Marine Biology (2020) 167:67
https://doi.org/10.1007/s00227-020-3669-z

COMMENT AND REPLY

Sound science, not politics, must inform restoration of Florida Bay and the coral reefs of the Florida Keys

Brian E. Lapointe[1] · Rachel A. Brewton[1] · Laura W. Herren[1] · James W. Porter[2] · Chuanmin Hu[3] · Jennifer P. Cannizzaro[3]

Received: 9 February 2020 / Accepted: 13 February 2020

Abstract
The comment by Julian (2020) criticizes aspects of our paper, "Nitrogen enrichment, altered stoichiometry, and coral reef decline at Looe Key, Florida Keys, USA." The comment begins by misrepresenting our extensive literature review, while providing no justification for the claim of a "skewed reading." Julian's critique focused on methods of data handling, statistics, and spatial awareness, which we demonstrate in every case to be either irrelevant or incorrect. We provide additional supporting data that refute these claims. For example, Julian criticized the removal of data points below the method detection limits (MDLs), but when these points are included, the results do not change. Further, Julian criticized our removal of outliers, but so few points were excluded that it did not change the results of the statistical analyses. Julian also misinterpreted the methods of our correlation and stepwise regression analyses but did not dispute the Kruskal–Wallis tests of our 30-year dataset that revealed significant decadal changes. Julian's closing paragraph is replete with misinformation and demonstrates a lack of understanding as to how increased freshwater flows associated with Everglades Restoration have led to a worsening of algal blooms and coral decline in the Florida Keys National Marine Sanctuary (FKNMS). This comment represents a smokescreen to confuse the scientific community about the physical connectivity of the Everglades basin and the FKNMS. Past water management policies based on politics, not sound science, have caused irreparable and ongoing environmental damage to sensitive coral reef communities in the FKNMS.

Introduction

For decades, Florida has attracted national and international headlines as a result of worsening harmful algal blooms and loss of critical marine resources, especially the biologically diverse coral reefs of the Florida Keys. The Florida Keys are home to the third largest coral barrier reef in the world and the only coral reef within the continental United States (Jaap et al. 2008). Nutrient pollution from land-based sources has been a major issue repeatedly identified by researchers as a driving factor in coastal algal blooms, water quality degradation, and coral reef stress in the Florida Keys (Hallock and Schlager 1986; Dustan and Halas 1987; NOAA 1988; Lapointe and Clark 1992; NOAA 1996; Hu et al. 2004; Ward-Paige et al. 2005; Voss and Richardson 2006; Wagner et al. 2010; Vega-Thurber et al. 2014). This was the focus of our recent paper, "Nitrogen enrichment, altered stoichiometry, and coral reef decline at Looe Key, Florida Keys, USA," which provided a unique long-term dataset and a synthesis of this worsening problem (Lapointe et al. 2019).

The comment by Julian (2020) was critical of some aspects of our paper, claiming that we used inappropriate data handling and misapplication of some statistical methods. Julian has not published any papers on water quality issues of coral reefs, seagrasses, macroalgae, or coastal phytoplankton blooms, and thus is not an expert on these subjects. Regardless, we show that Julian has misrepresented our study and the broader issues of water management policy in South Florida. This only serves to further confuse the scientific community and public about the critical water quality issues facing South Florida. We clarify why our data were

Responsible Editor: U. Sommer.

Brian E. Lapointe
blapoin1@fau.edu

[1] Harbor Branch Oceanographic Institute, Florida Atlantic University, 5600 US-1, Fort Pierce, FL 34946, USA

[2] Odum School of Ecology, University of Georgia, Athens, GA 30602, USA

[3] College of Marine Science, University of South Florida, St. Petersburg, FL 33701, USA

handled and analyzed as described in the paper and show that despite Julian's allegations, the conclusion of our paper remains the same: *A long-term increase in N availability has increased algal blooms and altered N:P stoichiometry, which have promoted metabolic stress and decline of stony corals at Looe Key.*

In the introductory paragraph, Julian begins misrepresenting our paper by stating that we provided a "brief literature review of nitrogen driven eutrophication." Our Introduction section included eight paragraphs and a very large summary of management actions and biotic events related to nutrient enrichment, algal blooms, and hypoxia at Looe Key and the Florida Bay/Florida Keys region, extending back to the 1970s (Lapointe et al. 2019, Table 1). In fact, the Introduction of our paper contained over 130 scientific references. These included papers documenting how increasing Everglades discharges worsened algal blooms and turbidity in Florida Bay in the 1990s as the incidence of coral diseases sharply accelerated in the downstream waters of the Florida Keys National Marine Sanctuary (FKNMS; Porter et al. 2002; Jaap et al. 2008).

Julian also stated that our paper "demonstrated a skewed reading of the literature and contradicts established understandings of ecosystem dynamics." There was no justification or explanation provided for those statements, which raises concerns about the validity of Julian's comment. Below, we address the comments that were limited to subjective aspects of data handling and statistical analysis, showing that none of the criticisms significantly change our overall results nor our interpretation of environmental changes in the hydrologically linked Everglades–Florida Bay–Florida Keys system.

Data handling

Julian stated that we should not have excluded dissolved nutrient data that were below the method detection limits (MDLs) and suggested simple substitution techniques would have been a better approach. Alternative approaches suggested included using either the value of the MDL or a value one-half of the MDL to replace these non-detects. While these simple substitution methods are "widely used", there is no "theoretical basis" for using them and these methods have been found to perform "poorly in comparison to other procedures" (see Fig. 13.1, Helsel and Hirsch 1992). In these recommendations, Julian (2020) neglected to address the poor performance of these simple substitutions and the fact that there is great disagreement on the best way to handle data below MDLs (Helsel and Hirsch 1992; Newman et al. 1989; Clark and Whitfield 1994; Clark 1998). Further, all methods for handling values below MDLs can bias statistical analyses, but this is proportional to the degree of censoring (Newman et al. 1989; Clark 1998). Because the MDLs were quite low in our Looe Key monitoring study, there were very few non-detectable data points. In fact, all data were above the MDLs for nitrate + nitrite and orthophosphate (SRP). For ammonium, only 4% of the samples fell below the MDL and were not used in statistical analyses. At this very low level of censoring, effects on statistical analyses would likely not be expected (Clark 1998).

The important thing to remember is that the *true value* is unknown for samples below MDLs, although information about its possible maximum value is available. While it may not be the best statistical approach for the reasons discussed above, we do agree that sometimes it is appropriate to report a numerical value even though it is below the MDL. For example, in a NASA-Research Opportunities in Space and Earth Science funded study of dissolved nutrients in the Caloosahatchee Estuary in 2010, we sent split samples for analysis of ammonium, nitrate + nitrite, and SRP to two different analytical laboratories, the Florida Department of Environmental Protection (FDEP) laboratory (Tallahassee, FL) and the Nutrient Analytical Services Laboratory (NAS-CBL), Chesapeake Biological Lab, University of Maryland (Solomons, MD). The MDL for the analytes at the two laboratories was quite different. For the FDEP lab, the MDL values were higher, 0.71 µM, 0.29 µM, and 0.13 µM for ammonium, nitrate + nitrite, and SRP, respectively. The corresponding MDLs for the NAS-CBL were lower, 0.21 µM, 0.01 µM, and 0.02 µM, respectively. The resulting analysis showed that the % undetectable samples from the FDEP lab were 68%, 58%, and 39%, respectively; for the NAS-CBL, the corresponding % undetectable samples were 38%, 0% and 0%. As such, if one was using the dissolved nutrient data from the FDEP lab, the use of a substitution method might be more appropriate because they would have very few *true values* to work with.

