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Daniel B. Gingold, Matthew J. Strickland, and Jeremy J. Hess

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Ciguatera Fish Poisoning and Climate Change: Analysis of National Poison Center Data in the United States, 2001−2011

Daniel B. Gingold,[1] Matthew J. Strickland,[1,2] and Jeremy J. Hess[2,3]

[1]Department of Epidemiology, Rollins School of Public Health, [2]Department of Environmental Health, Rollins School of Public Health, [3]School of Medicine, Department of Emergency Medicine, Emory University, Atlanta, Georgia, USA

Address correspondence to Daniel Gingold, 614 Wyeth St., Baltimore, MD 21230 USA. Cell phone: 301-502-5061. E-mail: dbgingo@gmail.com

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Abstract

Background: Warm sea surface temperatures (SST) are positively related to incidence of ciguatera fish poisoning (CFP). Increased severe storm frequency may create more habitat for ciguatoxic organisms. While climate change could expand the endemic range of CFP, the relationship between CFP incidence and specific environmental conditions is unknown.

Objectives: Estimate associations between monthly CFP incidence in the contiguous United States and SST and storm frequency in the Caribbean basin.

Methods: We obtained information on 1,102 CFP-related calls to US poison control centers between 2001-2011 from the National Poison Data System (NPDS). Time-series analysis was performed using Poisson regression to relate monthly CFP call incidence to SST and tropical storms. Associations were investigated across a range of plausible lag structures.

Results: Results showed associations between monthly CFP calls and both warmer SST and tropical storm frequency. The SST variable with the strongest association linked current monthly CFP calls to the peak August SST of the previous year. The lag period with the strongest association for storms was 18 months. If climate change increases SST in the Caribbean 2.5 – 3.5°C over the coming century as projected, this model implies that CFP incidence in the US is likely to increase 200-400%.

Conclusions: Using CFP calls as a marker of CFP incidence, these results clarify associations between climate variability and CFP incidence and suggest that, all other things equal, climate change could increase the burden of CFP. These findings have implications for disease prediction, surveillance, and public health preparedness for climate change.

Introduction

Ciguatera fish poisoning (CFP) is the most common non-bacterial illness associated with fish consumption, affecting 50,000 - 200,000 people annually (Dickey and Plakas 2010). Ciguatera toxin is produced by benthic dinoflagellate plankton in the genus *Gambierdiscus*, which live on dead coral surfaces and bottom-dwelling algae. Toxin accumulates in tissues of fish that eat the algae and bioaccumulates up the food chain (Tester et al. 2010). Humans eating contaminated fish are susceptible to the toxidrome caused by the ciguatera toxin, which includes gastrointestinal upset followed by neurologic symptoms including paresthesias and hot-cold reversal (Friedman et al. 2008).

CFP is a significant public health problem in endemic areas, including the Caribbean and Pacific Islands. CFP prevalence in these areas is affected by El Niño and warm sea surface temperature (SST) (Hales et al. 1999; Llewellyn 2010; Tester et al. 2010). CFP is most prevalent in tropical regions of warm and stable SST that remain above 24°C, and laboratory studies have shown that water temperatures of 29°C are optimal for *Gambierdiscus* growth (Hales et al. 1999; Tester et al. 2010). Climate change is projected to expand the range of suitable habitat for the organisms that cause ciguatera by expanding the range of warm SSTs and bleaching coral reefs (Moore et al. 2008). Increase in storm frequency also damages reefs and increases nitrate-rich soil runoff, which may increase the growth of marine algae and ciguatera toxin-producing organisms (Swift and Swift 1993).

We hypothesize that CFP incidence in the US is associated with warm Caribbean SST and high severe storm frequency. If true, projections of increased SST and storm frequency from climate change suggest CFP incidence in the US may increase. In addition, this study provides an opportunity to investigate the epidemiology of CFP in the United States and evaluate the suitability of the National Poison Data System (NPDS) for use in surveillance of CFP.

Methods

Summary

We used data from multiple sources to perform a time series analysis exploring plausible associations between SST, storm frequency, and CFP incidence. First, we produced descriptive statistics on timing and location of CFP calls. We also evaluated single variable associations between candidate variables (which were created with a range of lag times and parameterization techniques) and CFP calls to identify the lag time and weather variable parameterization technique most associated with CFP calls. Using these results, we developed a final model using stepwise selection, which included variables most strongly correlating with CFP calls and most consistent with known ecological mechanisms linking weather and CFP. Finally, we used rate ratios from this model to projected climate scenarios to hypothesize the magnitude of effect of weather on ciguatera cases in the US. Additional details regarding data sources, treatment, and analysis are presented below. We also present results from the single variable analysis to guide the reader through our selection of variables for the final model, and to inform future investigation to optimize weather variable parameterization for association with CFP.

Ciguatera cases data

Calls to US poison control centers with substance code "Ciguatera Fish Poisoning" affecting humans during 2001-2011 were obtained from the National Poison Data System (NPDS) run by the American Association of Poison Control Centers (www.aapcc.org). We obtained data for all calls from the lower 48 United States (US) states, the District of Columbia (DC), Puerto Rico

(PR), and the US Virgin Islands (USVI) (N = 1,124). Poison center calls are coded with the ciguatera substance code if information about ciguatera toxin is discussed. From these, we selected the subset of calls where ciguatera fish poisoning was the sole substance code listed (N = 1,102) Calls coded with "confirmed non-exposure" were excluded from analysis. Day, month, and year were available for all recorded calls. Location was coded by the state or country from which the call originated. Data regarding where the exposure occurred, type/origin of fish consumed, and other narrative notes were unavailable for analysis. Calls were assigned regions and division locations according to the US census regions.

