009 and 2018. They clearly present a seasonal change in spatial distribution with turtle locations being most restricted to the south in winter, which was a similar finding to other recent work (Winton et al. 2018). Under climate change scenarios, loggerheads are predicted to occur in greater numbers in higher latitudes between October and December (Patel et al. 2021), increasing their spatiotemporal distribution over the NWA shelf area.

Tracking data from Florida neonate loggerhead turtles indicate that they move offshore into oceanic habitats, following the Gulf Stream (Mansfield et al. 2014). After their initial passage from the nesting beaches into nearshore waters and onwards, they are not present in coastal neritic habitats for a number of years until they have grown to a sufficient size to undergo an ontogenetic shift in diet and habitat selection becoming benthic foragers (Bolten 2003).

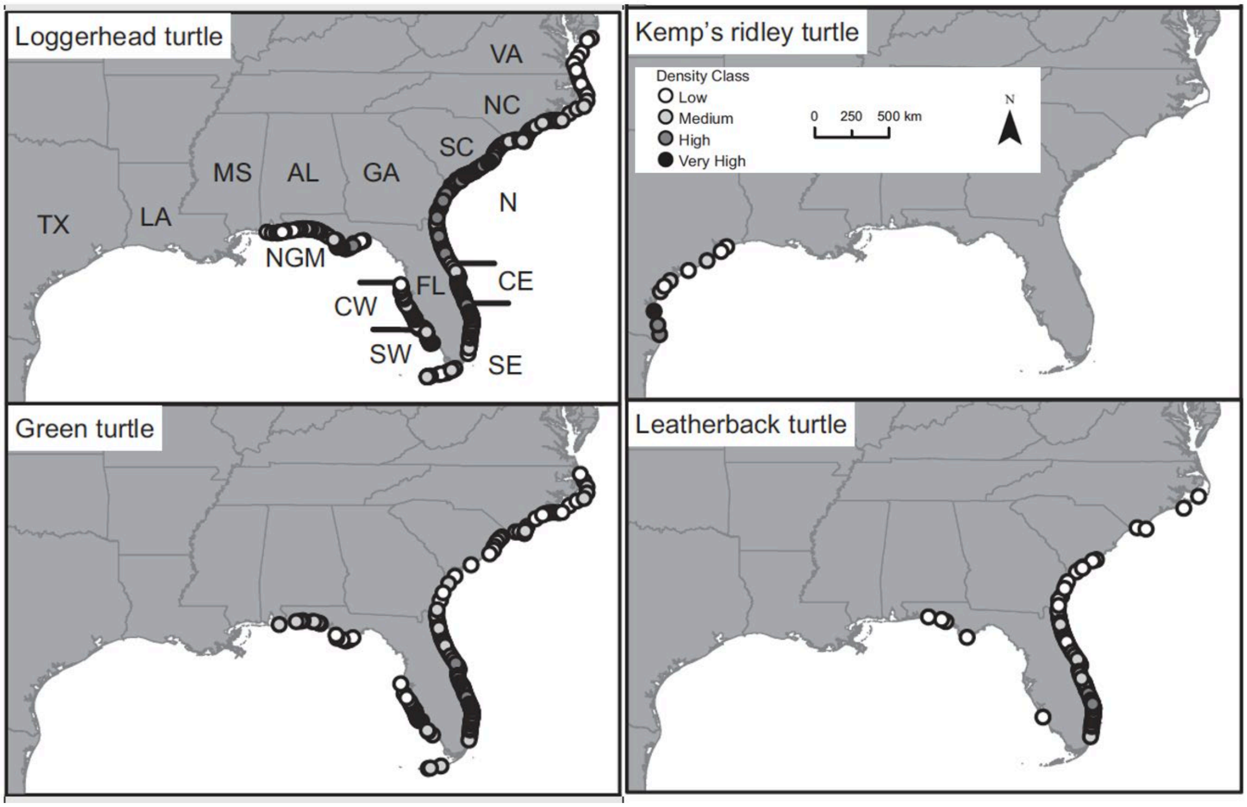

Figure 2. Sea turtle nesting areas in the US.
Reproduced from Fuentes et al. (2016). The hawksbill turtle is not present as its nesting is too sporadic to identify any specific site as even a "low density" nesting area.

4.1.2. Green Turtle

The green turtle is the second most numerous nesting species of turtle on the US East Coast, with the metapopulation increasing in size based on annual nest counts (Shamblin et al. 2015). Most nesting occurs in Florida with published figures exceeding 36,000 to 53,000 nests per year (Shamblin et al. 2015; 2018), decreasing to around 30 clutches per year further north in North Carolina (Shamblin et al. 2018).

Green turtle nesting lasts from May to early September in Florida (Witherington et al. 2006). The southeastern coast of the US is inhabited by large numbers of adult green turtles from April through August, and the region temporarily hosts dispersing hatchlings through September into October.

There is a paucity of data on the movements of adult turtles outside the breeding season. One study carried out on adult females at the minor nesting site of the Dry Tortugas showed that turtles remained at the extreme south of the Florida peninsula or around the Keys (Hart et al. 2013). A separate unpublished study, reported by Witherington (2006a), indicated that both adult male and female green turtles tracked from Florida East Coast beaches migrated south to the southernmost reach of the Florida peninsula, and even further south. In combination, these data suggested that US waters are not important feeding habitats for adult green turtles. In contrast, juvenile turtles are present in high and increasing numbers year-round in Florida (e.g., Ehrhart et al. 2007). Studies on juvenile green turtles have revealed notable behaviors that affect seasonal numbers present at coastal and neritic habitats. Juvenile green turtles from tracked from North Carolina (n = 20) were shown to exit the sounds in the fall to inhabit either neritic or oceanic habitats of the Atlantic for the colder winter months (Williard et al. 2017). A further study of 24 small juvenile turtles in the GOM showed that the turtles actively swam in directions to keep them in their preferred northern habitats (Putman and Mansfield 2015) even though they were not at a stage that they would actively exploit benthic food sources. Green turtles of the NWA evidently pass through several ontogenetic habitat stages. Neonates from Florida have been tracked in to the open ocean and the Gulf Stream (Mansfield et al. 2021). At around 30 cm carapace length, they shift to shallow protected coastal waters and then they leave Florida's waters and migrate south when they range from around 60–70 cm in length, still as juveniles (Witherington et al. 2006).

4.1.3. Leatherback Turtle

Leatherback turtles are the third-most numerous nesting species of turtle on the US East Coast. Again, most nesting occurs in Florida, with up to 1,000 or more nests recorded in recent year (FWS 2023). Fewer nests are made in Georgia and the Carolinas, and one leatherback nesting site has been recorded in Maryland (Rabon Jr et al. 2003).

The nesting season is earlier than that of hard-shelled turtles and runs in Florida from March to June (Stewart and Johnson 2006); however, nesting further north also occurs in July (Rabon Jr et al. 2003). Thus, the Atlantic Coast of Florida and to a lesser extent the proximate states host elevated numbers of adult leatherback turtles from February to June, with hatchling dispersal continuing into July and August.

Leatherback turtles can withstand cooler water temperatures than their hard-shelled counterparts. Consequently, they are present in greater numbers relative to their population size, in Atlantic coastal waters of the US year-round. Additionally, some turtles from nesting areas further south—such as Costa Rica, Panama, Suriname, and French Guiana—migrate into coastal US waters (Fossette et al. 2010; Evans et al. 2021). Adults and large juveniles are present in relatively large numbers in the NWA and coastal waters of the US (James et al. 2005; DFO 2012; Dodge et al. 2014, 2015; Fossette et al. 2014; Evans et al. 2021) and are present in the colder months when hard-shelled turtles have migrated south to warmer waters (Fossette et al. 2014). The extensive oceanic development phase of this species makes them hard to intercept. In addition, they are difficult to rear in captivity. Thus, there are no tracking studies on small juvenile or neonate leatherback turtles. Because of the exceptionally low frequency at which these life stages have been encountered, they can be considered not likely to be present in coastal waters where WEA developments may take place.

4.1.4. Kemp's Ridley Turtle

Most of the nesting of this fourth-most numerous nesting species of turtle on the US East Coast occurs in the GOM along the coasts of Mexico and Texas. Only a few isolated nesting events have been recorded historically from the Atlantic Coast of Florida and northward to North Carolina (NMFS and USFWS 2015).

Kemp's ridley nesting takes place from April to July (NOAA Fisheries 2023), with turtles thought to mate offshore of the nesting beaches from late March through to the early nesting season (NMFS and USFWS 2015). Hatchlings traverse the nearshore waters into offshore habitats through July into August.

Extensive tracking has revealed that almost all mature and large juvenile turtles remain in the shallow coastal corridors at the edges of the GOM (Renaud and Williams 2005; Seney and Landry Jr 2011; Shaver et al. 2013, 2016; Coleman et al. 2017; Hart et al. 2018). However, some juveniles and adults are also known to be present during summer months on the US Atlantic Coast as far north as Chesapeake Bay (DiMatteo et al. 2021).

The epipelagic phase of the Kemp's ridley lifecycle is thought to last only two years until they recruit to nearshore waters (NMFS and USFWS 2015). Therefore, most of this species' life-span takes place in with GOM shallow coastal habitats.

4.1.5. Hawksbill Turtle

This species is the least likely to nest on the US East Coast. Meylan and Redlow (2006) record the location of 31 nests, all from southern Florida. However, two nests by a single female have been more recently reported from South Carolina (Finn et al. 2016). In contrast, hawksbill turtles nest in the hundreds in the northern Caribbean Islands and the Yucatan Peninsula of Mexico (NMFS and USFWS 2013).

Nesting in Florida has been recorded from June to August but is too infrequent and variable to define a true nesting season (Meylan and Redlow 2006). Breeding hawksbills and their hatchlings are extremely rare along the US East Coast; however, some nesting hawksbills from Mexico have been tracked into Florida's waters (Uribe-Martínez et al. 2021). Furthermore, hawksbill strandings occur along the East Coast of Florida, and two have been reported in North Carolina (Avens et al. 2021), suggesting turtles present in at least the more southern locations are within their normal geographic range. This distribution is supported by capture-mark-recapture work, including juvenile turtles, carried out in Florida at the Dry Tortugas, Key West, and Palm Beach County (Hart et al. 2012; Gorham et al. 2014; Wood et al. 2017), with some turtles tracked year-round in a localized area (Wood et al. 2017). The foraging locations and habitats of small juvenile and neonate hawksbills from the region remain elusive. However, they are suggested to inhabit *Sargassum* (Witherington et al. 2012) until they reach 23 cm at around 1 to 3 years old (Avens et al. 2021), when they recruit to shallow coastal habitats.

5. Foraging and Migratory Area Use in NWA: Environmental Drivers, Corridors, Critical Habitat, and High-Use Areas

Most turtles present along the eastern US seaboard are loggerhead turtles; consequently, loggerhead turtle is the best studied species in the region. These turtles occupy marine habitats ranging from nearshore and shallow to offshore and deep. The Atlantic Marine Assessment Program for Protected Species (AMAPPS) reviewed abundance surveys along the whole NWA seaboard, which showed clear seasonality in loggerhead presence northwards of North Carolina and far fewer turtles present to the north of the warmer waters of the Gulf Stream (Palka et al. 2021). This change in distribution has been confirmed through tracking numerous individuals undertaking seasonal latitudinal migrations to avoid cooler waters (e.g., Hawkes et al. 2007; Patel et al. 2021). In relation to this migration, North Carolina waters off the Pamlico Sound and Cape Hatteras form a relatively narrow critical corridor for turtles moving to escape the colder waters in the north in the winter. Tracking, survey, and habitat data, as well as presence of *Sargassum* (the epipelagic habitat of small juvenile turtles), have all been considered by the US National Marine Fisheries Service in the designation of marine critical habitats for loggerhead turtles (NMFS 2013). The report concludes that "few to no turtles occur along the coast north of Cape Hatteras, North Carolina during January through March" for all demographic categories of loggerheads (juveniles, adult males, and adult females), and that the region south of Cape Hatteras, with waters 20–100 m deep, is a high-use area for loggerheads in the winter months. See below for potential distribution shifts due to future climate change.

Similar seasonal migrations can be assumed for other hard-shelled turtle species that are found north of Cape Hatteras in the summer. Figures 8-9 to 8-14 of Palka et al. (2021) depict quarterly location data for turtles identified by species and for unidentified hard-shelled turtles, shown with an overlay of Renewable Energy Areas. Loggerhead distribution is reproduced in Figure 3. Seasonal changes in distribution are clearly shown for all species of sea turtle, including the leatherback, which has a wider thermal niche than the other turtle species and routinely inhabit colder waters at higher latitudes (James et al. 2006), indicating there are far fewer turtles in general north of Cape Hatteras in the winter.

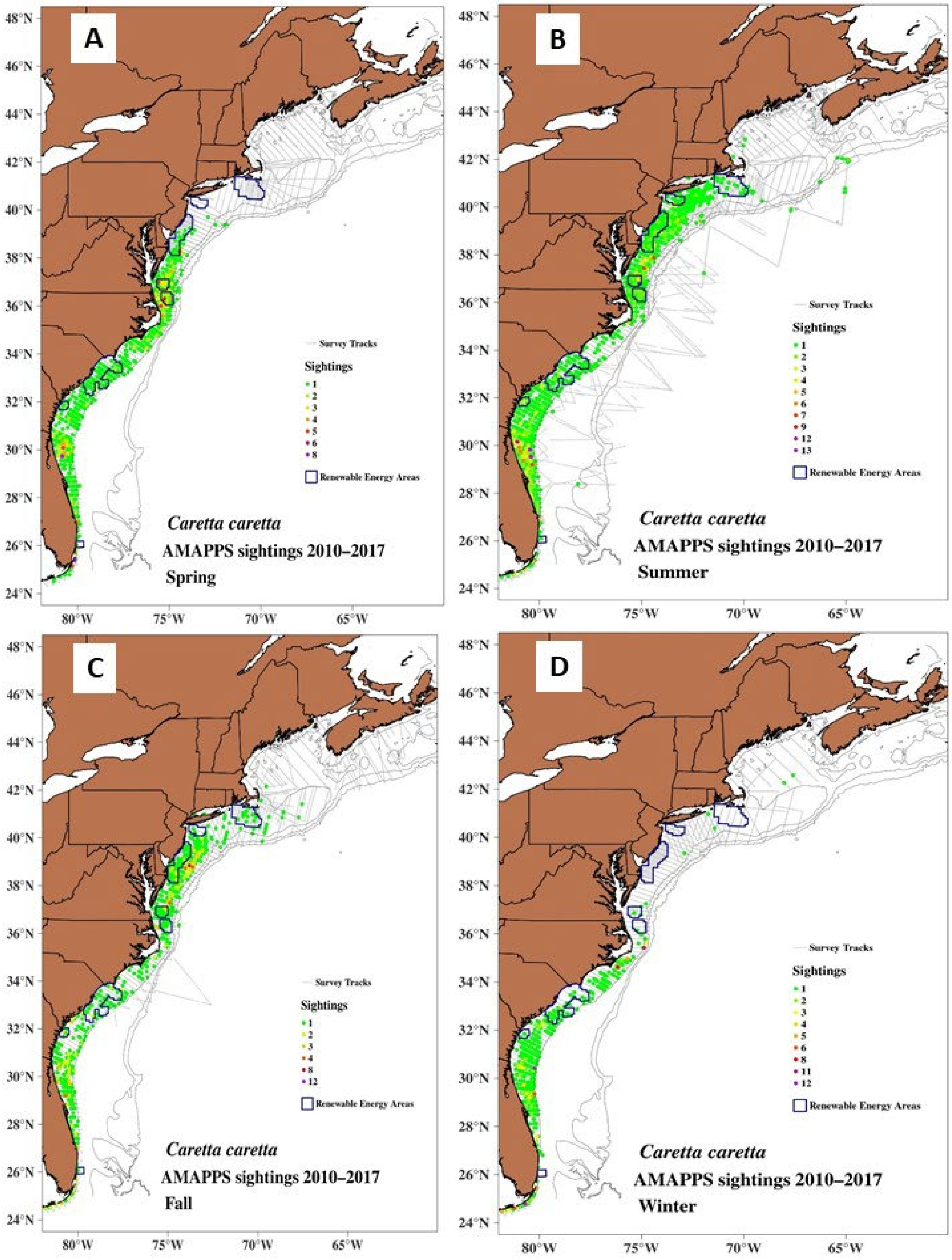

Figure 3. Locations of turtle sightings collected in visual surveys, by season.
Gray lines indicate track lines surveyed during the aerial and shipboard AMAPPS abundance surveys conducted during 2010 to 2017. Colored circles correspond to the sighting's group size. Spring is March 1 to May 31; summer is June 1 to August 31; fall is September 1 to November 30; and winter is December 1 to February28 (or 29). Adapted from (Palka et al. 2021).

Given the change in distribution related to ambient sea temperatures, distribution range and seasonality likely will change with global warming. Scientists modeled the current thermal and bathymetric niche of loggerhead turtles using tracks of 196 loggerhead turtles and predicted changes in distribution with increases in sea temperatures in the coming decades (Patel et al. 2021). The results showed that turtles are increasingly more likely to be encountered in the northern part of their range in the spring and fall, and that winter distribution is least likely to change dramatically. Further, increasing numbers of Kemp's ridley turtles are found cold-stunned in the winter in the Gulf of Maine, one of the most northern reaches for this species. The increase is suggested to be a result of warming temperatures luring the turtles further north and for longer than they have previously done; consequently, they are increasingly incapacitated when the waters cool (Griffin et al. 2019). This issue is likely to worsen and be applicable to other species as climate change progresses. For hawksbill turtles that have the most limited latitudinal range, with a strong preference for tropical waters, ocean warming because of climate change is likely to facilitate a northward expansion into new foraging habitats along the Florida Coast, potentially into Georgia and the Carolinas. Consequently, the location of WEA sites and timing of activity that are currently in areas of, at least seasonally, low sea turtle abundance may in the coming decades become parts of core turtle habitats.

Identifying the specific habitats that turtles use for critical life-sustaining behaviors, like foraging and resting, may further highlight which habitats are critical for these animals; this information would be essential to consider with regards to the impacts of WEA construction and operation.

5.1 Loggerhead Turtles

The larger juveniles have shifted to neritic habitats, and adult turtles are thought to generally feed on benthic invertebrates such as crabs and mollusks, but often opportunistically feed on fishery discards (NMFS and USFWS 2008; McClellan et al. 2010). However, prey specificity of individuals varies within foraging populations (Vander Zanden et al. 2010). To facilitate benthic foraging, large juvenile loggerheads in the NWA prefer shallow waters < 30 m deep (Arendt et al. 2012) or around 50 m, as predicted from modeled data (Patel et al. 2021). A recent study using an underwater remotely operated vehicle observed loggerhead turtles through complete dives and revealed hitherto unknown behavioral patterns (Smolowitz et al. 2015; Patel et al. 2016). Loggerhead turtles in waters 60 m deep or less spent most of their time near the surface and regularly consumed gelatinous prey in the water column; they did not primarily forage on benthic organisms, highlighting that there is much still to learn about the ecology of this well-studied species. Unlike in the Mediterranean, where loggerheads have been shown to aggregate in large densities in extremely shallow estuarine habitats (Rees et al. 2013), specific benthic habitats preferred by loggerhead turtles of the NWA are yet to be identified. This trend is a consequence of their opportunistic, omnivorous diet and their large population size, leading to a widely dispersed, pervasive presence. Consequently, loggerhead turtle encounters can be expected at any location along the eastern US seaboard, where sea temperatures are above the general sea surface thermal threshold of the species, around 15°C.

5.2 Green Turtles

Once recruited to neritic habitats, green turtles employ an increasingly herbivorous diet, feeding predominantly on sea grasses and algae (Bjorndal 1997). Thus, they often reside in nearshore habitats of only a few meters deep. From juvenile stage, green turtles show high fidelity to seasonal foraging sites (McClellan and Read 2009), though size-based partitioning of foraging habitat is noted with larger turtles inhabiting slightly deeper waters (Witherington et al. 2006). With few exceptions, turtles from around 60–70 cm shift south, often out of the US waters, and adults only return during their breeding migrations. Consequently, outside of the breeding season, when adult turtles aggregate at nesting beaches, green turtle encounters can be expected in shallow coastal habitats along the eastern US seaboard, where sea grasses and algae dominate, and suitable sea temperatures persist.

5.3 Kemp's Ridley

Neritic Kemp's ridleys have been observed in association with a variety of seabed types, from mangrove systems to sea grass meadows and oyster reefs (Schmid and Barichivich 2006). The diversity of habitats reflects the distribution of crabs, which are their primary prey (Bjorndal 1997). Subadult Kemp's ridley inhabit bays, coastal lagoons, and estuaries along the Atlantic seaboard (Márquez 1994) and are seasonally relatively common in Chesapeake Bay (DiMatteo et al. 2021). As such, species' distribution is not continuous, with notable absences along the Florida Coast (Schmid and Barichivich 2006). Because of the small population size, even in preferred habitats, Kemp's ridleys do not occur in the same numbers as loggerhead turtles along the US Atlantic seaboard.

5.4 Hawksbill Turtles

Hawksbill turtles are not common north of Palm Beach County in Florida (Wood et al. 2013). However, given the species' endangered species status under the ESA (NMFS and USFWS 2013) and the study of juvenile hawksbills being identified as a global priority (Wildermann et al. 2018), understanding their ecology and the potential impacts of WEA development on their populations is important. Juvenile hawkbills recruit to shallow coastal habitats from around 23-cm carapace length (Avens et al. 2021) and remain year-round in their chosen localities, showing a high degree of site fidelity; sponges constitute the main part of their diet (Wood et al. 2013). The Florida peninsula coastal waters act as a development habitat as most turtles there are juveniles. They leave this habitat before they reach adulthood, at around 15–25 years (Avens et al. 2021).

Hawksbill turtles are strongly associated with complex hard-bottom habitats (Wood et al. 2013, 2017; Selby et al. 2019) including those of manmade dolosse (Matley et al. 2021) less than 20 m deep (Selby et al. 2019). These rugose habitats provide plentiful food items and protection from large predators (Blumenthal et al. 2009a). Turtles use overhangs and small caves as refuges (Wood et al. 2013, 2017) with the 'roof' structures used to keep buoyant turtles underwater and extend resting dive durations (Houghton et al. 2003). Structural complexity is demonstrated to be more important than food abundance (Rincon-Diaz et al. 2011). Where habitat is suitable, vertical size partitioning has been observed with larger turtles using deeper waters (Blumenthal et al. 2009b). A clear understanding of suitable juvenile hawksbill habitat can be inferred, i.e., warm shallow waters with complex hard-bottom habitats that present a degree of vertical structuring, providing refuge and resting places and sponge growth as a food source.

5.5 Summary of Understanding

Strong seasonality in turtle presence north of Cape Hatteras exists for all hard-shelled species of sea turtle, mainly for juvenile but also adult turtles. There are more turtles in this northern area during summer and fall, when temperatures are conducive to normal sea turtle biology. In the winter and spring, the preferred habitat is north of the warmer Gulf Stream waters, which flows offshore, making neritic areas less suitable for survival. Leatherbacks exhibit less seasonal variation, as they can tolerate cooler sea temperatures, but they still show some seasonality in abundance. Loggerhead turtles are the most numerous species identified in the region in aerial surveys (reflecting their status as the most numerous nesting turtle). Leatherback turtles are the second most numerous; however, this species was not identified for around 40% of visually detected turtles in the aerial surveys (Palka et al. 2021), meaning species other than loggerheads have the potential to make up a large portion of turtles present. In the southern states, especially Florida, there is a spring and summer influx of breeding adult turtles that nest on the sandy coastline, followed by a flow of hatchling sea turtles making their way out to sea for the first time.

All hard-shell species of turtle in the shallow coastal waters of the US eastern seaboard likely feed primarily on benthic food items, especially green turtles, which are predominantly herbivorous, and hawksbill turtles, which are predominantly spongivorous. Loggerheads and Kemps' ridley turtles feed on more mobile benthic organisms, such as crabs. Leatherback turtles feed on gelatinous plankton.

5.6 Gaps in Understanding

- The feeding ecology of turtles in NWA is not fully known. This gap is especially true for loggerhead turtles, which may be benthic feeders, epipelagic feeders, or both. Additionally, it is suggested that leatherbacks may feed on mussels and tunicates from fishing gear lines (Kraus et al. 2019), but this hypothesis requires verification.
- Fine-scale, seasonal sea turtle distribution and abundance maps of turtles at targeted WEA sites and based on visual observation data (i.e., aerial surveys) are lacking. The production of such maps would contextualize the importance of seasonal considerations for WEA development. Sufficient spatiotemporal surveying may reveal sub-regional sea turtle hot spots that may be otherwise be overlooked by more broadscale assessments. Similarly, a fine-scale analysis of existing tracking data sets for all species of sea turtle that are observed in NWA region and specifically at proposed WEA sites is lacking. The timing and drivers of movements (e.g., temperature, ocean productivity, or breeding) require further investigation, can feed into predictive modeling of these movements, and can create adaptive management options for WEA development.
- Not all species and age classes of sea turtles are adequately represented in existing tracking projects. Movements of additional Kemp's ridley and green turtles should be acquired in projects with suitably large, stratified samples. This data could feed into fine-scale analyses of turtle distribution and abundance and complement the findings from the analysis of existing data.
- The effects of climate change on the spatiotemporal distribution of sea turtles is lacking, except for loggerheads and leatherbacks. These distribution models should be run, based on existing and newly acquired turtle and environmental data, to best predict neritic and coastal distribution of turtles in water depths less than 200 m, covering all WEA and proximate marine areas.
- Data on individual- and population-level effects for health, fecundity, overall fitness, and survivorship resulting from displacement caused by WEA developments is lacking. Accurate modeling of the impacts on populations and the relative benefits from changing actions and mitigation measures to minimize disruption and disturbance is hampered by this lack of information.

5.7 Recommended Priorities for Knowledge Acquisition

The priorities for improving our understanding of turtle distribution and abundance by considering environmental factors can be divided into several categories. Studies to assess impacts rely on either short-term assessments and re-investigation of existing data, or long-term monitoring, which may cover pre-development, construction, and operational periods. In all cases, the potential confounding aspects of interannual variation need to be considered when determining the robustness of conclusions that can be drawn from the data.

Develop an improved understanding of sea turtle movements, distributions, and habitat use patterns, including changes in habitat use in relation to offshore wind development

New technological solutions, such as new biologging tools for assessing behavioral response to noise, are in development (Boyle 2017; Tyson et al. 2017). Under certain circumstances, the new technology may already be feasible options for impact monitoring in test or live situations. The goal of the suggested actions is to "better understand potential risk of interactions with offshore wind facilities and to inform models of abundance and vessel strike risk that require information on dive behavior and other metrics." In addition, an improved understanding is needed of the feeding ecology of loggerhead and leatherback turtles within their chosen habitats irrespective of anthropogenic activity, as well as studies to quantitatively assess the impact of airguns and pile driving noise on the distribution and abundance of sea turtles during each phase of the development and maintenance of wind farms.

Identify environmental drivers of distribution and habitat use patterns, update abundance estimates, and determine possible data compilation and modeling approaches for using these data together to inform decision making

Existing sea turtle tracking and survey datasets should be integrated into models of sea turtle density and abundance estimates in relevant locations to better characterize baseline habitat use patterns prior to WEA development. These models should then be adapted to predict turtle distributions under potential climate change scenarios. A long-term priority related to this goal is to compare the detection probability of turtles detected in visual versus digital aerial surveys to understand the compatibility of various data streams.

Examination of turtle health, stress, and behavior near WEA developments compared to control sites, involving capture-mark-recapture and sampling

For behavioral and physiological response to noise, examination of turtle health and stress condition near WEA developments compared to similar control sites using capture-mark-recapture and sampling would help identify previously unstudied aspects of at sea disturbance. The goal of this priority is to understand if turtles that remain proximate to WEA developments are physiologically impacted (negatively or positively) by exposure to sound and other disturbances and the infrastructure present. Through simultaneous telemetry studies, it may also be possible to determine behavioral responses (changes in diving, foraging, migration, etc.) in turtles to acute and long-term exposure to WEA development.

Assessment of sea turtle use of offshore wind structures and potential reef effects that may occur due to the presence of these structures

This priority would involve site specific observations of sea turtles around the offshore wind structures conducted together with an assessment of the distribution of prey species. The goal of this assessment would be to identify possible positive impacts of WEA developments, such as the potential creation of *de facto* marine protected areas due to restrictions on fishing and other boat traffic within the WEA.

6 Conclusions

Given the overlap of locations for WEA development and the distribution of five species of sea turtles along the eastern US seaboard, it is clear there will be at least seasonal overlap between these species and this potential stressor. Given the potential range expansion of these animals due to warming sea temperatures under climate change, this overlap is likely to increase.

A basic understanding of the various impacts on sea turtles, as individuals and populations, of developing a WEA exists, along with frameworks for monitoring and mitigation based on limited data and inferences from other taxa. However, this understanding is rudimentary in comparison to other animals, such as marine mammals. An improved understanding of the auditory capabilities of sea turtles, along with how they respond to stress, is particularly lacking and warrants immediate attention.

WEA development plans need to be adaptive so that they include the latest scientific findings, such as any future insight about the susceptibility of turtles to anthropogenic sound. In the longer term, future WEA developments need to consider climatic changes in turtle distribution and abundance in their plans.

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Appendix A: Annotated Bibliography of Hearing and Behavioral Responses to Sound in Sea Turtles

The following table contains publications that present data on the hearing capabilities of sea turtles and turtle responses to sounds supplementary to details provided in Sections 3.1 and 3.2 of this report. This appendix includes additional publications related to the soundscape of turtle habitats and general reviews of the soundscape existing in today's oceans.

Table A-1. Annotated bibliography of hearing and behavioral responses to sound in sea turtles.

Notes: Sp. = Species codes: Cc = Loggerhead, Cm = Green, Dc = Leatherback, Ei = Hawksbill, Lk = Kemp's ridley, uk = unknown; Source: https://www.paludarium.net/uploads/4/4/1/8/4418601/sensory_biology_of_sea_turtles.pdf.

Citation	Main Findings	Sp.
Baker KP. 2000. Studies in behavioral and physiological conservation: I. evidence for phonotaxis in leatherbacks and geomagnetic orientation in olive ridley sea turtle hatchlings; II. water relations in eggs and growth of the scheltopusik limbless lizard [thesis]. Buffalo (NY): State University of New York.	Leatherback hatchlings, in air, were shown to positively orientate towards sound of surf at 93 dB, but not to music, an organ tone, or traffic sounds.	Dc
Bartol S, Bartol I. 2011. Hearing capabilities of loggerhead sea turtles throughout ontogeny. Prepared by Virginia Wesleyan College & Old Dominion University for E&P Sound & Marine Life Programme. Report No.: JIP TechReport Grant No. 22 07-14. http://www.seaturtle.org/library/BartolSM_2011d_JIPTechReport.pdf.	Hearing frequency range detected in both behavior and AEP experiments were consistent (50–1,200 Hz). Both post-hatchlings and juveniles had significantly higher AEP-derived (mean = 126.6 re 1 µPa over hearing range) than behavior-derived (mean = 97.1 re 1 µPa over hearing range) auditory thresholds. *This is an important finding indicating that AEP tests are less sensitive than behavioral tests and suggesting that AEP tests should not be used to set the standard for sound exposure levels in the field.*	Cc
Bartol SM. 1994. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*) [thesis]. Gloucester Point (VA): Virginia Institute of Marine Science.	Maximum sensitivity was in low frequency region of at least 250 to 1,000 Hz with maximum sensitivity at 250 Hz of 124.4 dB re: 1 gravity unit. Turtles were able to resolve the stimulus through a high level of white noise.	Cc
Bartol SM. 2008. A review of auditory function of sea turtles. Bioacoustics. 17:57–59.	This short paper reviews the knowledge of sea turtle ear anatomy and existing auditory studies, presenting no new data.	Cc Cm
Bartol S, Ketten D. 2006. Turtle and tuna hearing. In: Swimmer Y, Brill R, editors. Sea turtle and pelagic fish sensory biology: developing techniques to reduce sea turtle bycatch in longline fisheries. Honolulu (HI): U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Pacific Islands Fisheries Service Center. p. 98–100.	Assessed auditory Brainstem Responses (ABRs). Subadult green sea turtles detected frequencies between 100–500 Hz; their most sensitive hearing was between 200–400 Hz. Juvenile green turtles tested in Maryland have a slightly expanded range of hearing compared to subadult greens tested in Hawaii. These juveniles responded to sounds ranging from 100–800 Hz, with their most sensitive hearing range from 600–700 Hz. The two juvenile Kemp's ridleys studied had a more restricted range (100–500 Hz), with their most sensitive hearing falling between 100–200 Hz.	Cm Lk

Citation	Main Findings	Sp.
Bartol SM, Musick JA, Lenhardt ML. 1999. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). Copeia. 1999(3):836–840. doi:10.2307/1447625.	Early study using ABRs to assess auditory capabilities and confirm low frequency sound sensitivity. Effective range of hearing from 250 to 750 Hz with most sensitive threshold at 250 Hz.	Cc
Boyle J. 2017. High-resolution satellite and archival tracking of leatherback sea turtles [thesis]. Exeter (UK): University of Exeter.	A novel study assessing free-ranging adult leatherback turtles' three-dimensional behavior related to ambient sounds during an internesting period. Turtles were shown to react to sounds outside of previously accepted auditory frequency range (100–400 Hz).	Dc
DeRuiter S, Larbi Doukara K. 2012. Loggerhead turtles dive in response to airgun sound exposure. Endangered Species Research. 16(1):55–63. doi:10.3354/esr00396.	Basic assessment of turtle response to seismic airgun operations showing turtles exhibited a startle response (dived) immediately following an airgun shot or when they were close to the airgun array. Modeling predicts over 50% of turtles would dive within a ~200 m range of the array, equivalent to 187 dB.	Cc
Duarte CM, Chapuis L, Collin SP, Costa DP, Devassy RP, Eguiluz VM, Erbe C, Gordon TAC, Halpern BS, Harding HR, et al. 2021. The soundscape of the Anthropocene Ocean. Science. 371(6529):eaba4658. doi:10.1126/science.aba4658.	Review of the soundscape in today's oceans with predictions for the future and impacts on marine species	Any
Eckert SA, Bowles AB. 1997. The effect of seismic airgun surveys on leatherback sea turtles (*Dermochelys coriacea*) during the nesting season. Unpublished Report, BHP Petroleum (Trinidad) Ltd.	Study with twofold aims of 1) detecting behavioral changes at sea in relation to airgun noise and 2) generating aerial audiogram for adult turtles Logistical limitations meant that suitable results were not attained for either aim.	Dc
Elliott B, Read A, Godley B, Nelms S, Nowacek D. 2019. Critical information gaps remain in understanding impacts of industrial seismic surveys on marine vertebrates. Endangered Species Research. 39:247–254. doi:10.3354/esr00968.	This review on the effects of seismic surveys presents three research priorities for sea turtles, together with knowledge gaps and innovative methods on mitigation against the impacts of these surveys.	All
Holtz B, Stewart KR, Piniak WED. 2021. Influence of environmental and anthropogenic acoustic cues in sea-finding of hatchling leatherback (*Dermochelys coriacea*) sea turtles. PLoS ONE. 16(7):e0253770. Doi:10.1371/journal.pone.0253770.	Hatchlings were tested for phonotaxic response to wave sound, human conversation, and traffic noise on beaches. No response was observed.	Dc
Ketten D, Bartol S. 2006. Functional measures of sea turtle hearing. Woods Hole (MA): Woods Hole Oceanographic Institution. 5 p. Report No.: 13051000.	Assessed ABRs for underwater sound All turtles tested responded to low frequency sounds from at least 100 Hz to no greater than 900 Hz. Loggerhead and green turtle hearing range reduced with age/size. Juvenile Kemp's ridleys had most restricted sensitivity range (100–500 Hz).	Cc Cm Lk
Lavender AL, Bartol SM, Bartol IK. 2012. Hearing capabilities of loggerhead sea turtles (*Caretta caretta*) throughout ontogeny. In: Popper AN, Hawkins A, editors. The effects of noise on aquatic life. New York (NY): Springer. p. 89–92.	See Bartol and Bartol (2011)	Cc

Citation	Main Findings	Sp.
Lavender AL, Bartol SM, Bartol IK. 2014. Ontogenetic investigation of underwater hearing capabilities of loggerhead sea turtles (*Caretta caretta*) using a dual testing approach. Journal of Experimental Biology. 217(14):2580–2589. doi:10.1242/jeb.096651.	See Bartol and Bartol (2011)	Cc
Lenhardt ML, Bellmund S, Byles RA, Harkins SW, Musick JA. 1983. Marine turtle reception of bone-conducted sound. The Journal of Auditory Research. 23(2):119–125.	An early study verifying bone-conducted hearing in sea turtles [*PDF unavailable*]	Cc Lk
Lenhardt ML. 1994. Seismic and very low frequency sound induced behaviors in captive loggerhead marine turtles (*Caretta caretta*). In: Fourteenth Annual Symposium on Sea Turtle Biology and Conservation; 1994 Mar 1–5; Hilton Head (SC). p 238–241.	Tested captive turtles' behavioral responses to very low frequency sounds Broadscale responses are presented aligned with turtles starting to swim when reacting to stimuli that were previously known to be within the turtles' measured hearing range.	Cc
Lenhardt M. 2002. Sea turtle auditory behavior. The Journal of the Acoustical Society of America. 112(5):2314. doi:10.1121/1.1526585.	Study producing audiogram with lowest thresholds at 400–500Hz range (106 dB SPL re 1 µm). Behavioral responses were also tested against seismic airguns. Meeting abstract. [*PDF unavailable].*	Cc
Magyar T. 2008. The impact of artificial lights and anthropogenic noise on loggerheads (*Caretta caretta*) and green turtles (*Chelonia mydas*), assessed at index nesting beaches in Turkey and Mexico [dissertation]. Bonn (DE): Rheinische Friedrich-Wilhelms-Universität Bonn.	General study on sea turtle hatchling orientation including recording of ambient anthrophony The study includes comparing 1-m sea wave sounds to established green turtle auditory sensitivity and concludes that green turtles should be able to hear waves. Orientation and selection experiments with hatchlings on land produced no results, possibly due to excessively loud sound levels in the test box.	Cm Cc
Martin KJ, Alessi SC, Gaspard JC, Tucker AD, Bauer GB, Mann DA. 2012. Underwater hearing in the loggerhead turtle (*Caretta caretta*): a comparison of behavioral and auditory evoked potential audiograms. Journal of Experimental Biology. 215(17):3001–3009. doi:10.1242/jeb.066324.	Examined both auditory evoked potentials (AEPs) and behavioral responses underwater Sound thresholds to elicit behavioral responses were lower than for AEPs in the most sensitive range of sounds (100–400Hz). Authors suggest AEP is a good alternative to measuring a behavioral audiogram for wild / untrained turtle or in time-sensitive circumstances.	Cc
McCauley RD, Fewtrell J, Duncan AJ, Jenner C, Jenner M-N, Penrose JD, Prince RIT, Adhitya A, Murdoch J, McCabe K. 2000. Marine seismic surveys— a study of environmental implications. The APPEA Journal. 40(1):692–708. doi:10.1071/AJ99048.	Sea turtle response to airgun noise was tested and "based on the response of captive animals to an approaching single air gun and scaling these results, indicated sea turtles displayed a general 'alarm' response at an estimated 2-km range from an operating seismic vessel and behavior indicative of avoidance estimated at 1 km." Furthermore, turtles are suggested to show "behavioural responses to an approaching air gun array at a received level around 166 dB re 1 µPa rms and avoidance around 175 dB re 1 µPa rms."	Cc Cm
Moein Bartol S, Musick JA. 2003. Sensory biology of sea turtles. In: Lutz PL, Musick JA, Wyneken J, editors. The biology of sea turtles, volume II. Boca Raton (FL): CRC Press. Chapter 3; p. 79–102.	General chapter on hearing in sea turtles written prior to most published studies. It highlights the general sensitivity of sea turtles to low frequency sounds and presents a schematic of a sea turtle ear.	All

