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SEASONAL ABUNDANCE OF *AEDES SOLLICITANS* AND *AEDES TAENIORHYNCHUS* RELATED TO TEMPERATURE, RAINFALL AND TIDAL LEVELS IN NORTHEASTERN FLORIDA

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ABSTRACT. The Anastasia Mosquito Control District, which manages mosquitoes in St. Johns County in northeastern Florida, has observed that the maximum numbers of the salt marsh mosquitoes, *Aedes taeniorhynchus* and *Ae. sollicitan* appeared to shift or change relative to each other, as evidenced by the Centers for Disease Control and Prevention (CDC) light trap data in the past 17 years. The aim of this study was to analyze environmental data to identify and explore these changes. Data from CDC light traps, temperature, rainfall, and tidal levels were analyzed using ANOVA. Analyses showed the 2 species had maximum abundance at different temperatures, which translated into seasonal differences with peaks of *Ae. taeniorhynchus* in the summer and, to a lesser extent, later in the year, and *Ae. sollicitans* with a peak in the autumn. This seasonal pattern was reflected in rainfall (more rain in autumn than in summer) and also, in the general area, in tidal levels (mean highest tide levels at the recording station were in autumn). The research demonstrated that simplifying the mosquito data, initially using only very high trap numbers (Mean ± 2 SD) that are important for control, identified, and made the seasonal pattern very obvious. The pattern was also observed using all the data but, although significant, was not as clear. Having identified tide as a potential driving variable, further research needs to detail spatial tidal patterns to identify areas and timing of flooding and explore the relationship between salinity and mosquito species and abundance. This is important as sea levels rise and climate changes, both potentially changing the mosquito situation and affecting control actions.

KEY WORDS *Aedes sollicitans*, *Aedes taeniorhynchus*, rainfall, temperature, temporal patterns, tides

INTRODUCTION

Mosquitoes are a public health issue and mosquito control is implemented to protect people's health and quality of life. To do this, it is important to know when there are likely to be mosquito problems. In many control programs the information is obtained from adult mosquito light trapping in areas of human population. This is the information base in St Johns County, northeastern Florida, where there are problems with salt marsh mosquito species. Two major species are *Aedes taeniorhynchus* (Weidemann) and *Aedes sollicitans* (Walker), and both have been shown to be vectors of eastern equine encephalitis in the laboratory (Turell 1989). Based on the Centers for Disease Control and Prevention (CDC) light trap data collected by the Anastasia Mosquito Control District (AMCD) of St. Johns County, population numbers of *Ae. taeniorhynchus* and *Ae. sollicitans* were suspected of periodically shifting or changing relative to each other. Previous research has explored meteorological and tidal conditions associated with each species separately; for example, Shone et al. (2006) investigated combinations and cross correlations of 10 meteorological and tidal variables to create a model of female *Ae. sollicitans;* Qualls et al. (2022) focused on *Ae. taeniorhynchus* and found that land use was significantly related to the distribution of the species. Some studies considered both species together: (Ebsary and Crans 1977, Evans et al. 1987, Ailes 1998, Rueda and Gardner 2003, Walsh et al. 2008, Leisnham and Sandoval-Mohapatra 2011). However, although many variables were explored, there was no overall consensus about which specific ones would be useful to define or explore the observed shift or change for each species.

The aim here was to identify and explore the apparent shift or change in abundance of *Ae. taeniorhynchus* and *Ae. sollicitans* and the relationship to environmental factors, including temperature, rainfall, and tidal levels, as these are generally relatively simple determinants of mosquito abundance.

MATERIALS AND METHODS

Data

The Anastasia Mosquito Control District provided Excel data files including weekly mosquito CDC light trap (baited with octenol) data from 2004 to 2020, temperature records from the National Oceanic and Atmospheric Administration (NOAA) (2004–2019), rainfall data from the National Center for Environmental Information (NCEI), and local tidal levels at the St Augustine NAVD88 station #79 (2011–2019) from the Florida Department of Environmental Protection. Some of the files were not suitable for direct inclusion with the mosquito abundance data. For example, tidal data were recorded every 6 min resulting in 80K rows of data for each year and this could not be directly related to trap counts. First, an attempt was made to identify the nature of the shift or change using trap counts and temperature records. Temperature is generally considered to be an important influence on mosquito abundance. Because higher temperature can increase rates of development

