The Impact of Red Lionfish (Pterois miles and P. Volitans) at Little Cayman Island

Introduction to Data Science - Capstone Project

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1. Abstract

The purpose of this project is to determine if the introduction of the red lionfish (Pterois volitans) into the Tropical Western Atlantic has resulted in a significant decrease in biomass of native fish species. The red lionfish is native to the Indo Pacific region: tropical waters of the south-west Pacific Ocean and the Indian Ocean. Little Cayman Island was chosen as the location of interest as it is a popular scuba diving tourism destination. Loss of marine biodiversity will likely result in the decline of the health of the reef and subsequent reduction in tourism.

Data, consisting of over 162,800 fish surveys, was provided by REEF (Reef Environmental Education Foundation), a non-profit organization based in Key Largo, Florida. The surveys were conducted by scuba divers (both novice and expert surveyors) from 1994 to present day. This project focuses on species with an adequate number of surveys and excludes non-fish species such as sharks, turtles, eels and rays.

2. Background

Invasive species have been identified in countries all over the world. Often the invasion results in disastrous consequences for native species. Invasive species can be any living organism including mammals, plants, birds and fish. The common rabbit was once native to Southern Europe and North Africa. It has now spread to almost every continent on Earth. Kudzu (a vine), the European starling, the cane toad and water hyacinth are all invasive species. Asian carp native to Eastern Russia and China have invaded North America and Europe. Zebra Mussels native to the Black and Caspian Seas have invaded Russia, Europe and North America.

Recently, the red lionfish has become an invasive species in the Tropical Western Atlantic. The introduction of the red lionfish into these waters off of the coast of Florida is believed to have occurred in the mid 1980s via the aquarium trade[1]. The lionfish has since spread north along the east coast of the United States, into the Gulf of Mexico, south through the Caribbean Sea and is currently expanding southward along the east coast of South America[1].

Numerous studies have indicated a lack of natural predators in these waters, voracious appetites, a short time to reach sexual maturity and the ability to breed very rapidly[1]. One study of nine coral reefs off New Providence Island, Bahamas reported a 65% decline in the biomass of the lionfish's 42 Atlantic prey over a period of two years[2]. Lionfish reportedly have a large list of prey including several members of the wrasse family, lizardfish, filefish, cardinal fish, many members of the chromis, basslet and goby families, parrotfish and occasionally various species of shrimp[3].

Figure 1. A Red Lionfish (www.reef.org)

3. Study Area

The Cayman Islands (Grand Cayman, Little Cayman and Cayman Brac) are located in the Northwest Caribbean Sea. This British overseas territory receives income from the tourism industry, with a major contribution from scuba diving activities. Scuba diving is dependent upon healthy reefs and abundant aquatic life. A significant decline in aquatic life and coral would likely result in a drastic reduction in scuba activities and income for the territory. This scenario could adversely affect island nations or countries with coastline.

Figure 2. Region 5 of the Tropical Western Atlantic Consisting of the Northwest Caribbean (www.reef.org)

Figure 3. Little Cayman Island in the Northwest Caribbean (Google Maps)

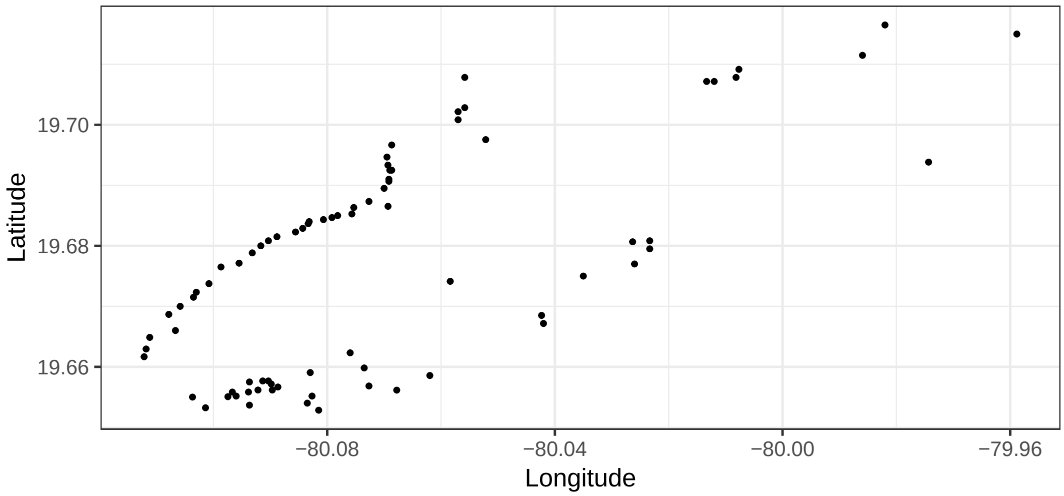


Figure 4. A Coordinate Map of the Dive Sites at Little Cayman Island

Notice in Figure 4 that many of the dive sites are concentrated at the West end of the island. Due to the proximity of so many sites, the analysis will concentrate on all sites as one large area. Fish are not interested in the boundaries we humans create. Speaking from experience, it is easy to make a dive from a dive boat and venture into the next dive site.

4. The Data

4.1 Details of the Data

Data for the REEF ('www.reef.org') fish surveys was provided by the Director of Science of REEF, Christy Pattengill-Semmens, Ph.D. REEF's mission is "to protect biodiversity and ocean life by actively engaging and inspiring the public through citizen science, education, and partnerships with the scientific community."

Three data files were provided. The first file consisted of actual survey data at Little Cayman from 1994 to April of 2018. Survey data includes the date of the survey, water temperatures, depths of the dive (maximum and average), visibility, species name and ID, the name of the dive site and the relative abundance of each species observed. Over 162,800 surveys have been conducted at Little Cayman. The relative abundance is categorized as follows. An abundance of 1 indicates 1 individual of a particular species is observed. An abundance of 2 indicates from 2 to 10 individuals, an abundance of 3 indicates 11 to 100 individuals and an abundance of 4 indicates more than 100 individuals were observed. The values of abundance are used in this study.

The second data file consisted of fish and non-fish (sharks, eels, rays, etc.) species data, to include the name of the family that each species belongs to. This list of 933 species represents the known species present in the Tropical Western Atlantic zone, which includes The Gulf of Mexico and the Caribbean Sea. Over 350 of these species have been observed and recorded in surveys at Little Cayman. The third file consisted of the names of the approximately 90 dive sites at Little Cayman, a geographic code representing each dive site (also found in the survey file) and latitude and longitude coordinates.

4.2 Limitations

The data set does not include information on predators and prey, in other words who eats whom, or feeding habits: piscivores, planktivores and herbivores. In addition, although the maximum depth and average depth of each dive is recorded, the specific depth at which a lionfish was observed was not recorded. Consequently, we cannot study the range of depths that lionfish are observed, although lionfish reportedly inhabit all marine habitat types down to 300m (1000 ft)[1].

4.3 Wrangling

A minimum amount of wrangling was necessary in order to prepare the data set. The three data files were imported and minor changes were made to the column headers. Latitude and longitude coordinates were converted from degrees and minutes to degrees. An abundance of zero was recorded on two rows of the data set, likely due to a data entry error; these rows were consequently deleted. The column for Family_ID in the survey data file was deleted, as it was redundant. The Family_ID column was present in the species data file.

4.4 Non-Fish Families

Sixty-seven (67) families were present in the species data file. Fourteen (14) were non-fish species, consisting of sharks, eels, rays, turtles, and a dolphin species. These families were removed from the data set.

5. Lionfish Exploration

The red lionfish, also known as the common lionfish, is a member of the scorpionfish family. Five members of the scorpionfish family have been observed at Little Cayman: mushroom, plumed, reef and spotted scorpionfish and the invasive red lionfish. Lionfish have been observed at 53 dive sites. The first recorded lionfish sighting at Little Cayman occurred on February 17, 2009.

Figure 5 shows the lionfish presence at all dive sites at Little Cayman. A smooth curve with corresponding confidence interval and a trendline were added to the plot. The negative slope of the trendline suggests a slight decrease in the numbers of lionfish in the nine years since the first recorded lionfish observation.

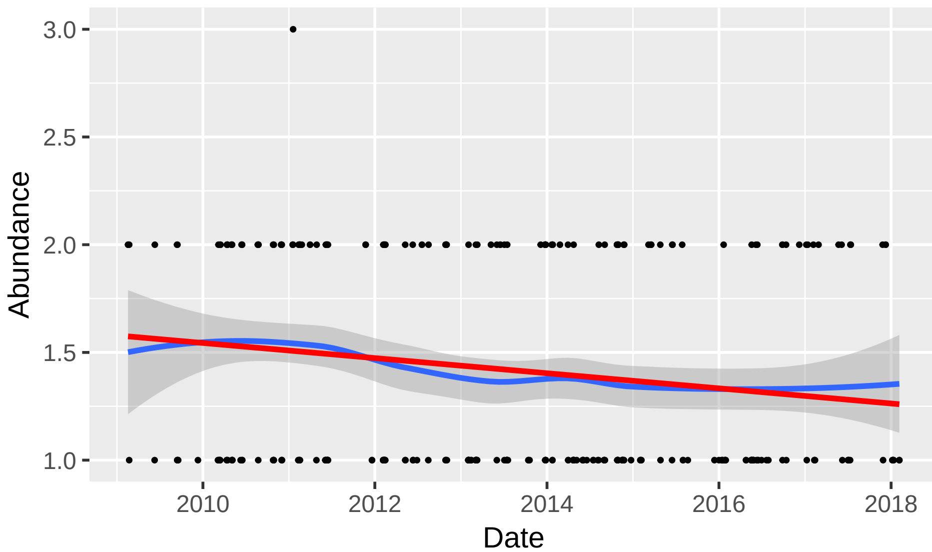


Figure 5: Abundance of Lionfish at Little Cayman

6. Fish Family Exploration

6.1 All Species

Figure 6 shows the abundance vs. date of all species (including lionfish) in all families at Little Cayman for the 24 years of data.

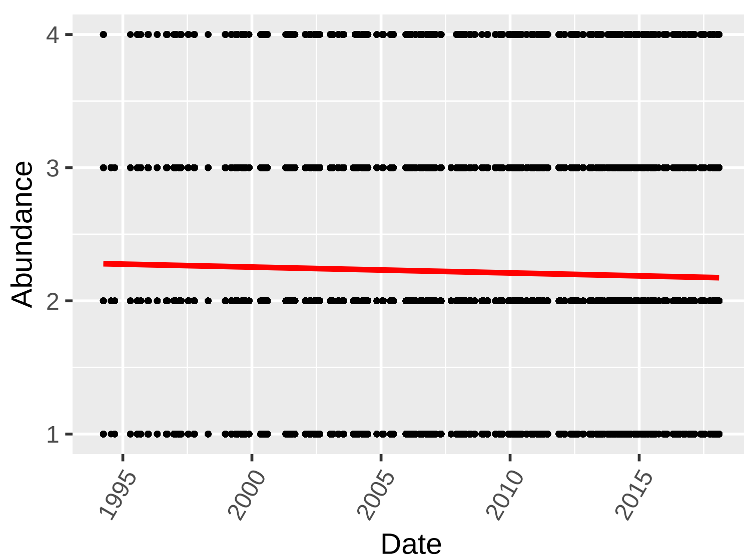


Figure 6: Abundance of All Fish Species at Little Cayman

February 17, 2009 was used as the date to separate the data into two groups: before the lionfish arrived and after. A plot of the abundance vs. date of all species was generated for each group and a trendline was added to each plot. The negative slope of the trendline in the plot of the post-lionfish time frame (Figure 7) suggests a slight decrease in the number of all fish species.