Citation	Main Findings	Sp.
Moein S, Musick J, Keinath J, Barnard D, Lenhardt M, George R. 1994. Evaluation of seismic sources for repelling sea turtles from hopper dredges, final report. Vicksburg (MS): U.S. Department of the Army, Corps of Engineers, Engineer Research and Development Center, Waterways Experiment Station. 42 p.	Loggerheads were shown to react and then acclimate to noise from seismic sources in this early study. *[Two versions of this report were unavailable as PDFs so took info from a third source].*	Cc
Nelms SE, Piniak WED, Weir CR, Godley BJ. 2016. Seismic surveys and marine turtles: an underestimated global threat? Biological Conservation. 193:49–65. doi:10.1016/j.biocon.2015.10.020.	This paper reviews the possible impact of seismic surveys on sea turtles and finds the following: 1) There are few studies on the response of turtles to seismic operations, and the results are hard to interpret. 2) The potential for airgun sound to cause hearing damage or other ecological effects are not yet properly investigated.	All
O'Hara J, Wilcox JR. 1990. Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. Copeia. 1990(2):564–567. doi:10.2307/1446362.	Early experiment to show if turtles avoid airguns in a large (l:300m - w:45m - d:10m) enclosure. Results show some avoidance behavior with an "exclusionary range of airguns fired at pressures of 140 kg/cm^2 at about 30m." Tihe paper recommends testing the potential for airgun deterrents in other situations.	Cc
Papale E, Prakash S, Singh S, Batibasaga A, Buscaino G, Piovano S. 2020. Soundscape of green turtle foraging habitats in Fiji, South Pacific. PLoS ONE. 15(8):e0236628. doi:10.1371/journal.pone.0236628.	Presents results of an acoustic survey of green turtle foraging habitat highlighting biophonic and geophonic components. No link between turtle presence and sound levels was categorically demonstrated.	Cm
Piniak W, Eckert S, Harms C, Stringer E. 2012a. Underwater hearing sensitivity of the leatherback sea turtle (*Dermochelys coriacea*): assessing the potential effect of anthropogenic noise. Herndon (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 35 p. Report No.: OCS Study BOEM 2012-01156.	Sound sensitivity recorded for the first time with leatherback hatchlings, using AEPs. Results showed that leatherback sea turtle hatchlings can detect sounds underwater and in air, responding to stimuli between 50 and 1,200 Hz in water and 50 and 1,600 Hz in air, with maximum sensitivity between 100 and 400 Hz in water and 50 and 400 Hz. Anesthesia of turtles reduced thresholds by up to 7dB, i.e., they were more sensitive to sound when anesthetized.	Dc
Piniak W. 2012. Acoustic ecology of sea turtles: implications for conservation [dissertation]. Durham (NC): Duke University. https://hdl.handle.net/10161/6159.	Thesis containing data subsequently published and reported by WED Piniak elsewhere, and an unpublished "Current knowledge" review chapter. Chapter I: Hearing in the juvenile green sea turtle Chapter II: Leatherback turtle hearing sensitivity overlaps with anthropogenic sound Chapter III: Underwater and aerial hearing in hatchling hawksbill sea turtles Chapter IV: Loggerhead turtle behavioral responses to acoustic deterrent devices Chapter V: The acoustic ecology of sea turtles: Current knowledge, data gaps, and future research directions	Cc Cm Dc Ei

Citation	Main Findings	Sp.
Piniak WED, Mann DA, Eckert SA, Harms CA. 2012b. Amphibious hearing in sea turtles. In: Popper AN, Hawkins A, editors. The effects of noise on aquatic life. New York (NY): Springer. p. 83–87. [accessed 2022 Jul 13]. doi:10.1007/978-1-4419-7311-5_18.	An overview of hearing in sea turtles, with data on green turtle hearing. The chapter concludes that “more research is urgently needed to investigate the potential physiological and behavioral effects of anthropogenic noise on sea turtles”.	Cm (All)
Piniak WED, Mann DA, Harms CA, Jones TT, Eckert SA. 2016. Hearing in the juvenile green sea turtle (*Chelonia mydas*): a comparison of underwater and aerial hearing using auditory evoked potentials. PLoS ONE. 11(10):e0159711. doi:10.1371/journal.pone.0159711.	Study confirms low frequency hearing in juvenile green turtles with differing sensitivities in air and underwater assessed using AEPs.	Cm
Ridgway SH, Wever EG, McCormick JG, Palin J, Anderson JH. 1969. Hearing in the giant sea turtle, *Chelonia mydas*. PNAS. 64(3):884–890. doi:10.1073/pnas.64.3.884.	One of the first, if not the first, study on hearing sensitivity in sea turtles, using green turtles as test subjects Low frequency hearing verified using cochlear potentials.	Cm
Samuel Y, Morreale SJ, Clark CW, Greene CH, Richmond ME. 2005. Underwater, low-frequency noise in a coastal sea turtle habitat. The Journal of the Acoustical Society of America. 117(3):1465–1472. doi:10.1121/1.1847993.	The study assesses underwater sound at Peconic Bay Estuary system in Long Island, NY, a juvenile sea turtle foraging habitat. The data from this study indicate that these foraging sea turtles spend nearly half of their “activity season” surrounded by higher than the baseline levels of underwater noise.	Cc Cm Lk
Simmonds M, Dolman S, Weilgart L, editors. 2004. Oceans of noise. Wiltshire (EU): Whale and Dolphin Conservation Society. 168 p.	This report *on marine mammals* includes chapters on • Physics of underwater sound • Sources of marine noise • Examples of regulation and national legal instruments protecting marine wildlife from noise pollution Solutions – mitigation and management that apply to noise and sea turtles	All
Southwood A, Fritsches K, Brill R, Swimmer Y. 2008. Sound, chemical, and light detection in sea turtles and pelagic fishes: sensory-based approaches to bycatch reduction in longline fisheries. Endangered Species Research. 5:225–238. doi:10.3354/esr00097.	This review article considers sound as one of a range of mechanisms to deter sea turtle bycatch in longline fisheries. It concludes that auditory deterrents are not practical or effective.	All
Tyson RB, Piniak WED, Domit C, Mann D, Hall M, Nowacek DP, Fuentes MMPB. 2017. Novel bio-logging tool for studying fine-scale behaviors of marine turtles in response to sound. Frontiers in Marine Science. 4:219. doi:10.3389/fmars.2017.00219.	Presentation of a novel technological method of examining behavioral responses of freely swimming turtles to sound The sensor device attached to a turtle includes a three-axis accelerometer, gyroscope, and magnetometer; a pressure sensor; a hydrophone; a temperature gauge; and two VHF radio telemetry transmitters and antennas.	Cm All
Weir C. 2007. Observations of marine turtles in relation to seismic airgun sound off Angola. Marine Turtle Newsletter. 116:17–20.	Sea turtles were observed during seismic testing in open ocean. Some startle reactions were recorded in response to airgun blasts, but data were too limited to draw firm conclusions.	Lo Dc Cc uk
Yudhana A, Din J, Sunardi S, Abdullah S, Raja Hassan RB. 2010. Green turtle hearing identification based on frequency spectral analysis. Applied Physics Research. 2(1):125–134. doi:10.5539/apr.v2n1p125.	This study aims to determine hearing capabilities of juvenile green turtles. However, the study report does not contain particularly useful results.	Cm

Appendix B: Annotated and Illustrated Bibliography of Sea Turtle Tracking Studies from the Eastern US Seaboard

The following bibliography presents the main results of each publication for turtle distribution and abundance, together with brief text on the main spatial inferences. Papers are listed from most recent to oldest. This appendix includes a few extra references on turtle distribution and abundance that are not based on tracking work but complement the other publications. This inclusion is especially the case for hawksbill turtles that are relatively unstudied, in terms of tracking, in the Southeast US.

Key studies indicate large sample sizes and/or under-represented demographic units.

Full references for each figure citation are listed at the end of Appendix B.

A.1 Loggerhead Turtle Studies

Loggerhead Turtle 1: Patel et al. 2021

- Some data under Winton et al. 2018 incorporated
- Seasonal distribution (Figure B-1)
- Projected more northerly distribution under climate change (Figure B-2)

Life Stage	Sex	Sample Size	Origin	Key Study?
Mixed	M&F	196	Mid-Atlantic Bight	**Yes** (large sample size)

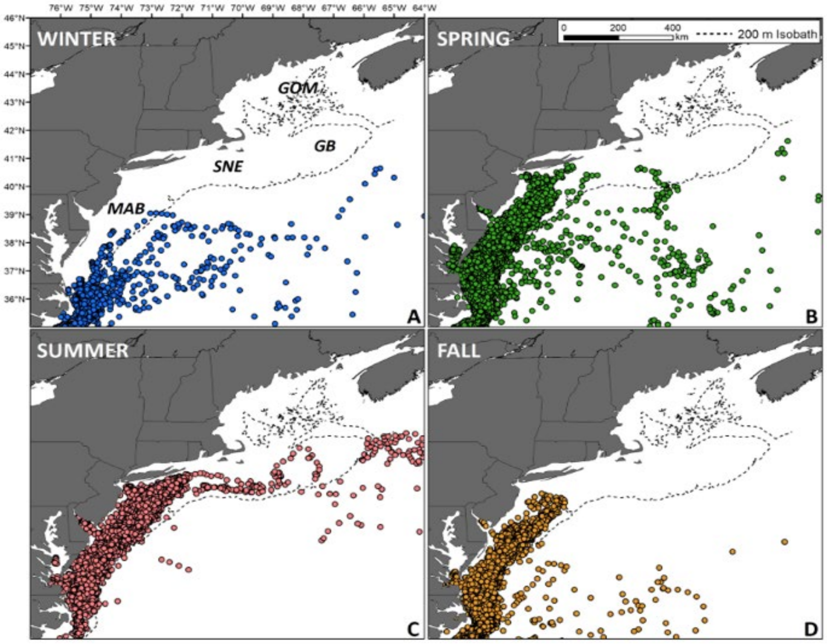

Figure B-1. Seasonal distribution

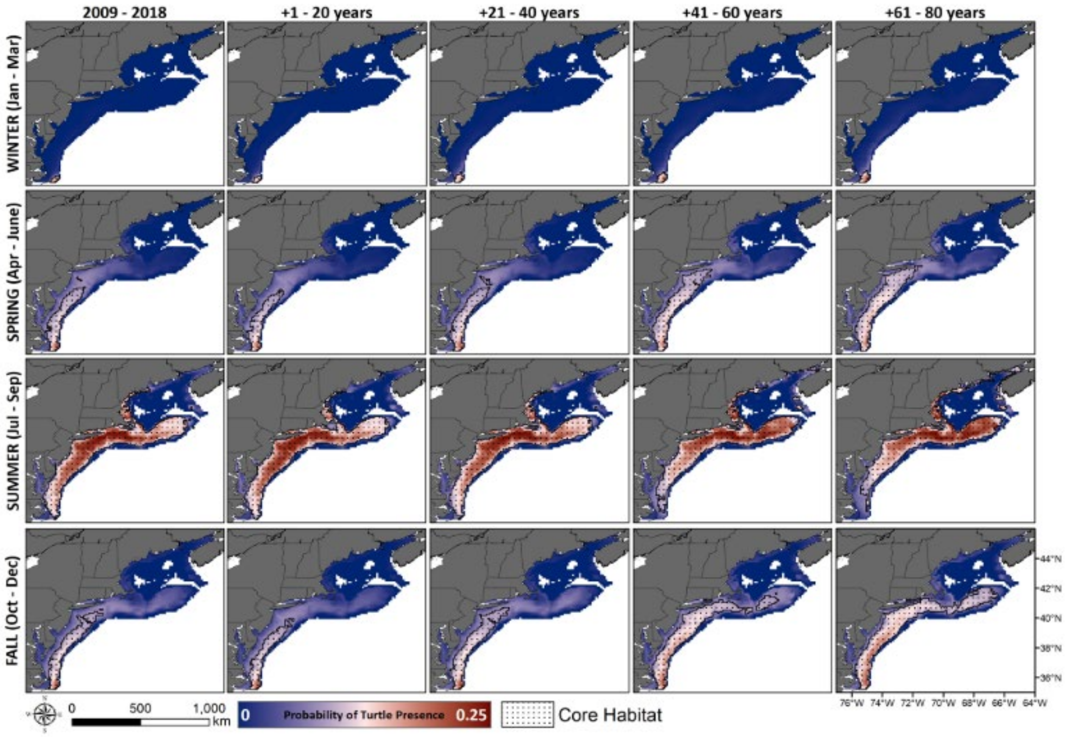

Figure B-2. Projected more northerly distribution under climate change

Loggerhead Turtle 2: Phillips et al. 2021

- Post-nesting habitat use in the eastern GOM mapped (Figure B-3, warmer colors) and data on internesting locations and fidelity to foraging locations (Figure B-3, cooler colors)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	46	W peninsular Florida	**Yes**

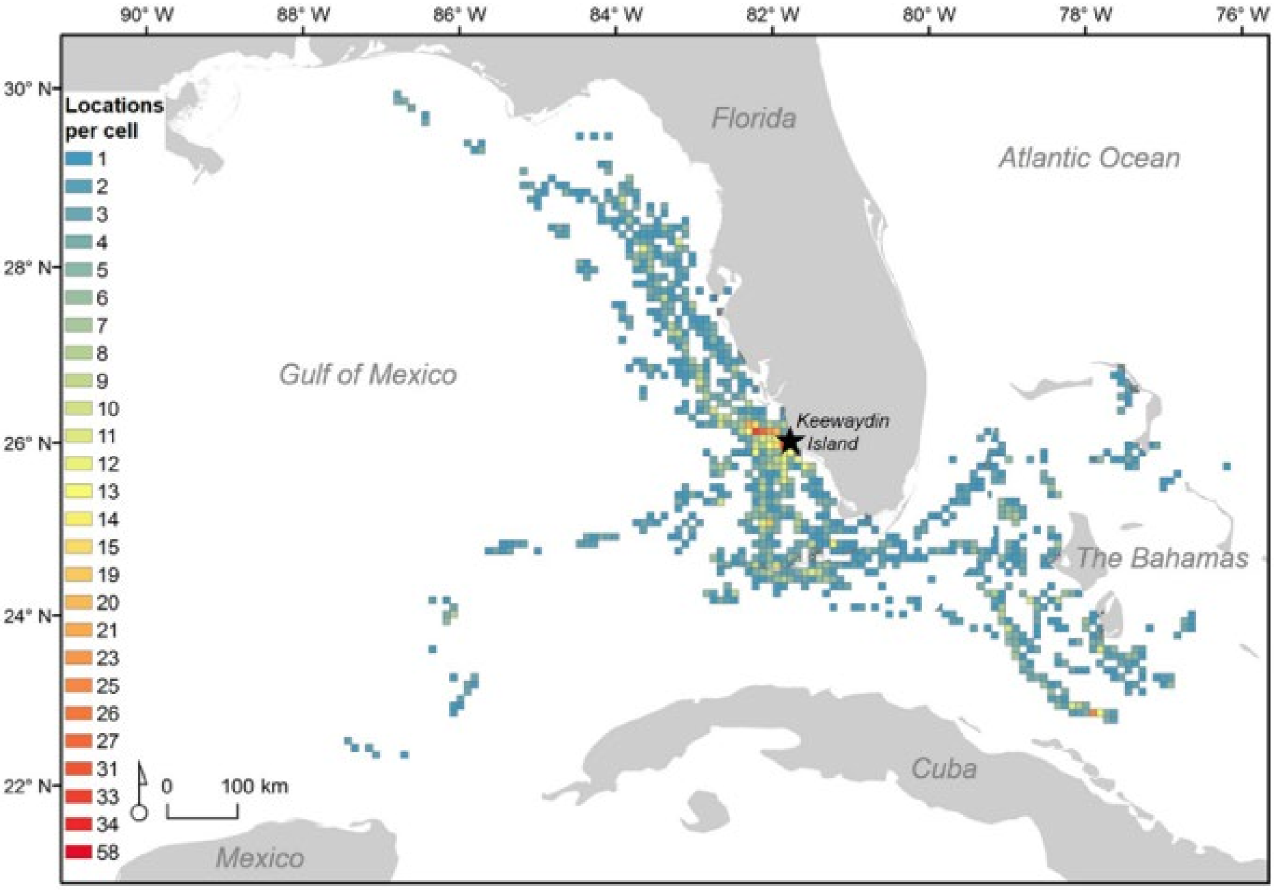

Figure B-3. Post-nesting habitat use in the eastern GOM (warmer colors) and internesting locations and fidelity to foraging locations (cooler colors)

Loggerhead Turtle 3: Uribe-Martínez et al. 2021

- Post-nesting tracks mapped; one passes through FL waters (Figure B-4)
- Presents internesting and foraging locations

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	12	Yucatan Peninsula	No

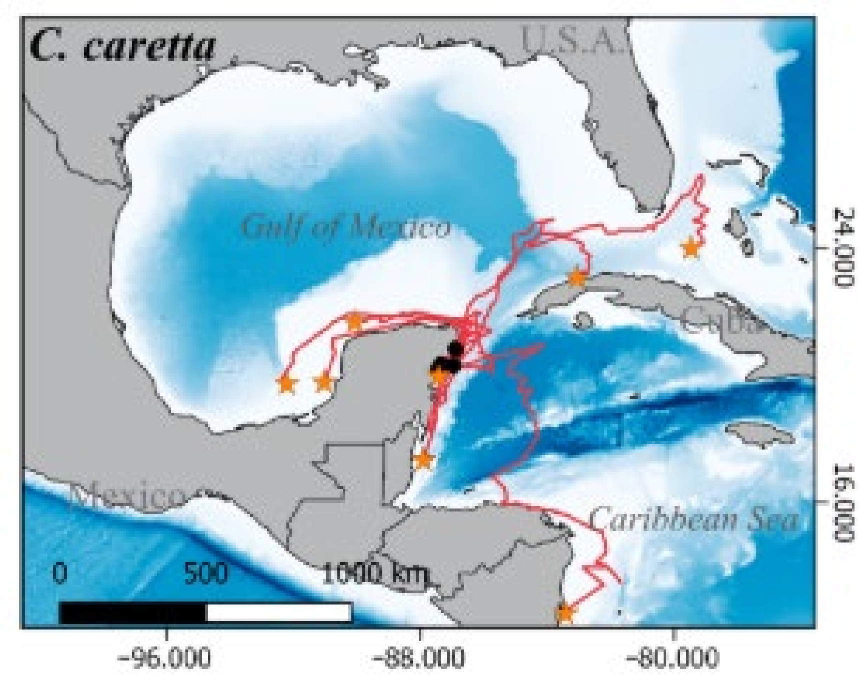

Figure B-4. Post-nesting tracks

Loggerhead Turtle 4: McNeill et al. 2020

- Summer and winter distribution (Figure B-5)
- Insights to core habitats and drivers for migration and foraging (Figure B-6)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	30	N. Carolina	No

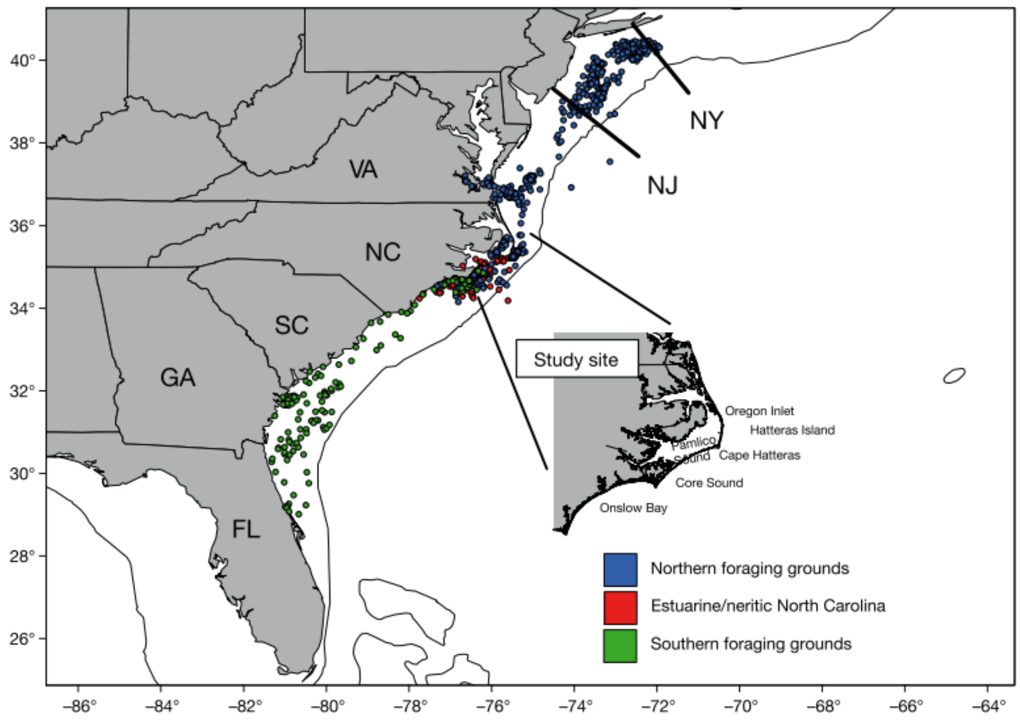

Figure B-5. Summer and winter distribution

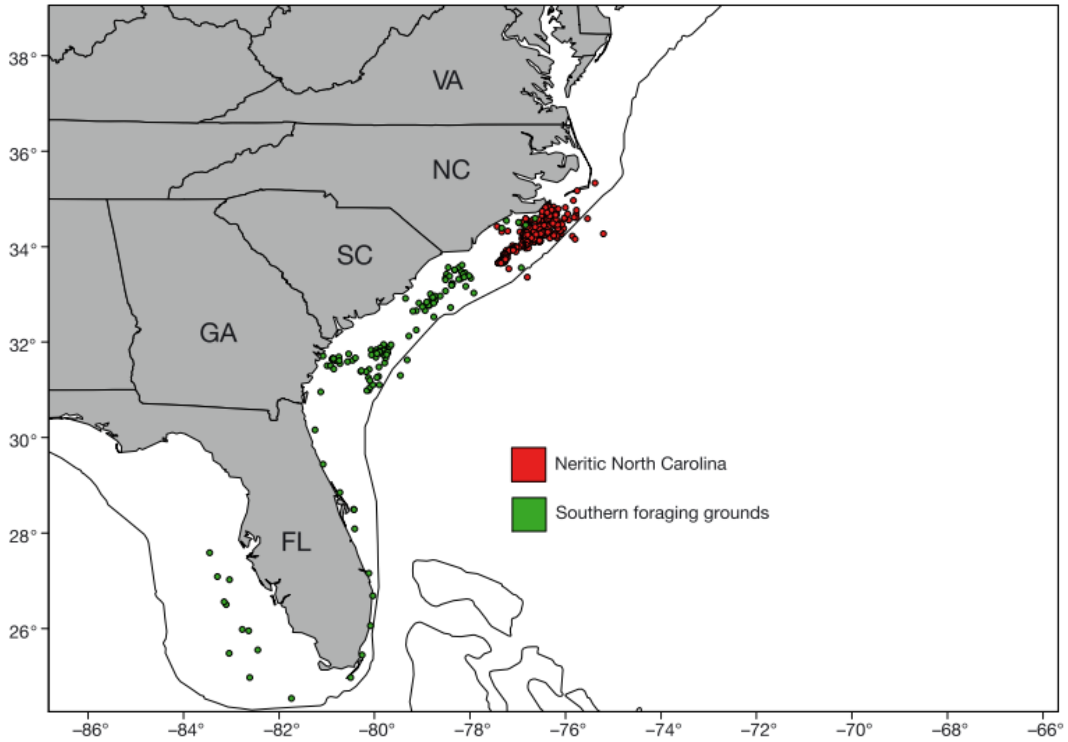

Figure B-6. Core habitats

Loggerhead Turtle 5: Evans et al. 2019

- Migration mapping and explanatory analyses (Figure B-7)
- Projected more northerly distribution under climate change

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	38	Archie Carr National Wildlife Refuge, Florida	**Yes**

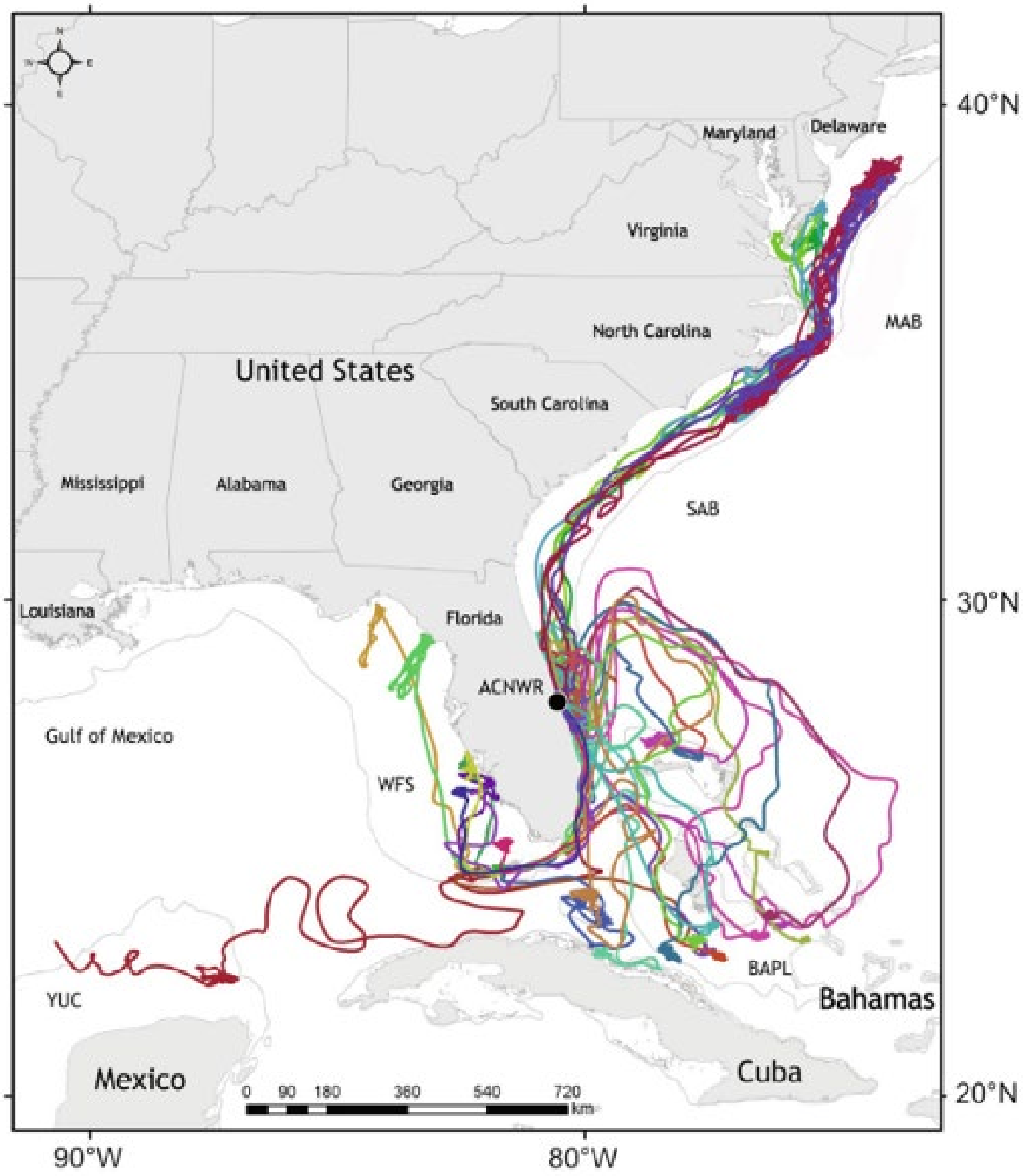

Figure B-7. Migration

Loggerhead Turtle 6: Barco et al. 2018

- Seasonal abundance and distribution assessment by surveying (Figure B-8)
- Assesses perception and availability bias in visual surveying

Life Stage	Sex	Sample Size	Origin	Key Study?
Mixed	M/F	n/a	Aerial survey of VA/MD & Chesapeake	No

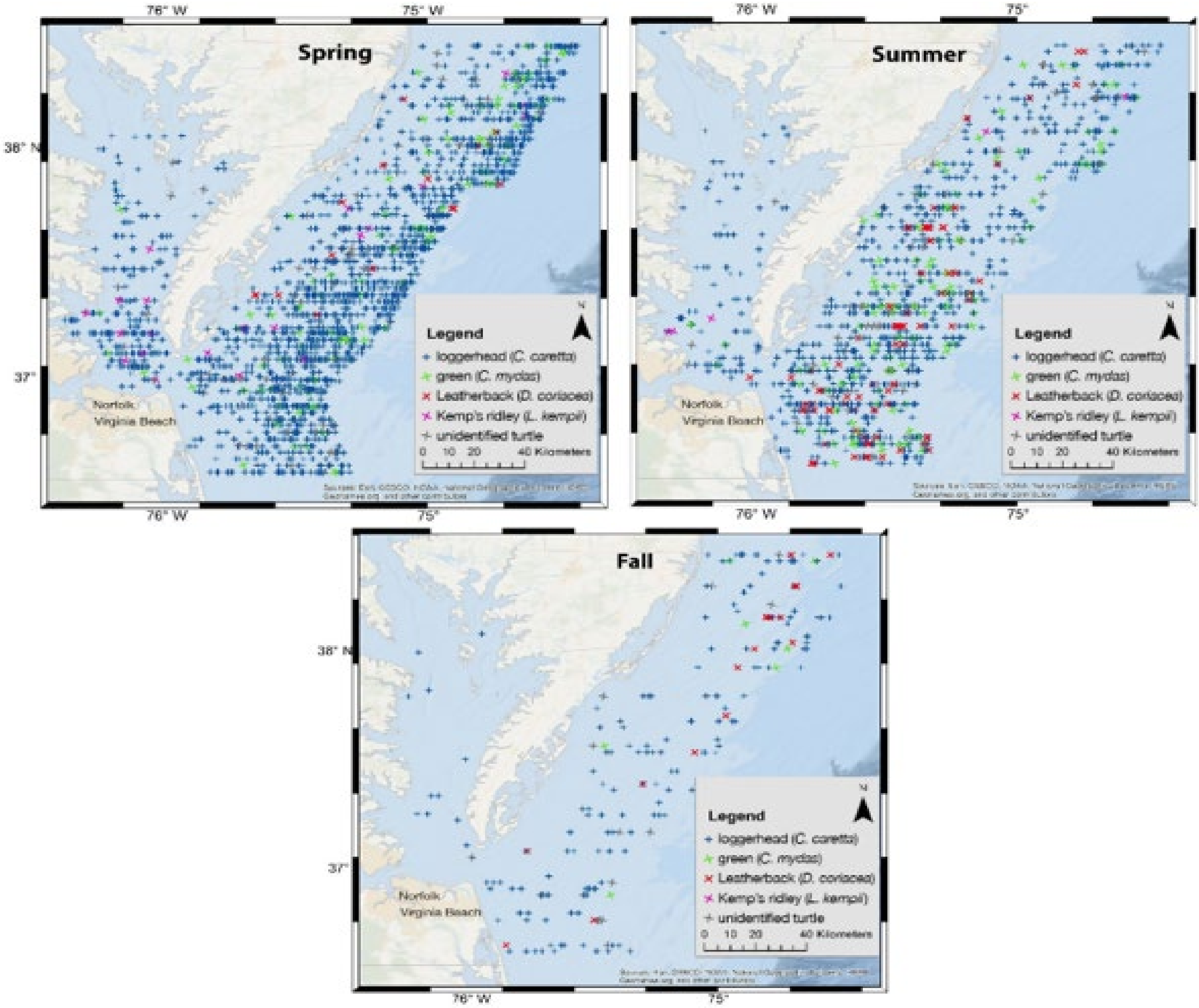

Figure B-8. Seasonal abundance and distribution assess by surveying

Loggerhead Turtle 7: Winton et al. 2018

- Models seasonal densities using multiple tracking datasets (Figure B-9)

Life Stage	Sex	Sample Size	Origin	Key Study?
Mixed	M/F	271	SE Florida to Massachusetts	**Yes**

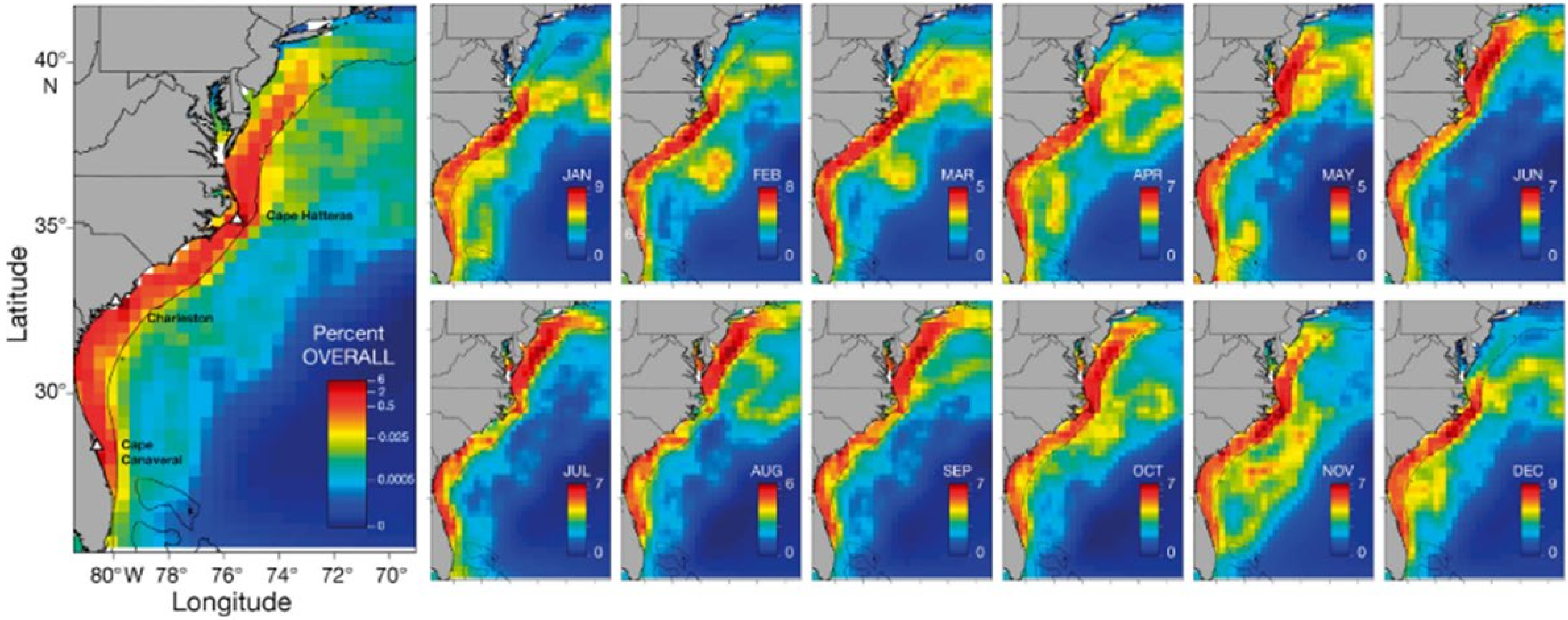

Figure B-9. Seasonal densities using multiple tracking datasets

Loggerhead Turtle 8: Hart et al. 2018

- Foraging locations plotted with relative importance (Figure B-10)
- Analyses turtle locations and anthropogenic threat overlap

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	63	AL, West FL (GOM)	**Yes**

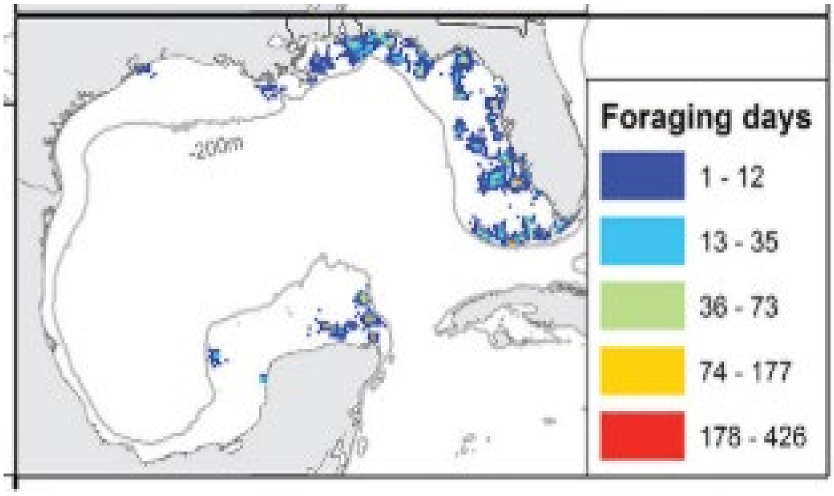

Figure B-10. Foraging locations plotted with relative importance

Loggerhead Turtle 9: Lamont and Iverson 2018

- Presents localized coastal foraging spots (Figure B-11)
- Highlights overlap with two other species in coastal locations (Figure B-12)