This inter-laboratory comparison illustrates the *most important* decision facing scientists who study status and trends in ambient nutrient concentrations—the selection of an appropriate analytical method to avoid undetectable results (D'Elia et al. 1989). Julian neglected to point this out, yet it speaks to the importance of using low MDLs to detect ambient nutrient concentrations in oligotrophic waters, which has been a serious problem for some coral reef biologists (see comment by Lapointe 2004). We recognized the need for low-level nutrient analytical methods in the early 1980s when we began monitoring nutrients at Looe Key. We specifically chose methods with low MDLs to obtain as many *true values* as possible. For our purposes, the MDL was considered *the lowest concentration at which the performance of a method was acceptable for use*. Had we substituted one-half of the MDL, that would have introduced uncertainty and skewed our nutrient data, especially the DIN:SRP ratios.

To illustrate that the removal of values below MDLs had no effect on the data analyses in Lapointe et al. (2019), we have reanalyzed the long-term Looe Key ammonium data dealing with values below MDLs in three ways: (1) using all the ammonium data including values below detection limits, (2) by substituting half of the MDL for values below detection limits, and (3) as done in the original paper. These datasets were compared overall and by year with Kruskal–Wallis tests in SPSS 25 for Windows V. 25. When the overall ammonium datasets were compared, there were no significant differences observed (Kruskal–Wallis test, $H_2=3.57$, $P=0.168$; Fig. 1a). Further, when the methods for handling data below the MDL were compared by year, there was also no significant difference between these three datasets for any of the years where data were removed. This includes 1984 (Kruskal–Wallis test, $H_2=0.57$, $P=0.753$), 1985 (Kruskal–Wallis test, $H_2=2.67$, $P=0.270$), 1987 (Kruskal–Wallis test, $H_2=3.41$, $P=0.182$), 1988 (Kruskal–Wallis test, $H_2=1.76$, $P=0.415$), 1989 (Kruskal–Wallis test, $H_2=3.17$, $P=0.205$), and 1996 (Kruskal–Wallis test, $H_2=0.37$, $P=0.832$; Fig. 1b). The lack of statistical significance between different methods for handling data points below the MDL confirms that the removal of values below MDLs did not have "significant impacts on data analyses, statistical evaluation, and interpretation of the results" as Julian (2020) stated in the comment (Fig. 1). For our paper published in *Marine Biolo*gy, we took a conservative approach using only data for which we had *true values*.

We acknowledge that if we had removed a larger percentage of the data, then it could have had a significant effect on the statistical analyses. For example, the Florida International University Southeast Environmental Research Center (FIU-SERC) dataset for Looe Key that Julian (2020) used for the example analyses includes both surface and bottom water samples. However, Julian decided to exclude the bottom water samples, which amounts to ~ 50% of the available data for some variables [see Julian (2020), Fig. 4 and https://serc.fiu.edu/wqmnetwork/FKNMS-CD/DataDL.htm]. For this same dataset, Boyer and Jones (2002) noted that salinity, nitrate, nitrite, ammonium, total phosphorus, and turbidity were significantly higher in bottom waters; so, presumably removing these data could have affected these analyses and Julian's results.

Julian then argued extensively that the use of Tukey's box plots in our study to identify extreme outliers prior to regression analyses was not appropriate. We do appreciate this concern and realize now that we could have provided more details regarding our outlier identification process. To clarify, visual examination of the data was employed (boxplots and others) to initially identify extreme outliers, which were then investigated further through inspection of individual data points. Others, such as Julian, have employed similar methods for identifying and removing data points that indicated a "potential data quality problem" (Julian et al. 2019) and only included "useable [sic] data" (Julian 2020, Fig. 1 caption). Unlike Julian et al. (2019) and Julian (2020), our data were not part of an agency database where suspect points are flagged upon entry; thus, this data inspection prior to analysis was very important to ensure quality. Despite not providing all the details relating to outlier identification, in the original paper, we did state the criteria used for exclusion and exactly how many samples were excluded from regression analyses for each parameter in the first paragraph of the results. Furthermore, the removal of these few "extreme outliers" accounted for just 1–2% of the data for these parameters (Table 1). Thus, it is not likely that removal

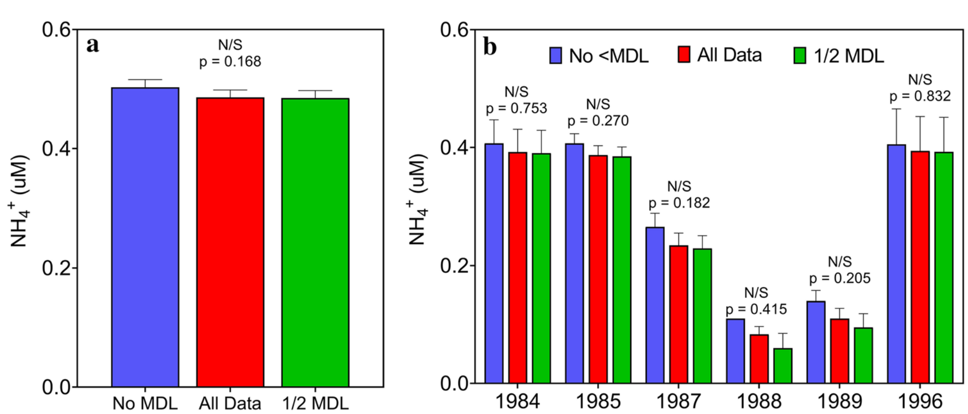

Fig. 1 Long-term ammonium data used in Lapointe et al. (2019), showing the lack of statistical differences resulting from the removal of concentrations below the method detection limits (MDLs) based on Kruskal–Wallis tests for **a** the overall datasets and **b** by individual year where any values lower than MDLs were removed. "No < MDL" represents the dataset with values below the MDL removed and was the dataset used in Lapointe et al. (2019), "All Data" represents all of the data available, and "1/2" MDL represents substituting data below the MDL with ½ the MDL as recommended by Julian (2020)

Table 1 All specific data points by analyte that were removed prior to regression analyses in Lapointe et al. (2019), showing date and value, as well as total percent removed for each analyte

Analyte	Date	Value	% Removed
NH_4^+ (uM)	7/1/1992	3.1	0.01
DIN (uM)	6/7/1992	3.03	0.02
	7/11/1992	4.53	
	7/24/1992	3.05	
SRP (uM)	1/31/1999	0.561	0.01
DIN:SRP	7/19/2014	104	0.01
Chlorophyll *a* (ug/l)	7/2/1996	1.71	0.02
	7/29/2007	1.65	

of these few data points would have increased the Type 1 error rate as suggested by Julian (2020). In fact, the inclusion of these data, which represent unusually high peaks in dissolved nutrient and chlorophyll *a* concentrations post-1980s reinforces the conclusions of Lapointe et al. (2019).

The decision was made to conserve as much data as possible, knowing that nutrient concentrations in the Looe Key study area are variable as a result of movement of the Florida Current, tropical storms, rain events, submarine groundwater discharge, wind mixing of bottom sediments, tidal-driven currents, and upwelling (Lapointe et al. 2004). In Lapointe et al. (2019), we provided the annual means (Fig. 6), as well as decadal nutrient and chlorophyll *a* values, which included the minimum, maximum, means, medians, SE, and Kruskal–Wallis test results (Table 2). The range of our values is well within the values reported for coral reef environments, with higher values typical of eutrophic reefs (Smith et al. 1981; Bell 1992; Lapointe 1997).

