



Leave No Trace ordinances for coastal species management: influences on sea turtle nesting success

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ABSTRACT: Coastal environments provide critical ecosystem services but experience a number of threats including marine debris and abandoned beach equipment. To address this threat, municipalities have begun enacting policy measures such as Leave No Trace ordinances. The impact of these ordinances on coastal species management has not yet been established. To evaluate the effectiveness of Leave No Trace ordinances in coastal species management, sea turtle crawl distribution, nesting success, and the frequency of obstructed crawls pre- and post-ordinance at a loggerhead sea turtle *Caretta caretta* nesting beach in Alabama, USA, were compared between 3 treatment groups: (1) Gulf Shores and Orange Beach with new Leave No Trace ordinances enacted in 2016, (2) Fort Morgan with no ordinance, and (3) the Bon Secour National Wildlife Refuge (NWR) and Gulf State Park with Leave No Trace ordinances but no resident human population. The ordinance had no significant effect on crawl distribution or nesting success across the study site post-ordinance. However, the frequency of obstructed crawls in populated areas declined by 18.1% with the ordinance. The presence of a resident population was a more significant driver of obstructed crawls than the ordinance, as the Bon Secour NWR and Gulf State Park had fewer obstructed crawls than either populated treatment. With time and increased compliance, Leave No Trace ordinances may have the potential to improve coastal species management and increase coastal ecosystem services through reduced marine debris entanglement and ingestion, reduced physical damage to the environment, and increased tourism revenue and environmental education.

KEY WORDS: Coastal zone management · Marine debris · Leave Only Footprints · Loggerhead marine turtle · *Caretta caretta* · Gulf of Mexico

1. INTRODUCTION

Sandy beaches provide valuable ecosystem services to coastal communities, including storm protection (Ruggiero et al. 2001, Defeo et al. 2009), tourism (Klein et al. 2004, Campbell & Smith 2006), wildlife viewing (Johnson et al. 1996, Tisdell & Wilson 2002, 2005, Stewart et al. 2016), and habitat for threatened species (NMFS & USFWS 2008, Stucker et al. 2010). These services, particularly habitat for threatened species, are being increasingly impacted by coastal

population growth and development (Roberts & Hawkins 1999, Brown et al. 2008, Defeo et al. 2009, Fuentes et al. 2016), erosion (Fish et al. 2008, Ranainghe 2016), and sea level rise (Baker et al. 2006, Schlacher et al. 2008, Fuentes et al. 2010, Neumann et al. 2010). With climate-change-associated sea level rise and cyclonic storm intensification, further habitat loss is expected (Emanuel 2005, Fuentes et al. 2011, Murdukhayeva et al. 2013, Bacmeister et al. 2018, Nerem et al. 2018). Efforts to protect coastal development from storm surge and flood damage, such as the

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construction of seawalls and revetments, are likely to increase with climate change and can exacerbate beach loss through increased erosion and restricted shoreline retreat (Pilkey & Wright 1988, Phillips & Jones 2006, Escudero-Castillo et al. 2018, Rangel-Buitrago et al. 2018).

The availability of optimal habitat for beach-dwelling or nesting species such as sea turtles and shorebirds is further reduced by anthropogenic pressures associated with coastal development, including abandoned beach equipment or marine debris, artificial lighting, and human activity (Arianoutsou 1988, Mosier & Witherington 2002, Weishampel et al. 2016, Oliver de la Esperanza et al. 2017). The introduction of plastics and other debris into the marine environment and its deposition in coastal environments has been increasing rapidly over the past several decades (Hidalgo-Ruz & Thiel 2013, Blickley et al. 2016, Löhr et al. 2017, Garrison & Fuentes 2019). Interest in reducing marine debris, and abandoned beach equipment in particular, is growing among both the conservation community and the general public given the breadth of its economic and ecological impacts (Beeharry et al. 2017, Löhr et al. 2017, Owens 2018). These impacts include lost tourism revenue (Blakemore & Williams 2008, Jang et al. 2014, Krelling et al. 2017), increased coastal zone management costs (de Araújo & Costa 2006, McIlgorm et al. 2011, Oosterhuis et al. 2014), entanglement and/or starvation of wildlife (Gall & Thompson 2015, Godoy & Stockin 2018, Lusher et al. 2018), and physical damage to the environment (Chiappone et al. 2005, Abu-Hilal & Al-Najjar 2009, Richards & Beger 2011).

