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RESEARCH ARTICLE

News media and fisheries-independent data reveal hidden impacts of hurricanes

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Abstract Climate change will likely intensify hurricane activity in coastal regions. A thorough understanding of hurricane impacts to marine fauna is necessary to prepare for and mitigate potential impacts to social systems dependent upon adjacent fauna. Yet, research attention, conservation funding, and policy all can be biased toward taxa of societal interest, potentially favoring a limited understanding of hurricane impacts. Here, we analyzed the frequency of mentions of taxa in newspaper articles in relation to hurricane activity at three coastal US locations coupled with analysis of long-term fisheries-independent data. While economically important taxa dominate media discourse, we observed long-term hurricane-related abundance declines in ecologically important taxa having little direct human utility. We conclude that there is a potential for research and policy biases related to hurricane impacts. Preparation and mitigation efforts will benefit from researchers and managers making directed efforts to identify and incorporate hurricane sensitive taxa into their work.

Keywords Climate change · Estuaries · Fish · Fisheries · Hurricanes · News media

INTRODUCTION

Warming ocean surface waters are expected to increase the frequency of intense hurricanes impacting coastal social–ecological systems (Knutson et al. 2010; Garner et al. 2017; Bhatia et al. 2018). Current studies suggest acute, but relatively transient responses of coastal aquatic fauna to hurricane activity (Paerl et al. 2001; Mallin et al. 2002; Piazza and La Peyre 2009). However, few studies have examined hurricane impacts that extend beyond a year following storms and the long-term effects of hurricanes on marine fauna remain poorly understood (Matlock 1987; Burkholder et al. 2004). Coastal human communities are often culturally and economically dependent upon the adjacent marine fauna (McKernan and Mulcahy 2008; NMFS 2018), making it important to understand the potential for intensified hurricane activity to alter these systems (Turner and Gardner 2015).

Understanding which taxa receive the most societal interest in relation to hurricane activity can help elucidate the potential for research and policy biases surrounding hurricane impacts (Troudet et al. 2017). The taxa scientists choose to study (Moustakas and Karakassis 2005), research and conservation funding (Wilson et al. 2007), as well as policy may all be influenced by societal interests (Martín-López et al. 2009). Available scientific information is often biased toward more charismatic taxa or those having the greatest utility to humans (Martín-López et al. 2009). Because public support is often critical to successful conservation fundraising and influences political decision making, conservation policy and practice often specifically target taxa of high value to the public (Macdonald et al. 2015). Such taxonomic bias has the potential to result in a skewed understanding of ecosystem status, as well as uninformed policy related to conservation of ecosystems (Troudet et al. 2017).

News media can be an indicator of societal values and perceptions (Scheufele and Tewksbury 2007) and therefore may provide insight into those taxa of greatest salience to society. A wide body of literature suggests news media may influence public perception by playing an agenda-

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setting role, influencing what topics or issues people think about (Scheufele and Tewksbury 2007). Nelkin (1995) credited news media with setting the public agenda and thereby directly influencing policy decisions. Other authors suggest news media is more reflective of already existing public views and perceptions (Soroka et al. 2015; Hopkins et al. 2017). Regardless of whether news media ultimately reflect or shape public opinion, media remains a useful barometer of culturally prominent items. For this reason, news media have been used to understand public perceptions relating to environmental issues from water policy (Hurlimann and Dolnicar 2012) to management of US national forests (Bengston et al. 1999).

Because societal interests exert large influence on policy, recent years have seen an increased emphasis on the need to incorporate social science into environmental research (Bennett et al. 2016). Along with this increased emphasis, there has been a large increase in the use of digital data to address these social aspects (Jarić et al. 2020). A relatively new field of conservation culturomics is emerging that uses computational techniques to analyze large databases of digital text to understand human attitudes and behaviors (Ladle et al. 2016). The related field of iEcology is developing simultaneously, using similar tools and techniques to address fundamental ecological questions (Jarić et al. 2020). These techniques have been advocated as tools to better understand public perceptions of biodiversity (Correia et al. 2017), understand ecological change through time (De Frenne et al. 2018), map species occurrences (Leighton et al. 2016; Schuetz and Johnston 2019), demonstrate public interest in nature (Kim et al. 2014), and to support conservation decision making (Bennett 2016).

Here, we use multivariate analyses of fisheries-independent data and digital databases of news media to answer two primary questions: (1) How do marine ecological communities respond over the long term to hurricane activity? (2) To what degree does the amount of media coverage of taxa in relation to hurricane activity reflect the responsiveness of taxa to hurricanes? Answering these questions will add to the growing body of knowledge about increased hurricane activity effects on marine ecosystems. Understanding the extent to which media attention reflects taxa most responsive to hurricanes will also shed light on the potential for research and policy biases and therefore the ability of human coastal communities to respond with relevant policy actions. In addition, the answers to these questions will serve to inform the emerging fields of conservation culturomics and iEcology as they continue to develop. Though we anticipate that economically important taxa will dominate media accounts, we have no a priori expectation regarding which taxa will be most responsive to hurricane activity.

MATERIALS AND METHODS

Study sites and hurricane activity

We identified three study locations based on their vulnerability to hurricanes (NOAA 2018) and availability of data that were collected by state agency programs sampled consistently over long-term time periods (Fig. 1): Albemarle-Pamlico Estuary in North Carolina (NC), Charlotte Harbor Estuary in southwest Florida (FL), and Lake Pontchartrain, Lake Borgne, and coastal portions of the Mississippi delta south of New Orleans, Louisiana (LA). Each location supports valuable commercial and recreational fishing industries (NMFS 2018).