Key variables in the descriptive analysis include date, state, and ZIP code of call; caller site (home, work, etc.); exposure site (home, work, etc.); age in years (134 missing values, but some of these were coded as "unknown adult", "child", "teen", etc., which were used in coding the age categorical variables); gender of patient; outcome; reason/route; clinical symptoms reported, clinical effect; and therapy. Outcomes are determined by the poison information specialist coding the call at the conclusion of the case, based on available information on the severity and duration of symptoms and need for treatment as a result of the exposure. "Major effects" are symptoms that are life threatening or result in significant residual disability or disfigurement. "Moderate" effects are less pronounced symptoms with no residual effects but typically required treatment; "mild" effects had short duration and were minimally bothersome.

Sea surface temperature data

Monthly SST data from years 1999-2011 contained in the Reynolds/NOAA (OI.v2) SST Data Set were downloaded from the IRI/LDEO Climate Data Library at Columbia University (IRI (The International Research Institute for Climate and Society) 2012). Weekly SST values are created on a 1° by 1° spatial grid from ship, buoy, and satellite measurements as well as SST simulated by sea-ice cover. (Reynolds and Smith 1995; Reynolds et al. 2002). Monthly values are created by linear interpolation of weekly data to daily fields, and averaging daily values in a 1° global spatial grid. Land-masking was used to remove values for SST that were over land. Monthly maximum and minimum SST in the Caribbean were found in bounds of 7°N-35°N latitude and 97°W-40°W longitude (exclusive of the Pacific Ocean included in this area). Maximum and minimum monthly SST values along 34.5°N and 24.5°N were found by restricting data to a 1° band around these parallels. Monthly maximum and minimum latitudes for the 25°C and 29°C contours were found by limiting the monthly data to all measurements within 0.25°C of the desired contour and finding the maximum or minimum latitude value for each month. Yearly maximums (minimums) were found by taking the largest (smallest) monthly value for that year. To create the peak August temperature variable, we assigned the maximum temperature value in August over the Caribbean region of a given year to all months of the same calendar year; the same was done for the nadir March temperature variable using the minimum temperature value in March.

Caribbean SST anomaly index data

Monthly Caribbean SST index values from years 1999-2011 were obtained online from the Earth System Research Laboratory at the National Oceanic and Atmospheric Administration (NOAA) (NOAA 2013). SST forecasts, based on NOAA Extended Reconstructed Sea Surface Temperatures version 3b employing linear inverse modeling, are used to calculate anomalies relative to 1981-2010 climatology (Penland and Matrosova 1998). These anomalies are averaged over the Caribbean (bounded by 26°N, 80°W, and the eastern coast of Central America) to create a monthly SST index value, identified by NOAA as the “CAR index”, that represents the deviation of current SST in the entire Caribbean region from historical averages.

Severe tropical storms data

Data for severe tropical storms (tropical depressions, tropical storms, and hurricanes) for years 1999-2011 are available online from Unisys Weather (Unisys 2012). Storms were assigned to months in which they began. Total storm-days for a month are the sum of the durations of all storms that began in that month. Severe storms are indicated by a category 3 or greater hurricane, according to the Saffir-Simpson scale. Data for Accumulated Cyclone Energy (ACE), a measure of the strength and duration of storms over a monthly period, is available from NOAA (Maue 2011; Policlimate 2012).

Fishing yields data

Caribbean fishing yields during years 2001-2010 are available from the Food and Agriculture Organization of the United Nations (United Nations 2012). The online query tool for global capture production provided yearly totals for fishing capture of marine and diadromous fishes in marine areas for the Western Central Atlantic Ocean (bounded by 35°N, 40°W, and the eastern coasts of North, Central, and South America). These data are in metric tons and are reported yearly. Fishing yields for 2011 were estimated using data from the previous decade based on a linear regression model.

Lagged variables

We created lagged variables for weather explanatory variables for 3, 6, 12, 18, and 24 month lags. A 3 month lag assigns the value of the original variable in January to the following April. Lagged variables for peak and nadir variables do not have a constant lag period. For example, the lag period for the August maximum SST variable of the previous calendar year are between 5 and 16 months: January values refer to the most recent August 5 months prior, but December values refer to the August 16 months earlier.

Analysis methods

We used Poisson regression to estimate associations between monthly CFP incidence and SST and storm frequency, using regional annual captured fish production yields as the offset (to compensate for the effect of changing fishing yields). Candidate explanatory variables included severe storm totals (by category), total storm days, monthly SST anomaly, each month's maximum and minimum SST in the Caribbean region and along the 34.5°N and 24.5°N parallels, and the maximum and minimum latitudes achieved each month by the 25°C and 29°C SST contours, as well as variables created to reflect the August maximum and March minimum temperatures for each year. Pairwise correlations between candidate variables were evaluated using Pearson coefficients.

