Assessment of the Dry Tortugas National Park
Sea Turtle Monitoring Program 1982–2006:
Ecological Trends & Conservation Recommendations

NPS Report # H5299–05–1010

Accepted 12 January, 2007

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EXECUTIVE SUMMARY

Despite recent increases in many Atlantic nesting surveys, sea turtles populations are roughly 10% of their pre–Columbian estimates. These historic declines are largely due to unabated overexploitation of adults and nests prior to 1900. Serious threats remain today, however. Adult turtles migrate long ocean distances where they are targeted for hunting and indirectly caught in long-line and shrimp fisheries. Accompanying these threats, sea turtle nesting suffers from habitat loss, egg poaching, and from poaching of nesting females. This report analyzes Dry Tortugas National Park Sea Turtle Monitoring Program surveys from 1982–2004. Though five turtle species are observed within park boundaries, only loggerhead (*Caretta caretta*) and green turtles (*Chelonia mydas*) regularly nest here. All species are protected by state, federal, and international regulations.

Nesting trends at the Dry Tortugas generally agree with the recent increases documented across the Caribbean since 1980. However, the Dry Tortugas loggerhead nesting populations decline since 2000. Nest excavations importantly reveal that while clutch sizes remain constant, hatching success decreases 50% since 1995 for both species. These decreases are largely from strong tropical storms that can wash away entire small islands as well as their nests, but invasive plants and nest predators are also factors. Though exotic *Casuarina* trees were extirpated from Loggerhead Key in 1997, remnant stumps and debris still harm nesting there. Nest predation today is significantly more widespread than when the study began, though the major sources are unknown. We also report the early onset of nesting with rising ocean temperatures, and note an increase of 0.5 °C per decade across the Gulf of Mexico. Fishing industry trends were not conclusive. Since many ecologists consider nesting beach protection critical for turtle conservation, the trends we observe prompt concern and require further research and conservation.

We recommend expanding the current monitoring effort broadly to collect demographic, tracking, and nesting success data. We also suggest building a correlate database of satellite imagery, fishery, and climate data to accompany the survey data. Because sea turtles do not reproduce until 20–30 years of age, results from management or conservation may not appear for some time. More extensive monitoring is essential to see if the past regimes are effective. Such additional data will provide a much clearer understanding of the threats the Dry Tortugas turtles face, both locally and elsewhere.
ACKNOWLEDGEMENTS

Many individuals helped with gathering the data for this report. We would like to particularly thank the following individuals.

Data acquisition:
   Richard Crout (NOAA, National Data Buoy Center)
   James Nance (NMFS, Pink Shrimp Fishery Statistics)
   Paul Teague (NPS, DRTO GIS)
   Craig Smith (NPS, Invasive Plant Management)
   Russell Reardon (NPS, DRTO Annual Reports)
   Fernando Colchero (Duke University)

Locating obscure publications:
   John Strom (Carnegie Institute, Marine Biology Laboratory Archives)
   Chris Kinner (NOAA, Miami Regional Librarian)
   David Talbert (Duke University Marine Laboratory, Librarian)

Background information on current research:
   Michael Coyne (Seaturtle.org)
   Ben Best (Duke University Geospatial Laboratory)

Reviewing this report and its analyses:
   Michael Coyne (Seaturtle.org)
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Durham, NC 2006
TABLE OF CONTENTS

ABSTRACT ................................................................. i

PREFACE AND ACKNOWLEDGMENTS ..................................... ii

TABLE OF CONTENTS .................................................. iii

LIST OF FIGURES .................................................... iv

INTRODUCTION ......................................................... 1

  Report Goals ...................................................... 1
  Dry Tortugas National Park ...................................... 2
  Sea Turtles and Their Conservation ............................. 3

METHODS ................................................................. 5

RESULTS ................................................................. 7

  Comparing Dry Tortugas to other sites ....................... 7
  Geographic Distribution of Nesting ............................ 8
  Nesting Seasonality and Effects of Climate .................. 8
  Clutch Size and Successful Hatchlings ....................... 9
  Effect of Local Fisheries ....................................... 10
  Effect of Casuarina and Nest Predators ...................... 10

DISCUSSION AND RECOMMENDATIONS ................................ 11

FIGURES ............................................................... 13

LITERATURE CITED .................................................. 27
LIST OF FIGURES

**Figure 1** Broad survey trends at Dry Tortugas, 1982–2004 13
**Figure 2** Loggerhead nesting at Dry Tortugas compared to Florida, 1991–2004 14
**Figure 3** Green nesting at Dry Tortugas compared to Florida, 1991–2004 15
**Figure 4** Geographic distribution of nests in Dry Tortugas 16
**Figure 5** Average annual nesting density for individual Dry Tortugas islands 17
**Figure 6** Nesting seasonality and hurricanes at Dry Tortugas 18
**Figure 7** Sea surface temperature trends locally and across the Gulf of Mexico 19
**Figure 8** Loggerheads nest earlier in years when spring seas are warmer 20
**Figure 9** Clutch sizes remain constant but hatching success drops sharply 21
**Figure 10** Local commercial fisheries show little impact to turtle nesting 22
**Figure 11** *Casuarina* removal and its effects to nesting on Loggerhead Key 23
**Figure 12** Nest predation increases sharply through the study 24
**Figure 13** Four genetically distinct loggerhead nesting populations in the U. S. 25
**Figure 14** Hurricane tracks from the 2004 and 2005 season 26
INTRODUCTION

Report Goals
The 2004 annual report from the Dry Tortugas National Park Sea Turtle Monitoring Program identifies several key patterns in the nesting populations gleaned from the 1995–2004 monitoring period (Grimshaw 2004). First, turtle nesting activity is unevenly distributed among the seven islands within the park boundaries. On any given year, East Key and Loggerhead Key host more than 90% of the observed nests. Of the remaining 10% of nesting activity, Bush Key, Hospital Key, and Garden Key hold the vast majority. Long Key and Middle Key see virtually no activity. Second, loggerhead and green turtles show decidedly different nesting population trends through the years. Loggerhead nesting, for example, gradually increased from 1995–2001, but has since declined. Green nesting, on the other hand, was highly variable from year to year: even-numbered years were relatively consistent, where odd-numbered years recorded little if any activity. Third, there was a distinctive seasonal pattern within years for both species. Loggerhead nesting activity peaked in June, where green nesting peaked roughly one month later.