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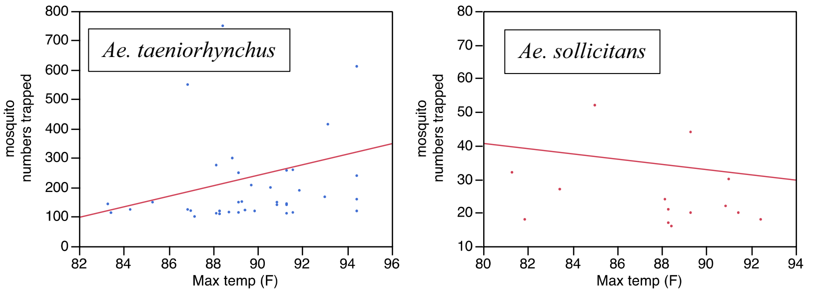

Fig. 1. Mean maximum temperature and mosquito abundance for *Aedes taeniorhynchus* and *Ae. sollicitans* (VHMN).

and ultimately trap counts, the analysis started with average maximum weekly temperature and weekly adult trap data. Those data sets were easily combined, as were the rainfall records (current week + 2 previous weeks, as there can be a time lag between rainfall and mosquito hatch and adult emergence). After the first analyses the rest of the data were organized by season, as that was identified as the key to the change or shift between the 2 species and enabled direct comparisons between variables.

Analysis

Descriptive and analytic statistics were used with ANOVA (SAS JMP®, Version 9, SAS Institute Inc., Cary, NC, 1989–2023) to assess relationships between the 2 species with mean weekly maximum temperature and with rainfall in the current and preceding 2 weeks. Because very high numbers of mosquitoes (VHMN) indicate a significant nuisance issue, the initial analysis used only those numbers from the light trap data for each species. That included only numbers above the mean for that species plus 2 standard deviations (SDs). Based on the temperature relationships it appeared that season was a key to identifying a shift or change in abundance of each species. The seasonal data were complete from 2004 to 2020. To assess the overall seasonal patterns and to see if any observed trends were general, the VHMN data were first used to analyze season and rainfall, then the complete but sparser data for the 2 species were also analyzed. Of the complete but sparser data, 25% were single occurrences for *Ae. taeniorhynchus* and 50% were for *Ae. sollicitans.* Tide levels could not be directly related to mosquito numbers, but seasonal patterns were used to complement information as in Lloyd et al. (2018).

RESULTS

Overall, there were more *Ae. taeniorhynchus* captured in the CDC light traps than *Ae. sollicitans*—a total of 20,384 mosquitoes for both species, of which 19,418 were *Ae taeniorhynchus* (95%) and 966 were *Ae. sollicitans* (5%).

For the first analysis light trap numbers greater than the mean ± 2 (SD) were taken as cut-offs, based on positive trap counts. For *Ae. taeniorhynchus* the cut-off was 100.81(mean 12.07 ± 44.37 (SD); for *Ae. sollicitans* it was 24.37 (mean 4.33 ± 10.02 (SD)). After the cut-offs *Ae. taeniorhynchus* comprised 72% of the records and *Ae. sollicitans* 28%. This accounts for Y axes with different scales in the figures.

There was a relationship between both *Ae. taeniorhynchus* and *Ae. sollicitans* and mean maximum temperature (Fig. 1). It was not statistically significant but did indicate a contrast between the 2 species with *Ae. taeniorhynchus* numbers increasing with higher temperature, whereas *Ae. sollicitans* numbers increased with lower temperatures.

As shown in Fig. 1, temperature is related to season and there was a significant effect of season for *Ae. sollicitans* ($F = 6.36$, $df = 1,14$, $P < 0.05$). *Aedes taeniorhynchus* was only significant at the 10% level ($F = 2.77$, $df = 1,39$, $P = 0.10$). There were no trap numbers in spring or winter that exceeded the cut-off values for the 2 species and so those seasons are absent in Fig. 2. Figure 2 shows a distinct difference in the seasonal distribution of the 2 species and this could contribute to understanding the shift or change. It showed that *Ae. taeniorhynchus* numbers peaked in summer when *Ae. sollicitans* had below average numbers and conversely when *Ae. sollicitans* numbers peaked in autumn, *Ae taeniorhynchus* had below average numbers.