To minimize anthropogenic impacts from human presence on sandy beach ecosystems, municipalities in coastal areas have begun adopting pollution-control measures such as product bans, environmental taxes, and Leave No Trace ordinances (James 2000, Ariza et al. 2008, Oosterhuis et al. 2014, Blickley et al. 2016). In the case of Leave No Trace ordinances, municipalities mandate that residents and visitors remove all beach equipment and disposable items by a specified time or forfeit their equipment and potentially face civil penalties such as fines (City Council of the City of Gulf Shores 2015, City Council of the City of Orange Beach 2015). Portions of beaches in the northern Gulf of Mexico have been protected by city and county Leave No Trace ordinances as early as 2010 (Board of County Commissioners of Santa Rosa County 2010, City Council of the City of Panama City Beach 2012, Bay County Board of County Commissioners 2013, Franklin County Board of Commissioners 2014, Board of Commissioners of

Gulf County 2015, Walton County Board of County Commissioners 2018).

Though Leave No Trace ordinances are most often used for social or economic benefits, they are likely to become increasingly utilized for ecological management as coastal populations increase (Arianoutsou 1988, Schlacher et al. 2008, Oliver de la Esperanza et al. 2017). For example, with respect to sea turtles, the enforcement of these ordinances may improve nesting success and increase the number of post-emergent hatchlings reaching the water by removing potential obstructions (Tucker et al. 2005, Fujisaki & Lamont 2016). Nesting females come onto shore to lay their eggs and may encounter large natural and anthropogenic physical obstructions during nesting (Tucker et al. 2005, 2009, Burkholder & Slagle 2015). These obstructions may cause them to abandon their nesting attempt and return to the water, become entrapped and die from dehydration, or entangled and drown when returning to the water (Laurance et al. 2008, Witherington et al. 2011, Ikarán 2013, Fujisaki & Lamont 2016). When obstructions are present on the beach, nests tend to be closer to the shoreline, increasing their risk of tidal inundation or erosion (Laurance et al. 2008, Witherington et al. 2011, Pike et al. 2015, Ware & Fuentes 2018) or, if having to circumvent obstacles, hatchlings spend more time on the beach, increasing their risk of predation and disorientation (Triessnig et al. 2012, Maurer et al. 2015).

Despite the potential benefits of Leave No Trace ordinances to species that use the coastal environment, the ecological benefits of these ordinances have not yet been demonstrated in these environments. To elucidate these potential benefits, our goal was to determine the influence of Leave No Trace ordinances on sea turtle nesting. This was achieved by determining changes in (1) sea turtle crawl and nest distribution, (2) nesting success, and (3) the frequency of obstructed nesting attempts before and after the implementation of a Leave No Trace ordinance at a loggerhead turtle *Caretta caretta* nesting beach in the northern Gulf of Mexico.

2. MATERIALS AND METHODS

2.1. Study area

This study took place along the Gulf of Mexico beaches of Baldwin County, Alabama, USA, stretching from Fort Morgan in the west to the Florida–Alabama state line in the east (30.22716° N, 88.02787° W to 30.28021° N, 87.51833° W). The county beaches were

divided into 5 subunits: Fort Morgan, the Bon Secour National Wildlife Refuge (BSNWR), Gulf Shores, Gulf State Park, and Orange Beach (Fig. 1).

The cities of Gulf Shores and Orange Beach jointly implemented their Leave No Trace ordinances within their respective city limits effective in 2016 (City Council of the City of Gulf Shores 2015, City Council of the City of Orange Beach 2015). These ordinances prohibit the erection of tents or similar canopy structures on the beach (excluding beach umbrellas) and require all beach equipment without a city permit to be removed from the beach no later than 1 h after sunset. This beach equipment includes, but is not limited to, chairs, loungers, umbrellas or other shelters, paddle vessels (e.g. kayaks, surfboards), fishing gear and other sports equipment, beach toys, bags, and coolers. As protected areas, the BSNWR and Gulf State Park have Leave No Trace policies in place in addition to no permanent residents. Fort Morgan is unincorporated within Baldwin County, so the Leave No Trace ordinance does not apply in this residential area.