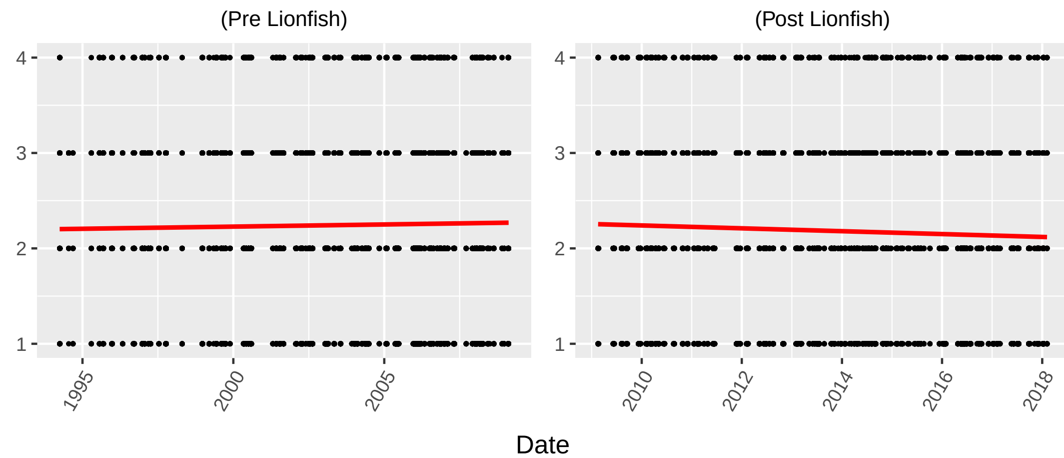


Figure 7: Relative Abundance of All Species Pre- and Post-Lionfish

The final steps of preparing the data frame consisted of removing various species. First, the red lionfish was removed from the data set. Next, the total number of surveys of all species in each family was determined. Families with fewer than 210 surveys for the entire 24-year period were removed from the data set.

6.2 Preliminary Family Exploration

In order to explore the general trend in relative abundance of each fish family, I generated plots of each family for the entire 24-year period. The majority of the trendlines in Figures 8 and 9 appear to have a negative slope indicating the need to investigate each family further. A negative slope is indicative of a decline in numbers.

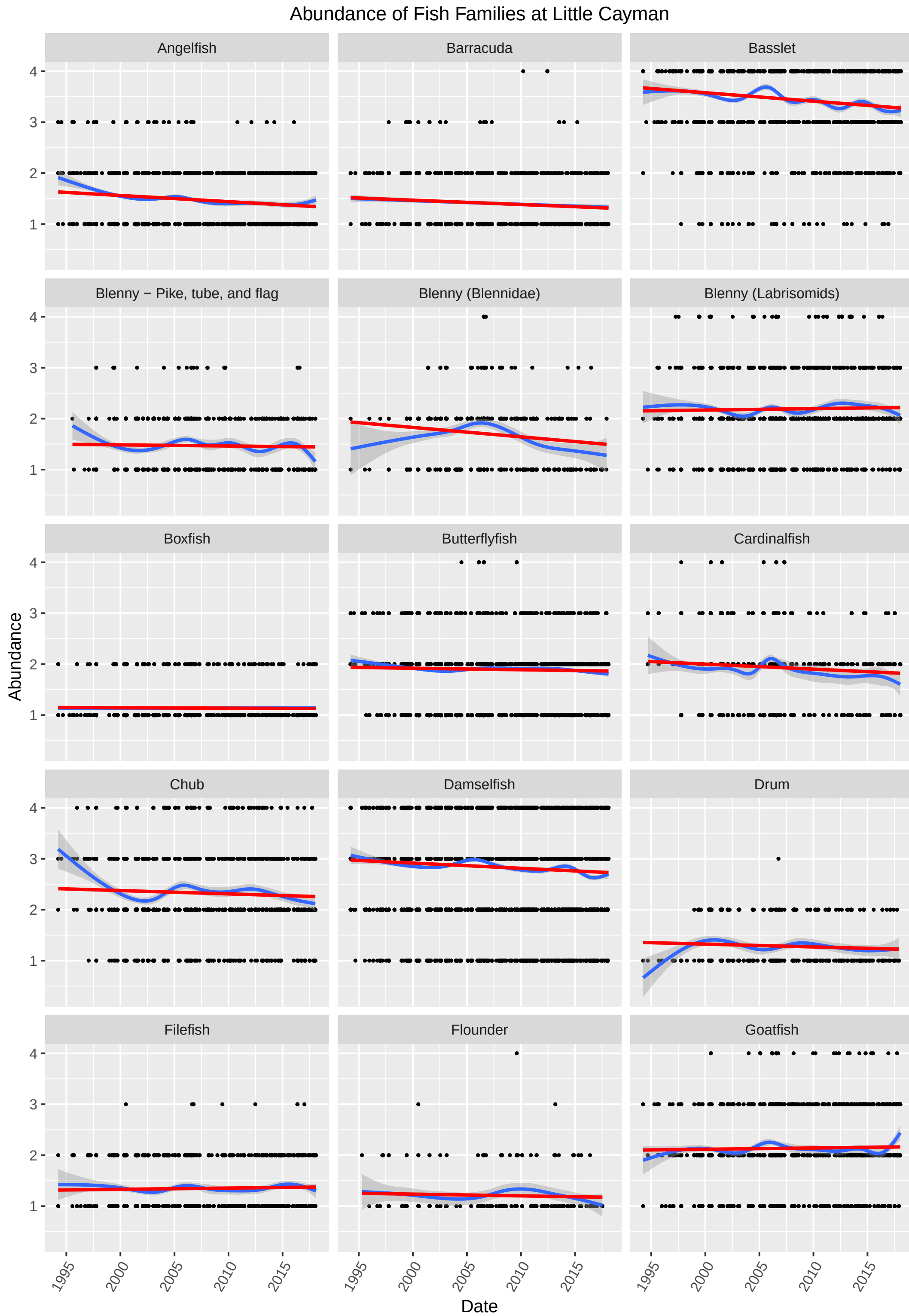


Figure 8: Abundance of Families 1

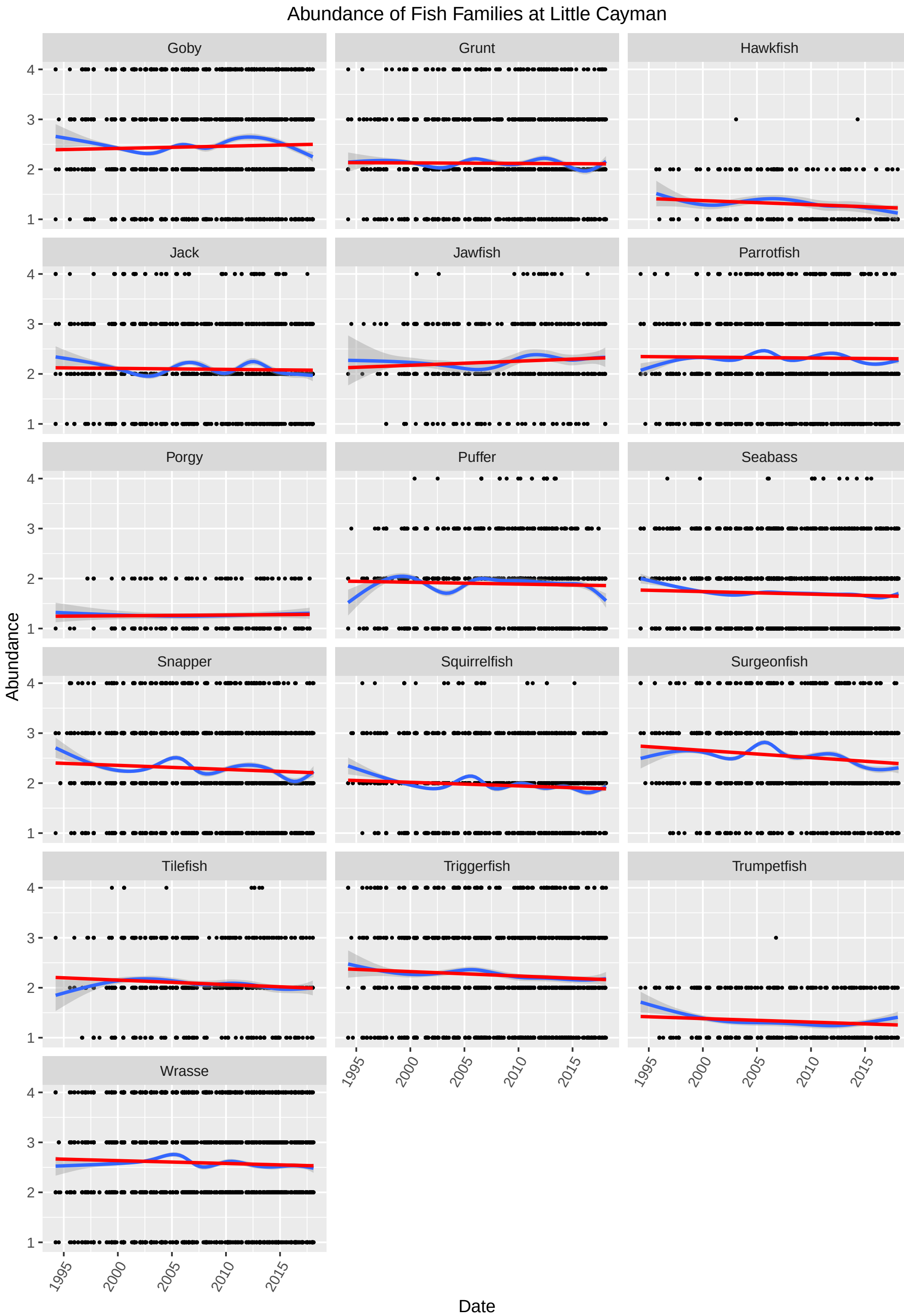
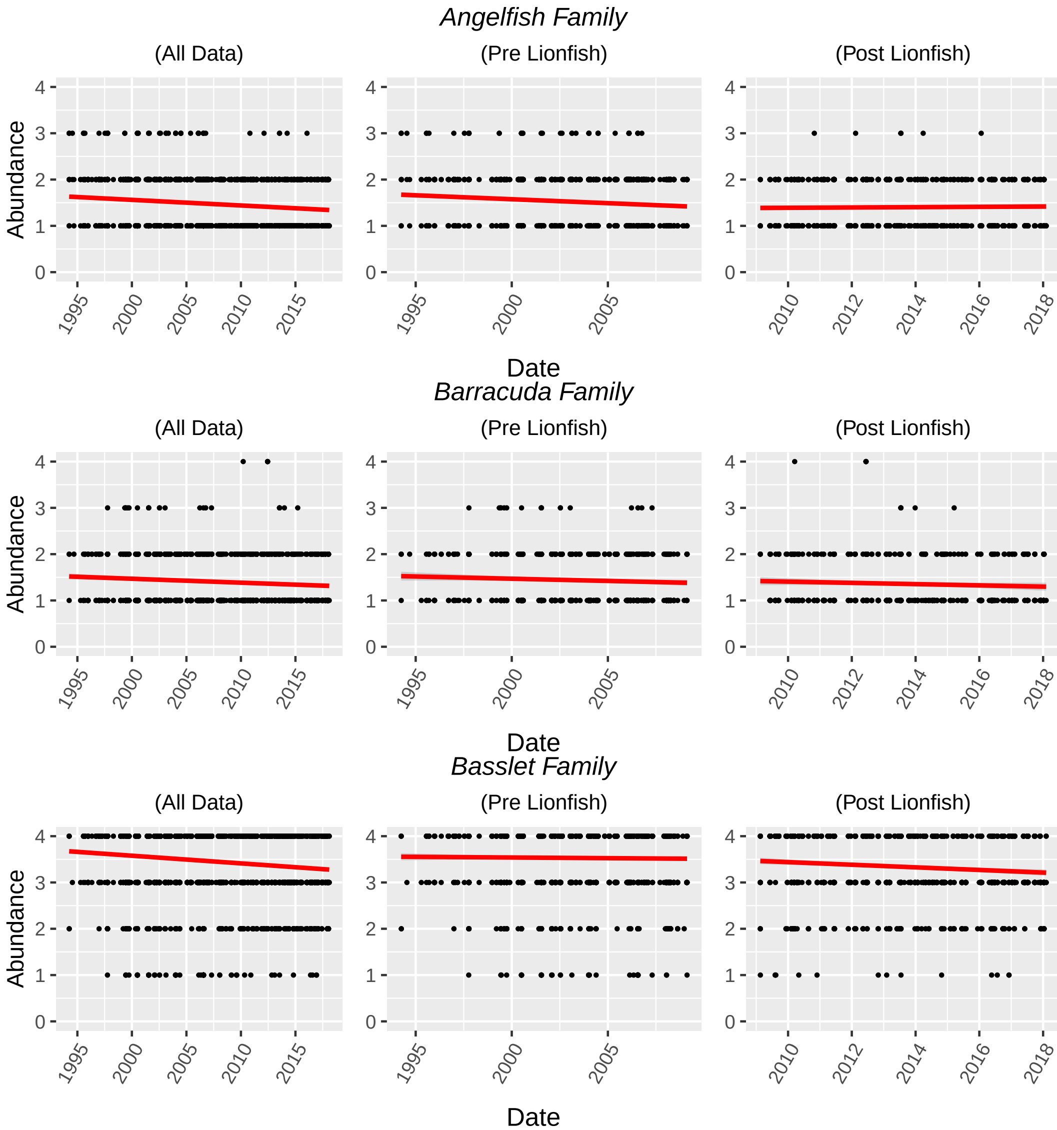
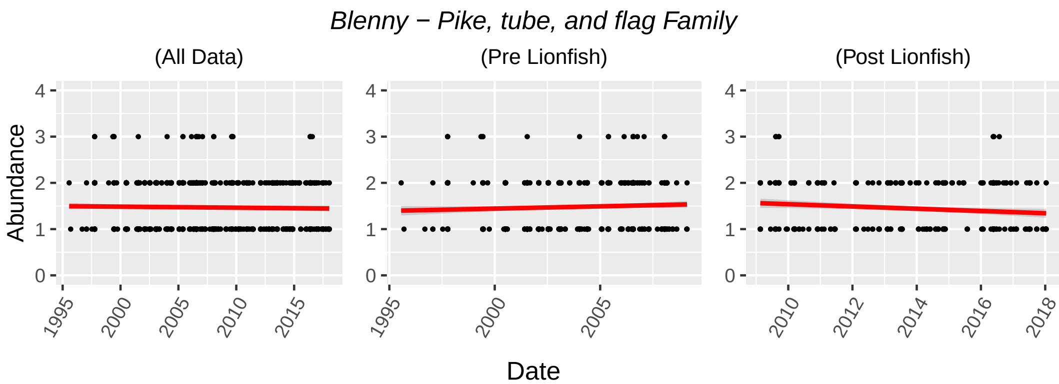


