Assessing Historical Shifts in the Data Limited Lower Keys Tarpon Fishery

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Prepared by Bonefish & Tarpon Trust

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Executive Summary

Efforts to document the history of the Lower Keys Tarpon Fishery and to identify potential drivers of decline began in May of 2022 as an internally funded project. This project was undertaken in response to concerns voiced by the Lower Keys Guide's Association—the fishery was yielding fewer and less consistent opportunities, with no obvious causes driving their long-term observations. The focus of this project is to provide a spatially and temporally explicit history of the Tarpon fishery in the Lower Keys, as told by the guides themselves, to identify potential drivers of decline using publicly and privately available datasets, and to provide direction for efforts to stem the declining trend and for future monitoring efforts. These efforts have resulted in the most comprehensive and detailed documentation of the fishery to date and have set a standard for future efforts examining other members of the Florida Keys flats fishery.

The project was divided into two complementary processes: 1) Guide interviews; and 2) Data synthesis and analysis. The guide interviews produced information detailing each guide's history in the fishery, their fishing practices, experiences and thoughts on the fishery throughout time, and a timeseries of map products depicting where fishing has occurred and the quality of the opportunities. The timeseries of maps were then analyzed in the context of environmental change, inclusive of global processes, physical and biological habitat, infrastructure, and anthropogenic pressure.

The guide interviews were conducted on a voluntary basis, with 10 guides participating in a semi-structured interview and mapping exercise. Guides were asked to recall the fishery in five-year bins, and to provide spatial assessments within a 6 km^2 structured grid system overlaid upon a digital navigational map. The history detailed in these interviews extends back to 1982. Across all products produced by the interview process, the timeseries of maps provided the most concise and readily analyzable history of the fishery. Analyzing the maps for areal coverage of the fishery showed a dramatic spatial decline and condensing of the fishery, with the area fished for large Tarpon reduced 62%, medium Tarpon reduced 71%, and small Tarpon reduced 57%.

To assess drivers of these declines, a large-scale assessment of data availability and applicability was undertaken. More than 100 data sources were assessed, while 40 were synthesized into 13 unique datasets (114 variables) representing global process, habitat, biological, infrastructure, and human pressure conditions of the Lower Keys from 1982 through 2022. Using a gradient boosted regression algorithm, the best predictors of the change in area fished for each size class were hierarchically ranked, producing an ordered strategy for directing efforts to address the decline.

Acute changes in water quality, possibly driven by tropical events, have led to a chronic reduction in habitat suitability for Tarpon. The mechanism by which Tarpon have been impacted, whether directly or indirectly, cannot be determined due to a paucity of foodweb community and diet data. Physical water conditions are contemporarily consistent with long-term averages, with the exception of water temperature. Water temperature was regularly an important predictor in

changes to Tarpon fishery areal coverage, with concomitant increases in mean temperature and decreases in areal coverage. Wet season water temperatures have increased 2 C (3.6 F) since 1982, while the large Tarpon fishery saw a 60% reduction in areal coverage. It is evident that climatic and environmental disturbances, such as warming waters, pose significant challenges to the ecosystem's integrity and the sustainability of fisheries in the Florida Keys. Cognizant applications of best handling practices are the most tractable means of mitigating climatic stress for Tarpon.

Southbound annual average daily vehicle traffic (FDOT) at Key Largo was one of the most important predictors of decline across size classes. Traffic data spanned 2007–2022, and over that span southbound traffic increased 36% from 11,870 vehicles daily to 15,151 vehicles daily. Over the same time-period, the large, medium, and small Tarpon fisheries were reduced in space by 35%, 66%, and 38%, respectively. While vehicle traffic does not have a direct effect on Tarpon abundance, habitat use, or residence time, it is a proxy for the subsequent anthropogenic pressures that are placed on the environment.

A more closely coupled relationship between human pressure and a decline in the Tarpon fishery was found with spatial overlap of high-density vessel traffic (Planet Labs & BTT). Vessel traffic measures were identified as an important correlate with large and medium Tarpon fishery areal coverage. Areas with statistically anomalous high-density vessel traffic showed high spatial association with areas where 0–22% of the large Tarpon fishery remained in 2022. Efforts to mitigate the declining Tarpon fishery should focus on improved aids to navigation to reduce instances of prop-scaring and damage to important flats, in addition to maintaining access to channels that are important to foraging and pre-spawn behaviors. A formal proposal should be a collective proposition among stakeholders (e.g., The Lower Keys Guides Association), and leverage the detailed drawings provided by the guides, those of which have been withheld from inclusion in this report and future documents due to their sensitive nature.

Premise

Over the last decade, a contingent of guides and anglers in the Lower Keys (west of the Bahia Honda Channel) have voiced concerns about a decline in the Tarpon fishery. Declines in number of fish sighted seemingly occurred consecutively among locations. In 2021, the decline appears to have been especially steep—nearly the entire Lower Keys guiding community had reached out to BTT reporting that the Tarpon fishery declined to an almost unfishable state. In contrast, although declines in Tarpon fishing have been reported in the Upper Keys, reports of a decline are inconsistent among guides. Reports from fishing guides in the Middle Keys indicate that the Tarpon fishery remains relatively stable. Interestingly, reports from Charlotte Harbor indicate very high Tarpon abundance in 2021, with similar reports from Tampa Bay prior to an ongoing red tide event (2021). Reports from the central east coast of Florida are of poor Tarpon fishing. Clearly, the movements of Tarpon are dynamic, and according to some guides are becoming much more variable year to year and within years.

With no long-term records of Tarpon landings, or other forms of population estimates, determining the status of the fishery and its trajectory over time necessitates alternative research approaches that rely on expert guide and angler knowledge to recall how the fishery has changed over time. We have used this approach successfully in the past to improve bonefish fishery management (Black et al. 2015). Anecdotal reports from guides and anglers were used to justify proposals for management changes (e.g., making bonefish catch and release only). BTT corrected this shortcoming by funding a study that used interviews of experts (guides and anglers with a long history in the Keys) and fishing logs to recreate the historical effort, catch, and quality of the bonefish fishery. This enabled BTT to show the decline, which spurred focused research to find causes and raised the profile of the fishery for fisheries managers.

Given a similar situation for Tarpon (reports of a decline by fishing guides coupled with lack of data), it is necessary to assess the current status of the Tarpon fishery in the Florida Keys, and document historical trends, using a similar yet more rigorous, intensive, and more holistic approach that we used for the bonefish fishery. This will enable us to focus research on potential causes and raise the profile of this issue with resource management agencies with the goal of advocating for appropriate corrective measures.

Method

Study Domain

The primary region of interest and impetus for the study is the Lower Keys—west of Bahia Honda Channel, though given the opportunity to assess the South Florida Tarpon fishery as a whole, the study domain was expanded northward to Chokoloskee on the west coast and Biscayne Bay on the east coast. Given the longitudinal and latitudinal boundaries of our area of interest, a bounding box (-82.22055, 24.47944) (-80.07204, 25.88344) was established. Within the bounding box, an unbiased 6 km^2 grid was created using the Create Fish Net tool on the bounding box polygon in ArcPro. The grid positions were then latitudinally and longitudinally adjusted to capture relevant areas (i.e., elimination of land and offshore grids) in the fewest number of grid cells. Grid cells were assigned region classifications that align with state and federal spatial management zones (Table 1; Figure 1).

The temporal domain for the study was demarcated into five-year bins, with the most recent year—2022— isolated. Accordingly, five-year bins were established going backwards in time to the earliest point that a guide established themselves in the fishery. The earliest year-bin in the timeseries was 1982–1986.

Table 1. Grid domain regional boundaries.

Region	SW Coordinates	NE Coordinates
Full AOI	(-82.22055, 24.47944)	(-80.07204, 25.88344)
Marquesas	(-82.22055, 24.47944)	(-81.84255, 24.69544)
Lower Keys	(-81.84255, 24.47944)	(-81.14055, 24.91144)
Middle Keys	(-81.14055, 24.64144)	(-80.65455, 24.9152)
Upper Keys	(-80.70855, 24.85744)	(-80.16855, 25.34344)
Florida Bay	(-81.19455, 24.8612)	(-80.38455, 25.28944)
Whitewater Bay	(-81.19455, 25.18144)	(-80.87055, 25.39744)
Chokoloskee	(-81.41055, 25.39744)	(-80.89817, 25.88344)
Biscayne Bay	(-81.19455, 25.18144)	(-80.87055, 25.39744)

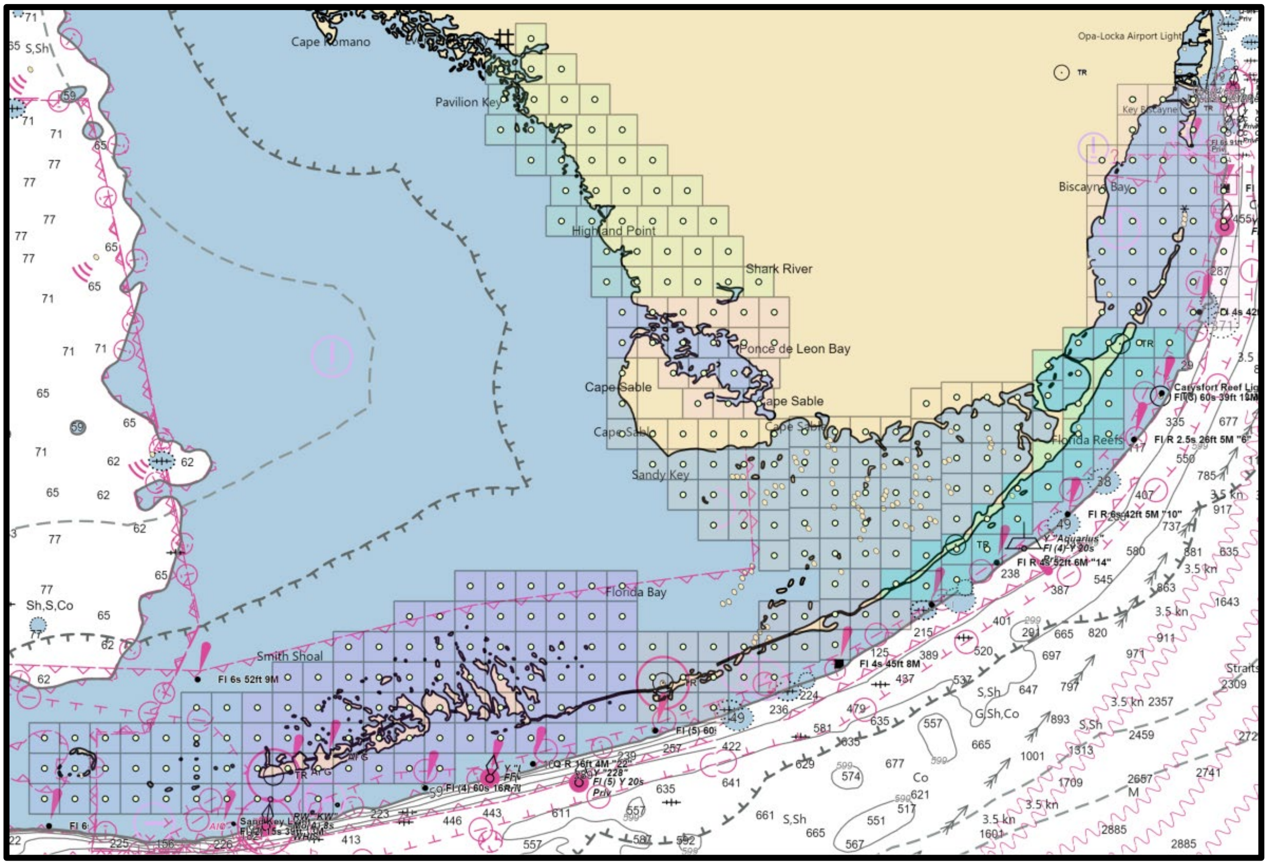

Figure 1. Survey grids color coded by management region. Basemap NOAA Maritime Chart Service. Grids appearing over land capture extensive backcountry tributary networks, and are a product of scale and tile resolution

Interview Map Dissemination

Interviews with guides were conducted with the goal of creating spatially explicit representations of the Tarpon fishery across time. The primary means for documenting the information and creating a dataset was drawing and annotating a map within the gridded zones of each region. To create the interactive interview map, a digital map for each region was created and output from ArcPro. The *NOAA Charts as a basemap* Map Server service layer was set as a streaming basemap (https://gis.charttools.noaa.gov/arcgis/rest/services/MCS/NOAAChartDisplay/MapServer/exts/MaritimeChartService/MapServer). The NOAA Charts tiling services allow for fine-scale bathymetry visualization that are useful for spatial referencing during recall exercises. A Mapframe Layout was created using a custom size Architectural E layout. Each region was placed centrally within the layout and maps were exported at dimensions that allowed for the finest bathymetric notations to be displayed. The map layouts were exported as Flattened PDF, compression LZW, and a DPI of 600.

Mapping exercises were done with each guide using an iPad (Apple Inc; Cupertino, CA) and the software Procreate (Savage Interactive; Tasmania, Australia). Each Tarpon classification—the size or behavior in question—was drawn as an individual toggle-capable layer. Isolating each classification as a unique layer allowed for the basemap/grid and each classification to be toggled on and off. The resulting region-specific year-bin map was exported with the basemap/grid toggled off (transparent background) and the Tarpon classifications toggled on. The map was exported as a .tiff file, which is a compatible raster format for importing into ArcPro.

Interview Process

Interviews with guides were conducted one-on-one in a location where guides were comfortable sharing confidential information (e.g., at home). Guides were asked to mark upon the maps corresponding to 2022 (the current state of the fishery) and five-year bins extending back in time to their establishment in the fishery. Two metrics of interest were collected:

(1) Provide a Likert Score (1–5) representing the overall quality of the fishery relative to 2022, with 1 being “much worse”, 3 being “the same”, and 5 being “much better”.

(2) Draw a 2-dimensional representation of the spaces fished for each Tarpon classification notable to the guide.

Tarpon Classifications were specifically color coded (Table 2).

Table 2. Tarpon Classifications specified by guides. Classification scheme was used for marking on maps.

Classification	**Color**	**Hex Code**
Layup	Magenta	#A116E2
Daisy	Orange	#FF7E00
Bodies	Pink	#E14192
Small	Yellow	#F5D90E
Subadult	Green	#9CFB9D
Medium	Teal	#00F8FF
Large	Purple	#5814F5
X Large	Red	#ED1010
Negative Space/Inverse sum of All Classifications	Black	#F00000

Quantification of Area Fished

Each region year-bin map drawn upon by the guides were exported as a .tiff with the naming scheme:

- BTT_AnonymousGuideID_Region_YearA-YearB.tiff

Corrections were required to be made to each map due to “hidden” markings on the maps that were not observable due to the transparent background. Using GNU Image Manipulation Program (GIMP; GIMP Development Team), a Convolutional Matrix was applied to each image with the default settings. This isolated all hidden pixels and allowed for them to be deleted and the .tiff map file to be re-exported without any image compression.

A single Python script was written in a Jupyter Notebook within ArcPro to automate the following processes into a singular workflow:

(1) Each map needed to be imported into ArcPro and georeferenced. An unmarked representative example of each region map (grid with NOAA service layer basemap) was manually georeferenced using the grid intersections and corners as anchor-points. Georeferencing was automated for each guide map (only Tarpon classifications, no basemap or grid) using the region designation in the filename as a key to determine which anchor-points to reference. The Python script also ensured that each map .tiff was imported with 32-bit unsigned color, which is imperative for accurate color representation and subsequent pixel classification (vis a vis identifying which Tarpon classification was drawn).

A Support Vector Machine (SVM) pixel classification algorithm was tuned in ArcPro. First, a Tarpon classification “key” .tiff file was compiled using GIMP. The key was comprised of three layers: markings in the Tarpon classification colors, a representative map drawn by one guide that contained a majority of the Tarpon classifications, and another guide map that contained any missing Tarpon classifications. In ArcPro, the Label Objects for Deep Learning tool was used to create a classification schema for each Tarpon classification. Between 20 and 30 training features (polygon shapefile) were created per classification by tracing portions of the classification key .tiff, capturing thin and thick portions of each classification to be inclusive of varying degrees of pixel aliasing; an issue that can be avoided if a hard-edge pen tool is selected during the drawing process, though this option is only available by custom program extension for ProCreate. Negative space (no markings) areas were also included as an additional classification. The Train Support Vector Machine Classifier tool was used with the classification key .tiff as the input raster, the training shapefile as the input training sample file, and the RGB values as the dimension value field. The output of this process is an SVM.ecd file that can be used in pixel classification to translate an RGB .tiff file to a classified raster that each classification can have the number of pixels counted (i.e., Grid 35 has 3400 pixels classified as “Large” Tarpon).

(2) Apply the SVM pixel classification algorithm to each georeferenced Tarpon classification-only guide map. Output a classified raster with the same naming scheme as the input guide map.

(3) Apply the Region Group tool for contiguous pixel classifications ≥10 pixels.

(4) Apply the Nibble tool to clean spurious misclassified pixels along edges and corners of classification features (Figure 2).

(5) Use the Tabulate Area tool with “Classes as Rows” to sum the number of pixels of each classification within each grid. Output the table to a .csv file.

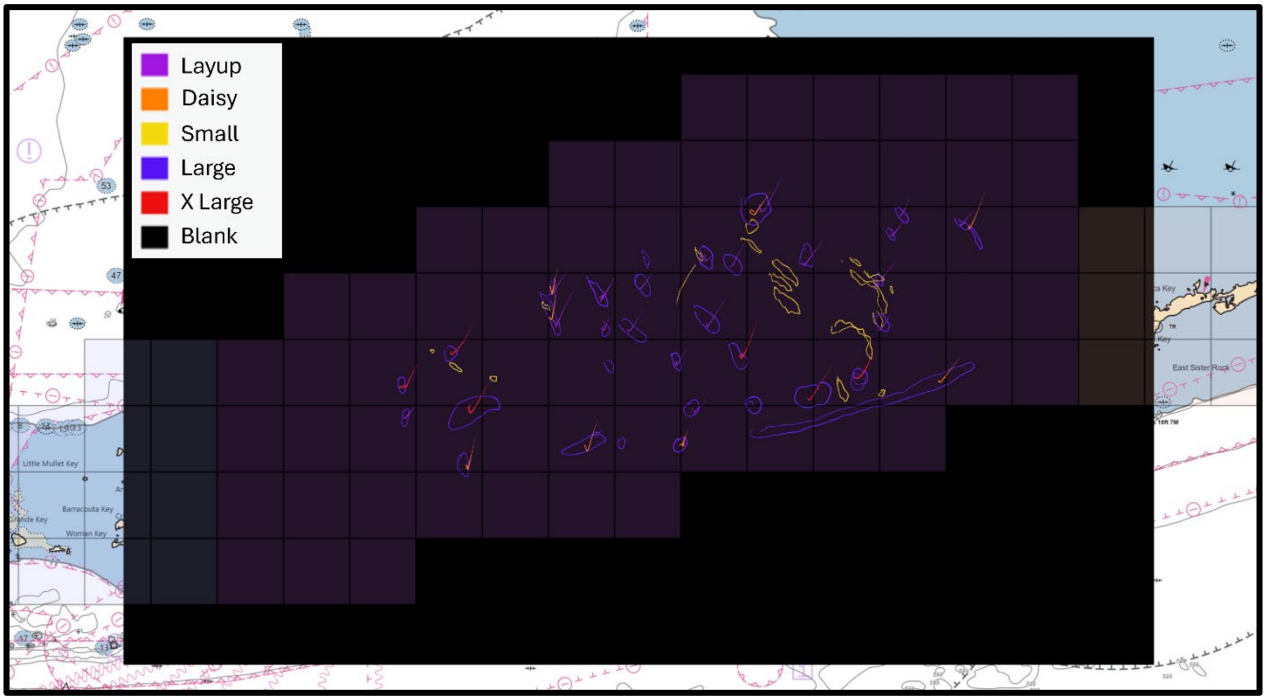

Figure 2. Example of a classified raster.

Summarizing of Changes in the Tarpon Fishery Through Time

Likert Score Assessment

Likert Scores, representing the quality of fishing within each grid cell, were tabulated and assessed for spatial and temporal variability. Upon inspection of the responses depicted on the maps, the decline in “quality” was overwhelmingly superseded in responses by elimination of fishing spots (i.e., spots did not gradually decline, but promptly became unfishable). Therefore, no additional analyses were conducted using the Likert Scores.