2.2. Sea turtle monitoring and analysis

Morning nesting patrols from 1 May through 31 August were conducted daily by US Fish and Wildlife Service personnel and members of the citizen-science, federally permitted sea turtle monitoring group 'Share the Beach' across all Alabama beaches from

2011–2018. During these patrols, all sea turtle activities were documented including crawl result (nest vs. false crawl—female emergences which do not result in the deposition of eggs), date, location including GPS, whether the crawl was obstructed, and distances of the nest or apex of the false crawl to the dune and previous night's high tide line.

A before–after control–impact paired sites (BACIPS) design was used to evaluate the effect of the Leave No Trace ordinance on nesting success and the proportion of obstructed crawls. This design separates natural spatial and temporal effects from those of the intervention by monitoring treatment and control sites both before and after the intervention (Torres et al. 2011, Thiault et al. 2017). Nesting success was defined as the proportion of all adult female sea turtle emergences which resulted in the successful deposition of eggs relative to the total number of emergences. Obstructed crawls were emergences which interacted with a physical object, regardless of whether or not the crawl resulted in a nest.

All crawl data were first separated into pre- and post-ordinance time categories with data from 2011–2015 listed as 'pre-ordinance' and data from 2016–2018 as 'post-ordinance'. Within each time category, each beach was then assigned to 1 of 3 groups based on the enforcement of the ordinance and the presence of a resident human population. The Leave No Trace treatment group included the cities of Gulf Shores and Orange Beach. Fort Morgan has a resident population but no ordinance, thus it served as a control for

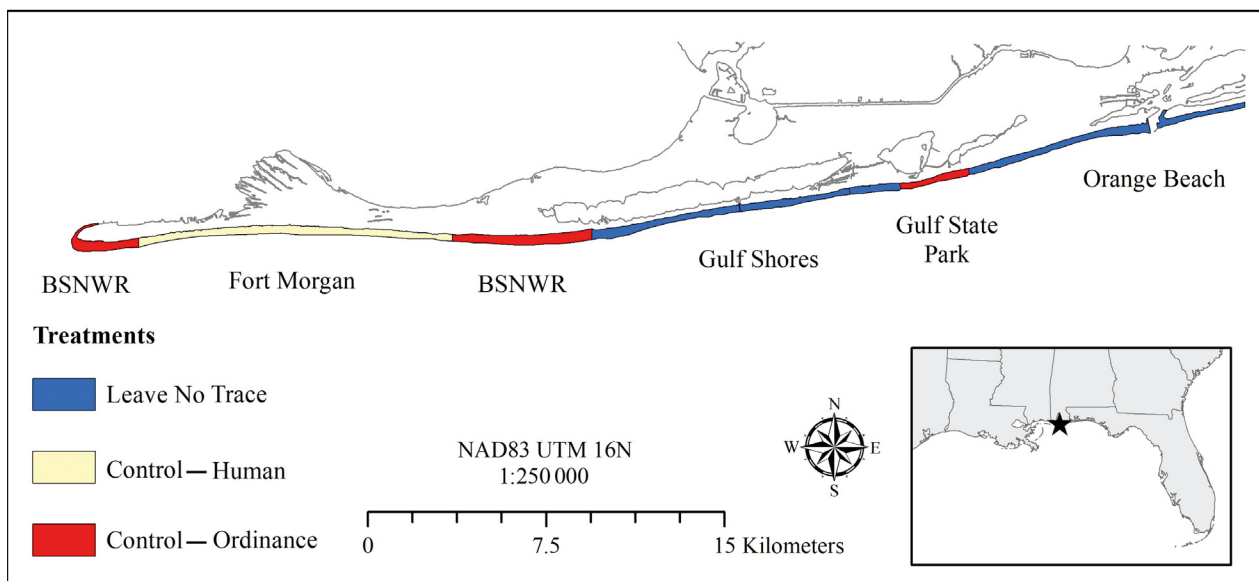


Fig. 1. Baldwin County, Alabama, USA beaches. BSNWR: Bon Secour National Wildlife Refuge. Control—Human: has a resident human population but no ordinance; Control—Ordinance: has an ordinance but no resident human population

human population. The BSNWR and Gulf State Park served as a control for ordinance as they have Leave No Trace ordinances but no resident population.