Figure 9: Abundance of Families 2

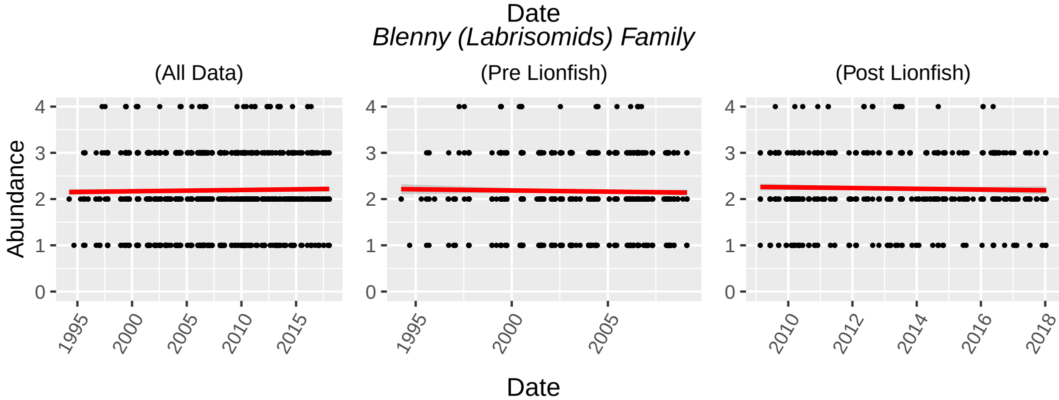
6.3 Family Exploration Before and After Lionfish Invasion

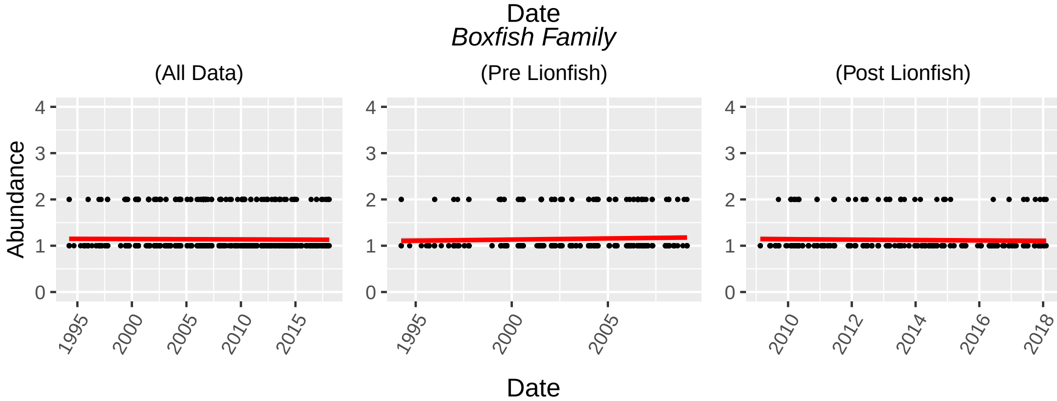
To investigate further, I generated three plots for each family side-by-side (Figure 10). The plot on the left shows the abundance vs. date of all species in the family as seen in Figures 8 and 9. The center plot shows the data from when the surveys began (1994-03-27) to when the first lionfish sighting occurred (2009-02-17). The plot on the right shows the data from the first lionfish sighting to the date when the data was provided (2018-04-09).

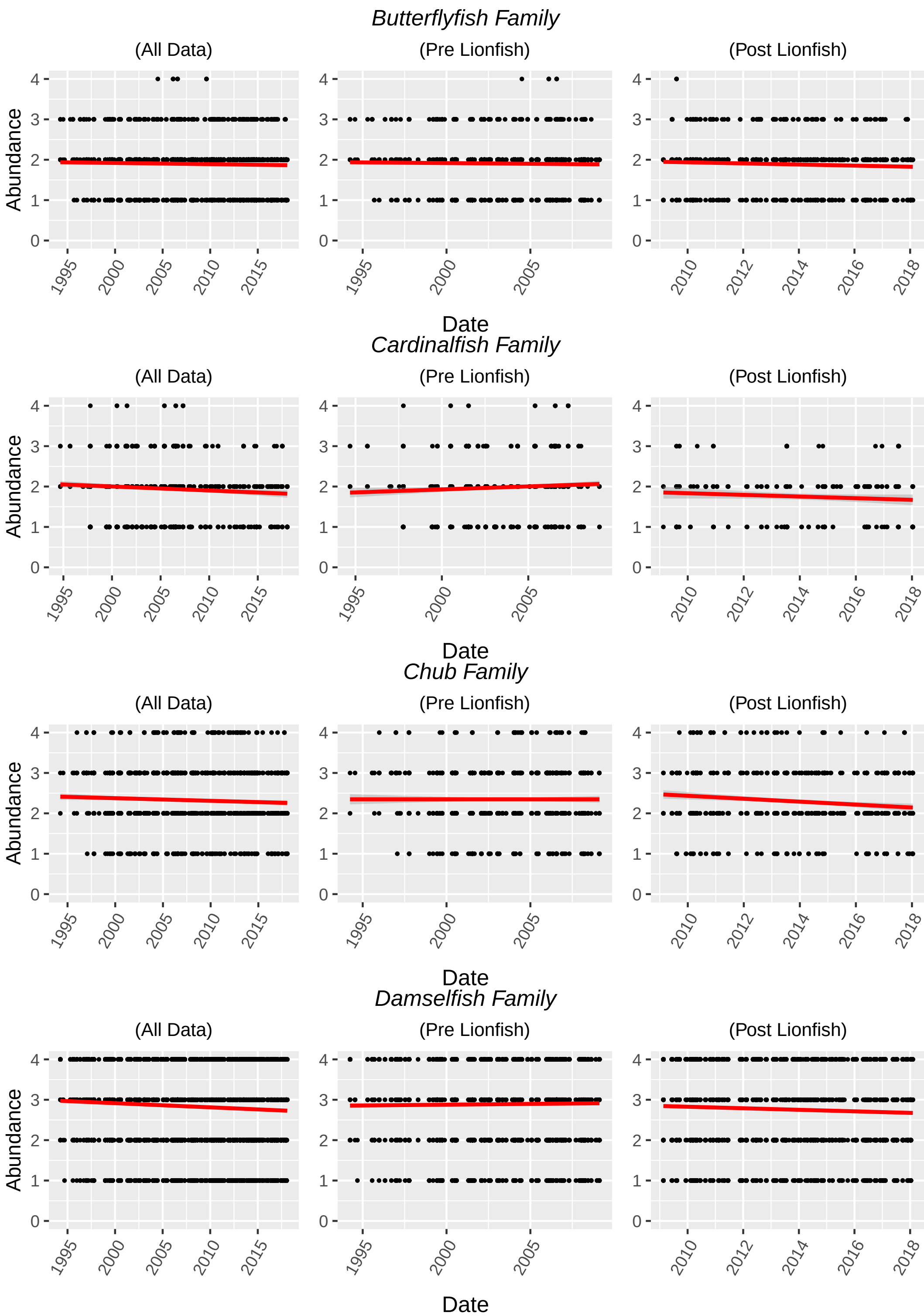


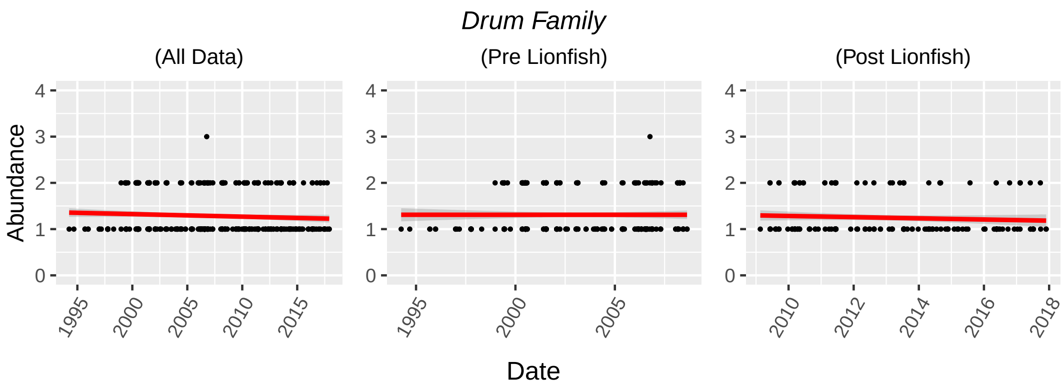

Blenny − Pike, tube, and flag Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date