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	7	Northwest FL	No

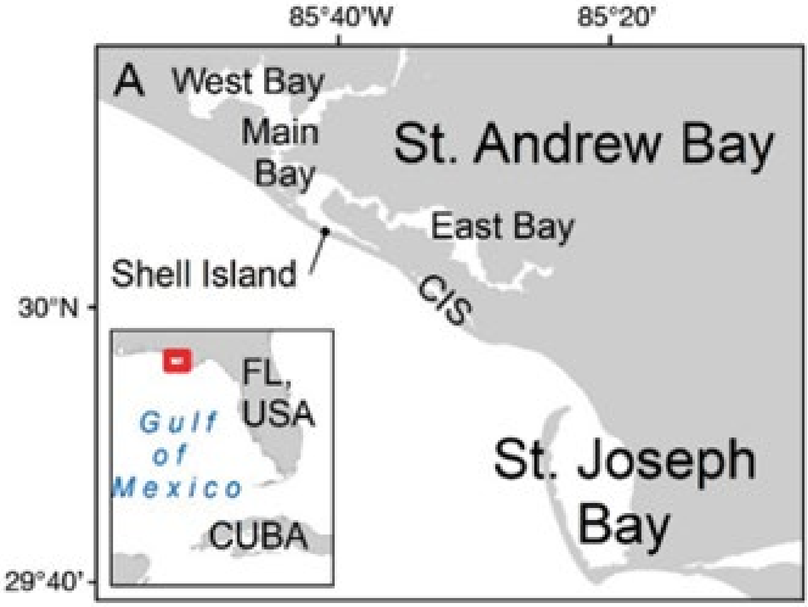

Figure B-11. Coastal foraging spots

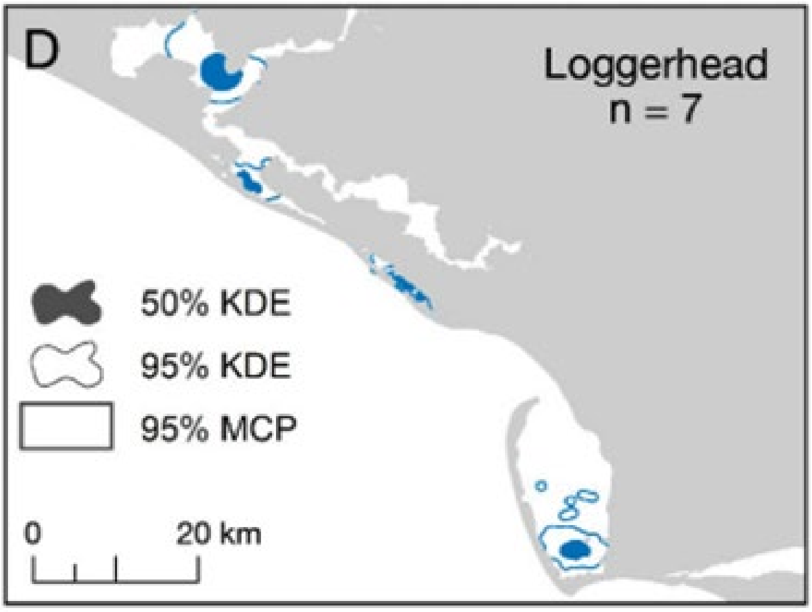

Figure B-12. Overlap with two other species in coastal locations

Loggerhead Turtle 10: Hart et al. 2015

- Selected to show tracks to Bahamas (Figure B-13)
- Discusses timing and repeatability of migration

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	19	Dry Tortugas National Park, Florida	No

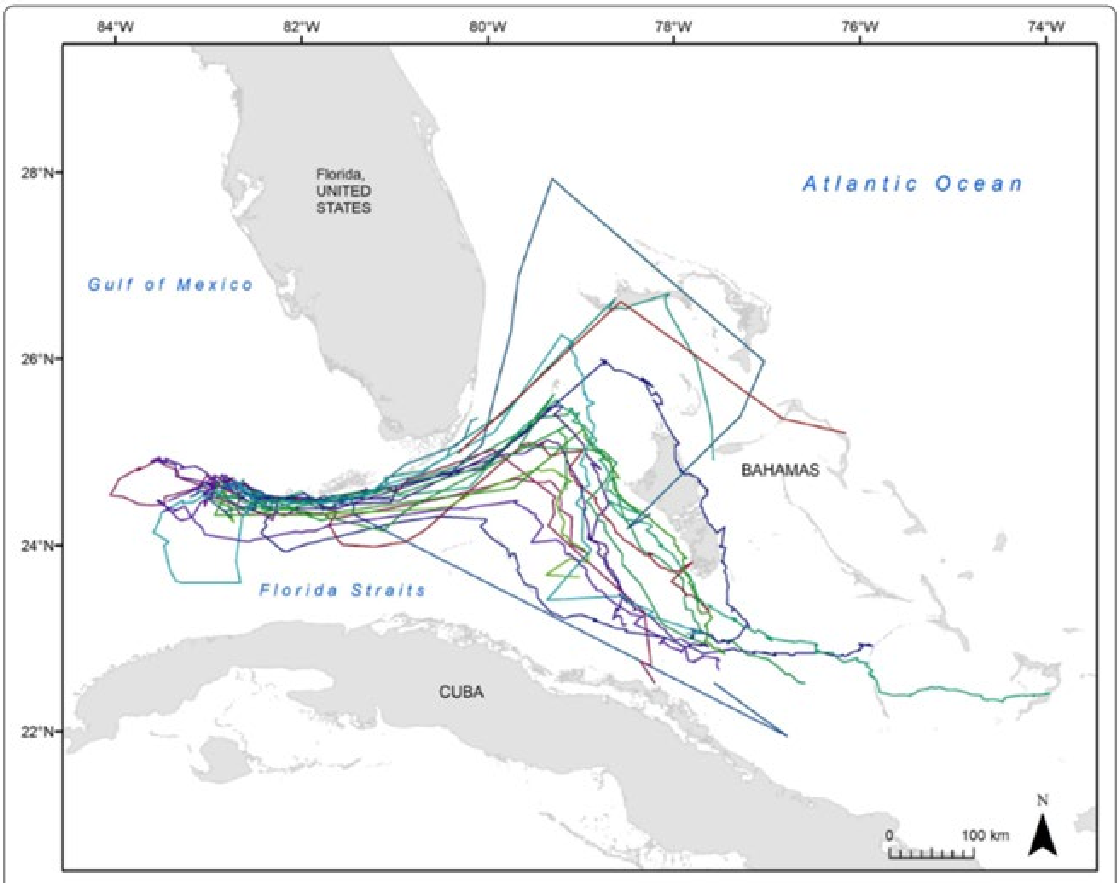

Figure B-13. Tracks to Bahamas

Loggerhead Turtle 11: Mansfield et al. 2014

- Distribution mapped (Figure B-14)
- Movements analyzed regarding bathymetry, temperature, and currents

Life Stage	Sex	Sample Size	Origin	Key Study?
Neonate	M/F	17	Southeast Florida	**Yes**

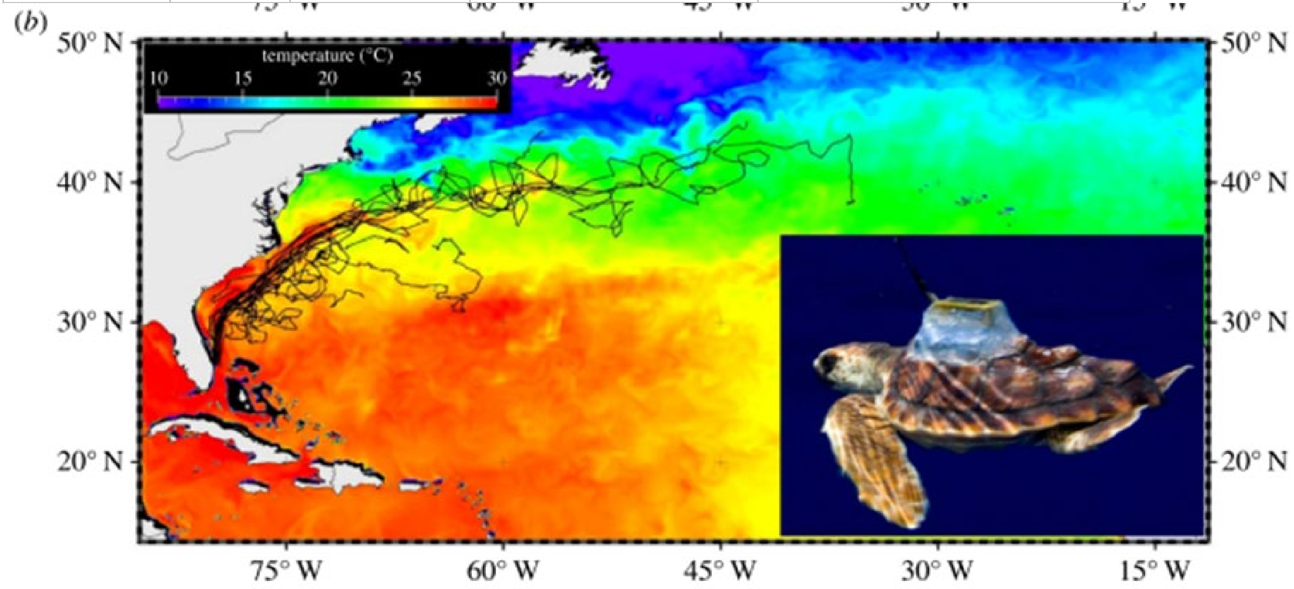

Figure B-14. Distribution

Loggerhead Turtle 12: Foley et al. 2013, 2014

- Post-nesting migrations end points and corridors in 2013 (Figure B-15)
- Reviews localized foraging behavior of individuals in 2014 (Figure B-16)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	42	Northwest, West & East FL	No

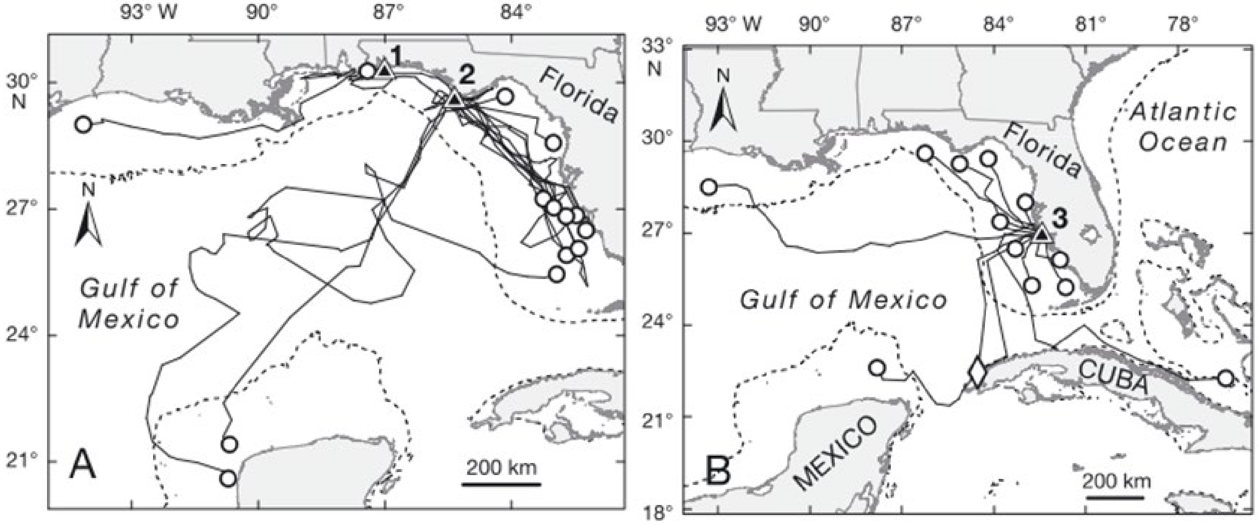

Figure B-15. Post-nesting migrations end points and corridors in 2013

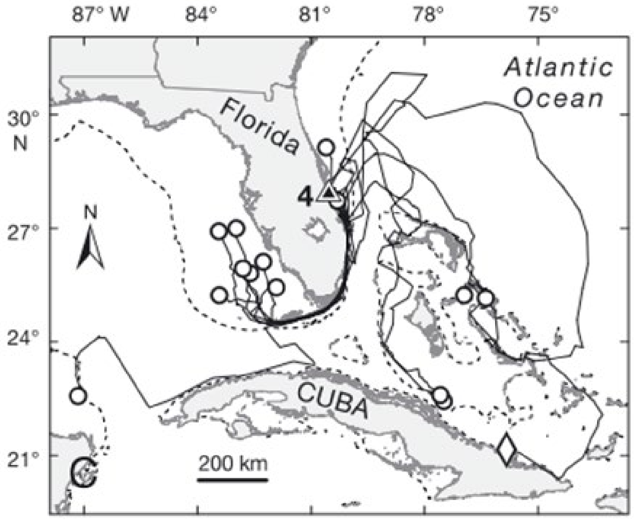

Figure B-16. Localized foraging behavior of individuals in 2014

Loggerhead Turtle 13: Griffin et al. 2013

- Presents seasonal densities (Figure B-17)
- Migration drivers and seasonality of distribution
- Combined three projects

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	68	GA, SC, NC	**Yes**

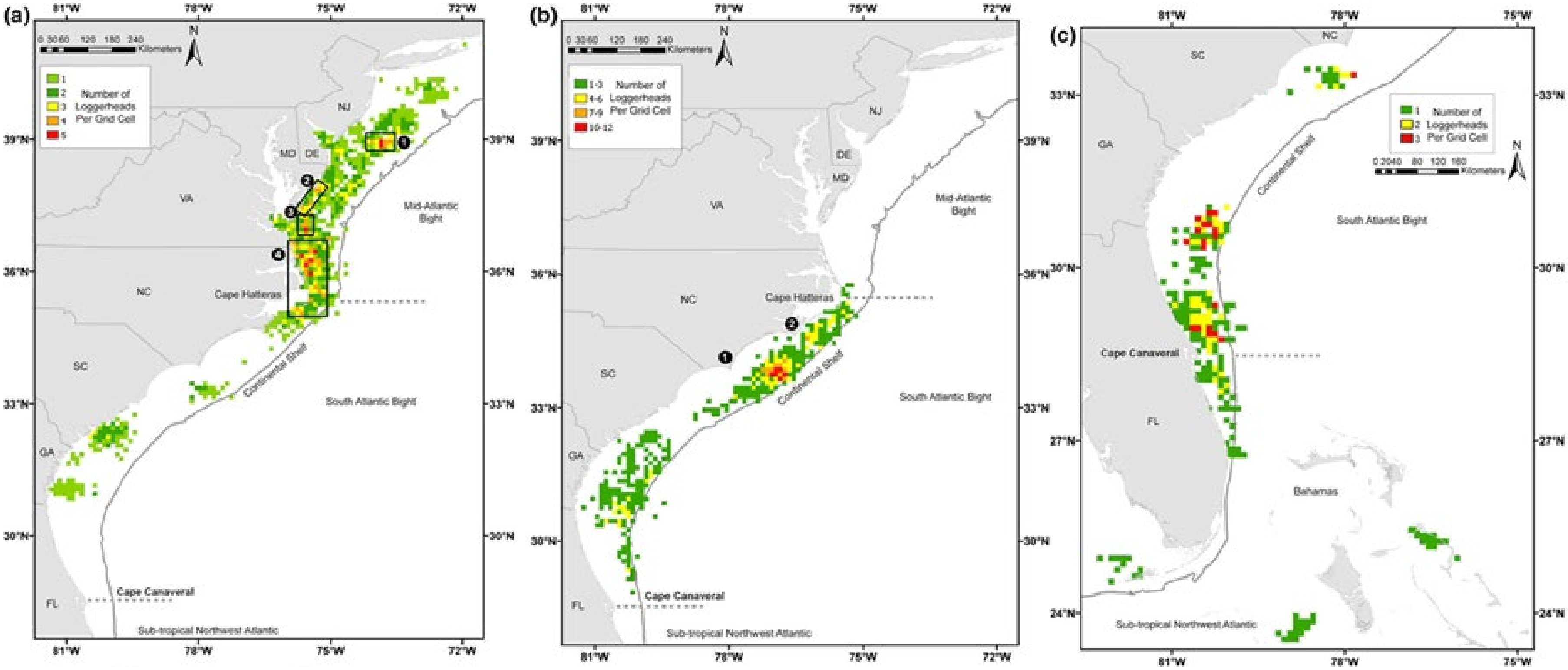

Figure B-17. Seasonal densities

Loggerhead Turtle 14: Arendt et al. 2012a, 2012b

- Some turtles remained resident and others migrated from Cape Canaveral (Figure B-18)
- Presents data on dives per month

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	M	29 (16)	Cape Canaveral FL	**Yes**

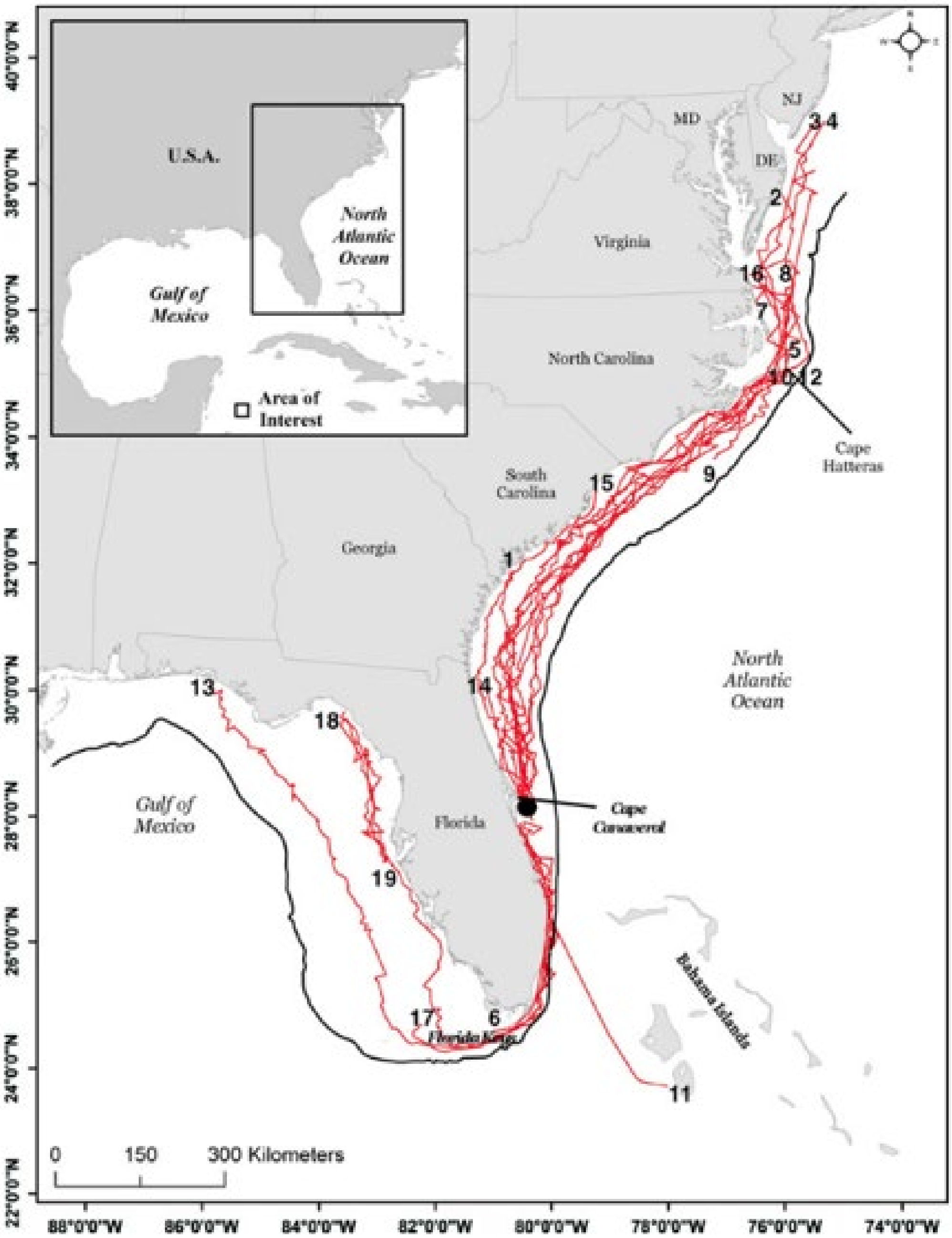

Figure B-18. Loggerhead turtle movement

Loggerhead Turtle 15: Ceriani et al. 2012

- Migrations and foraging sites mapped (Figure B-19)
- Uses Stable Isotope Analysis to define three distinct foraging regions

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	14	Archie Carr National Wildlife Refuge, Florida	No

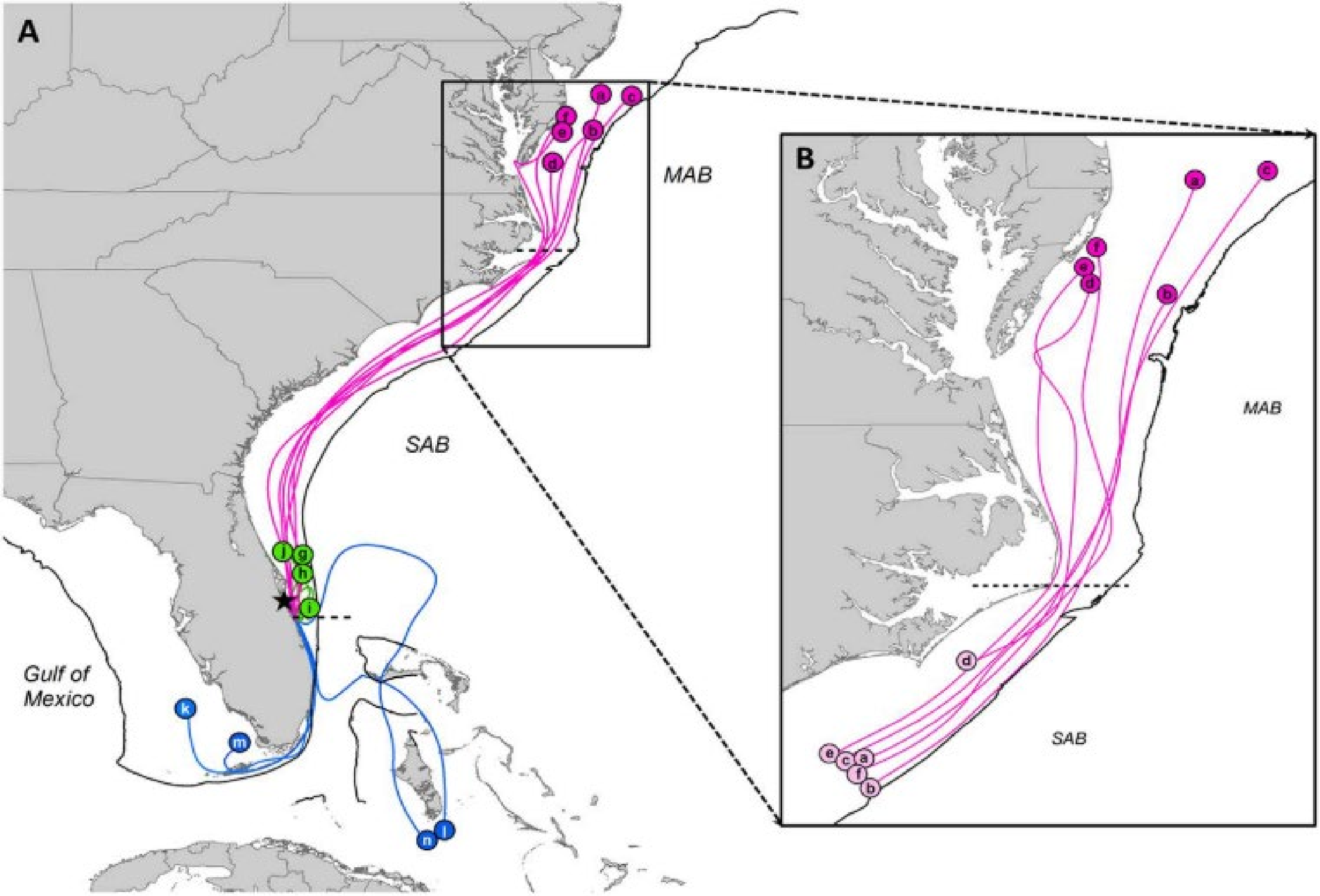

Figure B-19. Migrations and foraging sites

Loggerhead Turtle 16: Hart et al. 2012a

- Migrations and foraging sites mapped (Figure B-20)
- Gives estimates of core foraging area sizes and their habitats

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	10	Northwest & Southwest FL and Dry Tortugas National Park	No

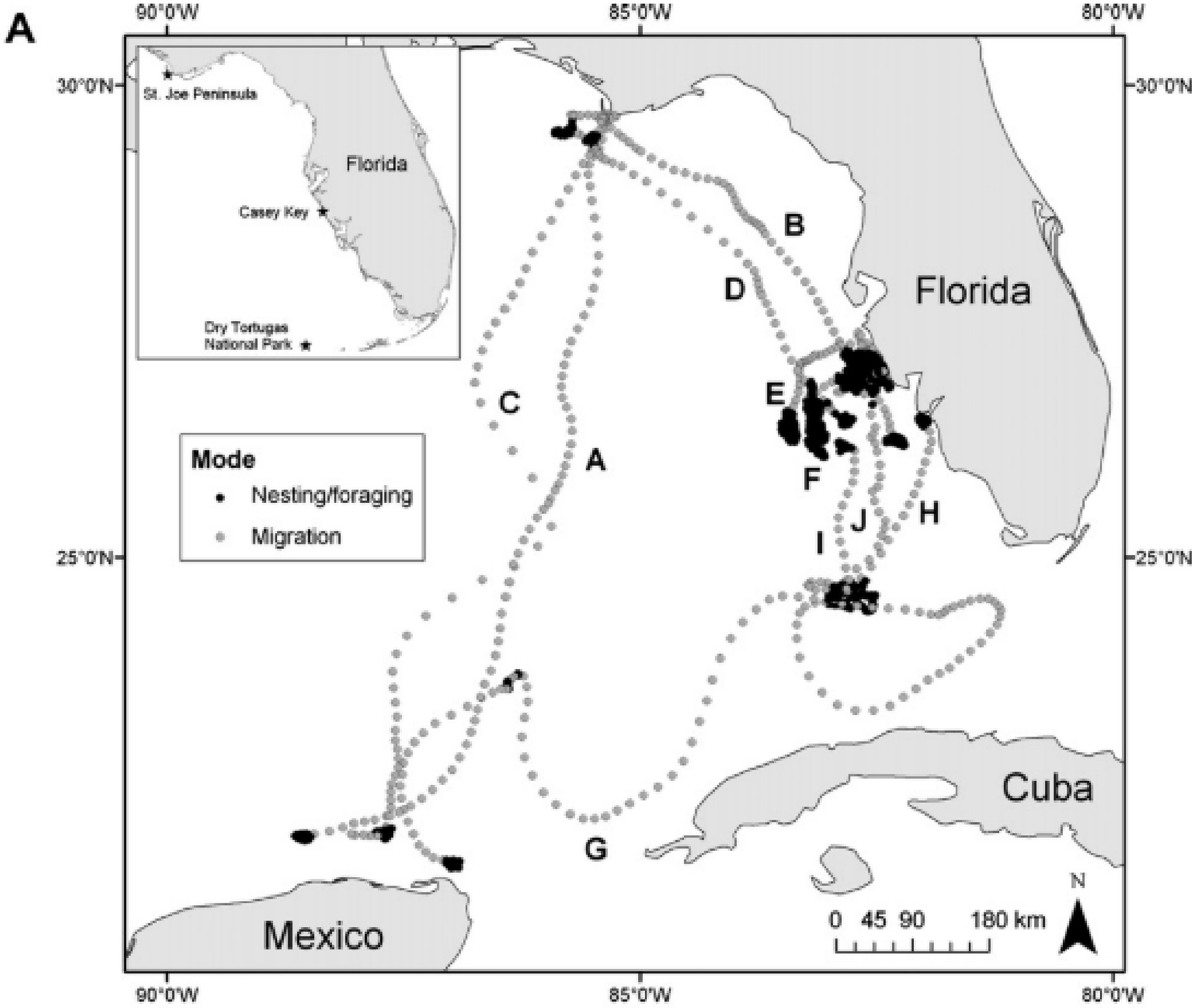

Figure B-20. Migrations and foraging sites

Loggerhead Turtle 17: Lockhart et al. 2012

- Location points mapped in relation to WEAs (Figure B-21)
- Also presents seasonal visual survey data from the Chesapeake area
- Includes one Kemp's ridley in the data

Life Stage	Sex	Sample Size	Origin	Key Study?
Unknown	Unknown	6	Chesapeake	No

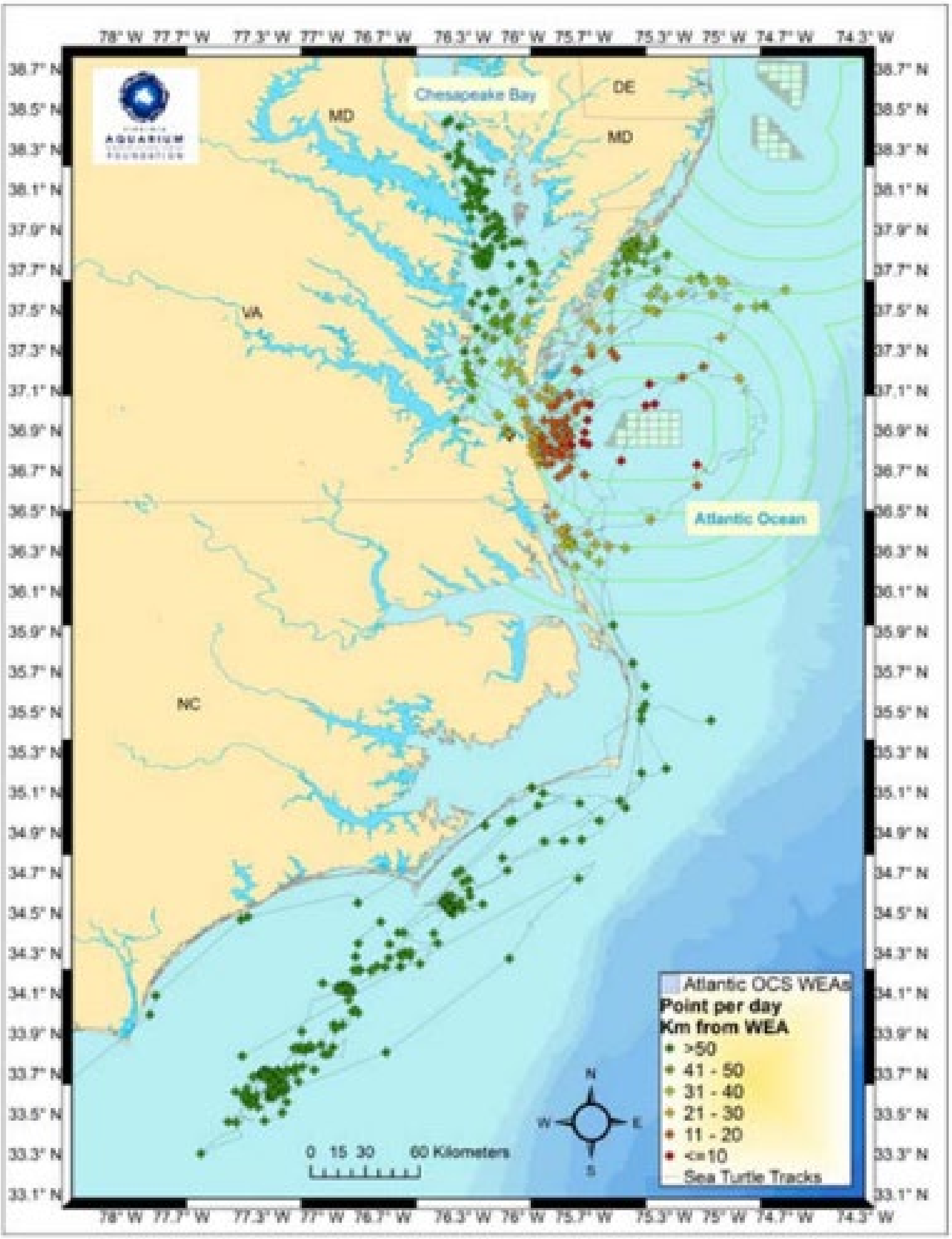

Figure B-21. Location points in relation to WEAs

Loggerhead Turtle 18: Hawkes et al. 2011

- Presents seasonal and year-round locations (Figure B-22)
- Predicts summer and winter habitat suitability

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	68	NC, SC, GA	**Yes**

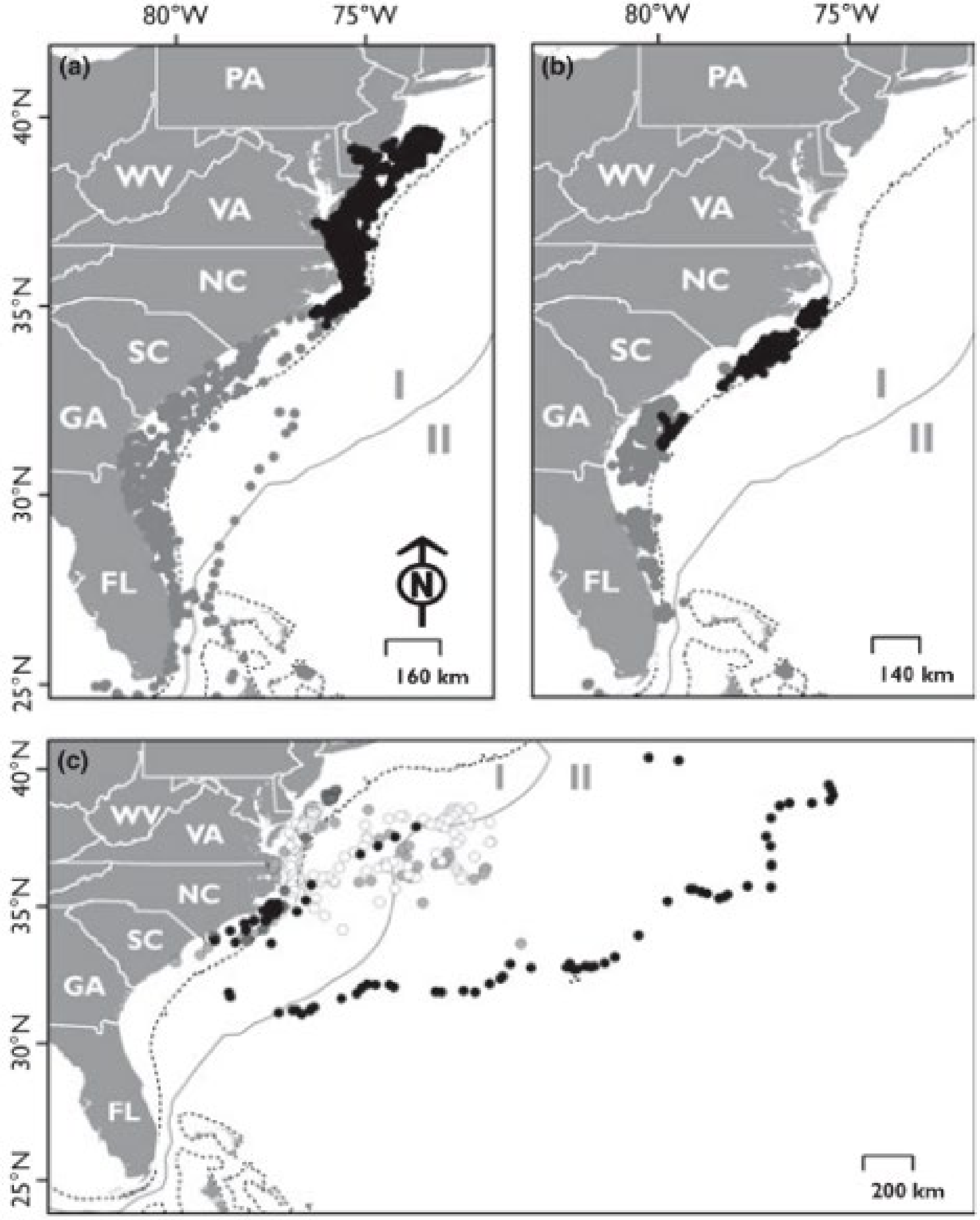

Figure B-22. Seasonal and year-round locations

Loggerhead Turtle 19: Turtle Expert Working Group 2009

- Comprehensive presentation of tracking and surveying abundances per season (Figure B-23)
- General assessment of the entire NWA population including nesting

Life Stage	Sex	Sample Size	Origin	Key Study?
Mixed	M/F	n/a	Southeastern USA	**Yes**