Areal Coverage Representation

Spatiotemporal changes in the Tarpon fishery were quantified for each classification and overall—a summation of all Tarpon classifications. The areal coverage of each classification was translated from pixel counts to Km^2, however the areal coverage is not a strict representation of fishery area as guides expressed area fished using different drawing techniques (i.e., 2-dimensional hollow shapes, 2-dimensional filled shapes, 1-dimensional lines, and annotations that an area represents multiple classes with checkmarks (See Figure 2)). The areal coverage in Km^2 is used for analyses throughout the assessment of change over time. Another quantification is based upon the Km^2 areal coverage, and that is the calculation of areal coverage over time in relation to the maximum classification area fished within a grid over the timeseries calculated on a by-guide basis and represented as a percentage (0–100)—herein, Percent of Maximum Areal Coverage.

Breakpoint Analysis of Areal Coverage

Two methods of breakpoint analysis were used to identify structural changes in the timeseries of Tarpon classification areal coverage on a per-guide per-grid basis, and an aggregate of all guides within a grid. Structural change breakpoints imply that the data are best represented by coupling more than one linear model (i.e., the rate of change in Tarpon classification areal coverage strongly differs at different time periods). The application of structural change procedures has been used in timeseries representations of fishing effort in data-limited fisheries similar to the Florida Tarpon fishery (Boucek et al. 2022). Method 1 calculated an F-statistic per year-bin to identify breakpoints using the package *strucchange* (Zeileis et al. 2002, 2003). This method is most capable at identifying changes within the central portion of the timeseries. As our timeseries were truncated due to being represented in year-bins, obvious breakpoints at the tails of the timeseries were not identifiable using this method. Thus, a Z-score was calculated for each year-bin and breakpoints were identified by the Z-score being greater than 1.645 sd, or the equivalent of significantly different at alpha = 0.05 (95% confidence). Breakpoint timeseries by individual guide and in aggregate were plotted and overlaid upon the map grid for visualization (Figure 3; Supplementary 1).

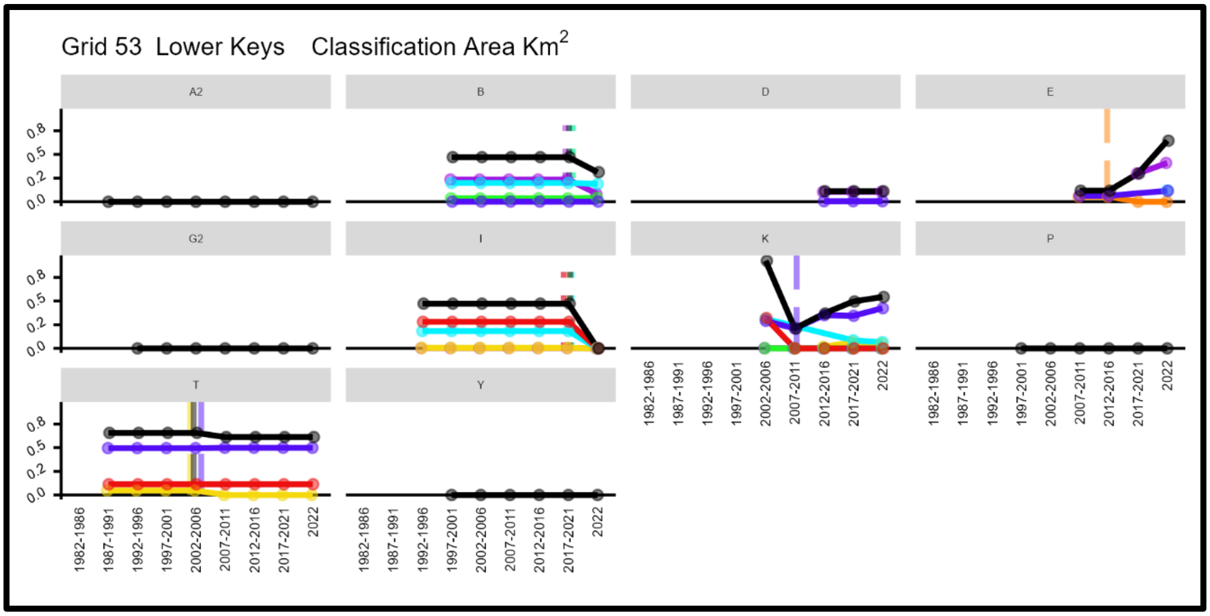

Figure 3. Example of areal calculations and breakpoint analyses per guide within a grid cell. Tarpon classifications are colored according to Table 2. F-statistic breakpoints are dashed lines, and Z-score breakpoints are indicated by dotted lines. Breakpoints and point measures of areal coverage are horizontally jittered for visualization, and are colored according to Table 2.

Mapping of Tarpon Classification Breakpoint Trends

Tarpon classification breakpoints by-grid per-guide were assessed for agreeance among guides for the existence of a breakpoint, the directionality of the structural change at the breakpoint (i.e., is the areal coverage decreasing or increasing post-breakpoint?), and the most commonly identified year-bin breakpoint. The summarization identifies when, if at all, there is a decline in the Tarpon fishery per grid.

Mapping of Tarpon Classification Areal Coverage

Areal coverage changes over time could not be mapped as a summation of guide representations as guides came into the fishery at different time periods, and thus would result in spurious increases of areal coverage each time a new guide came into the fishery (i.e., an additional representation of a fished area artificially inflates the area fished by counting the area repeated times). To aggregate individual guide responses into a cohesive single value to track through time, the following process was followed: For each guide series of maps, within each grid, the area fished was calculated as a percentage of the maximum area fished within that grid for that guide. The series of percentages was then averaged for each time-bin, thus creating a timeseries of the average space use for a time-bin relative to the maximum space use within a grid.

Assessment and Aggregation of Abiotic and Biotic Data to Assess Drivers of Change

An expansive review of publicly available and upon-request data sources was conducted to compile data that could be leveraged in identifying correlates and potential drivers of changes in the areal coverage of the Tarpon fishery. Data were acquired and synthesized into a master dataset for the regions and time periods of interest (Table 3). Data were summarized in multiple ways: into daily means and then into year-bin means, kriged surfaces using Empirical Bayesian Kriging Regression (EBKR; by dry/wet season for water quality), sum total and percent areal representation within a grid, temporal linear regression, point density inverse distance weighting (IDW), and minor and major (least/most) present classifications. Large dataset synthesis, especially those that bring together data from multiple agencies and timeseries, requires careful review of data quality and reporting units. Measurement units were all converted into consistent units, and spurious values were interrogated for all physical and chemical water quality metrics. Extreme quantile values, 10th and 90th percentiles, were reviewed for spatiotemporal consistency with dimensional neighbor measurements. All anomalies were removed from the datasets.

Table 3. Abiotic and biotic data evaluated and included in gradient boosted regression models. See Supplementary 2 for detailed sourcing of data.

Classification	Data Product	Unit	Measure Method	Span	Per Grid?	Source Contributors*
Water Quality						
	Temperature (Water)	°C	In Situ/Lab	1982–2022	Yes	FWC, FDEP, EPA, USGS, NOAA, SFNRC, FIU
	Dissolved Oxygen	mg·L^{-1}	In Situ/Lab	1982–2022	Yes	FWC, FDEP, EPA, USGS, NOAA, SFNRC, FIU
	Salinity	Ppt	In Situ/Lab	1982–2022	Yes	FWC, FDEP, EPA, USGS, NOAA, SFNRC, FIU
	Chlorophyll A	µg·L^{-}	In Situ/Lab	1982–2022	Yes	FWC, FDEP, EPA, USGS, NOAA, SFNRC, FIU
	Turbidity	NTU	In Situ/Lab	1982–2022	Yes	FWC, FDEP, EPA, USGS, NOAA, SFNRC, FIU
Traffic						
	Vessels Count	Type, Activity	Digitized	2016–2022	Yes	Planet Labs Inc, BTT
	Vehicle Count	South Moving	In Situ	2007-2022	No	FDOT
Wastewater						
	Septic	IDW Density	Derivation	<2000, 2010–2015, 2016–2022	Yes	FDEP, BTT
	Class V Injection Well	IDW Density	Derivation	2022	Yes	FDEP, BTT
	Wastewater Site	IDW Density	Derivation	2022	Yes	FDEP, BTT

	Vessel Pump Out	IDW Density	Derivation	2022	Yes	FDEP, BTT
Habitat						
	Bathymetry	-m	Derivation	2022	Yes	NCEI
	Benthic Functional Class	Km^2, % Grid, Major/Minor	Remote Sensed, Derivation	2020	Yes	Allen Coral Atlas, NOAA, FWC
	Benthic Geomorphic Class	Km^2, % Grid, Major/Minor	Remote Sensed, Derivation	2020	Yes	Allen Coral Atlas, NOAA, FWC
	Benthic Biological Class	Km^2, % Grid, Major/Minor	Remote Sensed, Derivation	2020	Yes	Allen Coral Atlas, NOAA, FWC
	Seagrass	Density, Change	In Situ, Derived	1996–2021	Yes, Nearest Grid	FIU
Climate						
	Temperature (Air)	°C	In Situ, Derived	1982–2022	No	Iowa Environmental Mesonet ASOS
	Wind	Knts, Dir	In Situ, Derived	1982–2022	No	Iowa Environmental Mesonet ASOS
	Air Pressure	millibar	In Situ, Derived	1982–2022	No	Iowa Environmental Mesonet ASOS
	METAR Codes	Codes per Day	In Situ, Derived	1982–2022	No	Iowa Environmental Mesonet ASOS
	Tropical Events	Count	Derived	1982–2022	No	NCEI

	AMO	SST Anomaly	Derived	1982–2022	No	NOAA PSL
Prey						
	Mullet	Live Lbs·Yr^{-1}	Derived	2000–2022	No	ACCSP, ASMFC, GSMFC
	Menhaden	Live Lbs·Yr^{-1}	Derived	2000–2022	No	ACCSP, ASMFC, GSMFC

*Source contribution is in relation to data distributor. Distributors often have data contributions from other agencies, organizations, or laboratories.

Identification of Drivers and Correlates of Tarpon Classification Areal Coverage

To identify correlates and potential determinates of the areal coverage of the Tarpon fishery, a series of Gradient Boosted Regression models were fit for each Tarpon classification areal coverage. Areal coverage within the models was represented as a mean relative proportion, with the areal coverage for each year-bin being an average across guide responses of the ratio *year-bin areal coverage:maximum year-bin areal coverage*.

Models were fit in R using the *gpboost* package (Sigrist et al. 2021). The models were structured for Gaussian processes (space and time) with repeated measures, as grids were assessed for Tarpon classification areal coverage through time. Grid ID was included as random effect, year-bin was a grouped random coefficient, the likelihood distribution was Gaussian and the covariance function was exponential. The number of boosting iterations was set to 10000 and the learning rate was adjusted for each model so that the negative log-likelihood stabilized. Default limitations were used for the maximum number of leaves (n = 30), minimum data per leaf was set to 10, and the maximum depth was set to five. Model selection was done by minimizing the negative log-likelihood. Data were split into 80:20 train:test partitions divided by Grid ID (i.e., grid data were solely in either the training or test dataset), and a Root Mean Square Error (RMSE) calculated for the predictions on the test dataset. Less commonly reported Tarpon classifications, daisy [chain] and [stacked] bodies, did not have enough respondents to fit and evaluate model performance using the train:test split; therefore, models for these classifications have been omitted.

The variables within the top models were assessed for importance by calculating SHAP (SHapely Additive exPlanation) values. SHAP values provide a measure and directionality of influence that each covariate value exerts on the modeled response. The development of the SHAP value calculation unifies six traditional methods for assessing and visualizing variable importance for black-box machine learning algorithms (Lundberg and Lee 2017). SHAP value calculations and visualizations were produced using the R package *SHAPforxgboost* (Liu and Just 2023) and ggplot (Wickham 2016). Covariate mean SHAP value weighted-rank importance was assessed across small, medium, and large Tarpon to identify shared influential features. Additional interrogation of spatial relationships across data layers was conducted in both R and ArcPro.

Results

Likert Score Assessment

Likert Scores over space and time declined uniformly, and declining measures of quality were overwhelmingly superseded in responses by elimination of fishing spots (i.e., spots did not gradually decline, but promptly became unfishable). No guide responses indicated periods of increasing quality after a decrease in quality was noted. Accordingly, the response scale provided resulted in a truncated representation of the quality of the fishery, limiting responses to Likert Scores of 5, 4, and 3, progressing over time from “Much Better” to “The Same” in relation to 2022 fishery conditions.

Area Fished Assessment

Respondents most commonly reported fishing areas for large, medium, and small Tarpon. Other classifications were less commonly reported, with daisy [chain] and [stacked] bodies—behavioral descriptions—being least common. Overall, areal coverage of all Tarpon classifications decreased throughout time (Supplementary 1). The average of the per-guide percent of the maximum area fished overtime shows the spatial expansion of the Tarpon fishery as more guides joined the fishery, and collectively a decrease in the percent of the maximum area fish were observed across grids over time (Figure 3; Supplementary 3). In aggregate, declines in area fished progressed from 2002–2006, with the Gulf of Mexico-facing, eastern Lower Keys grids losing their fishing grounds first, followed by more extensive decline along the Gulf of Mexico-facing, central Lower Keys (aka the Backcountry) until the Backcountry, south of Key West, and the northwest Marquesas were lost in 2022.

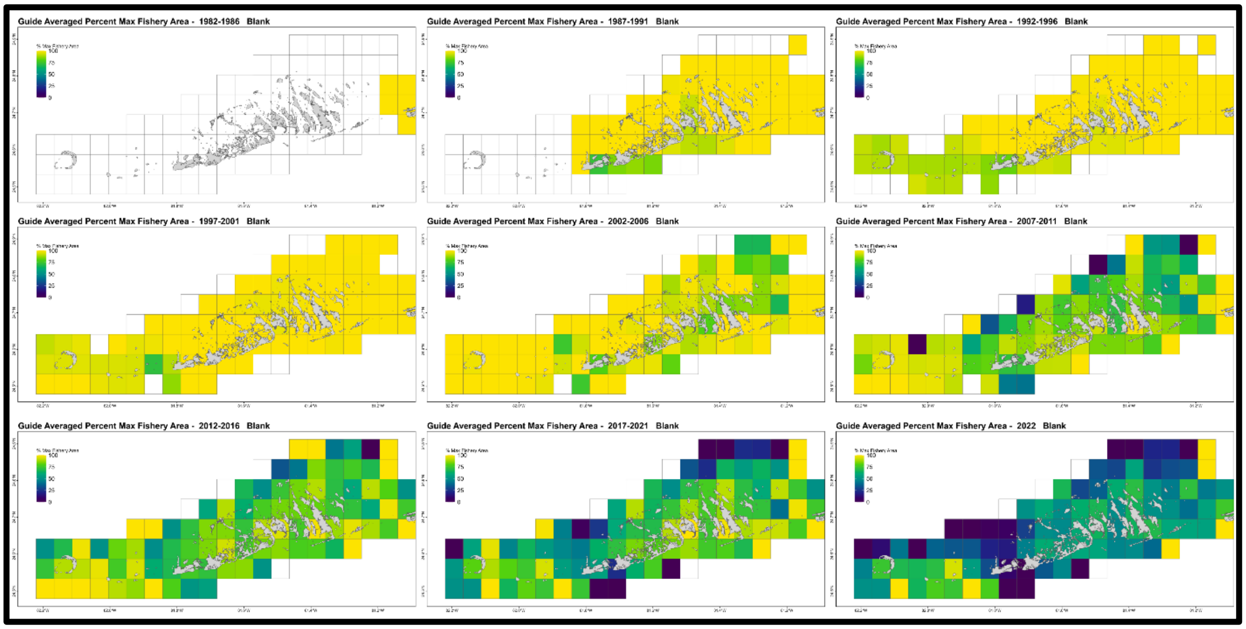

Figure 3. Tarpon classifications aggregated, the percent of each grid's maximum area fished per guide was calculated, and then averaged within each year-bin. As grids darken, the area fished within a grid declines.

Breakpoint analyses on Tarpon classification areal coverage yielded breakpoints that were most commonly found in year-bin 2017–2021 for small, medium, subadult, extra-large, layup, daisy [chain], and [stacked] bodies Tarpon classifications (Figure 4). Breakpoints were most commonly found in 2002–2006 for large Tarpon.

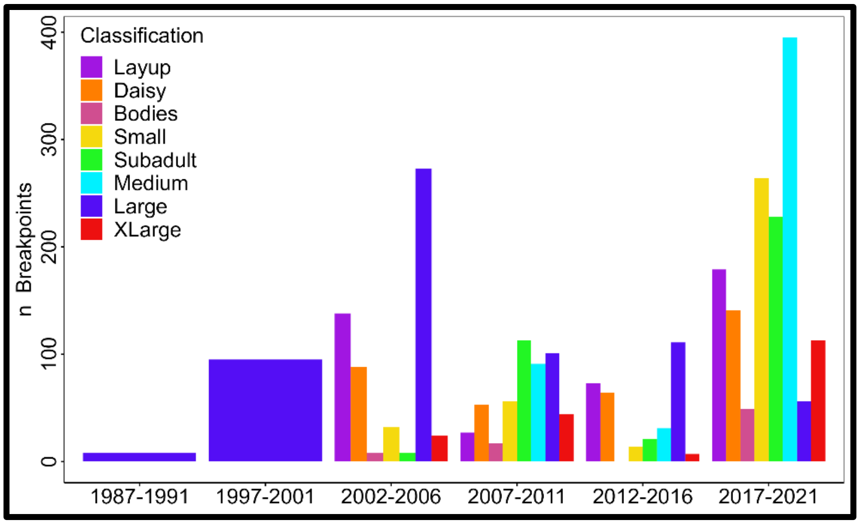

Figure 4. Number of breakpoints identified by F-Statistic and Z-Score breakpoint analysis across all guides and grids.

The spatial patterns when examining all Tarpon classifications combined show the earliest declining breakpoints along the Gulf of Mexico-facing, eastern portion of the Lower Keys in 1997–2001, followed by the Gulf of Mexico-facing, central Lower Keys (the Backcountry) in 2002–2006, then west of Key West (the Marquesas and the Lakes) mostly in 2007–2011, and the central Atlantic-facing, Lower Keys at the latest time period 2017–2021 (Figure 5).

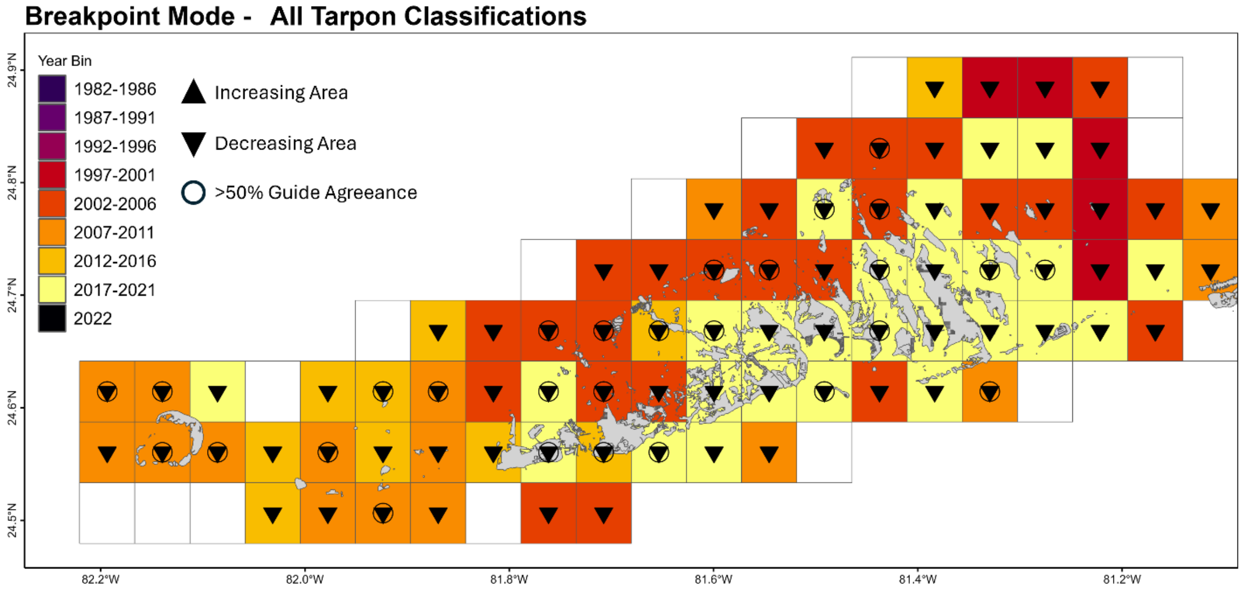

Figure 5. Most frequent breakpoints per grid for all Tarpon classifications combined. Increasing or decreasing trends were determined from the breakpoint to the end of the timeseries. Guide agreeance is in reference to the percent of guides where individual analyses yielded the presence of a breakpoint at any year-bin of the classification depicted within the grid. Agreeance for all Tarpon classifications combined indicates a full ontogenetic decline. Agreeance was more prevalent on a per-size-class basis (See Supplementary 4).