The primary interest of this report is the continued funding of the Dry Tortugas National Park Sea Turtle Monitoring Program and what ecological knowledge can be determined from the last decade of surveys. Though the data and analyses from the nine years of surveys present important information, they are limited both spatially and temporally. Making broad ecological conclusions or forming conservation management decisions from the existing survey data is therefore risky and could compromise the long term success of these nesting colonies. In essence, the results of the 1982–2004 surveys raise more questions than they answer, encouraging further monitoring, analysis, as well as comparisons to similar research programs in the Western Atlantic.

Several questions are of immediate concern for evaluating the Dry Tortugas monitoring program. Are there long term patterns in nesting populations across the Caribbean and Western Atlantic region? What factors drive them? Are the Dry Tortugas nesting colonies in step with these other populations? How variable is turtle nesting from year to year? Do green turtles elsewhere exhibit at two year cycle in nesting numbers? How do long term climate changes affect nesting? What role do hurricanes and tropical storms to play in determining turtle numbers? Assessing the Dry Tortugas Sea Turtle Monitoring Program needs to take such information into account. Such an analysis cannot be completed only on the decade or so of information from the Tortugas. The current record is too limited.

A variety of factors make the current assessment urgent. One pressing issue is the rise of recreational use of park and its potential impacts to turtle nesting. The numbers of visitors to these islands has increased dramatically over the last decade, putting particular pressure on East Key and Loggerhead Key – the two most important turtle rookeries in the park. Boating, snorkeling, diving, fishing, and beach traffic all pose serious risks to both turtles and their nests. As this recreational use will likely only increase in the coming years, and as the reserve status of the park remains uncertain (Dahlgren & Sobel 2000), monitoring and management decisions that consider these impacts are urgently needed. Another somewhat more recent concern is the severe hurricane seasons of 2004
and 2005. Though no surveys were conducted in 2005, when four major hurricanes passed directly over the park, two major hurricanes decimated turtle nesting in the Dry Tortugas in 2004. Finally, the five turtle species documented at the Dry Tortugas are of global conservation concern and are protected by state, federal, and international regulations. The three species known to nest in the park boundaries are of primary concern, as they are federally listed as “threatened” or “endangered” by the U. S. Endangered Species Act.

Given these concerns, this report analyzes the Dry Tortugas National Park Sea Turtle Monitoring Program data to date to detect what ecological inferences can be made and what conservation and monitoring strategies should be taken. We further examine appropriate data from other monitoring programs in the Caribbean and Western Atlantic to answer such questions. With such answers in hand, we believe we can provide better statements about the likely causes of turtle numbers in the Tortugas and what, if any, management recommendations should follow.

**Dry Tortugas National Park**

The Dry Tortugas National Park (24°38′53″ N, 82°51′55″ W) lies roughly 98 km west of Key West, Florida, and approximately 65 km west of the Marquesas Keys (24°38′00″ N, 82°55′12″ W), the closest land formation. The park is comprised of seven islands (Bush Key, East Key, Garden Key, Hospital Key, Loggerhead Key, Long Key, and Middle Key) that have a collective land area of 4.2 km² and a total beach length of 7 km. Four additional islands (Southwest Key, Bird Key, North Key, Northeast Key) formerly existed in the current park boundaries, but disappeared between 1875–1935 due to natural ocean and coastal processes. The park also holds roughly 260 km² of ocean that supports diverse and abundant coral reef and sea grass ecosystems (Davis 1982).

The islands of the Dry Tortugas became known to Europeans from the 1513 description by Ponce de Leon who named the area *Las Tortugas* from the local abundance of sea turtles. These large turtle populations were immediately challenged. Numerous historical records document the prevalence and exploitation of loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles at the Dry Tortugas and in the wider Caribbean (Safina 2006, Grimshaw 2004, Steadman & Stokes 2002). The building of Fort Jefferson on Garden Key in the mid 1800’s institutionalized turtle exploitation and devastated local populations. Both adult turtles and entire nests were culled in great numbers. In one example, from 1858–1859 soldiers stationed at Fort Jefferson provisioned nearly 20 tons of turtle meat (Dawson & Williams 1985). This records comprises some 150–300 adult turtles, or perhaps twice the number of females currently nesting in the Dry Tortugas each year.¹

As the demand for turtle meat and eggs rose in Key West markets, exploitation peaked in the early to mid 1900’s. Federal protection of the Dry Tortugas and its wildlife first came in during this period when the area was designated as a bird sanctuary in 1908. In 1935, the area was further protected becoming the Fort Jefferson National Monument

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¹ Nesting number today is average annual sum of all turtle species (150/year), assuming female turtles nest three times a season. Carcass dressed weight considered as 60% of total biomass, which was calculated as the average masses of adult loggerhead and green turtles.
of the National Park Service. For the first time, sea turtles and their nesting colonies in the Dry Tortugas were legally protected from hunting. However, poaching of nest eggs remained a threat likely through the 1960’s, but it is unknown for how long Dry Tortugas turtle nests were exploited. In 1992, Fort Jefferson National Monument became Dry Tortugas National Park. But even with decreased hunting and federal protection of the islands, turtle populations had little respite. Large numbers of turtles continued to be killed as bycatch in the shrimp fishing industry that began in the Gulf of Mexico in earnest after World War II. In 1994, the National Marine Fisheries Service (NMFS) first required that all shrimp trawlers include turtle excluding devices (TEDs) in their nets. However, federal regulations only required TEDs to be 35” wide and 10” high for trawlers in the Gulf of Mexico – dimensions not large enough for adult green or loggerhead turtles, not to mention the much larger leatherbacks. Not until August 2003 did larger dimension (35” x 16”) TEDs become mandatory (Safina 2006). Though the Dry Tortugas area and its turtles have been legally protected since 1935, sufficient measures to protect turtles in the wider region were not in place until after the 2003 nesting season, 500 years after their exploitation began.