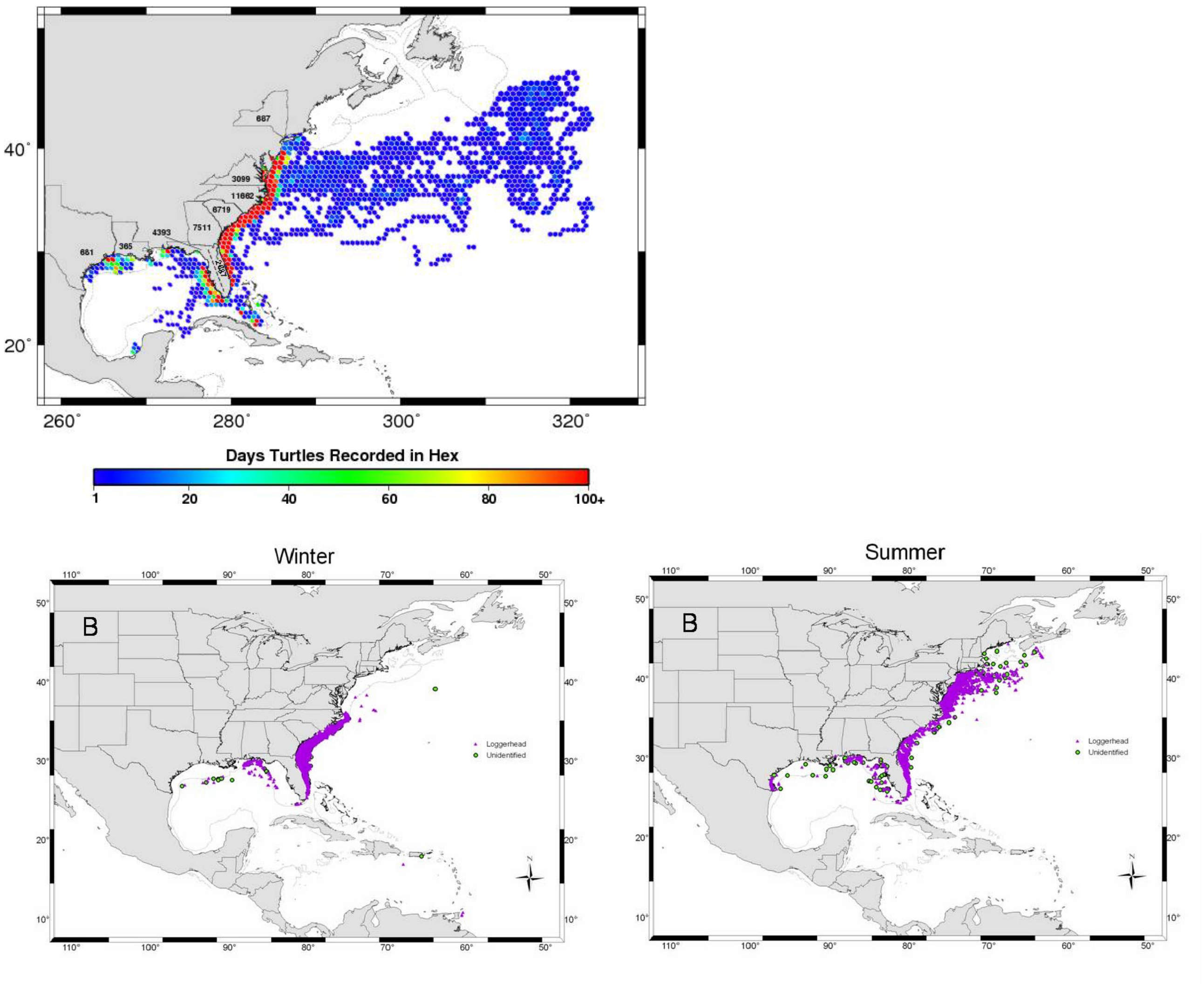

Figure B-23. Abundances per season

Loggerhead Turtle 20: Girard et al. 2009

- Migrations mapped (Figure B-24)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	28	West Peninsula FL	No

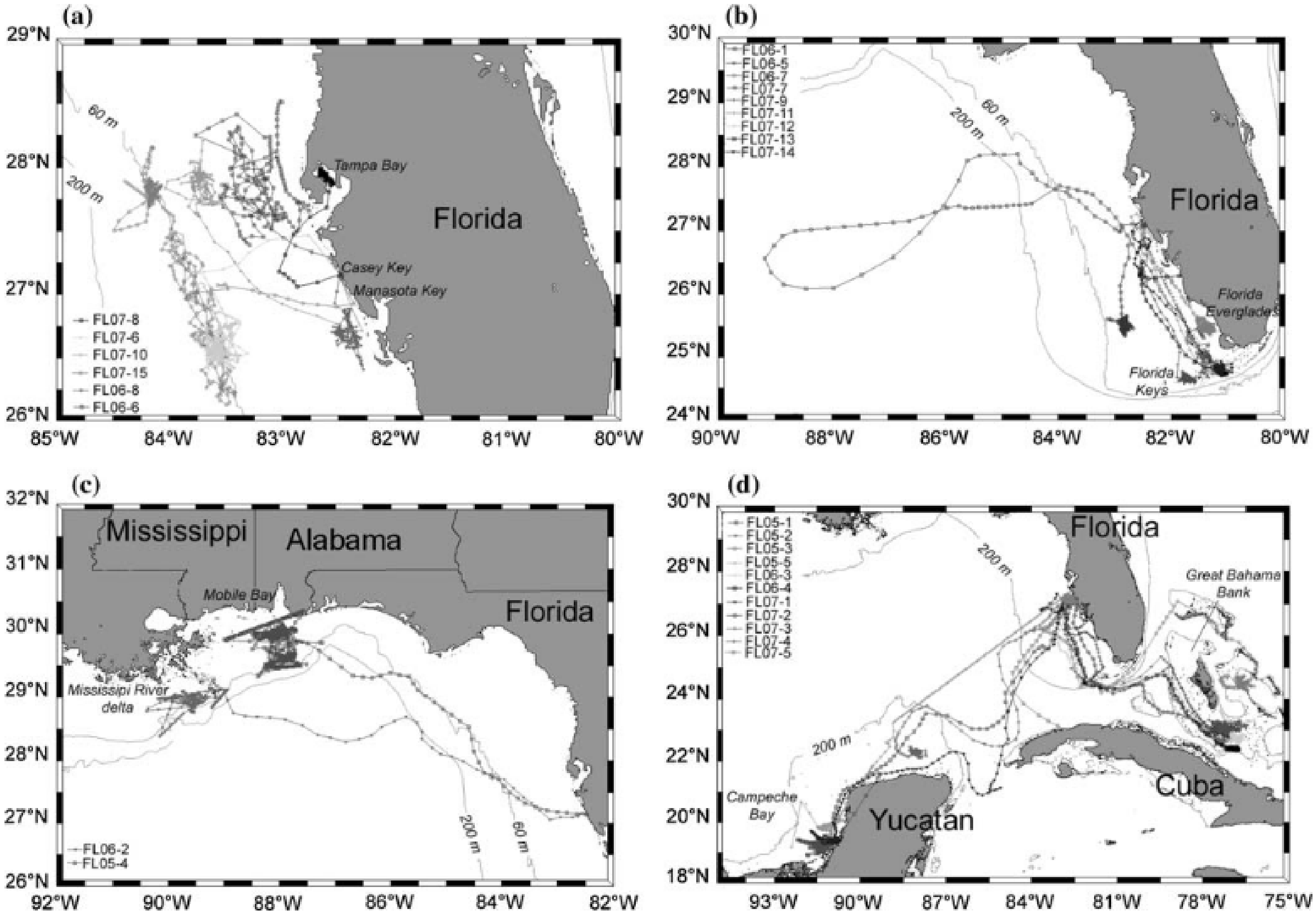

Figure B-24. Migrations

Loggerhead Turtle 21: Mansfield et al. 2009

- Residency patterns presented including summer/winter divide (Figure B-25)
- Some interpretation regarding sea surface temperature and Cape Hatteras as a bottleneck

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	23	Chesapeake Bay	No

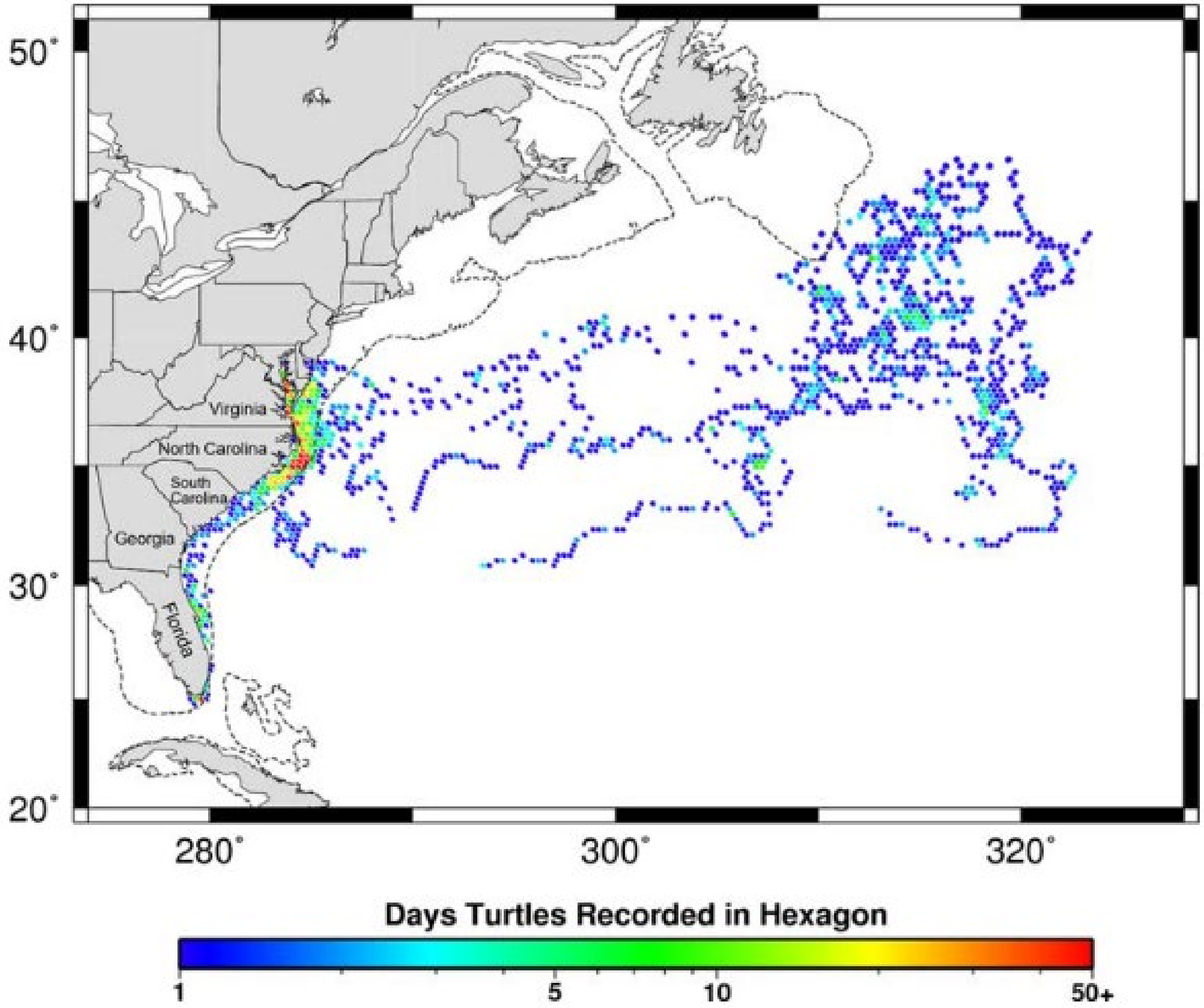

Figure B-25. Residency patterns including summer/winter divide

Loggerhead Turtle 22: Hawkes et al. 2007

- Summer / winter distribution with migration or not (Figure B-26)
- Some data on seasonal effect on dive durations

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	12	NC	No

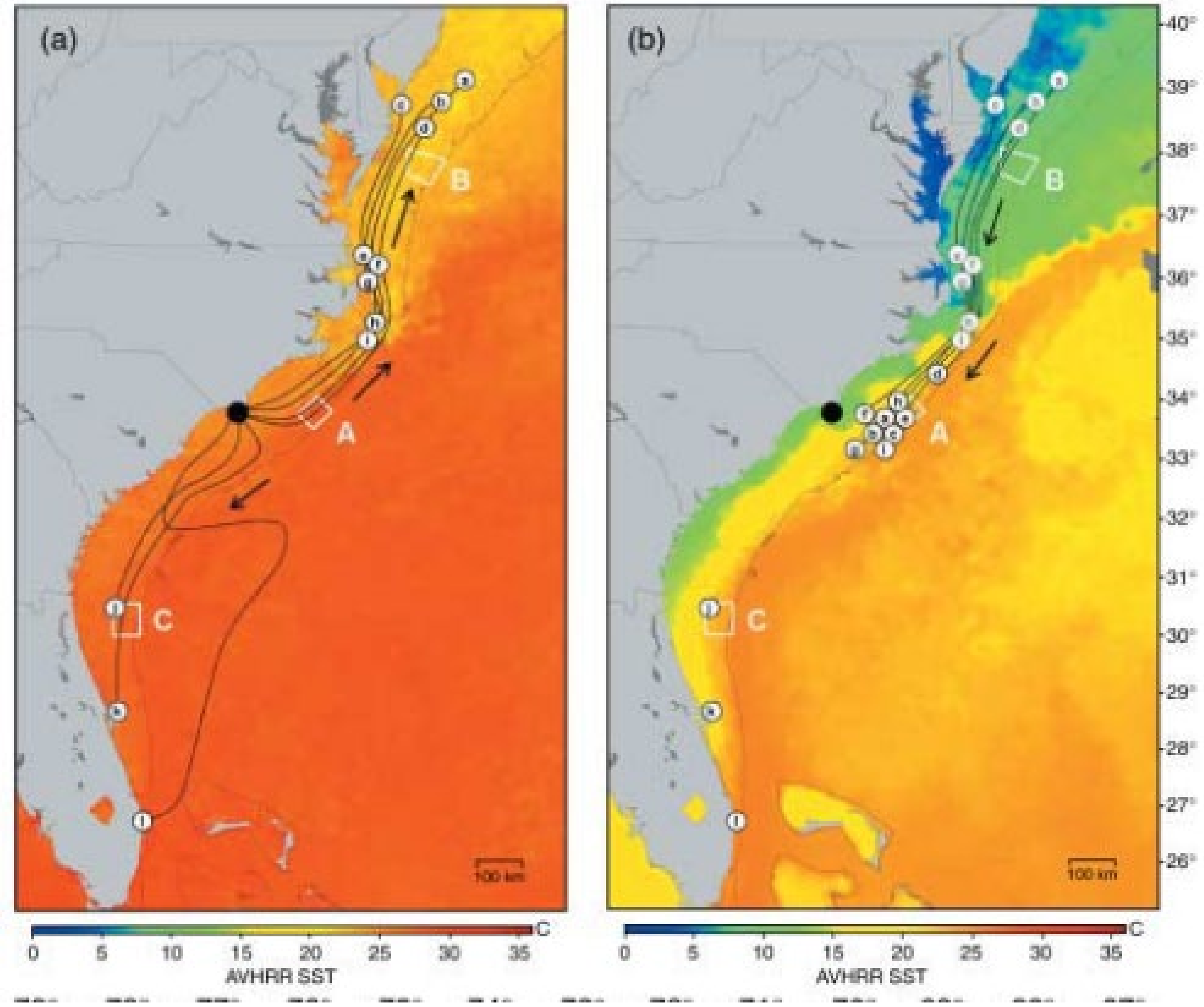

Figure B-26. Summer / sinter distribution

Loggerhead Turtle 23: McClellan and Read 2007

- Neritic/oceanic foraging dichotomy presented (Figure B-27)
- Shows switching between offshore and nearshore

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	30	NC	**Yes**

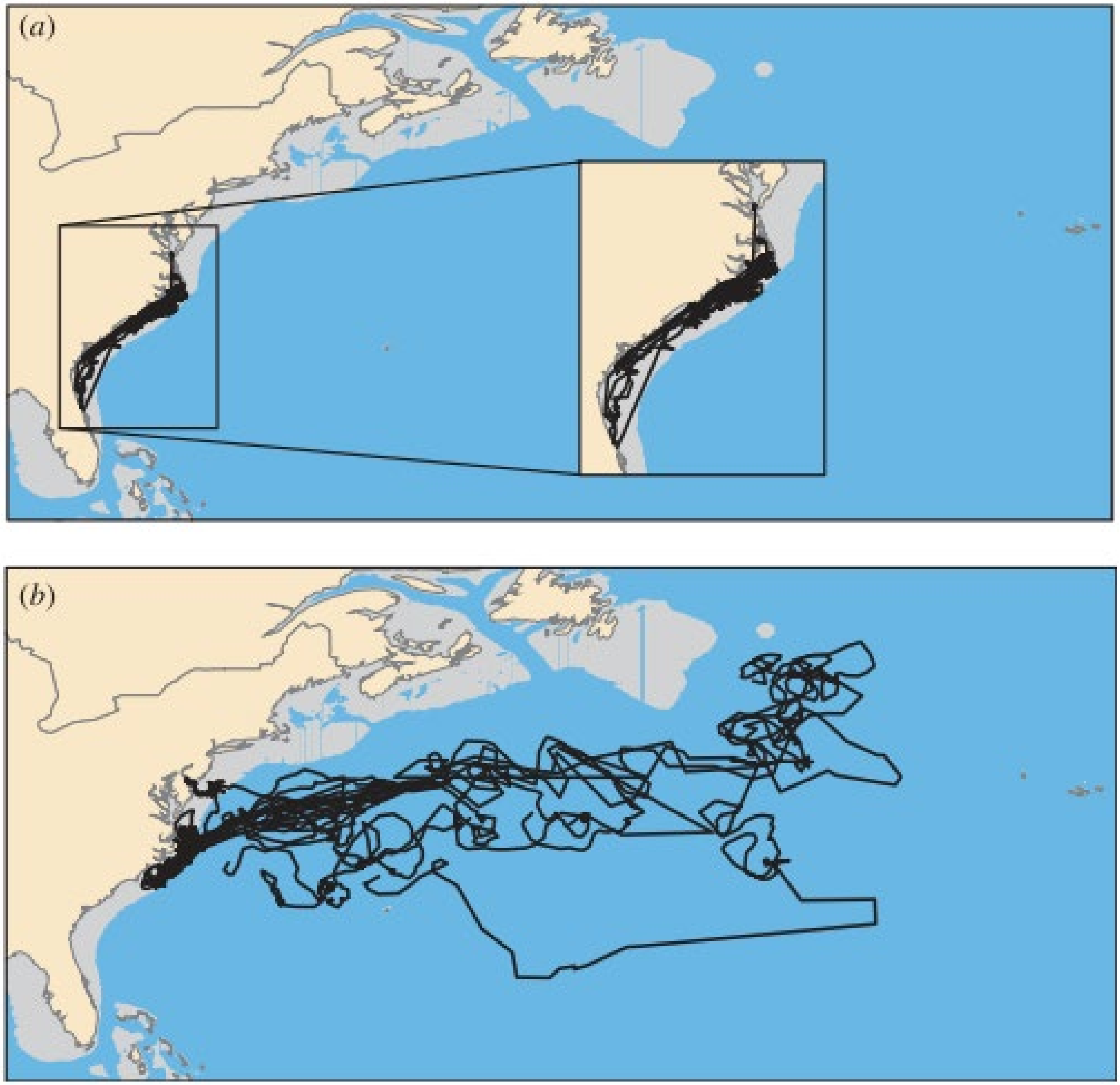

Figure B-27. Neritic/oceanic foraging

Loggerhead Turtle 24: Plotkin and Spotila 2002

- Gives first indications of N-S seasonal shuttling for this species (Figure B-28)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	5	Georgia	No

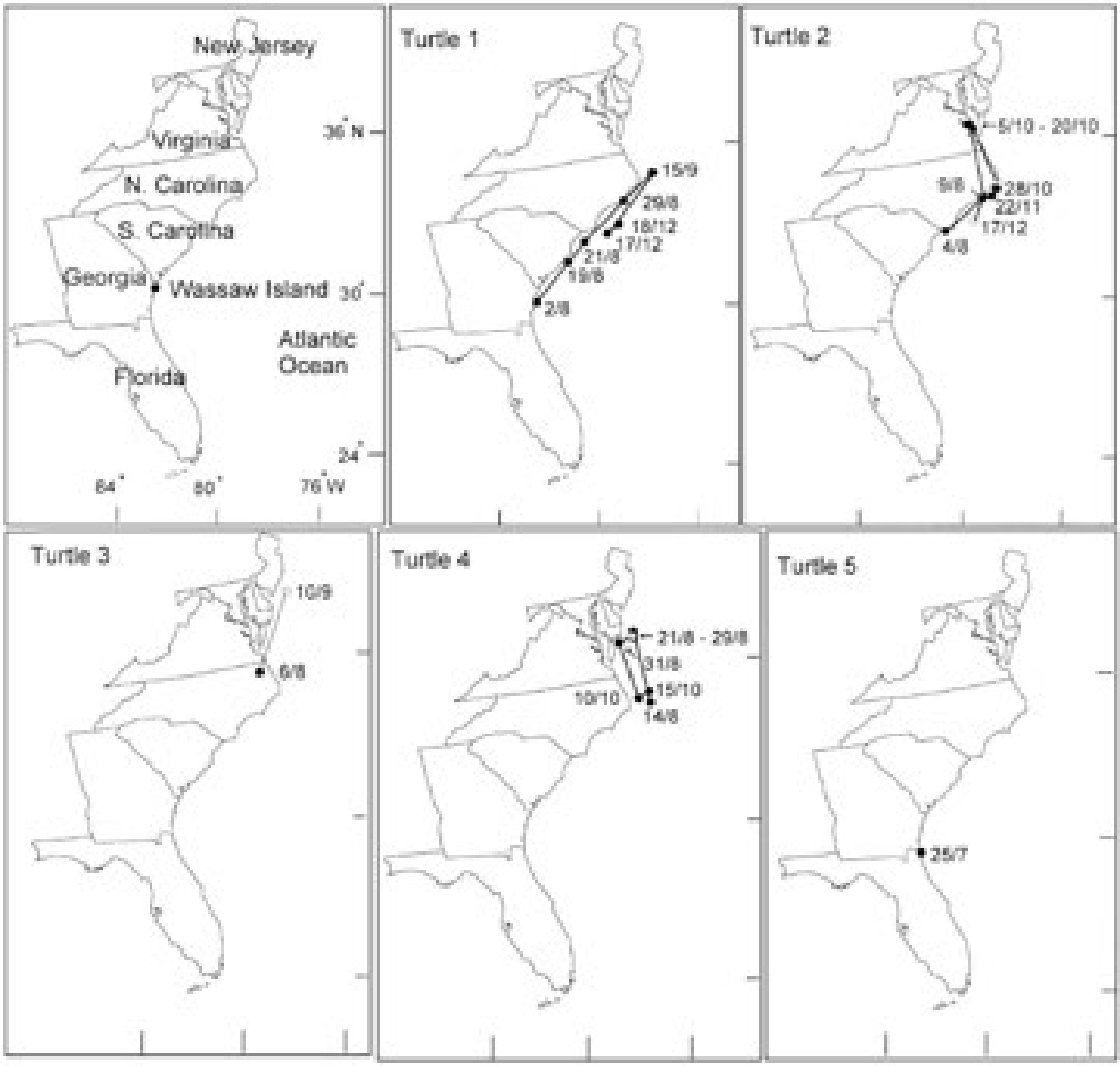

Figure B-28. N-S seasonal shuttling

Loggerhead Turtle 25: Stoneburner 1982

- First publication on tracking. A bit of internesting habitat shown. Not very useful (Figure B-29)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	8	Georgia Bight	No

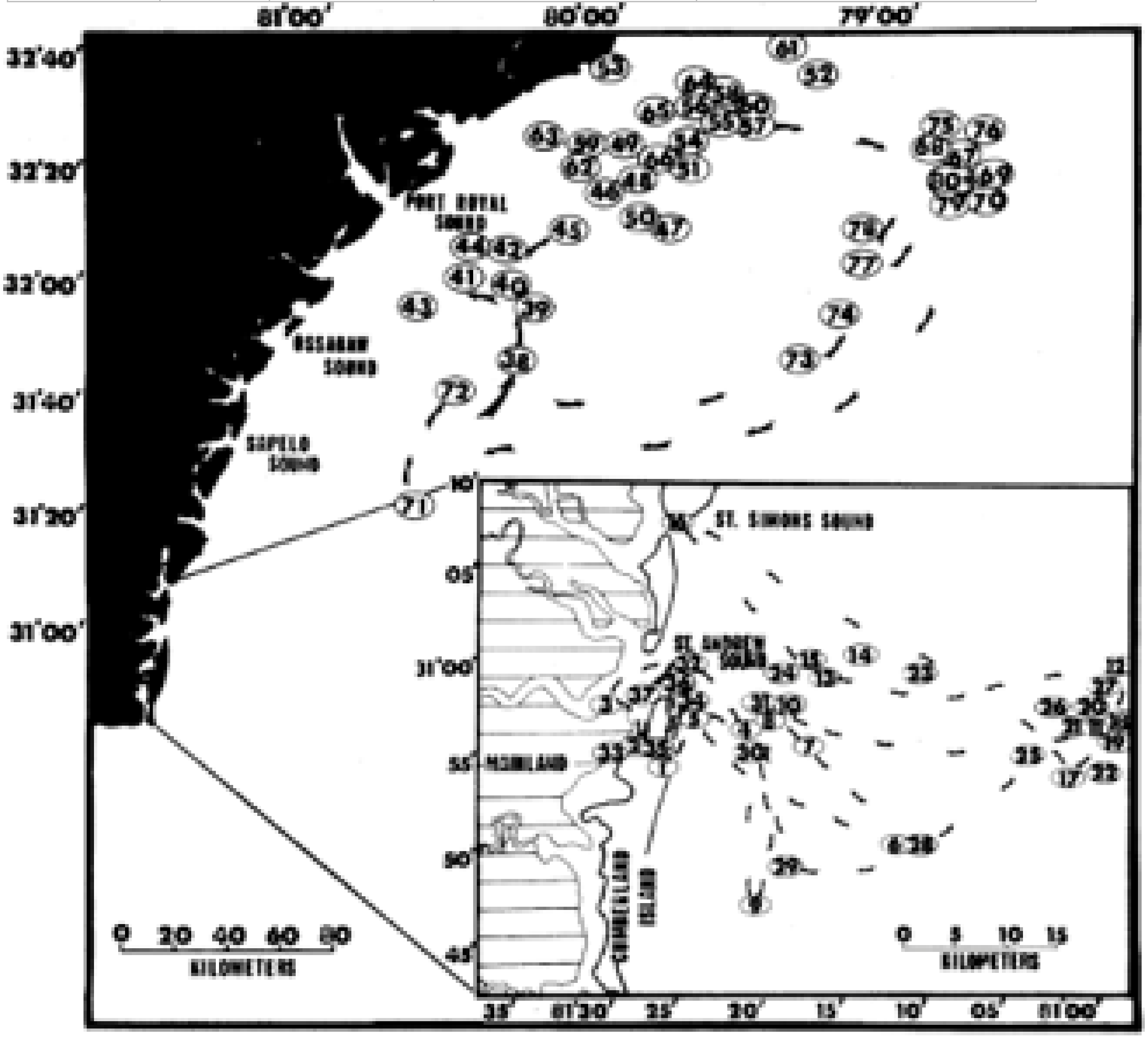

Figure B-29. Internesting habitat

A.2 Green Turtle Studies

Green Turtle 1: Uribe-Martínez et al. 2021

- Post-nesting tracks mapped. One passes through FL waters (Figure B-30)
- Presents internesting and foraging locations

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	43	GOM Mexico	No

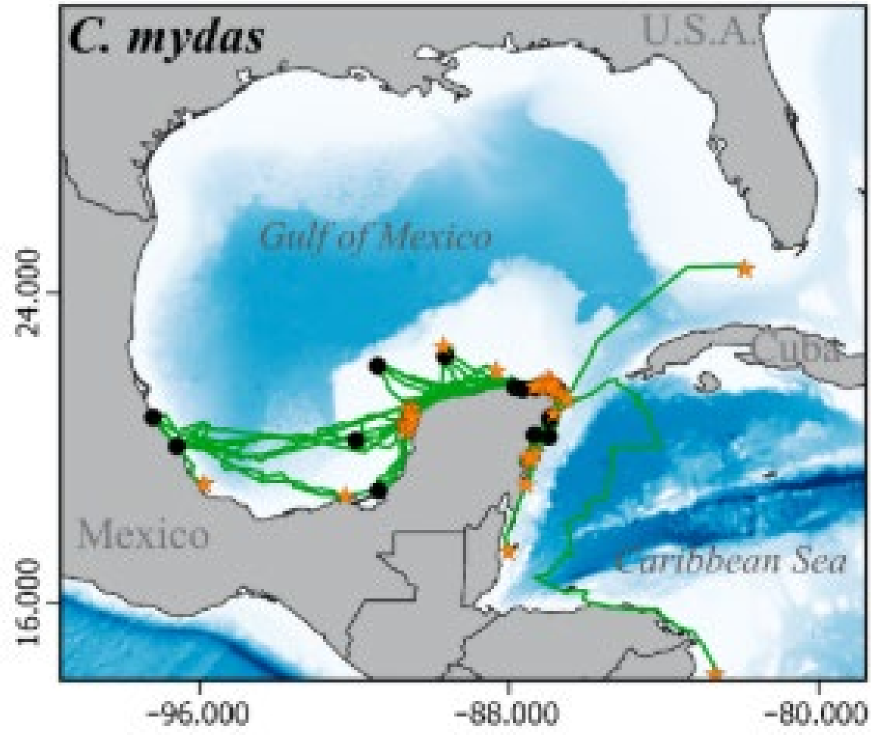

Figure B-30. Post-nesting track

Green Turtle 2: Mansfield et al. 2021

- Dispersal tracks mapped (Figure B-31)
- Movements analyzed regarding bathymetry, temperature, and currents

Life Stage	Sex	Sample Size	Origin	Key Study?
Neonate	M/F	21	East FL	**Yes**

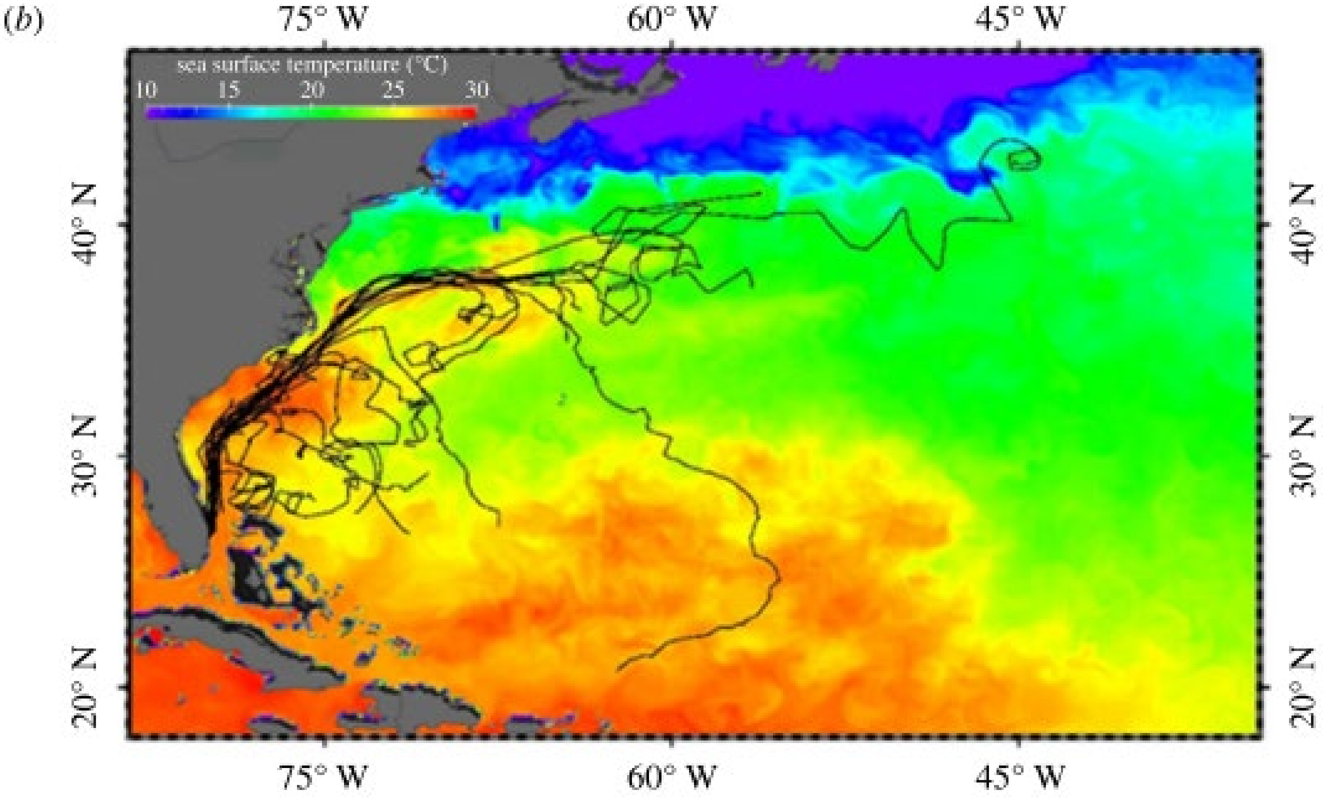

Figure B-31. Dispersal tracks

Green Turtle 3: Wildermann et al. 2019

- Maps core foraging areas (Figure B-32)
- Relates species habitat overlap and dive depths

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	9	W peninsula FL	No

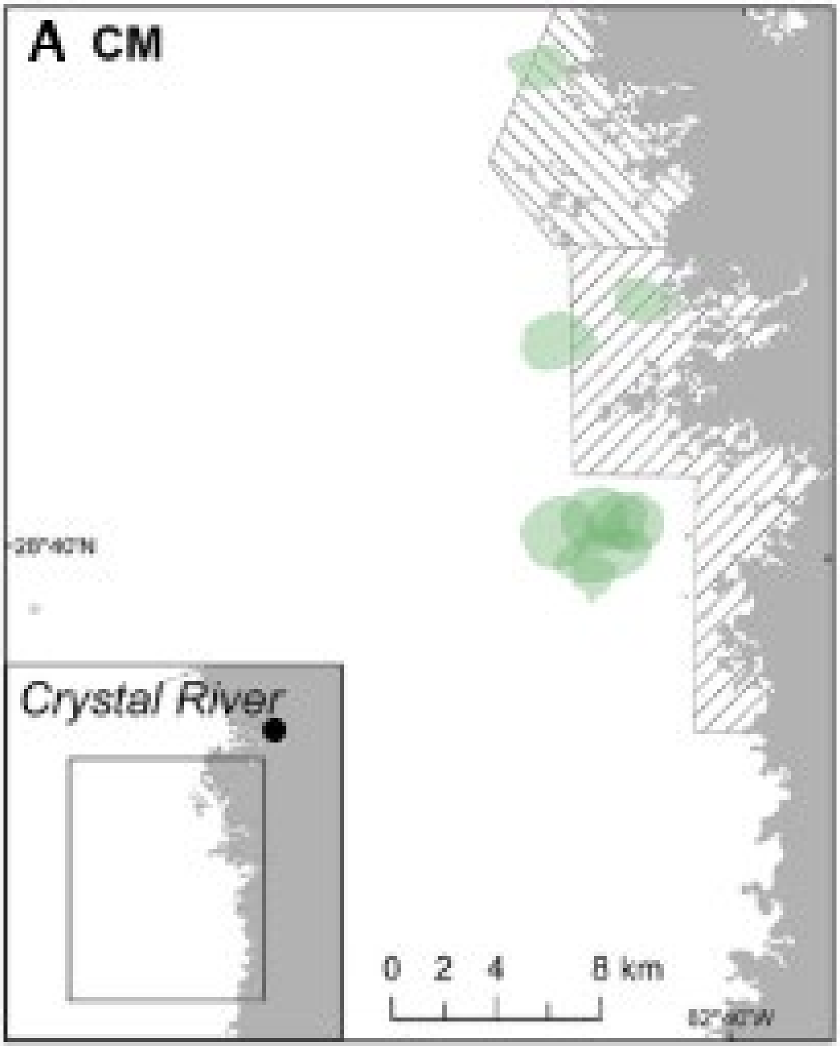

Figure B-32. Core foraging areas

Green Turtle 4: Lamont and Iverson 2018

- Presents localized coastal foraging spots (Figure B-33)
- Highlights overlap with two other species in coastal locations

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	7	Northwest FL	No

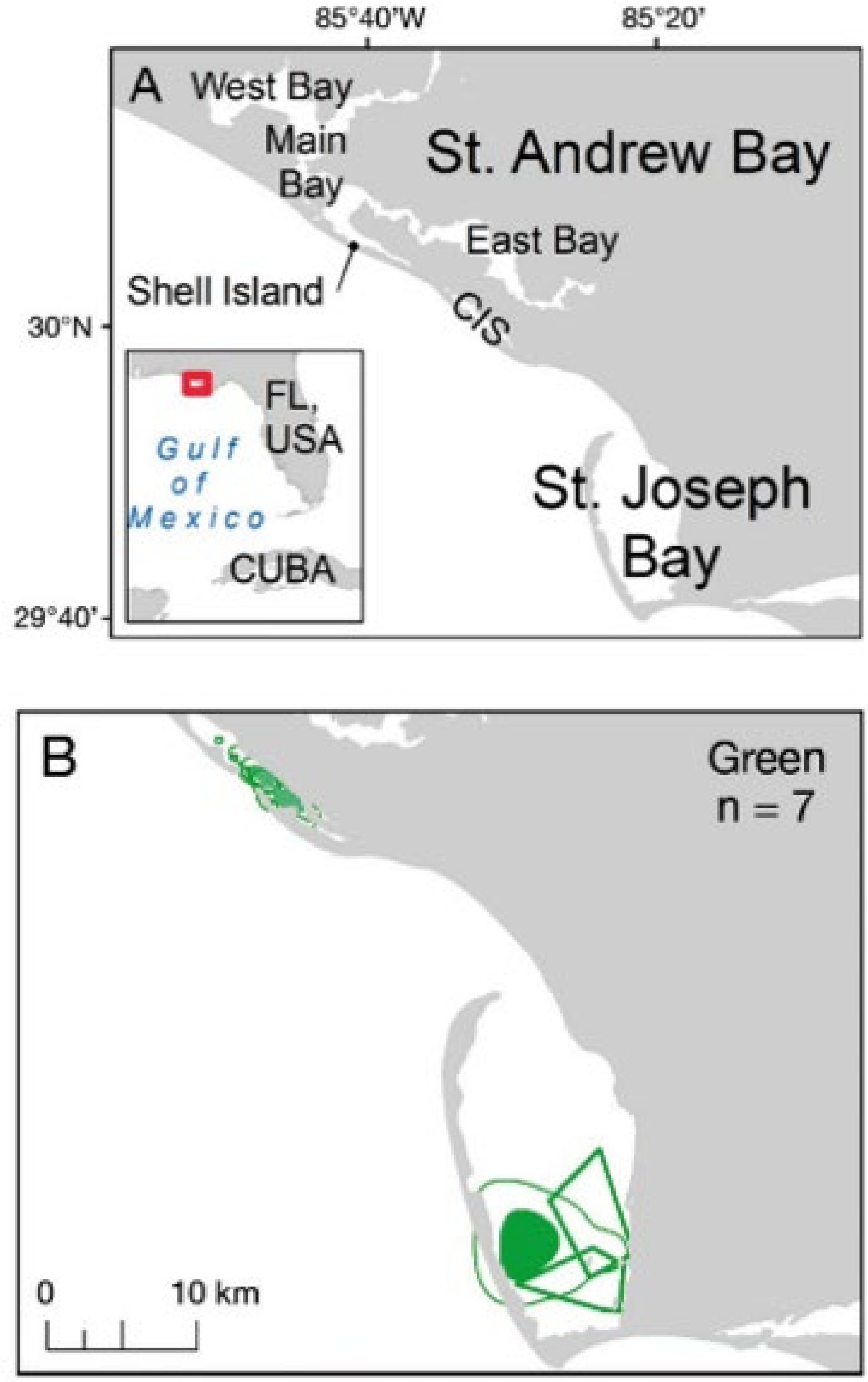

Figure B-33. Localized coastal foraging spots

Green Turtle 5: Williard et al. 2017

- Presents oceanic and neritic habitat use (Figure B-34)
- Shows oceanic use in colder months