Poisson regressions were conducted to evaluate changes in the number of crawls or nests as a function of treatment group, time (pre-/post-ordinance), and the interaction between treatment group and time. Logistic regressions were then conducted to evaluate (1) nesting success as a function of treatment group, time, presence of an obstruction, and distance to the high tide line and (2) the frequency of obstruction as a function of treatment group, time, and distance to the high tide line. In the event a turtle hit multiple objects during her emergence, this event was treated as a single obstructed emergence for the logistic regressions. Each object was treated independently when detailing the prevalence of each type of obstructing object. Distance of the nest or apex of the false crawl to the high tide line was included as it is a commonly recorded metric to assess the risk of inundation exposure to the site and has been shown in previous research to be an important factor in nest site selection (Whitmore & Dutton 1985, Eckert 1987, Horrocks & Scott 1991, Kamel & Mrosovsky 2004, Ávila-Aguilar 2015, Ware et al. 2019). All statistical analyses were performed in R v.3.5.0 (data and R analyses underlying the manuscript are available from the first author's FigShare site: https://figshare.com/projects/The_influence_of_Leave_No_Trace_ordinances_on_coastal_species_management/59132).

3. RESULTS

3.1. Sea turtle crawl and nest distribution

From 2011–2018, there were 1679 crawls across the study area. Of these, 901 were successful nesting attempts resulting in an overall nesting success of 53.7% (Table S1 in the Supplement at www.int-res.com/articles/suppl/n041p197_supp.pdf). When evaluating the number of crawls as a function of treatment group, time (pre-/post-ordinance), and the interaction of treatment group and time, only treatment group and time were statistically significant (group χ^2 $p = 0.045$; time χ^2 $p = 0.001$). Though the proportion of crawls in Gulf Shores and Orange Beach increased by 18% after the ordinance relative to pre-ordinance levels, there was no interaction effect between treatment group and time (χ^2 $p = 0.537$), indicating that the distribution of crawls was not significantly different after the ordinance was enacted (Fig. 2).

The number of nests were also significantly related to treatment group (χ^2 $p = 0.043$) and time (χ^2 $p = 0.005$) but not the interaction term (χ^2 $p = 0.790$), indicating no significant change in nest distribution after the ordinance. Though the proportion of nests in Gulf Shores and Orange Beach increased by 12% after the ordinance relative to pre-ordinance levels, this was not significant. Across Baldwin County, both the mean number of crawls and nests increased after the ordinance by approximately 70 and 50%, respectively, relative to pre-ordinance levels (Figs. 2 & 3).

3.2. Sea turtle nesting success

When evaluating nesting success as a function of treatment group, time, presence of an obstruction, and distance to the high tide line in a logistic regression, only time and distance to the high tide line were significant (Fig. 4; χ^2 $p < 0.0001$ for both time and distance to high tide line, respectively; group χ^2 $p = 0.375$, obstruction χ^2 $p = 0.331$). There

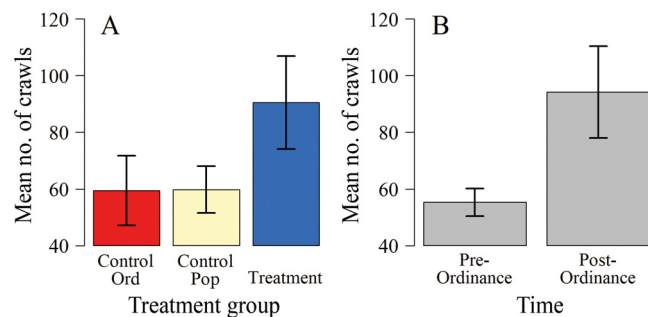


Fig. 2. Mean (± 1 SE) number of sea turtle crawls by (A) treatment group and (B) time. Treatment: Gulf Shores and Orange Beach; Control Pop (population): Fort Morgan; Control Ord (ordinance): Bon Secour National Wildlife Refuge and Gulf State Park. The interaction between treatment group and time was not significant

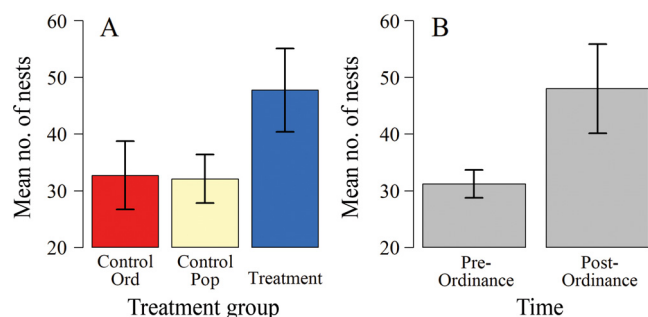


Fig. 3. Mean (± 1 SE) number of sea turtle nests by (A) treatment group and (B) time. See Fig. 2 for abbreviations. The interaction between treatment group and time was not significant

was no interaction effect between treatment group and time ($\chi^2 p = 0.314$).