We evaluated the association between CFP calls and explanatory storm and SST variables using 0, 3, 6, 12, 18, and 24 month time lag windows, controlling for month with dummy variables and using the yearly regional fishing yields as an offset. Direction and magnitude of the regression coefficients were examined graphically to identify the lag period for each variable that achieved the highest statistical significance by Wald chi-squared statistic. Standard errors were scaled by the Pearson's chi-square statistic in order to inflate the standard errors of the model's beta coefficients to account for over-dispersion of observed data relative to the Poisson assumption of variance = mean. We selected variables for inclusion in the multivariate model based on the individual variable analysis. The multivariate model retained the monthly dummy variables and offset. We used rate ratios from the multivariate model to estimate the expected number of ciguatera calls due to a 10% or 25% increase in storm frequency (Henderson-Sellers et al. 1998;

Oouchi et al. 2006) and 2.5°C or 3.5°C increase in SST (Christensen et al. 2007; Moore et al. 2008; Sheppard and Rioja-Nieto 2005). All analysis was performed using SAS version 9.3 (SAS Institute, Inc., Cary, NC).

Results

There were 1,102 calls exclusively coded as ciguatera and made from the lower 48 US states, PR, DC, or USVI. Descriptive statistics for these calls are presented in Table 1. The South census region, which includes Florida and other Gulf and Atlantic coast states, has the largest proportion of calls (62.2%). 412 (37.4%) calls resulted in moderate or major clinical effect (including death). The most common symptom reported was diarrhea (39.3%), followed by vomiting (32.1%) and numbness (22.3%) (data not shown). While volatile, yearly CFP totals demonstrated a moderate overall increase in CFP calls across the decade of available data (Table 1, Supplemental Material, Figure S1, S2).

Descriptive statistics for candidate monthly variables for regression are shown in Table 2; for conciseness these results are presented for alternating months. There is a clear seasonal pattern of CFP calls, with more calls being made during the summer months. As expected, there was a seasonal pattern to both storms and SST data: during summer months, water temperatures were warmer, extended farther northward, and storms were more frequent. Pairwise correlations among these variables are shown in the supplemental material, Table S1. Positive correlations were present for all of the variables except the minimum latitude of the 29-degree contour. The August maximum regional SST is positively correlated with the August CAR index ($R=0.88$, $p<0.001$) and mean yearly CAR index ($R=0.66$, $P=0.014$) and less so with yearly storms ($R=0.41$, $P=0.16$). Yearly ACE is correlated with yearly total storms ($R=0.75$, $P = 0.003$) (Supplemental material, Table S1). Trends of yearly calls, storms, and maximum August SST in the Caribbean are shown in Supplemental Material, Figures S1 and S2. While yearly CFP call totals generally increased over the decade, there is less of an obvious pattern to peak temperatures and storm frequency, which peaked in 2005.

Results from the univariate analyses are shown in the supplemental material, Tables S2 and S3. Parameter estimates for the storm variables by lag time are displayed graphically in Figure 1. The beta coefficient estimates are largest at the 18-month lag time, at which point the total storms variable (which has the most observations) is significantly associated with the number of CFP calls (Wald chi-squared statistic 4.22, $p = 0.04$) (Table S2). A similar pattern was less apparent among the SST variables. While 12 months is a relatively consistent inflection point, most of these associations were not statistically significant (see Supplemental Material, Tables S2 and S3). Among peak variables, the peak August SST for the previous calendar year variable was positively associated with the outcome in the individual variable model ($p = 0.004$). There were other peak and nadir variables that were associated with the outcome, although most lost significance when included in a multivariate model.

Candidate variables for the multivariate model were identified by the strength of their association with the outcome in the univariate analysis (Supplemental Material, Tables S2 and S3). Many variables no longer had significantly parameter estimates when included in the Poisson model simultaneously. Significant associations persisted with the total storm variable lagged at 18 months and the peak Caribbean SST from August of the preceding calendar year (variable 5-16 month lag); these variables were included as the explanatory variables in the final multivariate Poisson model (Supplemental material, Table S4). The rate ratio for an increase of one severe storm per month was 1.11 (95% CI [1.03, 1.23]) and the rate ratio of an increase in SST of 1°C per month is 1.61 (95% CI [1.17, 2.24]) (Table 3). These rate ratios did not change substantially with inclusion of borderline variables in the multivariate model (see Supplemental Material, Table S4). Restricting ciguatera cases to only those with moderate or major clinical effects resulted in rate ratios of similar values, although confidence intervals were wider (and included the null) because the number of calls was reduced by 65% (see Supplemental Material, Table S5). Limiting fishing yields to fish species commonly found to be ciguatoxic resulted in rate ratios for SST between 1.2 and l.4, consistent with our original model's results, although the 95% CIs do not include one. Statistical significance varied depending on which fish were used, but most excluded the null. Rate ratios for storms and their statistical significance did not change under this sensitivity analysis (see Supplemental Material, Table S5).

As climate change progresses the effect of increases in SST on storm frequency is uncertain. Several possible scenarios are displayed in Table 3, with predictions in CFP cases provided by the final multivariate model. Percent change in storms is relative to the baseline of our data, years 2001-2011, during which there was an average of 17.5 storms per year (1.46 per month) and 100.2 CFP calls per year (8.35 per month) (Table 2). For example, if the maximum SST in the Caribbean increases by 2.5°C as projected, and storm frequency increase by 10%, then 238.5 additional calls per year can be expected based on the regression model results (95% CI [49.5, 665.9]) (Table 3). These estimates assumes that population, rate of fish consumption, clinical recognition, and other factors affecting CFP calls in the US remain similar to 2001-2011 levels.