When examined by size-class, small and medium Tarpon declined in the same spatial and temporal manner, while large Tarpon declined differently across the two scales (Supplementary 4). Small and medium Tarpon both declined west of Key West (the Marquesas and Lakes) in the 2007–2011 year-bin, and throughout the remainder of the Lower Keys in 2017–2021. Large Tarpon presented a more spatially and temporally diverse decline, with declines spanning all year-bins between the 1997–2001 year-bin and the 2017–2021 year-bin. Two spatial and temporal clusters of decline are notable for large Tarpon: the northeast region of the Lower Keys (beyond Big Pine) in the 1997–2001 year-bin, and the Backcountry in the 2002–2006 year-bin. West of Key West declines for large Tarpon were later than those observed in small and medium Tarpon.

Environmental Correlates of Area Fished

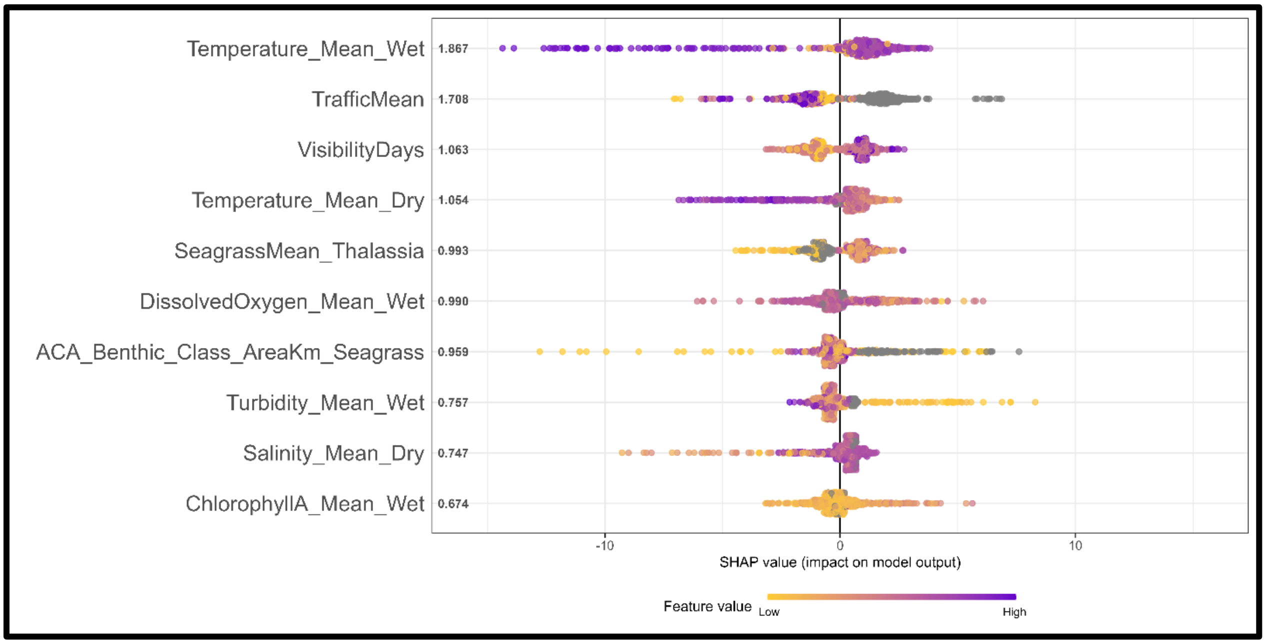

Figure 6. Top-10 variables with the highest mean SHAP value for the gradient boosted regression model for all Tarpon classifications aggregated. Mean SHAP in noted along the Y-axis (ranked importance). SHAP values indicate the strength and directionality (negative/positive) of the response in relation to the range of values for a given variable. Points are colored to range of values for a given variable. Feature NA values, either by spatial or temporal absence in the dataset, are colored gray.

Gradient Boosted Regression models performed well, scaling with the commonality of Tarpon classifications reported in space and time, across guides (Table 4). SHAP values for the aggregated Tarpon classification model (Figure 6), the covariate whose variability had the strongest influence on changes to the areal coverage of the fishery was the mean wet season temperature. Elevated wet season temperatures, and dry season temperatures, correlated with decreases in the fisheries areal coverage. The core of the Tarpon season for the Lower Keys falls predominantly within the wet season, from April to July. Mean wet season temperatures have increased from 28.3 °C to 30.3 °C from 1987–1991 to 2022, respectively. Dry season mean temperatures have fluctuated between 23 °C and 24 °C. Longitudinal temperature measurements, when assessed for annual long-term trends, show that water temperatures within seasons have warmed most rapidly west of Key West, while seasonal dry and wet temperatures show the area northeast of Big Pine to warm the slowest and second fastest, respectively. Dissolved oxygen, a strong correlate of temperature, had a period of decreased concentrations from 2002–2006 that spatially and temporally correlates with large Tarpon decline in the Backcountry (Supplementary 6).

Table 4. Learning Rate and RMSE of Gradient Boosted Regression models for each Tarpon classification. RMSE is on the response scale, percent of maximum area fished: 0–100%.

Classification	Learning Rate	Mean Squared Error (MSE)
Small	0.075	26.4
Subadult	0.1	31.5
Medium	0.1	22.5
Large	0.075	22.7
X Large	0.1	29.1
Layup	0.1	23.3
Negative Space/Inverse sum of All Classifications	0.05	22.0

Spatial and temporal mean salinity during both dry and wet seasons was identified across models as a discriminate means for delineating change and persistence of the Tarpon fishery. Relationships with salinity follow ontogenetic shifts, with small and medium Tarpon having a stable neutral relationship with salinity up to approximately 36 ppt, followed by a negative response to higher salinities. Large Tarpon had a more positive response to increasing salinity. Along the temporal gradient, salinities had the widest distribution in 2007–2011 followed by 2017–2021. The time periods of reduced mean salinity captures two tropical events, hurricane Fay in 2008 and hurricane Irma in 2017. Mean turbidity during these time periods also increased beyond historical relative norms, *Syringodium filiforme* areal coverage decreased, and calcareous green algae areal coverage increased (2017–2021 small Tarpon), while *Thalassia testudinum* areal coverage also decreased (2017–2021 medium Tarpon) (Supplementary 7).

The mean annual average daily southbound traffic into the Florida Keys also strongly correlated with the decline for the extent of the traffic timeseries data. Measures of inbound traffic, which is a proxy variable for human pressure on infrastructure and the environment, was the highest weighted-rank covariate when looking across the small, medium, and large Tarpon models (Table 5). The traffic data collected by FDOT spanned 2007–2022 and saw an increase in annual average daily traffic from approximately 11,500 vehicles to 15,100 vehicles. The 36% increase in human pressure coincided with a 38% reduction in the small Tarpon fishery, a 66% reduction in the medium Tarpon fishery, and a 35% reduction in the large Tarpon fishery (Figure 7).

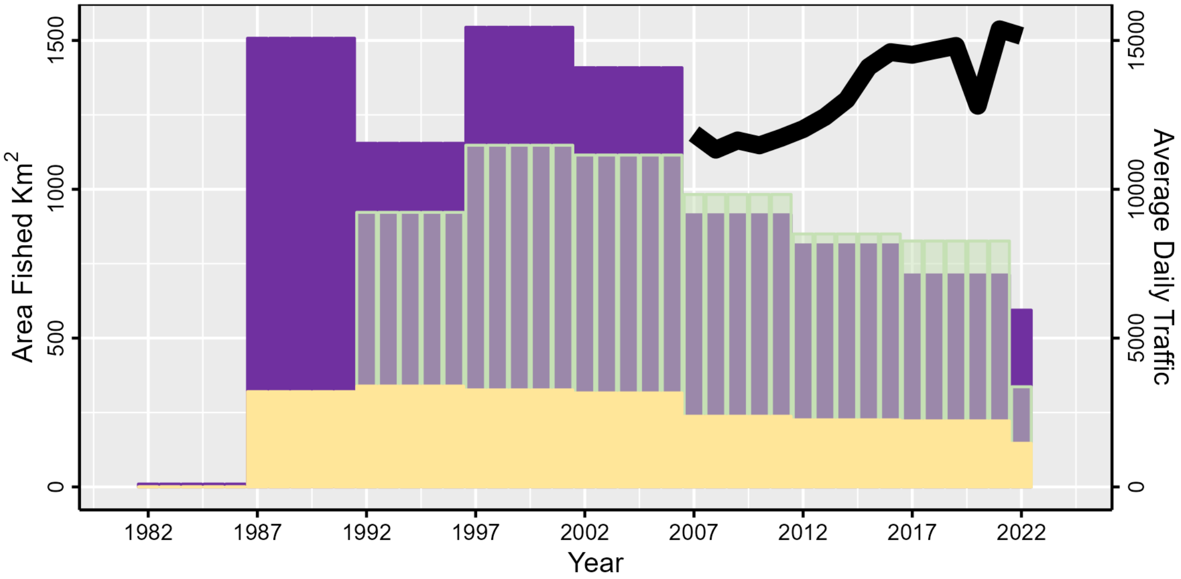

Figure 7. Areal coverage of the small (yellow), medium (green), and large (purple) Tarpon fisheries 1982–2022. Annual average daily southbound traffic is indicated by the black trend line.

Table 5. Weighted rank of variable importance to gradient boosted regression models for the most commonly reported Tarpon classifications: small, medium, and large.

Rank	Variable	Frequency	Weighted Rank
1	TrafficMean	3	1
2	Salinity_Mean_Dry	2	2
2	TropicalEvents	2	2
4	Salinity_Mean_Wet	2	3
5	Temperature_Mean_Dry	2	4
6	Turbidity_Mean_Dry	1	5
7	SeagrassChange_Syringodium	1	6
8	Sailing	1	7
9	SeagrassMean_CalcGreen	1	8
9	Temperature_Mean_Wet	1	8
11	ChlorophyllA_Mean_Wet	1	9
12	DissolvedOxygen_Mean_Wet	1	10
13	ACA_Benthic_Class_AreaKm_Seagrass	1	11
14	TmpCMuMean	1	12
15	SeagrassChange_Thalassia	1	13
16	ChlorophyllA_Mean_Dry	1	14
17	Bathy_Pct_75	1	15
18	Turbidity_Mean_Wet	1	16

While vessel traffic was not promoted by the model as an important predictor in the spatiotemporal decline of the Tarpon fishery, it was one of the most commonly voiced concerns of the guide community (Black pers. comm.). Covariates that are most informative to the model have both spatial and temporal cardinality, where due to historical limitations of remote sensing technology the vessel traffic data was restricted to only a spatial dimension. Vessel traffic spanning 2016–2022 was temporally aggregated into single measures of density. The spatial patterning of these densities was assumed to have been maintained through time, only changing in magnitude—unmeasurable across time given the limitations of historical imagery. Examining the informative capacity across all Tarpon classifications, vessel traffic (dominated by powered small vessel < 20 m) density was ranked 61st out of 101 informative covariates. For large Tarpon, the most common target in the fishery, vessel traffic was ranked 59th out of 108 informative covariates.

The low-ranking of vessel traffic density may have been attributed to the absence of temporal representation. Given the data limitation and the high importance placed on the issue by fishing guides, the spatial relationship between vessel traffic density and the decline of large Tarpon fishery was isolated and further examined. When anchorages were removed from the vessel density data, a strong linear correlation with the current spatial status (2022) of the large Tarpon fishery was evident (Pearson r = -0.2). This correlation, despite lacking temporal information, was twice as strong as within 2022 wet season temperature—the top informative covariate for the large Tarpon model (Pearson r = 0.1).

Spatial overlap between high density vessel traffic areas and the current 2022 remainder of the large Tarpon fishery strongly aligns (Figure 8.). Areas most aligned include Key West and Boca Chica out to the Backcountry (Gulf) and the Sambo Shoals (Atlantic), Saddlebunch Harbor (Atlantic inlet), American Shoals to west of Looe Key, Newfound Harbor Channel (leading to Coupon Bight), and northeast of Big Pine Key. Counter to the high concentration of boat traffic, Bahia Honda Channel and Seven Mile Bridge to Marathon have either sustained or seen relatively minimal reductions in the fishery (Supplementary 1). While vessel traffic appears to be an exclusionary influence to Tarpon habitat access (proxied by the reduction in areas fished), some locations, such as Bahia Honda and Seven Mile Bridge, may be resilient to these pressures due to strong biological ties with the physical properties of the location (e.g., pre-spawning aggregations). Further consideration for these differences may be attributable to refugia provided by the contrasting availability of deeper waters.

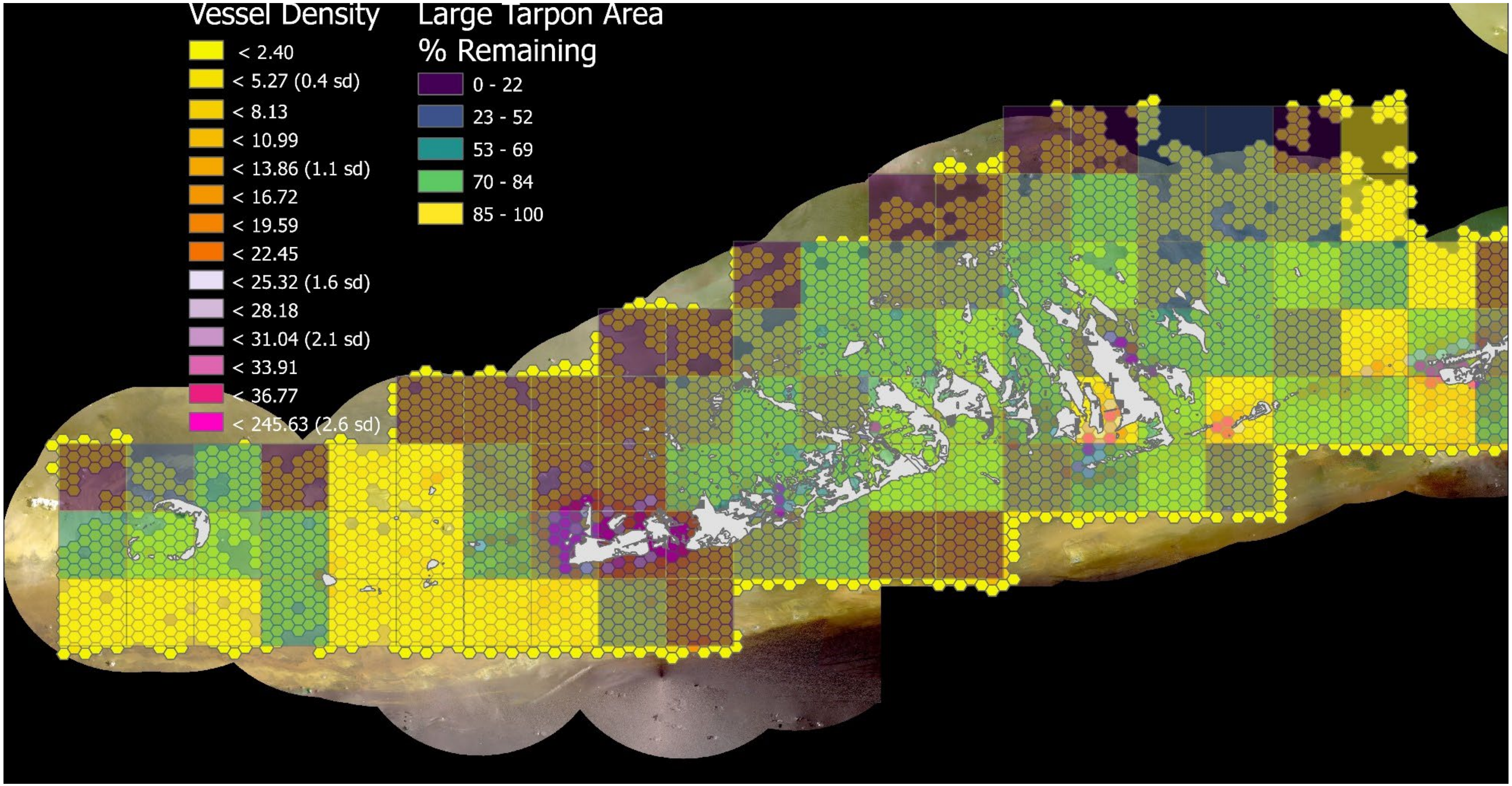

Figure 8. Vessel densities 2016–2022 per 1 km^2 hexagons (yellow to pink). Statistical outliers in density are indicated ≥1.6 sd. Large grids, as filled in by guides, are colored to the percent remaining of the peak of the large Tarpon fishery. Areas with high vessel density (dark orange to pink) show high spatial overlap with areas where the large Tarpon fishery has been depleted (blue and dark purple).

Discussion

The recreational Tarpon fishery decline in the Lower Keys has been a priority topic of concern for the local guiding industry. At stake is a long and storied history where both Tarpon and angler prospered, with cultural and economic benefits. The history of the fishery has been documented through stories, pictures, and cinematography, though this study is the first to document the history of the fishery explicitly in space and time. The uniform decline in Likert Scores across the Lower Keys, preceded by the complete disappearance of fishing spots, indicates that the ecosystem capacity to sustain the Tarpon fishery is characterized by low resistance—the capacity to resist functional change due to disturbance—or high levels of disturbance beyond reasonable levels of resistance (Walker et al 2004). The impact of disturbances, natural and unnatural, resulting in habitat degradation, has be reported as a top concern of anglers and fishing guides (Griffin et al. 2023).

System shifts in climatically and anthropogenically degraded habitats may have been exacerbated by tropical events driving acute changes in physical water quality, resulting in a chronic reduction in habitat suitability. The latent effects of these changes may directly affect Tarpon, as evidenced through the timeseries reduction in guide fishing areal coverage, though indirect affects through shifts in foodweb dynamics post-disturbance may be either the primary driver or have additive effects. Unfortunately, longitudinal foodweb dynamics for Tarpon in the Lower Keys cannot be investigated due to the lack of standardized abundance data for potential prey items, nor information on Tarpon diet. While the ACCSP—through the GSMFC and ASMFC—houses commercial data for mullet (*Mugil* spp.) and menhaden (*Brevoortia patronus*), the data are not readily standardized for abundance, nor are they spatially explicit. Moreover, Tarpon diet is considerably diverse, so a more robust record of multiple prey species would be needed. Thus, changes in prey species abundances cannot be readily attributable to declines in the Lower Keys Tarpon Fishery.

With the objective of providing guidance on ways to ameliorate or mitigate the decline in the Lower Keys Tarpon Fishery, climatic and environmental disturbances pose a difficult challenge. Global scale phenomena, such as climate change, cannot be directly mitigated with local action. The conducted study preceded the heatwave of July 2023, though long-term trends indicate that warming waters were and will remain a persistent threat to ecosystem integrity and thus the capacity for the Florida Keys to sustain vulnerable resources (i.e., fisheries). Water temperature was identified as the top correlate to the areal coverage of the Tarpon fishery as a whole, with a negative relationship at extreme ends—colder dry season waters and hotter wet season waters. With no means to address system temperature changes, mitigation is the only possible strategy, and mitigation requires a focus on how communities and visitors interact with the environment.

The most basic means to mitigate population reduction are through the use of best handling practices when angling for Tarpon. The scale of conservation and restorative impact will not return the Lower Keys Tarpon Fishery to historical conditions, but their support within the community and capacity to stem unnecessary acceleration in population decline warrants inclusion and consideration. Best handling practices have been a primary focus of BTT and the guide community. Angler perceptions of promoting quick fight times, less handling, breaking off in the presence of sharks, and other catch-and-release regulations are widely supported, though more so by fly anglers than spin anglers (Griffin et al. 2023). The general support for regulations pertaining to handling practices provides the most tractable means for mitigating stress mortality amid increasing water temperatures. Adaptive spatial regulations in response to seasonal thermal dynamics of flats and channels has not been investigated scientifically or in perception across user-groups, though it may be a holistic mitigation tool for Florida Keys fisheries.