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	20	NC	**Yes**

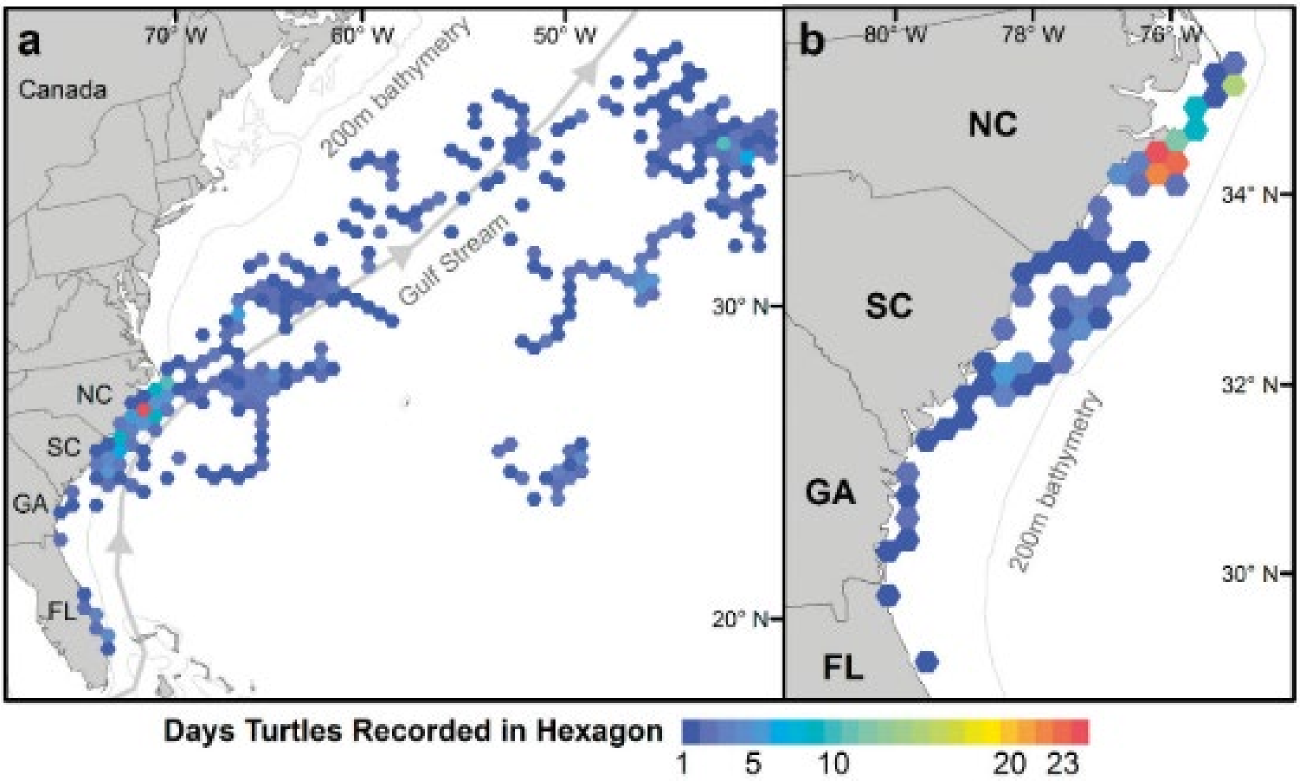

Figure B-34. Oceanic and neritic habitat use

Green Turtle 6: Putman and Mansfield 2015

- Shows relative density of water use in GOM (Figure B-35)

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	24	Northeast GOM	No

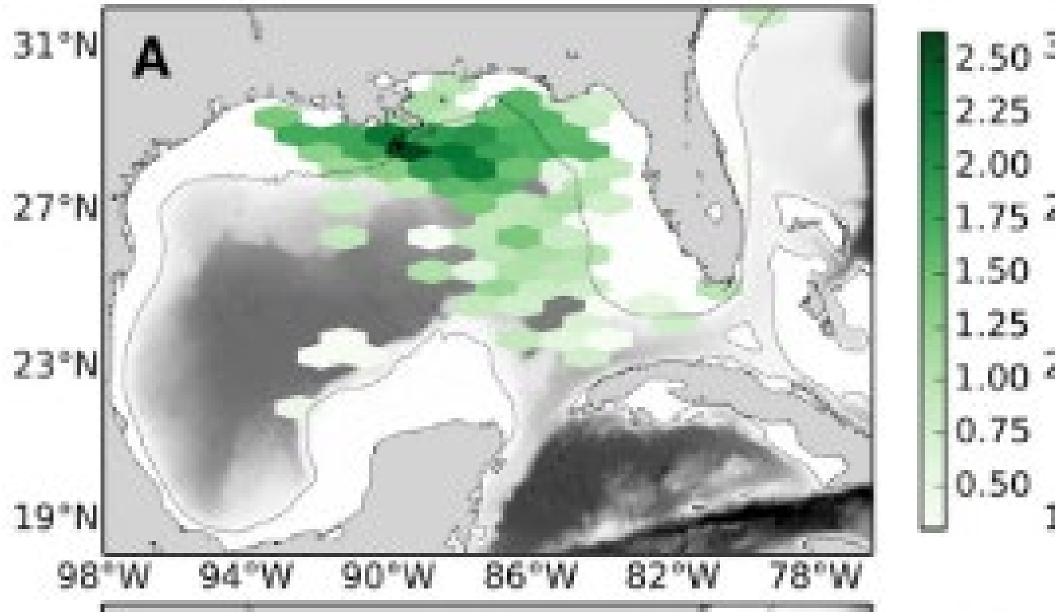

Figure B-35. Relative density of water use in the GOM

Green Turtle 7: Méndez et al. 2013

- One turtle migrates to Dry Tortugas, FL (Figure B-36)
- Home ranges assessed

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	4	Yucatan Mexico	No

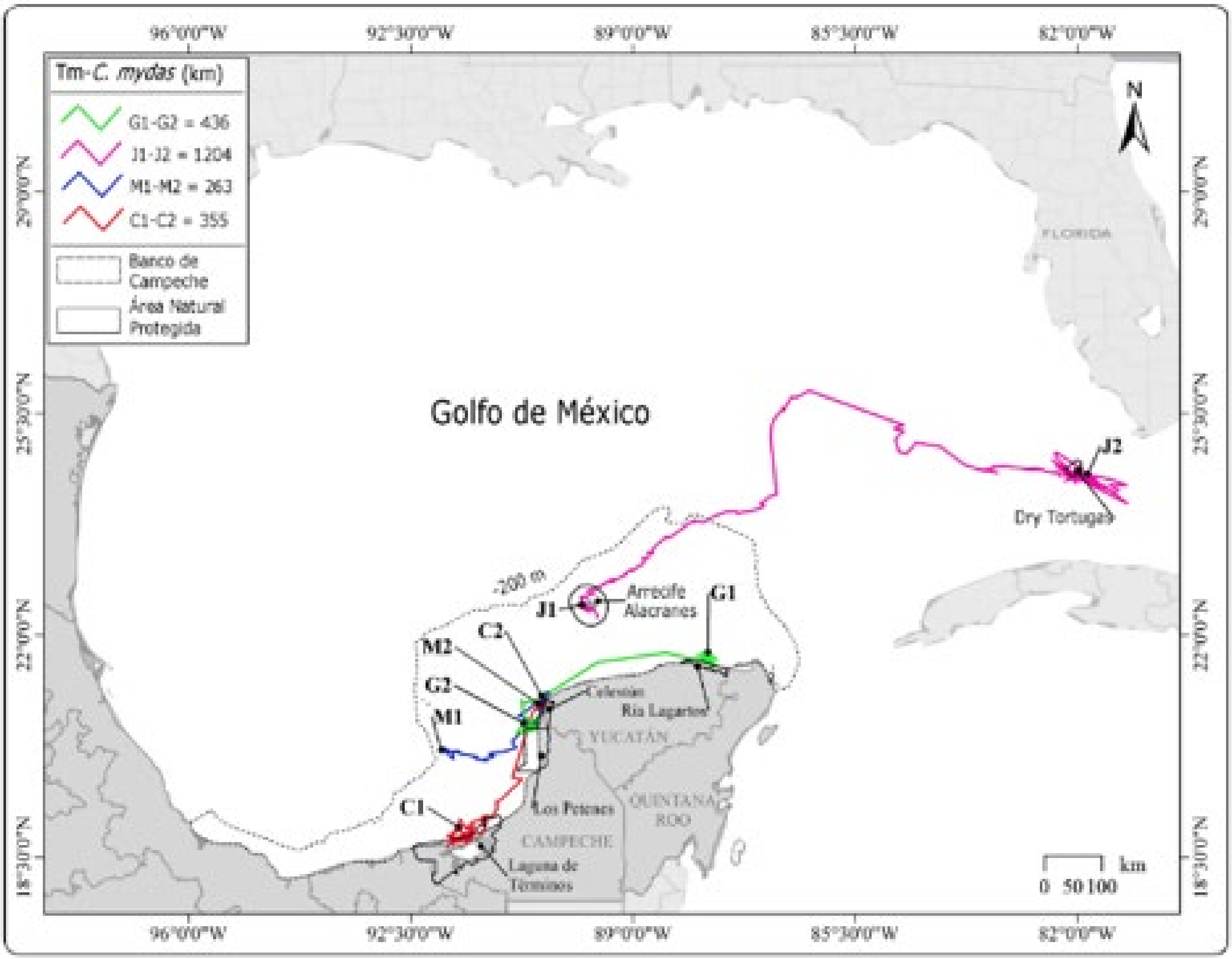

Figure B-36. One turtle migrates to Dry Tortugas, FL

Green Turtle 8: Hart et al. 2013

- Presents endpoints for migrations: all in FL (Figure B-37)
- Home ranges and habitats assessed

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	11	Dry Tortugas FL	**Yes**

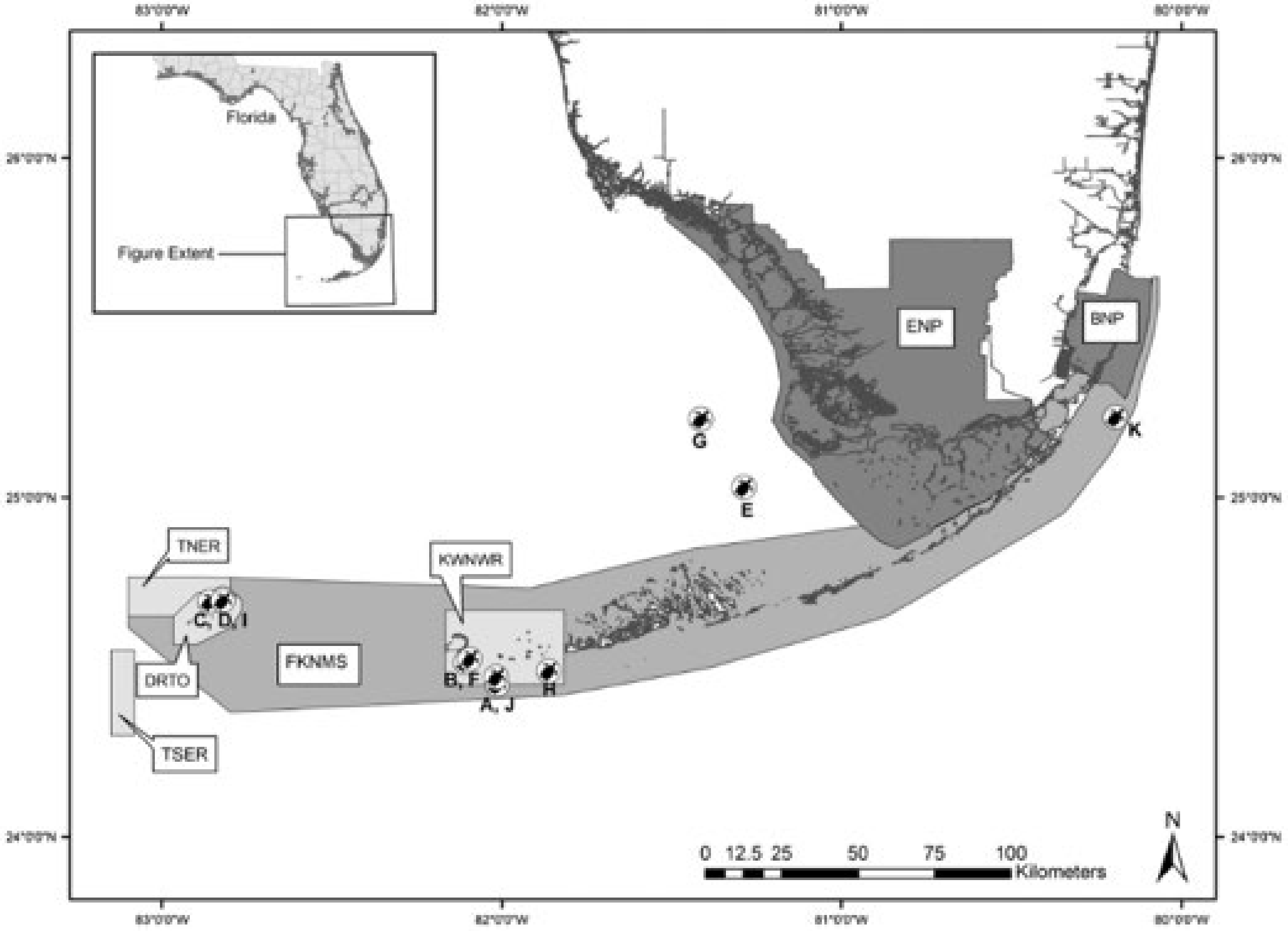

Figure B-37. Endpoints for migrations

Green Turtle 9: Hart and Fujisaki 2010

- Describes localized foraging in W Florida (Figure B-38)
- Home ranges and habitats use described

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	6	Southwestern FL Everglades	No

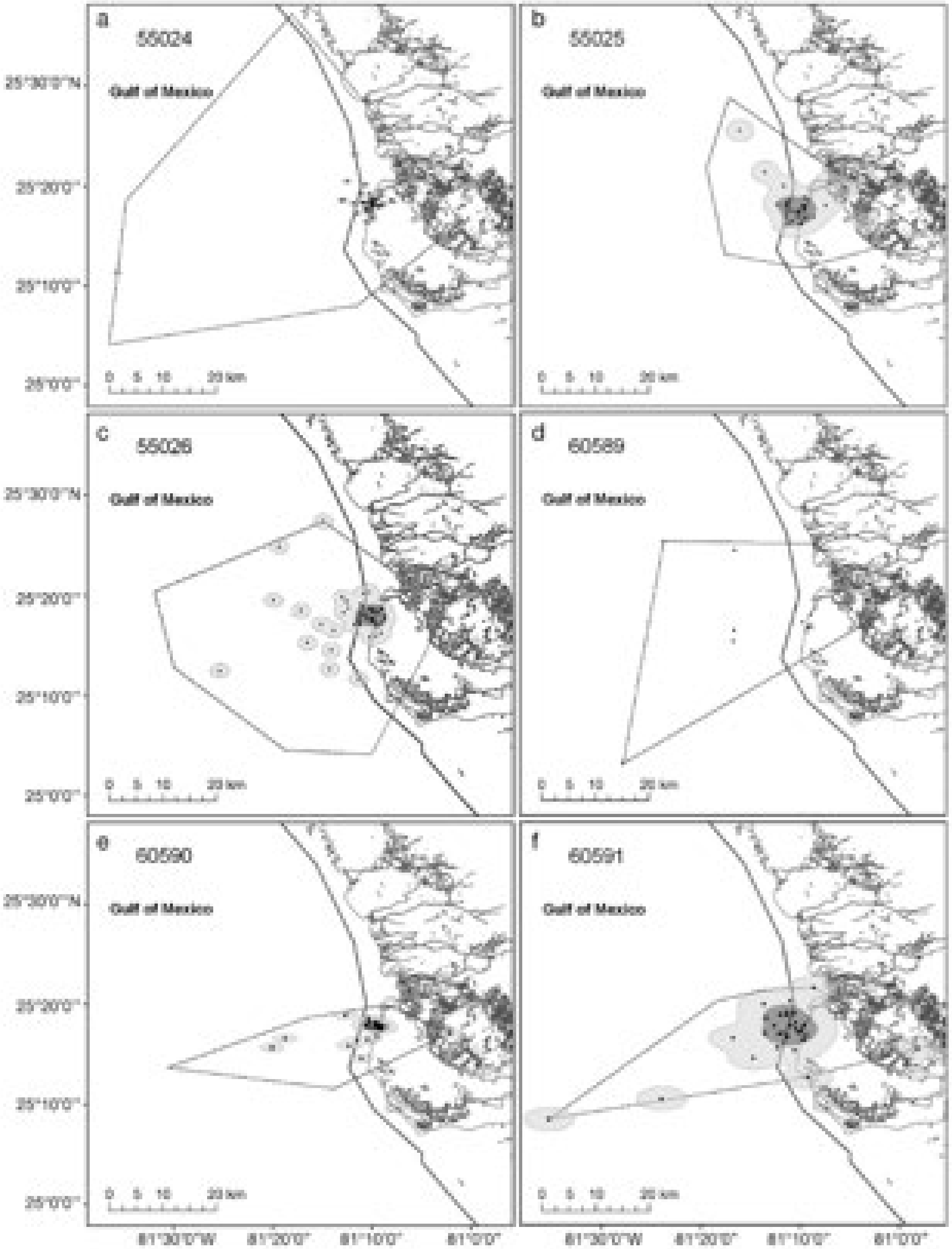

Figure B-38. Localized foraging in W Florida

Green Turtle 10: McClellan & Read 2009

- Describes localized foraging (Figure B-39)
- Relates locations to habitats and threats (Figure B-40)

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	10	NC estuaries	No

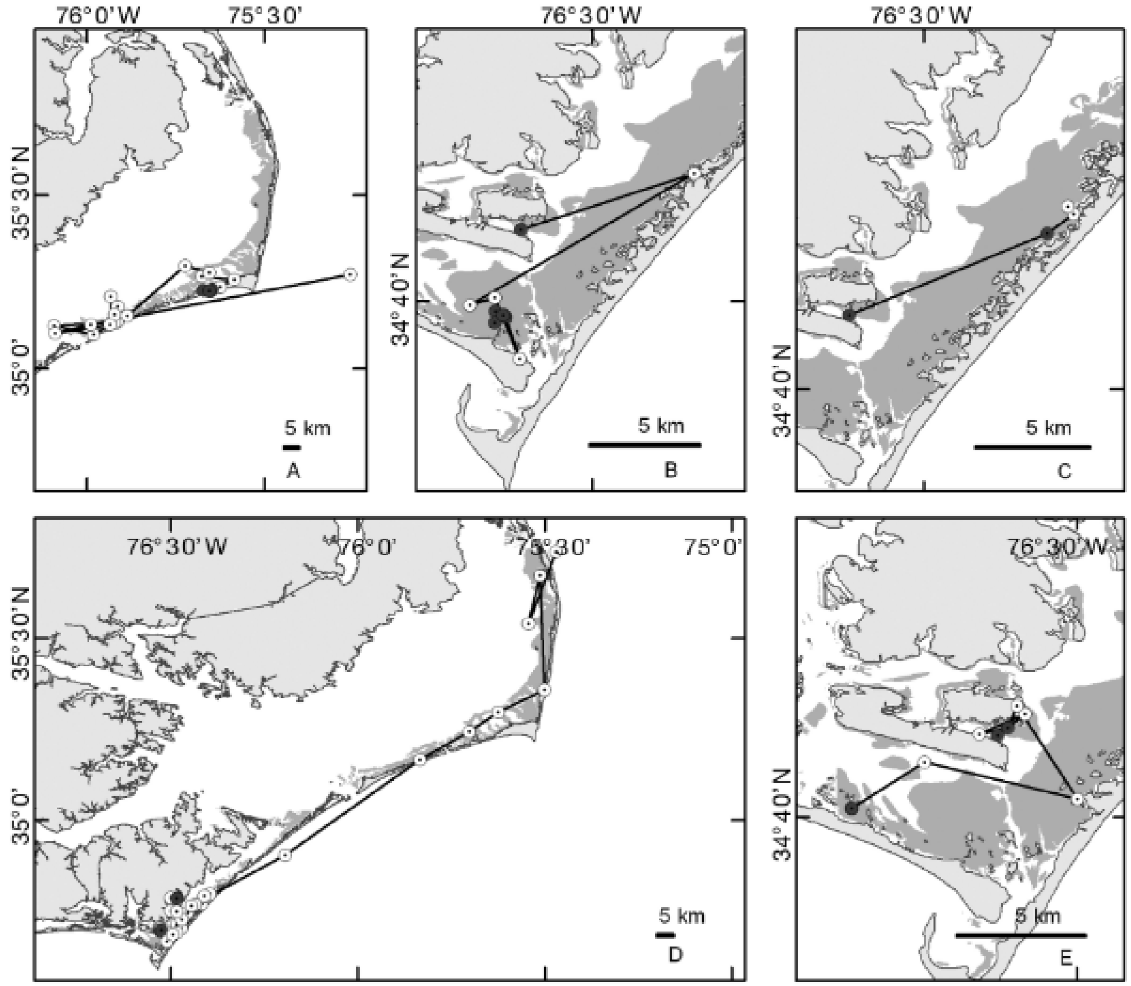

Figure B-39. Localized foraging

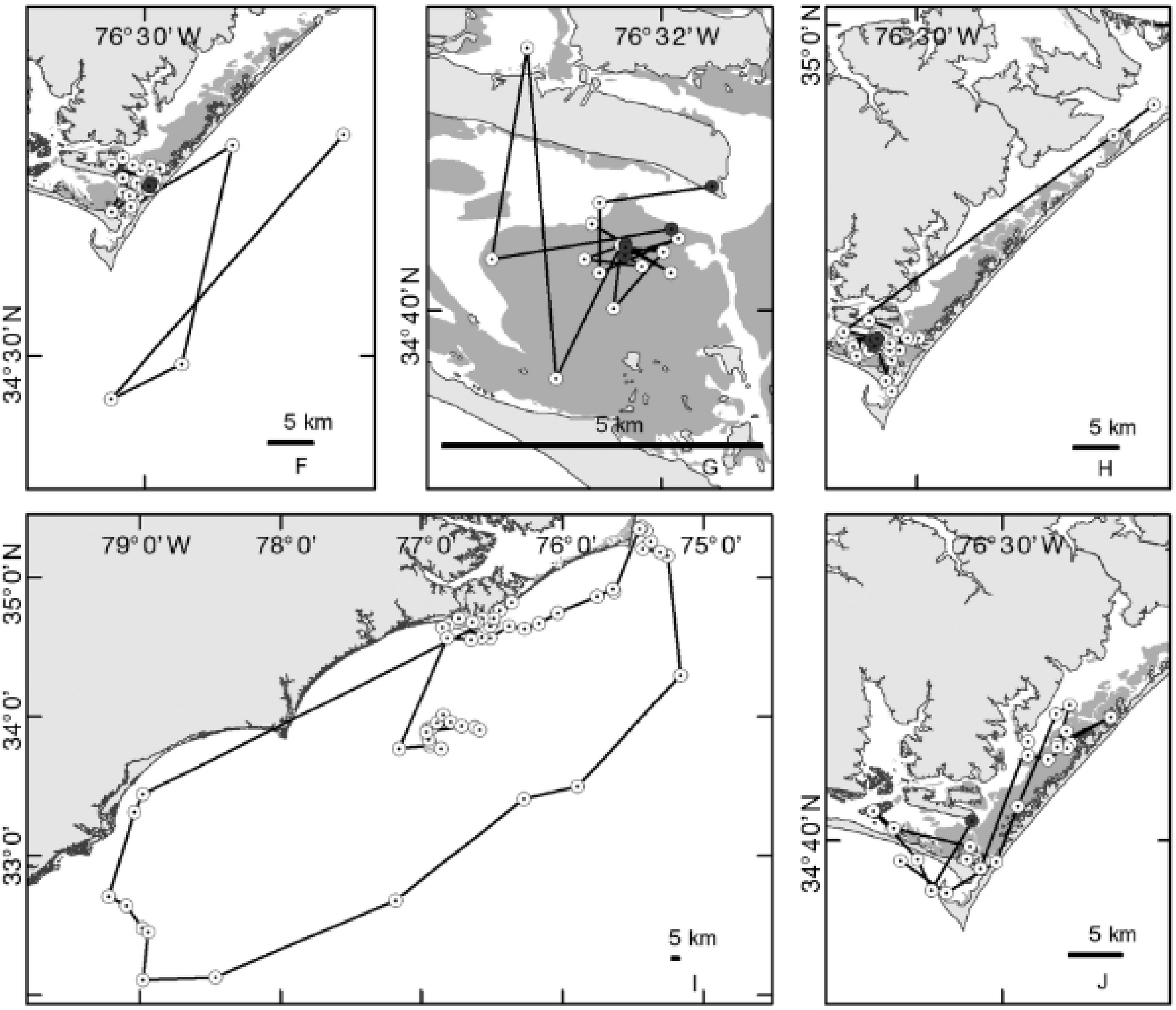

Figure B-40. Habitats and threats

Green Turtle 11: Makowski et al. 2006

- Localized home ranges with sonic telemetry (Figure B-41)
- Looks at diet and diving behavior

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	6	Eastern FL	No

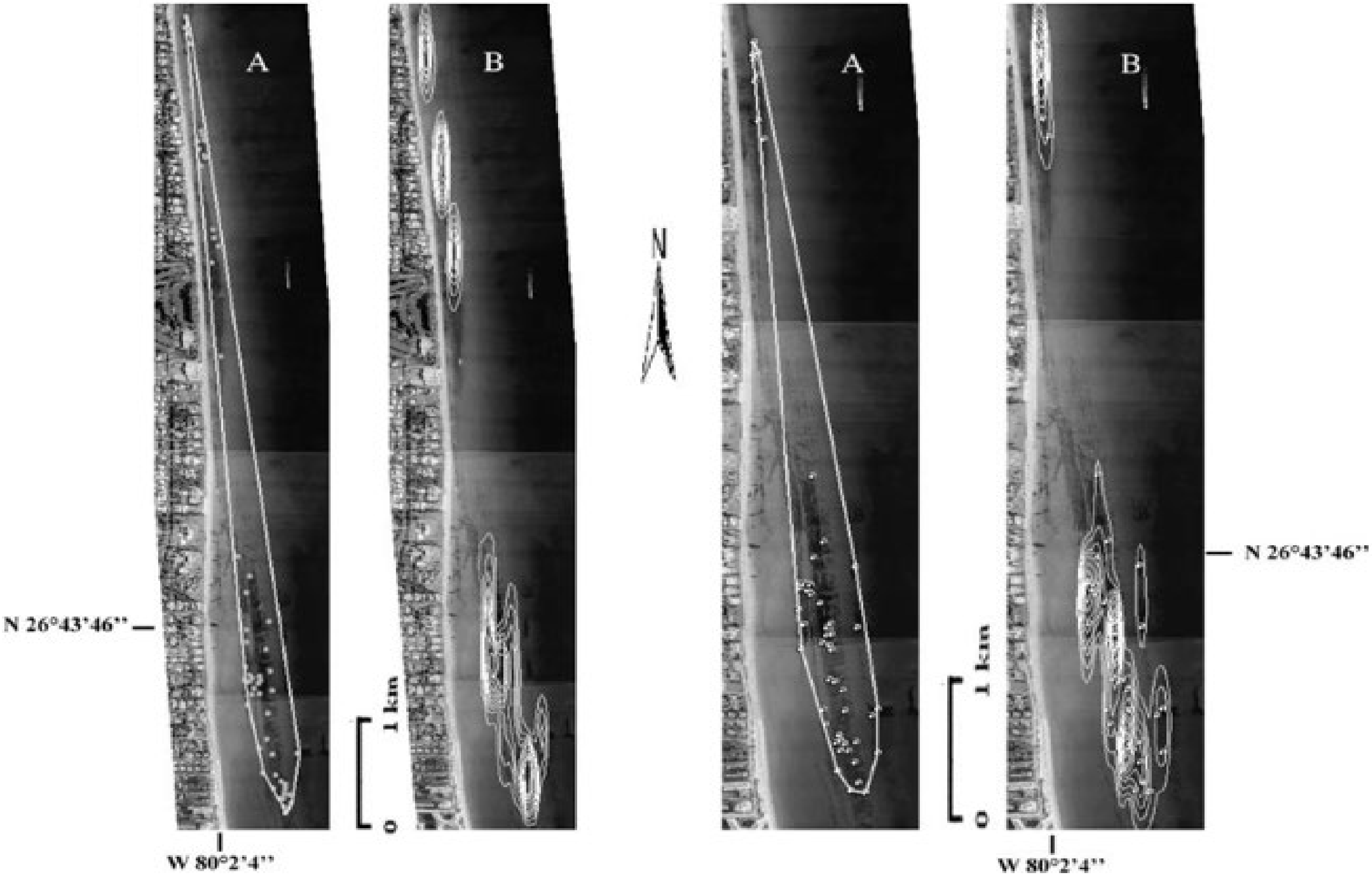

Figure B-41. Localized home ranges with sonic telemetry

A.3 Leatherback Turtle Studies

Leatherback Turtle 1: Evans et al. 2021

- High-use areas in northern GOM and Atlantic waters (Figure B-42)
- Seasonal distribution is presented (Figure B-43)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	33	Costa Rica & Panama	**Yes**

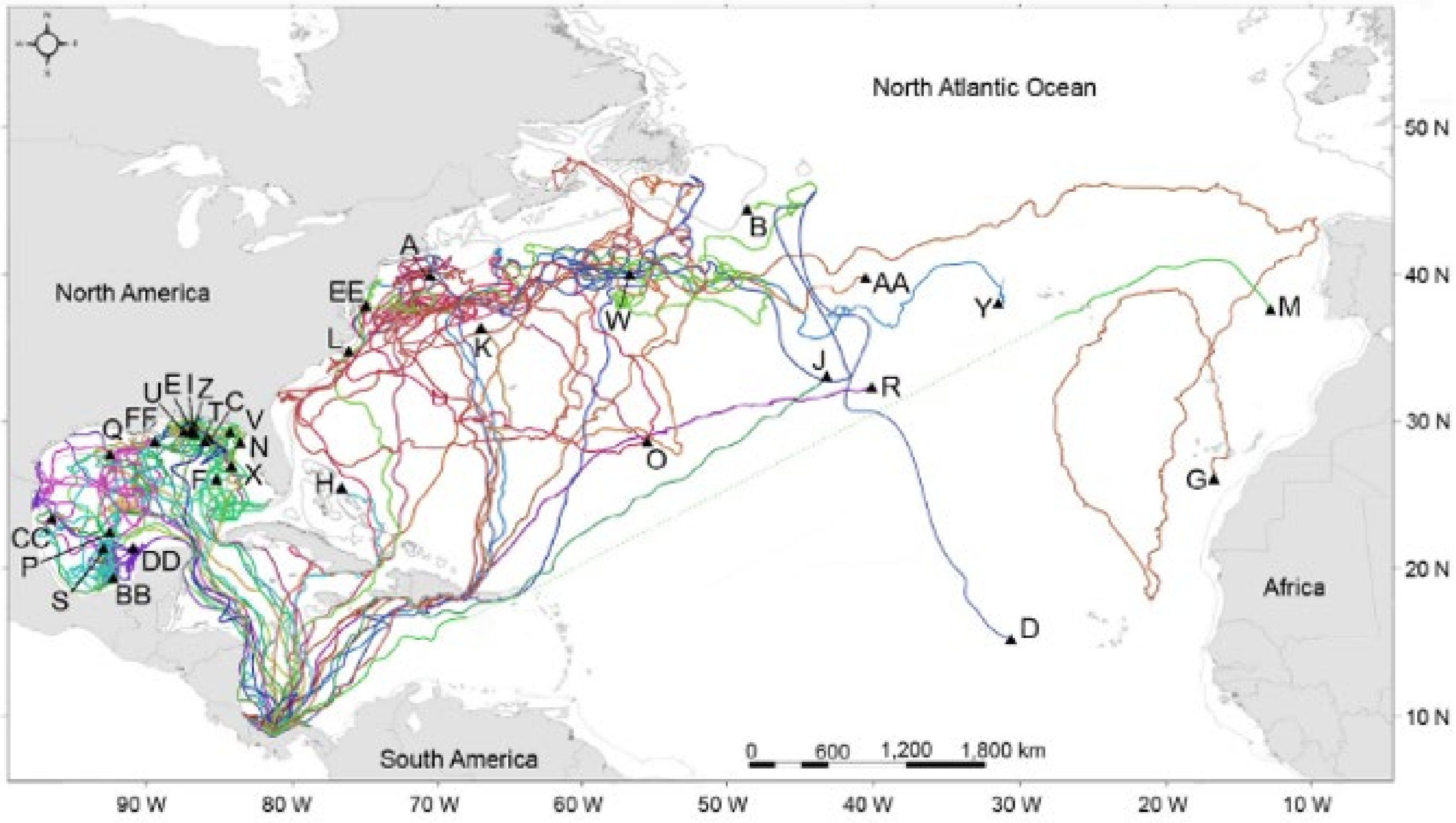

Figure B-42. High-use areas in northern GOM and Atlantic waters

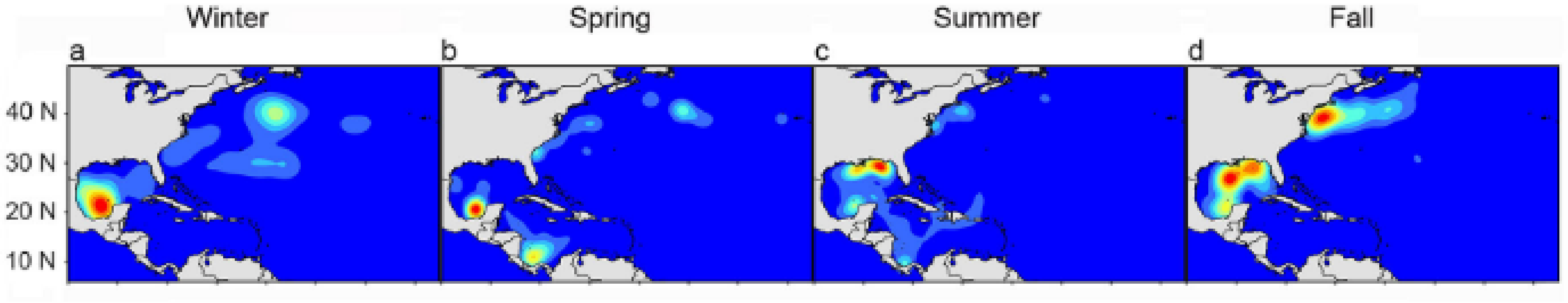

Figure B-43. Seasonal distribution

Leatherback Turtle 2: Nordstrom et al. 2020

- Presents hotspot map in Nova Scotia (Figure B-44)
- Uses jellyfish presence to predict Dc occurrence

Life Stage	Sex	Sample Size	Origin	Key Study?
Unknown	Unknown	62	Unknown	No

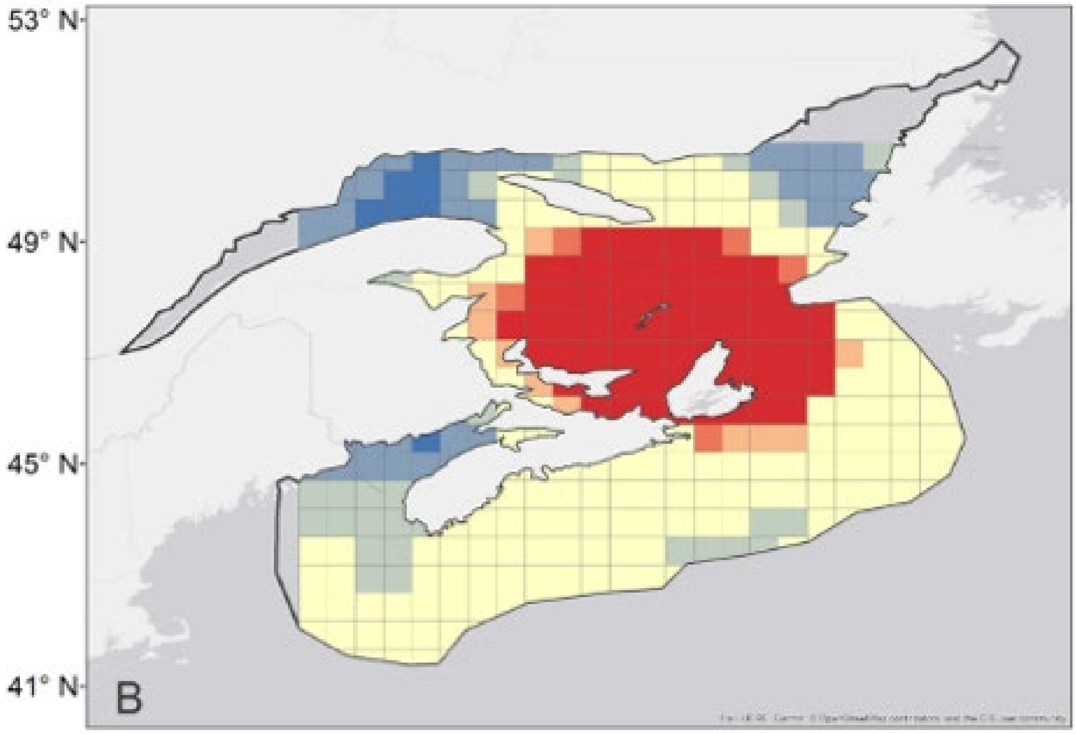

Figure B-44. Hotspots in Nova Scotia

Leatherback Turtle 3: Evans 2019

- Tracks to GOM and NWA (Figure B-45)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	7	Panama	No