To rate hurricanes, we used mapped and coded storm tracks from the National Oceanic and Atmospheric Administration (NOAA) and used the classification recorded at the time the storm tracked over the study site (NOAA 2018). The NC site had the most hurricane activity, with 11 hurricanes making landfall between 1990 and 2017. In the years with fisheries-independent data (2004–2016), there were five hurricanes that were all categories 1 and 2 (Fig. 2). The FL site was generally low activity. Only two hurricanes occurred over the site after 1990, both of which occurred during the period of available fisheries-independent data (2000–2016) (Fig. 2). Though the frequency of hurricanes was low at this site, both were stronger than any storms at NC (Charley category 4, Wilma category 3), while Charley was the highest rated storm across our sites. The LA site had seven hurricanes after 1990, with all but two occurring during the period of available fisheries-independent data (2000–2016), including Hurricane Katrina in 2005. Although this storm was officially category 3 at landfall, it was unusually destructive, being one of the costliest and deadliest in US history at the time (Knabbe et al. 2005).

Ecological analysis

We used fisheries-independent data collected by (1) North Carolina Division of Marine Fisheries, (2) Louisiana Department of Wildlife and Fisheries, and (3) Florida Fish and Wildlife Conservation Commission (Fig. 1; Table S1). In most cases, taxa were resolved to species, but in some cases, taxonomic resolution did not go beyond genus. Detailed sampling protocols can be obtained from the respective state agencies. At each site, we aggregated all samples of each fish and invertebrate taxa per month and used the aggregated data as the response variable in all further analyses. A total of 166 taxa were sampled at NC, 200 at LA, and 173 at FL. All of these operations and all further ecological analyses were conducted using R version 3.4.4 (R Core Team 2018).

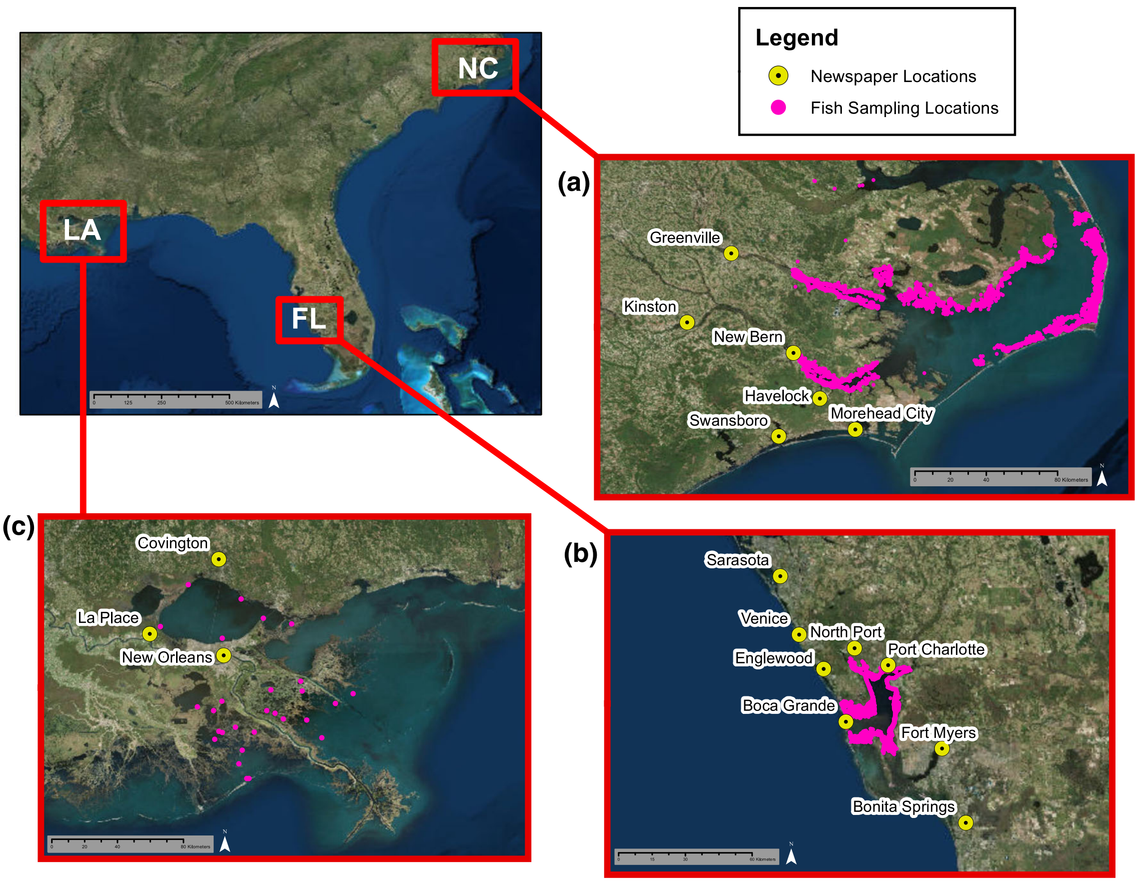

Fig. 1 Maps of the three study locations: **a** NC, **b** FL, and **c** LA

We used non-metric multidimensional scaling (NMDS) (Minchin 1987) to visualize the relationships in faunal community composition over time for each study location (Oksanen et al. 2018). Raw taxa abundances were square root transformed to minimize the influence of highly abundant taxa. Ordinations were based on the Bray–Curtis dissimilarity index. We conducted one NMDS for each study location, utilizing the following time periods: 2004–2016 in NC, 2000–2010 in LA, and 2000–2016 in FL (Table S1). Although data were available through 2017 at LA, sampling became erratic for a period of time following 2010, so we did not include this time period.

To further examine biotic community response to hurricanes we conducted permutational multivariate analysis of variance (PERMANOVA) tests (Anderson 2001). For each study location, we identified a 3-year window of low hurricane activity ("low") and compared this to a 3-year window of high hurricane activity ("high"). We used 3-year windows because we were interested in extending the subannual to 2-year post-storm period used in the majority of studies (Greenwood et al. 2006; Piazza and La Peyre 2009). Limiting the window to 3 years ensured that we did not include years in NC immediately following high hurricane activity in the low period at this site. PERMANOVAs were conducted with the corresponding species abundance matrix as the response, with hurricane activity (low vs high), and month (1–12) as predictors (Oksanen et al. 2018). We identified the following windows: 2002–2004 (LA low), 2006–2008 (LA high), 2001–2003 (FL low), 2007–2009 (FL high), 2004–2006 (NC high), and 2009–2011 (NC low) (Fig. 2). We conducted a separate PERMANOVA for each site because we expect taxa communities to be quite different at each location. To account for the three separate tests, we used a Bonferroni correction and considered a significant result to be an alpha of 0.05/3, or 0.017 (VanderWeele and Mathur 2019).