Discussion

Summary

We found that the monthly ciguatera-related calls to poison control centers in the continental US were associated with both tropical storm frequency and peak SST in the Caribbean basin during the study period. An increase of one storm per month (lagged 18 months) was associated with an increase in CFP calls of 11% (95 CI [0.4, 23]), while an increase in one degree SST during August of the previous calendar year was associated with a 62% (95% CI [17, 1242]) increase in calls. As SST and storms are positively correlated, any meteorological change that causes one of these factors to increase will likely cause an increase in the other as well.

Recent increases in Caribbean SST are very likely due to climate change, and projections predict an increase of 2.5°C or greater during the twenty-first century (Christensen et al. 2007; Moore et al. 2008; Sheppard and Rioja-Nieto 2005). Increases in storm frequency are less certain, although regional storm frequency has been linked to SST and it is possible storm frequency will increase in the North Atlantic (while it is very likely that storms become more intense) (Christensen et al. 2007; Oouchi et al. 2006). Our model suggests that for moderate increases in both SST and storms, the effect of SST would dominate, with the effect of storm increases accounting for a small proportion of the expected increase in CFP calls (Table 3). In these scenarios, our model estimates that two to four hundred calls a year could be attributable to climate change assuming constant population and fish consumption. This represents a large (200-400%) increase in yearly CFP incidence (using poison center calls as a marker for true incidence) relative to 2001-2011 baseline. While these estimates are uncertain, they imply that the fears of an increase in CFP in the US may be justified and that this increase may be significant from both a clinical and public policy perspective.

Comparison of results to literature

Using the yearly average calls of 100 and US population of 300 million (roughly average for the decade) our dataset had a yearly call incidence of 0.003 per 10,000 residents. This is significantly lower than other reports in the US literature (0.3 in Hawai'i, 5 in Dade County, FL) (Azziz-Baumgartner et al. 2012; Friedman et al. 2008). However, using an expected reporting rate of 1%

this may represent a true yearly incidence of 0.3 per 10,000, which is a reasonable order of magnitude given that the study area included both high and low CFP incidence areas (Lawrence et al. 1980). Incidences of CFP calls in PR and USVI were lower than previously reported survey data there, as residents in CFP endemic areas are familiar with the disease and probably rarely seek assistance from health professionals or poison control centers (Azziz-Baumgartner et al. 2012). Numbers of CFP calls identified in our data are consistent with US incidence estimates in previous literature, as is the seasonal trend of more cases in the summer than winter months (Tosteson et al. 1988).

Commonly associated symptoms in our dataset were similar to previous reports (Azziz-Baumgartner et al. 2012; Friedman et al. 2008), although the percentages of observations with each type of symptom were generally lower in our data. This may be because our data has more low-severity or unconfirmed cases, and the reports in the literature are more likely to be confirmed and therefore more likely to have more substantial clinical effects.

The literature provided little guidance on choice of lag structure for the regression variables. For SST lags, previous literature reported 13 months or more as appropriate (Parsons et al. 2010). Our 5-16 month lag is consistent with previous work as well as the proposed mechanism of the effect of weather on CFP, in which warmer SST increase ciguatoxic organism growth that after bioaccumulation increases human exposure to ciguatera toxin For storms the literature had no guidance, but we expected the lag time for the effect of storms (18 months) to be longer than that of SST since the proposed mechanism adds habitat destruction and re-colonization by toxic dinoflagellates to the SST timeline. More research must be done to better measure and understand these lag structures.

Notably, 2005 was a peak year for SST and storms in our data, possibly due to an ENSO/El Niño warming event during the last part of 2004 and early 2005 (NOAA 2012). Globally, 2005 was the hottest year since 1880 to date, and has only been matched by 2010 since (Hansen et al. 2010; NASA (National Aeronautics and Space Administration) 2011). While there has been some evidence that Pacific CFP is affected by ENSO events, calls did not peak in 2005, although years after 2005 did experience a rise in call frequency (Hales et al. 1999).

Limitations

There are several limitations to our data and approach. Our outcomes are not confirmed cases. As mentioned above, poison center calls are coded with the ciguatera substance code if information about ciguatera toxin is discussed. Often there are several codes for similarly presenting illnesses and the call is to discuss this differential diagnosis. Follow-ups to confirm the diagnosis are rare, although ciguatera is always a clinical diagnosis since there are no reliable diagnostic tests or biomarkers for detection in humans. Apart from a reduction in the severity of symptoms associated with cases identified in this way, it is difficult to determine the impact of this potential bias on the findings.

More importantly, the information about location of the call is limited to what call center took the call and does not include exposure location or fish origin. It is common for travelers to present with symptoms upon return from a trip. For this reason, we chose to correlate calls with Caribbean basin weather instead of making the resolution of these data finer than is warranted by the method of data collection. We assume broadly that fish causing a ciguatera-associated illness in the continental US are very likely to have come from the Caribbean and been exposed to ecological and meteorological conditions there. Given that most US cases are from regions where CFP is locally endemic, this is not an unreasonable assumption. We also assume that while ciguatoxin can survive freezing and other food preservation methods, fish are consumed around the same time (same year) they are harvested (Friedman et al. 2008). Lag times are meant to incorporate the ecological lag time between meteorological conditions that increase ciguatoxic dinoflagellate production and the increased number of ciguatoxic fish harvested. We speculate that biases from these limitations and assumptions would result in an underestimate of true effects.