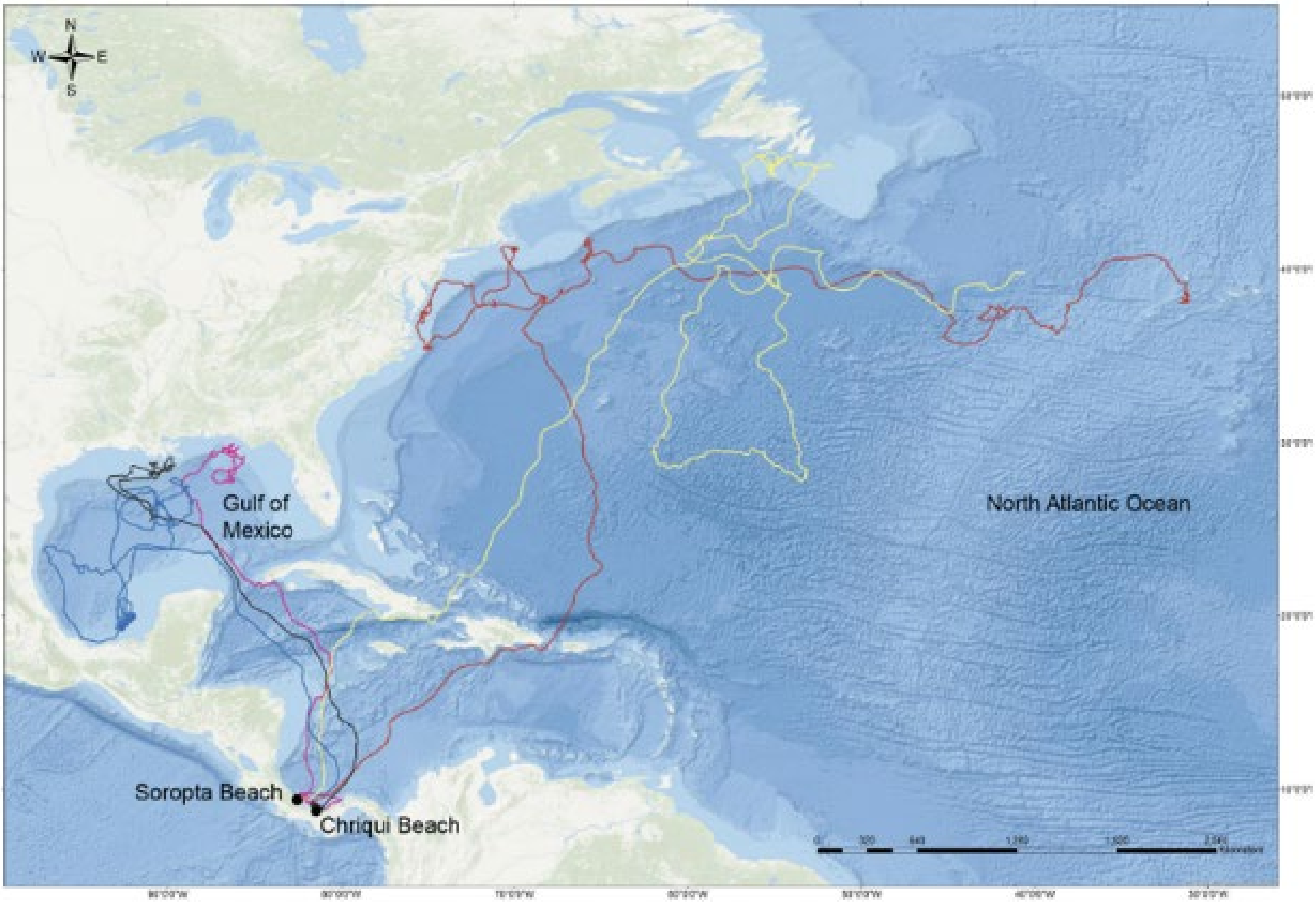

Figure B-45. Tracks to GOM and NWA

Leatherback Turtle 4: Dodge et al. 2014, 2015

- Presents tracks and migrations (Figure B-46)
- Assesses orientation and diving (Figure B-47)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	M/F	15 (20)	At sea off Massachusetts	**Yes**

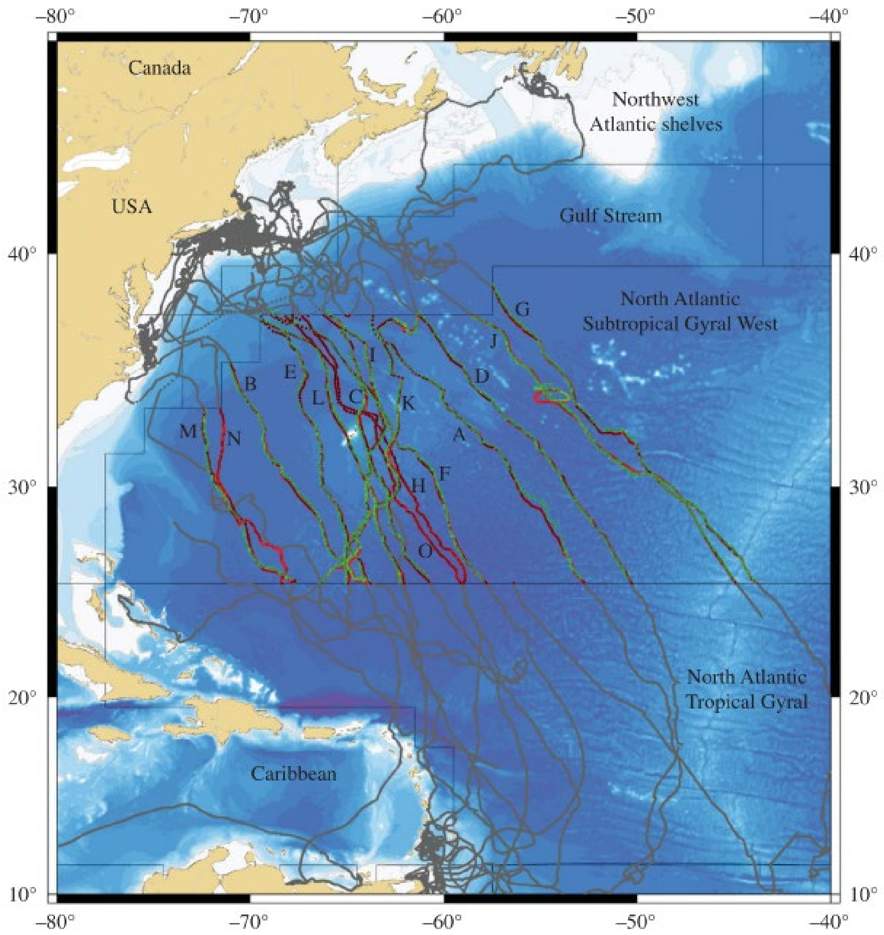

Figure B-46. Tracks and migrations

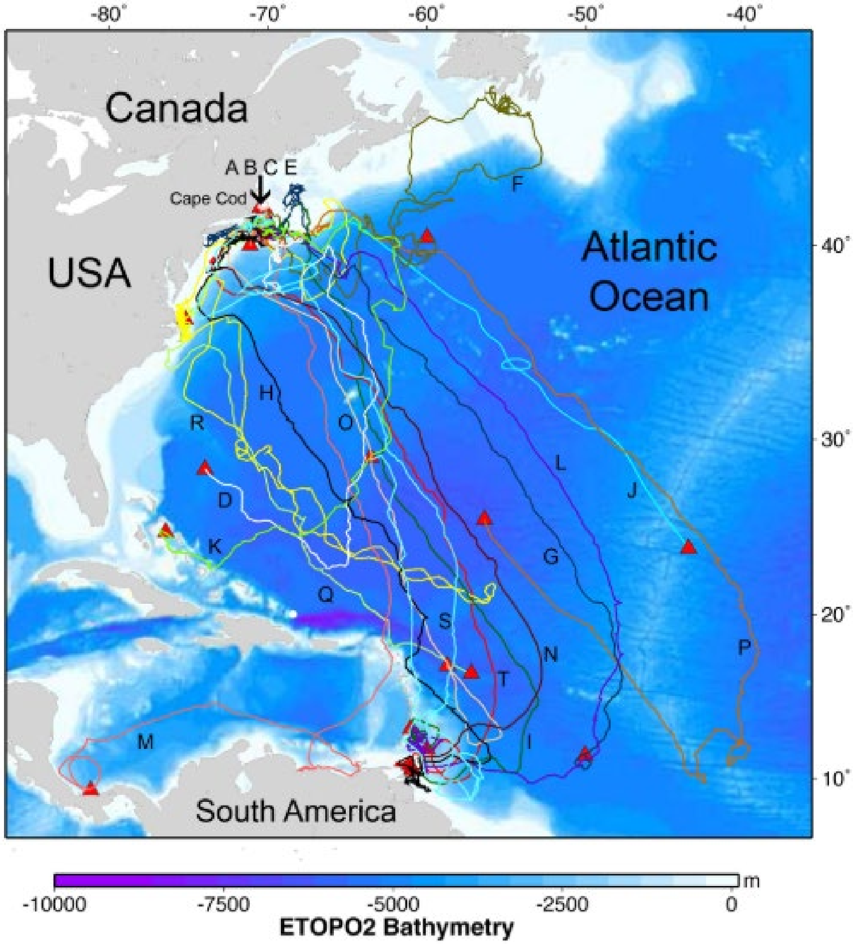

Figure B-47. Orientation and diving

Leatherback Turtle 5: Fossette et al. 2014

- Distribution map; seasonal presence published in supplement (Figure B-48)
- Overlaps with fishing pressure
- Atlantic meta-study

Life Stage	Sex	Sample Size	Origin	Key Study?
Mixed	M/F	~36	Various Western Atlantic	No

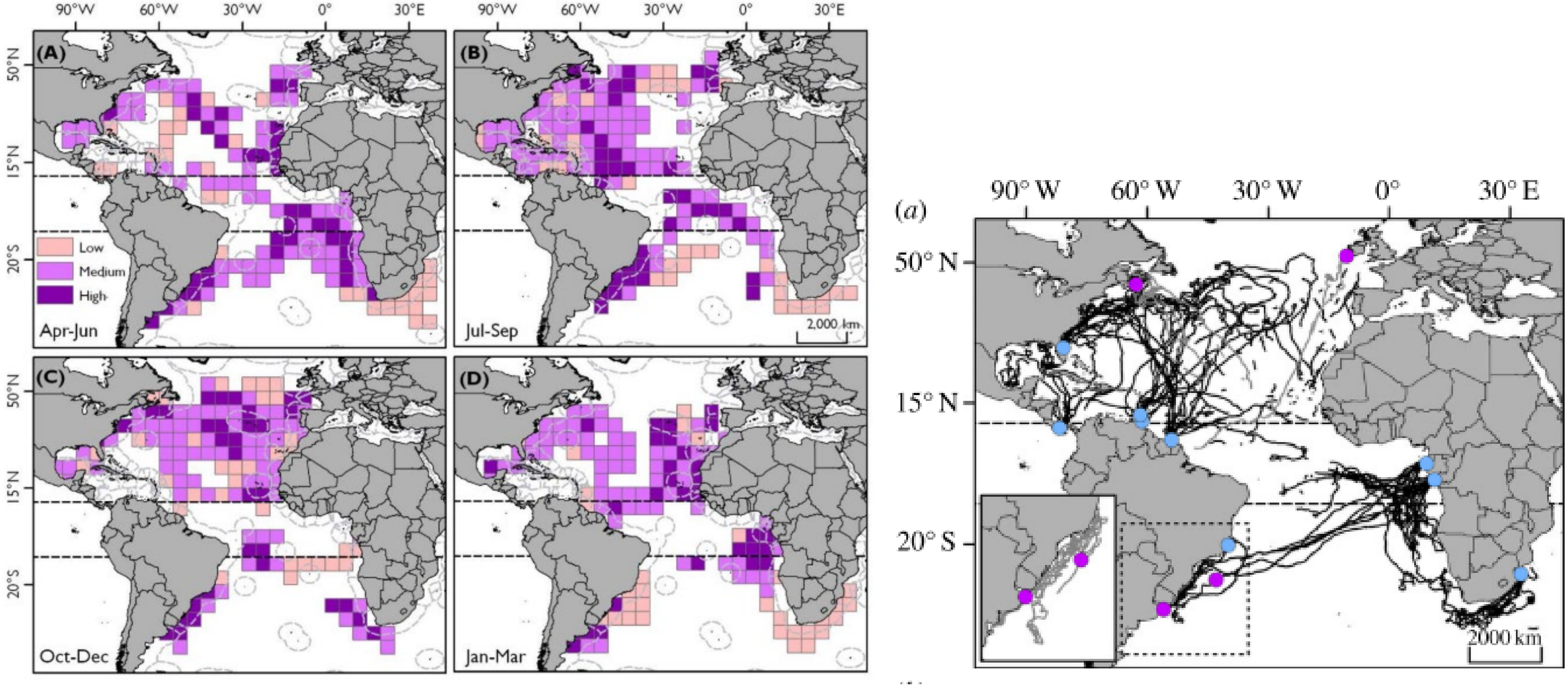

Figure B-48. Distribution

Leatherback Turtle 6: Bailey et al. 2012

- Presents migration map (small; Figure B-49)
- Assesses dive behavior

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult, Unknown	F, Unknown	21	Various Western Atlantic	No

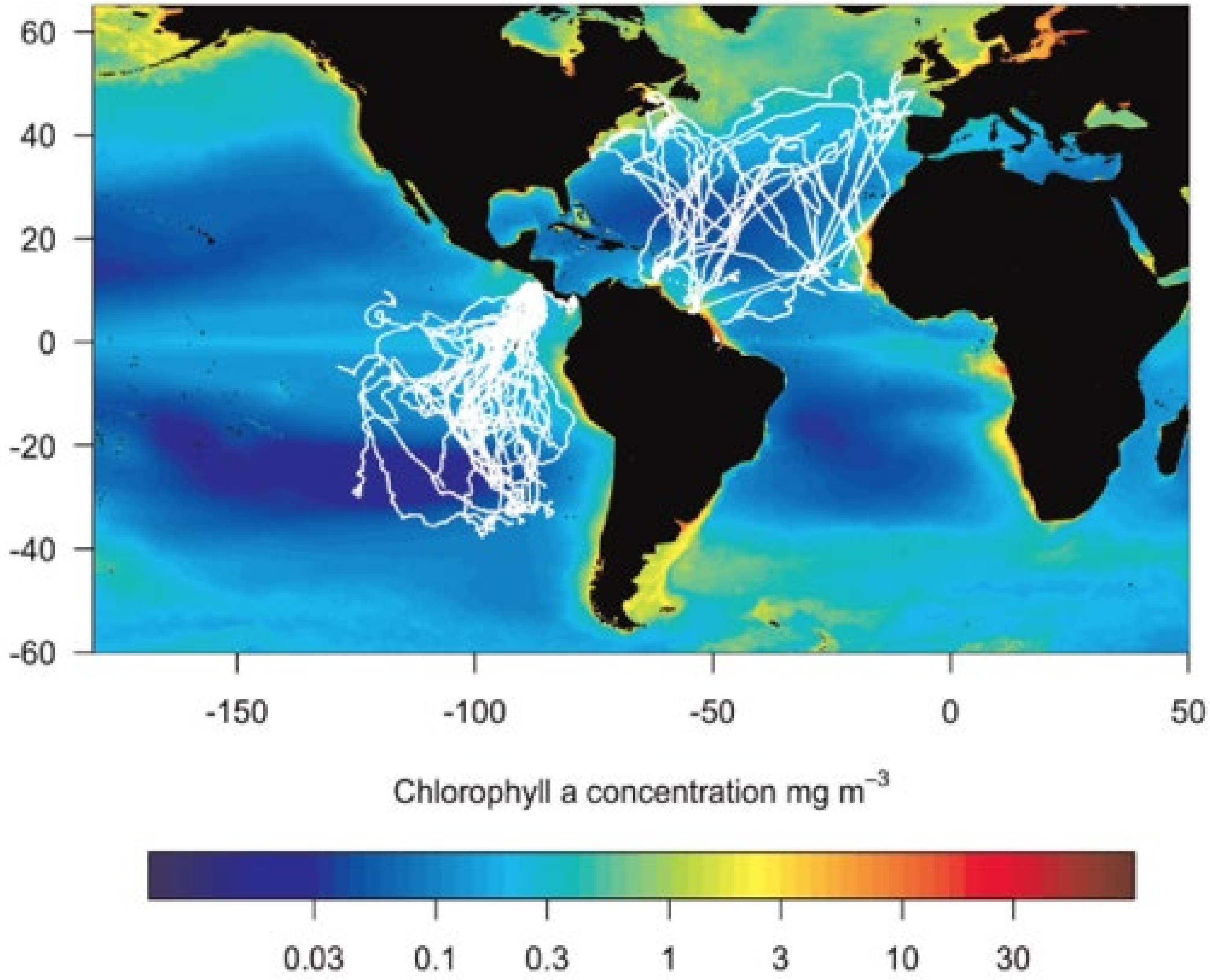

Figure B-49. Migration

Leatherback Turtle 7: DFO 2012

- Presents presence residency maps of previous studies (Figure B-50)
- Focus is on Canada
- Atlantic meta-study
- Recycling older tracks

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	94	Various Western Atlantic	**Yes**

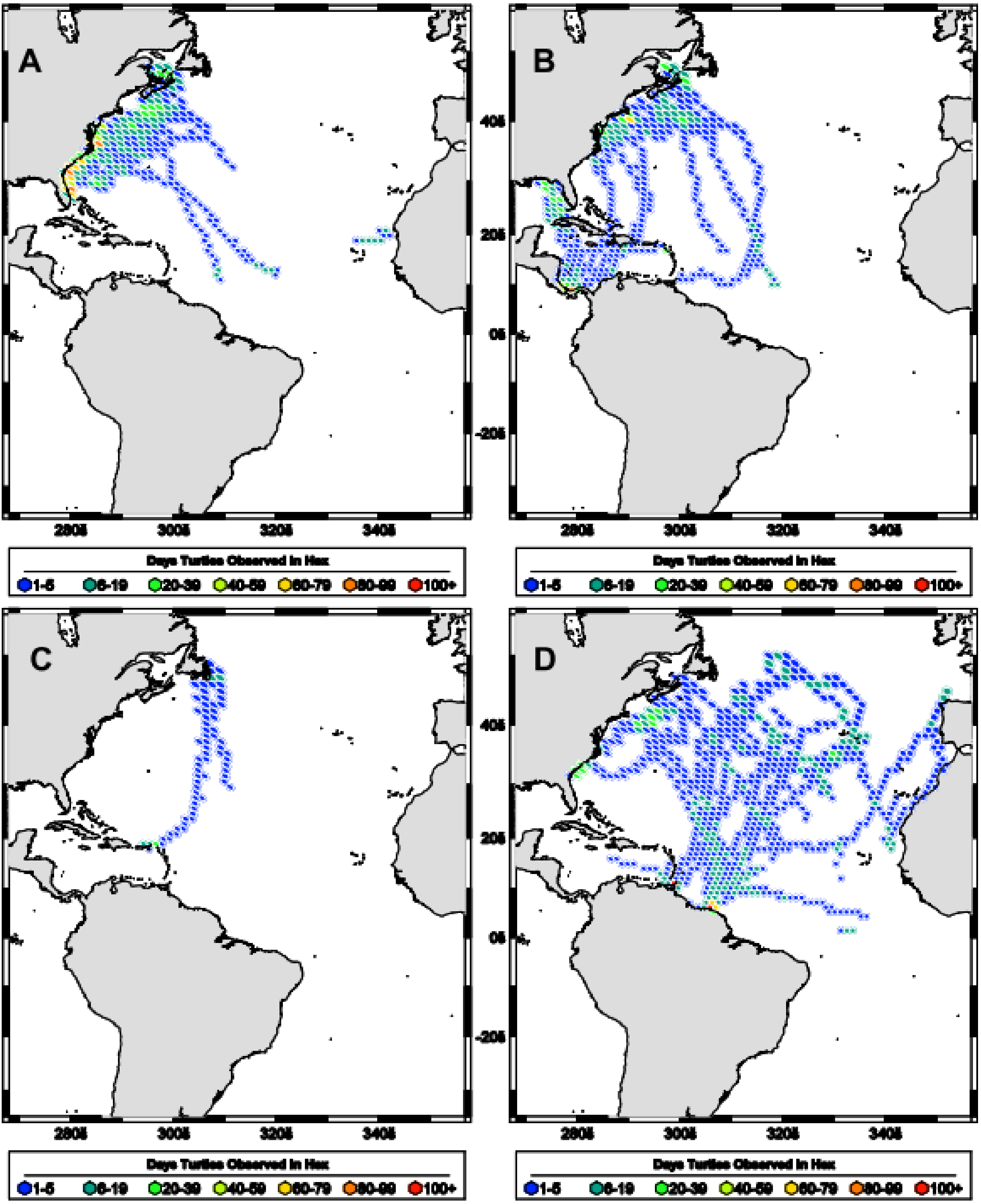

Figure B-50. Presence residency of previous studies

Leatherback Turtle 8: Galli et al. 2012

- Migrations map of a few turtles (Figure B-51)
- Focus on orientation

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	11	South America / Grenada	No

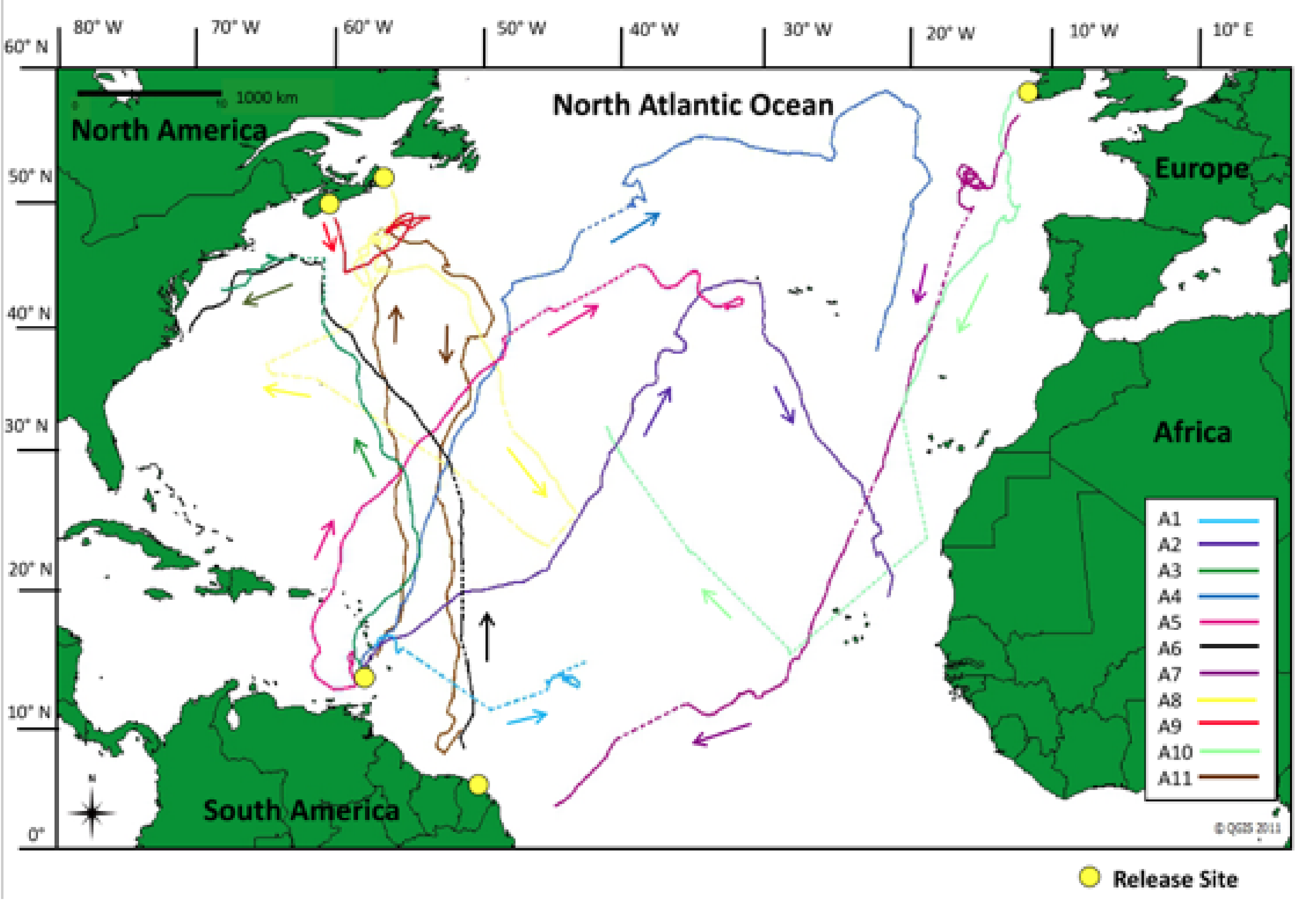

Figure B-51. Migrations map of a few turtles

Leatherback Turtle 9: Fossette et al. 2010a

- Migration map (small; Figure B-52)
- Discusses temporary residency areas in neritic and oceanic habitats

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F (mostly)	18	Panama / Suriname/ French Guiana	No

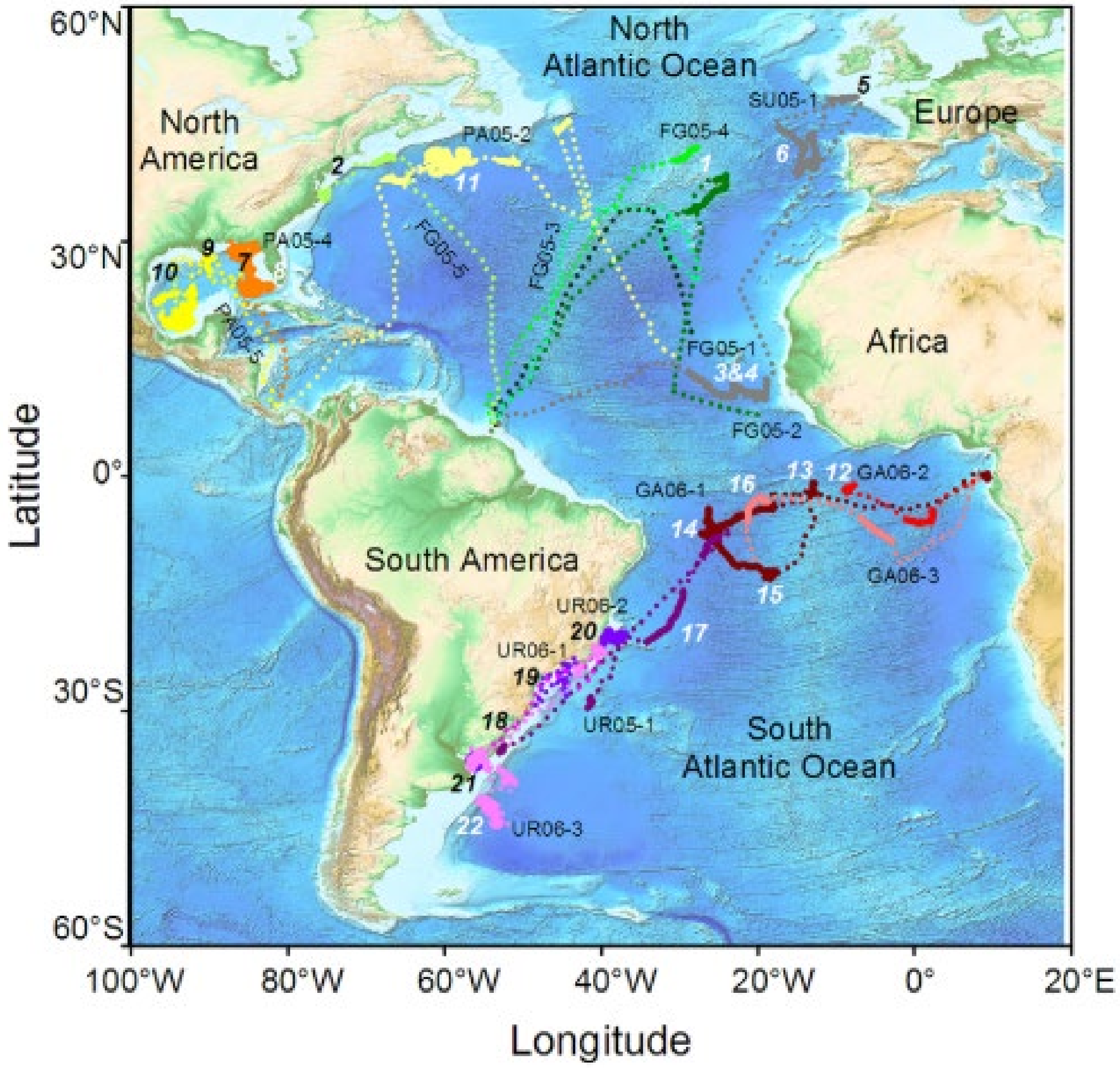

Figure B-52. Migration map (small)

Leatherback Turtle 10: Fossette et al. 2010b

- Migration map (small; Figure B-53)
- Assesses round trip migrations and diving

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F (mostly)	~21	Grenada and Suriname/ French Guiana and more	No

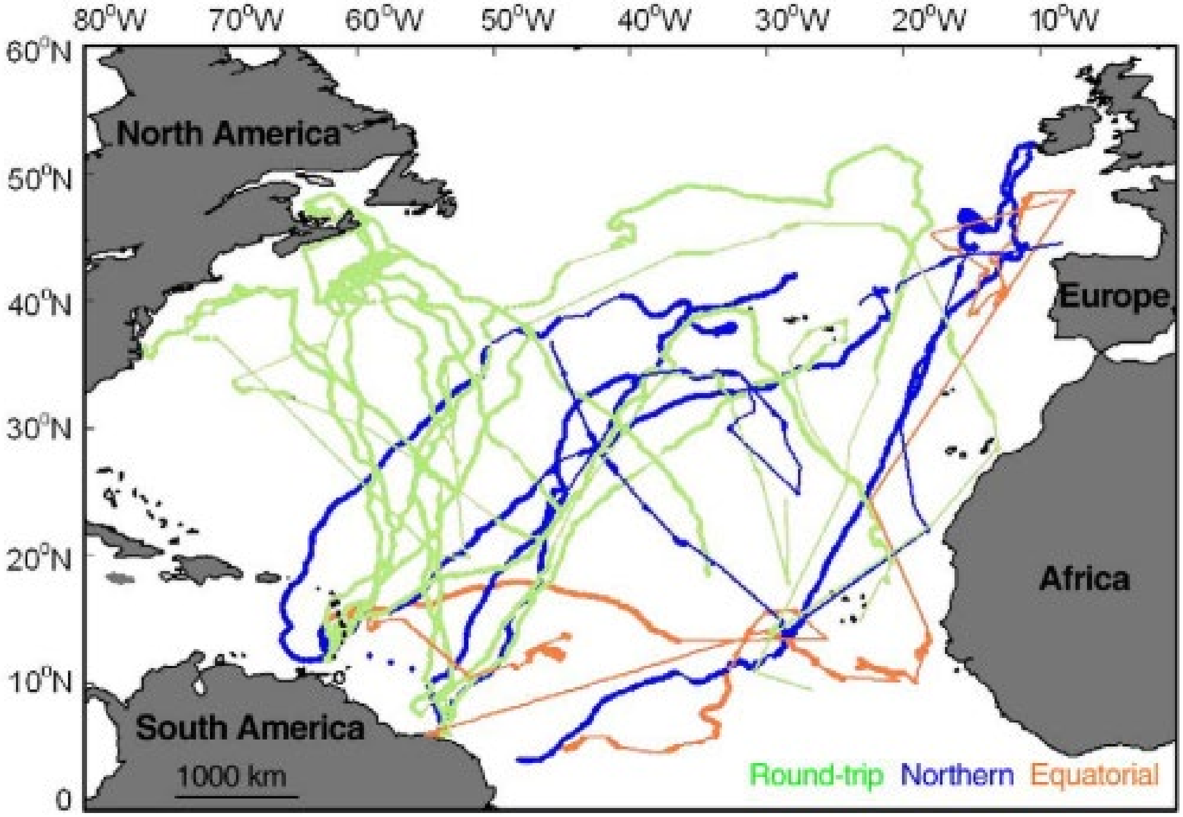

Figure B-53. Migration map (small)

Leatherback Turtle 11: Sherrill-Mix et al. 2008

- Predicts when turtles will start migrating based on sea surface temperature and chlorophyll a
- Small map of turtle locations (Figure B-54)

Life Stage	Sex	Sample Size	Origin	Key Study?
Unknown	Unknown	27 (32)	Nova Scotia	No

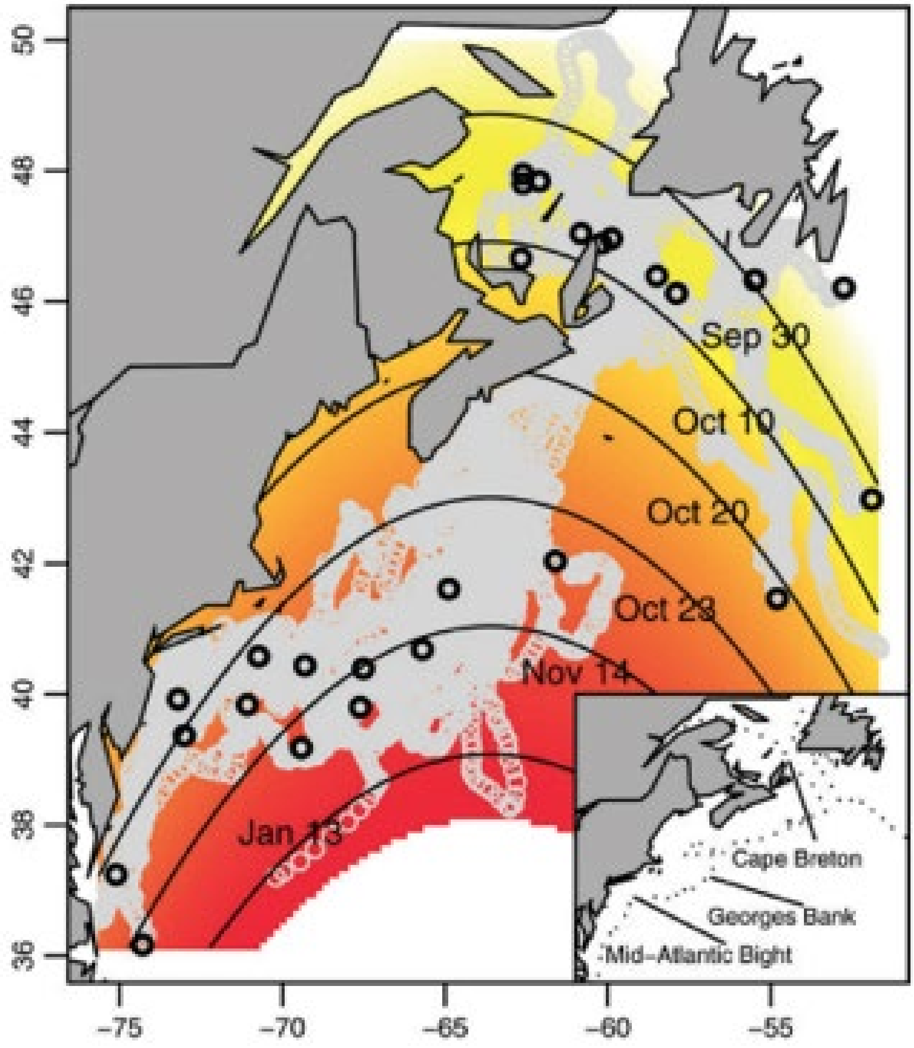

Figure B-54. Small map of turtle locations

Leatherback Turtle 12: Eckert et al. 2006

- Small post-nesting and KDE and seasonal maps presented (Figure B-55)
- Internesting habitat also presented

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	10	Atlantic FL	No

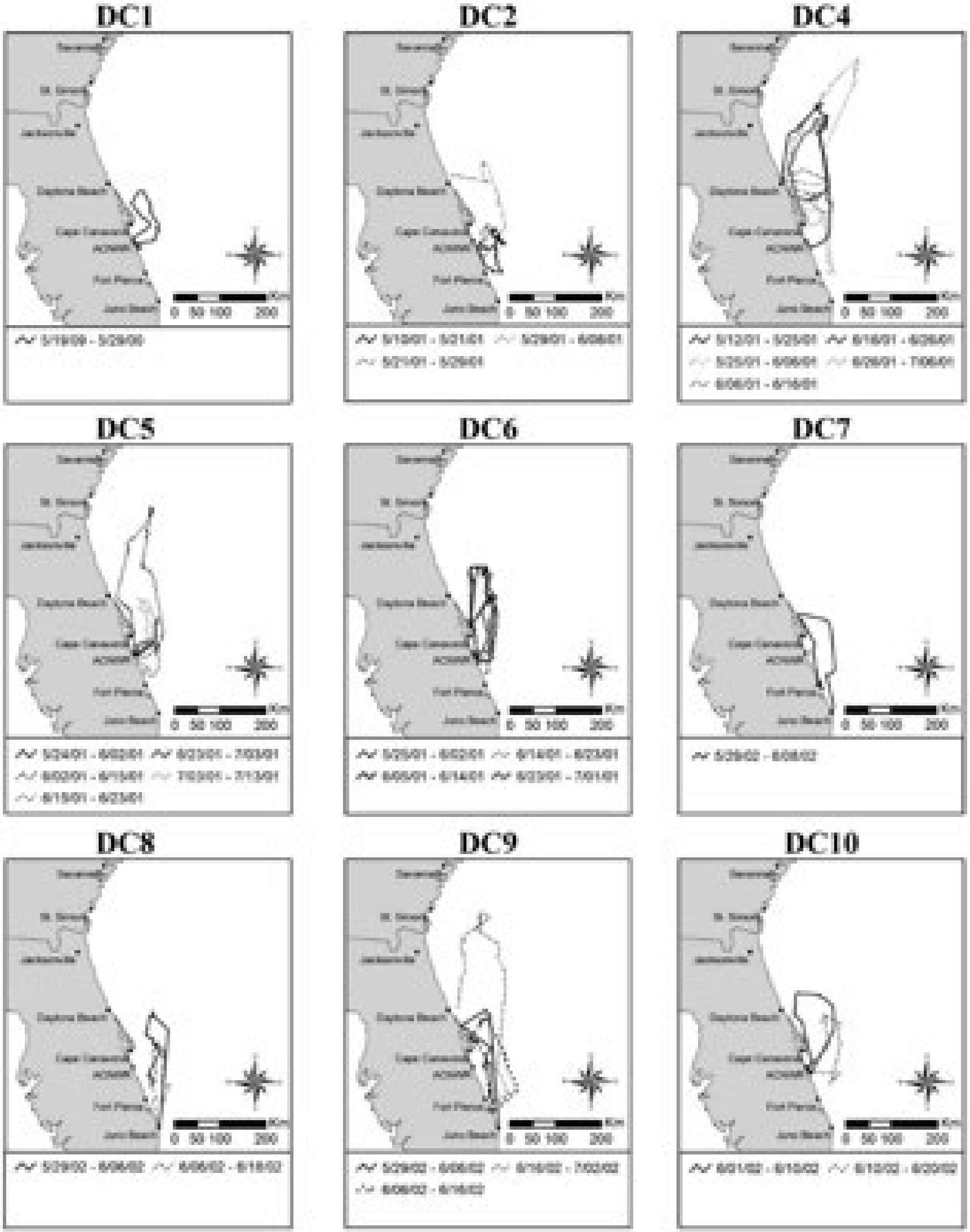

Figure B-55. Small post-nesting and KDE and seasonal maps

Leatherback Turtle 13: James et al. 2006

- Turtle's movements in cold waters presented (Figure B-56)
- States Canada is critical habitat for this species in the Atlantic
- Remains in Canada