Julian brought the criticism of our data handling to an end by stating that we did not include analytical methods relating to "other inorganic nitrogen species". We assume that the author is referring to nitrite (NO_2^-) as there were no further details provided to support this claim. In fact, under "Long-term monitoring at Looe Key" and in Table 2 of Lapointe et al. (2019), it is qualified that nitrite was included together with nitrate, as it is a common practice in water quality research. For example, Julian did this in the comment. Furthermore, FDEP, which is listed as one of the Julian's affiliates, frequently combines nitrate + nitrite (FDEP 2016), as does the United States Geological Survey (USGS, see https://waterwatch.usgs.gov/wqwatch/map?state=ks&pcode=00630; Fishman 1993).

Statistical analyses

It was Mark Twain who said "lies, damned lies, and statistics" to illustrate how overutilizing statistics can be used to prove or disprove anything. This exemplifies Julian's criticism of our use of a correlation matrix and regression analyses to dispute our findings. Below we defend the choices we made in our statistical analyses by explaining instances where Julian (2020) incorrectly represented our analyses and providing support for our methods.

The correlation matrix was presented to allow the readers to see the relationships between variables and was conducted to guide our subsequent analyses. Contrary to what Julian (2020) states, no claims were made that an increase in Monroe County populations caused a decrease in surface water temperature at Looe Key reef. We understand correlation does not imply causation and did not suggest that it did. In the Results section of Lapointe et al. (2019) we presented correlations where the relationship might be of interest to a reader, never as cause and effect. For example, as Julian (2020) stated, the population of Monroe County was positively correlated with increased flows from Shark River Slough, revealing potentially additive threats to water quality for this sensitive ecosystem.

Julian (2020) then criticized the use of stepwise regressions in the original paper as adding no explanatory value to the study. We disagree and feel the stepwise regressions served as a non-biased approach to modeling the biological responses against potential drivers of change. However, these regressions were conducted using annual means, not maximum values as Julian (2020) stated. As such, under "Statistical analyses", Lapointe et al.(2019) specified that annual averages were used in stepwise regressions. This did include the *annual average of daily maximum water temperature* because we sought to include the highest temperature observed each day due to the relationship between coral bleaching and elevated temperatures. We also did not distill our thirty-year dataset into single values for each variable as suggested by Julian (2020) for these analyses. Because we were using annual averages, there was a data point for every year of the study where data were available.

Further, Julian (2020) criticized other aspects of the stepwise regressions without providing supporting literature. For example, in Lapointe et al. (2019), stepwise regressions were performed forward and backward, as Julian recommends. However, despite the contention that this always must be done, in many instances, stepwise regression models may be run forward or backwards, based on what is appropriate for the study question (Leavey-Roback et al. 2016; Zhou et al. 2016; Yang et al. 2017; Alemu et al. 2018; Fowler et al. 2018). Similarly, as noted in the methods section of Lapointe et al. (2019), stepwise model section was performed using both AIC and *P* values as criteria for choosing the most parsimonious model, as well as the "all possible" and "best subset" options. All of these options were considered to determine what model had the best fit based on the lowest AIC and highest R^2. The stepwise regression performed using *P* values was the most parsimonious and, thus, was selected. The olsrr package in R (Hebbali 2018) includes all of these methods for variable selection; so, we disagree with Julian's assertion that this is not a valid model section approach, a claim for which he provides no support. Despite Julian's multiple concerns and misinterpretations of our methods, we are confident that the stepwise regressions allowed us to identify important relationships in the dataset.

Julian also criticized the fifth-order polynomial regressions as "nothing more than data smoothing functions", which is all that is truly needed to see how concentrations of dissolved nutrients and chlorophyll *a* have changed over time. It is important to note that Lapointe et al. (2019) did not describe the polynomial regressions as "trend analysis" because the intention was simply to explore the temporal relationship of the variables over time without constraining it to be monotonic because many of the variables had high peaks in the 1990s. Further, while Lapointe et al. (2019) only discussed "relationships" of variables over time to alleviate the concerns discussed in Julian (2020), we employed the Mann–Kendall Trend Test on the annual data in R 3.6.1 using the package, trend (Pohlert 2020). As one would expect by examining Fig. 3 in Lapointe et al. (2019), the trend analysis of these data confirms the significance of the trend of increasing DIN at Looe Key (Table 2).

Additionally, the Sen's Slope of these data is alarming, particularly given that the slope for DIN suggests an increase of 1 µM over twenty years (0.05 µM/year). Though this may sound insignificant, in an oligotrophic coral reef environment such as the FKNMS, enrichment to 1 µM is enough to drive shifts in community structure (Smith et al. 1981; Bell 1992; Lapointe et al. 1993; Lapointe 1997). As such, the United States Environmental Protection Agency (USEPA) has set the DIN Strategic Target for reef sites at 0.75 µM (Briceno and Boyer 2018). This effect is well known in freshwater oligotrophic ecosystems, such as the Everglades, where phosphorus enrichment above very low concentrations (10 ppb; Florida Public Law 62-302.540) can alter wetlands communities from native sawgrass *Cladium jamaicense* to cattails *Typha domingensis* (Davis 1994).

Despite these significant results, we do not believe this trend analysis that is intended for use with monotonic trends (McLeod et al. 1991; Helsel and Hirsch 1992; Meals et al. 2011; Mozejko 2012) accurately described relationships in the long-term data at Looe Key. For example, in Fig. 3, Table 2, and Fig. 6 of Lapointe et al. (2019), a spike in DIN:SRP and chlorophyll *a* is evident in the 1990s. Therefore, because this relationship is not monotonic, the Mann–Kendall Trend test is not an appropriate test for understanding the change over time. Further, seasonality of data must also be considered when it has the potential to affect statistical trend analyses (Helsel and Hirsch 1992). As such, due to the seasonal nature of water quality at Looe Key (Lapointe and Smith 1987; Lapointe and Matzie 1996; Lapointe et al. 2004), it is arguable that unlike the tests performed by Julian (2020), only a seasonal Mann–Kendall Trend Test would be appropriate. We suggest that the best way to present the long-term Looe Key data remains the polynomial regressions or with a LOWESS curve.

Julian did not dispute the decadal statistical analyses of dissolved nutrient and chlorophyll *a* presented in Lapointe et al. (2019; Table 2, Kruskal–Wallis test) or the annual average values we presented in Fig. 6. What is clear from both Table 2 and Fig. 6 is the obvious "breakpoint" in DIN, chlorophyll *a*, and the DIN:SRP ratio that occurred at Looe Key in 1992 (Lapointe et al. 2019, Fig. 2). The 1992 breakpoint occurred when major increases in freshwater discharges from both Taylor Slough and Shark River Slough began increasing nitrogen loads with high DIN:SRP ratios to Florida Bay and the southwest Florida shelf (Rudnick et al. 1999). This triggered widespread phytoplankton blooms that extended to downstream offshore reefs, including Looe Key (Fig. 2). This DIN breakpoint was obvious in our annual mean DIN value in 1992 (Lapointe et al. 2019, Fig. 6), after which the annual mean DIN values were significantly and

Table 2 Mann–Kendall Trend Test results on annual means for dissolved nutrient data from long-term monitoring at Looe Key collected between 1984 and 2014 showing number of years (*N*), Kendall tau (τ), *P* value, and Sen's Slope for time series data; data below the method detection limit (MDL) were replaced with one-half the MDL as suggested by Julian (2020), years with no data were removed prior to trend analysis, and statistical significance was considered at $P = 0.10$

Data	Parameter	N	Kendall τ	*P* value	Sen's Slope
Annual Mean	**Ammonium**	**20**	**0.28**	**0.09**	**0.02 µM / year**
	Nitrate + nitrite	**21**	**0.34**	**0.03**	**0.02 µM / year**
	DIN	**20**	**0.43**	**< 0.01**	**0.05 µM / year**
	SRP	21	0.17	0.29	< 0.01 µM / year
	DIN:SRP	21	0.23	0.16	< 0.01 / year
	Chlorophyll *a*	19	0.19	0.26	< 0.01 µg/l / year

Values in bold are statistically significant consistently higher than the 1980s (Lapointe et al. 2019, Table 2, Fig. 6).