Sea Turtles and Their Conservation

Today five sea turtle species are documented at Dry Tortugas National Park: loggerhead (Caretta caretta), green (Chelonia mydas), hawksbill (Eretmochelys imbricata), leatherback (Dermochelys coriacea), and Kemp’s Ridley (Lepiochelys kempii) – listed in decreasing order of abundance. During surveys from 1982–2003, only loggerheads and greens were observed nesting in the park’s beaches. These two species are by far the most common turtle species in the park. In 2004, for the first time, three leatherback nests were documented (in addition to the loggerhead and green nests). Hawkshill turtles are not known to nest in the park, but juveniles are commonly seen foraging in the reefs in the park or wash up dead as strandings. Kemp’s Ridleys are observed but seldomly.

All five species documented in the park are listed and protected by state, federal, and international regulations. The Florida Game and Freshwater Fish Commission lists loggerheads as “threatened”, and the remaining four species as “endangered” and Florida state Statute 370.12 prohibits one to “catch, molest, injure, kill or annoy or otherwise interfere with the normal activity and well-being” of sea turtles of any species. Like the state of Florida, the U. S. Endangered Species Act lists loggerheads as “threatened,” and the remaining four species as “endangered” in the United States, but federal regulatory requirements are less clear. The World Conservation Union’s (IUCN) assessment is more dire than Florida or U. S. listings; considering loggerheads and greens as “endangered” and leatherbacks, hawksbills, and Kemp’s Ridleys as “critically endangered” globally.

Whatever one considers their conservation status, the reality is that sea turtle species in the Western Atlantic today are 99% depleted from their pre–Columbian populations (McClenachan et al. 2006, Safina 2006). These historic declines are largely

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2 Text available at: [http://www.dep.state.fl.us/law/Grants/CMP/CleanBoatingHabits.htm](http://www.dep.state.fl.us/law/Grants/CMP/CleanBoatingHabits.htm)
due to unabated overexploitation of adults and nests that occurred before 1900. Though
officially protected today, all sea turtle species remain under threat from a multitude of
sources. Each year, adult sea turtles migrate long distances over open ocean (sometimes
several 1000 km) encountering direct threats from: hunting, long–line fisheries, gill–net
fisheries, shrimp fisheries, boat collisions, and pollution. Sea turtle nesting also continue
to suffer from: beach habitat loss, egg poaching, poaching of nesting females, climate
change, and invasive nest predators. In recent decades sea turtle nesting populations
worldwide have continued to dwindle, with most reaching low points in the early 1980’s.
Since the 1980’s, surveys show sea turtle nesting populations in the Western Atlantic
have increased, while many populations in the Pacific and Indian Oceans still continue
their decline.

What is causing the rebound in Western Atlantic sea turtles? Though adult mortality
plays a significant role in population numbers, many ecologists consider nesting beach
protection the most critical aspect of sea turtle conservation, for three main reasons. First,
the large global population crashes after 1900, in addition to the continued decline in the
Pacific and Indian ocean populations, were all areas where egg poaching, poaching
nesting females, and loss of beach habitat was rampant (Safina 2006, Kaplan 2005,
population surges of western Atlantic turtle populations have followed exerted efforts to
protect nest beaches, where the Pacific and Indian population remain largely unprotected
from various fishing industry activities decreases adult populations, it has been shown
that boosting turtle hatchlings can outweigh this negative effect and produce population
increases (Safina 2006, Dutton et al. 2005).

But as simple as these relationships may seem, interpreting the causes of sea turtle
populations trends is notoriously difficult. To begin, like many other large–bodied marine
vertebrates, most sea turtles do not reach sexual maturity for several decades. This means
protecting known turtle nesting areas may cause immediate increases to turtle populations
by promoting juvenile recruitment. However, these increases may not correspond to
nesting population increases for 20 to 30 years at those locations (Spotila 2005, Lewison
et al. 2003, Heppell 1997). Even though nesting females return to the very same beaches
where they were hatched (Stoneburner et al. 1980), most only nest every two to four
years. Because nesting intervals are based on environmental conditions (Solow et al.
2002), this period can be several years longer. Complicating matters further is that sea
turtles migrate over large distances and are subject to pressures at various life stages, in
For example, a loggerhead turtle may hatch on a beach in Honduras, float as a juvenile in
the Gulf Stream off the eastern seaboard of the United States, and as an adult forage from
the Azores down to the Cape Verde islands off Africa (Safina 2006). These ecological
realities make sea turtle conservation difficult, requiring a long term commitment to
research and protection at many locations around the oceans.
METHODS

Our analyses consist of analyzing the data from the annual reports from the Dry Tortugas National Park Sea Turtle Monitoring Program from 1982 through 2004, enriching these data with other published studies of turtle nesting, climate data, and with Geographic Information Systems (GIS) analyses. We examine six key topics: (1) Dry Tortugas nesting trends in comparison to similar studies, (2) distribution of nests within the islands of the Dry Tortugas, (3) nesting seasonality and climate change, (4), clutch size and successful hatchlings, (5) local fisheries, and (6) *Casuarina* and nest predators. Our aim is to assess the monitoring program to date, to suggest further areas of research interest, and to recommend basic and effective conservation strategies.