Rainfall is another factor. Figure 3 shows the linear relationships between rainfall in the current and preceding 2 weeks for the 2 mosquito species. There was no significant relationship for *Ae. taeniorhynchus,* but *Ae. sollicitans* was significantly positively influenced by rainfall at the 10% level ($F = 3.23$, $df = 1,14$, $P < 0.10$,). Examining the rainfall data by season established that rainfall was much greater during autumn than in summer, again matching the abundance for *Ae. sollicitans.*

Although major differences were clear from the VHMN data set, it is useful to examine whether the trend is obvious in the whole data set for the 2 species. The more general relationship, using all the positive data, for the 2 species still showed a significant, though less obvious, relationship with season (Fig. 4). It was significant for *Ae. taeniorhynchus* ($F = 2.71$, $df = 3,2109$, $P < 0.05$) and *Ae. sollicitans*

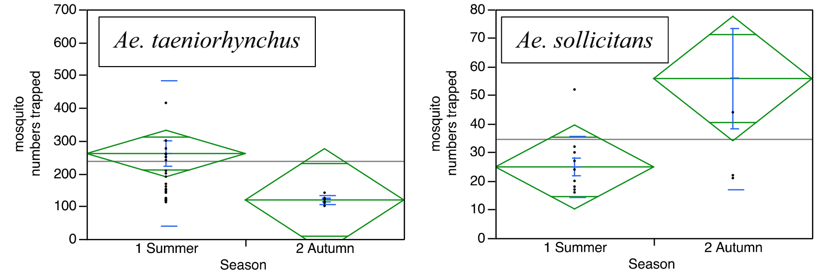

Fig. 2. Season x species x mosquito numbers (VHMN): Mean diamonds, grand mean (gray line) ± standard error.

($F = 2.18$, df $= 3{,}54$, $P < 0.10$). The most obvious difference was in the summer peak for *Ae. taeniorhynchus* and the autumn peak for *Ae. sollicitans*. An extended Student's *t*-test confirmed the findings and also showed that there were 2 peaks for *Ae. taeniorhynchus* (summer and winter), which were significantly different from spring and autumn ($t = 1.96$, $P < 0.05$) and that there was a single peak for *Ae. sollicitans* (in autumn and winter), which was significantly different from spring or summer ($t = 1.07$, $P < 0.05$).

Marsh flooding from tides is another factor that influences salt marsh mosquito abundance. The available data were organized to check for patterns, especially in seasonal flooding. As depicted in Fig. 5, autumn stands out with very high high-water levels. The effects of season were significant for both the highest tides ($F = 10.81$, df $= 3{,}69$, $P < 0.0001$) and also for the lowest tides ($F = 12.42$ df $= 3{,}69$, $P < 0.0001$) with maximum levels in autumn (Fig. 5).

DISCUSSION

This study has highlighted that focusing on the VHMN data characteristics (for example, using the VHMN data before considering all the data), can identify trends that might be obscured by including large amounts of small mosquito numbers (and those may not be contributing a great deal to the mosquito nuisance).

The identification and the understanding of the observed shift or change was developed by stages. The first factor was the temperature relationships, as temperature has been well documented to be important for mosquito development times. This led to exploring seasonal patterns. Then rainfall patterns indicated that *Ae. sollicitans* were more numerous with increased rainfall, which was higher in autumn, and this also supported the autumnal peak in *Ae. sollicitans*.