For the time-series analyses, Julian (2020) used the FIU-SERC dataset from Looe Key for total nitrogen (TN), total phosphorus (TP), dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP), DIN:SRP, and chlorophyll *a* that begins in 1995. As such, this dataset began several years following increased Everglades discharges, DIN enrichment, and regional phytoplankton blooms that began in 1991 (Boyer et al. 1999) and was reflected in the downstream waters at Looe Key in 1992. This breakpoint at Looe Key in 1992 coincided with peak annual ammonium concentrations (~ 14.0 μM) measured in central Florida Bay when increased Everglades discharges were occurring (Boyer and Jones 1999; Lapointe et al. 2002).

Importantly, the dataset that Julian used in these analyses was biased low and not fully representative of Looe Key water quality because these data represented only surface samples due to exclusion of the bottom samples (Julian 2020). This is of particular concern as the bulk of human wastewater generated in the Florida Keys is disposed of in either shallow or deep groundwaters through the use of cesspits, septic systems, shallow injection wells (Class V), and deep injection wells (Class I), all of which can enter coastal waters through submarine groundwater discharge at the benthic boundary layer (Simmons 1992; Shinn et al. 1994; Lapointe et al. 1990, 2004). Using only surface water data would also not capture more dense, hypersaline, nutrient enriched bottom waters discharging from Florida Bay to the offshore reefs. Another limitation of Julian's data analysis is the low sampling frequency at Looe Key (quarterly) with no replication (only one data point per season). As Boyer and Jones (2002) noted, at quarterly intervals the FKNMS monitoring program may not be able to detect small trends because of "seasonal variability and background noise." Finally, no details of the sampling location at Looe Key were provided; thus, comparing the two datasets would be comparing "apples to bananas" to use the words of Julian (2020).

Furthermore, the analytical method used by FIU-SERC researchers to measure chlorophyll *a* [i.e., the data used by Julian (2020)] is known to be spurious. A USEPA intercalibration study of eight labs measuring chlorophyll *a* in the Florida Bay and the Florida Keys region in 1996 demonstrated that the FIU-SERC laboratory was reporting concentrations 2–5 times lower than what other participating laboratories reported (Brand 2002). This is another example of how flawed methods can result in bias and in this case, gross underestimation of true values for chlorophyll *a*.

According to the intercalibration study, our long-term chlorophyll *a* method provided accurate data (Brand 2002). As such, our chlorophyll *a* data at Looe Key showed a significant correlation with Shark River flows (Lapointe et al. 2019), in agreement with Brand (2002). The chlorophyll *a* concentrations at Looe Key spiked to a wet season maximum of 0.72 ug/l in 1996 (Lapointe et al. 2004) following peak nitrogen loads and water discharges to Shark Slough in 1995 (~ 3000 metric tons of nitrogen and 2900 million m^3 of water; Rudnick et al. 1999). These high chlorophyll *a* concentrations in 1996, together with associated turbidity advected from upstream waters in western Florida Bay (Boyer and Jones 1999), reduced light availability to corals at Looe Key and other reefs in the FKNMS. Reduced light is known to decrease the photosynthesis:respiration (P/R) ratio and compensation irradiance in corals (Yentsch et al. 2002), as well as induce physiological stress and bleaching (Bessell-Browne et al. 2017). This was the time period when a catastrophic coral disease outbreak occurred at Looe Key and other reefs in the Florida Keys (Jaap et al. 2008), resulting in an overall 38% loss of living coral cover throughout FKNMS (Porter et al. 2002; Jaap et al. 2008).

Julian did not dispute any of the long-term macroalgae tissue C:N:P data from Looe Key (Lapointe et al. 2019, Table 3, Fig. 8), which mirror the temporal changes and breakpoint we observed in the water column DIN, SRP, and DIN:SRP data between the 1980s and 1990s. Macroalgal blooms are a common ecological response to nutrient enrichment in shallow coral reef environments and can be used very effectively as bioindicators of nutrient availability as they integrate nutrients in the water column over time (Smith et al. 1981; Lapointe 1997; Nixon 2009). The fact that the decadal changes in both the water column nutrient data, chlorophyll *a*, and macroalgae tissue data all show the same temporal pattern of increase from the 1980s to the 1990s provides multiple lines of evidence that DIN enrichment and higher DIN:SRP ratios triggered the increased N:P and C:P ratios in the macroalgae. This provides compelling evidence of increased P limitation on the shallow reef at Looe Key since the 1990s.

Nitrogen enrichment associated with increasing Everglades discharges between 1991 and 1996 triggered widespread macroalgal blooms in Florida Bay and the FKNMS that were described in our previous research (Lapointe et al. 2004). These macroalgal blooms were widely observed by local fishers, divers, and tourists, and reported by the *Miami Herald* in June 1992 (Keating 1992). In particular, the blooms were especially harmful at the Rock Pile reef on the north side of the lower Florida Keys, which was impacted directly by the Shark River discharges (Lapointe et al. 2007). This reef was comprised of numerous hemispherical brain coral colonies (*Pseudodiploria strigosa*) up to 2-m height. Researchers with the FKNMS Coral Reef Monitoring Project observed very high *P. strigosa* mortality between 1995 and 1996 at the Rock Pile. Benthic surveys in 1997 confirmed extensive coral mortality and overgrowth of the dead coral skeletons by the boring sponge, *Cliona lampa*, an indicator of land-based nutrient enrichment (Ward-Paige et al. 2005).

A variety of macroalgal (*Caulerpa* spp., *Cladophora vagabunda*) and cyanobacterial (*Lyngbya* spp.) blooms have also overgrown the skeletal remains of these once magnificent corals (Lapointe et al. 2007); video of the time sequence of this rapid coral mortality and overgrowth by sponges and macroalgae can be accessed on YouTube (https://www.youtube.com/watch?v=l5IO0RpYsgc&t=1s).

Julian provided no support for the criticism relating to our conclusions that the altered stoichiometry and increased DIN:SRP could increase metabolic stress on corals at Looe Key. The mean decadal DIN:SRP values we reported in Table 2 increased significantly from 10:1 in the 1980s to 27:1 in the 1990s with increasing freshwater inputs and nitrogen loading to the Florida Bay–Florida Keys region (Lapointe et al. 2019). The low DIN:SRP ratios in the 1980s are supported by our Florida Keys-wide monitoring in 1989–1990, which showed DIN:SRP ratios were ~ 7:1 on the offshore bank reefs between Key Largo and Key West during both winter and summer ($n = 72$); this reflected a healthy DIN:SRP ratio during a period with very low freshwater discharges from the Everglades during these drought years (Lapointe and Clark 1992). Subsequent research along an offshore transect to Looe Key during 1992 documented how increasing stormwater runoff was contributing to increased DIN, DIN:SRP ratios, and P limitation of algal blooms in the wet season, and we specifically noted the upstream contributions associated with the increasing Everglades discharges at this time (Lapointe and Matzie 1996).