First we address the nesting population trends within the park and compare them to other studies. Beginning with the 1982 survey, we plot the number of nests observed for loggerhead and green sea turtles, through 2004, when monitoring ceased. We consider the surveys prior to 1995 differently, as they followed no standard sampling protocol. With these numbers in hand, we compare them to surveys across the state of Florida from 1991–2004, obtained from the Florida Fish and Wildlife Conservation Commission’s Fish and Wildlife Research Institute (FWRI).\(^5\) We plot annual nesting, grouped by county and colored according to nesting intensity. To account for differences in sampling effort, we normalize each county’s data for the amount of coastline that was searched for nests (km linear distance) yielding a nesting density. We consider the Dry Tortugas separately from Monroe county, as the Tortugas numbers are not included in the FWRI data for Monroe County. We calculated coastline length of the Dry Tortugas islands from a GIS map obtained from Geocommunity\(^6\) using the software package ARCGIS.

Next, we analyze the geographic distribution of nesting activity at the Dry Tortugas from the monitoring program data. As the surveys prior to 1996 did not record nest locations, we only present data from 1996–2004. To present the simple differences between island activity, we plot the total annual surveys of turtle nests for all species, for each island. Using GIS as before, we then plot the average annual nesting densities on every island, separating loggerhead and green turtle nesting data. Each island is color coded according to density, using the same scale as in the previous GIS figures.

Third, we analyze turtle nesting seasonality in the park and any potential relationship to changes in climate. To begin these questions we first calculate the number of active nests for every day from 1996–2004 for each species. A nest is considered active from the day it is discovered until either the day (a) hatchlings emerge, or (b) the nest was observed to be destroyed. From these data we plot the number of active nests throughout the nesting season, for each species, on each year. We average the peak number of active nests throughout the surveys and place a dotted line at this value as a reference point for each species on each year. From first glance, most nests seemed prematurely terminated from tide washouts, typically associated with hurricane events. To see the effect of hurricanes on nesting activity, we place a hurricane graphic at the date each storm came closest to the park, for each year.

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\(^5\) These data are now available at [http://research.myfwc.com/features/category_sub.asp?id=3618](http://research.myfwc.com/features/category_sub.asp?id=3618)

\(^6\) Available at [http://data.geocomm.com/](http://data.geocomm.com/)
Next we tested the relationship between nesting seasonality and sea surface temperature. As a recent study from the south east coast of Florida demonstrates that loggerheads nest earlier in years when SST is higher (Weishampel et al. 2004), we considered a similar analysis and therefore sought a consistent source for SST records for the Dry Tortugas area. Records are available from three main sources: local thermometer readings, National Oceanic and Atmospheric Administration (NOAA) buoys, and government satellites. Each source has their own pros and cons, and though local thermometer readings were the most desired for their proximity, they were the least available and were subject to user differences. (We did locate an archive from Loggerhead Key from 1879–1906 [Vaughn 1918] and we plot these data as a baseline for comparing recent SST records.) NOAA maintains a network of data stations and buoys throughout the coastal waters of the U. S., and even monitored a station within the park boundaries. Station DRYF1, as it was known, malfunctioned periodically and did not present us enough data.\footnote{Available at \url{http://www.ndbc.noaa.gov/station_history.php?station=DRYF1}} We settled on SST records from the Physical Oceanographic Distributed Active Archive Center (PO.DAAC) using the AVHRR Pathfinder 5 satellite.\footnote{Available at \url{http://poet.jpl.nasa.gov/}} SST readings from this AVHRR satellite are reported to be accurate within 0.5°C, and are available from 1985–2005. As AVHRR 5 data are in 4 km pixels, we averaged the temperature over the geographic region from 24.6–24.7° N and 82.8–82.9° W for the Dry Tortugas, and from 20–30° N and 80–96° W for the entire Gulf of Mexico. Due to turtle sensitivity to SST at the onset of nesting, we are most interested in SST from 1 March through 30 April, the period immediate preceding loggerhead nesting on most years. Therefore we average and plot the SST values as annual series for the Dry Tortugas from 1879–1906 and from 1985–2005, and for the entire Gulf of Mexico from 1985–2005. We then compare the local SST to the onset and peak of loggerhead nesting, when those data are available.

We then examine the average clutch sizes and successful hatchlings recorded each year to further dissect the health of the Dry Tortugas nesting colonies. Aside from looking at raw numbers of nest surveys from year to year, changes in clutches and successful hatches can reveal demographic shifts in nesting females as well as threats to nesting. From nest excavation data, we average the clutch sizes for each year and species, and then average the number of successful hatchlings from the hatching data. We plot these values as annual series for both species.

As commercial fishing practices have been widely implicated in the decline of sea turtles in U. S. waters (National Research Council 1990, Lewison et al. 2003), we seek the relationship of fishery activity to local nesting activity. First examining the Gulf pink shrimp fishery, we tally its activity through the nesting months of April–August (as the Dry Tortugas nesters likely spend the rest of the year elsewhere) and plot it against total nests for those years. We only include data from the NMFS statistical subarea 2 as it encompasses the national park and its vicinity.\footnote{Source: James Nance (James.M.Nance@noaa.gov), NMFS, NOAA, Galveston, Texas, personal communication of unpublished NMFS data.} If shrimp trawlers are catching turtles, we might expect years of high fishery activity to be low years for nesting. Conversely, if shrimp trawlers use turtle excluders effectively then we might find no relationship. Fisheries might also compete with turtles for their food as well. This may be true for

\footnote{Available at \url{http://www.ndbc.noaa.gov/station_history.php?station=DRYF1}}

\footnote{Available at \url{http://poet.jpl.nasa.gov/}}

\footnote{Source: James Nance (James.M.Nance@noaa.gov), NMFS, NOAA, Galveston, Texas, personal communication of unpublished NMFS data.}
loggerheads that feed on sea floor crustaceans, such as stone crabs and spiny lobsters – two species for which there are detailed fishery records. We plot the annual landings of stone crabs and spiny lobsters in Monroe County against nest surveys for those years.10