We identified "low" and "high" activity time periods based on the frequency of hurricanes (i.e., storms that were at least category 1 on the Saffir-Simpson scale) using the following reasoning: At NC, there were very few intervals lacking hurricanes. The time period 2006–2011 was the longest hurricane-free period at this site going back to 1990, so we selected 2009–2011 as the low activity period while the early years were very active so we selected 2004–2006 as the high activity period (Fig. 2). NC was the only site where the "low" hurricane activity period was designated after the "high" activity period (Fig. 2). In FL,

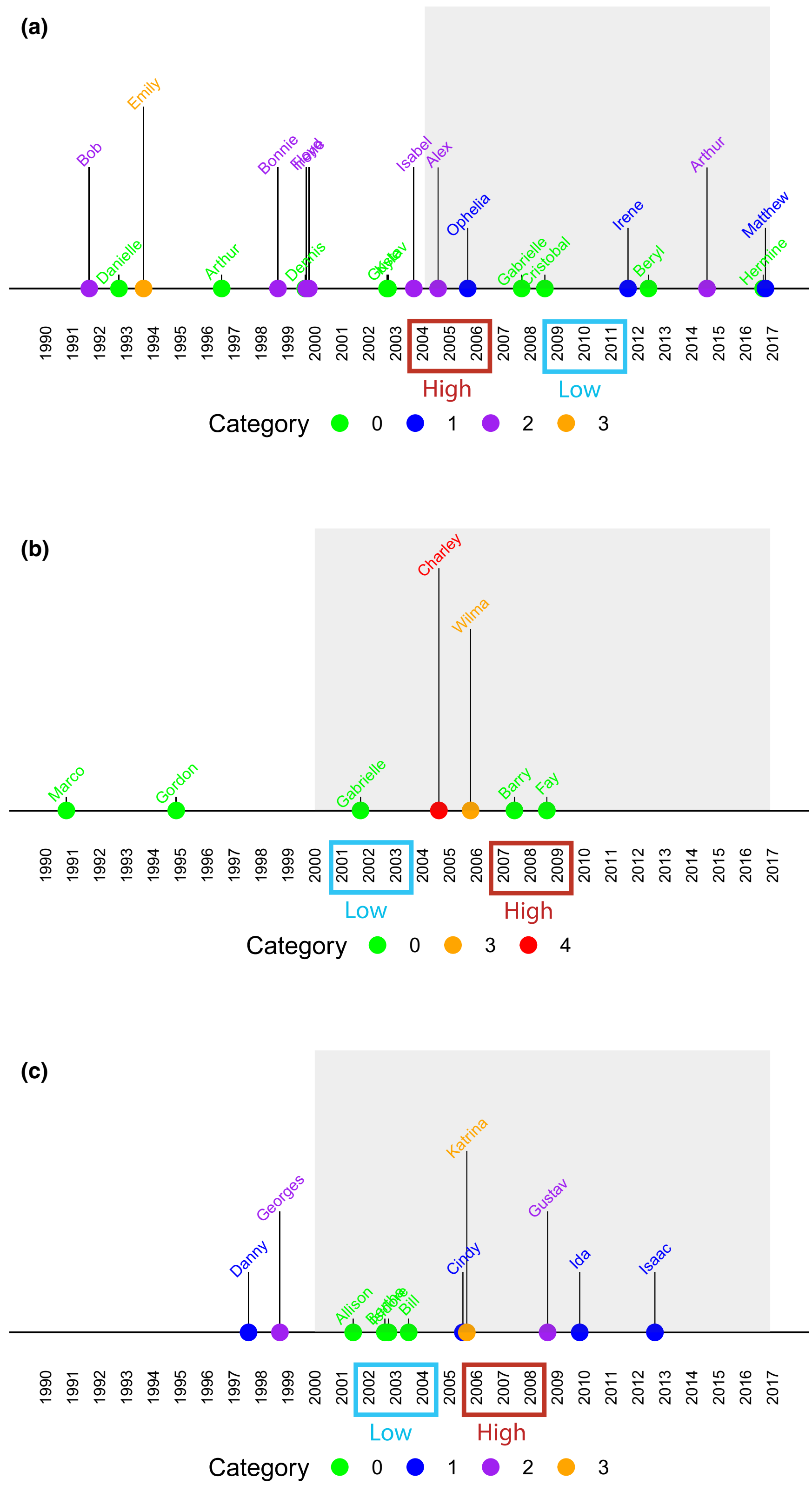

Fig. 2 Timelines of hurricane activity at: **a** NC, **b** FL and **c** LA. Gray-shaded areas represent the time period having fisheries-independent data. Timelines begin at 1990 to give an indication of baseline storm activity at each site. Category 0 storms (green) represent tropical storms

there were only two hurricanes in the period from 1990 to 2016 and these occurred in consecutive years (Charlie 2004 and Wilma 2005). In this case, the selected time periods actually represent before and after hurricane activity periods. In LA, though there were tropical storms in the period prior to 2005, there were no hurricanes (Fig. 2). Because hurricanes Katrina and Cindy occurred late in 2005, most of the months in this year were actually low activity. Therefore, we chose the years 2006–2008 following this intense hurricane season to represent high activity.

We used outputs from the fitted PERMANOVA model to identify the 20 taxa that most differentiated between ecological communities in low vs high windows (i.e., coefficients with the greatest positive or negative magnitude). For each of these taxa, we calculated the mean abundance across the chronologically earlier 3-year period and the later 3-year period. We then ranked taxa by magnitude of the percent change in abundance. We compare the ten taxa at each site having the greatest abundance change with the results of the news media analysis described below.