Lapointe et al. (2019) discussed in detail the experimental lab and field research by a variety of scientists who have collectively elucidated how DIN enrichment can result in P limitation and metabolic stress in corals. While we considered the average DIN:SRP values of 27:1 in the 1990s at Looe Key as being high and potentially stressful to corals, the range and median values reported by Boyer and Jones (2002) and Julian (2020) are even much higher than the median (20:1) and maximum values (205:1) we reported for the 1990s, further supporting our conclusions. For example, DIN:SRP ratios reported by Boyer and Jones (2002) for the FKNMS between 1995 and 1998 ranged up to a maximum of 935:1 (Table 22.1), while "hot spot" median values in Florida Bay ranged between 80:1 and 160:1 and those on offshore bank reefs of the lower Florida Keys ranged from ~ 48:1 to 80:1 (Fig. 22.10).

The recent massive flooding and freshwater runoff from Hurricane Irma in September 2017 was followed in 2018 by the most widespread and diverse array of harmful algal blooms (red tides, brown tides, blue–green algae, pelagic *Sargassum*) ever seen in Florida. In addition, the Hurricane Irma runoff was followed by an extremely high DIN:SRP ratio of ~ 200:1 at Looe Key in 2018 (see Fig. 4, Julian 2020), which matches the maximum value we observed in the 1990s and is one of the highest values observed for the entire 34-year record (Lapointe et al. 2019; Julian 2020). These DIN:SRP ratios are an order-of-magnitude higher than the Redfield Ratio of 16:1 (Redfield 1958) for marine waters and provide a useful tracer demonstrating that the spatial impacts of land-based nitrogen-rich runoff extend offshore to Looe Key. It is reasonable to assume that this runoff from Hurricane Irma caused P starvation and metabolic stress at Looe Key and throughout the FKNMS. Our interpretation helps to explain the recent acceleration and progression of Stony Coral Tissue Loss Disease to the lower Florida Keys in Spring 2018 (https://floridakeys.noaa.gov/coral-disease/disease.html).

Spatial reasoning

Another issue raised by Julian was a lack of "spatial awareness." Why can Looe Key be influenced by "rainfall across an approximate 400 km distance" and by "a selected set of discharge locations 150 km away"? This is all due to physical connectivity. First, field measurements through drifters, numerical models, and satellite imagery all indicate direct connectivity between the discharge locations (e.g., Shark River Slough, Taylor Slough) and the lower Florida Keys. Further, the discharge is modulated by rainfall across the Everglades drainage basin, regardless of the physical distance. Such a connectivity has already been shown in Lapointe et al. (2019) through several cases where discolored water was continuous from the Shark River Slough to the lower Florida Keys (Lapointe et al. 2019, Fig. 10). Here, Figs. 2 and 3 show the three different pathways of connectivity:

1) The connectivity from the lower Everglades to the lower Florida Keys has been demonstrated in Cannizzaro et al. (2019), where an example from their Fig. 10c is presented in Fig. 2a below. Similar cases have also been found in other years, as shown in other panels of Fig. 2.
2) The connectivity between Charlotte Harbor and the lower Florida Keys has been discussed in Hu et al. (2004), as demonstrated in Fig. 3a below. Excessive rainfall and river discharge caused water discoloration, which clearly showed the connectivity.
3) The connectivity between the Shark River Slough and the lower Florida Keys has been shown in Hu et al. (2003) and later by Zhao et al. (2013), as demonstrated in two examples in Fig. 3b, c. In these examples, discolored waters are continuous from the Shark River Slough and the lower Florida Keys, which carried medium to high concentrations of *Karenia brevis*.

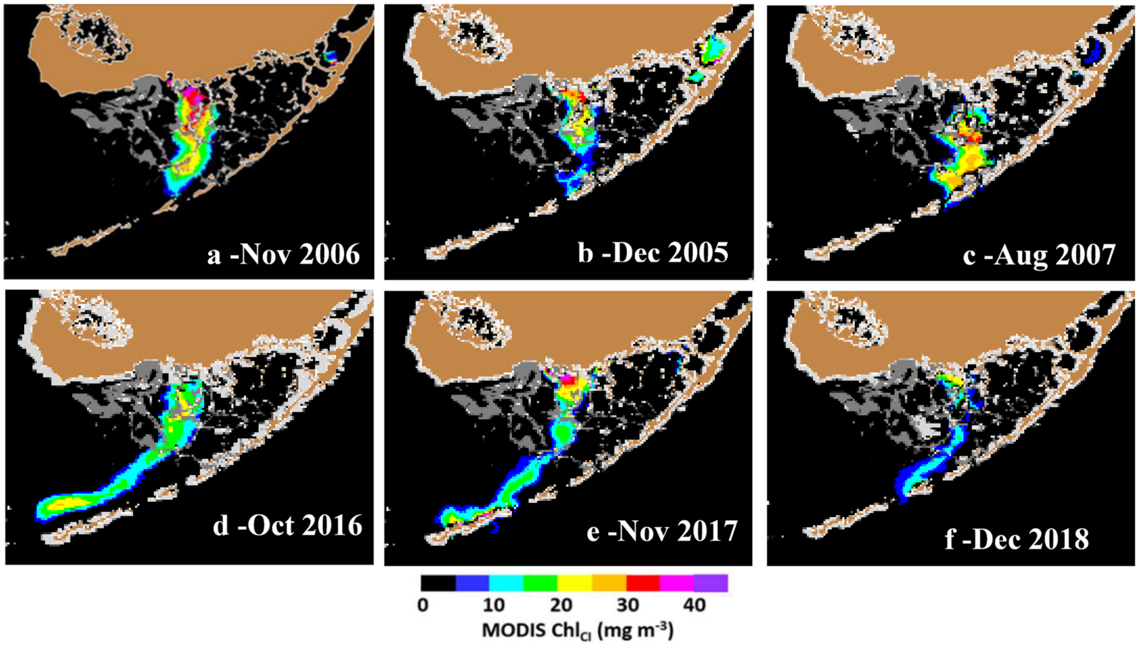

Fig. 2 MODIS imagery of chlorophyll concentration show cyanobacteria (*Synechococcus*) blooms in Florida Bay. The image in (**a**) is adapted from Fig. 10c of Cannizzaro et al. (2019), where the algorithm to quantify cyanobacteria blooms is detailed. Other images (**b**–**f**) were derived from MODIS measurements using the same algorithm