Using poison center calls also likely resulted in an underestimate of effect, as CFP has been shown to be widely underreported due to non-specific symptoms, frequent low acuity, and low awareness among providers in the US (Lawrence et al. 1980). We view calls to poison centers as a proxy for true incidence, and while we expect trends in both calls and true incidence to be similar it is likely that the number of calls per year grossly underestimates the true incidence. It is possible changes in clinical awareness of the disease through the decade may have resulted in detection bias, although it is not clear why this would be associated with weather trends (which did not necessarily increase uniformly across the decade).

We did not control for changes in tourism to endemic areas, and although this is not as likely to be correlated with annual variations in spring as summer SST, it could conceivably be related to storm frequency. However, it is difficult to hypothesize a relationship that would link tourism with the lag structures we observed. Similarly, we did not control for changes in fishing or eating practices that could confound the relationship, such as seasonal fishing closures or prohibition of sale of high-risk fish species from ciguatoxic areas. It is likely that the effect of these behaviors would be very local, not related to regional weather, and would underestimate effects of weather on CFP incidence. Changes in SST, storms, or decreased fishing yields might lead to changes in types and ages of fish captured, or cause fishermen to seek out fish in alternate areas previously avoided due to concerns for CFP. This may or may not alter the likelihood of harvesting ciguatoxic fish. We included fish production in our model in an attempt to control for any systemic regional effect of these behaviors. An increase in awareness of providers regarding ciguatera poisoning during the study period is another potential uncontrolled-for confounder.

With only 10 years of ciguatera call data, we could not estimate the effect of climate change (i.e. a warmer, stormier climate) on ciguatera incidence. Instead, we can only examine the effect of climate variability; i.e., correlations between warmer or stormier years and call incidence. Such a relationship supports the theory that, as the regional climate warms and storm frequency increases as projected by climate models, all other things being equal, the range of ecological suitability for ciguatoxic organisms and the burden of CFP are likely to increase in the US.

Selecting variables for the final multivariate model was challenging. Examining a large number of candidate variables to represent SST may have increased the possibility of type I error. Ultimately the variable selected was a relatively intuitive and broad regional measure of SST and had a lag structure similar to that presented in the literature. We have higher confidence in the validity of the storm variable we selected since the pattern between lag months and beta parameter significance was as we anticipated *a priori*. Even though the magnitude of effect for our SST variable is larger than that for the storms, and therefore is the main driver of projected CFP increase, we must acknowledge greater uncertainty in the validity of the structure and measurement of the SST variable compared to the storm variable.

Finally, our future projections of CFP disease burdens may be overestimates, as they do not take into account changes in technology, detection, and clinical and public education and awareness that may affect both the detection of the disease and its incidence. If CFP does indeed increase in the US as projected, implementation of clinical and public health measures to reduce transmission of the toxin may blunt the expected rise in cases.

Public health implications

Increased incidence of CFP in the US would have numerous public health impacts. Burden of disease would increase, resulting in increased utilization of healthcare resources, particularly poison control centers and emergency departments (EDs). Education targeting emergency providers and toxicologists may help address these concerns. In addition, areas that have not experienced high levels of CFP and therefore have low awareness of the condition might begin to see the disease more frequently. Adaptation measures such as education of health professionals (Hess et al. 2009) and the public, as well as enhanced surveillance (Frumkin et al. 2008) may mitigate these risks. Preventive strategies, such as regulation of fishing industry catches and imports, may prove necessary, although the development of a method for identifying ciguatoxic fish will be essential in developing more effective surveillance, monitoring, and prevention strategies. Further characterization of the temporal and spatial relationships between storms, SST, and CFP may enable the development of a weather-based early warning system for CFP outbreaks that could better target prevention strategies.

Conclusions

This hypothesis-generating study substantiates concern that CFP could increase in the United States due to climate change, despite limitations discussed above. More specific data on outcomes, exposures, and ecological factors are all needed to investigate these findings further. The NDPS was sufficient for this study but likely does not accurately represent the epidemiology of the disease in the US. Data on cases with confirmed disease (or ED reports from state and federal sources), perhaps initially from high-incidence areas, may be better suited to identifying weather-related patterns. Additional ecological data regarding changes in the distribution of suitable habitat for ciguatoxic dinoflagellates (due to SST warming, coral bleaching events, man-made structures, and storm damage) and their overlap with US fishing areas would also help clarify exposure pathways. Identifying toxic fish and their origin would also be very useful in identifying ciguatoxic areas allowing more specific analysis for what weather and climate parameters play a role in CFP. Finally, more work must be done to identify the proper lag time between weather and SST disturbance and CFP incidence, and determine if the length of this lag period is dependent on severity or type of weather disruption. As more data are gathered on CFP and its ecology, associations between longer climate variability and CFP incidence can be investigated. Despite these concerns, the results of this study are consistent with others signaling that CFP may become more prevalent as the climate continues to change, and appropriate investment in public health preparedness is prudent.