Finally, we examine the impact of the invasive tree *Casuarina equisetifolia* and nest predators on turtle nesting. In 1997, park botanists cleared the well established *Casuarina* colony on Loggerhead Key that had been thriving since its planting around 1920. Having supplanted native grasses and brush, these trees disrupted turtle nesting by colonizing the island’s sandy beach perimeter where their root bound loose sand and their fallen branches blocked nesting access. To document the vegetation cover change on Loggerhead Key, we compare aerial photographs and satellite images from before and after the 1997 *Casuarina* removal. We show digital orthophoto quarter quadrangle images (DOQQ) displaying bands red (1), green (2), blue (3) from 1995 and 2004 and LANDSAT images displaying bands red (6), green (4), blue (1) from 1985 and 2001. Displayed this way, a LANDSAT image will display trees as dark green, saplings and brush as light green, grass as yellow, sand as white, and water as blue. We display all images at 1:15000 scale. Next to these images we plot the percentage of nests on Loggerhead Key affected in some way by *Casuarina* annually, from 1996–2004. Unlike many other turtle nesting colonies in the U. S., the Dry Tortugas colonies do not reportedly suffer heavily from nest predators, invasive or otherwise. To quantify this relationship, we plot the number of nests (from all species) predated to some degree, and document the predator when known. We only consider predation of nest eggs, not predation on hatchlings after they left their nest.

**RESULTS**

**Comparing Dry Tortugas to other sites**

As a general rule, the Dry Tortugas National Park Sea Turtle Monitoring Program presents similar population trends when compared to other nesting colonies in the Western Atlantic. Figure 1 shows the raw surveys of nests for loggerhead and green turtles. Loggerhead surveys show an increasing trend from 1982 through 1999 and decrease thereafter, though the low numbers in the 1980s could be from a smaller survey effort. Green turtles show a rough two year periodicity, where even-numbered years have between 50–100 nests and odd-numbered years have little activity. Green turtles, however, show no overall trend through the period.

Figure 2 compares the nesting densities of loggerheads at the Dry Tortugas in comparison to other Florida counties. Loggerheads nest most densely from Brevard county south to Palm county – seen as the green strip on the map. This comes as no surprise as this region is one of the largest loggerhead colonies in the western hemisphere. Trends between the Dry Tortugas loggerhead populations and other Florida counties are similar as well, where nesting increases from 1991, peaks in the late 1990’s, and decreases thereafter. Similar to Figure 2, Figure 3 compares nesting densities of green turtles across Florida. Though nesting densities are much lower – by comparison

the figure is dominated by dark red – the trends through time are similar as Figure 2. The same area of southeast Florida that hosts high numbers of loggerheads also hosts the highest densities of green turtles. Importantly, the entire state of Florida shows the undulating population pattern seen at the Dry Tortugas, where a year of moderate nesting is followed by a year with little activity.

The Florida trends broadly match those from across the Caribbean (Safina 2006). But interestingly, they well match those from Tortuguero, Costa Rica (Bjorndal et al 1999) as well as the surveys at Ascension Island, Chile (Hays 2004). That similar patterns exist in Florida and Tortuguero is significant because the latter is by far the largest green turtle nesting population in the Atlantic. Like the rest of Florida, Tortuguero green turtles also show the periodicity seen in Florida, but the peak years at the two locations are out of phase, peaking at even years in Florida and on odd years in Costa Rica (Solow et al. 2002). Solow et al. (2002) link the nesting years in green turtles to favorable SST conditions. Though there may be some correlation between SST and green turtle nesting years in Tortuguero, this obviously does not explain the Florida patterns (same SST trends, but different nesting patterns) nor does it explain why other turtle species do not show synchronized nesting periodicity. Like Kemp’s Ridley turtles that nest in the Atlantic coast of Mexico spectacularly large numbers in synchrony (Spotila 2005, Heppell 1997), green nesting synchronies may also be the predominate result of social organization, in addition to environmental variables.

Geographic Distribution of Nesting

Figure 4 plots nesting population differences for all turtle species between the islands in the Dry Tortugas. As previously reported, East Key and Loggerhead Key hold the lion’s share of nests in the park, year after year. Bush Key is a distant third, Garden Key and Hospital Key have a few nests from year to year, and Long Key and Middle Key see very little activity. These differences are represented geographically in Figure 5, where the annual nests are averaged for greens and loggerheads, and normalized by available habitat (beach length). For ease of comparison, we use the same scale and color scheme as Figures 2–3. For both species, East Key reaches nesting densities similar to the major turtle colonies of southeast Florida. This underscores the particular importance of East Key as a turtle sanctuary. Even though East Key is less than a tenth the size of Loggerhead Key it consistently hosts many more nests from year to year. This could be explained by several factors. One, since over–exploitation of nests likely caused the historic decline of the Dry Tortugas colonies, East Key’s size and remoteness from Garden Key protected it from egg gatherers, more than other islands. Secondly, unlike Loggerhead Key, East Key is relatively free of exotic plant species, and completely free from the harmful effects of Casuarina. Nevertheless, today East Key hosts the most turtle nests, and therefore deserves a priority of research and conservation focus.

Nesting Seasonality and Effects of Climate

Figure 6 shows the number of active loggerhead and green nests from the nesting seasons 1996–2004. Again, 1999 was easily the highest year for loggerhead nesting, as 2000 was
for greens. This is reflected in the peak heights of the curves, which follow a classic normal distribution. As such we can accurately estimate the peak activity for each species, from the mean of the peaks of all years. For loggerheads, the number of active nests peaks on 13 July, and for greens the peak is 16 August – meaning egg laying peaks approximately 45 days earlier for both species. Figure 6 also underscores the devastating role hurricanes can have to nesting on the Dry Tortugas. Both in 2000 and 2004, sharp vertical drops in the bell shaped curves accompany hurricane events. In 2000, a category 1 hurricane (Gordon) washed away 75% of the then–active green turtle nests. In 2004, a category 3 (Charley) and 5 (Ivan) hurricane decimated nests for both species, as well as destroying the only leatherback nests ever recorded here.