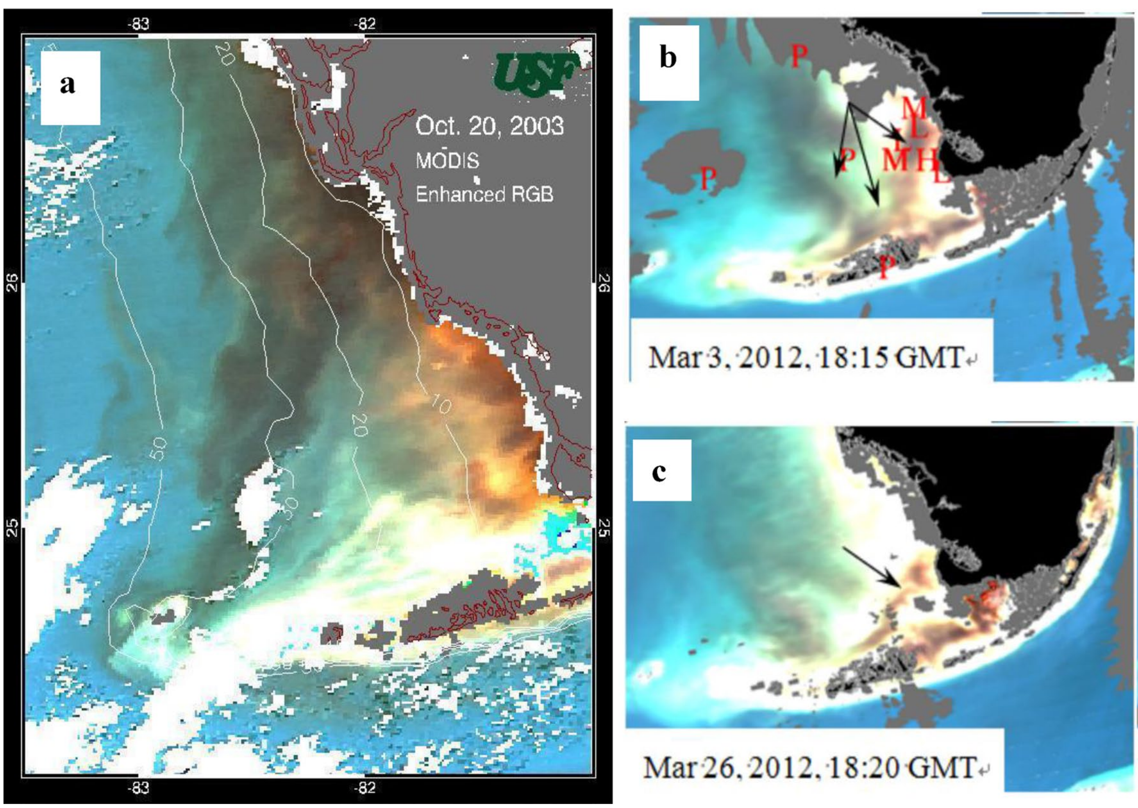

Fig. 3 MODIS enhanced Red–Green–Blue (RGB) imagery showing connectivity **a** between coastal waters off Charlotte Harbor and lower Florida Keys (Hu et al. 2004) and **b**, **c** between Shark River Slough (SRS) and lower Florida Keys (Zhao et al. 2013). The red letters in **b** mark the concentrations of *Karenia brevis* (*H* high, *M* medium, *L* low, *P* present). Note the presence of *K. brevis* near Looe Key due to the water transport from the SRS to the lower Florida Keys

Further, Julian (2020) did not recognize the importance of groundwater, another physical connection between the Florida mainland, Florida Bay, and the lower Florida Keys (Top et al. 2001). For example, the Florida Keys Aqueduct Authority (FKAA) pumps approximately 17 mgd of potable freshwater from wellfields near Florida City to Key West, a distance of ~ 200 km. In recent years, we have analyzed the FKAA tap water on Big Pine Key for DIN and SRP. In 2018, the DIN averaged 266 µM, which consisted mostly of nitrate + nitrite (239 µM). The corresponding SRP concentration averaged 1.85 µM, resulting in a DIN:SRP ratio of 144:1. This high DIN:SRP ratio from groundwater in the Biscayne Aquifer on the Florida mainland is within the range of values reported for Florida Bay (80:1–160:1; Boyer and Jones 2002), suggesting that these high nitrate groundwaters could be contributing directly to the eutrophication of Florida Bay and the Florida Keys. The trend analysis in Julian (2020) suggests a decrease over time of nitrate in surface water of Shark River Slough, however DIN is a relatively small fraction (~ 6%; Rudnick et al. 1999) of the total nitrogen in Shark River Slough, which is dominated by dissolved organic nitrogen. Because the algal blooms in central and western Florida Bay are strongly nitrogen limited and can utilize dissolved organic forms of both nitrogen and phosphorus (Brand 2002; Glibert et al. 2004), these blooms expand when flows into the bay increase, such as between 1991 and 1994 (Boyer and Jones 1999; Brand 2002; Lapointe et al. 2002).

This speaks to another important point that Julian (2020) ignored, which is that nitrogen loading to downstream waters of Florida Bay and the Florida Keys is primarily a result of changes in flow (Rudnick et al. 1999). Freshwater flow has been increasing on average since 1943, but especially since 1983 as the Florida Bay algae blooms have spatially expanded and worsened. The increased flows from Shark River Slough primarily affect western Florida Bay and the downstream Florida Keys (Lapointe et al. 2019, Fig. 10).

Water management policy must be based on sound science

In conclusion, Julian accused Lapointe et al. (2019) of using "selective literature citations and a skewed and improper evaluation of limited data". As noted, Lapointe et al. (2019) cited over 130 scientific references in the Introduction alone, and Julian provided no evidence to support the claim of selectivity in these references. Further, we have demonstrated that our data handling and statistical methods were not "skewed or improper", but rather conducted to be as conservative as possible. Julian also claimed that Lapointe et al. (2019) ignored "published interpretations of the data that they selectively used to create their narrative that Everglades restoration has the potential to impact coral reef ecosystems." For this strong statement, Julian provided no context that would enable us to respond.

Julian also claimed that our conclusion "flies in the face of countless studies that call for Everglades restoration for the benefit of the ecosystem in totality…" but provided no citations of these "countless studies" and disregarded the extensive body of literature and multiple lines of supporting evidence that we provided in Lapointe et al. (2019). Our previous citations (e.g., Voss et al. 2006; Wiedenmann et al. 2013; Vega-Thurber et al. 2014; Rossett et al. 2017) documented the harmful impacts of DIN enrichment and altered stoichiometry to the downstream waters of Florida Bay and the FKNMS, which included the designation of the FKNMS as a "dead zone" as a result of increased land-based nutrient enrichment and hypoxia in the 1990s (Pew Oceans Commission 2003). Julian also ignored the conclusions of the National Research Council report that we quoted at the end of our Discussion regarding the how the popular assumption that increased flows to the Everglades would help to restore Florida Bay were not correct and could, in fact, cause harm to the downstream coral reefs (NRC 2002).

We believe that responsible environmental restoration efforts in South Florida must ensure that no harm is done to sensitive downstream coral reef ecosystems from nitrogen enrichment and simultaneous low P stress (Wiedenamann et al. 2013; Shantz and Burkepile 2014). This is especially important considering the physical linkages of the Everglades–Florida Bay–Florida Keys region, which are evident in satellite imagery (Hu et al. 2003, 2004; Zhao et al. 2013; Cannizzaro et al. 2019) and in published studies of water circulation and nutrient transport (Klein and Orlando 1994; Smith 1994; Brand 2002; Smith and Pitts 2002). Restoration efforts in the hydrologically linked Everglades–Florida Bay–Florida Keys system must be conducted holistically considering the past irreparable damage resulting from political decisions to restore Florida Bay and the FKNMS by sending more freshwater south to Florida Bay (Lapointe et al. 2019). This raises the issue of philosophical bias, which best describes Julian's arguments but unfortunately cannot be avoided (Andersen et al. 2019). Until sound science rather than politics is used to inform water management policy in Florida, the future of coral reefs in the Florida Keys, and ecosystem health in other critical water bodies like Lake Okeechobee, the Indian River Lagoon, and the Florida Springs, will be compromised.

Acknowledgements This work was supported in part by the US NASA Earth Science Applied Sciences Program-Water Resources, Grant # 80NSSC19K1200.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights statement This article does not contain any studies with human participants or animals performed by any of the authors.