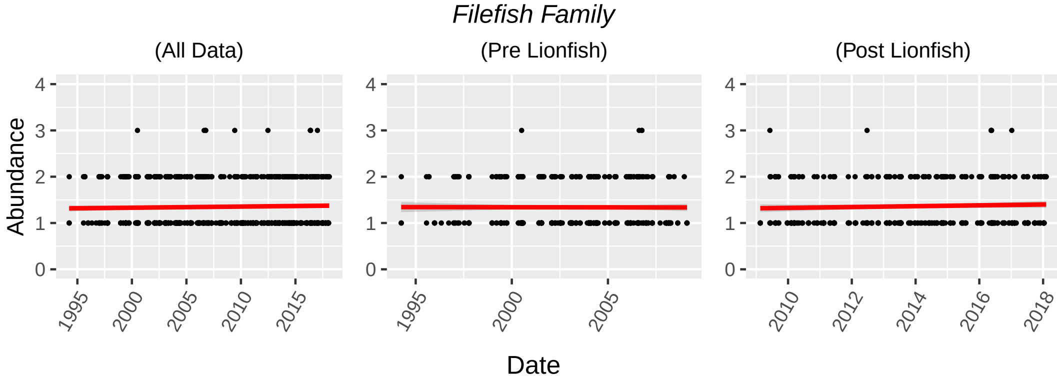

Blenny (Blennidae) Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date

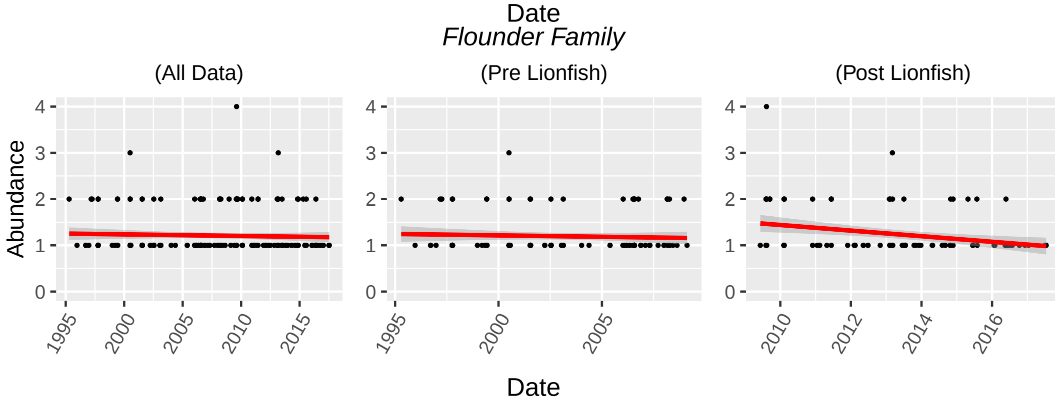

Blenny (Labrisomids) Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date

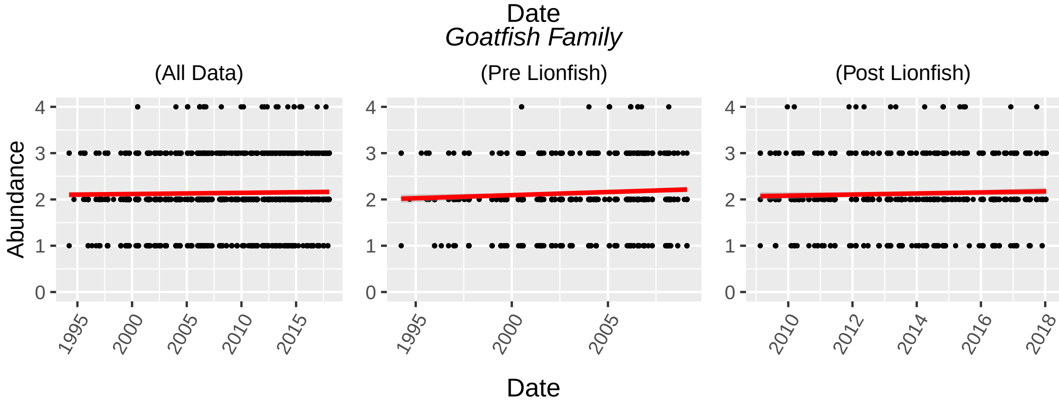

Boxfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date

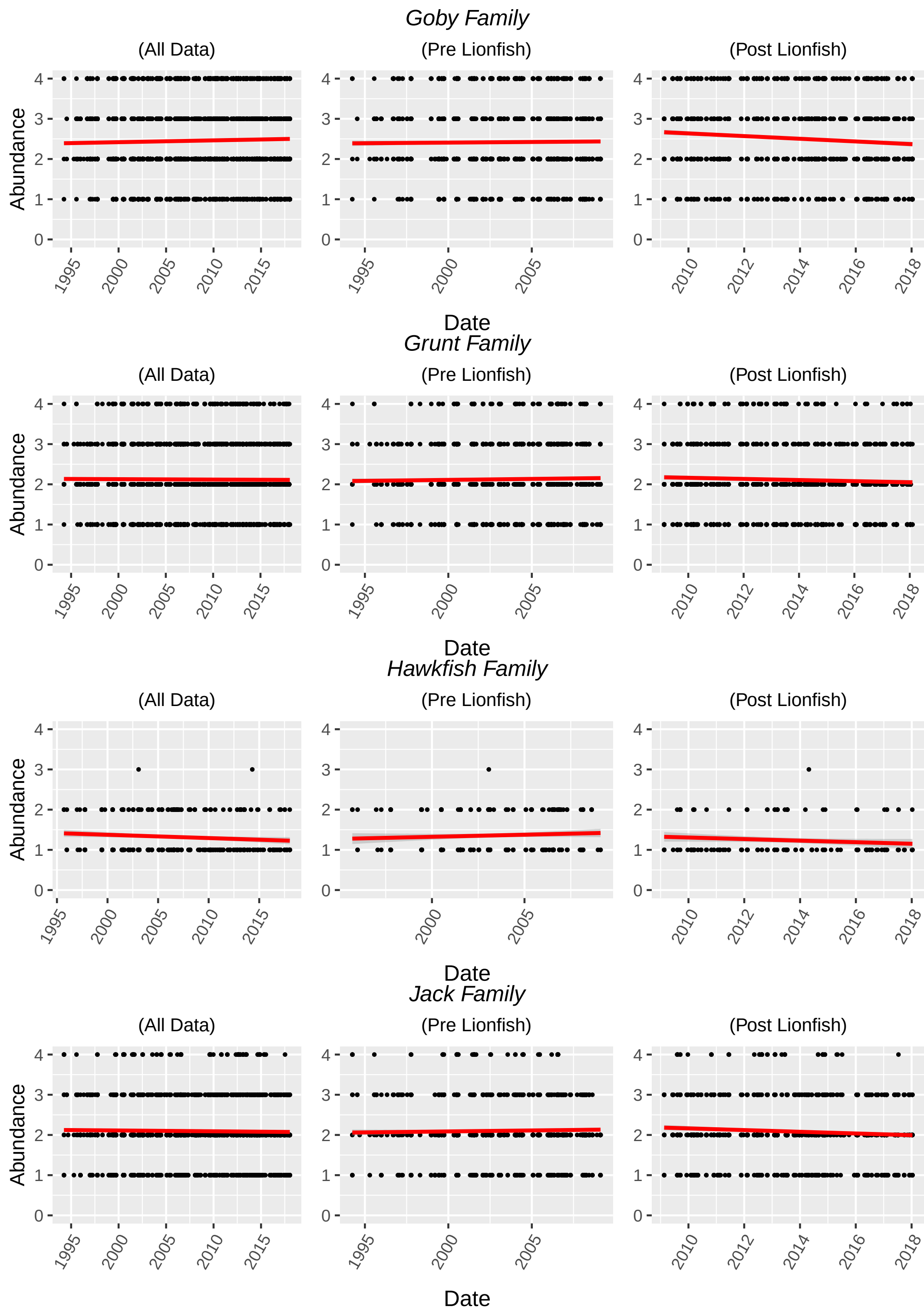

Butterflyfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date
Cardinalfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date
Chub Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date
Damselfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date

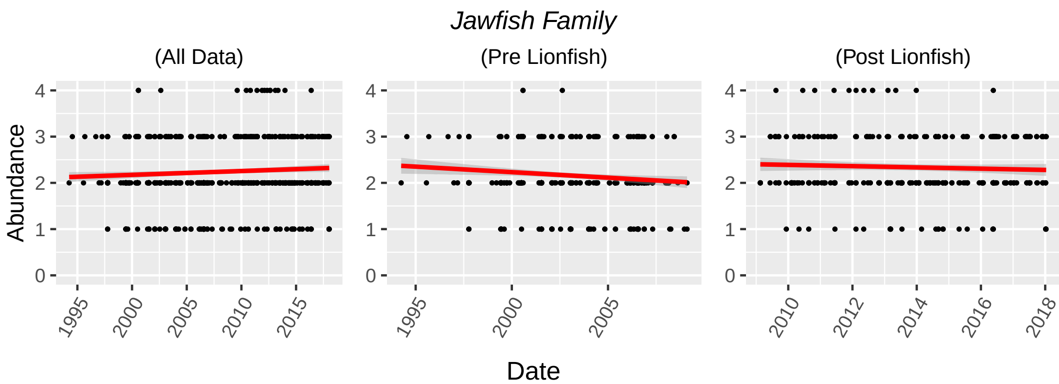

Drum Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
0
1
2
3
4
1995
2000
2005
2010
2015
2012
2014
2016
2018
Date

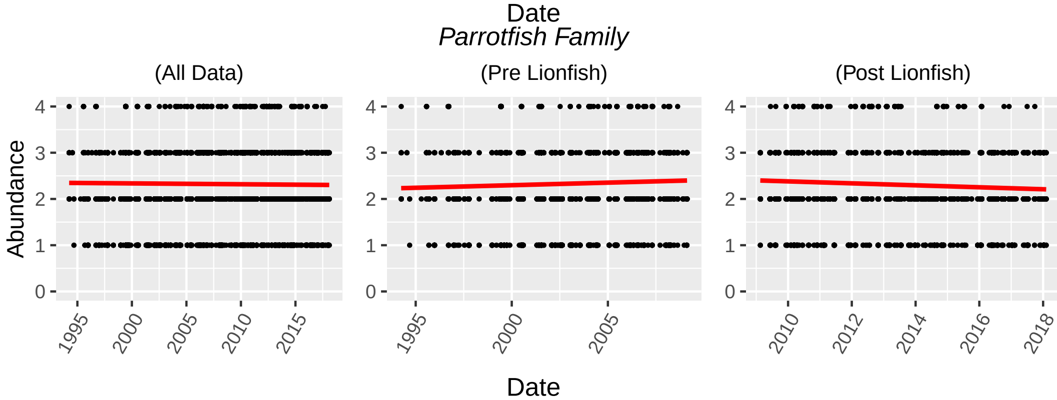

Filefish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
0
1
2
3
4
1995
2000
2005
2010
2015
2012
2014
2016
2018
Date