Sea surface temperature data are shown in Figure 7. All graphs plot the mean daytime SST from 1 March through 30 April for each year, and display the linear trend for the period. Figure 7A plots the earliest known SST record for this area, taken by thermometer at Loggerhead Key from 1879–1906. From the linear trend, SST increases ~0.1°C/decade, but the relationship is weak. Figure 7B plots the longest SST record in recent history for the park area, using AVHRR 5 data from 1985–2005. Here there is virtually no trend, but the mean value for this period is 24.1°C, or 0.8°C higher than the mean recorded a century earlier. Figure 7C shows the SST records from 1985–2005 for the entire Gulf of Mexico region. Here there is a significant warming trend of more than 0.5°C/decade. It is uncertain how SST across such a large region could affect turtle nesting locally, but the rapid rise is an ominous sign.

We then compare the local SST records to the onset, Figure 8A, and peak, Figure 8B, of loggerhead nesting. Loggerhead nesting both begins and peaks earlier in years with higher SST. This relationship between SST and nesting seasonality is strong in the Dry Tortugas – and may be a general one for loggerheads – as this result confirms a similar study in eastern central Florida (Weishampel et al. 2004). As seas have warmed regionally, loggerheads likely shifted their nesting to earlier in the dates across the Caribbean.

**Clutch Size and Successful Hatchlings**

Figure 9 plots the number of eggs laid versus those successfully hatched for loggerhead and green turtles. Throughout the study, loggerheads show a remarkably consistent clutch size, mean = 102, yet is slightly lower than the expected value (115) for Western Atlantic loggerheads (Eckert et al. 1999). Green turtles clutch size decreases slightly through the study period, having a mean = 123, which is just higher than the expected value (120) for this species (Eckert et al. 1999). A decrease in clutch size could be attributed to several factors, including a decrease in average age or health of nesting females, or to degrading environmental conditions. However, few data of this latter kind are available, making these analyses presently not possible. For both species, the number of successful hatchlings decreases by more than 50% during the study period. This trend raises significant concern for the future of the Dry Tortugas turtle nesting colonies and places a priority on determining the source of this decline.
**Effect of Local Fisheries**

Concerned about commercial fisheries, Figure 10 plots the activity of three local fisheries against nesting activity. Because loggerhead diet largely consists of sea floor crustaceans, we plot the annual landings of stone crab, Figure 10A, and spiny lobster, Figure 10B, fishery from Monroe County, Florida. For both fisheries, years with high landings correspond to high nesting years. This suggests that years with more stone crabs and spiny lobsters will be more productive for both turtle nesting as well as their fishery. Next, we plot the annual pink shrimp fishery activity in the Dry Tortugas grounds against the numbers of green and loggerhead nests, Figure 10C. Because shrimp trawlers snare turtles by deploying nets (and not by catching shrimp) we plot total fishery effort, measured in boat days fished. As expected, years with more boat trawling days have less nests, but the relationship is extremely weak statistically. We therefore do not report any correlation between the pink shrimp fishery and turtle nesting activity. As TEDs were first required before our data begin (effective in the 1995 nesting season) and were not sufficiently required until the end of our study (effective in the 2004 season) more survey data is required to make any meaningful conclusion on the impacts of the Gulf shrimp industry.

**Effect of Casuarina and Nest Predators**

Figure 11 shows vegetation cover change on Loggerhead Key from the 1997 removal of invasive *Casuarina* and its effect on nesting activity. Figure 11A demonstrates how widespread Casuarina was before its removal. The aerial photograph shows the trees (and their large shadows) directly, where the LANDSAT image represents tree canopy with green and dark green pixels. Figure 11B shows *Casuarina* is nonexistent on Loggerhead Key on both imagery products as well. The aerial image shows no tall vegetation, and the LANDSAT image is dominated with yellow and light green pixels, representing grass and shrubs. These four images together show a vegetation cover transformation from one dominated by trees, to one dominated by grass and shrubs. Figure 11C plots the percentage of nests annually impacted by *Casuarina*. The impact peaks in 1997, the year the trees were cut. This makes some sense, as a management program of this scale necessarily created large amounts of woody debris that may have obstructed beach nesting by female turtles. After the removal, however, *Casuarina*’s harmful effects to nesting remain on Loggerhead Key. This could be from the continued presence of *Casuarina* debris on the beach margins, or from persisting *Casuarina* stumps whose roots block females from digging nests. After 1997, the percent of nests affected never exceeds 15%, yet these numbers may still be too high as they impact endangered species.

Figure 12 plots the percent of nests (all species, all islands) with some degree of nest predation. The percentage of nests with evidence of predation increases steadily, with a large spike in 2003. This only means that more nests are affected by predation – that predation is more widespread – and not a direct comment on the number of eggs predated. Only some of the predation is explained by ghost crabs (*Ocypode quadrata*) which are a native species and a natural predator of turtle nests. That predation is increasing, and increasingly unknown, is a significant concern. Though exotic ants occur
throughout the islands (Wetterer & O’Hara 2002), only a handful of occurrences of ants predating nests exist.

CONCLUSIONS AND RECOMMENDATIONS

After a 90% population crash since the pre–Colombian era, turtle populations in the Western Atlantic currently experience a modest rebound (McClenahan et al. 2006, Safina 2006, Dutton et al. 2005, Spotila 2005, Hays 2004, Steadman & Stokes 2002, Bjorndal et al. 2000). In both a historical sense and to the extant populations today, Florida’s nesting colonies are a critically important segment of turtle populations in the Atlantic. The Dry Tortugas nesting colonies are an important part of this group, both for their genetic distinctiveness (Pearce 2001) and their isolation from many of the threats facing most turtle nesting areas.