References

Alemu T, Weyuma T, Alemayehu E, Ambelu A (2018) Identifying riparian vegetation as indicator of stream water quality in the Gilgel Gibe catchment, southwestern Ethiopia. Ecohydrol 11(1):e1915. https://doi.org/10.1002/eco.1915

Andersen F, Anjum RL, Rocca E (2019) Philosophical bias is the one bias that science cannot avoid. eLIFE. https://doi.org/10.7554/eLife.44929

Bell PR (1992) Eutrophication and coral reefs—some examples in the Great Barrier Reef Lagoon. Water Res 26(5):553–568. https://doi.org/10.1016/0043-1354(92)90228-V

Bessel-Browne P, Negri AP, Fisher R, Clode PL, Jones R (2017) Impacts of light limitation on corals and crustose coralline algae. Sci Rep 7:11553. https://doi.org/10.1038/s41598-017-11783-z

Boyer JN, Jones RD (2002) A view from the bridge: external and internal forces affecting the ambient water quality of the Florida Keys National Marine Sanctuary. In: Porter JW, Porter KG (eds) The everglades, Florida Bay, and coral reefs of the Florida Keys. CRC Press, Boca Raton, pp 609–628

Boyer JN, Fourqurean JW, Jones RJ (1999) Seasonal and long-term trends in the water quality of Florida Bay. Estuaries 22(2):417–430

Brand LE (2002) The transport of terrestrial nutrients to South Florida coastal waters. In: Porter JW, Porter KG (eds) The everglades, Florida Bay, and coral reefs of the Florida Keys. CRC Press, Boca Raton, pp 353–406

Briceno HO, Boyer JN (2018) 2017 Annual report of the water quality monitoring project for the water quality protection program of the Florida Keys National Marine Sanctuary. Technical report of the southeast environmental research center, Florida International University

Cannizzaro JP, Barnes BB, Hu C, Corcoran AA, Hubbard KA, Muhlbach E, Sharp WC, Brand LE, Kelble CR (2019) Remote detection of cyanobacteria blooms in an optically shallow subtropical lagoonal estuary using MODIS data. Remote Sens Environ 231:111227. https://doi.org/10.1016/j.rse.2019.111227

Clark MJ, Whitfield PH (1994) Conflicting perspectives about detection limits and about the censoring of environmental data. J Am Water Resour Assoc 30:1063–1079. https://doi.org/10.1111/j.1752-1688.1994.tb03353.x

Clarke JU (1998) Evaluation of censored data methods to allow statistical comparisons among very small samples with below detection limit observations. Environ Sci Technol 32(1):177–183. https://doi.org/10.1021/es970521v

Davis SM (1994) Phosphorus inputs and vegetation sensitivity in the Everglades. In: Davis SM, Ogden JC (eds) Everglades. The Ecosystem and Its Restoration. St. Lucie Press, Boca Raton, pp 357–378

D'Elia CF, Sanders JG, Capone DG (1989) Analytical chemistry for environmental sciences. Env Sci Tech 23(7):768–774. https://doi.org/10.1021/es00065a005

Dustan P, Halas JC (1987) Changes in the reef-coral community of Carysfort reef, Key Largo, Florida: 1974 to 1982. Coral Reefs 6:91–106. https://doi.org/10.1007/BF00301378

Fishman MJ (1993) Methods of analysis by the US Geological Survey National Water Quality Laboratory: determination of inorganic and organic constituents in water and fluvial sediments. US Department of the Interior, US Geological Survey. pp. 93–125 https://doi.org/10.3133/ofr93125

Florida Department of Environmental Protection (FDEP) (2016) Final Integrated water quality assessment for Florida: 2016 Sections 303(d), 305(b), and 314 (2016) Report and Listing Update. https://floridadep.gov/sites/default/files/2016-Integrated-Report.pdf. Accessed 20 Jan 2020

Fowler AE, Leffler JW, Johnson SP, DeLancey LB, Sanger DM (2018) Relationships between meteorological and water quality variables and fisheries-independent white shrimp (*Litopenaeus setiferus*) catch in the ACE basin NERR. South Carolina Estuar Coasts 41(1):79–88

Glibert PM, Heil CA, Hollander D, Revilla M, Hoare A, Alexander J, Murasko S (2004) Evidence for dissolved organic nitrogen and phosphorus uptake during a cyanobacterial bloom in Florida Bay. Mar Ecol Prog Ser 280:73–83. https://doi.org/10.3354/meps280073

Hallock P, Schlager W (1986) Nutrient excess and the demise of coral reefs and carbonate platforms. Palaios. https://doi.org/10.2307/3514476

Hebbali A (2018) Olsrr: tools for building Ols regression models. R package version 0.5, 1

Helsel DR, Hirsch RM (1992) Statistical methods in water resources, 49th edn. Elsevier, Amsterdam

Hu C, Hackett KE, Callahan MK, Andréfouët S, Wheaton JL, Porter JW, Muller-Karger FE (2003) The 2002 ocean color anomaly in the Florida Bight : a cause of local coral reef decline? Geophys Res Lett 30(3):1151. https://doi.org/10.1029/2002GL016479

Hu C, Muller-Karger FE, Vargo GA, Neely MB, Johns E (2004) Linkages between coastal runoff and the Florida Keys ecosystem: a study of a dark plume event. Geophys Res Lett 31:L15307. https://doi.org/10.1029/2004GL020382

Jaap WC, Szmant A, Jaap K, Dupont J, Clarke R, Somerfield P, Ault JS, Bohnsack JA, Kellison SG, Kellison GT (2008) A perspective on the biology of Florida Keys coral reefs. In: Riegl BM, Dodge R (eds) Coral Reefs of the USA. Springer, Berlin, pp 75–125

Julian P II (2020) Getting the science right to protect and restore our environment. A critique of Lapointe et al. (2019) Nitrogen enrichment, altered stoichiometry, and coral reef decline at Looe Key, Florida Keys, USA: a 3-decade study. Mar Biol. https://doi.org/10.1007/s00227-020-3667-1

Julian P, Freitag A, Payne GG, Xue SK (2019) Chapter 3A: water quality in the Everglades Protection Areas. In 2018 South Florida environmental report. South Florida Water Management District, West Palm Beach, FL

Keating D (1992) Blanket of algae smothers Keys reef: 60-mile growth creates dead zone. Miami Herald, June 17

Klein CJ, Orlando SP (1994) A spatial framework for water-quality management in the Florida Keys National Marine Sanctuary. Bull Mar Sci 54(3):1036–1044

Lapointe BE (1997) Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and south- east Florida. Limnol Oceanogr 42:1119–1131. https://doi.org/10.4319/lo.1997.42.5_part_2.1119

Lapointe BE (2004) Phosphorus-rich waters at Glover's Reef, Belize? Mar Poll Bull 48:193–195

Lapointe BE, Smith NP (1987) A preliminary investigation of upwelling as a source of nutrients to Looe Key National Marine

Sanctuary. NOAA Technical Memorandum. NOS MEMD 1, Marine Sanctuaries Division

Lapointe BE, Clark MW (1992) Nutrient inputs from the watershed and coastal eutrophication in the Florida Keys. Estuar Coast 15(4):465–476. https://doi.org/10.2307/1352391

Lapointe BE, Matzie WR (1996) Effects of stormwater nutrient discharges on eutrophication processes in nearshore waters of the Florida Keys. Estuaries 19(2):422–435. https://doi.org/10.2307/1352460

Lapointe BE, O'Connell JD, Garrett GS (1990) Nutrient couplings between on-site sewage disposal systems, groundwaters, and nearshore surface waters of the Florida Keys. Biogeochemistry 10(3):289–307. https://doi.org/10.1007/BF00003149

Lapointe BE, Littler MM, Littler DS (1993) Modification of benthic community structure by natural eutrophication: the Belize Barrier Reef. In: Proceedings of the seventh international coral reef symposium, pp 323–334

Lapointe BE, Matzie WR, Barile PJ (2002) Biotic phase-shifts in Florida Bay and fore reef communities of the Florida Keys: linkages with historical freshwater flows and nitrogen loading from Everglades runoff. In: Porter JW, Porter KG (eds) The Everglades, Florida Bay, and Coral Reefs of the Florida Keys. CRC Press, Boca Raton, pp 629–648. https://doi.org/10.1201/9781420039412-28