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Table 1. Descriptive statistics of ciguatera related calls to poison centers 2001-2011.

Variable	**Lower 48 states, PR, USVI true cases (N = 1,102)**
Male (%)[a]	515 (48.1)
Median Age (IQR) [a]	40 (28 - 51)
No. Under 18 (%)	91 (10.0)
No. 20 to 29 (%)	150 (15.3)
No. 30 to 39 (%)	211 (21.5)
No. 40 to 49 (%)	234 (23.8)
No. 50 to 59 (%)	163 (16.6)
No. 60 to 69 (%)	87 (8.9)
No. 70+ (%)	29 (2.9)
Region[a]	
Midwest (%)	79 (7.2)
Northeast (%)	174 (15.8)
Other (PR, USVI, territories, overseas) (%)	12 (1.1)
South (%)	685 (62.2)
West (%)	152 (13.8)
Outcome	
Death (%)	1 (0.1)
Major Effect (%)	26 (2.4)
Minor Effect (%)	237 (21.5)
Moderate Effect (%)	385 (34.9)
No Effect (%)	29 (2.6)
Not followed, nontoxic exposure (%)	11 (1.0)
Not followed, minor effect (%)	232 (21.1)
Unable to follow, potentially toxic (%)	139 (12.6)
Unrelated effect, exposure probably not responsible (%)	42 (3.8)
Year of Call	
2001 (%)	70 (6.4)
2002 (%)	92 (8.4)
2003 (%)	86 (7.8)
2004 (%)	72 (6.5)
2005 (%)	61 (5.5)
2006 (%)	95 (8.6)
2007 (%)	116 (10.5)
2008 (%)	123 (11.2)
2009 (%)	127 (11.5)
2010 (%)	137 (12.4)
2011 (%)	123 (11.2)

[a]Number of missing values: Gender (32), Age (223), Decade (139), State/Region (5).

Table 2. Descriptive statistics for regression analysis variables, years 2001-2011.

Variable	February	April	June	August	October	December	All Year
Ciguatera Cases							
Ciguatera cases in Lower 48 states, DC, PR, USVI coded exclusively as ciguatera substance							
mean ± SD	6.6 ± 3.4	7.3 ± 4.4	11.0 ± 3.8	15.3 ± 9.3	6.4 ± 3.1	4.9 ± 3.3	100.2 ± 26.3
range	4–16	3 – 17	6 – 18	3 – 28	2 – 12	1 – 12	61 – 137
Sea Surface Temperature							
CAR Index ± 1981-2010 climatology							
mean ± SD	0.1 ± 0.17	0.16 ± 0.15	0.15 ± 0.13	0.16 ± 0.11	0.16 ± 0.12	0.1 ± 0.14	0.1 ± 0.1
range	-0.13 – 0.36	-0.03 – 0.41	-0.06 – 0.4	-0.06 – 0.35	-0.05 – 0.41	-0.14 – 0.29	-0.2 – 0.4
Max SST in Caribbean							
mean ± SD	29.6 ± 0.5	30.3 ± 0.3	30.1 ± 0.3	30.6 ± 0.3	30 ± 0.2	29.3 ± 0.3	30 ± 0.5
range	29 – 30.3	29.7 – 30.7	29.6 – 30.6	30 – 31.2	29.7 – 30.3	29 – 29.9	28.7 – 31.2
Min SST in Caribbean							
mean ± SD	29.6 ± 0.5	30.3 ± 0.3	30.1 ± 0.3	30.6 ± 0.3	30 ± 0.2	29.3 ± 0.3	20.7 ± 3.8
range	13.6 – 17.4	17.7 – 18.7	21.1 – 22.8	25.8 – 26.6	23.1 – 24.2	17.5 – 19.7	13.6 – 26.7
Max Latitude of 25°C SST							
mean ± SD	25.8 ± 0.8	27.6 ± 1.9	37 ± 1.3	41 ± 0.5	38.4 ± 0.9	28.9 ± 2.1	32.8 ± 6
range	24.5 – 26.5	25.5 – 32.5	34.5 – 38.5	40.5 – 41.5	36.5 – 39.5	26.5 – 32.5	24.5 – 41.5
Min Latitude of 25°C SST							
mean ± SD	14.5 ± 2.4	14.9 ± 2.7	23 ± 5.8	38.4 ± 0.9	30.8 ± 1.3	19.7 ± 1.6	23.7 ± 8.9
range	12.5 – 19.5	12.5 – 20.5	13.5 – 28.5	36.5 – 39.5	29.5 – 32.5	18.5 – 23.5	12.5 – 39.5
Max Latitude of 29°C SST							
mean ± SD	13.5 ± 0	15 ± 0.7	27.4 ± 2.5	31.6 ± 2.2	24.3 ± 1.5	13.3 ± 0.4	21.4 ± 7.3
range	13.5 – 13.5	13.5 – 15.5	23.5 – 29.5	28.5 – 34.5	21.5 – 26.5	12.5 – 13.5	12.5 – 34.5
Min Latitude of 29°C SST							
mean ± SD	13.5 ± 0	10.5 ± 0	10.5 ± 0	10.5 ± 0	10.5 ± 0	12.8 ± 0.9	11.1 ± 1.1
range	13.5 – 13.5	10.5 – 10.5	10.5 – 10.5	10.5 – 10.5	10.5 – 10.5	10.5 – 13.5	10.5 – 13.5
Max SST at 24.5°N Latitude							
mean ± SD	25.4 ± 0.4	26.3 ± 0.4	29 ± 0.4	30.3 ± 0.2	28.8 ± 0.3	26.4 ± 0.5	27.7 ± 1.8
range	24.9 – 26.4	25.8 – 26.9	28.7 – 30	29.9 – 30.6	28.3 – 29.4	25.6 – 27.1	24.8 – 30.6

