Impacts of the Caribbean *Sargassum* Influx on Sea Turtle Nesting Ecology

Impactos de la Afluencia Caribeña del Sargazo en la Ecología de la Anidación de las Tortugas Marinas

Impacts de l'Afflux de Sargasses des Caraïbes sur l'Ecologie de la Nidification des Tortues de Mer

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EXTENDED ABSTRACT

Sargassum macroalgae biomass spiked to unprecedented quantities in 2011 and has been increasing since (Schell et al. 2015, Wang and Hu 2016). As a result, seaweed has been episodically inundating western Atlantic shorelines, especially on windward coasts. These *Sargassum* arrivals often occur on the same beaches that serve as essential habitats for protected species such as marine turtles. On Long Island, Antigua, *Sargassum* arrivals are impacting a regionally important nesting population of hawksbill sea turtles (*Eretmochelys imbricata*; Maurer et al. 2015). Large quantities of the macroalgae pose a potential threat to females coming ashore to nest and to hatchlings leaving the beach (Figure 1), but these impacts remain mostly unassessed for any sea turtle species.

We quantified the effect of *Sargassum* accumulation on hawksbill nesting ecology during the 2015 nesting season. Specifically, we tested two hypotheses:

i) The spatial distribution of nesting crawls (emergence onto the beach to nest) would vary according to *Sargassum* presence, with more *Sargassum* associated with fewer crawls, and
ii) Beach zones most heavily affected by *Sargassum* in 2015 would receive a lower proportion of total seasonal crawls than the same zones in nesting seasons when little to no *Sargassum* was present.

Figure 1. A hawksbill sea turtle (*Eretmochelys imbricata*) attempts to pass through *Sargassum* accumulated on the shoreline at Pasture Bay of Long Island, Antigua in 2015. The post-nesting female is trailing a vine. The macroalgae commonly amassed into a substantial "barrier" along the shoreline and saturated the nearshore water column.

We collected data on hawksbill nesting and shoreline *Sargassum* abundance at Pasture Bay, Long Island, Antigua. We estimated an index of *Sargassum* quantity (ranging from 0 to 7) and counted all hawksbill crawls in designated beach "zones" (delineated perpendicular to the shoreline) nightly during the nesting season. To test our first hypothesis, we modeled 2015 hawksbill crawl counts with a negative binomial generalized linear mixed modeling approach, including predictor terms for the *Sargassum* index, sampling period (11 sequential periods of 14 days) and its square, and a random effect for beach zone. To test our second hypothesis, we used two regressions to compare "high *Sargassum* impact" data from 2015 to historical data (2008 - 2010 nesting seasons) that predated the start of the *Sargassum* invasion, as well as to 2016 data (negligible levels of *Sargassum*). We used the annual mean, per-zone *Sargassum* index to predict the percent change in proportion of crawls per zone between (1) 2008 - 2010 and 2015 and (2) 2015 and 2016.

Sargassum may also collect on the sand surface above incubating egg clutches and affect the incubation environment. This is particularly important given that temperature affects egg survival and primary sex ratios in sea turtles. Thus, to simulate effects on incubation temperatures, we buried temperature data loggers under experimental, factorial *Sargassum* treatments. We calculated 5-day mean temperatures for each of 30 logger deployments (3 treatments x 10 replicates) to use as the response variable in a two-way ANOVA including factors for treatment (none, low, high), season (wet, dry), and their interaction. During the "wet" season (n = 6 replicates), precipitation was higher by roughly an order of magnitude than the "dry" season (n = 4).