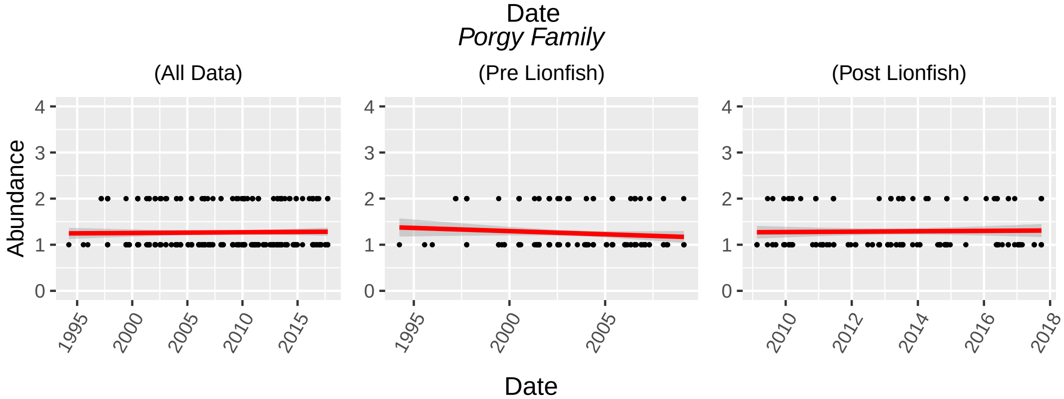

Flounder Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
0
1
2
3
4
1995
2000
2005
2010
2015
2012
2014
2016
Date

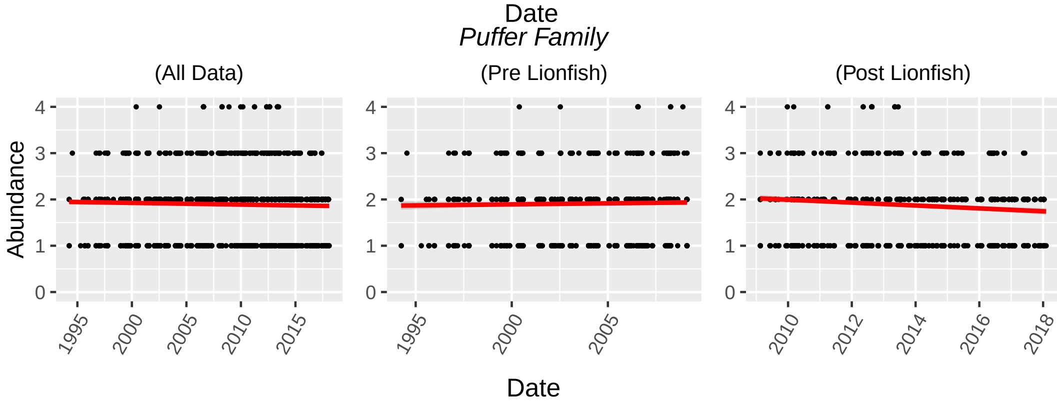

Goatfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
0
1
2
3
4
1995
2000
2005
2010
2015
2012
2014
2016
2018
Date

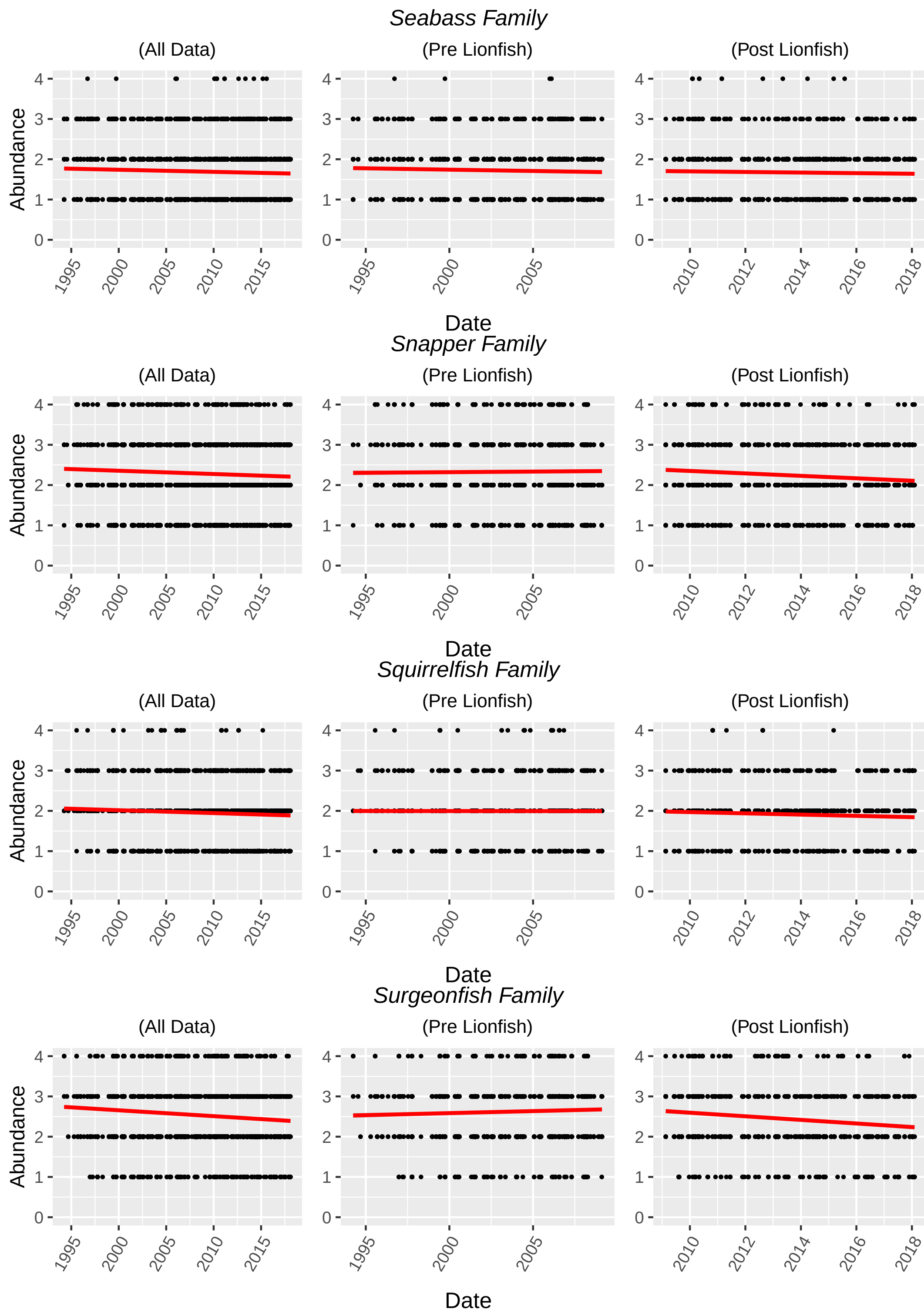

Goby Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date
Grunt Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date
Hawkfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date
Jack Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date


Jawfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
0
1
2
3
4
1995
2000
2005
2010
2015
2012
2014
2016
2018
Date


Parrotfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
0
1
2
3
4
1995
2000
2005
2010
2015
2012
2014
2016
2018
Date


Porgy Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
0
1
2
3
4
1995
2000
2005
2010
2015
2012
2014
2016
2018
Date


Puffer Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
0
1
2
3
4
1995
2000
2005
2010
2015
2012
2014
2016
2018
Date


Seabass Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date
Snapper Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date
Squirrelfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date
Surgeonfish Family
(All Data)
(Pre Lionfish)
(Post Lionfish)
Abundance
Date

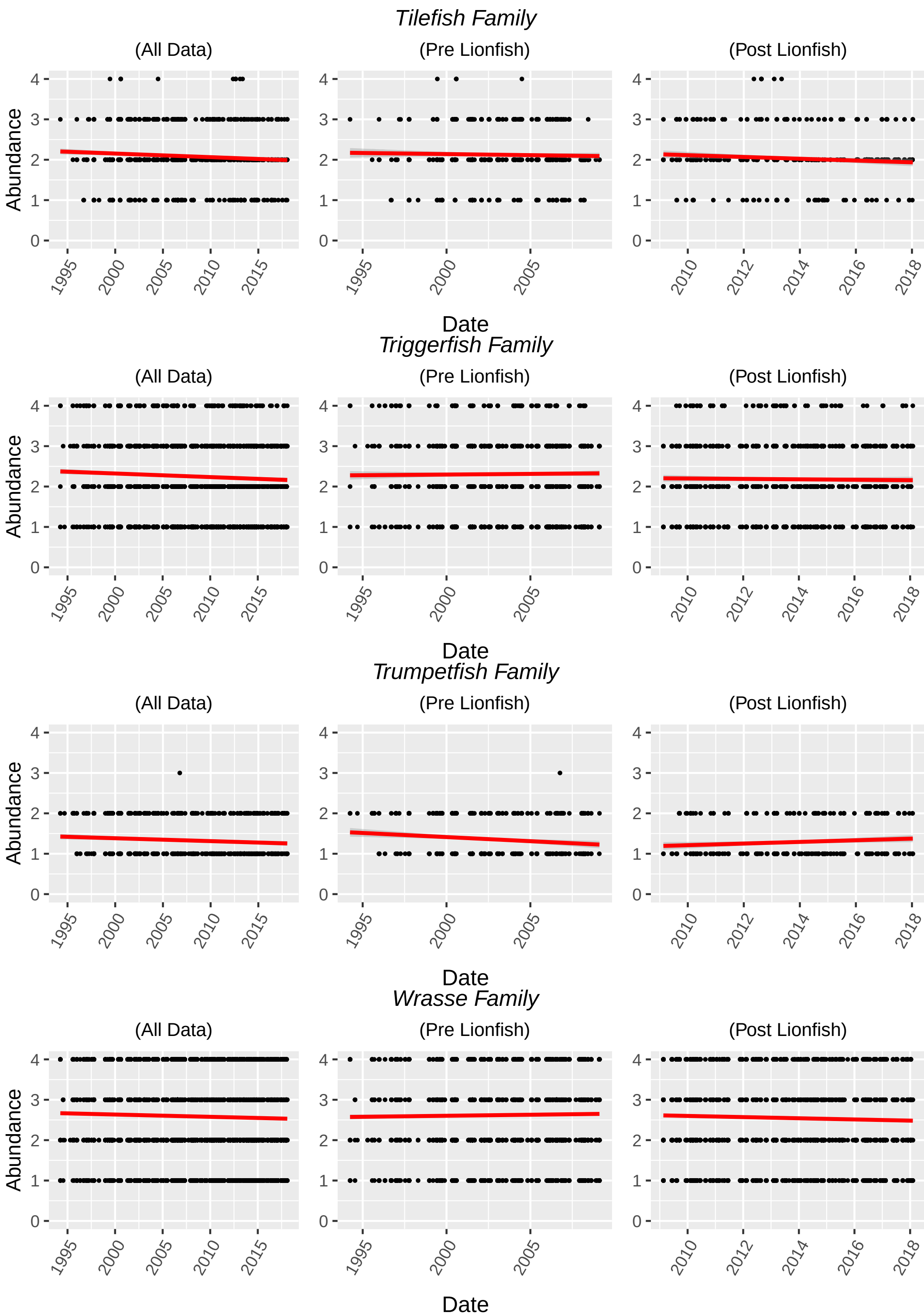


Figure 10: Abundance of Families Pre- and Post-Lionfish

7. Density Comparison

The next step was to conduct a density comparison on the slopes of the trendlines in the plots above. The slopes of the trendlines in the center (pre-lionfish) and right (post-lionfish) plots above were determined using linear regression (lm() function in R). These values were added to a corresponding vector (pre_slope and post_slope) and these two vectors were used to generate a density plot for the two time periods. Figure 11 shows the two density curves with blue corresponding to pre-lionfish data and orange corresponding to post-lionfish data.