Variable	February	April	June	August	October	December	All Year
Max SST at 34.5°N Latitude							
mean ± SD	20.6 ± 0.7	21.7 ± 0.8	26.3 ± 0.6	28.3 ± 0.5	25.9 ± 0.3	22.5 ± 0.5	24.1 ± 2.9
range	19.5 – 22	20.5 – 23.4	25.5 – 27.5	27.4 – 29.1	25.4 – 26.3	21.5 – 23.2	19.1 – 29.1
Min SST at 24.5°N Latitude							
mean ± SD	21.2 ± 0.6	23.1 ± 0.4	25.4 ± 0.5	26.6 ± 0.5	27 ± 0.3	23.4 ± 0.5	24.4 ± 2.1
range	20.2 – 22.1	22.3 – 23.7	24.1 – 25.8	25.9 – 27.4	26.4 – 27.4	22.7 – 24	20.1 – 28.1
Min SST at 34.5°N Latitude							
mean ± SD	17.8 ± 0.7	18.4 ± 0.4	22.1 ± 0.5	26.5 ± 0.3	23.7 ± 0.3	19.9 ± 0.8	21.4 ± 3.1
range	16.8 – 18.7	17.8 – 18.9	21.1 – 22.8	26.2 – 27.2	23.1 – 24.2	18.2 – 20.7	16.8 – 27.2
Severe Storms							
Total storms							
mean ± SD	0 ± 0	0.09 ± 0.3	0.73 ± 0.79	4.64 ± 1.91	2.64 ± 2.25	0.27 ± 0.47	17.5 ± 5.8
range	0 – 0	0 – 1	0 – 2	3 – 8	0 – 7	0 – 1	9 – 31
Hurricanes							
mean ± SD	0 ± 0	0 ± 0	0.09 ± 0.3	1.64 ± 1.12	1.36 ± 1.8	0.09 ± 0.3	7.8 ± 3.7
range	0 – 0	0 – 0	0 – 1	0 – 4	0 – 5	0 – 1	3 – 16
Tropical Depressions							
mean ± SD	0 ± 0	0 ± 0	0.09 ± 0.3	0.45 ± 0.52	0.27 ± 0.47	0 ± 0	2.1 ± 1.4
range	0 – 0	0 – 0	0 – 1	0 – 1	0 – 1	0 – 0	0 – 5
Tropical Storms							
mean ± SD	0 ± 0	0.09 ± 0.3	0.55 ± 0.69	2.55 ± 1.13	0.82 ± 0.87	0.18 ± 0.4	7.6 ± 2.2
range	0 – 0	0 – 1	0 – 2	1 – 5	0 – 2	0 – 1	4 – 11
Category 3 or greater storms							
mean ± SD	0 ± 0	0 ± 0	0 ± 0	1.09 ± 0.83	0.55 ± 0.82	0 ± 0	3.7 ± 1.7
range	0 – 0	0 – 0	0 – 0	0 – 2	0 – 2	0 – 0	2 – 7
Total storm-days							
mean ± SD	0 ± 0	0.91 ± 3.02	5.1 ± 5.5	35.5 ± 15.6	16.9 ± 13.9	2.0 ± 3.5	138 ± 46.7
range	0 – 0	0 – 10	0 – 15	17 – 66	0 – 43	0 – 9	70 – 245
ACE							
mean ± SD	0 ± 0	0.2 ± 0.8	1.5 ± 1.8	26.9 ± 17.8	17.7 ± 15.4	1.8 ± 4	132.7 ± 66
range	0 – 0	0 – 2.6	0 – 5.8	3.4 – 64.7	2.6 – 50.9	0 – 13.2	51 – 250

This table displays mean monthly value from years 2001-2011 ± standard devation along with range (minimum to maximum) shown for each variable for alternating months

Table 3. Rate ratios and excess CFP calls expected for hypothetical scenarios compared to 2001-2011 baseline.