News media analysis

We identified and downloaded newspaper articles from Newsbank, a digital database (Jarić et al. 2020) that consolidates current and archived newspaper titles across the globe. We selected newspaper sources based on their publication location within, or adjacent to, counties where fisheries-independent survey data were collected. To select relevant articles, we used Boolean operators, which included, "hurricane OR 'tropical storm'" in their lead or first paragraph, as well as "fish* OR habitat OR ecosystem OR ecolog*" in the body of the text (Morris 1994). We used the OR operator here in order to include articles that mention fish taxa without explicitly using the word "fish," as well as to capture some invertebrate fauna important to our study, such as shrimp or crabs. Returned articles were then manually read and selected based on whether or not they included marine faunal names in relation to hurricanes. For each study site, we also used geographical locators Charlotte Harbor, Mississippi delta, and Pamlico. We included all articles published between January 1, 2000, and December 31, 2017, that fit these terms. In the case of NC, an expanded search was conducted by applying the search phrase "hurricane OR 'tropical storm'" to all text, because restricting the phrase to the lead or first paragraph returned too few results.

We manually assigned identifiers to fish and shellfish taxa using NVivo qualitative analysis software. We included all articles from NC and FL and applied NVivo's Auto Coding Wizard program to narrow the sample size from LA. The Auto Coding Wizard recognizes patterns in data resulting from the coding structure and applies those patterns to new data (Table S2).

News article coding scheme and data analysis

Articles were manually coded using a mixed-method approach. First, all mentions of fish and shellfish taxa, as well as each hurricane and tropical storm were individually coded and the frequency of each was tallied. This resulted in a comprehensive word frequency list of all fish and shellfish taxa and hurricanes mentioned within the selected news articles at each site. We do not necessarily provide scientific names for media-derived taxa because common names extracted from news media can be ambiguous identifiers.

After consulting with local fisheries experts at each study site, we combined some taxa names when we were certain they referred to the same species. This was the case for red drum and redfish in FL ("reds" can refer to the same thing, but also to red grouper at this site), and for red drum, redfish, and reds in LA.

Relationship between news media attention and response to hurricanes

We tested to see whether there was any relationship between the amount of attention taxareceived in news media and their response to hurricanes. To do this, we took the top ten most mentioned taxa at each site by percentage. For each of these taxa, we then calculated the percent change in abundance between the 'low' and 'high' periods using the approach outlined for the ecological data. This resulted in paired values of percent media mentions and percent change in abundance for each of these taxa. Because these common names derived from news media were not unambiguous identifiers, we combined all taxa in the fisheries-independent data that could fall under the news media identifier before conducting calculations. For example, at the LA site, for the generic news media term 'shrimp,' we combined brown shrimp, pink shrimp, white shrimp, and seabob. We then conducted a linear regression with percent abundance change as the response variable and percent media mentions as the explanatory variable. We note that not all taxa having the greatest news media attention appeared in the fisheries-independent data, or appeared so rarely that percent changes in abundance were not meaningful indicators of abundance change. We did not include these taxa in this regression analysis.

RESULTS

Several taxa had reduced abundances during high hurricane activity across all study sites (Fig. 3). Results from our PERMANOVA indicated that biotic communities were significantly different in the low vs high hurricane activity periods: FL ($P = 0.008$), NC ($P = 0.001$), LA ($P = 0.001$). However, NMDS showed biotic communities at FL and NC grouped more closely by month than by any clear effect of hurricanes (Fig. 4). NMDS indicated LA was the most dramatically impacted site, with hurricane effects completely obscuring seasonal patterns (Fig. 4).

Biotic communities in LA demonstrated a clear pre-post hurricane grouping, with samples prior to late 2005 (hurricanes Katrina and Cindy) tending to group above the 0 line on NMDS axis 2 while samples from late 2005 onward tended to group below (Fig. 4). One crab taxon increased dramatically (5,659%) during high hurricane activity, but is listed as unidentified mud crab (Xanthidae). The remaining nine taxa decreased in abundance (Fig. 3; Fig. S1; Table S3). Seven of the ten highly impacted taxa at this site experienced abundance reductions greater than 75% and three 90% (Fig. 3).

Relative to taxa most referenced in media, most taxa that exhibited substantial change in response to hurricanes were not of commercial or recreational importance (NMFS 2019a, b). Only two taxa were both in the most referenced and among those with the greatest abundance changes (Fig. 3). The ten most referenced taxa at LA were as follows: red drum (redfish), shrimp, trout, crab, oyster, crawfish, specks, bass, drum, and bream (Fig. 3). One exception to the general pattern is that bluegill (*Lepomis macrochirus*) had reduced abundance and is a popular freshwater sportfish in LA (Sea Grant Louisiana 2019).

Following the hurricane events in FL, three taxa increased in abundance while seven decreased in abundance (Fig. 3; Fig. S1; Table S3). In FL, red drum (redfish) appeared to have hurricane-induced abundance declines that lasted several years following the 2004 hurricane season (Fig. S1). Red drum (redfish) is one of the ten most referenced in media at this site (Fig. 3). The most referenced taxa at FL also included snook, spotted sea trout, bass, shrimp, tarpon (*Megalops atlanticus*), reds, mangrove