Water quality is a long-standing issue in the Florida Keys, with initiatives to revise wastewater treatment practices being promoted and accomplished over the last two decades. Large scale conversion from septic to municipal sewer has been completed in the Lower Keys, starting with Key West in 2000–2010, progressing up the Florida Keys through 2017. Despite these efforts, chemical water quality continues to be an issue in nearshore waters, with concentrations of Dissolved Inorganic Nitrogen (DIN) and Soluble Reactive Phosphorus (SRP) exceeding EPA Strategic Targets of 0.75 micromolar and 0.25 micromolar, respectively (Lombardo 2021). The Strategic Targets were set through EPA project SP-47 in an effort to return water quality to conditions pre-2001 that would promote coral and ecosystem health. Chemical water quality was not included in the suite of gradient boosted regression models due to the limited timeseries, and Florida Keys wastewater infrastructure impact was not effectively translated into geospatial data for the models either. Despite this, chemical water quality conditions remain a concern of the public (Griffin et al. 2023) and have remained at substandard concentrations of contaminants, and thus still warrant further examination.

Human pressure on the Florida Keys system, integrated as a proxy variable under "Annual Daily Average Southbound Traffic", was the most influential predictor of the decline of the Tarpon fishery. The strong temporal correlation, as there was no spatial variation attributed, indicates that increases to human presence in the Florida Keys strongly translates to system degradation. While traffic is a proxy for human pressure, human pressure may negatively influence system health through many avenues. Again, wastewater volume, and the contents of the volume, can directly enter the system through failures and inadequacies in the wastewater treatment process. Wastewater leaks are an ongoing problem (200,000 gallons of sewage quietly leaked in the Florida Keys — some during a hurricane | News | thebrunswicknews.com; Florida Sewage Spill and Pollution Notice Tracker | floridatoday.com). The contents of wastewater may have negative implications for fish health and their capacity to contribute reproductively (see Castillo et al. 2023). A challenge to integrating human pressure through wastewater into longitudinal models are the paucity of data, from both a biological and infrastructural perspective. To better understand the wastewater dynamics within the Florida Keys, regulatory documentation needs to be tabulated for treatment volumes. Furthermore, additional studies on the impacts and chemical distributions of deepwater injection wells need to be conducted (see Flower et al. 2017).

A direct measure of human impact included in the models was vessel traffic. Unfortunately, high-resolution (≤3 m) satellite imagery was not available prior to 2016, therefore a longitudinal assessment of impacts could not be conducted. However, the methods used within this study can be carried forward, though prohibitive expense is incurred. The strong correlation between high vessel density and highly degraded Tarpon fishing areas provides a strong impetus for evaluating spatial dynamics and regulation of Florida Keys boating. Current regulations only require a state of Florida online boater safety course certificate, which is largely insufficient for navigating the large expanse of sensitive habitats throughout the Florida Keys. This low barrier to entry has resulted in higher vessel traffic and more damage to sensitive habitats (Kruer 2017; Anderson 2022). Spatial regulations for motorboat operation within the Florida Keys is limited to designated Sanctuary areas, inclusive of Backcountry and Atlantic reef locations, that employ either a pole-troll zone, no motor, no fishing, or no entry regulation. These methods could be proposed and enacted elsewhere, using the data layers produced by this study to guide implementation of such regulations.

Motorboat regulation areal coverage was included as covariates for Tarpon models: no motor, idle speed, no access, and all regulated area. In the aggregated Tarpon model, the spatially regulated areas within FKNMS showed a slight positive relationship to sustained Tarpon fishing area. The protected areas of FKNMS are predominately found in more difficult to access flats and tidal creek habitats of the Backcountry. Spatial regulations in easier access, high traffic locations, would likely require a more involved approach as user-group dynamics shift when moving from the Backcountry to the channels of the main Florida Keys. Regulations for the general boating population should be easily understood and maintain visual reminders through aids to navigation. Improving visibility of navigational structures and increasing their numbers would likely reduce "short-cutting" of entry to channels across seagrass flats, thus reducing physical habitat damage. Additionally, addressing how boaters interact with channels and bridge accesses is key to Tarpon conservation. Tarpon preferentially aggregate at high-current channels, and their access and sustained presence in these channels is threatened not only by fishing pressure and depredation, but vessel traffic. Demarcation of designated access lanes may promote accessibility and sustainability of channel occupancy by Tarpon. Spatial regulations directly applied to the Tarpon fishery—bridge or pass area closures—is a strongly divided initiative. Fly anglers most strongly support regulation, while guides and spin anglers are more averse to such actions. The regulation of these high traffic, high confluence areas will require further dialogue among stakeholders and FKNMS to find the most tractable and amenable solution across the diverse user-groups.

A post hoc assessment of the methodologies employed in this study provides guidance for future studies using this local ecological knowledge semi-structured interview approach. An emergent characteristic of the Likert Score questionnaire was that in a monotonically declining fishery with a reference point of "the present", the score scale is reduced by half, thus limiting the contrast available within the data (low cardinality). While the scale became limited, it was still informative in that we ascertained that fishing spots did not degrade slowly, but promptly vanished. In future applications of the Likert Score approach, a broader scale (e.g., 1–10) could be employed to improve contrast over time. The mapping exercise, while costly in time and computational capacity by those executing the analysis, has proven to be the most detailed examination of the history of a spatially expansive and diverse fishery. The information documented from this process is generationally important to the ecological and cultural history of the Lower Keys Tarpon Fishery, and is of the utmost sensitive nature. These data provide both the historical baseline and the contemporary status of the fishery, to which status updates should be conducted in a decadal manner. It is imperative to do so to both monitor the health of this data-limited fishery, and to document the transition of the guide community from its founders to a new generation. The study system provides a unique opportunity to conduct such studies, as there is a wealth of data in reasonably high spatial and temporal resolution from more research and management groups than any other habitat in the continental United States.

The gradient boosted regression model framework, using a Gaussian process to account for spatial and temporal autocorrelation, allowed for a systematic investigation into environmental and anthropogenic influences on the Lower Keys Tarpon Fishery. The model framework is capable of handling missing data, making it highly functional for data aggregation exercises such as this. Care should still be taken to understand how the models respond to disjunct data in both space and time. We benefitted from smoothing effects brought by conducting our interviews and data aggregation into 5-year year-bins; also a means for limiting recall bias. Information loss at smaller timescales, over large areas, can bias the models to fit to instances of information gain and loss as data sources become available to model. Future work in this ecosystem and analytical space should be conducted on other species that compose the flats fisheries of the Florida Keys, including both bonefish (*Albula vulpes*) and permit (*Trachinotus falcatus*).

Acknowledgements

We collectively recognize the guides of the Lower Keys Guide's Association for their willingness to participate in this process, and for their trust in our team to steward their life experiences and livelihoods that they so generously shared with us.

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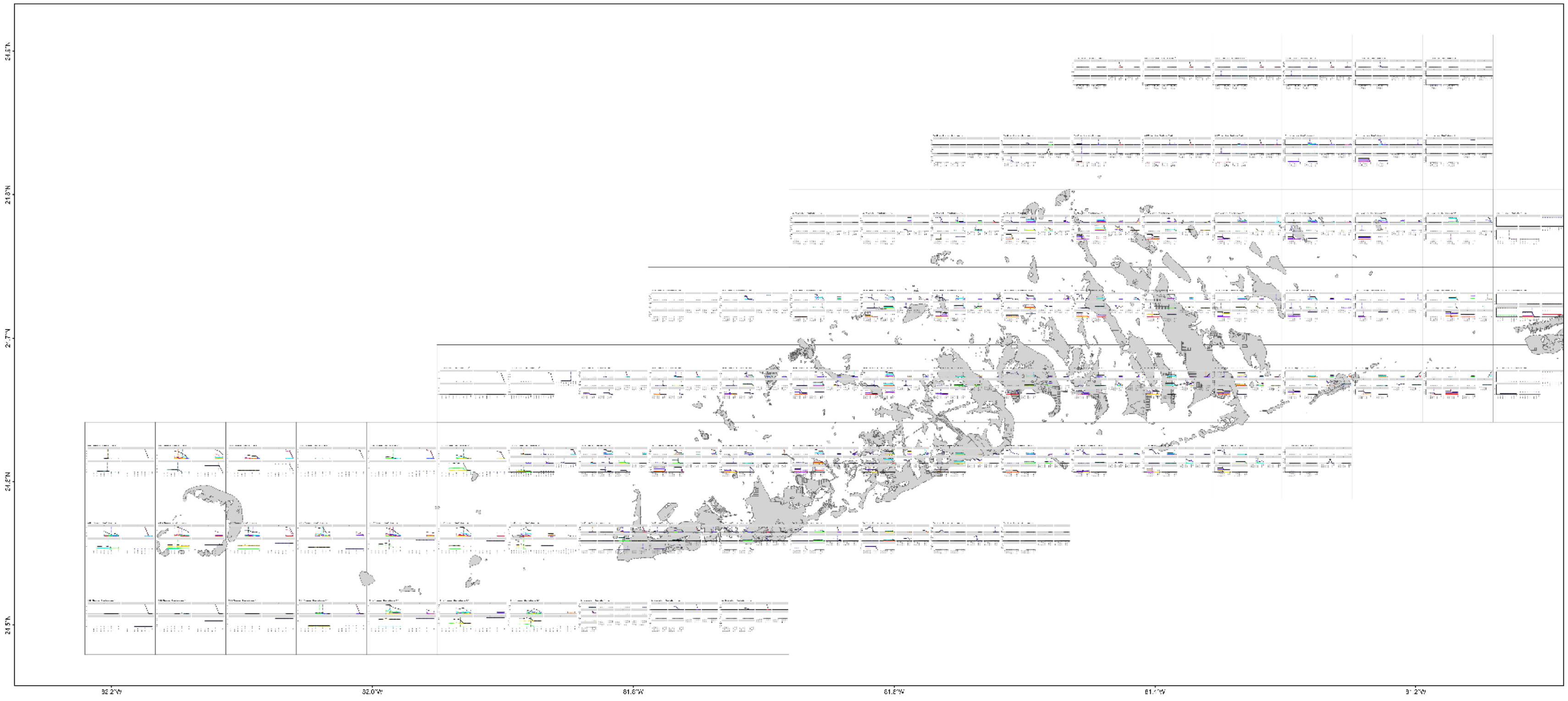
Supplementary

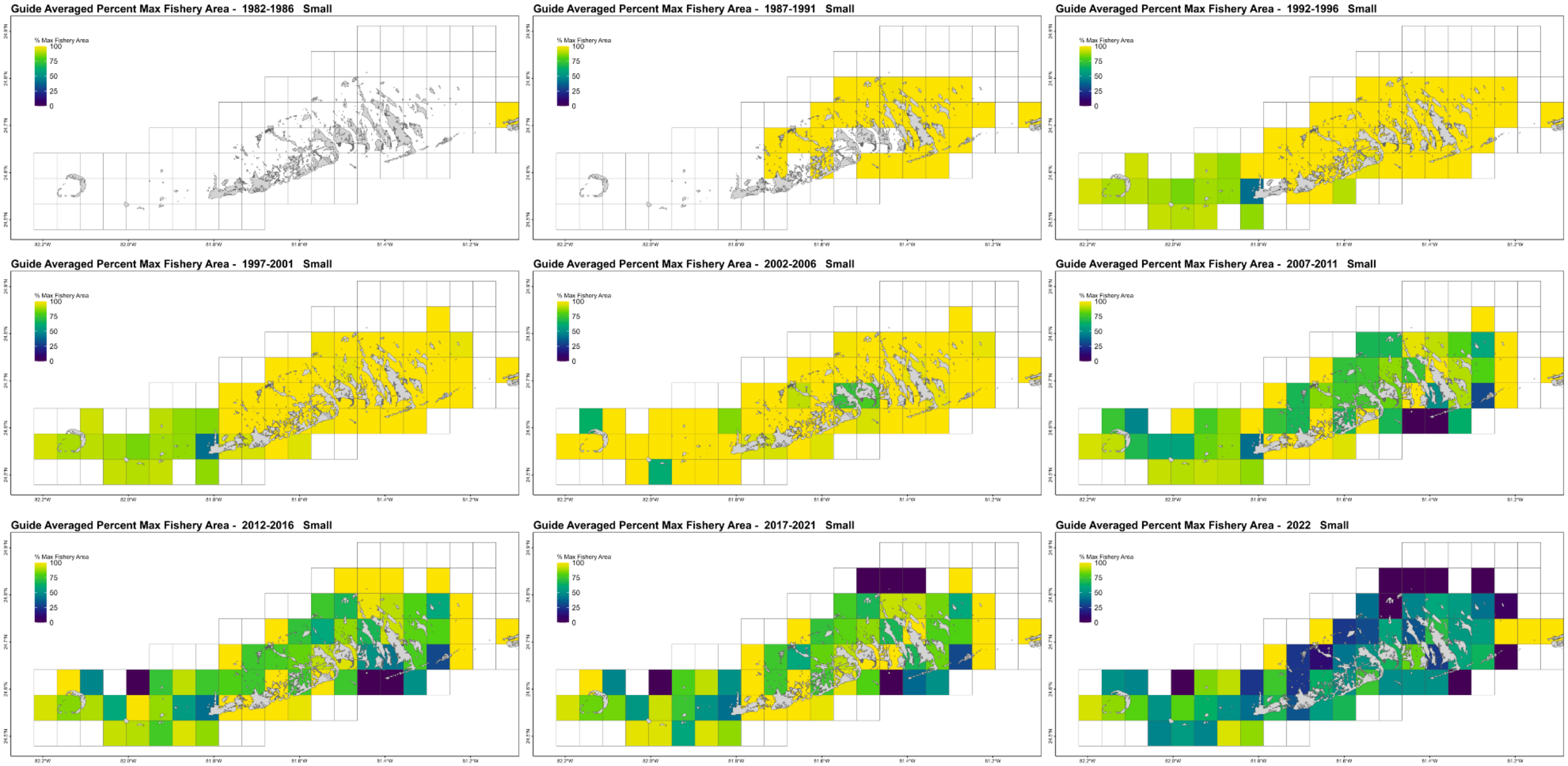


S1. Grid-level breakpoint analysis to identify areas of decline in the Lower Keys Tarpon Fishery. See Table 2 for color correspondence to size classifications. F-statistic breakpoints are dashed lines, and Z-score breakpoints are indicated by dotted lines. Breakpoints and point measures of areal coverage are horizontally jittered for visualization, and are colored according to Table 2.

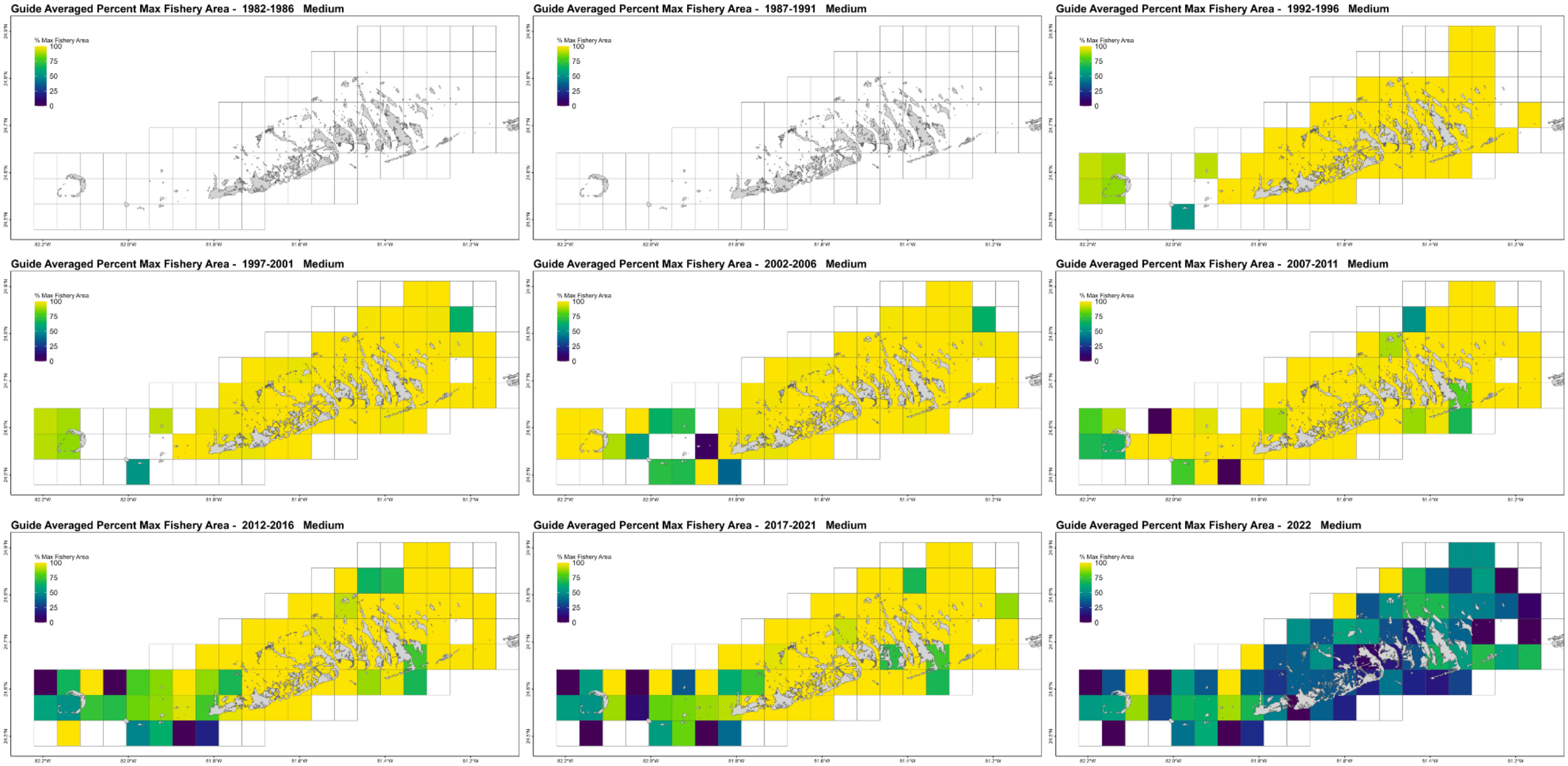
S2. Data sources for gradient boosted regression models.