Lapointe BE, Barile PJ, Matzie WR (2004) Anthropogenic nutrient enrichment of seagrass and coral reef communities in the Lower Florida Keys: discrimination of local versus regional nitrogen sources. J Exp Mar Biol Ecol 308(1):23–58. https://doi.org/10.1016/j.jembe.2004.01.019

Lapointe BE, Bedford BJ, Littler MM, Littler DS (2007) Shifts in coral overgrowth by sponges and algae. Coral Reefs 26:515. https://doi.org/10.1007/s00338-007-0242-x

Lapointe BE, Brewton RA, Herren LW, Porter JW, Hu C (2019) Nitrogen enrichment, altered stoichiometry, and coral reef decline at Looe Key, Florida Keys, USA: a 3-decade study. Mar Biol 166:108. https://doi.org/10.1007/s00227-019-3538-9

Leavey-Roback SL, Sugar CA, Krasner SW, Suffet IHM (2016) NDMA formation during drinking water treatment: a multivariate analysis of factors influencing formation. Water Res 95:300–309. https://doi.org/10.1016/j.watres.2016.02.060

McLeod AI, Hipel KW, Bodo BA (1991) Trend analysis methodology for water quality time series. Environmetrics 2(2):169–200. https://doi.org/10.1002/env.3770020205

Meals DW, Spooner J, Dressing SA, Harcum JB (2011) Statistical analysis for monotonic trends, Tech Notes 6, November 2011. Developed for U.S Environmental Protection Agency by Tetra Tech Inc, Fairfax, p 23

Mozejko J (2012) Detecting and estimating trends of water quality parameters. Water Qual Monit Assess. https://doi.org/10.5772/33052

National Research Council (NRC) (2002) Florida Bay research programs and their relation to the Comprehensive Everglades Restoration Plan. National Academy Press, Washington

Newman MC, Dixon PM, Looney BB, Pinder JE (1989) Estimating mean and variance for environmental samples with below detection limit observations 1. JAWRA J Am Water Resour As 25(4):905–916

Nixon S (2009) Eutrophication and the macroscope. Hydrobiologia 629:5–19. https://doi.org/10.1007/s10750-009-9759-z

NOAA (1988) Results of a workshop on coral reef research and management in the Florida Keys: a blueprint for action. Technical Report. National Undersea Research Program, Florida

NOAA (1996) Florida Keys National Marine Sanctuary final management plan/environmental impact statement, vol 1. NOAA Silver Spring, Maryland

Pew Oceans Commission (2003) America's living oceans: charting a course for sea change. Pew Oceans Commission, Arlington, pp 1–166

Pohlert T (2020) trend: non-parametric trend tests and change-point detection. R package version 0.2.0. https://cran.r-project.org/web/packages/trend/vignettes/trend.pdf. Accessed 20 Jan 2020

Porter JW, Kosmynin V, Patterson KL, Porter KG, Jaap WC, Wheaton JL, Hackett K, Lybolt M, Tsokos CP, Yanev G, Marcinek DM (2002) Detection of coral reef change by the Florida Keys coral reef monitoring project. In: Porter JW, Porter KG (eds) The Everglades, Florida Bay, and Coral Reefs of the Florida Keys. CRC Press, Boca Raton, pp 749–769. https://doi.org/10.1201/9781420039412-32

Redfield AC (1958) The biological control of chemical factors in the environment. Am Sci 46(3):230A–221. https://www.jstor.org/stable/27827150. Accessed 20 Jan 2020

Rosset S, Wiedenmann J, Reed AJ, D'Angelo C (2017) Phosphate deficiency promotes coral bleaching and is reflected by the ultrastructure of symbiotic dinoflagellates. Mar Pol Bull 118(1–2):180–187. https://doi.org/10.1016/j.marpolbul.2017.02.044

Rudnick DT, Chen Z, Childers DL, Fontaine TD (1999) Phosphorus and nitrogen inputs to Florida Bay: the importance of the Everglades watershed. Estuaries 22(2):398–416. https://doi.org/10.2307/1353207

Shantz AA, Burkepile DE (2014) Context-dependent effects of nutrient loading on the coral-algal mutualism. Ecology 95(7):1995–2005. https://doi.org/10.1890/13-1407.1

Shinn EA, Reese RS, Reich CD (1994) Fate and pathways of injection-well effluent in the Florida Keys. Open-file report 94-276. US Geological Survey, Department of the Interior, Washington

Simmons GM (1992) Importance of submarine groundwater discharge (SGWD) and seawater cycling to material flux across sediment water interfaces in marine environments. Mar Ecol Prog Ser 84:173–184

Smith NP (1994) Long-term Gulf-to-Atlantic transport through tidal channels in the Florida Keys. Bull Mar Sci 54(3):602–609

Smith NP, Pitts PA (2002) Regional-scale and long-term transport patterns in the Florida Keys. The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: an ecosystem sourcebook. CRC Press, Boca Raton, pp 343–360

Smith SV, Kimmerer WJ, Laws EA, Brock RE, Walsh TW (1981) Kaneohe Bay sewage diversion experiment: perspectives on ecosystem responses to nutritional perturbation. Pac Sci 35(4):279–395

Top Z, Brand LE, Corbett RD, Burnett W, Chanton J (2001) Helium and radon as tracers of groundwater input to Florida Bay. J Coast Res 17(4):859–868

Vega-Thurber RL, Burkepile DE, Fuchs C, Shantz AA, McMinds R, Zaneveld JR (2014) Chronic nutrient enrichment increases prevalence and severity of coral disease and bleaching. Glob Chang Biol 20(2):544–554. https://doi.org/10.1111/gcb.12450

Voss JD, Richardson LL (2006) Nutrient enrichment enhances black band disease progression in corals. Coral Reefs 25(4):569–576. https://doi.org/10.1007/s00338-006-0131-8

Wagner DE, Kramer P, Van Woesik R (2010) Species composition, habitat, and water quality influence coral bleaching in southern Florida. Mar Ecol Prog Ser 408:65–78. https://doi.org/10.3354/meps08584

Ward-Paige CA, Risk MJ, Sherwood OA (2005) Clionid sponge surveys on the Florida Reef Tract suggest land-based nutrient inputs. Mar Pollut Bull 51:570–579. https://doi.org/10.1016/j.marpolbul.2005.04.006

Wiedenmann J, D'Angelo C, Smith EG, Hunt AN, Legiret FE, Postle AD, Achterberg EP (2013) Nutrient enrichment can increase the susceptibility of reef corals to bleaching. Nat Clim Change 3(2):160–164. https://doi.org/10.1038/nclimate1661

Yang X, Liu Q, Luo X, Zheng Z (2017) Spatial regression and prediction of water quality in a watershed with complex pollution sources. Sci Rep 7(1):8318. https://doi.org/10.1038/s41598-017-08254-w

Yentsch CS, Yentsch CM, Cullen JJ, Lapointe B, Phinney DA, Yentsch SW (2002) Sunlight and water transparency: cornerstones in coral research. J Exp Mar Biol Ecol 268(2):171–183. https://doi.org/10.1016/s0022-0981(01)00379-3

Zhao J, Hu C, Lapointe BE, Melo N, Johns EM, Smith RH (2013) Satellite-observed black water events off Southwest Florida: Implications for coral reef health in the Florida Keys National Marine Sanctuary. Rem Sens 5:415–431. https://doi.org/10.3390/rs510415

Zhou P, Huang J, Pontius RG, Hong H (2016) New insight into the correlations between land use and water quality in a coastal watershed of China: Does point source pollution weaken it? Sci Total Environ 543:591–600. https://doi.org/10.1016/j.scitotenv.2015.11.063