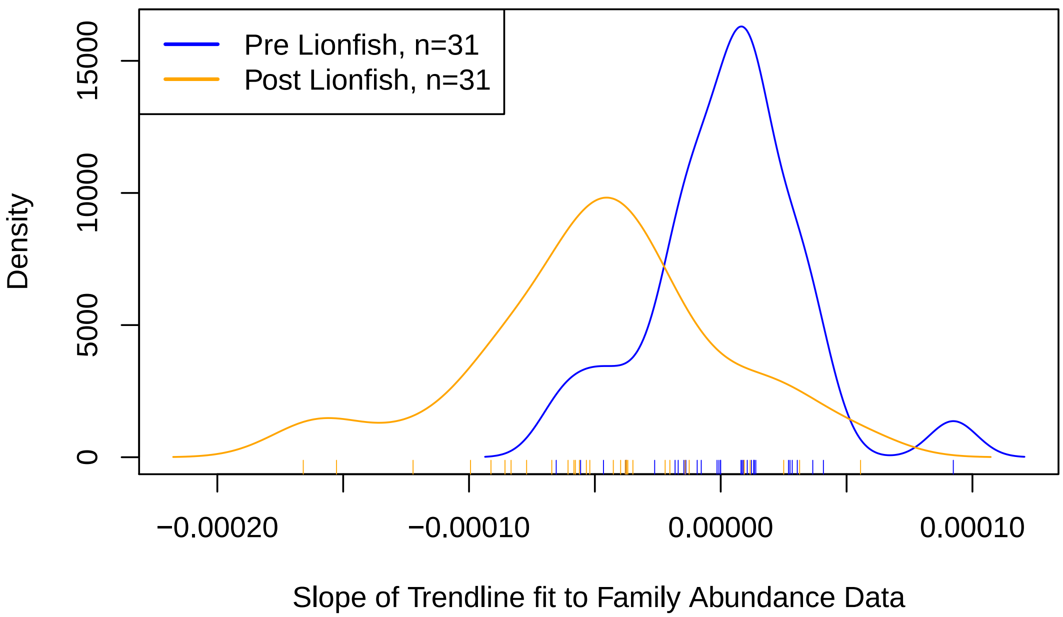


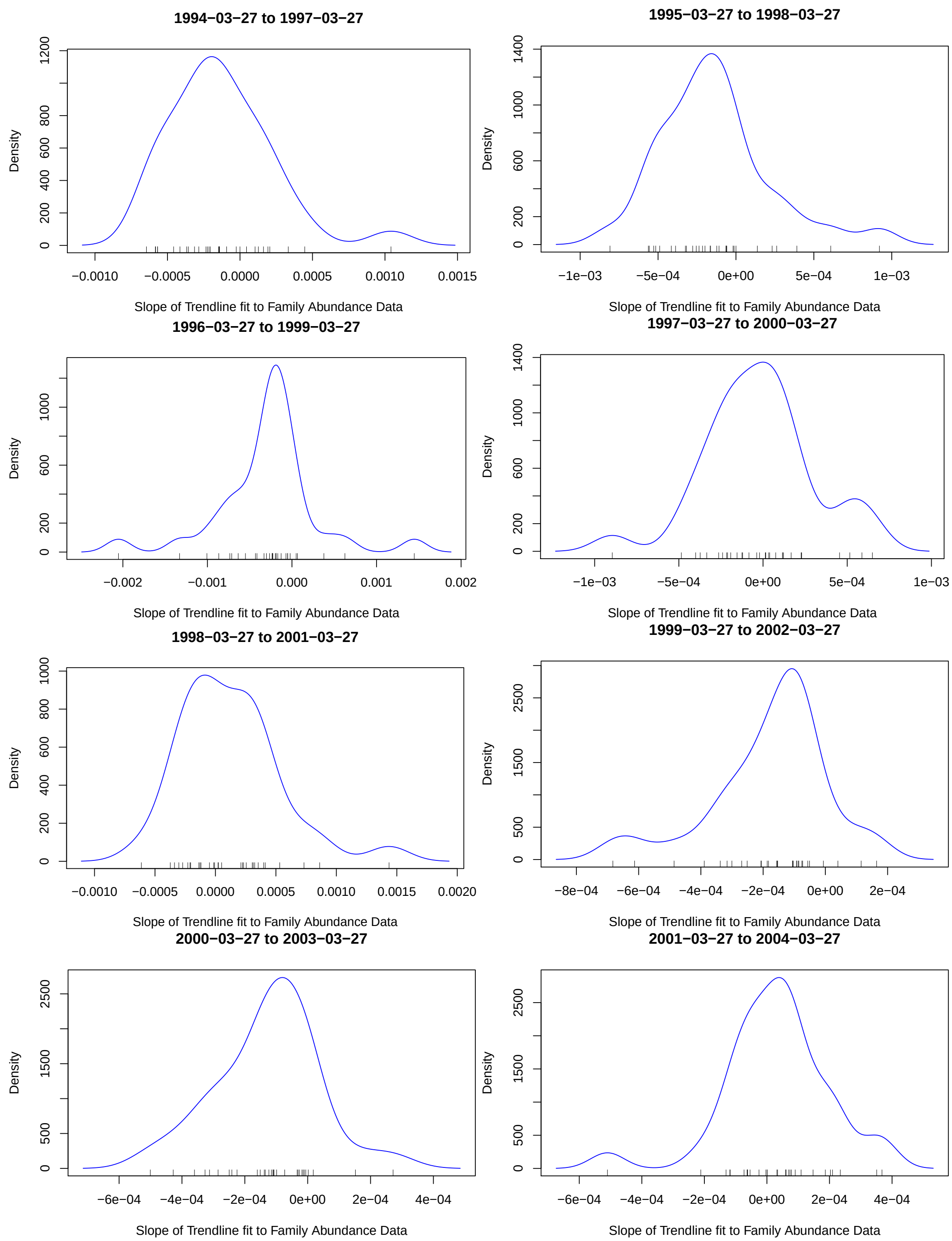
Figure 11: Density Plot Comparison Pre- and Post-Lionfish

As indicated in Figure 11, the pre-lionfish data shows a concentration of slopes higher than the slopes of the post-lionfish data. This indicates that the abundance of fish has decreased slightly since the arrival of lionfish.

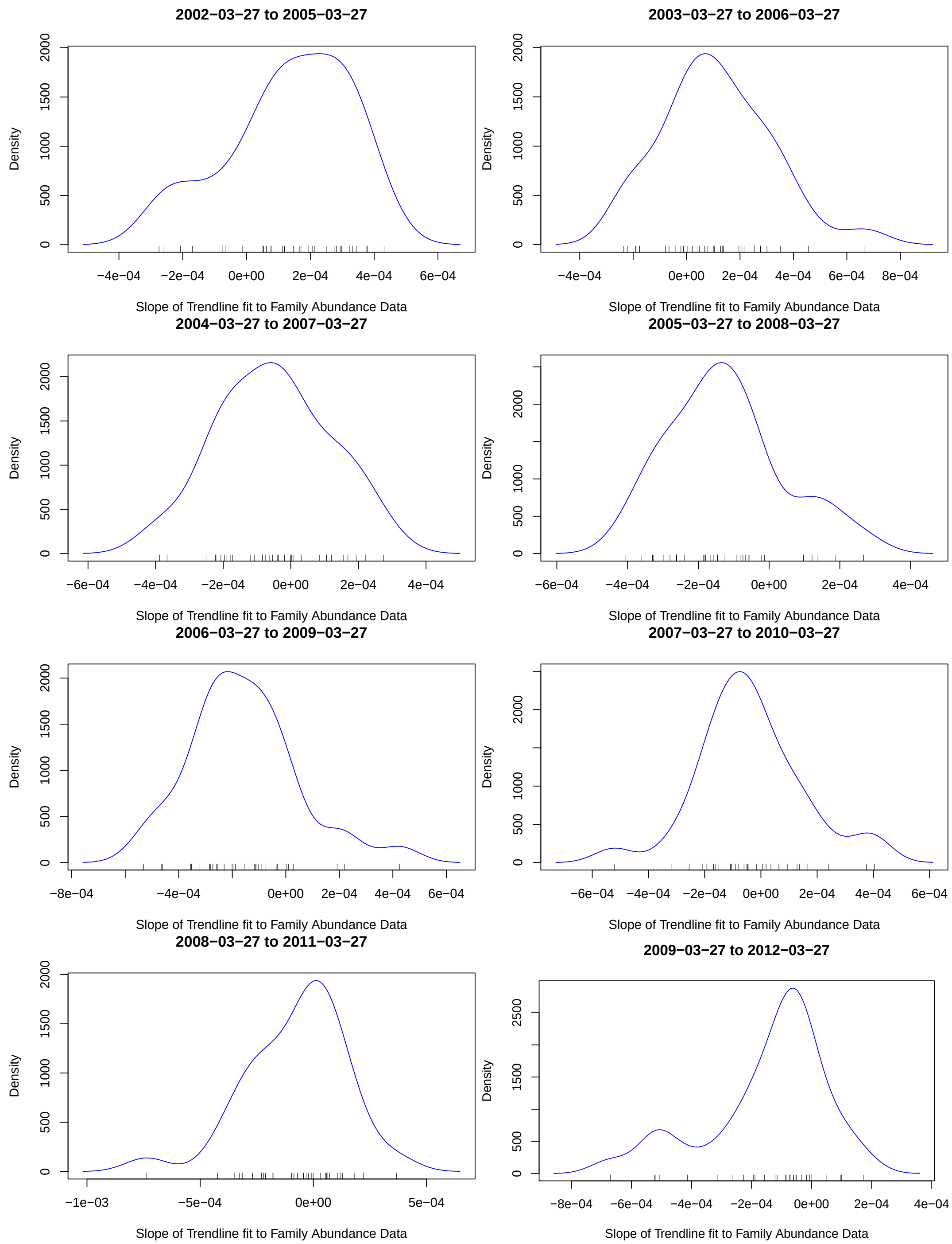
8. Moving Window Mean Slope

The next step of the analysis consisted of using a moving window to study the survey data of each family. The date of the first survey recorded is 27 March 1994 and the date of the last survey available is 09 April 2018. Survey windows of 3, 4, 5 and 6 years were studied. The start date of each window was chosen as March 27 and the survey window was shifted by one year for each consecutive window. Partial windows at the end of the 24-year period were not used.