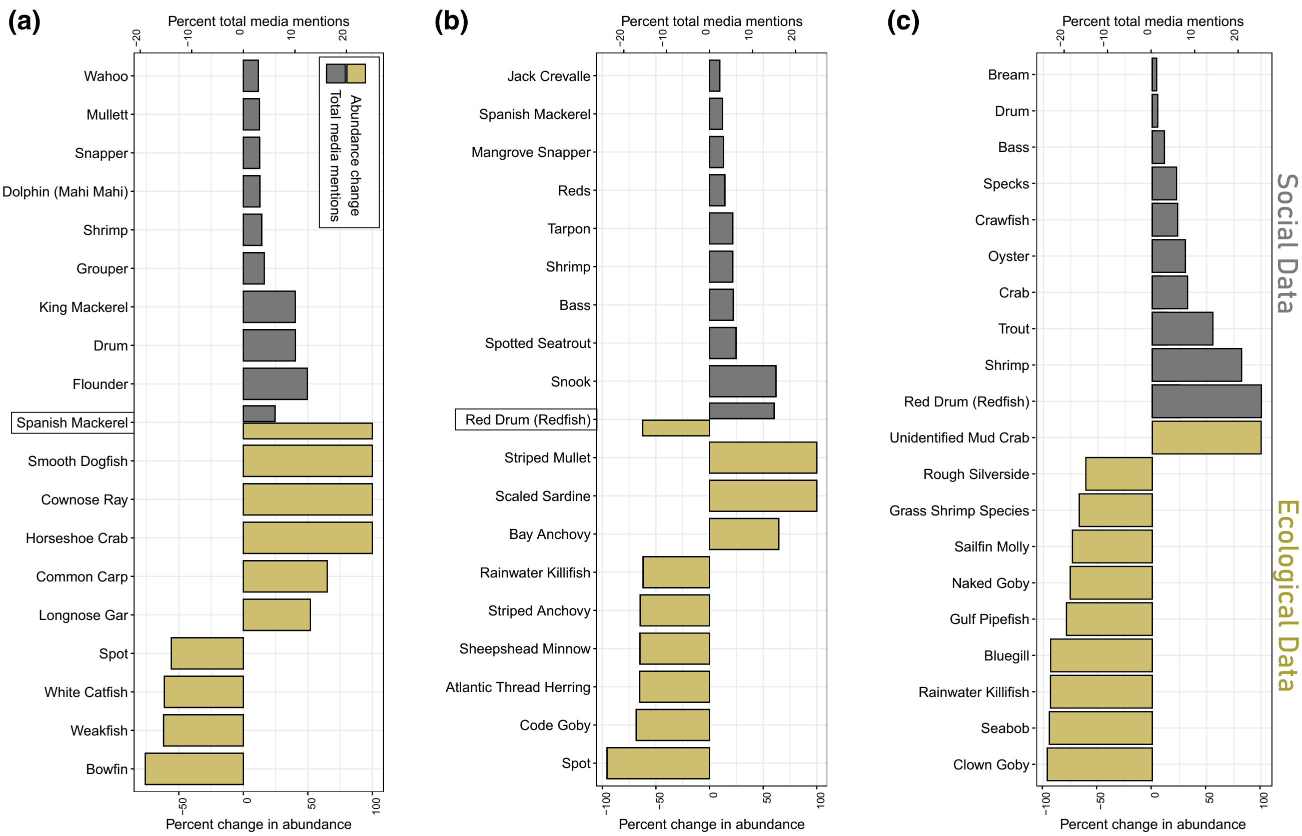

Fig. 3 Ten taxa at each site with both large coefficients in PERMANOVA and large percent change in abundance in low vs high hurricane activity periods. These are compared with the ten taxa at each site with the largest percent total mentions in newspapers. Boxes enclose taxa names for cases that appear in both the social and ecological data. For purposes of visualization, abundance increases exceeding 100% were cropped to 100%. These included **a** Spanish mackerel (513%), smooth dogfish (1487%), cownose ray (186%), and horseshoe crab (130%) at NC, **b** striped mullet (305%) and scaled sardine (106%) at FL and **c** unidentified mud crab (5659%) at LA