Our results suggest that *Sargassum* displaces crawl activity from preferred areas of the nesting beach. Within the 2015 season, the global model (i.e., including all terms) was the most highly supported based on AICc. *Sargassum* was a significant predictor and had a negative effect on crawl counts (coefficient estimate = -0.136 ± SE 0.33, p = 0.04). In our second approach comparing 2015 to less impacted seasons, *Sargassum* index was a significant predictor in both regressions. With increasing levels of *Sargassum*, the proportion of crawls in heavily affected zones decreased in 2015 relative to historical reference data (coefficient estimate = -0.233 ± SE 0.10). Subsequently, when *Sargassum* did not appear in 2016, the abundance of *Sargassum* in 2015 was positively related to proportion of crawls (coefficient estimate = 1.14 ± SE 0.21), i.e., crawl numbers rebounded in those zones that were most impacted in 2015 (Figure 2). Temperature data revealed a significant interaction between treatment and season (df = 2, F = 6.65, p = 0.004), suggesting that *Sargassum's* effects on belowground nest temperatures may differ with moisture conditions. *Sargassum* coverage had a cooling effect when dry and a warming effect when wet.

These findings have important implications for regional sea turtle conservation. In oceanic habitats, the macroalgae may provide habitat and shelter to young sea turtles (Mansfield et al. 2014, Hardy et al. 2018). However, our results show that on windward coastlines *Sargassum* has the potential to inhibit access to key nesting habitats and alter incubation temperatures. Nesting beach managers and conservationists should monitor the *Sargassum* influx closely, as it creates complex trade-offs for beach management. Removing the macroalgae from beaches can generate impacts such as sand compaction, inadvertent sand removal, and the alteration of natural erosion-accretion regimes, especially when heavy machinery is used. Impacts associated with removal must be weighed against economic effects (e.g., lost tourism revenue) and ecological consequences. In closing, we acknowledge the hard work of Jumby Bay Hawksbill Project field team members tenured during this project. The Jumby Bay Hawksbill Project is generously supported by the Jumby Bay Island Company and is a member of the Wider Caribbean Sea Turtle Conservation Network.

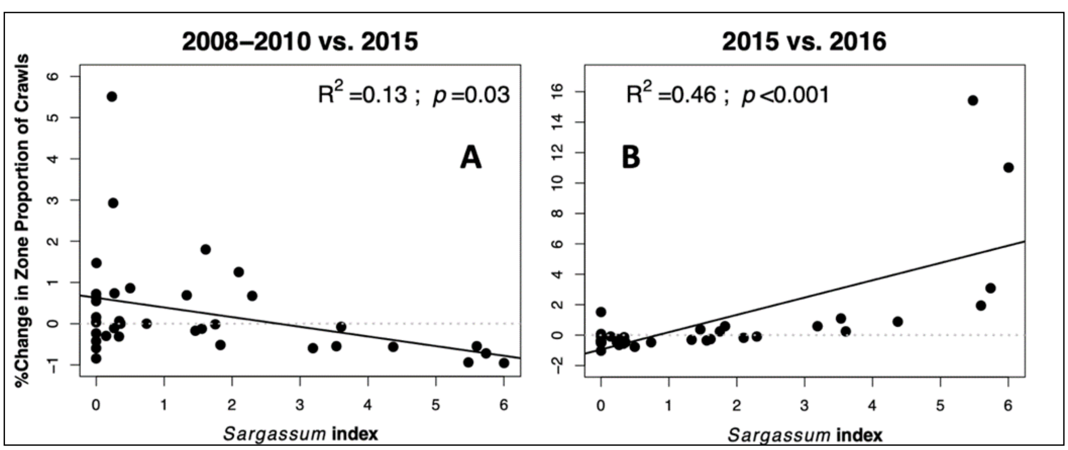

Figure 2. Linear regressions show the relationship between 2015 *Sargassum* abundance and crawl frequencies at a hawksbill sea turtle (*Eretmochelys imbricata*) nesting beach in Antigua, West Indies. In A, more *Sargassum* in 2015 is associated with a percent decrease in crawl frequency relative to historical reference data. After the macroalgae receded in 2016, B shows how crawls counts rebounded in those zones that were most affected by *Sargassum* the year before.

KEYWORDS: Invasion, hawksbill, *Eretmochelys imbricate, Sargassum*

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