Tide levels are important but could not be directly related to mosquito numbers because the data sets did not match. As well as tidal flooding a marsh, dissolved oxygen is reduced and this stimulates egg hatch (Horsfall et al. 1958, Knight et al. 2013), so that larval develpment proceeds as soon as possible after flooding. The higher autumnal tidal pattern supported the autumnal peak in *Ae. sollicitans*, especially when considered in the light of the Florida White paper (Lloyd et al. 2018), which noted that *Ae. sollicitans* was common in high marsh locations. Similarly, Shone et al. (2006) noted that *Ae. sollicitans* larvae develop in pools flooded by high tides in Maryland. If that were so in St. Johns County, then times of flooding from high tides as well as seasonally higher rainfall would both have contributed to flooding the higher *Juncus* marsh areas, providing habitat for *Ae. sollicitans*. This is further potentially explained by egg laying preference/behavior—if *Ae. sollicitans* oviposit in the high marsh then, if the marsh is not inundated, the eggs would not hatch and the species would not complete its life cycle, i.e., none or very few would ultimately reach CDC traps. This may help explain why there were many fewer *Ae. sollicitans* in the CDC light traps than *Ae. taeniorhynchus*. This may be offset somewhat by immatures

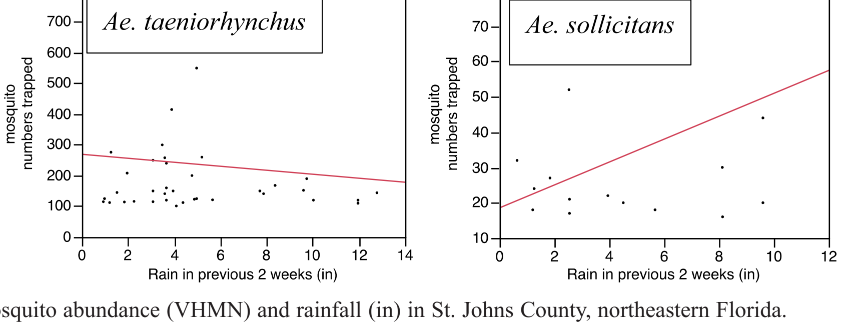

Fig. 3. Mosquito abundance (VHMN) and rainfall (in) in St. Johns County, northeastern Florida.