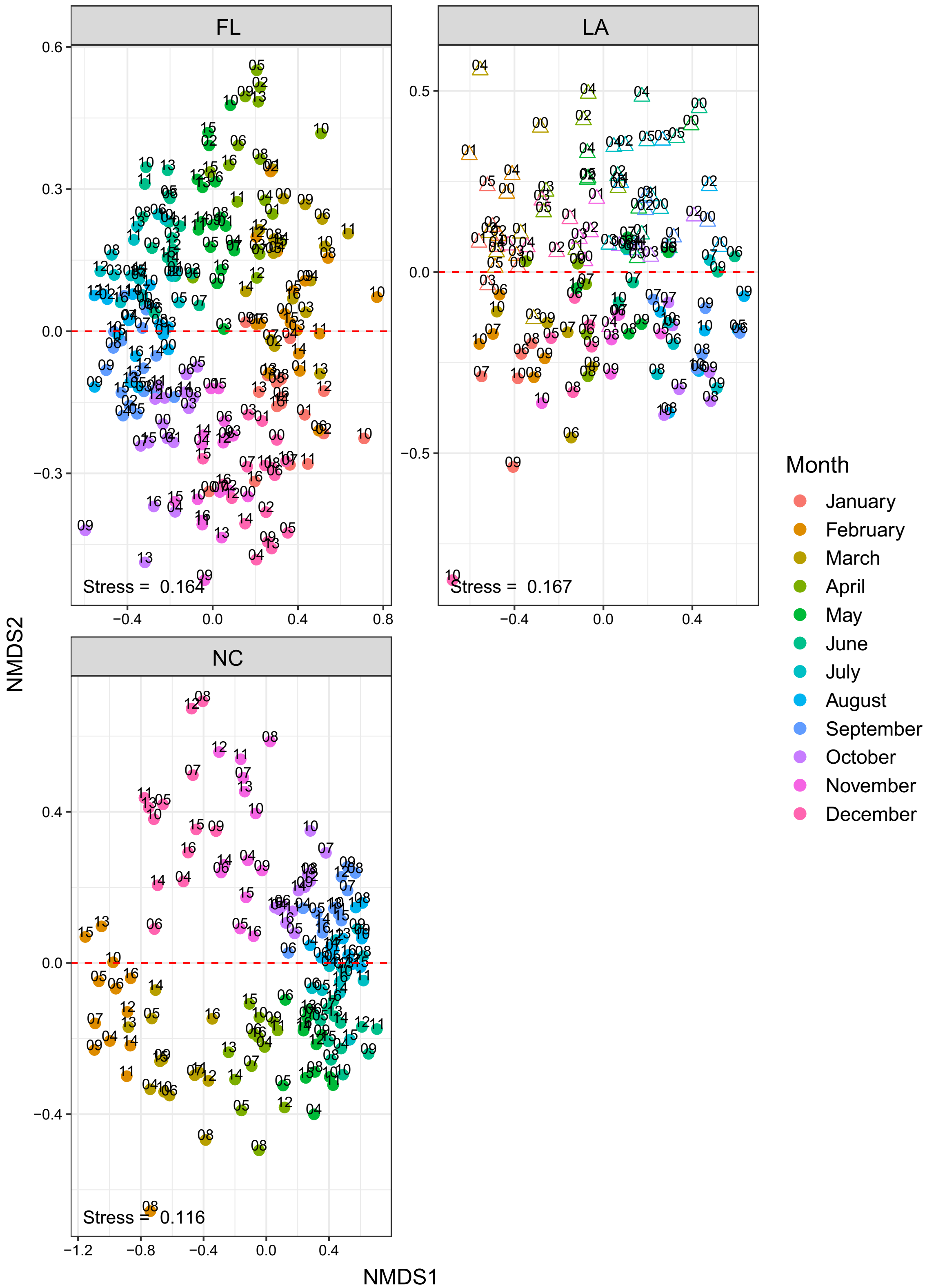

Fig. 4 Non-metric multidimensional scaling (NMDS) plots. Characters are color coded by month of sampling. The two-digit label for each character is the two-digit year for that particular month. In the LA site, plot characters for samples prior to the 2005 hurricanes are open triangles

snapper, Spanish mackerel (*Scomberomorus maculates*), and jack crevalle.

During and following hurricane activity, both Gulf of Mexico sites (LA and FL) showed reduced abundances in gobies (code goby *Gobiosoma robustum,* naked goby *Gobiosoma bosci,* and clown goby *Microgobius gulosus*), and rainwater killifish (*Lucania parva*). We consider these the taxa most impacted by, and therefore susceptible to, hurricane activity because abundances were reduced at multiple sites.

While abundance changes for several taxa in both FL and LA corresponded to individual hurricane events, most taxa in NC exhibited gradual multi-year changes in abundance less clearly tied to hurricanes (Fig. S1). At NC, six taxa increased in abundance in the later low hurricane activity period (2009–2011) while four taxa decreased in abundance (Fig. 3; Fig. S1; Table S3). However, we note that some taxa (e.g., longnose gar *Lepisosteus osseus*) had clear long-term trends in abundance that appeared unrelated to hurricane events (Fig. S1). The ten most referenced taxa at NC from most to least referenced were: flounder, drum, king mackerel (*Scomberomorus cavalla*), Spanish mackerel, grouper, shrimp, dolphin (*Coryphaena hippurus*, also referred to as mahi mahi), snapper, mullet, and wahoo (Fig. 3).

It is unclear whether abundance changes of some commercially important taxa were hurricane-induced (e.g., seabob (*Xiphopenaeus kroyeri*) in LA, striped mullet (*Mugil cephalus*) in FL, and several NC taxa including spot (*Leiostomus xanthurus*), weakfish (*Cynoscion regalis*), and Spanish mackerel). In addition, shrimp were often referenced by the generic term ‘shrimp,’ but there are several species of shrimp that vary in economic importance. For example, grass shrimp (*Palaemonetes* spp.) are not economically important whereas pink shrimp (*Farfantepenaeus duorarum*) are (Table S4).

Our regression analysis found no relationship between attention taxa received in news media and the response of abundance to hurricane activity ($P = 0.694$; $R^2 = 0.010$). There were problems with normality in the regression due to four points with high percentage abundance change relative to all other points. We removed these points and re-ran the regression to check whether this resulted in a different result. This did not change the result of no relationship ($P = 0.409$; $R^2 = 0.057$).

Media mentions of taxa varied in how they referenced taxa in relation to hurricanes. Some quotes reference habitat changes to systems and how this will impact fishing: ‘“The amount of marsh we lost during those storms and since then is just staggering,” said Ryan Lambert, owner/operator of Cajun Fishing Adventures and lodge in Buras, which he completely rebuilt following the storm. “You know we can rebuild marinas and lodges, but when that marsh is gone, we won’t have any fish, shrimp, oysters or crabs.”’[1] Others suggest a positive impact of storms on fishing: ‘The hurricane caused “the best year ever” for shrimp, said Donna Sharp, co-owner of Law’s Seafood on Deltona Drive in Punta Gorda. The hurricane “stirred up the bottom” of the harbor, and that dislodged the coveted crustaceans, she said.’[2] Others speculate on connections between storms and fishing: ‘The Port Charlotte fishing guide believes that many of the breeder stock redfish in Charlotte Harbor and Pine Island Sound, got out of Dodge when Hurricane Charley rumbled through the area on Aug. 13. “We’re just not catching those larger fish,” Latham said. “We’re catching plenty of redfish, but not the 30 inchers and larger we usually catch.”’.[3]

DISCUSSION

Few if any parallels were observed between the emphasis of news media accounts and the population dynamics of taxa most impacted by hurricane events. We found that storms significantly impacted ecological communities on long-term scales (Figs. 4–5 and Fig. S1). For example, naked goby abundance remained depressed following Katrina 5 years post-storm (Fig. 5; Fig S1). Despite this observation, taxa most affected by hurricanes were rarely those most referenced in news media. While it is not necessarily surprising that the focus of news media is divergent from the response of taxa to hurricanes, the almost complete lack of relationship highlights the potential for biases related to hurricane planning and preparedness. Our regression analysis demonstrated no relationship between media mentions of taxa in relation to hurricane activity and observed abundance changes in response to hurricane activity. Only Spanish mackerel in NC and red drum (redfish) in FL were among the top ten taxa with both the greatest abundance change and most media references (Fig. 3).

News media articles focused almost exclusively on taxa of economic importance. Many of these are highly prized gamefish such as mahi mahi (also known as dolphin), red drum (redfish), sea trout, snook, and tarpon (Hughes 2015),

[1] Marshall, Bob. “TREADING WATER – Fishing in the metro area has shown signs of recovery, but there is growing concern for coastal land loss and the future of this habitat.” *The Times-Picayune (New Orleans, LA)*, 26 August 2007, p. 10. (Accessed December 9, 2021 via Newsbank).