Before the ordinance went into effect, nesting success was greatest in the BSNWR and Gulf State Park at 58.5%, while after the ordinance it was greatest in Fort Morgan at 54.3% (Table 1). However, nesting success both before and after the ordinance was not significantly different between treatment groups. Within treatment groups, average nesting success in Gulf Shores and Orange Beach declined by 15.6%, increased in Fort Morgan by 2.1%, and decreased in the BSNWR and Gulf State Park by 11.6% relative to pre-ordinance levels.

3.3. Obstructions at nesting beaches

With respect to the percentage of obstructed crawls as a function of treatment group, time, and distance to the high tide line from 2011–2018, only treatment group and distance to the high tide line were significant (Fig. 5; treatment group $\chi^2 p < 0.0001$; distance $\chi^2 p = 0.003$; time $\chi^2 p = 0.540$). There was no interaction effect between treatment group and time ($\chi^2 p = 0.367$).

Before the ordinance went into effect, the percentage of obstructed crawls was lower in the BSNWR and Gulf State Park compared to either Fort Morgan or Gulf Shores and Orange Beach (Table 1). This trend was consistent after the ordinance went into effect as well. Within treatment groups, Fort Morgan had an increase in obstructed crawls of 45.5% relative to pre-ordinance levels, while Gulf Shores/Orange Beach and BSNWR/Gulf State Park had decreases of 18.1 and 17.3% relative to pre-ordinance levels, respectively.

However, the number of obstructing objects increased by 71% in the 3 yr after the ordinance implementation relative to pre-ordinance levels (Table 2). Tents were the most commonly identified obstruction to sea turtle crawls both before and after the ordinance was initiated, followed by metal beach chairs and wooden loungers. ‘Other’ objects included items such as kayaks, housing pilings, volleyball nets, and even an old shipwreck (Table 2). Obstructing objects were not identified in reports until 2013—only whether or not the crawl was obstructed. Therefore, the 2011 and 2012 obstructing object data were excluded from this particular level of the analysis. From 2016–2018, roughly 600 t of material were removed from the beaches of Gulf Shores and Orange Beach as part of the Leave

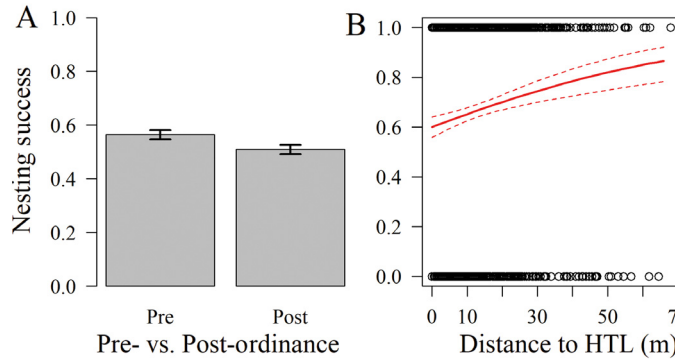


Fig. 4. Sea turtle nesting success (A) by time with all treatment groups aggregated and (B) distance to the high tide line (HTL). Treatment group, presence of an obstruction, and the interaction between treatment group and time were not significant. Error bars: ± 1 SE

Table 1. Mean (\pm SE) sea turtle nesting success and percent obstructed crawls by treatment group before (2011–2015) and after (2016–2018) implementation of the Leave No Trace ordinance. Leave No Trace: Gulf Shores and Orange Beach; Control for Ordinance: Bon Secour National Wildlife Refuge and Gulf State Park; Control for Population: Fort Morgan

	Leave No Trace (%)	Control for ordinance (%)	Control for population (%)
Nesting success			
Pre-ordinance	57.7 \pm 2.7	58.5 \pm 3.2	53.2 \pm 3.0
Post-ordinance	48.7 \pm 2.5	51.7 \pm 3.2	54.3 \pm 3.4
Obstructed crawls			
Pre-ordinance	22.1 \pm 2.3	8.1 \pm 1.8	16.7 \pm 2.3
Post-ordinance	18.1 \pm 1.9	5.1 \pm 2.9	24.3 \pm 3.0