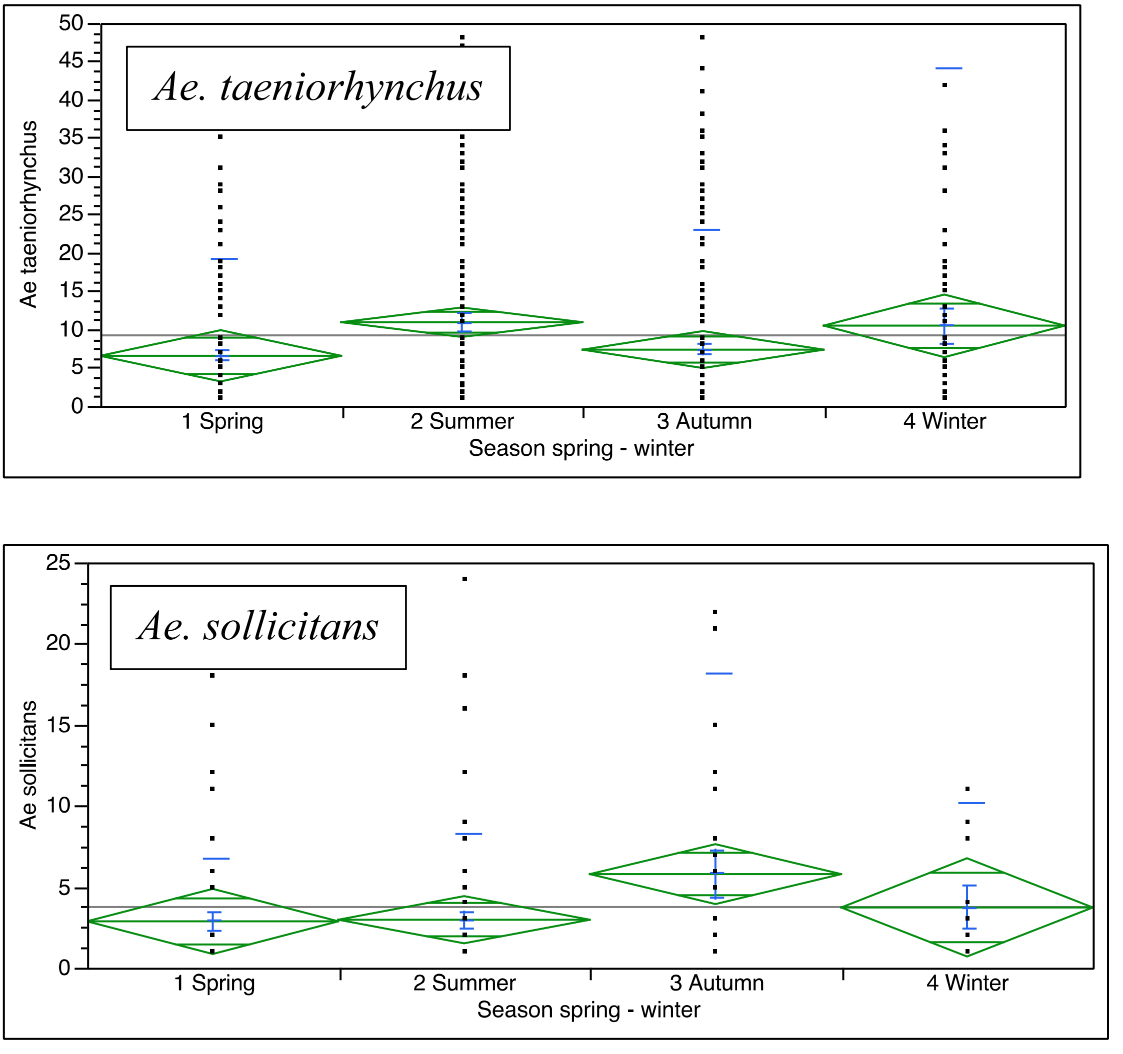

Fig. 4. The general picture using all positive trap data: Mean diamonds, grand mean (gray line) ± SD.

of *Ae. sollicitans* developing faster than those of *Ae. taeniorhynchus* (O'Meara 1992). When *Ae. sollicitans* high marsh habitat is inundated then larvae would be found there and possibly, with high water level, be flushed into the low marsh explaining why both species might be found together in the traps.

Turell (1989) reported that both *Ae. taeniorhynchus* and *Ae. sollicitans* larvae can tolerate a wide range

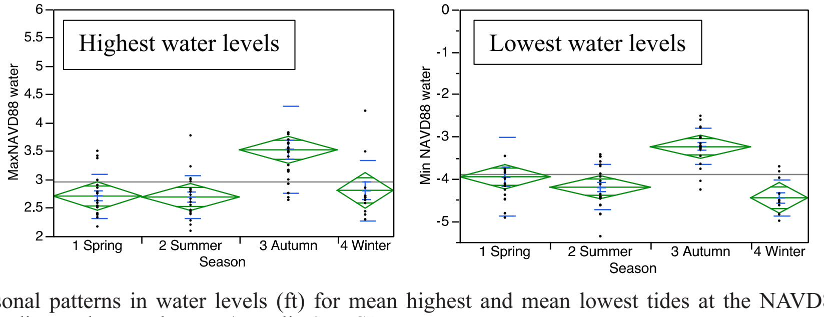

Fig. 5. Seasonal patterns in water levels (ft) for mean highest and mean lowest tides at the NAVD88 station in St Augustine: Mean diamonds, grand mean (gray line) ± SD.

of salinities from fresh to saline. As the higher marshes in St Johns County are often close to development and subject to freshwater run-off, salinity levels may be periodically lower than in the lower tidal areas and this may benefit *Ae. sollicitans.* Land use/cover was not considered, but (Qualls et al. 2022) found it to be relevant to *Ae. taeniorhynchus*. It may be that although temperature was the variable that first identified the seasonal pattern, it could be that salinity or tidal flooding is the driving variable. This cannot be determined at present, but it could be a focus of further research, and assist mosquito control by being better able to forecast the abundance of nuisance species. A factor not considered was that the 2 peaks for *Ae. taeniorhynchus* shown in Fig. 4 may be related to wind speed, as was noted by Hribar et al. (2010). Wind speed was not part of the data provided but this could be another avenue for research.

This project has identified the value of using the VHMN light trap data to initially identify patterns. It also opened up ideas for further research, including researching the spatial and temporal distribution of salinity in the marshes and the implications for mosquitoes, identifying spatial tidal flooding patterns and larval habitats. This could assist mosquito control preparedness especially as dealing with sea level and climate change impacts become more urgent.

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