Classification	Organization	Dataset	Access
Water Quality			
	FWC	Fisheries Independent Monitoring Program	Contact FWRI
	FDEP	SPA	STORET
		WIN	WAVES
	EPA	WQP	Water Quality Portal
	USGS	Daily Data for the Nation	NWIS
	SFWMD	DBHYDRO	DBHYDRO
	NOAA	Harmful Algal Blooms Observing System	HABSOS
	ENP	South Florida Natural Resources Center	Contact SFNRC
	FIU	Seagrass Temperature	Fourqurean Lab
		South FL Coastal Water Quality Monitoring Network	SERC
Traffic			
	Planet/BTT	Dove 3m monthly basemaps – vessel digitization	Contract Purchase
	FDOT	Archive Daily Traffic Volume	FDOT FTP
Wastewater			
	FDOH	Septic	FWMI
	FDEP	Class V Injection Well	UIC
	FDEP	Wastewater Site	WAFR
	FDEP	Vessel Pump Out	CVA
Habitat			
	NCEI	Bathymetry	CUDEM
			CRM
	Allen Coral Atlas	Benthic Classifications	ACA

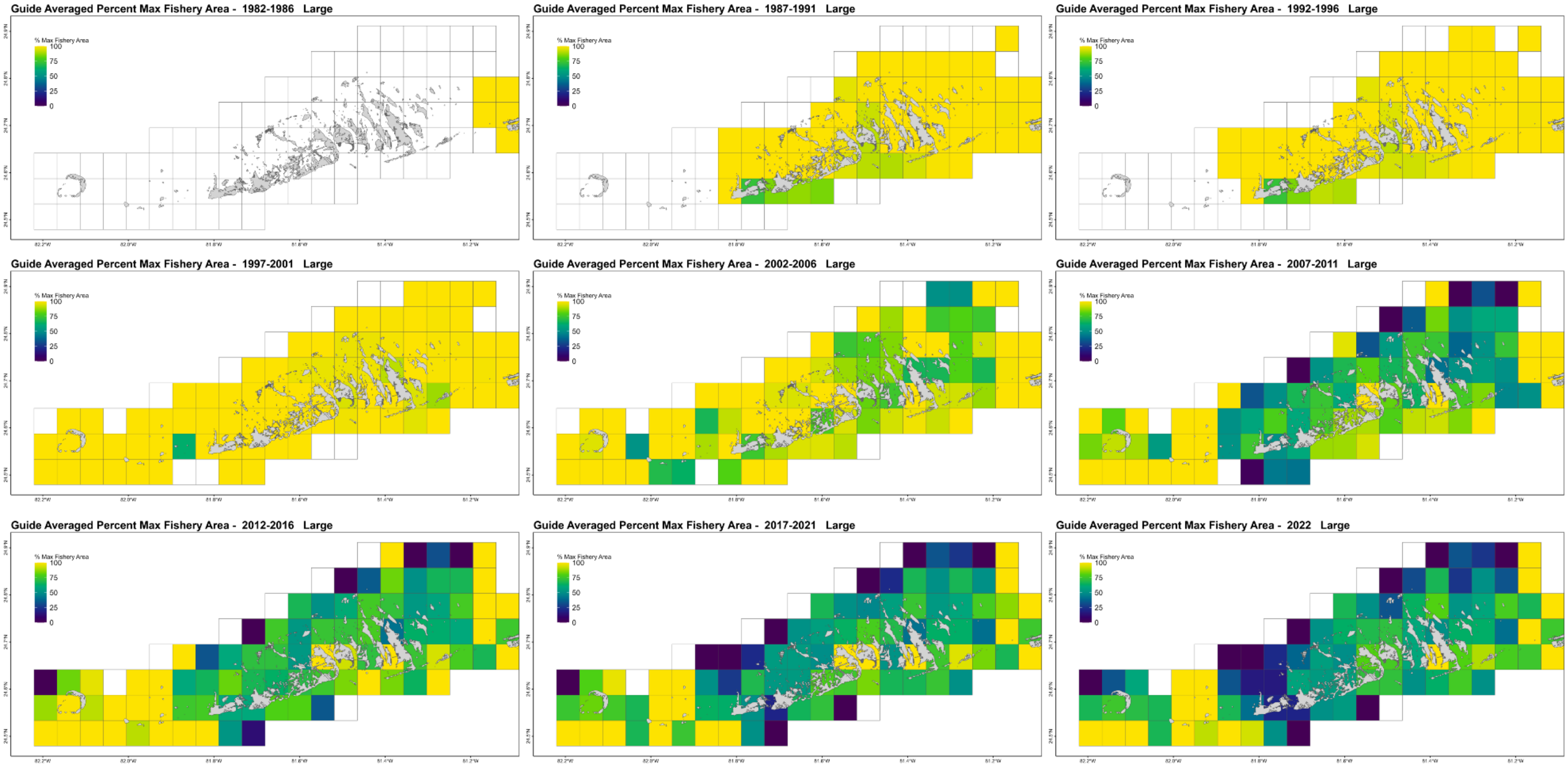
	NOAA/FWC	Benthic Classifications	UFRTM
	FIU	Seagrass	Fourqurean Lab
Climate			
	ISU	Florida ASOS	IEM
	NCEI	Track Archive	NCEI FTP
	NOAA	PSL AMO	PSL
Prey			
	ACCSP	ASMFC/GSMFC Confidential Daily Landings	ACCSP



S3.1. Small size-class Tarpon maps for each year-bin are colored according to the fraction of the maximum area fished within a grid. A representation of what percent of the maximum fishery remained for each year-bin.



S3.2. Medium size-class Tarpon maps for each year-bin are colored according to the fraction of the maximum area fished within a grid. A representation of what percent of the maximum fishery remained for each year-bin.



Guide Averaged Percent Max Fishery Area - 1982-1986 Large

Guide Averaged Percent Max Fishery Area - 1987-1991 Large

Guide Averaged Percent Max Fishery Area - 1992-1996 Large

Guide Averaged Percent Max Fishery Area - 1997-2001 Large

Guide Averaged Percent Max Fishery Area - 2002-2006 Large

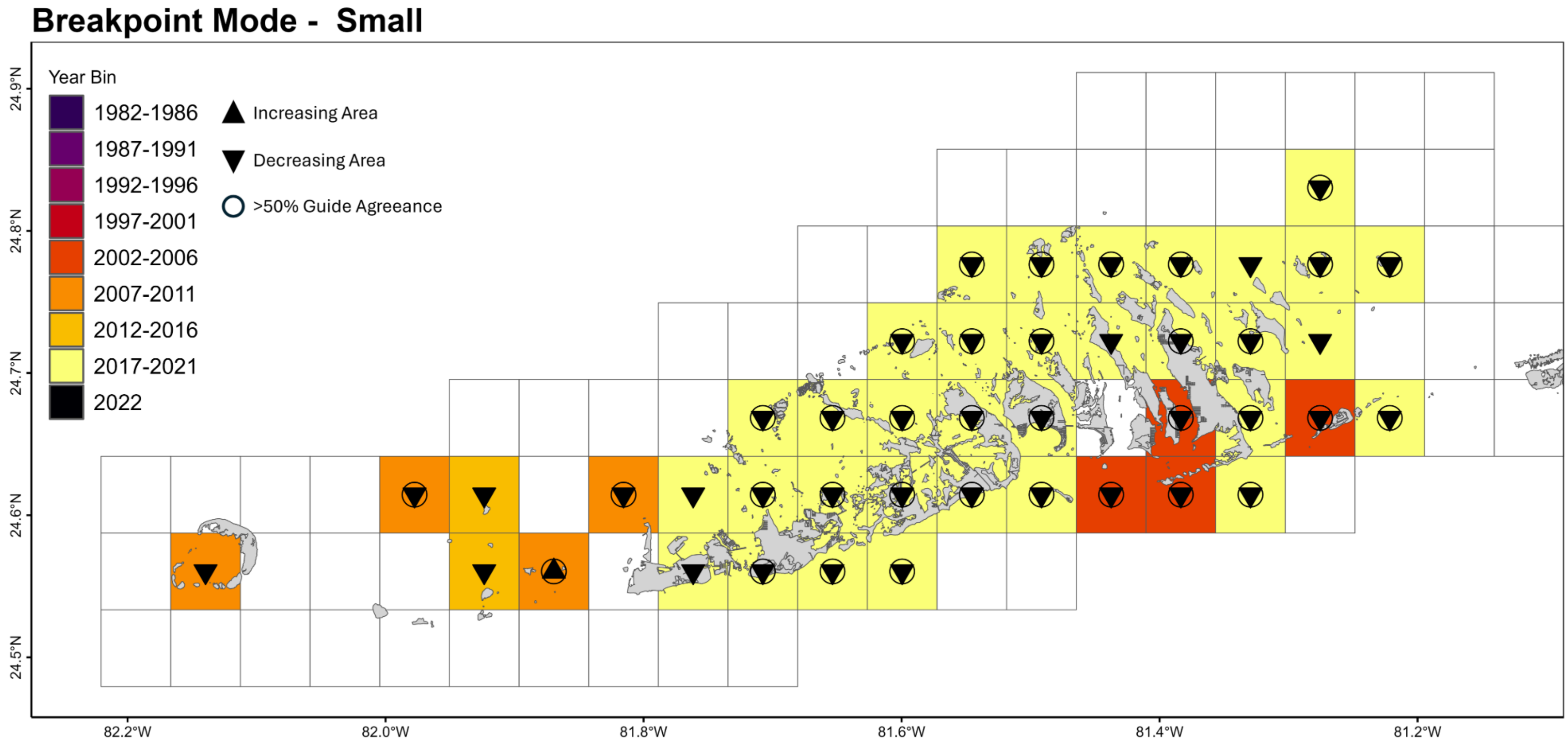
Guide Averaged Percent Max Fishery Area - 2007-2011 Large

Guide Averaged Percent Max Fishery Area - 2012-2016 Large

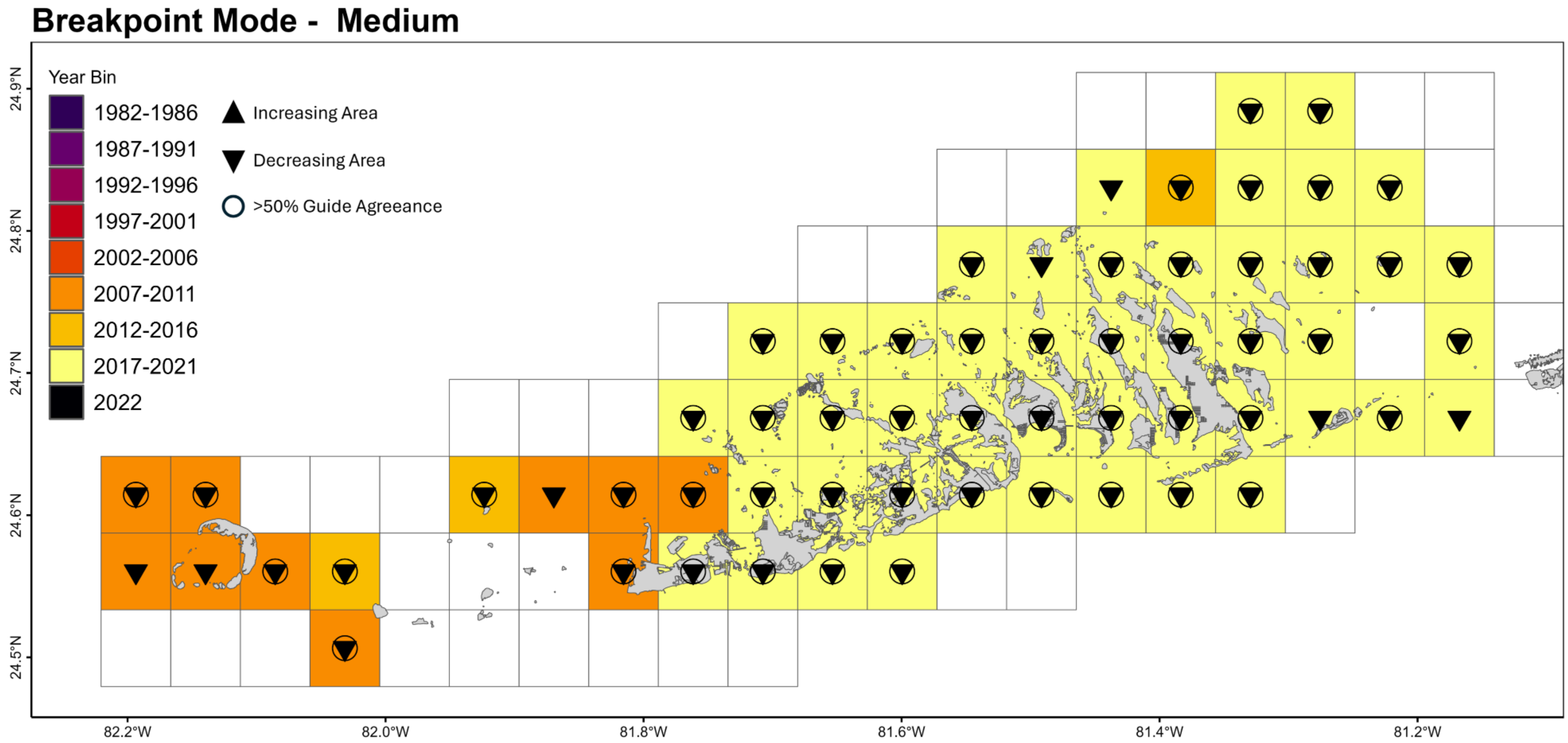
Guide Averaged Percent Max Fishery Area - 2017-2021 Large

Guide Averaged Percent Max Fishery Area - 2022 Large

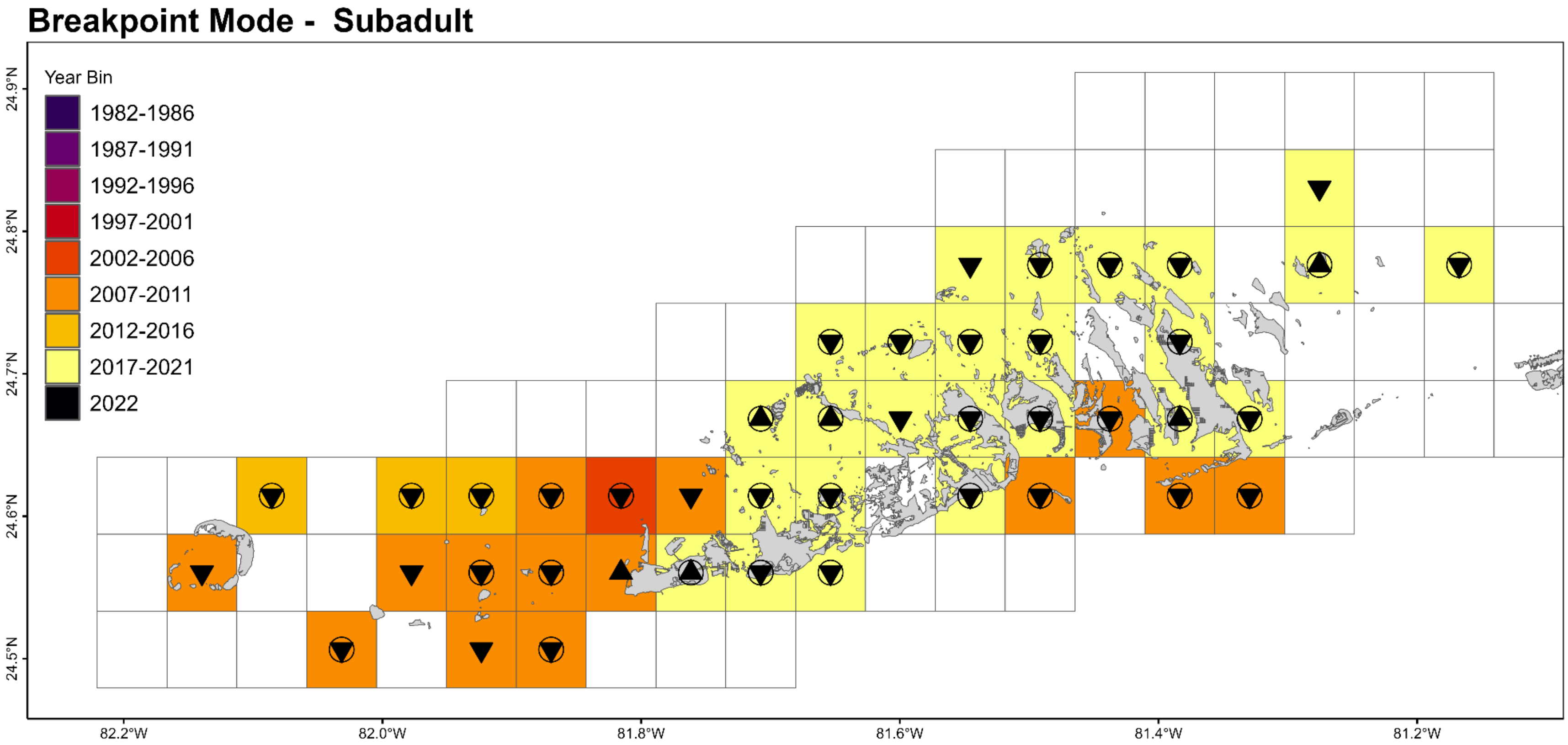
S3.3. Large size-class Tarpon maps for each year-bin are colored according to the fraction of the maximum area fished within a grid. A representation of what percent of the maximum fishery remained for each year-bin.



S4.1. Most frequent breakpoints per grid for small Tarpon. Increasing or decreasing trends were determined from the breakpoint to the end of the timeseries. Guide agreeance is in reference to the percent of guides where individual analyses yielded the presence of a breakpoint at any year-bin of the classification depicted within the grid.

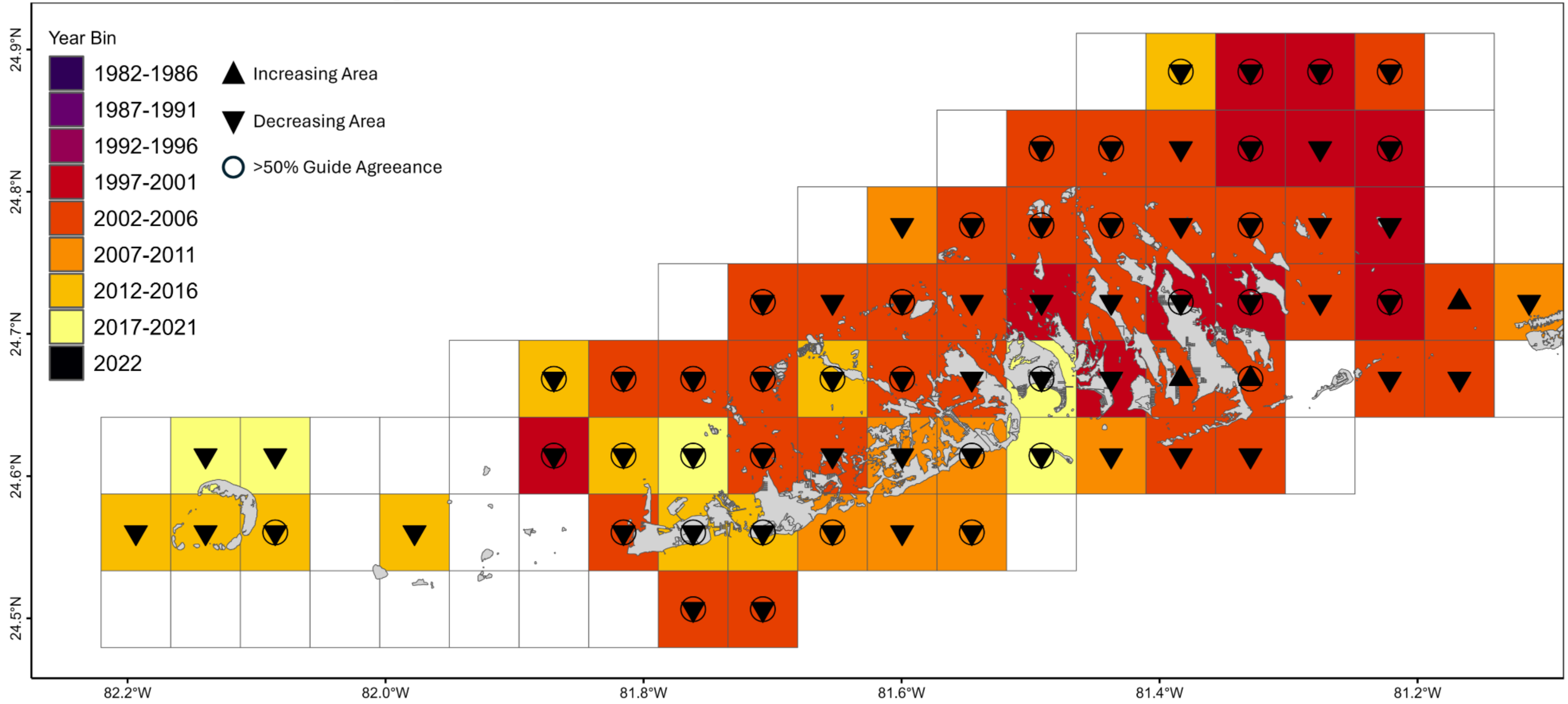


S4.2. Most frequent breakpoints per grid for medium Tarpon. Increasing or decreasing trends were determined from the breakpoint to the end of the timeseries. Guide agreeance is in reference to the percent of guides where individual analyses yielded the presence of a breakpoint at any year-bin of the classification depicted within the grid.