[2] Martin, Greg. “Storm boosted commercial fishing – Opinions vary on hurricane impact.” *Englewood Sun (FL)*, 27 December 2004. (Accessed December 9, 2021 via Newsbank).

[3] Gibson, Steve. “Tails of woe – Sightfishing for tailing redfish is popular, but it’s not fast action on numbers of fish.” *Sarasota Herald-Tribune (FL)*, 19 December 2004. p. C8. (Accessed December 9, 2021 via Newsbank).

or are commercially important (Table S4). Shrimp was among the most referenced taxa at every site. Brown shrimp (*Farfantepenaeus aztecus*) and white shrimp (*Litopenaeus setiferus*) are among the most profitable commercial taxa in LA, bringing over $21,000,000 and $112,000,000 in landings, respectively, in 2017 (NMFS 2019a). In FL, pink shrimp are a highly profitable commercial species with landings worth over $35,000,000 in 2017, the most of any species in West Florida (NMFS 2019a).

Our analysis identified hurricane-induced ecological changes that are likely to go unrecognized by the adjacent social systems that are tied to them. Our results contrast with some other studies by specifically identifying long-term persistent hurricane-induced changes in abundance of estuarine resident taxa that are important contributors to these highly productive systems (Breitburg 1999). Taxa such as grass shrimp, gobies, and silversides are a forage base for many economically important predators (Markle and Grant 1970; Huh and Kitting 1985; Anderson 1985; Breitburg 1999) and play other ecological roles such as transporting energy and nutrients between trophic levels (Anderson 1985; Breitburg 1999).

We recognize that a wide variety of drivers can influence population dynamics of aquatic fauna. Abundance shifts of some of our highlighted taxa (i.e., longnose gar) were likely not hurricane related. However, plots of abundance through time strongly suggest that many of the top impacted taxa are in fact responding to hurricane activity. At NC, cownose ray (*Rhinoptera bonasus*) abundance consistently increased from year to year in intervals without hurricanes yet was low in all years following hurricanes (2006, 2012, 2015) (Fig. 5a). The year with the highest abundance was 2011, the last year of a 6-year period without hurricane activity, the longest such period in the study interval. Cownose rays are a highly migratory organism that feed upon invertebrates such as bivalve mollusks, crustaceans, and polychaetes (Fisher et al., 2013). It is possible that these rays are responding to hurricane impacts to prey taxa and are spending more time at less hurricane-impacted portions along migration routes during high hurricane activity. In contrast, gobies are shallow benthic associated and non-migratory taxa often found in seagrass meadows (Huh and Kitting 1985; Schofield 2003). Therefore, they may be less able to respond to hurricane impacts by moving long distances. At LA, mean summer naked goby abundance was five times higher in the 5 years prior to Hurricane Katrina than the 5 years following Katrina, with the storm marking a clear dividing line (Fig. 5b). This pattern was observed for several taxa at this site (Fig. S1). Similarly, at FL, code goby abundance never reached levels as high as those prior to Charley for the remaining 12 years of the study interval (Fig. 5c). Other

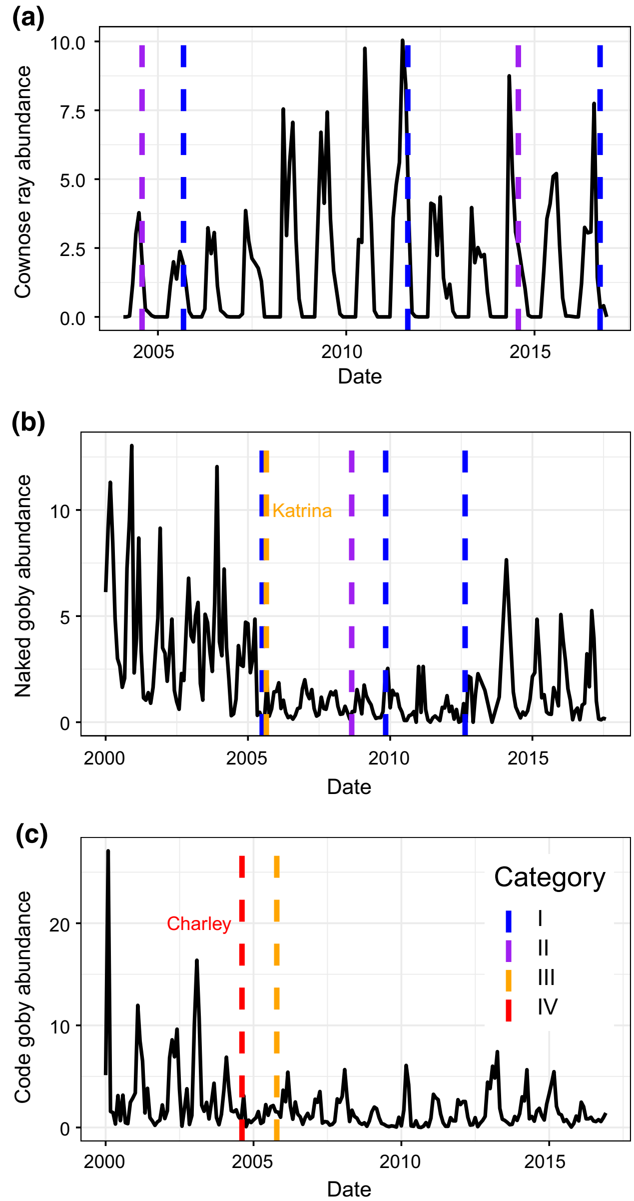

Fig. 5 Abundance per sample of select species through time at **a** NC, **b** LA, and **c** FL. Dashed vertical lines represent dates hurricanes passed over the site. Hurricane Charley is labeled because it was the strongest storm across all sites and Hurricane Katrina is labeled because it was unusually destructive

taxa at this site also demonstrated multi-year declines following Charley (Fig. S1).