Linear regression was again used to identify trendlines in the abundance versus date data and to calculate the slope of each trendline. Density plots of slopes were generated for each window, in the same manor as the pre-lionfish and post-lionfish data above. The density plots for the 3-year moving window are shown in Figure 12.



1994−03−27 to 1997−03−27
Density
0
200
400
600
800
1200
−0.0010
−0.0005
0.0000
0.0005
0.0010
0.0015
Slope of Trendline fit to Family Abundance Data
1995−03−27 to 1998−03−27
Density
0
200
600
1000
1400
−1e−03
−5e−04
0e+00
5e−04
1e−03
Slope of Trendline fit to Family Abundance Data
1996−03−27 to 1999−03−27
Density
0
200
600
1000
−0.002
−0.001
0.000
0.001
0.002
Slope of Trendline fit to Family Abundance Data
1997−03−27 to 2000−03−27
Density
0
200
600
1000
1400
−1e−03
−5e−04
0e+00
5e−04
1e−03
Slope of Trendline fit to Family Abundance Data
1998−03−27 to 2001−03−27
Density
0
200
400
600
800
1000
−0.0010
−0.0005
0.0000
0.0005
0.0010
0.0015
0.0020
Slope of Trendline fit to Family Abundance Data
1999−03−27 to 2002−03−27
Density
0
500
1500
2500
−8e−04
−6e−04
−4e−04
−2e−04
0e+00
2e−04
Slope of Trendline fit to Family Abundance Data
2000−03−27 to 2003−03−27
Density
0
500
1500
2500
−6e−04
−4e−04
−2e−04
0e+00
2e−04
4e−04
Slope of Trendline fit to Family Abundance Data
2001−03−27 to 2004−03−27
Density
0
500
1500
2500
−6e−04
−4e−04
−2e−04
0e+00
2e−04
4e−04
Slope of Trendline fit to Family Abundance Data


2002−03−27 to 2005−03−27
Density
Slope of Trendline fit to Family Abundance Data
2003−03−27 to 2006−03−27
Density
Slope of Trendline fit to Family Abundance Data
2004−03−27 to 2007−03−27
Density
Slope of Trendline fit to Family Abundance Data
2005−03−27 to 2008−03−27
Density
Slope of Trendline fit to Family Abundance Data
2006−03−27 to 2009−03−27
Density
Slope of Trendline fit to Family Abundance Data
2007−03−27 to 2010−03−27
Density
Slope of Trendline fit to Family Abundance Data
2008−03−27 to 2011−03−27
Density
Slope of Trendline fit to Family Abundance Data
2009−03−27 to 2012−03−27
Density
Slope of Trendline fit to Family Abundance Data

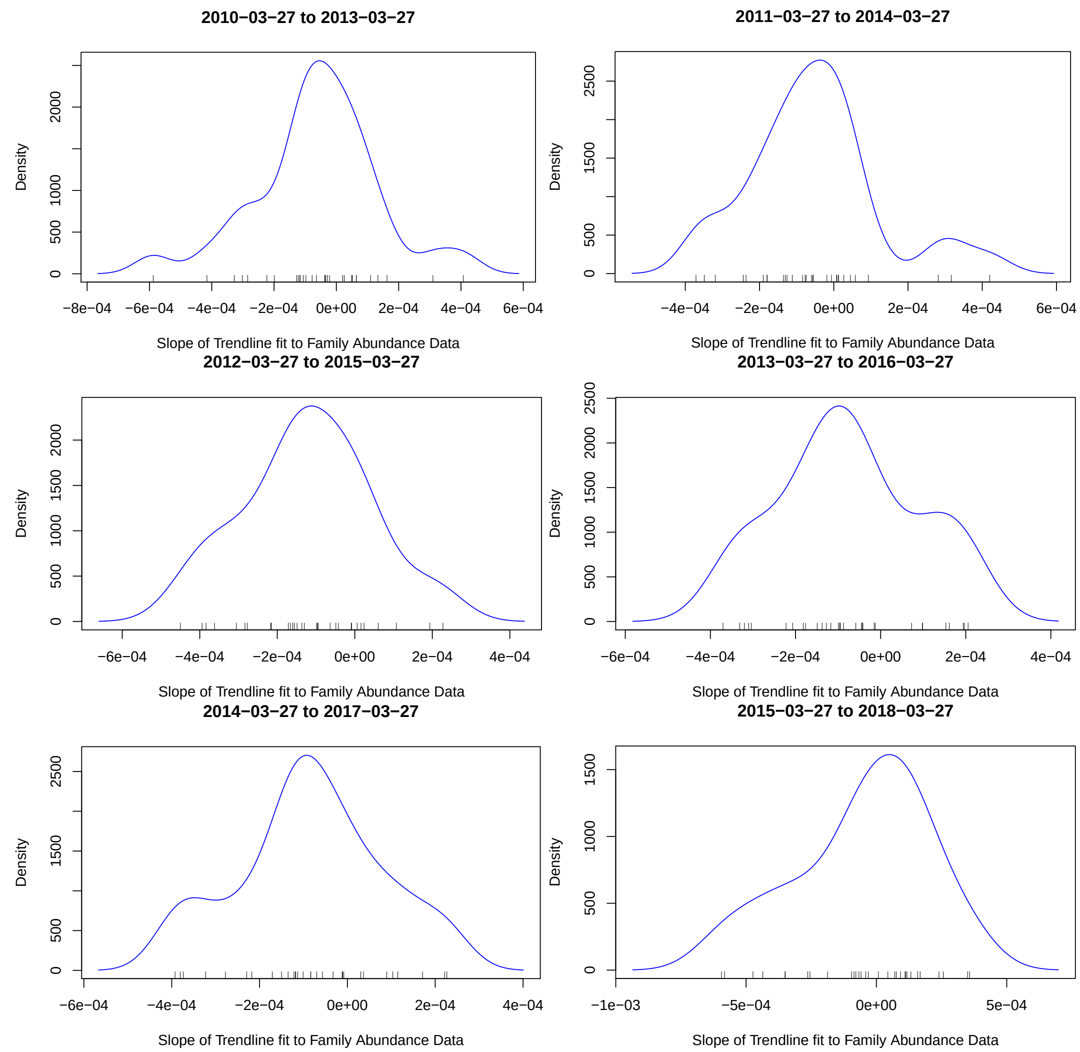


Figure 12: The Density Plots for a 3-Year Window

The mean slope for each density plot was determined and these mean values were plotted over the coarse of the 24 years (see the upper left plot in Figure 13 for the 3-year window). The mean trendline slope of all fish families remains negative following the introduction of the lionfish suggesting that there are fewer fish families with a positive slope to the trendline of abundance versus date. The remaining plots in Figure 13 show the mean slope values for 4, 5 and 6-year windows. The results for these three window sizes are similar.

The slopes of the trendlines of abundance vs. date are extremely small (on the order of 10^{-4}) and cannot be used as an indication of significant decline in fish numbers. Hunting efforts of the invasive red lionfish near Little Cayman may be successful in preventing a serious decline in native species.

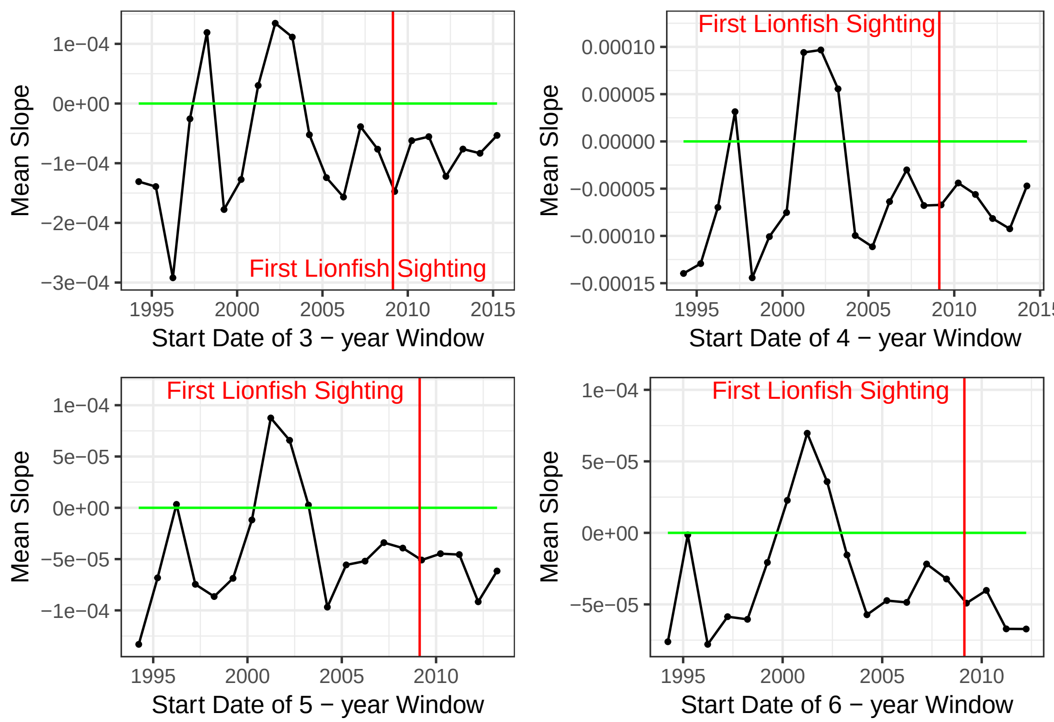


Figure 13: Mean Slope of Trendlines for Moving Windows of Abundance vs. Date for all Families

9. Fish Species Exploration for Specific Families

One study has identified key characteristics in fish species to be ideal prey for lionfish[4]. Ideal prey species reportedly have long, slender bodies, display solitary behavior and are commonly found near the seafloor at dusk or during the night. Identification of species that display these characteristics would provide a list of species for further analysis.

Snapper and grouper (part of the seabass family) are primary predators in Caribbean waters. Although adult populations are not threatened by the lionfish, juveniles are. A significant reduction of these species may result in drastic changes to the food web. In addition, coral health is at risk if lionfish decimate algae-eating populations of fish resulting in an overabundance of algae on otherwise healthy coral.

The juveniles of species in the snapper and grouper families, the species in the goby family and the species in the wrasse family have small, cigar-shaped bodies, ideal prey for the lionfish. The following figures show the abundance vs. time for species in the goby, snapper, seabass and wrasse families. There are too few surveys for many of the species in these families to identify a reasonable trend in their numbers.