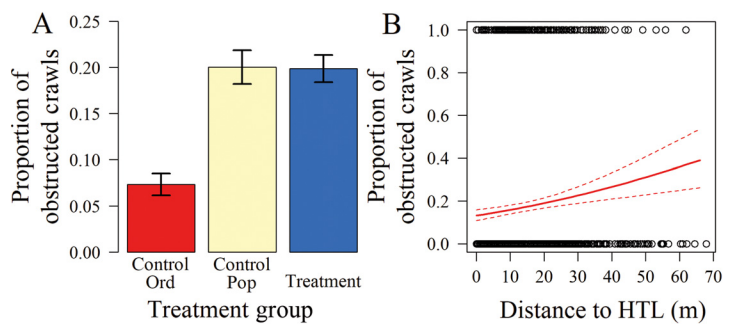


Fig. 5. Proportion of obstructed sea turtle crawls by (A) treatment group and (B) distance to the high tide line (HTL). See Fig. 2 for abbreviations. Time and the interaction between treatment group and time were not significant. Error bars: ± 1 SE

No Trace ordinance (N. Hand & N. Woerner pers. comm.). In Orange Beach in 2018 alone, approximately 500 tents, 5000 chairs, and 1200 umbrellas were removed during 5500 collection stops (N. Woerner pers. comm.).

Table 2. Relative contribution of common beach objects to obstruction of sea turtle crawls pre- and post-ordinance implementation (mean \pm SE) across the complete study area. Obstructing objects were not included in nesting reports until 2013—only whether or not the crawl was obstructed. Therefore, the 2011 and 2012 data are not included in this table

	Pre-ordinance (2013–2015) n = 107 objects (%)	Post-ordinance (2016–2018) n = 183 objects (%)
Tents	13.7 \pm 3.2	21.1 \pm 1.7
Chairs	12.3 \pm 2.7	17.2 \pm 3.8
Wooden loungers	10.6 \pm 5.1	17.5 \pm 4.5
Umbrellas	9.0 \pm 2.4	0.7 \pm 0.7
Toys	6.7 \pm 0.3	6.1 \pm 2.9
Large driftwood ^a	3.9 \pm 2.3	5.5 \pm 1.5
Holes	3.1 \pm 1.7	10.1 \pm 1.8
Sand fencing ^a	1.2 \pm 1.2	2.4 \pm 2.4
Signage ^a	0.0 \pm 0.0	5.1 \pm 2.4
Other	3.7 \pm 0.2	9.8 \pm 2.3
Unidentified	35.9 \pm 7.1	4.4 \pm 2.2

^aItems not included in the Leave No Trace ordinance

4. DISCUSSION

Sea turtle emergences and nesting have been increasing, on average, in Baldwin County, Alabama. If the presence of an obstructing object deters sea turtle emergence from the water and reduces the probability of nesting, fewer obstructions on the beach as a result of a Leave No Trace ordinance should result in an increase in crawls and/or nesting success. However, in the 3 yr since the implementation of the Leave No Trace ordinance, the distribution of sea turtle crawls and nests has not changed, and nesting success was not significantly different between treatment groups. Though the frequency of obstructed crawls did decline in Gulf Shores and Orange Beach after the ordinance was implemented, this was not statistically significant. Despite the small effect sizes observed in this study directly related to sea turtle nesting, cleaner beaches as a result of Leave No Trace ordinances have other social and ecological benefits.

Nesting success declined by 15.6% relative to pre-ordinance levels in Gulf Shores and Orange Beach; however, this is most likely attributable to natural variation, as nesting success also declined by 11.6% in the BSNWR and Gulf State Park despite no change in ordinance enforcement at these latter locations. This supposition is supported by the logistic regression of nesting success, as the presence of an obstruction and treatment group were not significant components, consistent with Witherington et al. (2011) and Fujisaki & Lamont (2016). Rather, nesting success was driven by inter-

annual variability across the study site and increasing distance of nests from the high tide line.