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	1	Nova Scotia	

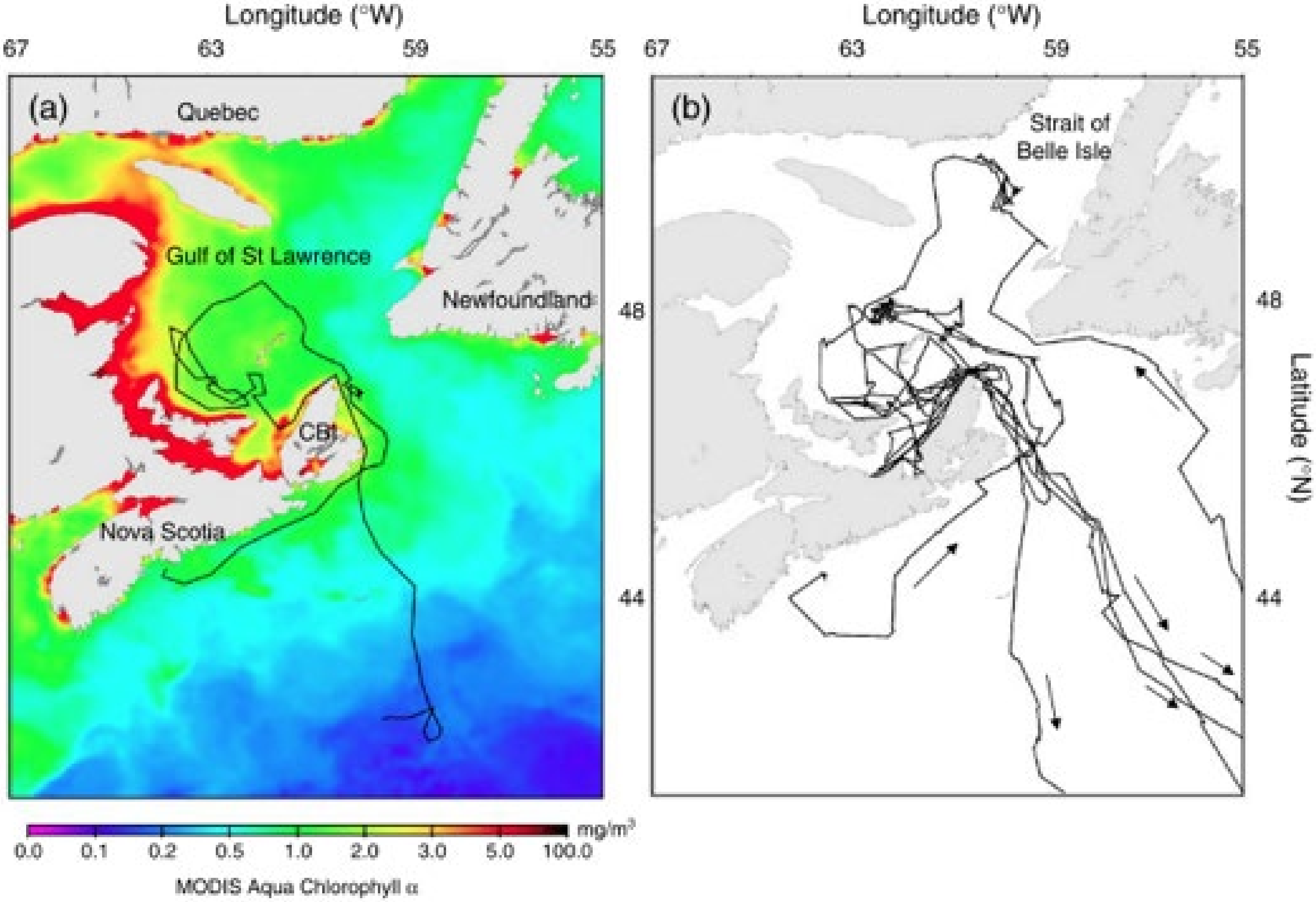

Figure B-56. Turtle's movements in cold waters

Leatherback Turtle 14: McMahon and Hays 2006

- Tiny track map (Figure B-57)
- Defines thermal niche of leatherbacks – which has been superseded

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	9	Western tropical Atlantic	No

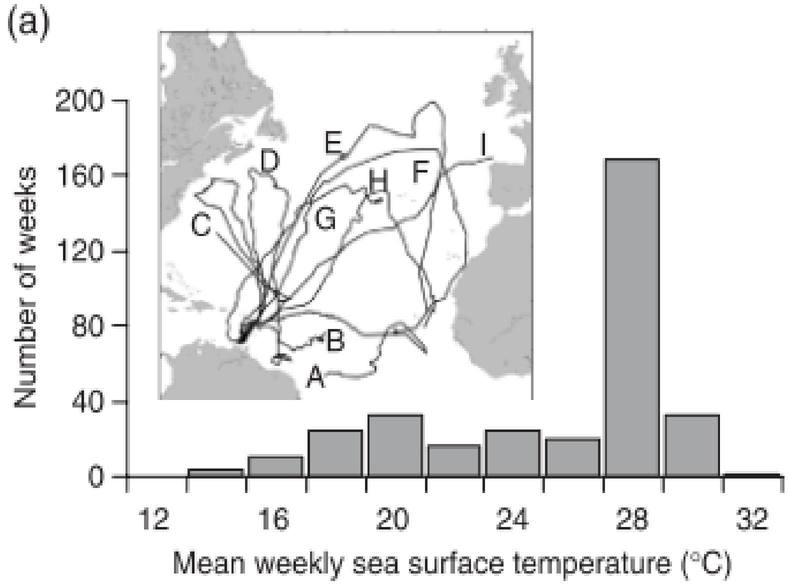

Figure B-57. Tiny track map

Leatherback Turtle 15: James et al. 2005

- Residency and distribution mapped (Figure B-58)
- Identifies high-use habitats

Life Stage	Sex	Sample Size	Origin	Key Study?
Unknown	M/F	38	Nova Scotia	**Yes**

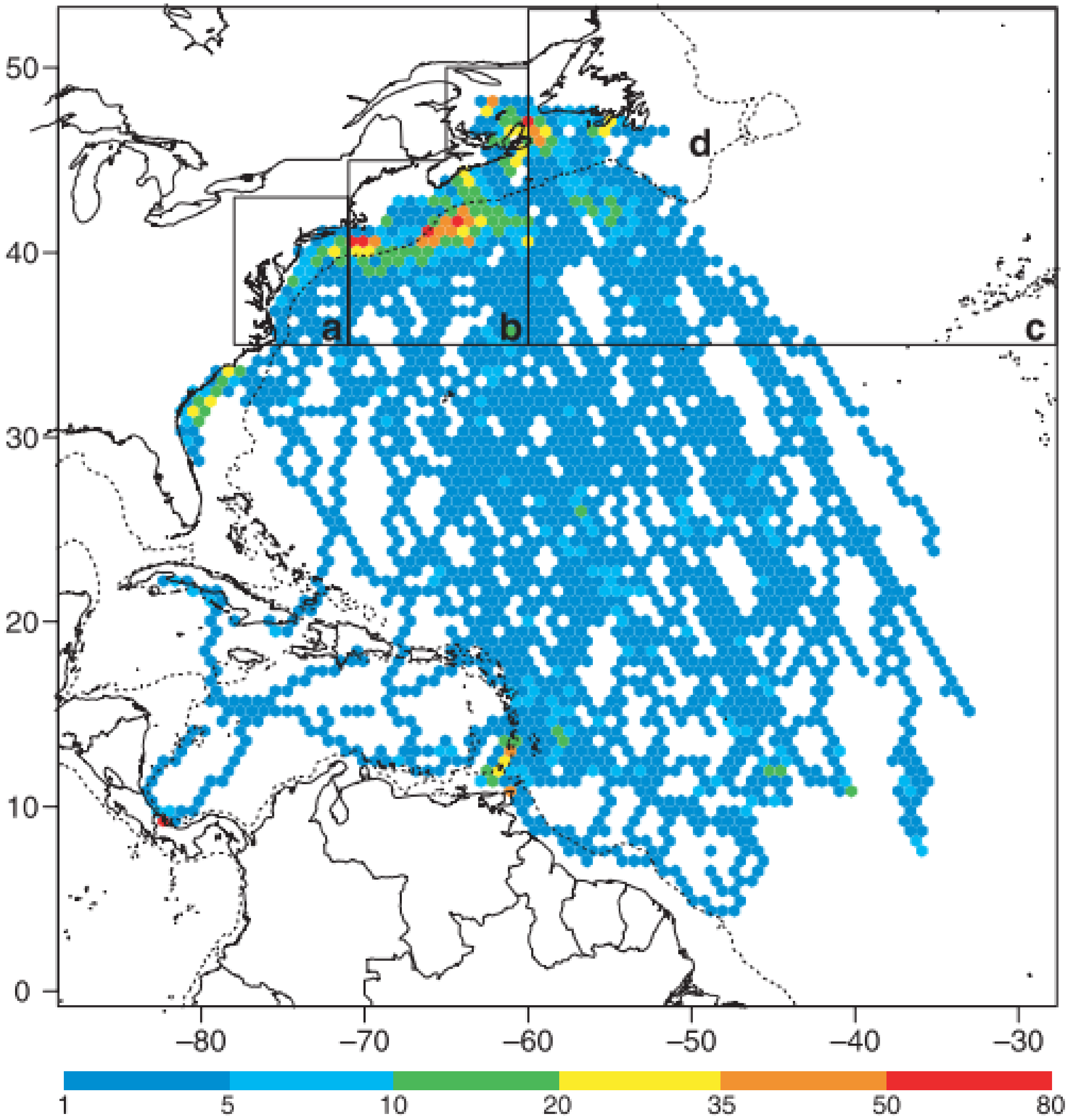

Figure B-58. Residency and distribution

A.3.1 Kemp’s Ridley Turtle Studies

Kemp’s Ridley Turtle 1: DiMatteo et al. 2021

- Presents summer foraging locations (Figure B-59)
- Models home ranges
- NWA

Life Stage	Sex	Sample Size	Origin	Key Study?
Mixed	M/F	26	Chesapeake	No

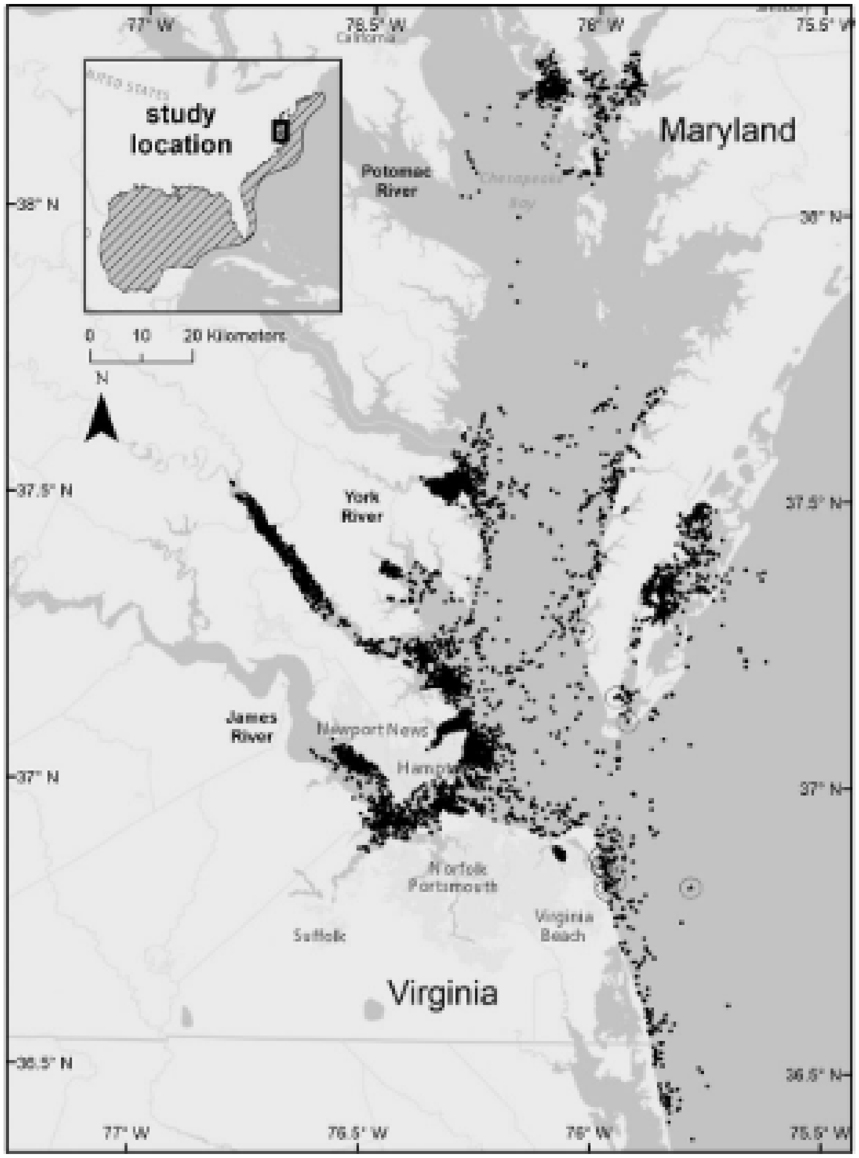

Figure B-59. Summer foraging locations

Kemp's Ridley Turtle 2: Uribe-Martínez et al. 2021

- Post-nesting tracks mapped, one track passes through FL waters (Figure B-60)
- Presents internesting and foraging locations

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	9	Mexico	No

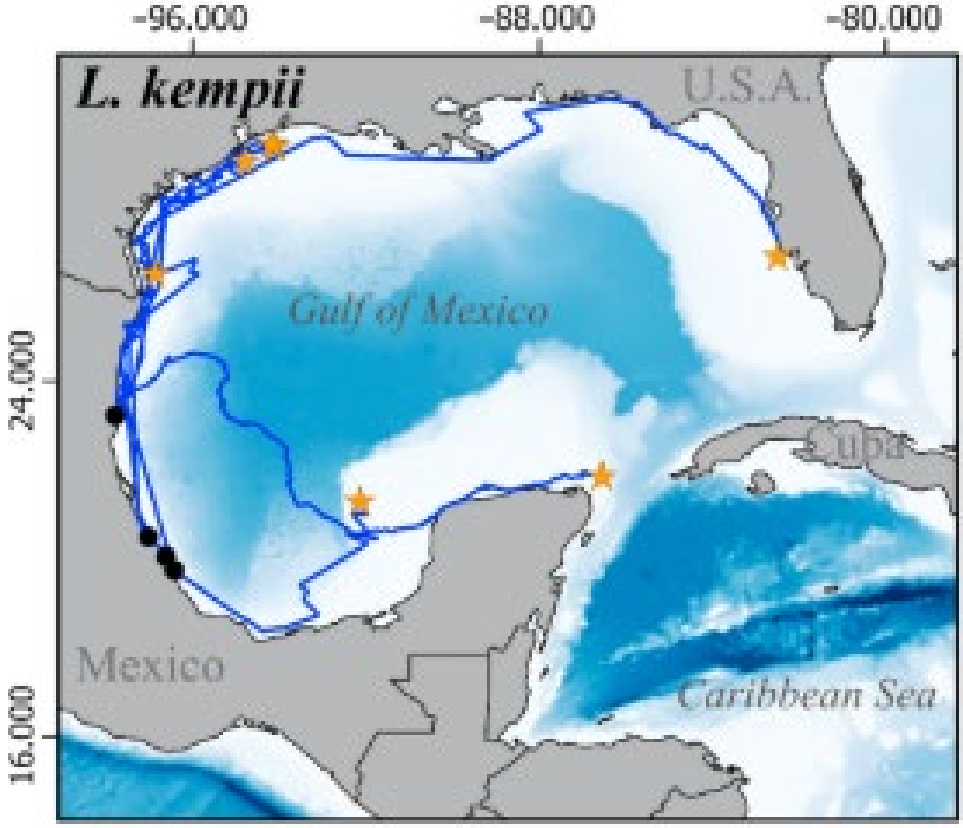

Figure B-60. Post-nesting tracks

Kemp’s Ridley Turtle 3: Caillouet Jr and Gallaway 2020

- Indicates turtles found in Atlantic are generally ‘lost’ to the breeding population
- Not a tracking paper but relevant

Life Stage	Sex	Sample Size	Origin	Key Study?
All	M/F	n/a	GOM	No

Kemp’s Ridley Turtle 4: Wildermann et al. 2019

- Maps core foraging areas (Figure B-61)
- Relates species habitat overlap and dive depths

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	Unknown	5	Western peninsula FL	No

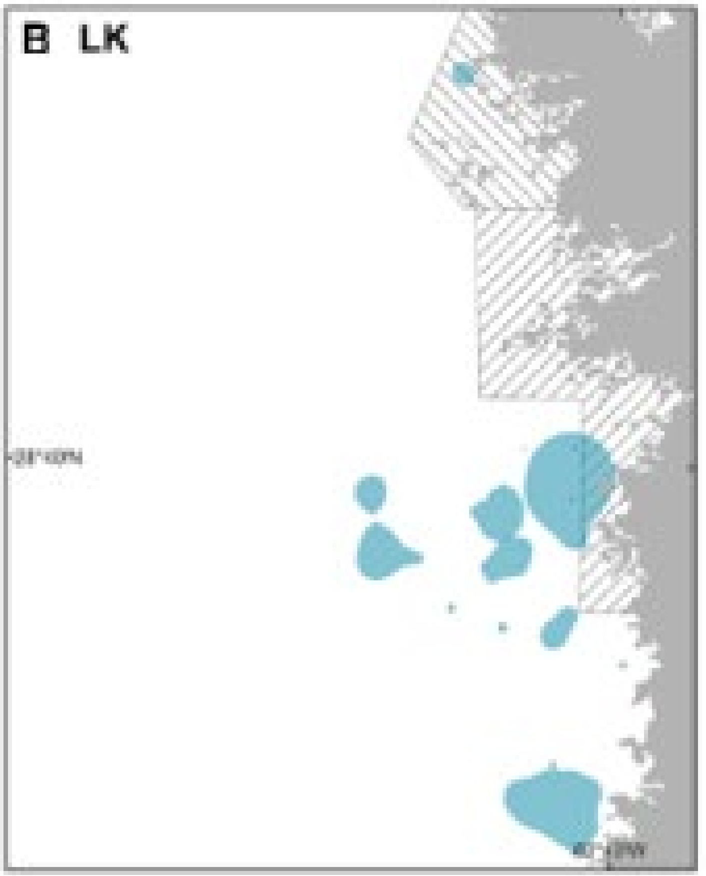

Figure B-61. Core foraging areas

Kemp’s Ridley Turtle 5: Hart et al. 2018

- Foraging locations plotted with relative importance (Figure B-62)
- Analyses turtle locations and anthropogenic threat overlap

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	64	AL, Western FL (GOM)	**Yes**

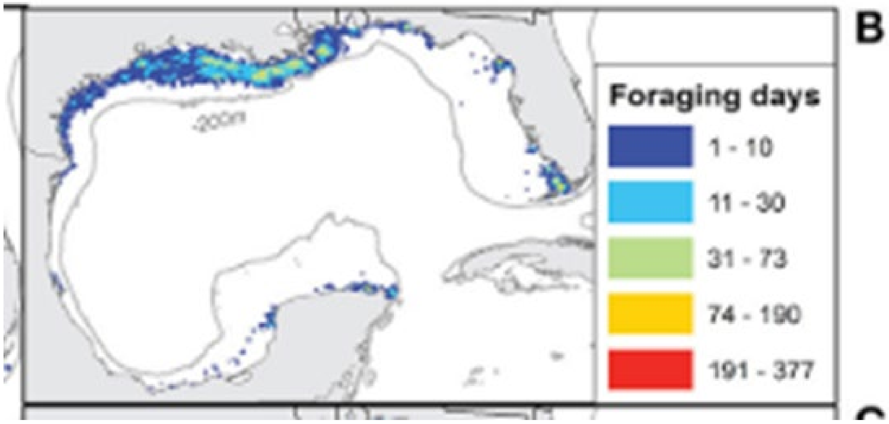

Figure B-62. Foraging locations plotted with relative importance

Kemp's Ridley Turtle 6: Lamont and Iverson 2018

- Presents localized coastal foraging (Figure B-63)
- Highlights overlap with two other species in coastal locations

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	Unknown	7	Northwestern FL	No

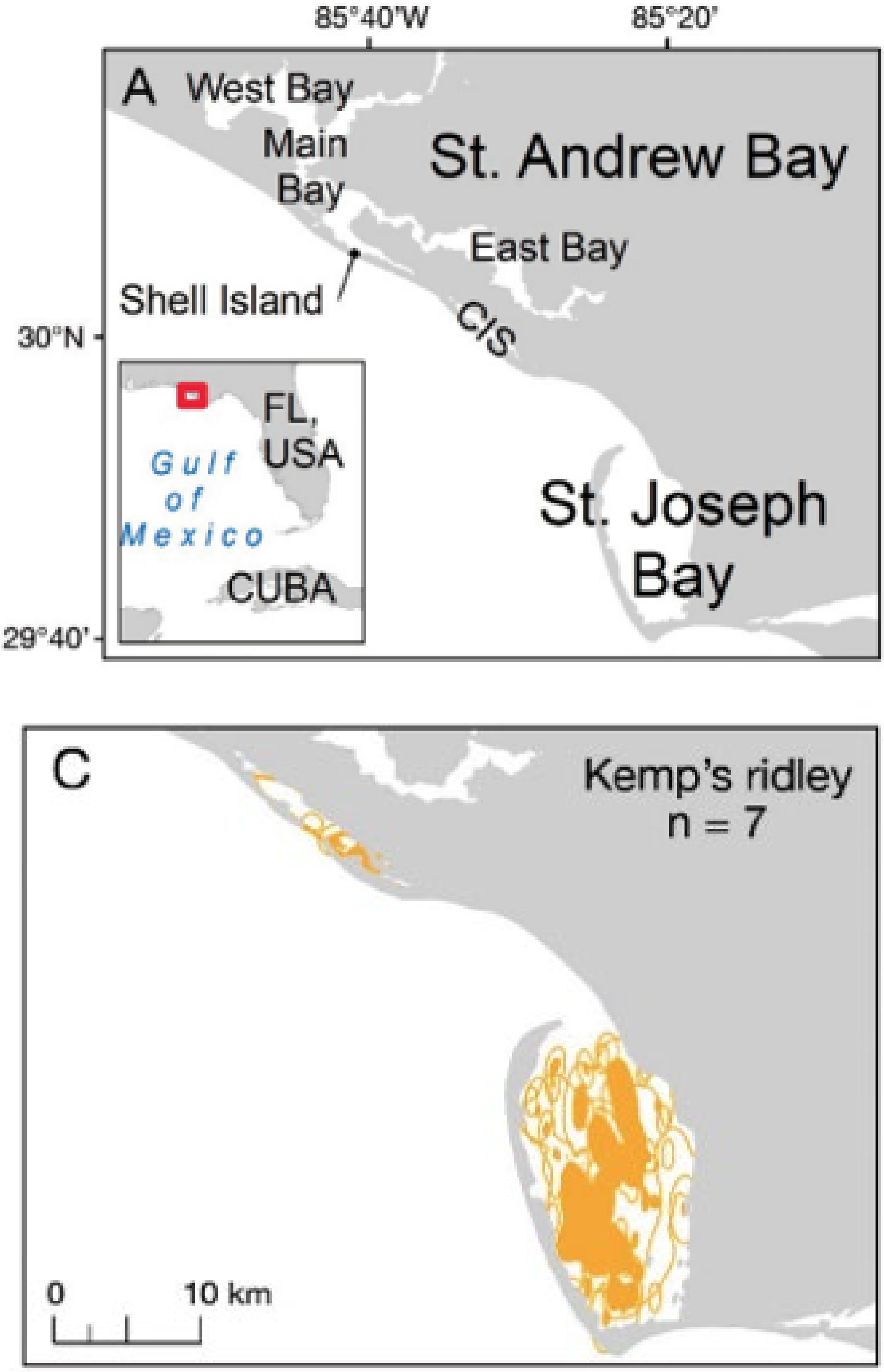

Figure B-63. Localized coastal foraging

Kemp's Ridley Turtle 7: Coleman et al. 2017

- Seasonal neritic habitat use in the GOM depicted (Figure B-64)
- Relates habitat use to temperature and chlorophyll a and primary productivity.

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	Unknown	36	Northern GOM	No

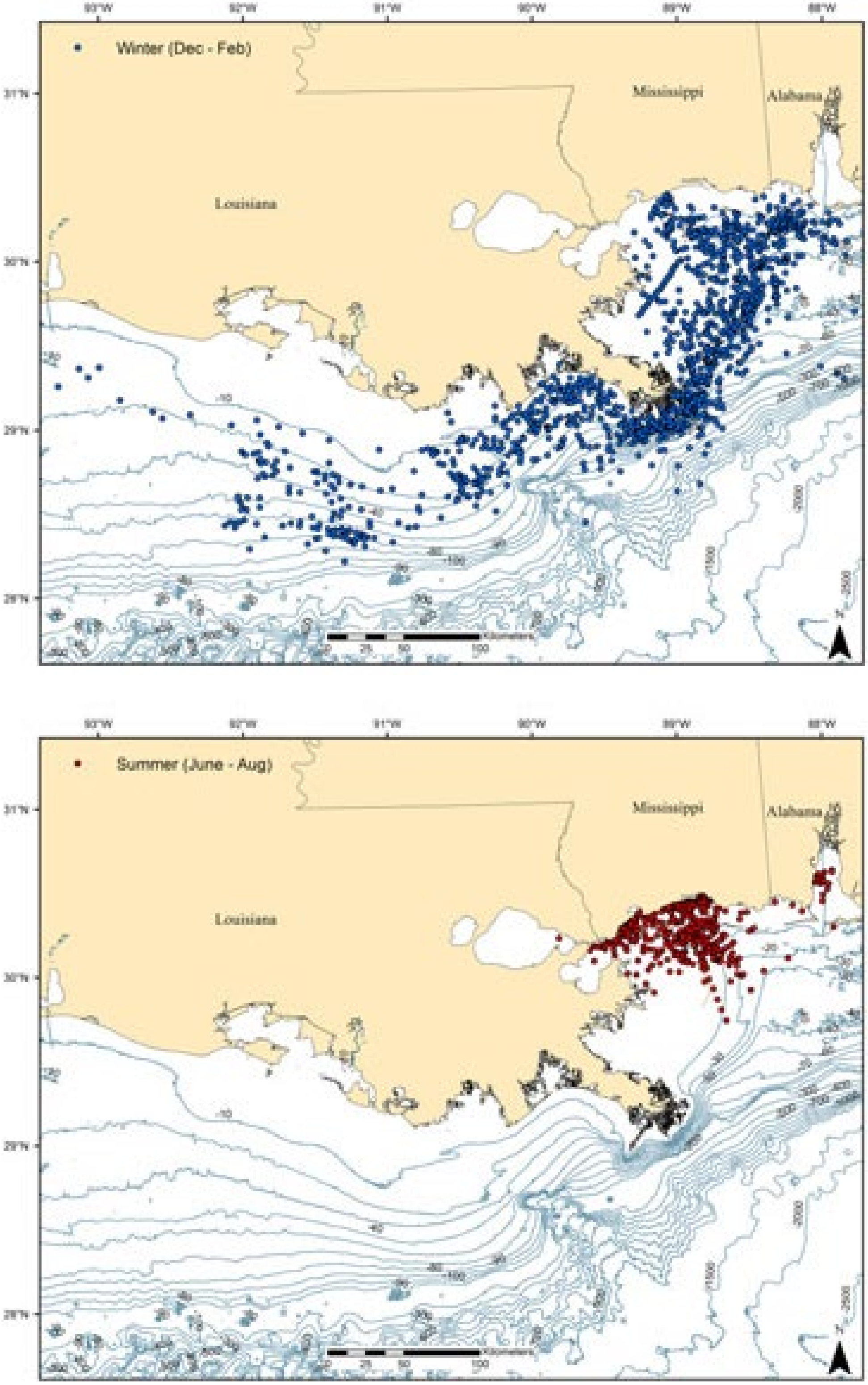

Figure B-64. Seasonal neritic habitat use in the GOM

Kemp’s Ridley Turtle 8: Hughes and Landry 2016

- Neritic US GOM foraging areas presented (Figure B-65)
- Swim speed presented

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	M	1	Texas	No

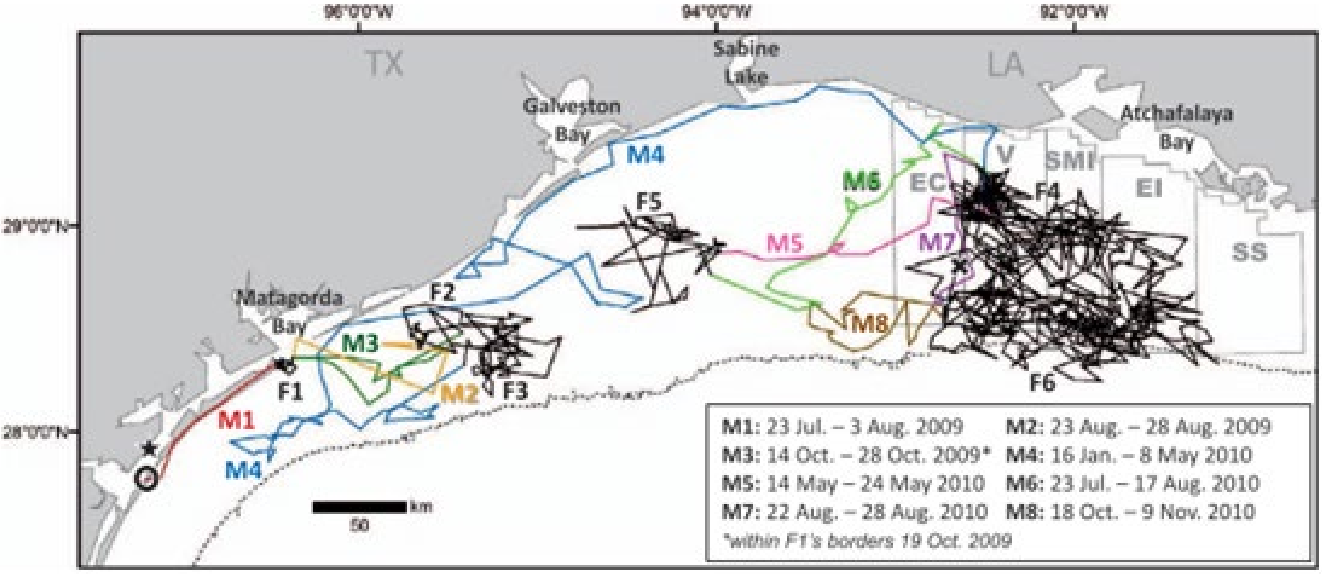

Figure B-65. Neritic US GOM foraging areas

Kemp’s Ridley Turtle 9: Shaver et al. 2016

- Distribution and residency clearly shown around the GOM (Figure B-66)
- Distribution per month after nesting is shown (Figure B-67)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	108	TX, Mexico, and AL	**Yes**

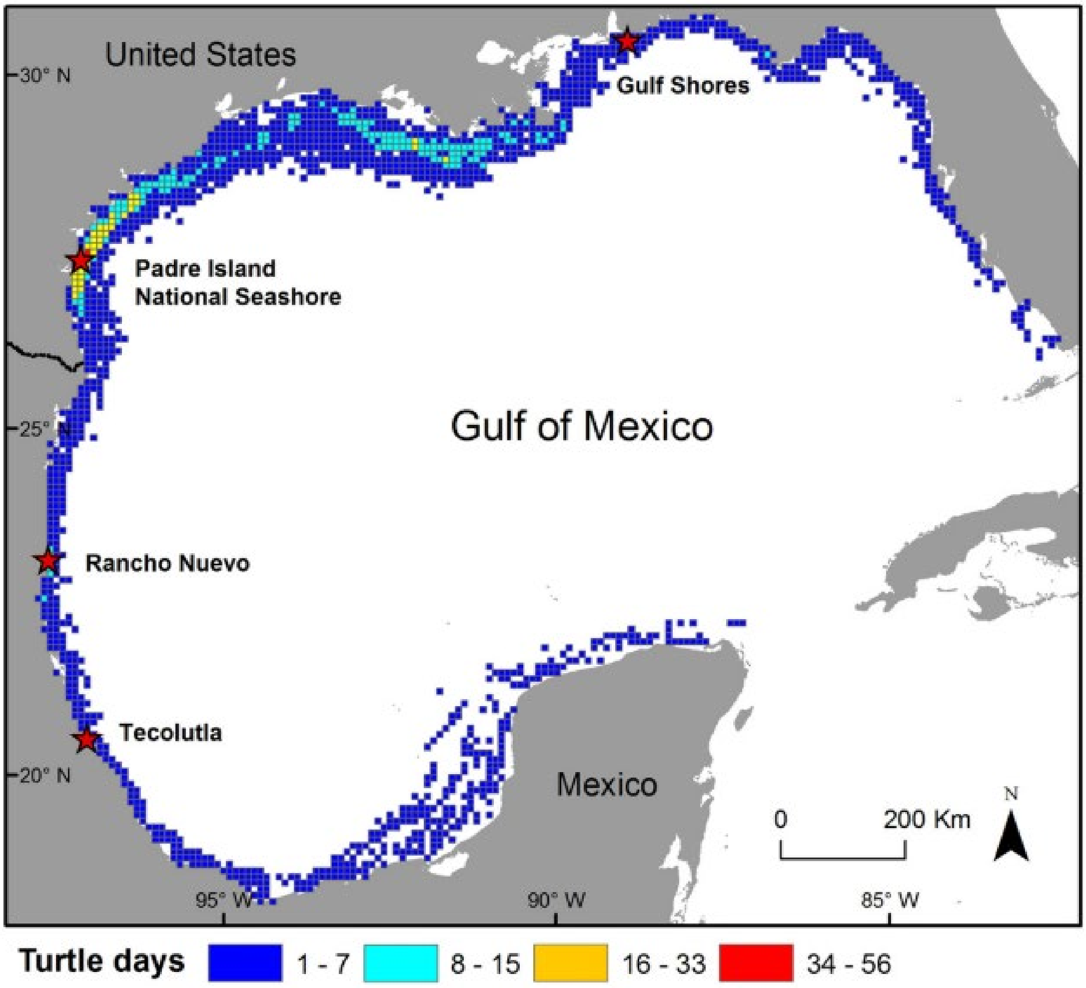

Figure B-66. Distribution and residency around the GOM

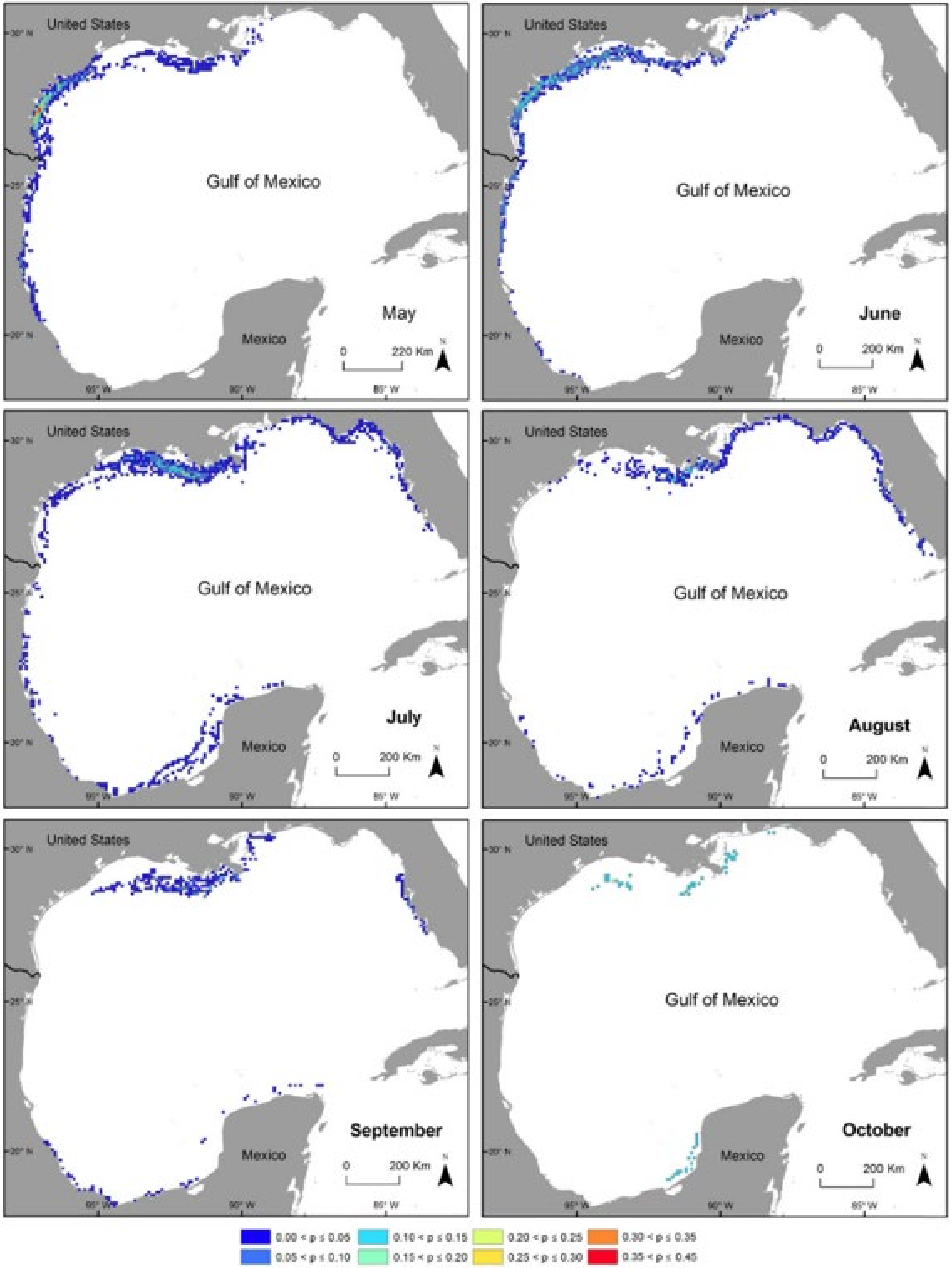

Figure B-67. Distribution per month after nesting

Kemp's Ridley Turtle 10: Epperly et al. 2013

- Migration westwards (Figure B-68)
- This turtle was recovered from The Netherlands