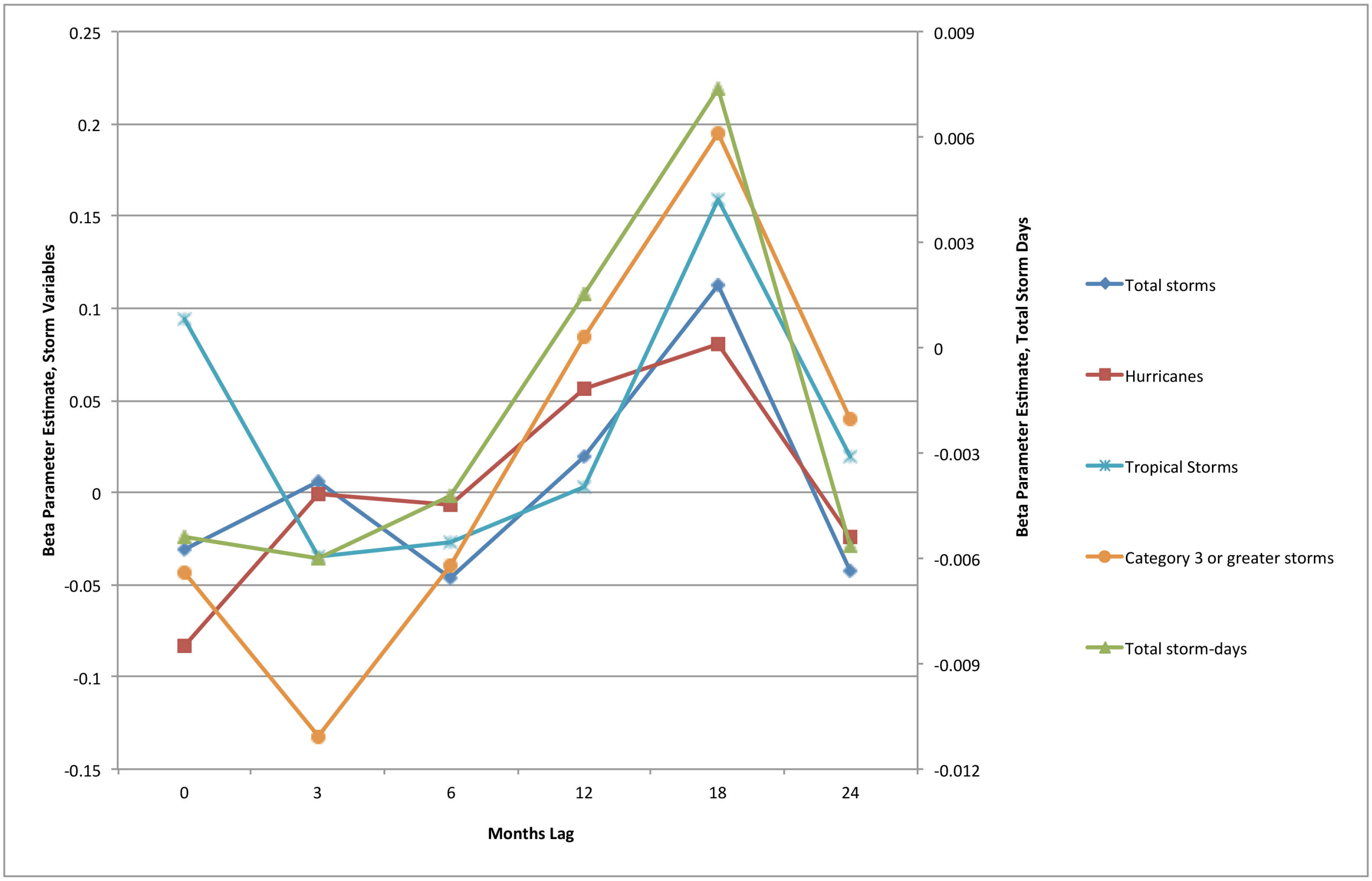
Hypothetical Scenario	**Rate Ratio ± SE (95% CI)**	**Extra CFP calls (95% CI)**
Increase in 1 storm per month	1.11 ± 0.06 (1, 1.23)	11.3 (0.4, 23.4)
Increase in 1 degree for one month	1.62 ± 0.27 (1.17, 2.24)	61.9 (16.7, 124.5)
Increase in 1 degree for one month and 1 storm per month	1.8 ± 0.31 (1.28, 2.53)	80.1 (28.3, 153)
Increase in storm frequency 10%	1.02 ± 0.01 (1, 1.03)	1.6 (0.1, 3.1)
Increase in storm frequency 25%	1.04 ± 0.02 (1, 1.08)	4 (0.1, 8)
Increase in max August SST 2.5°C	3.33 ± 1.39 (1.47, 7.53)	233.3 (47.2, 654.4)
Increase in max August SST 3.5°C	5.38 ± 3.14 (1.72, 16.89)	439.3 (71.8, 1592)
Increase in max August SST 2.5°C and increase storm frequency 10%	3.38 ± 1.41 (1.49, 7.65)	238.5 (49.5, 665.9)
Increase in max August SST 3.5°C and increase storm frequency 25%	5.6 ± 3.26 (1.79, 17.55)	460.7 (78.7, 1658)

This table applies the final multivariate model to several possible weather scenarios based on current climate prediction models for the Caribbean region. Rate rations are translated into the number of excess CFP calls attributable hypothetical changes in SST or storms compared to 2001-2011 baseline.

Figure legend

Figure 1. Poisson beta estimates by lag time for selected tropical storm variable. The beta parameter estimate for single variable Poisson regression (controlling for month) for total storm days is plotted on the right vertical axis. Beta parameter estimates for all other variables are plotted on the left vertical axis.

Figure 1.


0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
0.009
0.006
0.003
0
-0.003
-0.006
-0.009
-0.012
Beta Parameter Estimate, Storm Variables
Beta Parameter Estimate, Total Storm Days
0
3
6
12
18
24
Months Lag
Total storms
Hurricanes
Tropical Storms
Category 3 or greater storms
Total storm-days