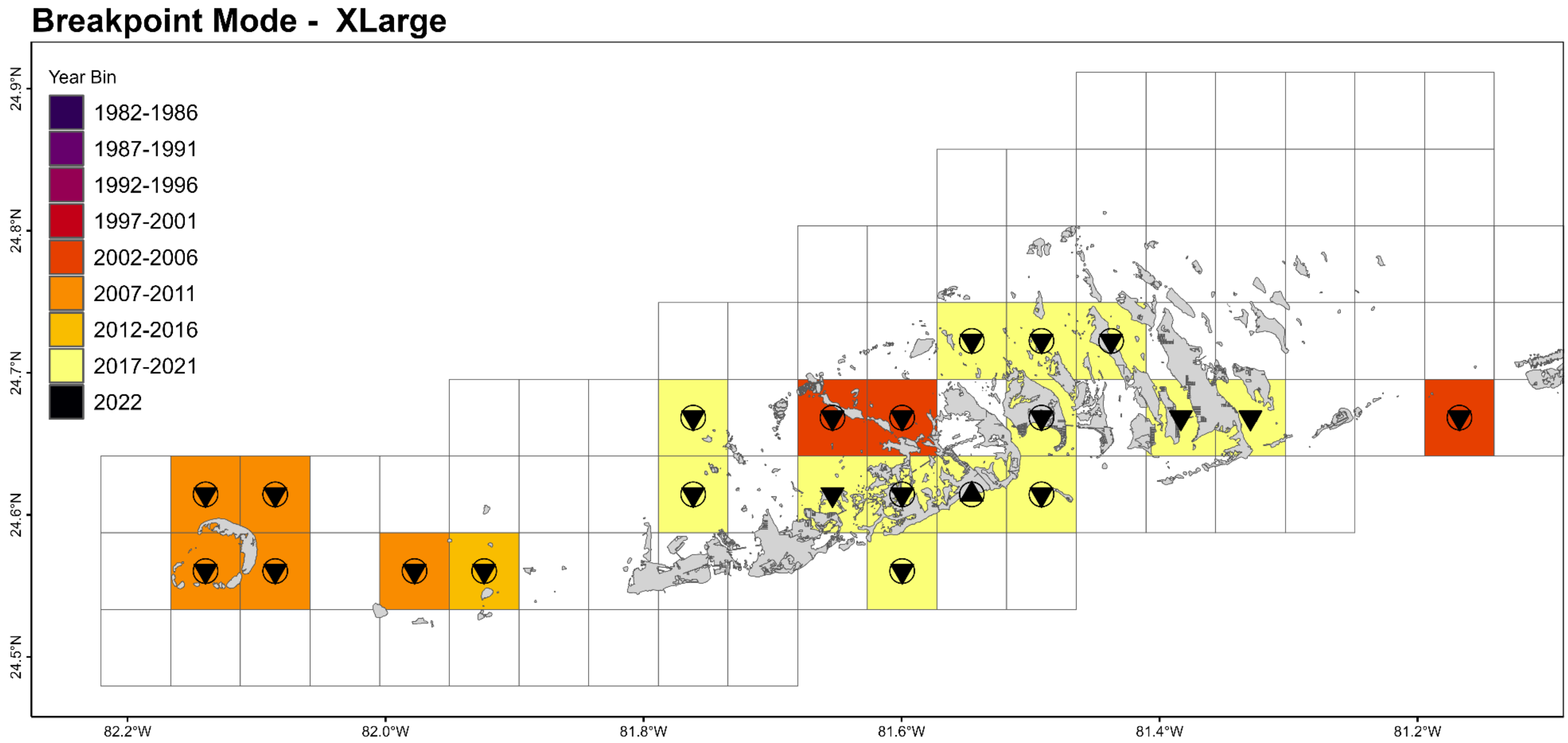


S4.3. Most frequent breakpoints per grid for subadult Tarpon. Increasing or decreasing trends were determined from the breakpoint to the end of the timeseries. Guide agreeance is in reference to the percent of guides where individual analyses yielded the presence of a breakpoint at any year-bin of the classification depicted within the grid.

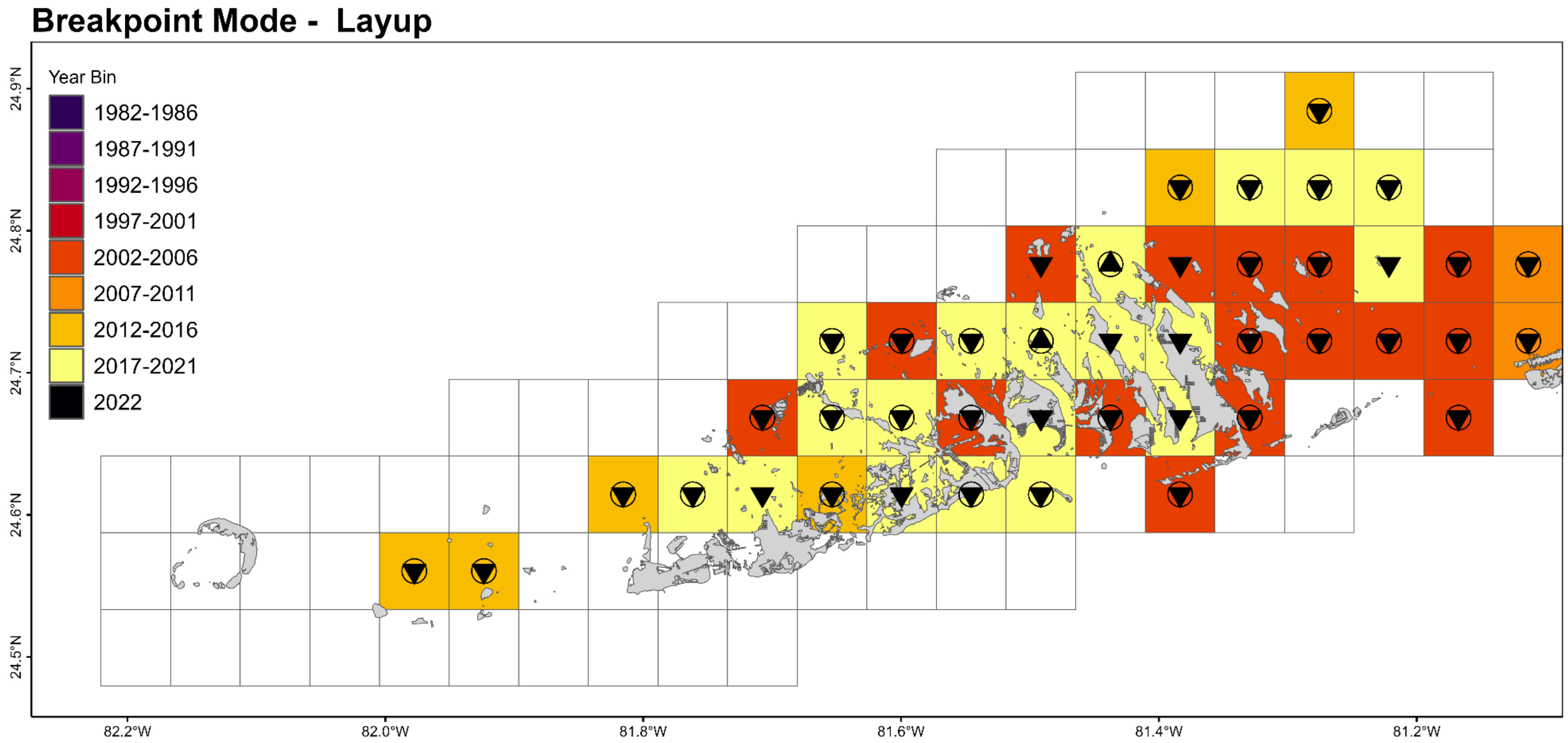
Breakpoint Mode - Large



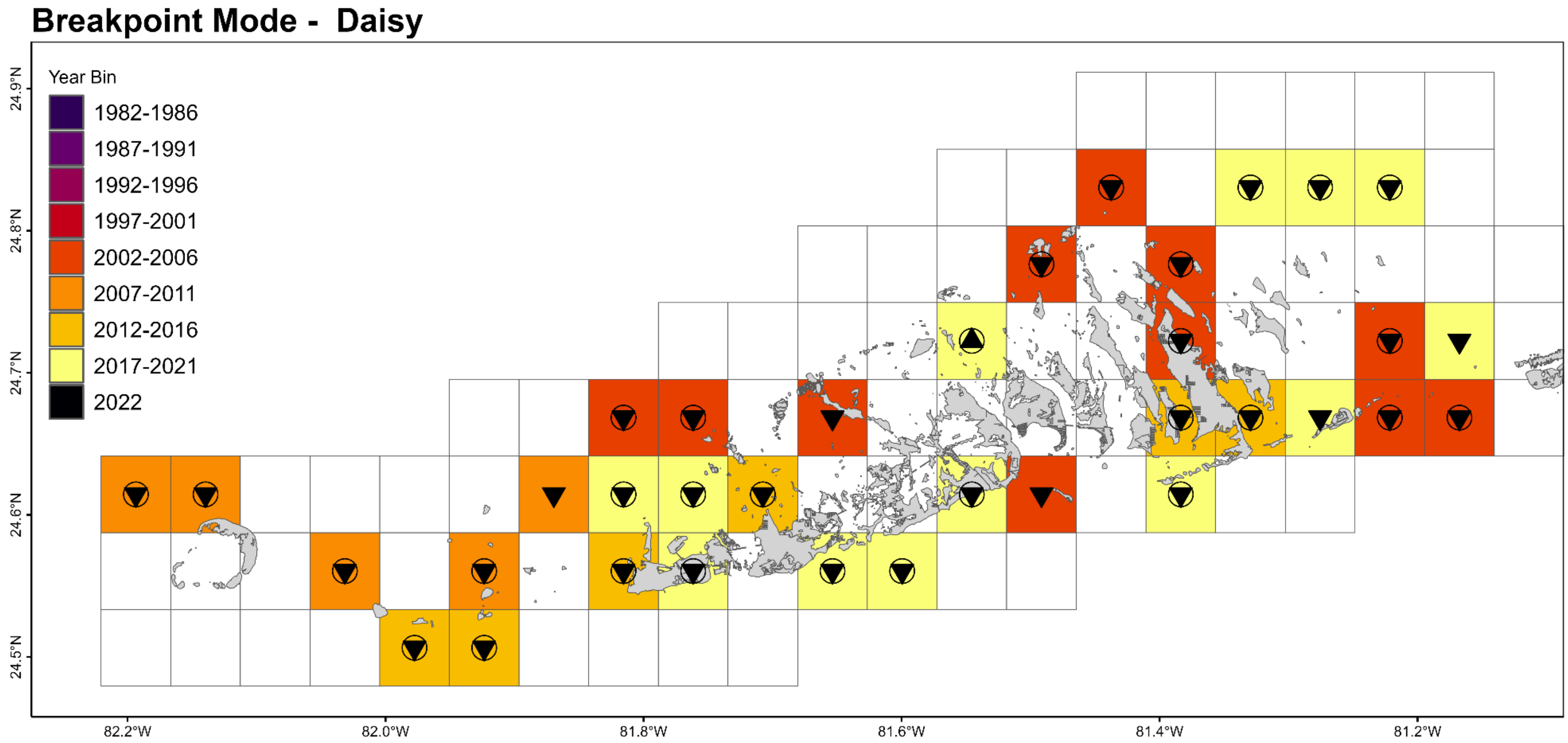
S4.4. Most frequent breakpoints per grid for large Tarpon. Increasing or decreasing trends were determined from the breakpoint to the end of the timeseries. Guide agreeance is in reference to the percent of guides where individual analyses yielded the presence of a breakpoint at any year-bin of the classification depicted within the grid.



S4.5. Most frequent breakpoints per grid for extra-large Tarpon. Increasing or decreasing trends were determined from the breakpoint to the end of the timeseries. Guide agreeance is in reference to the percent of guides where individual analyses yielded the presence of a breakpoint at any year-bin of the classification depicted within the grid.

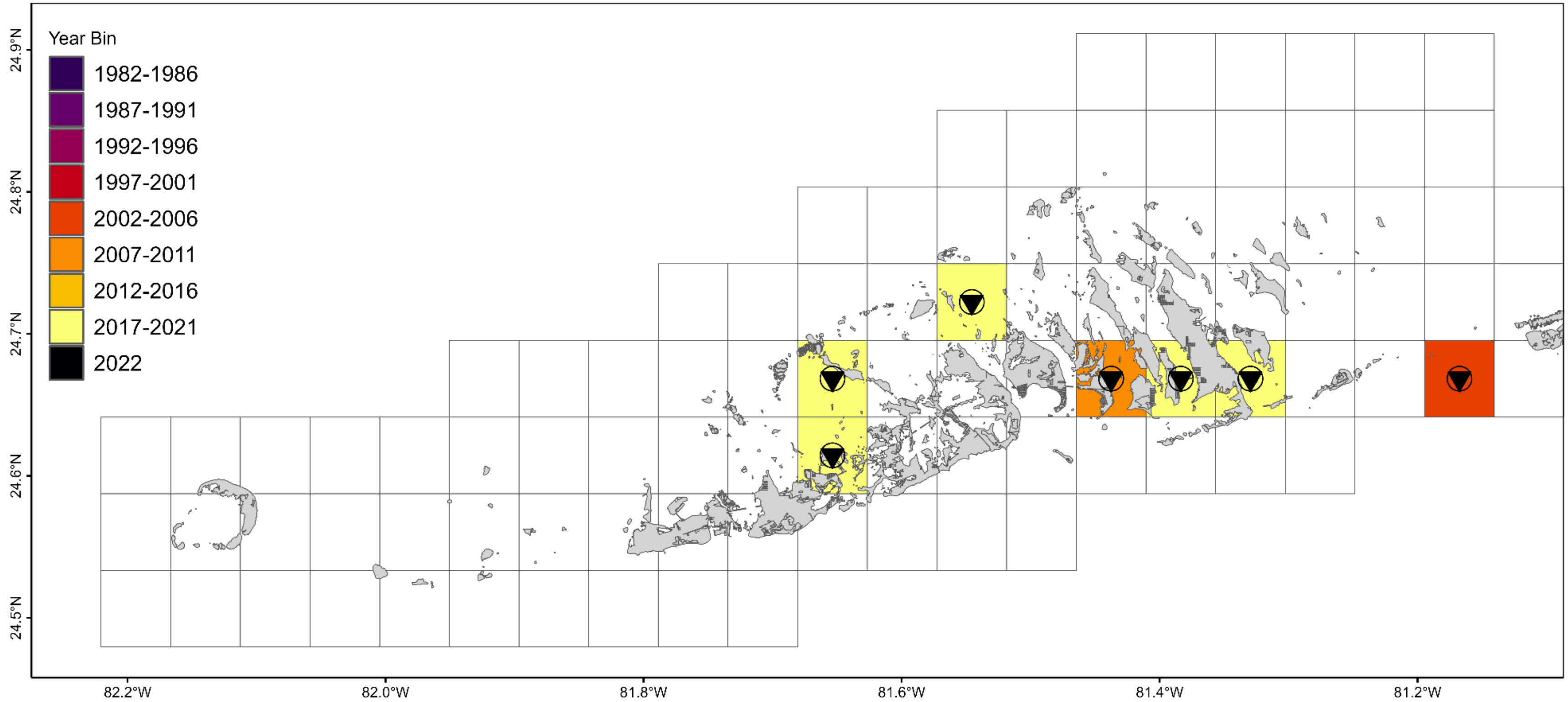


S4.6. Most frequent breakpoints per grid for layup Tarpon. Increasing or decreasing trends were determined from the breakpoint to the end of the timeseries. Guide agreeance is in reference to the percent of guides where individual analyses yielded the presence of a breakpoint at any year-bin of the classification depicted within the grid.

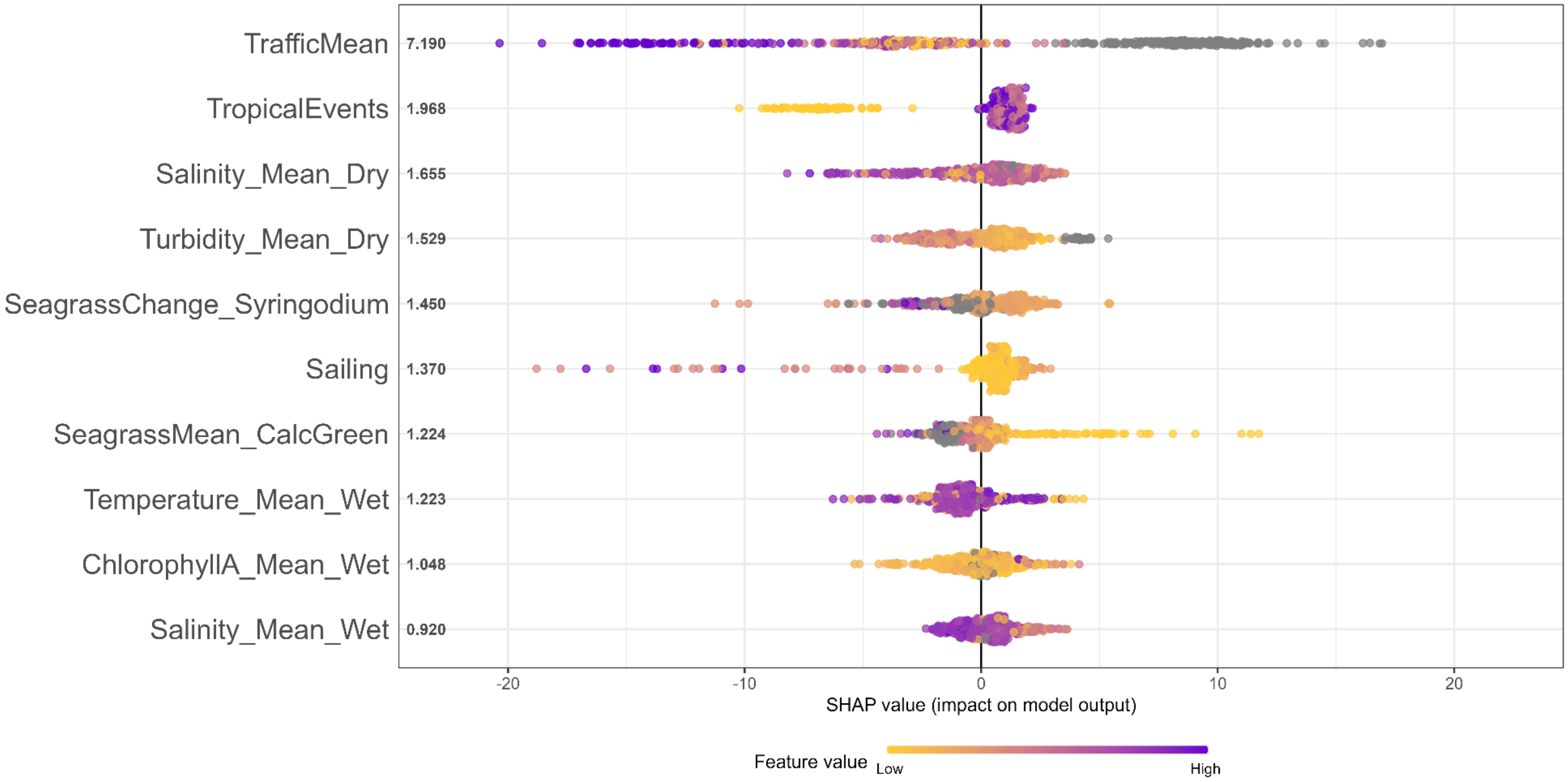


S4.7. Most frequent breakpoints per grid for daisy [chain] Tarpon. Increasing or decreasing trends were determined from the breakpoint to the end of the timeseries. Guide agreeance is in reference to the percent of guides where individual analyses yielded the presence of a breakpoint at any year-bin of the classification depicted within the grid.