However, much remains unknown of the Dry Tortugas colonies. From the current analyses, we recommend several changes to the Dry Tortugas National Park Sea Turtle Monitoring Program. These additional tasks are not logistically or technically difficult, and will allow a wealth of additional data that will provide a much clearer understanding of the threats the Dry Tortugas turtles face, locally and elsewhere. Crucially, this will help to understand and predict the population changes from year to year. To begin, the nesting surveys are not sufficiently lengthy, and should be extended beginning in 2007. This is important for understanding the long term ecological ramifications of previous conservation efforts, as well as ensuring these legally threatened species remain protected. Because sea turtles do not reproduce until 20 or 30 years of age, results from management or conservation may not appear for some time. More monitoring is essential to see if the past regimes are effective.

Secondly, the lack of demographic, tagging, and tracking data severely limit understanding these nesting colonies. Are these populations growing older? Are first time nesting females being added to the population every year? What is the annual survivorship of these turtles? Where do the nesting females spend the rest of the year? How often do they return (how long are nesting intervals)? Night time surveys would be necessary for these data – to measure female carapaces while they nest, affix GPS units to some, and apply metal ID tags to their hind flippers. Basic tagging and tracking could also accompany existing daytime surveys, and target non–nesting species, such as the many juvenile hawksbills known to frequent the Dry Tortugas reefs. Understanding where the Dry Tortugas hawksbills, leatherbacks, and Kemp’s Ridleys hatch from, and where they migrate to, would significantly increase the value of this program, and present many collaborative opportunities with other state, federal, and international scientific organizations. Figure 13 is a good example of a potential product from such research. This map shows the spatial population structure of loggerhead turtles in the U. S. Pointing to the distinctiveness of the Dry Tortugas colony, this information is helpful for conservation planning.

Thirdly, more information on interpreting nesting success is urgent. We document an alarming trend of decreasing nesting success (Figure 9) that stems from several causes: climatic events (Figure 6), invasive species (Figure 11), and nest predation (Figure 12). Perhaps in a surprise, local commercial fisheries do not seem to impact the
colonies (Figure 10). Some questions that require attention are as follows. Are ghost crabs the major active source of predation of Dry Tortugas turtles nests? Are the widespread invasive ant colonies documented by Wetterer & O’Hara (2002) a factor? What other predators exists, if any? How natural is the current effect of tidal washouts? Is this related to a long term trend of sea level rise (e.g. Fish et al. 2005)? What does this mean for the immediate future? For 50 years from now? Are hurricanes and tidal effects impacting nesting elsewhere to such a degree? If future years see hurricane seasons such as 2004 and 2005 (see Figure 14) where storms arrive earlier, are more frequent and more intense, this poses significant risks to turtle nesting in the Dry Tortugas where beaches are exposed and vulnerable to high surf and storm surge.

Accompanying the recommended monitoring changes should be an easily accessible database of abiotic data for comparison to turtle surveys. Indeed one of the most laborious aspects of the current assessment was tracking down various data required to make these analyses. Climate data such as SST, wave heights, sea level, hurricane tracks, etc. are crucial to understanding the Dry Tortugas nesting populations. Fishery data are also freely available and important to reading long term population changes. Satellite imagery is also indispensable, and though these kinds of data do not tend to be freely available, they do exist. Long term databases of such types would immeasurably extend the research options and strengthen the efficacy of conservation decisions. Practically speaking, once compiled, such databases can be automated with computer scripts to update themselves as new data become available – this does not need to take one away from the park and the turtles. An added benefit from pursuing such data is the potential collaborations with other government, academic, and non–profit institutions, such as NOAA’s NDBC, NASA, NMFS, the Carnegie Institute, FWRI, and Seaturtle.org, to name but a few.