Further, these observations suggest that increased frequencies of intense hurricanes will have long-term impacts on the ecology of aquatic fauna in these systems. Though the relatively mild storms of NC appeared to affect taxa such as cownose ray (Fig. 5), these impacts generally did not last more than a couple years following a storm. In contrast, changes in abundance following category four

Charley, and particularly following Katrina, were long lasting. For some taxa, abundances never recovered to pre-storm levels (Fig. 5; Fig. S1). This suggests that even if absolute hurricane numbers do not increase, increased storm intensities alone may be sufficient to alter these ecological communities.

Although our findings are suggestive, we note there are potential alternative explanations for the less pronounced long-term impacts at the NC site. For example, the NC site is located on the Atlantic whereas the other two locations are along the Gulf coast. Habitats at each location are certainly very different from one another and likely contribute to varied responses in marine organisms. It is also possible that because hurricane activity is so high at the NC site, that the organisms that inhabit these waters are adapted to these frequent hurricane events. However, despite these considerations, it remains the case that we find long-lasting responses to hurricanes following our most intense storms.

Because of the agenda-setting role of news media (Nelkin 1995), as well as the inordinate influence these taxa of high societal interest may have on research, conservation, and policy (Moustakas and Karakassis 2005; Wilson et al. 2007; Martín-López et al. 2009), it is likely that future policy related to hurricanes and coastal aquatic fauna will be biased in favor of the highlighted economically important taxa. We believe this situation lends itself to management that is reactive rather than proactive (Adger et al. 2005). Management based on these media 'star' taxa, those of commercial or recreational interest, may result in an approach where actions are initiated long after a system has undergone substantial change. Potentially, such management may result in cascading effects, such as declines in carrying capacity, that eventually will impact economically important taxa.

Additional research that helps to identify those taxa that are most impacted by hurricanes may help to ensure the best use of limited resources required to protect habitats and coastal fauna. Such research should not be exclusive to species targeted by fisheries economies, as our study here demonstrates that there may be substantial changes in an ecosystem before such species are impacted. Future studies could also focus on identifying potentially emblematic species in hurricane-impacted regions. Species can be considered emblematic if they draw public attention, serve as indicators of environmental conditions and ecosystem stress, and represent a specific ecosystem (Guerra et al., 2011). Additionally, this study highlights the necessity for scientists to continue to work across disciplinary boundaries, as well as with state and federal management agencies, to identify and develop ways to communicate the importance of taxa to human communities beyond the immediate economic value. Further, many studies that examine vulnerability of taxa to climate change tend to focus largely on the direct effects of changing temperatures (Pecl et al. 2014; Hare et al. 2016). Our research here suggests that a full understanding of climate impacts to these organisms may require incorporating the indirect effect of changing hurricane activity in locations where these events occur regularly.

Our findings have relevance for the emerging fields of conservation culturomics and iEcology, highlighting potential pitfalls to be wary of as these fields continue to develop. In some cases, iEcology methods have been employed to make inferences about species distributions and gain other ecological insights (Hart et al. 2018). The results of our work emphasize the need to be aware of potential biases in these approaches associated with varied societal interest in the taxa under study. It is conceivable, for example, that societal interest in a study organism may differ across the geographic range of the organism. In such a case, our results suggest that patterns obtained using digital databases could be more reflective of varying societal interest than of actual responses in the population of a focal organism. These precautions have been noted by others in these emerging fields (Ladle et al. 2019; Jarić et al. 2020). Nevertheless, our work stands as a case study that provides a vivid illustration of why these precautions are important to consider.

We note that our use of fisheries-independent data may have influenced some of our results. We used fisheries-independent data in our study rather than fisheries dependent for a couple of reasons. First, fisheries-dependent data by definition focus on taxa of commercial importance, making it unlikely we would be able to draw conclusions about the response of taxa having little commercial value. Second, fisheries-dependent catch rates can be due to multiple mechanisms that are disconnected from actual population dynamics, including changes in market value of target taxa and improvements in fishing efficiency with changes in technology (Walters and Maguire 1996; Glaser et al. 2013; Dennis et al. 2015). Hurricanes themselves are likely to alter catch by damaging fisheries infrastructure and reducing the number of boats available to fish (Petterson et al. 2006), potentially causing hurricane-related changes to catch that are independent of population dynamics. We used fisheries-independent data designed by state agencies specifically to monitor ecosystem status and that were sampled consistently through time and space. However, we acknowledge that even the most robust sampling programs have limited resources and do not match the spatial extent covered by fisheries-dependent data. This means that it is likely our findings may be biased toward taxa that are more closely associated with estuaries and coastlines rather than more pelagic-oriented taxa. Had we used fisheries-dependent data, it is likely that more such taxa may have been highlighted. On the other hand, hurricane impacts on aquatic taxa are often related to loss of coastal vegetation and other habitats (Piazza and La Peyre 2009), shifting of sediments (Nyman et al. 1995), and decreasing salinities as discharge from coastal rivers increases (Burkholder et al. 2004). These phenomena tend to be concentrated near coasts and estuaries, making our approach relevant to taxa likely to be relatively more vulnerable to the impact of hurricanes.

In conclusion, we find that hurricanes are an overlooked driver of system-level changes to coupled coastal socio-environmental systems and should be accounted for in current policy efforts. Social interest does not reflect the response of marine fauna to hurricane events. Whereas coastal ecological communities can be altered by hurricanes over multi-year time scales, culturally and economically salient taxa are not necessarily impacted by hurricane events to the same degree as largely overlooked taxa. Fisheries managers and scientists may improve hurricane preparedness and mitigation efforts by allocating resources to assessing and studying taxa that are ecologically important, but perhaps garner less media attention. Additionally, government and non-government organizations that fund ecological research should solicit research proposals specifically for taxa that are understudied, and specifically with respect to the effects of hurricanes on these taxa in the face of climate change. Our use of a novel inter-disciplinary approach allowed us to identify this knowledge gap, paving the way for proactive management interventions that can help mitigate effects of otherwise unrecognized changes in the face of increasing storm intensities.

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