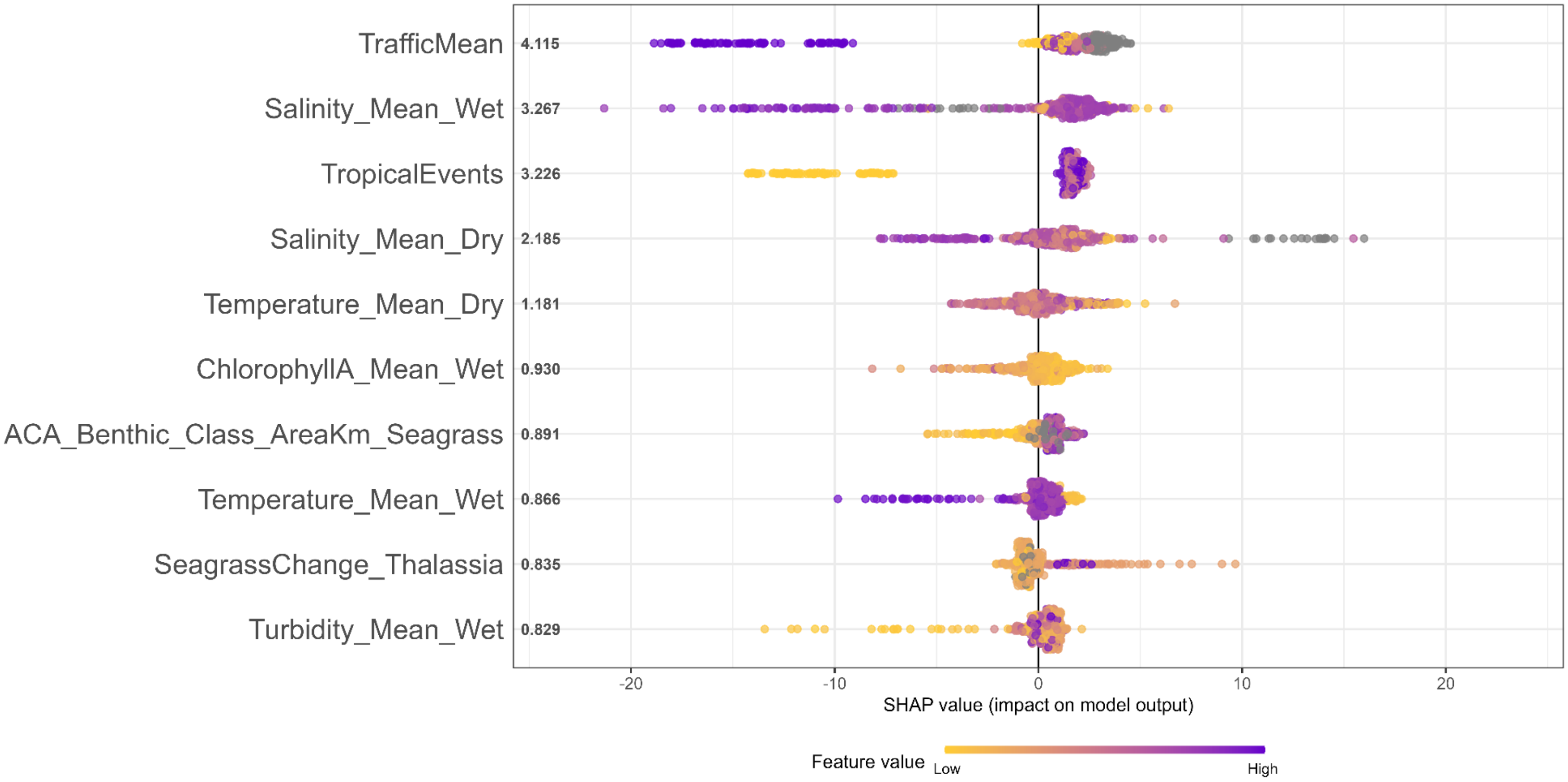
Breakpoint Mode - Bodies



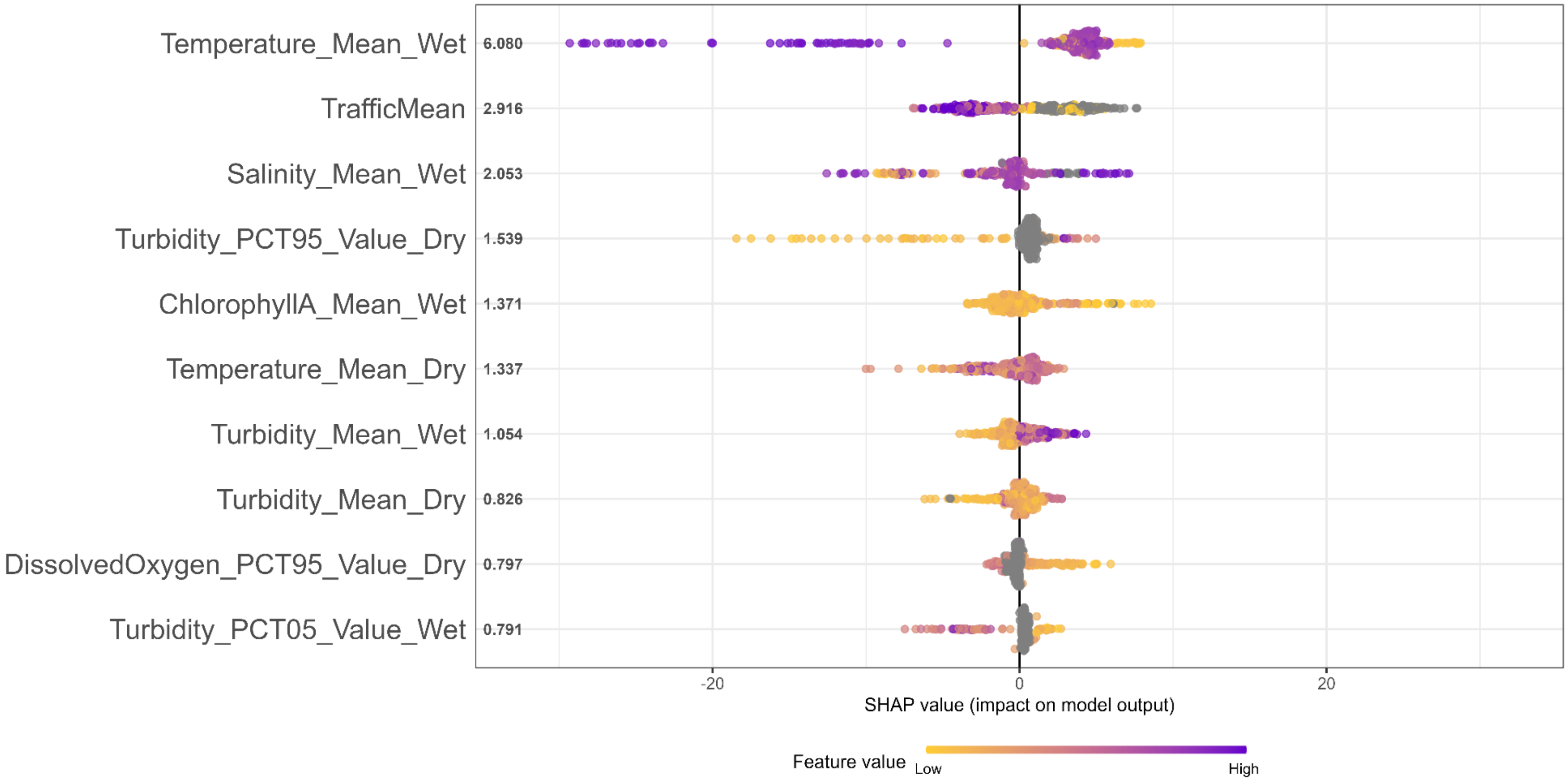
S4.8. Most frequent breakpoints per grid for [stacked] bodies Tarpon. Increasing or decreasing trends were determined from the breakpoint to the end of the timeseries. Guide agreeance is in reference to the percent of guides where individual analyses yielded the presence of a breakpoint at any year-bin of the classification depicted within the grid.



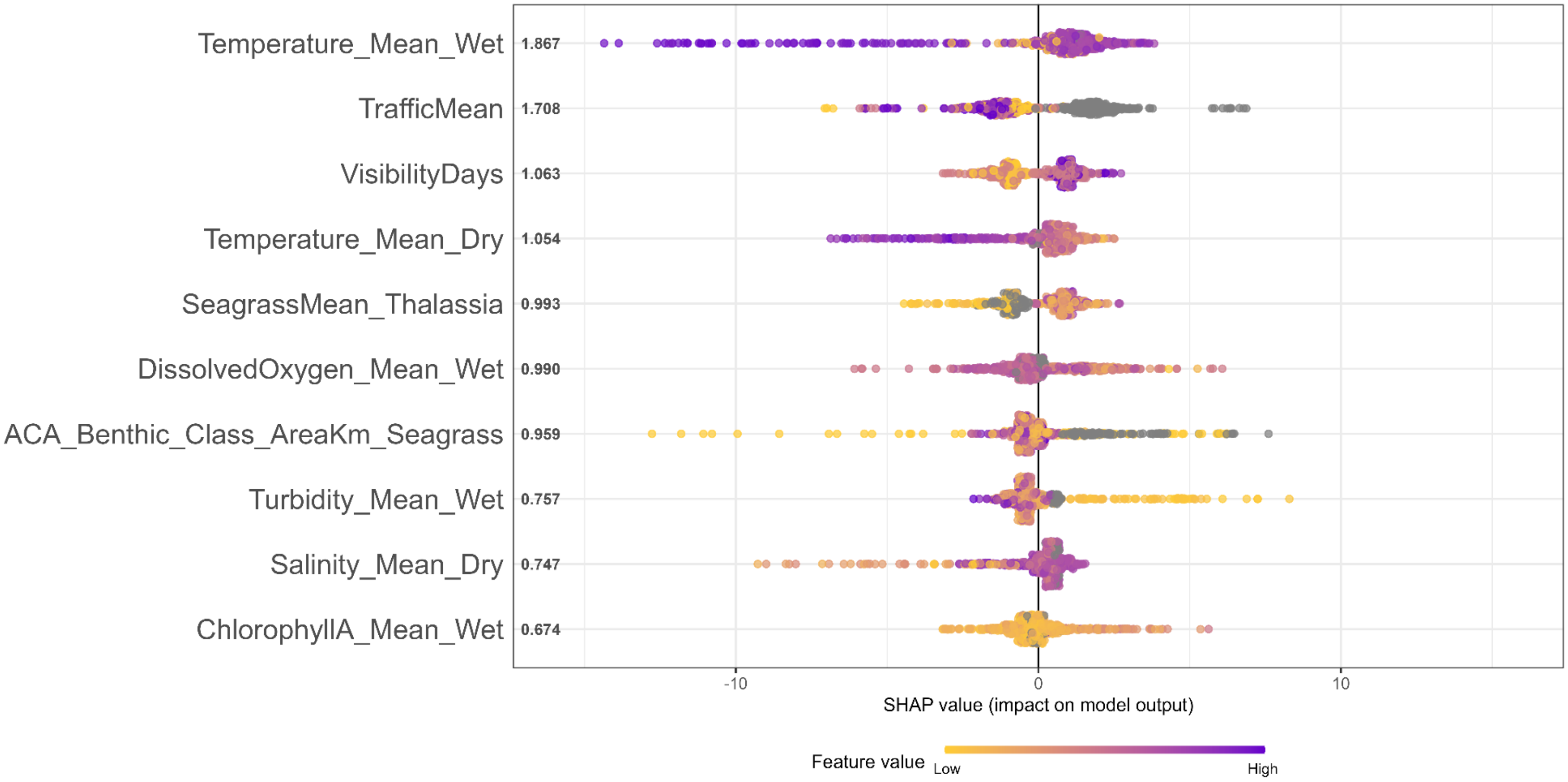
S5.1. Small Tarpon top-10 variables with the highest mean SHAP value for the gradient boosted regression model. Mean SHAP in noted along the Y-axis (ranked importance). SHAP values indicate the strength and directionality (negative/positive) of the response in relation to the range of values for a given variable. Points are colored to range of values for a given variable. Feature NA values, either by spatial or temporal absence in the dataset, are colored gray.



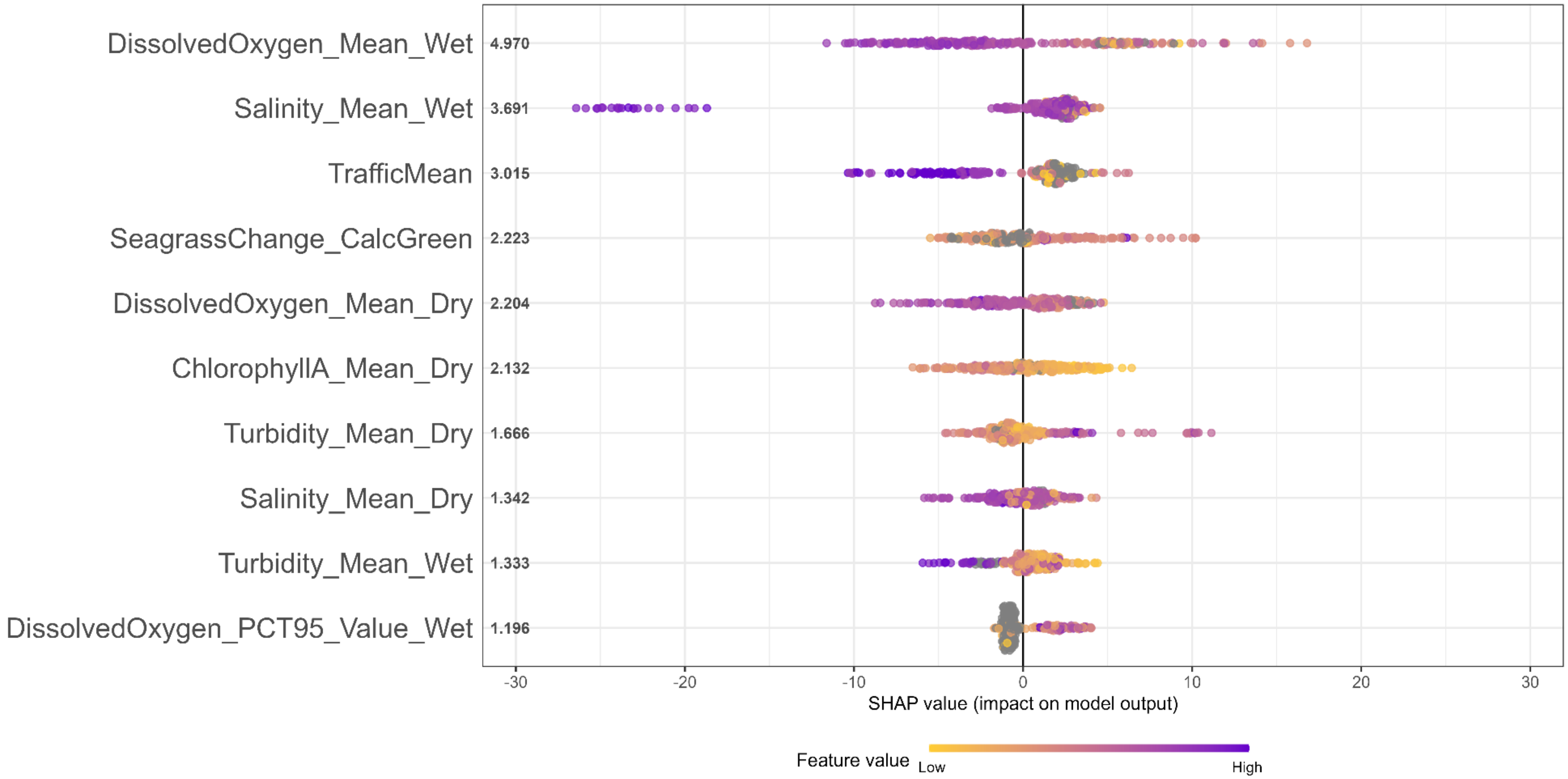
S5.2. Medium Tarpon top-10 variables with the highest mean SHAP value for the gradient boosted regression model. Mean SHAP in noted along the Y-axis (ranked importance). SHAP values indicate the strength and directionality (negative/positive) of the response in relation to the range of values for a given variable. Points are colored to range of values for a given variable. Feature NA values, either by spatial or temporal absence in the dataset, are colored gray.



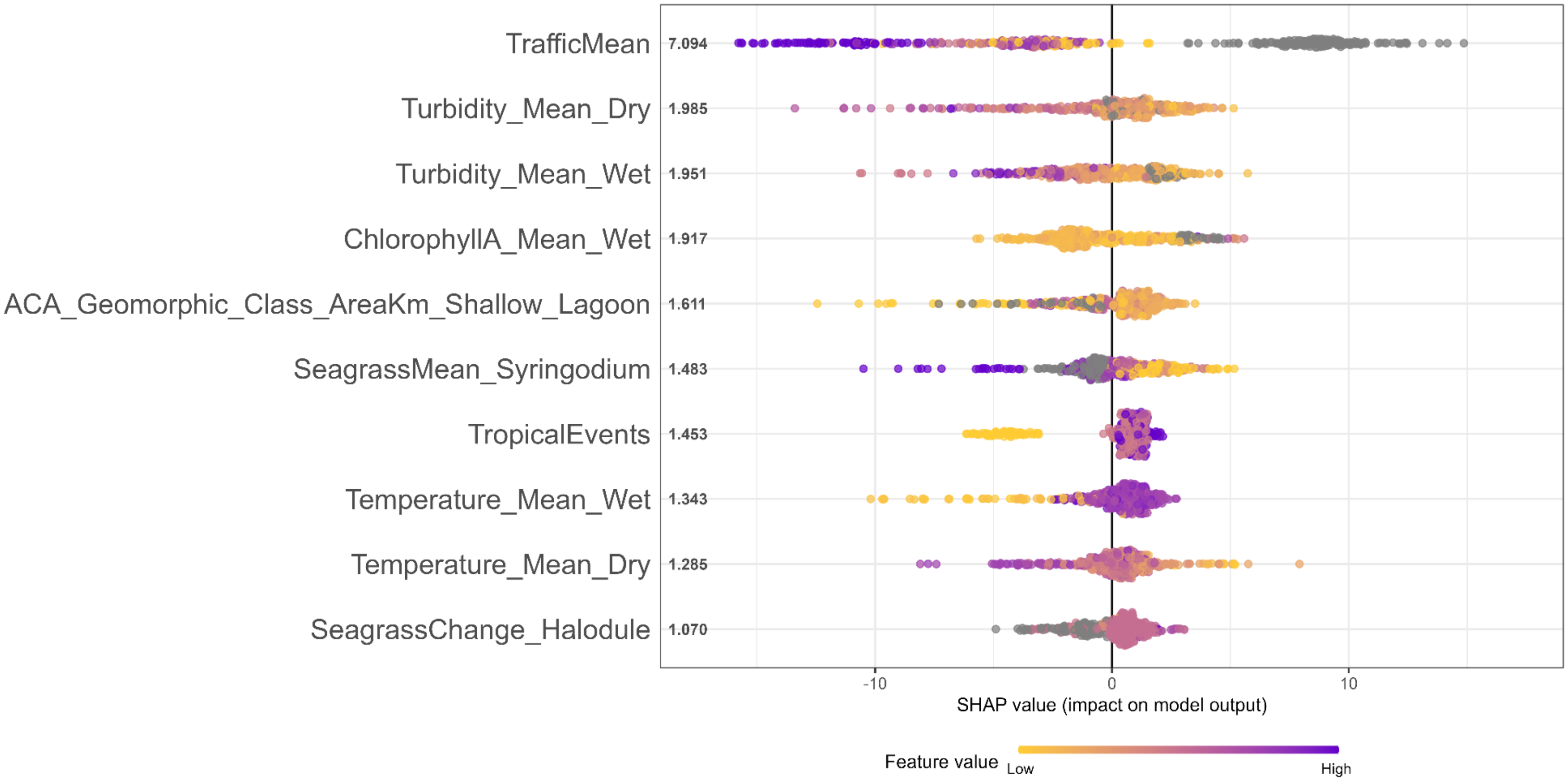
S5.3. Subadult Tarpon top-10 variables with the highest mean SHAP value for the gradient boosted regression model. Mean SHAP in noted along the Y-axis (ranked importance). SHAP values indicate the strength and directionality (negative/positive) of the response in relation to the range of values for a given variable. Points are colored to range of values for a given variable. Feature NA values, either by spatial or temporal absence in the dataset, are colored gray.