The statistically insignificant changes in sea turtle crawl and nest distribution reported in the present study is in opposition to Fujisaki & Lamont (2016), who noted large increases in the number of crawls (89%) and nests (300%) in cleared sections of beach on Eglin Air Force Base in northwest Florida. Fujisaki & Lamont (2016) indicated that most of their debris was large, coarse woody debris (e.g. fallen trees, tree stumps) which covered up to 2% of the potential nesting area. Clearing this debris along a 1.7 km stretch of beach resulted in a significant shift of turtle activities from obstructed

sections into this cleared section of Eglin Air Force Base. Such a significant shift between cleared and non-cleared sections of beach was not observed in Baldwin County, Alabama. Debris in Baldwin County is largely abandoned beach equipment (which may be easier for sea turtles to navigate around or move out of the way compared to fallen trees or other natural debris) and covered a much smaller fraction of the available nesting beach. In addition, Baldwin County has approximately 10 times the potential nesting area as Eglin Air Force Base. Thus, turtles emerging in Baldwin County have more room to reach suitable nesting habitat, which explains the small effect size noted in the present study. It is possible that Leave No Trace ordinances may result in similar effect sizes to Fujisaki & Lamont (2016) in locations where abandoned beach equipment covers a percentage of available nesting area equal to or greater than that reported at Eglin Air Force Base. Fujisaki & Lamont (2016) did not report the frequency of obstructed crawls, so a direct comparison in this respect is not possible.

The presence of a resident human population was a more significant factor in determining the frequency of obstructed crawls than enforcement of the Leave No Trace ordinance, as the BSNWR and Gulf State Park had consistently lower rates of obstruction than the populated beaches both before and after the ordinance implementation. Gulf Shores and Orange Beach observed a decrease in obstructed crawls of 18.1% relative to pre-ordinance levels, while neighboring, non-ordinance Fort Morgan had a significant

relative increase of 45.5%. Tents, beach chairs, and wooden loungers were the most common obstructing objects, accounting for up to 56% of obstructed crawls. Unfortunately, early reporting during the pre-ordinance time period did not consistently identify the obstructing object, resulting in the large 'unidentified' category during this period (2013–2015; object identity was never reported in 2011–2012 and, as such, was removed in this object-identity trend analysis). Combined with increased interest in obstructions post-ordinance, any interpretation of the change in frequency of any particular object should be undertaken with caution.

Despite frequent enforcement of the Leave No Trace ordinance, hundreds of tents and thousands of chairs continue to be left behind overnight for the cities to remove. The direct and indirect effects of this abandoned equipment on coastal species and environments is not well documented in the published literature. Documentation of impacts from this equipment on coastal species and ecosystems (both on land and once it enters nearshore waters carried by storms, wave or tidal action, or attached to marine species) such as restricted mobility, increased energy expenditure, or changes in predation, erosion, or human spatial use need to be reported in order to improve coastal zone management. Entanglement in derelict fishing line, netting, carrying straps for beach chairs, or tent guy lines can restrict adequate feeding and mobility, open wounds susceptible to infection, or result in death from strangulation (Baulch & Perry 2014, Stelfox et al. 2016, Duncan et al. 2017). The consumption of plastics, fabrics, and other marine debris can lead to starvation from malnutrition or impaction of the gastrointestinal tract (Jacobsen et al. 2010, Di Benedetto & Arruda Ramos 2014, Duncan et al. 2019). When carried by wind, waves, and currents, derelict equipment can damage nearshore reefs or sensitive coastal vegetation (Chiappone et al. 2005, de Araújo & Costa 2006, Abu-Hilal & Al-Najjar 2009, Richards & Beger 2011). A reduction in abandoned equipment and improved trash disposal would limit exposure of coastal species to potential entanglement or ingestion hazards and decrease physical damage to marine environments (Bergmann et al. 2015, Gall & Thompson 2015, Nelms et al. 2016). Structures permitted on the beach by the ordinance (e.g. sand fencing, natural debris, business stands, facilities for public events) may still obstruct sea turtle activities; however, their rates of obstruction in Baldwin County were significantly less than that caused by ordinance-prohibited equipment. In higher concentrations, abandoned beach equipment

can pose significant risks to the adults and emergent hatchlings through entrapment, laceration, or drowning (Laurance et al. 2008, Rizkalla & Savage 2011, Ware & Fuentes 2018). It is also important to note that enforcement activities themselves, such as nighttime beach cleaning, may deter sea turtle emergence, alter spatial distribution, and/or reduce nest success through increased human activity (Witherington 1992, Jacobson & Figueroa Lopez 1994, Drobles et al. 2019).