A final recommendation pertains to the vegetation management of Loggerhead Key. The 1997 removal of invasive Casuarina trees was extremely effective, perhaps too effective (see below), and immediately changed the vegetation cover of the island. In a few months, the island nearly returned to its condition a century ago. Two problems remain however. One is the continued presence of Casuarina stumps and debris. These remnants continue to affect turtle nesting on Loggerhead Key (Figure 11C) and potentially limit this island’s nesting densities, especially in comparison to the much smaller East Key (Figure 4–5). All remaining evidence of Casuarina should be removed to maximize the nesting niche of Loggerhead Key. Loggerhead Key historically was more heavily vegetated with bay cedar (Suriana maritima) and perhaps in its interior with Florida buttonwood (Conocarpus erectus). The island’s current cover of scattered shrubs and grasses (Figure 11B) may alter the sex ratio of turtle hatchlings there. Sparsely vegetated nesting beaches offer little insulation from the tropical sun, potentially raising below–surface nest temperatures several °C, in comparison to nests near shrubs or trees. Higher nest temperatures from un–shaded nests produce a disproportionate amount of female nestlings, biasing the sex ratios of future breeders (Kamel & Mrsovsky 2006). This deserves attention at Loggerhead Key, and may suggest a more active management program to advance the recolonization of native plants.
Figure 1 Loggerhead and green turtle nest surveys from the Dry Tortugas National Park, 1982–2004. Monitoring from 1982–1993 (empty squares) was not standardized and followed a different protocol than later surveys from 1995–2004 (filled circles). General patterns for both species are in accord with records from Florida and the Caribbean: loggerhead nests appear to increase from 1980–2000 and decline thereafter, green turtles exhibit a general two–year periodicity of nesting activity with a steady and gradual increase in observed nesting. There is no survey data from 1987–1990, nor in 2002. Illustrations by Cézar Landazabal (SWoT 2006).
Figure 2 Loggerhead sea turtle nesting populations in the Dry Tortugas National Park (inset) in comparison to other Florida counties. Populations are normalized by monitoring effort (km coastline searched). Annual population shifts at the Dry Tortugas are consistent with other Florida populations. The large nesting concentration from Brevard county south to Palm Beach is the largest loggerhead nesting site in the western hemisphere, and is of great conservation significance.
Figure 3 Green sea turtle nesting populations in the Dry Tortugas (inset) in comparison to other Florida counties. Populations are normalized by monitoring effort (km coastline searched). A mostly tropical species, the green turtle nesting colony from Brevard county south to Palm Beach is the largest in the United States, and few green turtles nest north of Florida. Historical records suggest a major green turtle nesting population existed in the Dry Tortugas, but was hunted to oblivion in the 1800’s (see text).
**Figure 4** Geographic distribution of sea turtle nests 1996–2004. The number of nests observed on East Key typically exceeds nest counts from the others islands’ combined. East and Loggerhead Key together comprises roughly 90% of the turtle nests annually. Estimating the number of nesting females form these data should consider that most females nest 2–3 times a season. The 3 leatherback nests observed on East Key in 2004 were therefore from the same female. Middle Key has only one nesting record, from the 1998 season.
Figure 5 Average annual nesting density for individual islands at the Dry Tortugas for loggerhead and green sea turtles. East Key maintains the highest nesting densities for both species, and was the only location observed with nesting leatherback turtles. Loggerhead Key has the second highest nesting densities to East Key and fewer total nests despite having more beach habitat. This is likely from the presence of the invasive Australian pine (Casuarina equisetifolia) which decreases turtle nesting habitat and disrupts nesting behavior. Nest numbers are normalized by available beach habitat, which for all islands except Garden Key, was determined from polygon perimeter length. Because Garden Key’s perimeter is mostly human made structures – not sandy beach habitat – sandy beach on Garden Key was estimated from aerial photographs.
Figure 6 Seasonality of nesting activity for green and loggerhead turtles in the Dry Tortugas, 1996–2004. Green turtles nest one average one month later in the year than loggerheads naturally predisposing their nesting season to hurricane events. In 2000, a category 1 hurricane (Gordon) washed away 75% of the then–active green turtle nests. In 2004, a category 3 (Charley) and 5 (Ivan) hurricane decimated nests for both species. Earlier, more frequent, and more intense hurricanes pose a serious threat for turtle nesting colonies in the Dry Tortugas where beaches are exposed and vulnerable to high surf and storm surge. No green turtle nests were observed in 2001.
Figure 7 Sea surface temperature (SST) trends locally at the Dry Tortugas and over the entire Gulf of Mexico region. Though we tested a variety of SST data products, AVHRR data was the most consistently available during the entire study period from the 1980’s to present day. SST records local to the Dry Tortugas, either from NOAA buoys, from Carnegie Institute records, or from other sources are likely more accurate than AVHRR data, but are not as widely available. A, Thermometer reading averages for the 1 March through 30 April period on Loggerhead Key from 1879–1906 are lower, yet broadly similar, to B, local AVHRR readings from 1985–2005; over a century later. C, AVHRR temperature averages from 1 March – 30 April for the entire Gulf of Mexico from 1985–2005 show an increase of $>0.5\,^\circ\text{C}$ per decade.
Figure 8 Loggerhead turtles nest earlier when local SST is higher, confirming similar patterns in loggerhead nesting colonies on Hutchinson Island, St. Lucie county, Florida (Weishampel et al. 2004). SST is average of 1 March through 30 April readings from derived from AVHRR data. Beginning of loggerhead nesting season (first observed crawl), A, and peak activity, B, arrive at an earlier Julian date when SST is warmer.
Figure 9 Average number of eggs laid and eggs successfully hatched. Loggerheads show a remarkably consistent clutch size (mean = 102), while green turtles clutch (mean = 123) decreases slightly. Both species show a 50% decrease in hatchling success over the study period, attributed mostly to nest washout from high tides and hurricane storm surge. For greens, a decrease in clutch sizes may indicate the average age of nesting females is decreasing, suggesting the nesting population of green turtles is recruiting younger breeders that lay fewer eggs. 1995 survey did not document initial clutch sizes.
Local fisheries show little evidence of negative impact to the Dry Tortugas turtle nesting activity. Though sea floor crustaceans are a primary forage for loggerhead turtles, increase landings of stone crabs, $A$, and spiny lobster, $B$, correspond to an increase in recorded nests. Both loggerheads and fishermen seem to benefit in years with high crustacean populations. $C$, The Dry Tortugas grounds pink shrimp fishery shows a weak negative relationship for nesting of both species, indicating that the fishery’s impact is moderately consistent over the period. As sufficiently large turtle excluders (TEDs) were not mandated by the NMFS until August 2003, however, we presently cannot make conclusions about the impact of TEDs to Dry Tortugas nesting.
Figure 11 The 1997 effort to remove Australian pine (*Casuarina equisetifolia*) at Loggerhead Key shows a decrease in tree cover, but *Casuarina* remains a threat to nesting. A–B, DOQQ and LANDSAT imagery from before the invasive management show many *Casuarina* trees, where images from after removal show a more scrubby, open vegetation cover. C, After the 1997 removal, however, *Casuarina* continues to impact nesting (root interference) or female behavior (tree debris entanglement) indicating that further work remains to remove *Casuarina* debris, especially underground stumps.
Figure 12 The percent of nests observed with some egg predation has steadily increased since monitoring began. Predation from the dominant natural predator locally, however, the ghost crab (*Ocypode quadrata*), remains relatively constant. As egg survival is of the utmost importance for turtle conservation, we encourage further study to identify the unexplained predation.
Figure 13 The four genetically distinct Loggerhead subpopulations in the southeastern United States – Northern, South Florida, Dry Tortugas, and Northwest Florida – determined from mitochondrial DNA. The Northern subpopulation stretches from the Outer Banks of North Carolina south to Volusia county, Florida. Despite its close proximity to south Florida, the Dry Tortugas National Park hosts a highly distinct subpopulation, increasing its conservation significance.
Figure 14  Hurricane tracks for the 2004 and 2005 nesting season. Both years represent extraordinary storm activity, but are of serious concern as a harbinger of things to come (Emmanuel 2005, Webster et al. 2005). The Dry Tortugas (inset polygon) were seriously affected by every hurricane displayed here (also see Figure 6). Hurricane Ivan of 2004 (red track) even though it did not pass within 300 km of the islands wiped out > 90% of the active turtle nests in the Dry Tortugas.
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