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	Unknown	1	Release – West peninsula FL	No

Figure B-68. Migration westwards

Kemp’s Ridley Turtle 11: Shaver et al. 2013

- Distribution and residency clearly shown around the GOM (Figure B-69)
- Water depth and distance from shore are presented

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	31	TX, Mexico	**Yes**

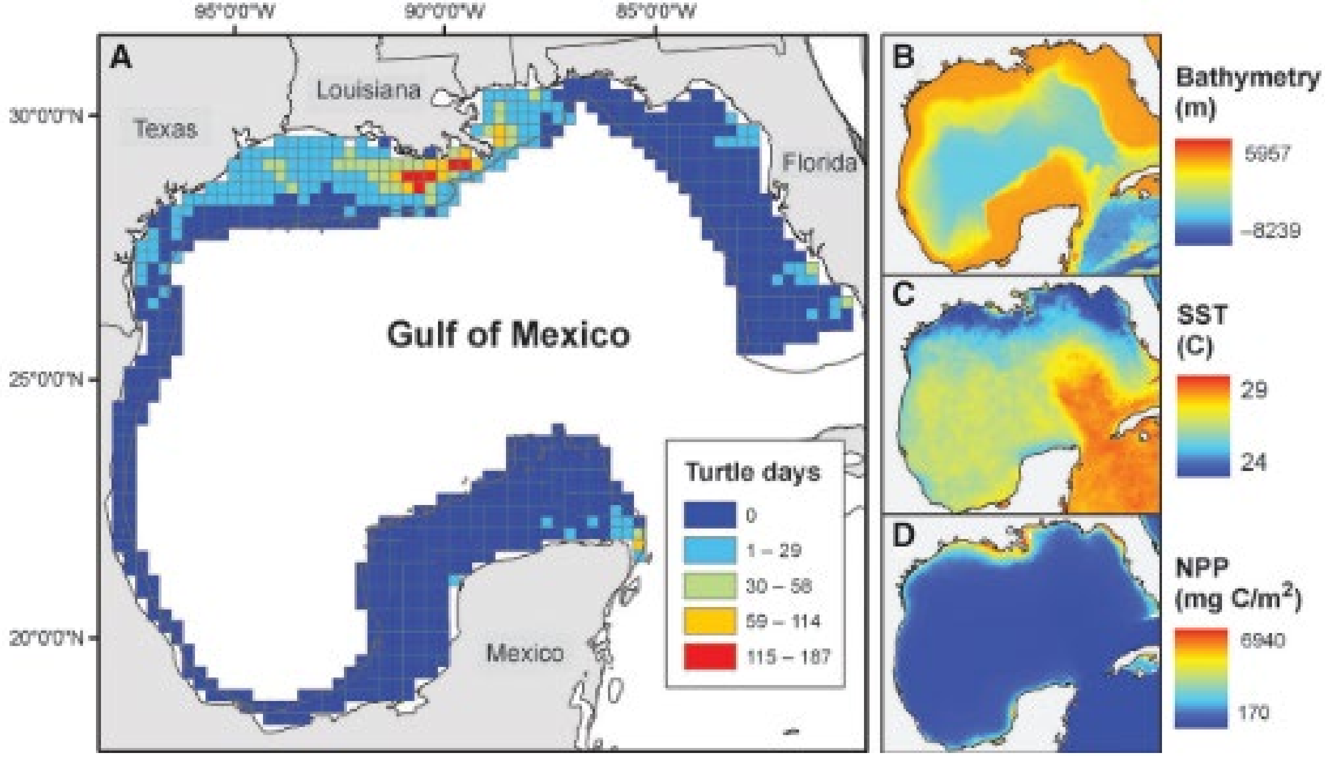

Figure B-69. Distribution and residency around the GOM

Kemp's Ridley Turtle 12: Lyn et al. 2012

- Turtles remained in shallow coastal waters (Figure B-70)
- FL turtles moved west

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	Unknown	12	Release MS & FL (GOM)	No

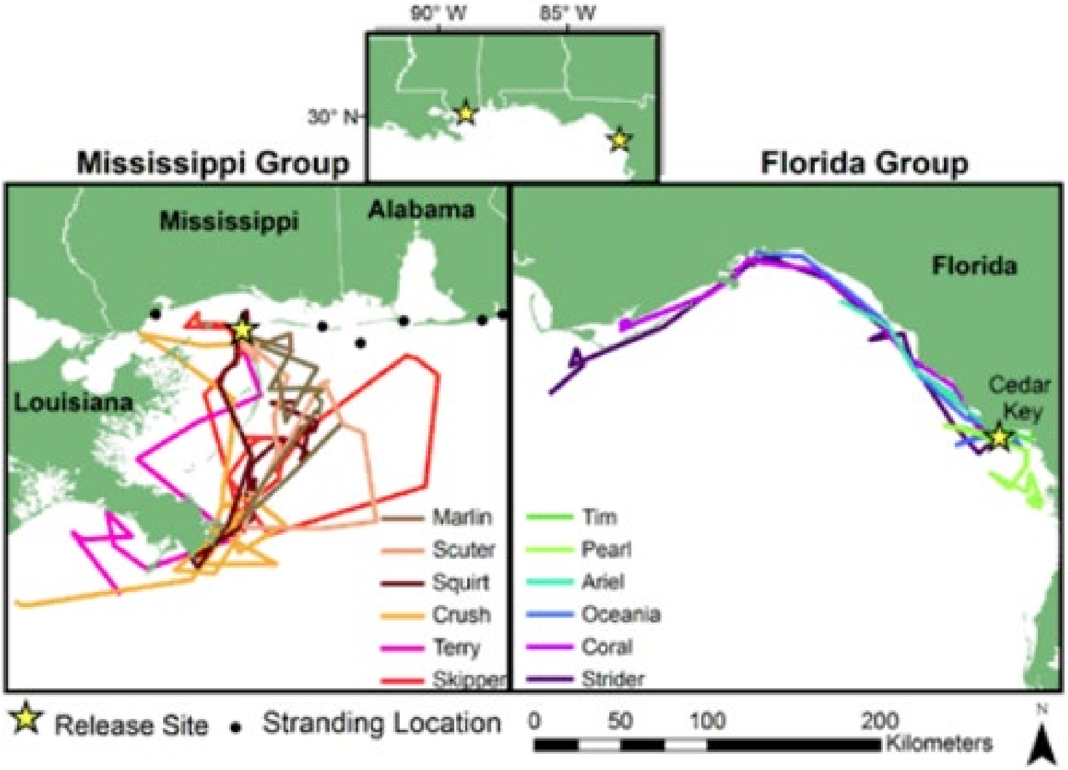

Figure B-70. Turtles in shallow coastal waters

Kemp’s Ridley Turtle 13: Seney and Landry Jr 2011

- Presents tracks and KDE of coastal foraging and migration (Figure B-71)
- Turtles remained in shallow waters, with adults in more broad range than juveniles.

Life Stage	Sex	Sample Size	Origin	Key Study?
Mixed	F, Unknown	22	Texas	No

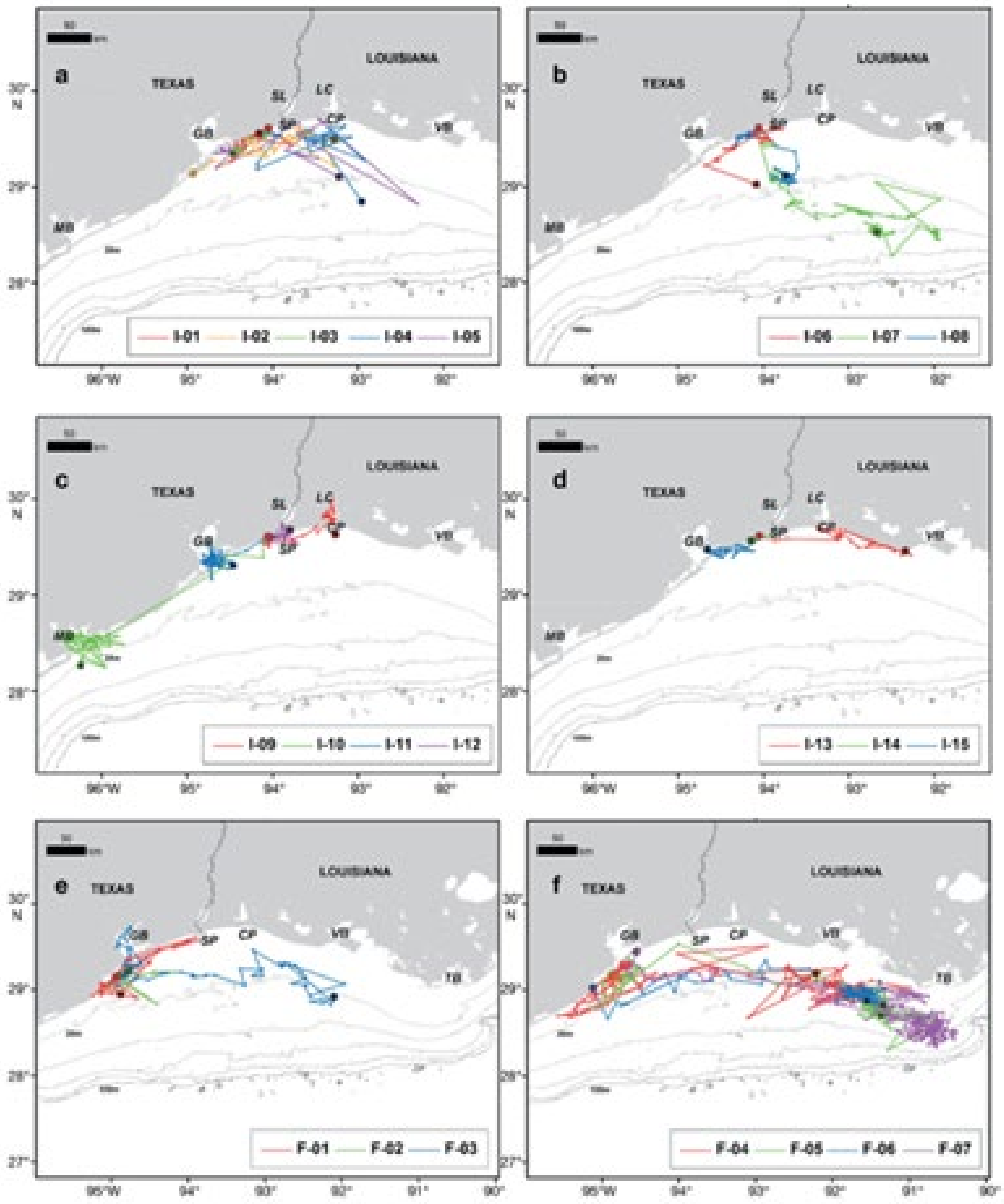

Figure B-71. Tracks and KDE of coastal foraging and migration

Kemp's Ridley Turtle 14: Seney and Landry 2008

- Presents tracks and KDE of coastal foraging and migration (Figure B-72)
- Presents table on stakeholders for upper Texas coast

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	6	Texas	No

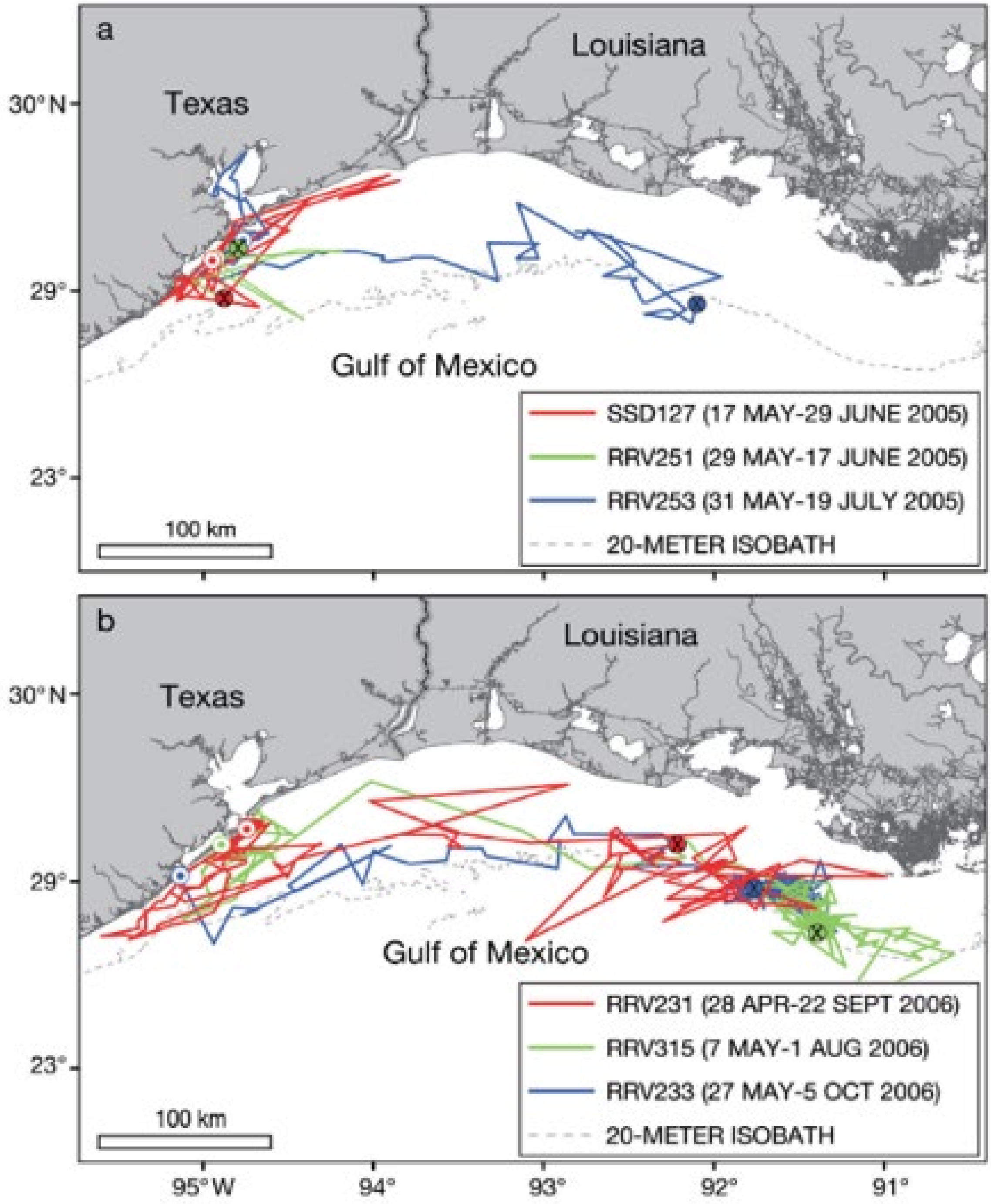

Figure B-72. Tracks and KDE of coastal foraging and migration

Kemp's Ridley Turtle 15: Renaud and Williams 2005

- Presents tracks and KDE of coastal foraging and migration (Figure B-73)
- Includes 59 sonic tags

Life Stage	Sex	Sample Size	Origin	Key Study?
Mixed	M/F	106	US GOM and NWA	No

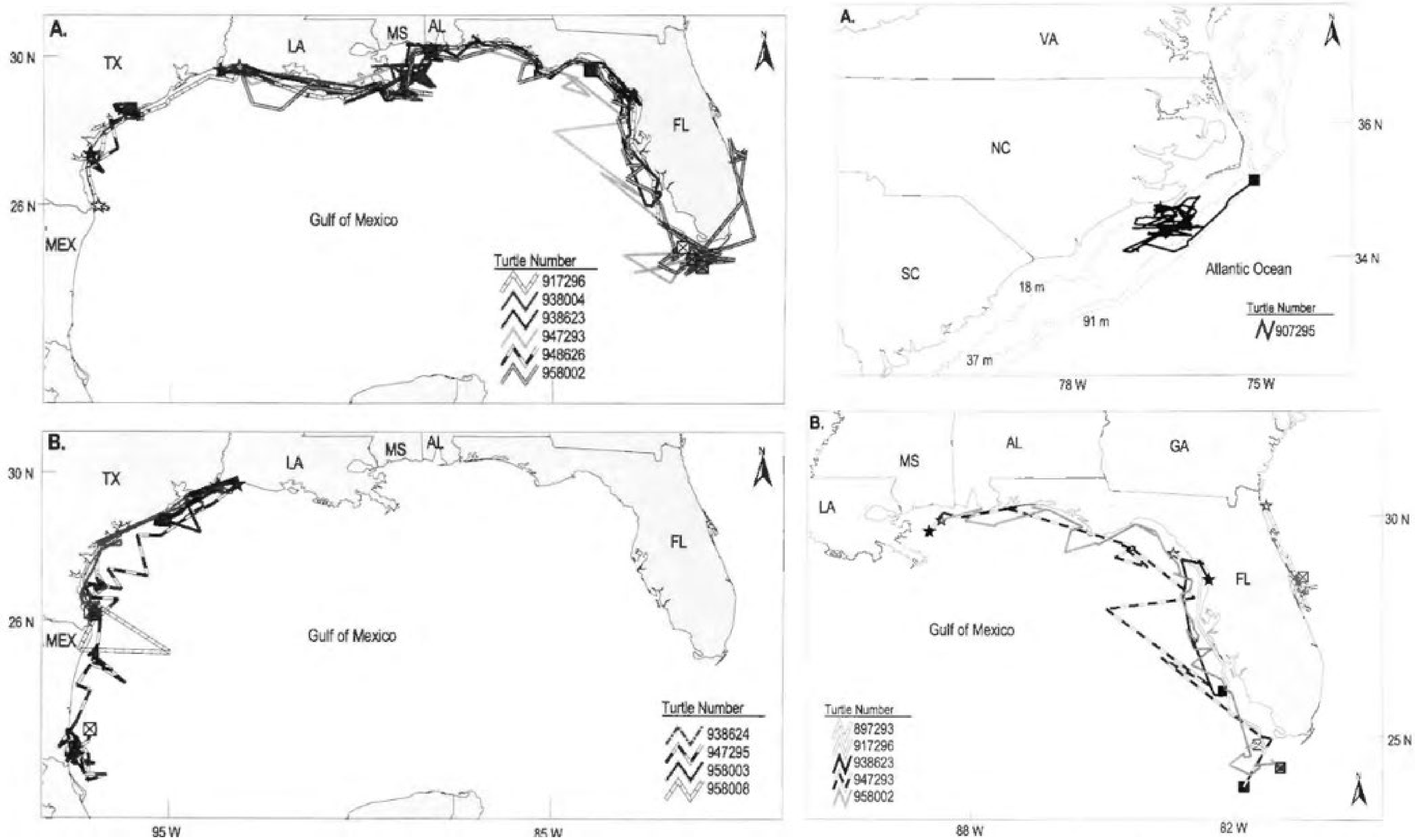

Figure B-73. Tracks and KDE of coastal foraging and migration

Kemp’s Ridley Turtle 16: Gitschlag 1996

- Three short-term tracks presented (Figure B-74)
- One satellite tag, two radio/sonic tags

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	Unknown	3	GA Atlantic coast	No

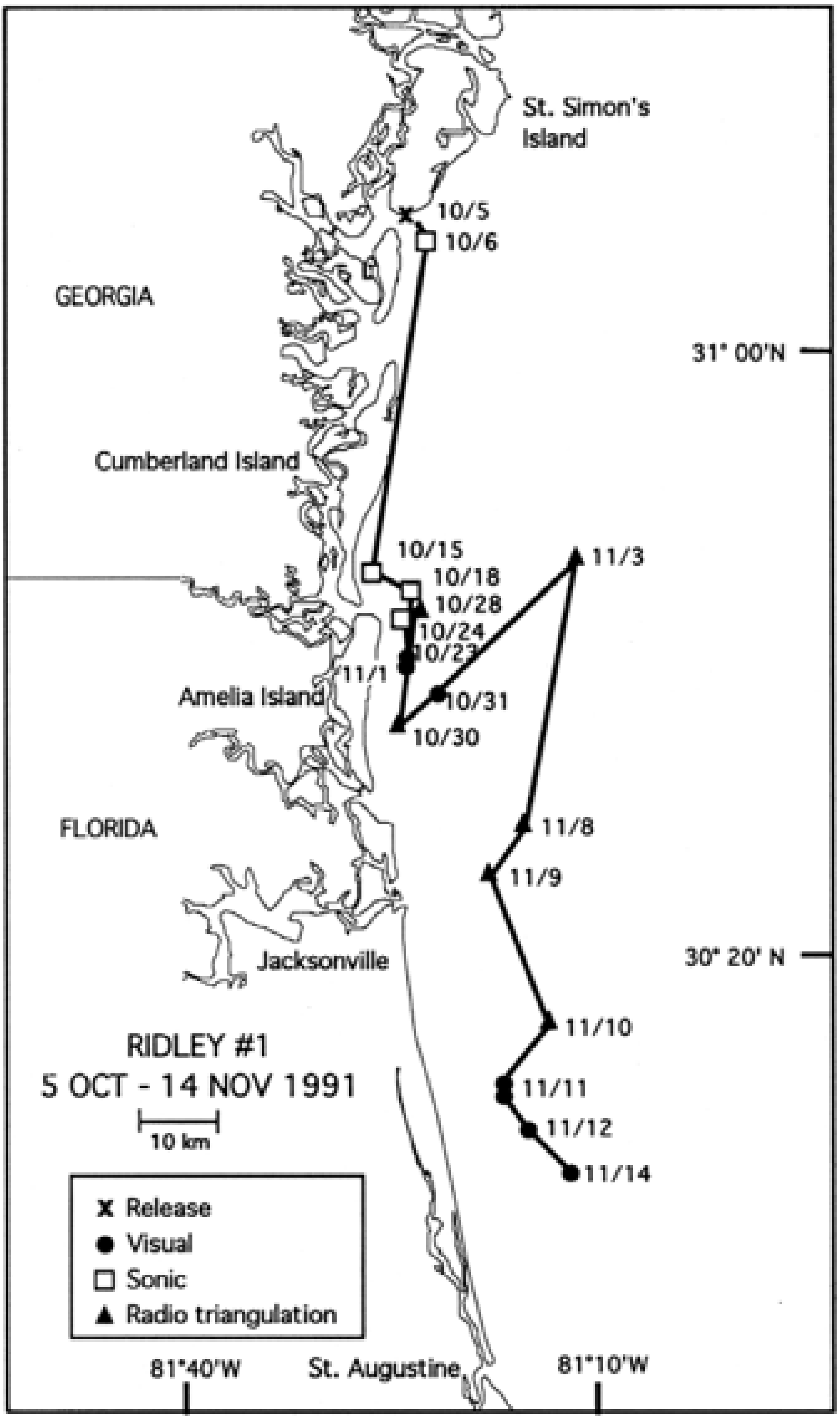

Figure B-74. Short-term tracks

A.4 Hawksbill Turtle Studies

Hawksbill Turtle 1: Avens et al. 2021

- Distribution map of strandings and therefore hawkbill locations (Figure B-75)
- Demography and ecology of turtles
- Stranding not tracking data

Life Stage	Sex	Sample Size	Origin	Key Study?
All	M/F	94	GOM, Atlantic Coast to NC	No

Figure B-75. Distribution of strandings

Hawksbill Turtle 2: Uribe-Martínez et al. 2021

- Three turtles tracked to FL waters
- Presents internesting and foraging locations (Figure B-76)

Life Stage	Sex	Sample Size	Origin	Key Study?
Adult	F	21	Yucatan	No

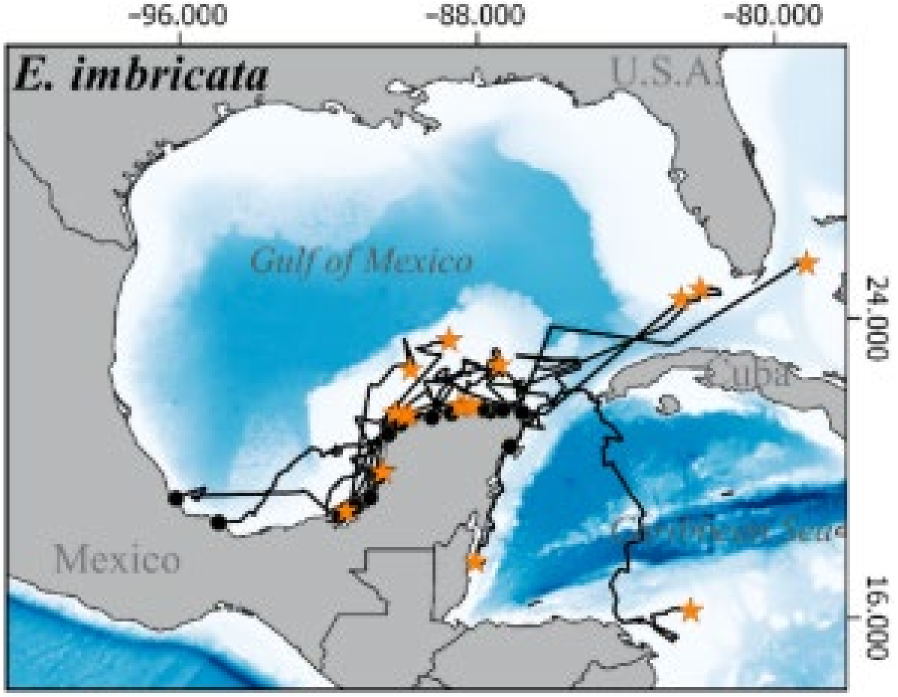

Figure B-76. Internesting and foraging locations

Hawksbill Turtle 3: Wood et al. 2017

- Nearshore local home ranges
- Habitat preference and diel patterns presented (Figure B-77)

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	6	Atlantic FL coast	No

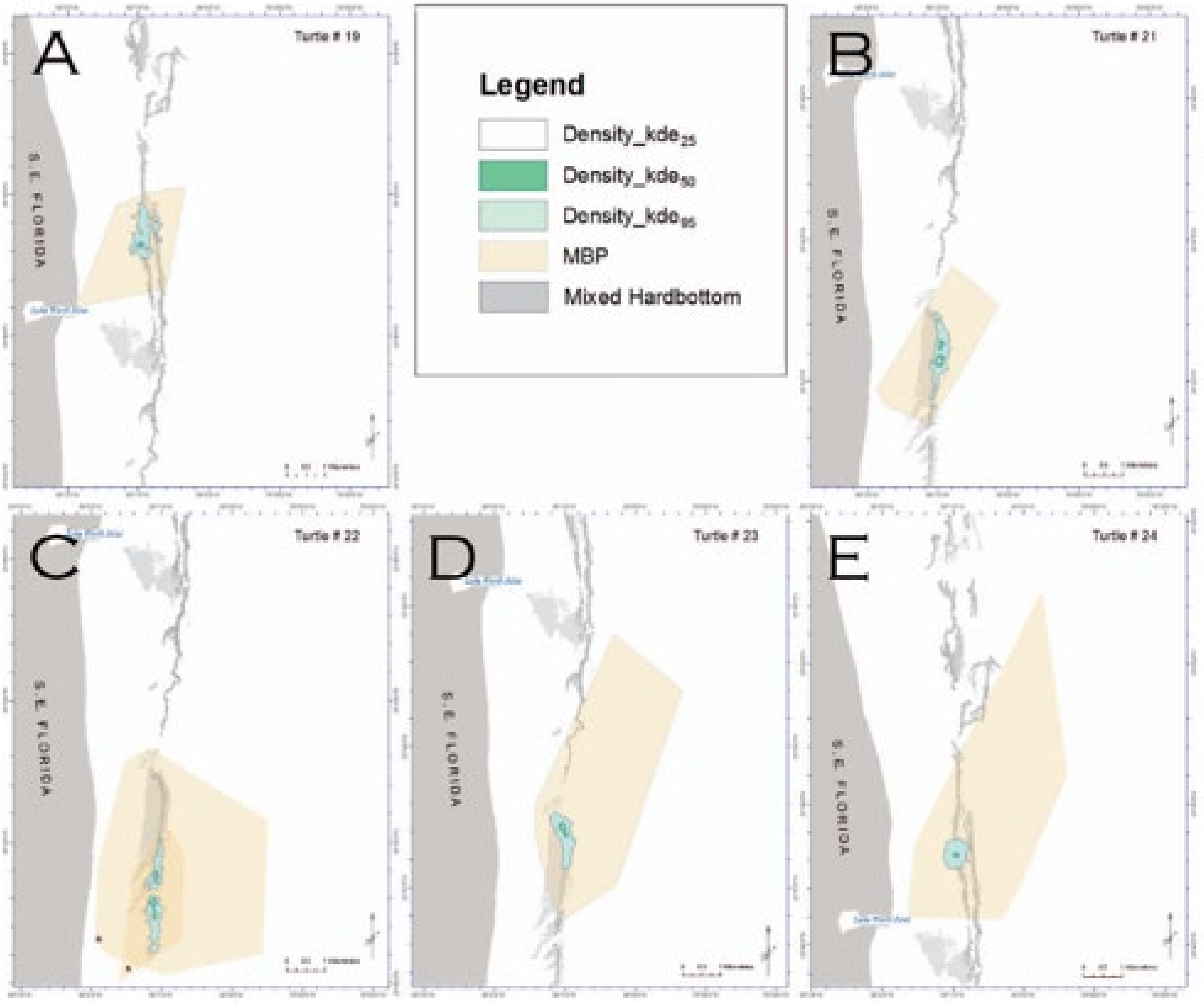

Figure B-77. Habitat preference and diel patterns

Hawksbill Turtle 4: Gorham et al. 2014

- Capture-mark-recapture study presents capture locations (Figure B-78)
- Turtle sightings not tracking

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	82	Key West National Wildlife Refuge	No

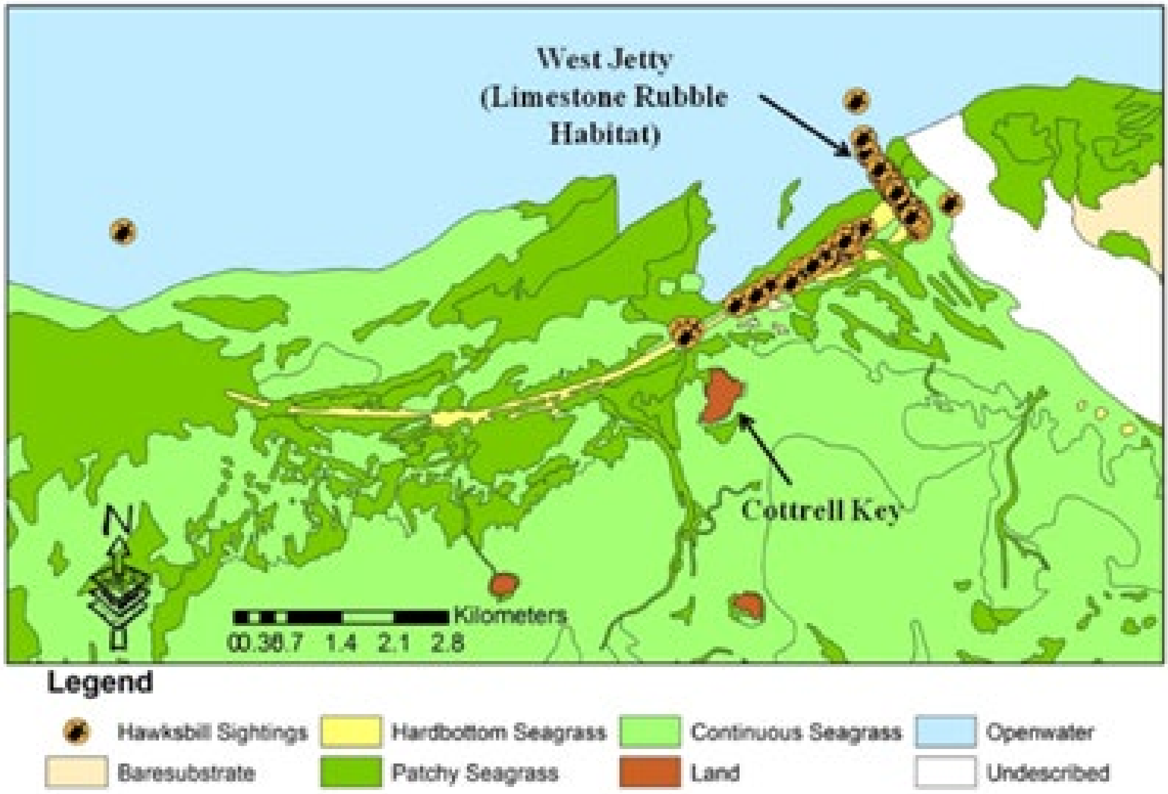

Figure B-78. Capture locations

Hawksbill Turtle 5: Hart et al. 2012b

- Presents long-term localized home ranges and migrations south to Cuba (Figure B-79)

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	Unknown	3	Dry Tortugas FL	No

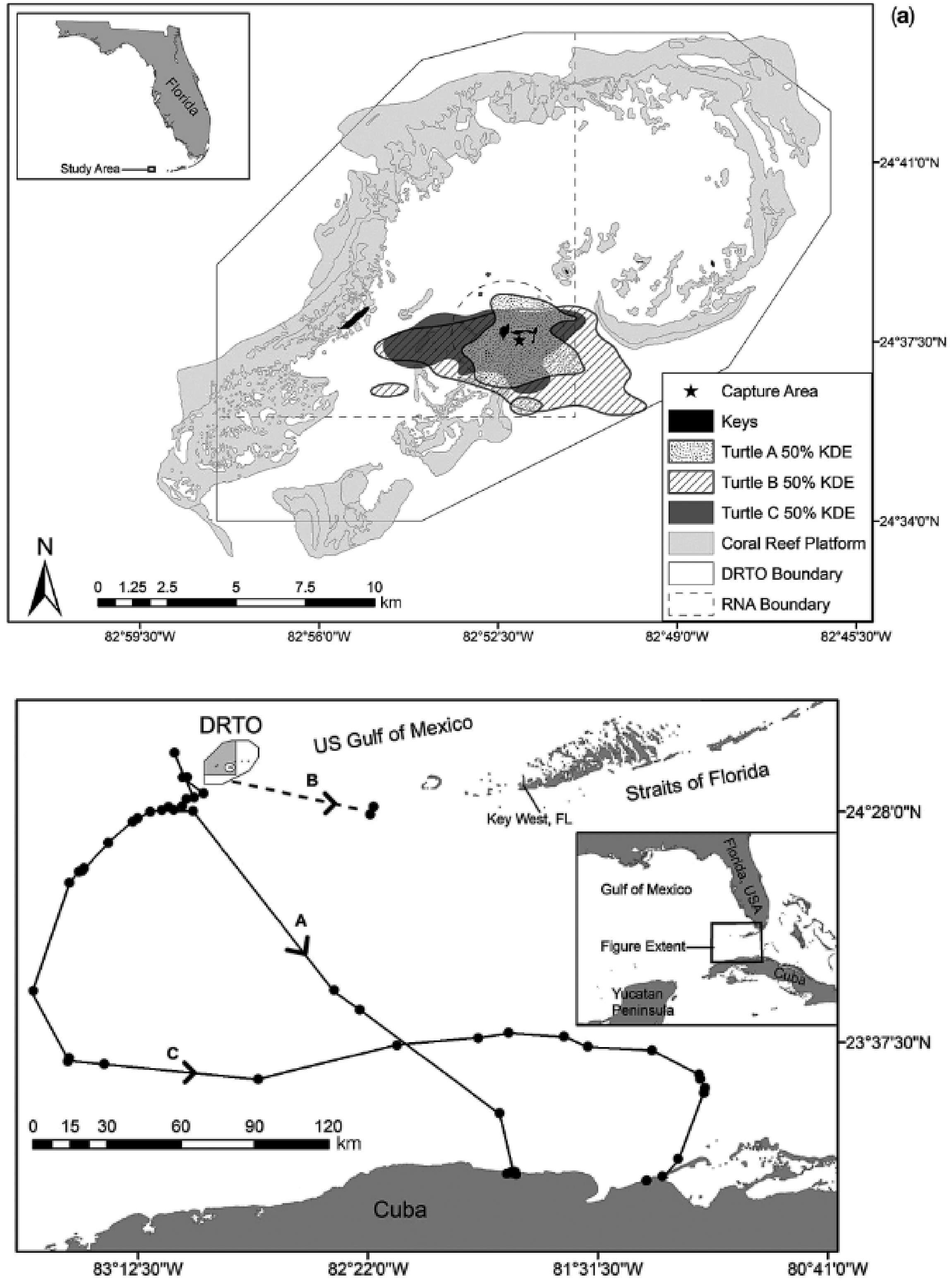

Figure B-79. Long-term localized home ranges and migrations south to Cuba

Hawksbill Turtle 6: Blanvillain et al. 2008

- Capture-mark-recapture study mentions this is the "most northerly hawksbill turtle population in the Atlantic Ocean which has been studied"
- Not a tracking paper but suggesting this is one of the most northerly sites for hawksbills in the US

Life Stage	Sex	Sample Size	Origin	Key Study?
Juvenile	M/F	69	Palm Beach County FL	No

Full citations for the references in Appendix B figures

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