Sea turtle nest site selection is highly variable, and a female turtle may abandon her nesting attempt at any time for reasons beyond obstructions, including human disturbance, artificial lighting, the presence of predators, and unfavorable sand conditions (Hailman & Elowson 1992, Garmestani et al. 2000, Chen et al. 2007, Kelly et al. 2017, Silva et al. 2017). Nests laid too close to the water are at increased risk of inundation and erosion, while nests closer to the dune risk increased predation of the eggs and emergent hatchlings (Fowler 1979, Mazaris et al. 2009, O'Connor et al. 2017, Ware & Fuentes 2018, Ware et al. 2019). Significant obstructions on the nesting beach may force sea turtles to nest closer to the water, increasing the risk of nest loss due to wave or tidal action (Rizkalla & Savage 2011, Witherington et al. 2011).

The environment of the nest site also plays a significant role in sea turtle embryonic development and nest productivity. Factors such as temperature, moisture, gas exchange, salinity, and sediment geology impact the sexual, morphological, and physiological development of the embryo during the roughly 2 mo incubation (Mrosovsky & Yntema 1980, McGehee 1990, Garmestani et al. 2000, Matsuzawa et al. 2002, Glen et al. 2003, Wallace et al. 2004, Chen et al. 2007). Thus, tents or other canopy structures may alter the incubating environment through shading of the nest (Kamel 2013, Hernandez-Cortes et al. 2018).

Assuming adequate pre-/post-ordinance data and a sufficient nearby control site are available, the BACIPS approach can be applied to other localities with similar ordinances. Tucker et al. (2006) credited the lack of beach equipment-obstructed crawls on Lido Key, Florida to a Leave No Trace ordinance passed the previous year. However, Oliver de la Esperanza et al. (2017) observed that 41% of the obstructed crawls at Kanzul Beach, Mexico were impacted by beach furniture despite their Leave No Trace ordinance. As these ordinances have been effective conservation measures for more inland ecosystems (Turner 2002), additional investigation is required to clarify the effectiveness of these ordi-

nances for coastal species management given these mixed results, with particular emphasis on enforcement and the types of obstructions specifically included in the ordinance.

The benefits of Leave No Trace ordinances for coastal species management extend beyond potential changes in sea turtle nesting success. Leave No Trace offers the opportunity for increased tourism, environmental education, and reduced production of marine debris. While it began as a series of educational and land-management principles released by the US Forest Service, US Bureau of Land Management, and US National Park Service in the 1960s to encourage outdoorsmen to leave the environment as undisturbed as possible (Marion & Reid 2001), Leave No Trace has encouraged a significant increase in protected area visitation, regardless of visitor duration in the area (Taff et al. 2014). This increased visitation at cleaner beaches can increase tourism revenue by millions of dollars, offsetting potential increases in municipal costs for waste removal (de Araújo & Costa 2006, McIlgorm et al. 2011, Jang et al. 2014, Williams et al. 2016, Krelling et al. 2017). Education about the impacts of human use on sensitive areas can encourage compliance with Leave No Trace principles and reduce human–ecosystem conflicts, including outside of the Leave No Trace area, such as minimized disturbance to wildlife and coastal ecosystems, reduced littering or equipment abandonment resulting in marine debris, and increased participation in environmental cleanups (Zeppel 2008, Lawhon et al. 2013, 2017, Beeharry et al. 2017, Mascovich 2018).

Improvements may not be immediate, as enforcement of, and behavioral changes associated with, a new ordinance require time (Sheavly & Register 2007, Owens 2018). Visitors and residents in a newly enforced area need time to learn about, and adjust their behavior to comply with, the ordinance. Strategic communications and marketing of the benefits of Leave No Trace ordinances tailored to multiple applications (e.g. threatened species conservation, increased tourism revenue, improved beach aesthetics) may increase adoption of positive environmental behaviors (Ockwell et al. 2009, Kamrowski et al. 2014, Fuentes et al. 2016). With time and compliance, fewer enforcement patrols will be needed, limiting the potential deterrent effect of nighttime human activity on sea turtle nesting, reducing coastal zone management costs, and increasing tourism revenue through cleaner beaches (Jacobson & Figueroa Lopez 1994, Ballance et al. 2000, de Araújo & Costa 2006, Jang et al. 2014, Krelling et al. 2017).

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