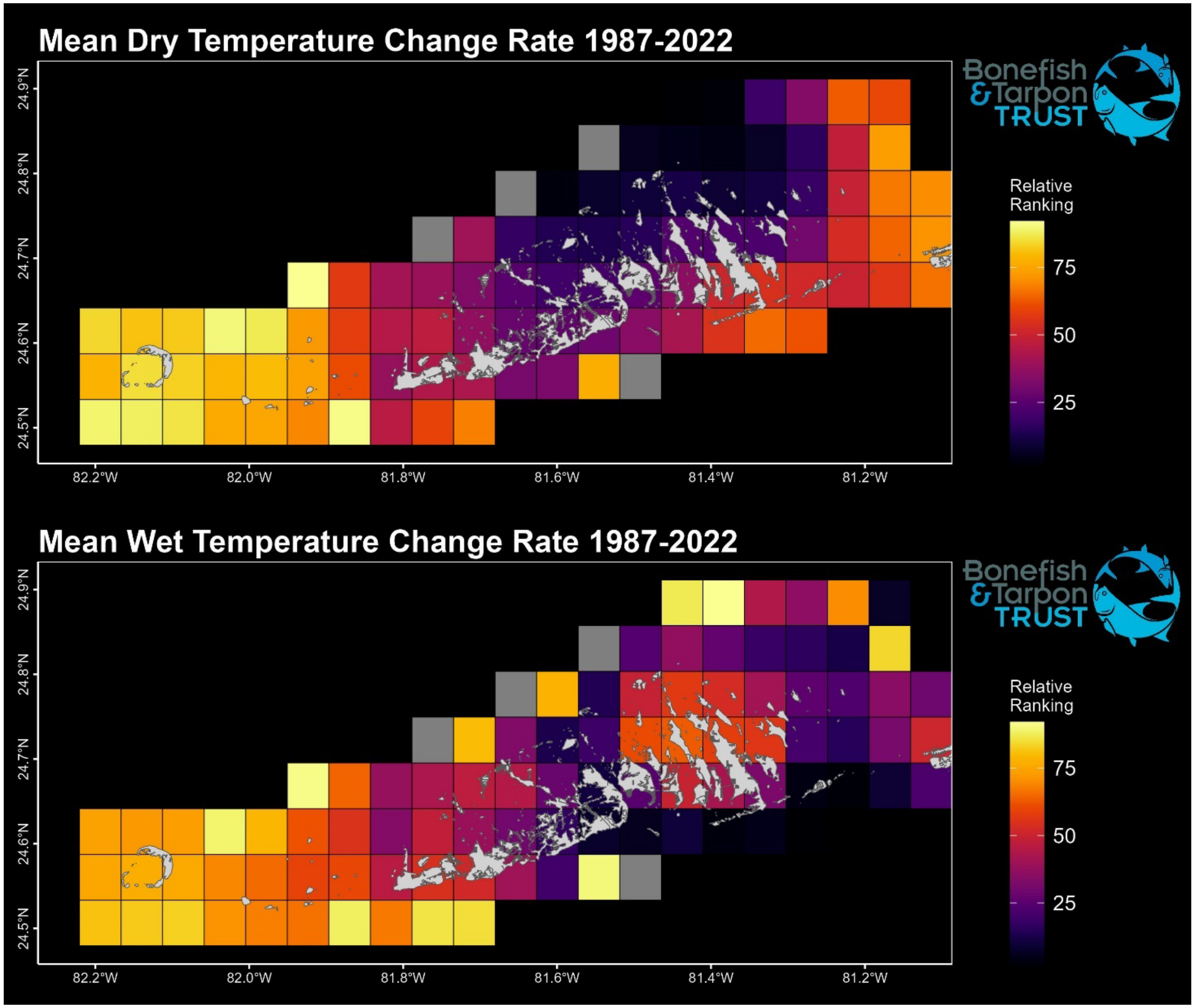
S5.4. Large Tarpon top-10 variables with the highest mean SHAP value for the gradient boosted regression model. Mean SHAP in noted along the Y-axis (ranked importance). SHAP values indicate the strength and directionality (negative/positive) of the response in relation to the range of values for a given variable. Points are colored to range of values for a given variable. Feature NA values, either by spatial or temporal absence in the dataset, are colored gray.



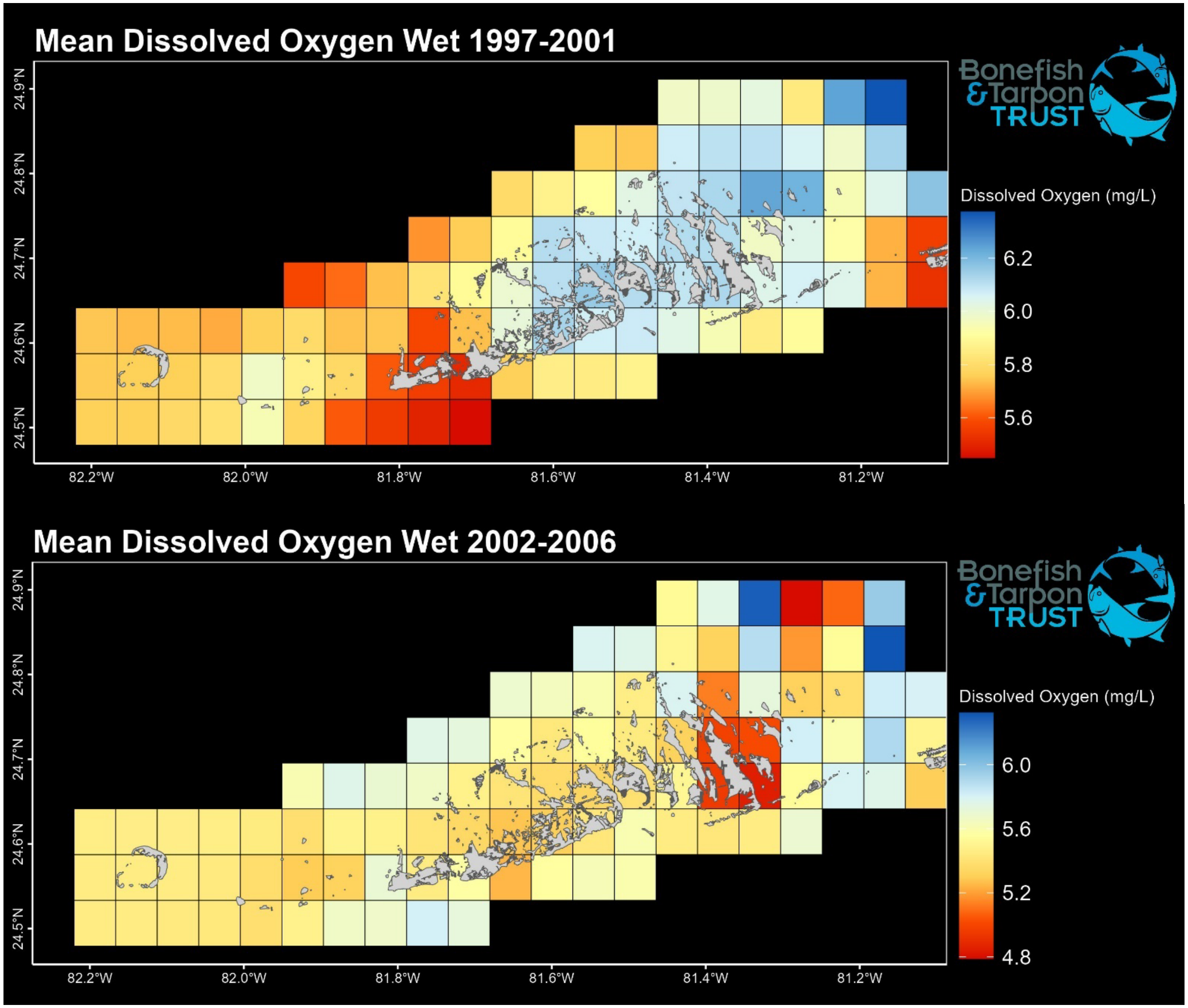
S5.5. Extra-large Tarpon top-10 variables with the highest mean SHAP value for the gradient boosted regression model. Mean SHAP in noted along the Y-axis (ranked importance). SHAP values indicate the strength and directionality (negative/positive) of the response in relation to the range of values for a given variable. Points are colored to range of values for a given variable. Feature NA values, either by spatial or temporal absence in the dataset, are colored gray.



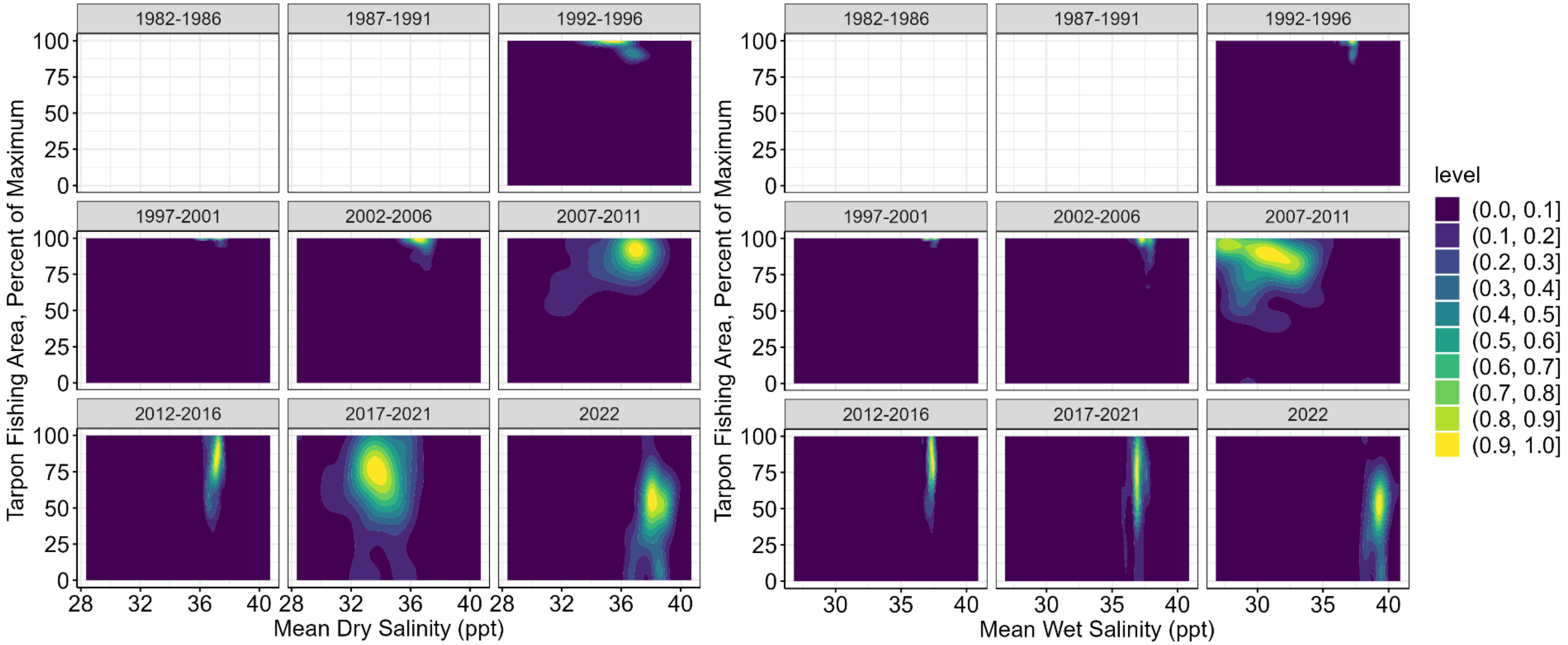
S5.6. Layup Tarpon top-10 variables with the highest mean SHAP value for the gradient boosted regression model. Mean SHAP in noted along the Y-axis (ranked importance). SHAP values indicate the strength and directionality (negative/positive) of the response in relation to the range of values for a given variable. Points are colored to range of values for a given variable. Feature NA values, either by spatial or temporal absence in the dataset, are colored gray.



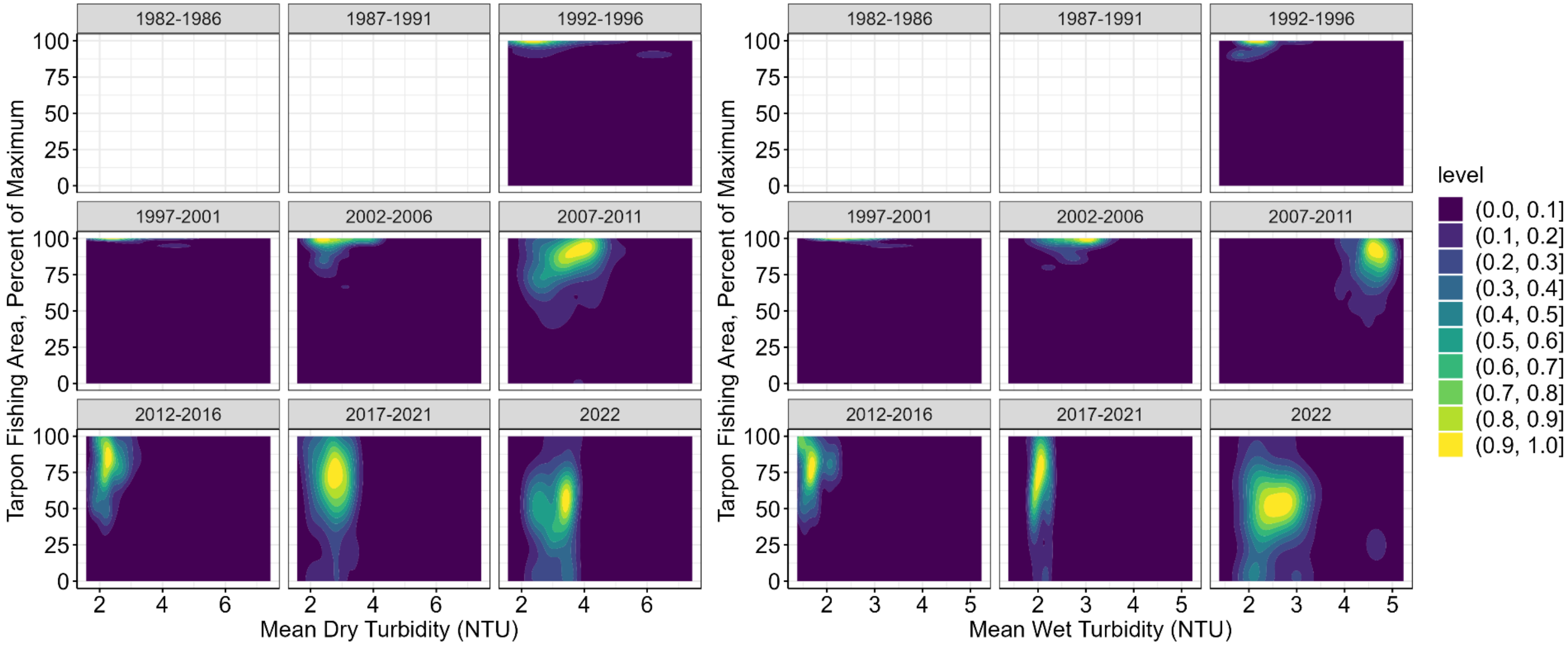
S6.1. Relative rankings of mean dry and wet season water temperature changes from 1987 to 2022. Raw dry/wet season water temperatures were kriged using Empirical Bayesian Kriging Regression, and summarized as within-grid as an average, and then a linear regression was fit to the timeseries to estimate a rate of change over time. Changes all trended towards warmer conditions. The magnitudes of changed were then ranked, with the highest rank equaling the highest rate of warming over time.



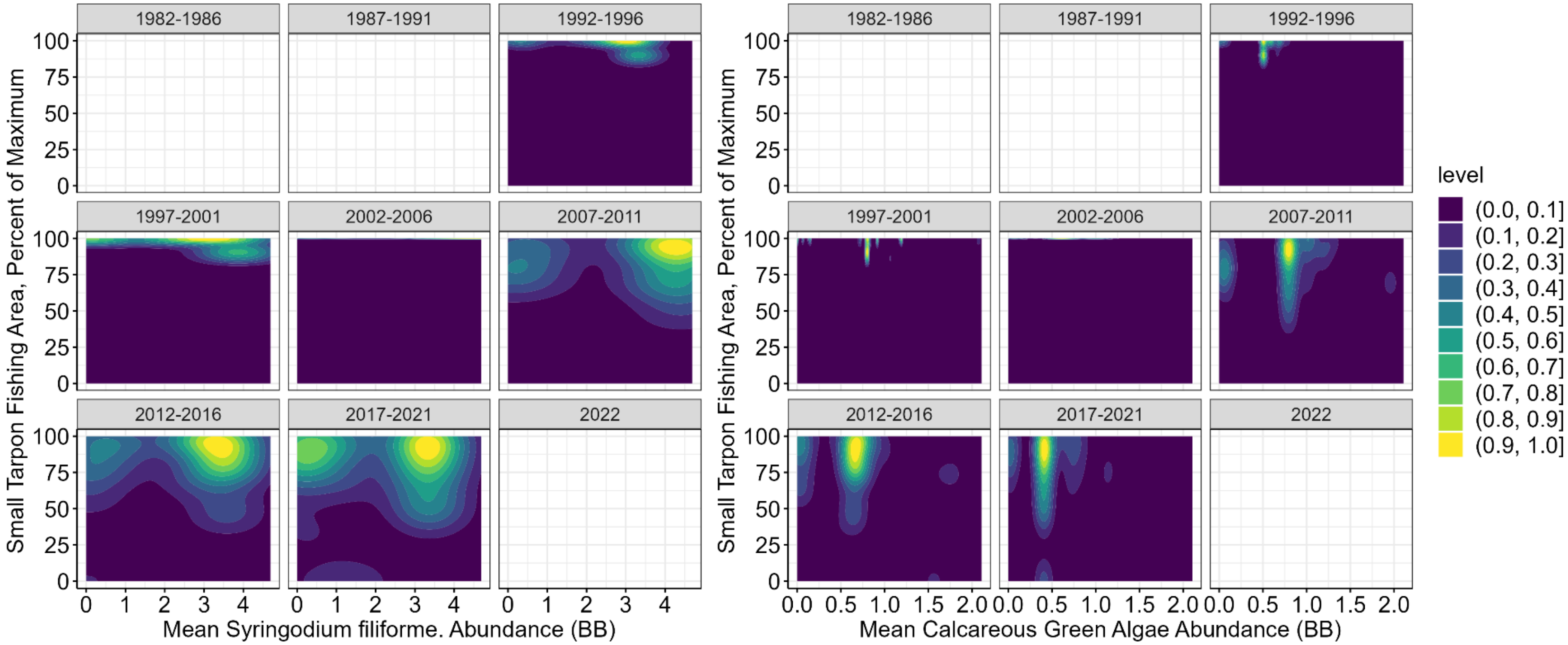
S6.2. Mean dissolved oxygen concentrations during the wet season for the 1997–2001 and 2002–2006 year-bins.



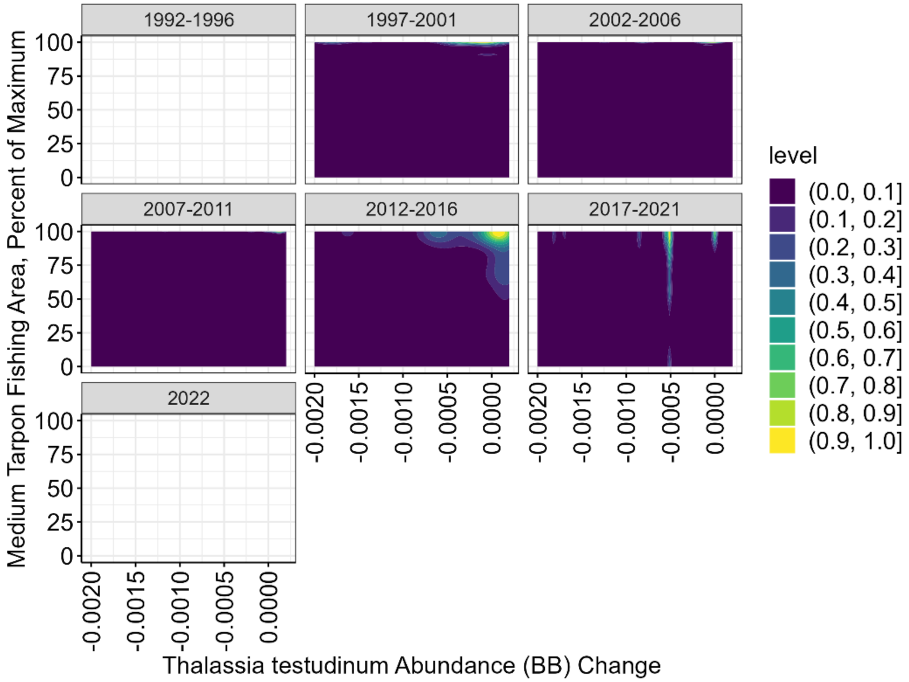
S7.1. Season mean salinity and Tarpon fishery area density plots through time. Reduced salinities can be observed 2007–2011 and 2017–2021.



S7.2. Season mean turbidity and Tarpon fishery area density plots through time. Increased turbidity can be observed 2007–2011 and 2022.



S7.3. Density plots for the relationship between small Tarpon fishing area and *Syringodium filiforme* and calcareous green algae abundance. Decreasing *Syringodium filiforme* and increasing calcareous green algae correlated with decreasing small Tarpon fishing area. Mean abundance rather than mean change is visualized for calcareous green algae due to scaling of linear regression change values.



S7.4. Density plots for the relationship between medium Tarpon fishing area and change in *Thalassia testudinum* abundance. Active reduction in *Thalassia testudinum* abundance correlated with decreasing medium Tarpon fishing area.