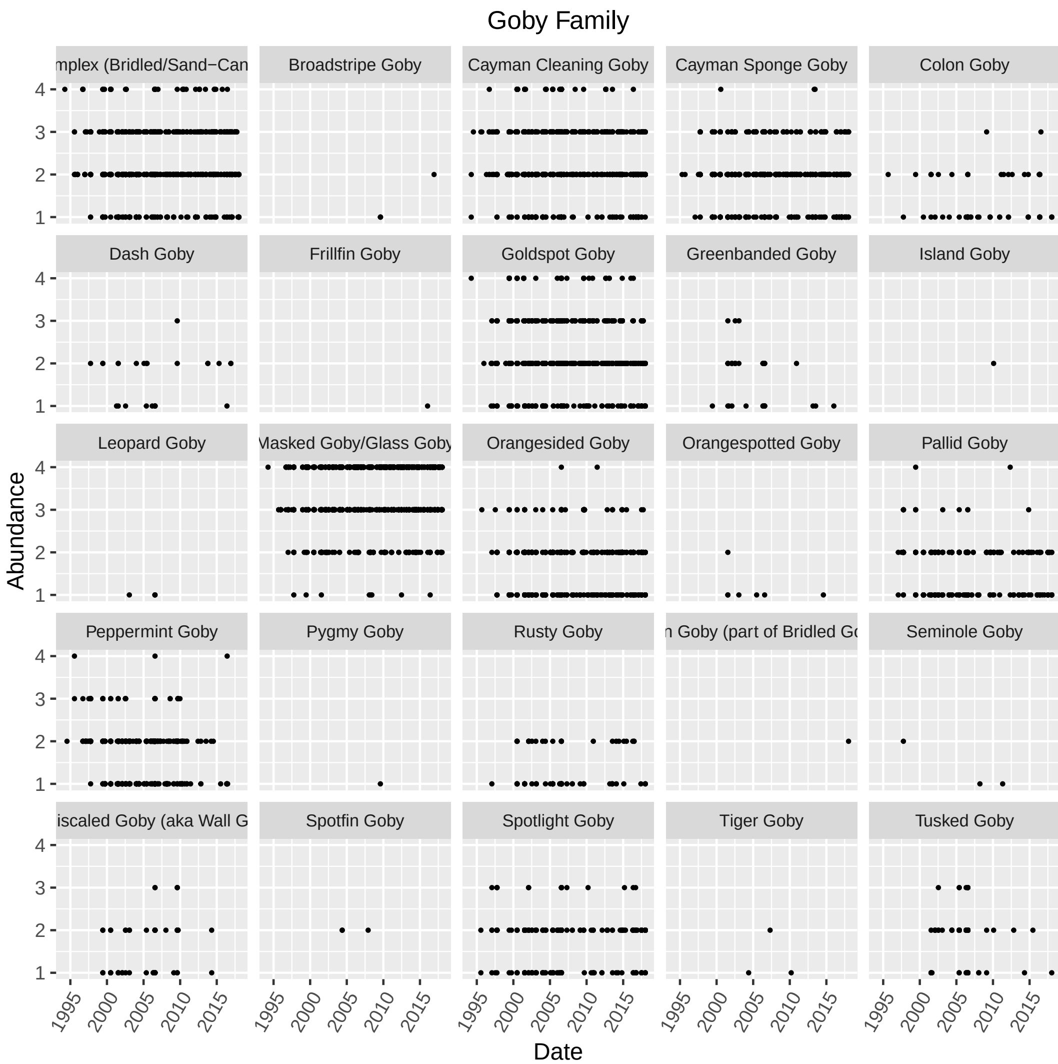


Figure 17: Relative Abundance of Species in the Goby Family

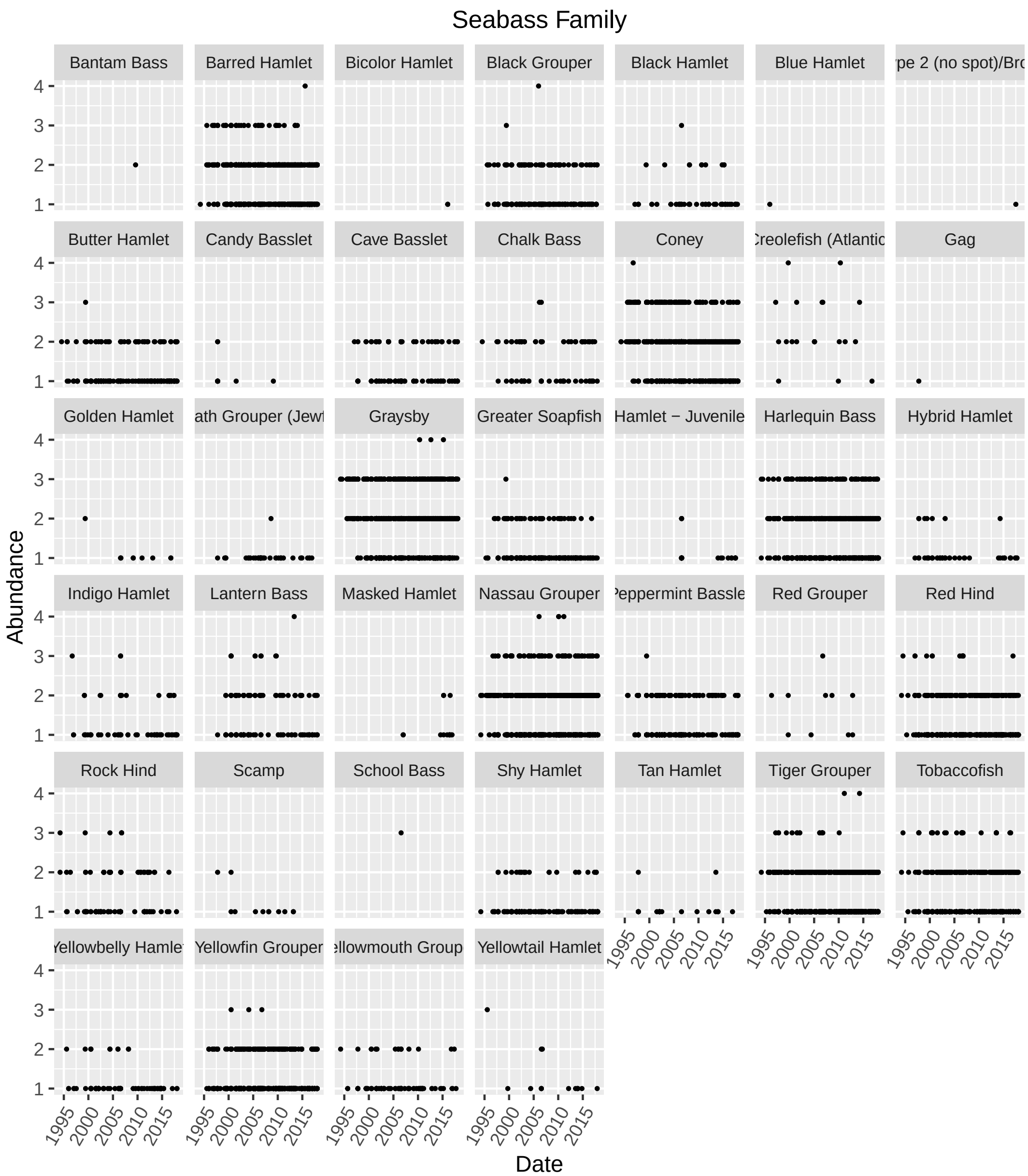
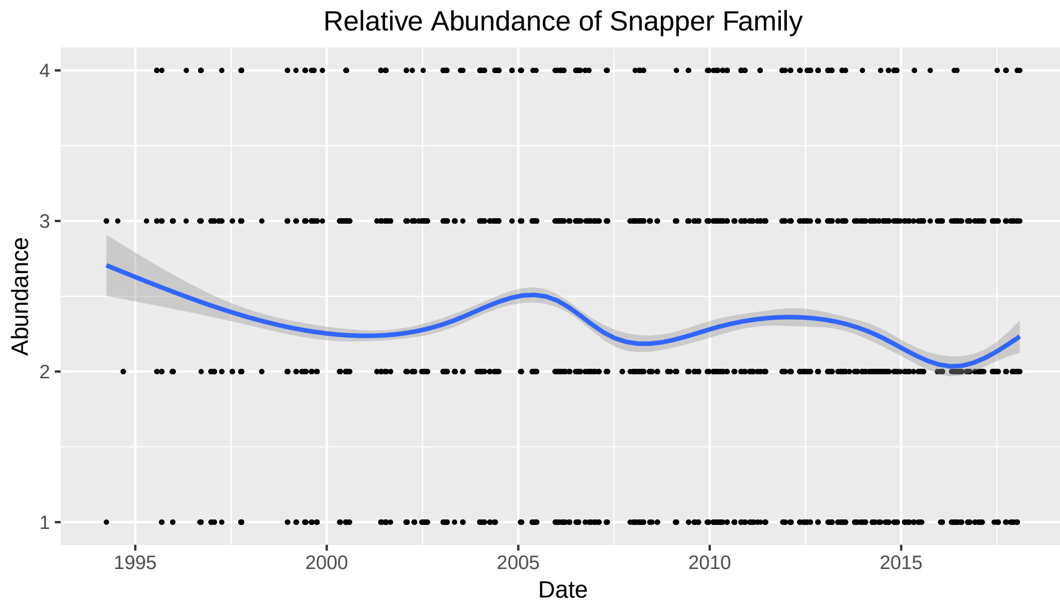
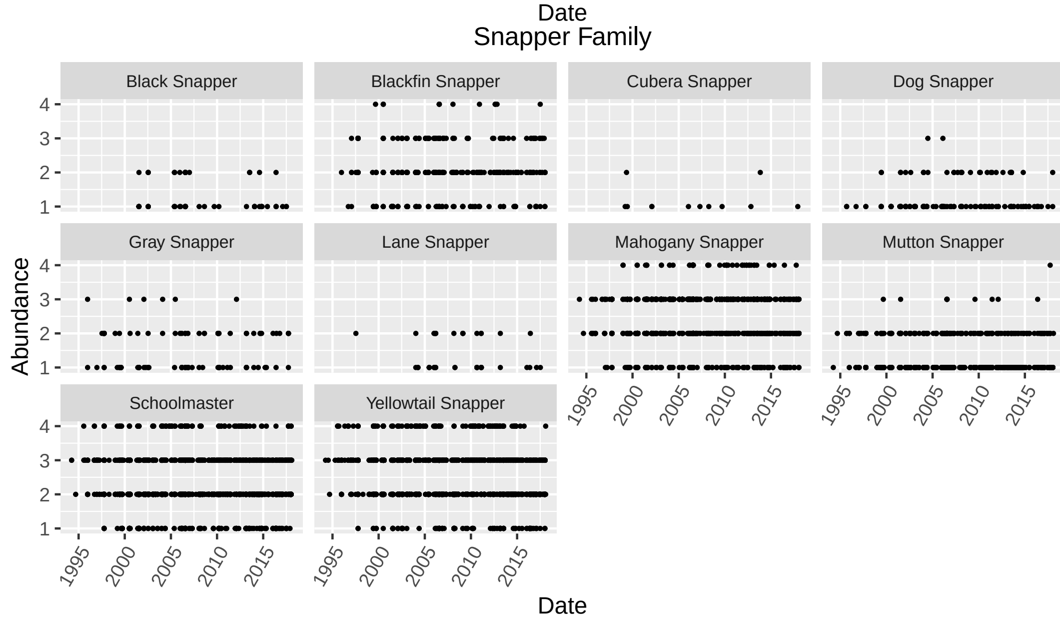


Figure 18: Relative Abundance of Species in the Seabass Family


Relative Abundance of Snapper Family
Abundance
Date
1
2
3
4
1995
2000
2005
2010
2015


Snapper Family
Black Snapper
Blackfin Snapper
Cubera Snapper
Dog Snapper
Gray Snapper
Lane Snapper
Mahogany Snapper
Mutton Snapper
Schoolmaster
Yellowtail Snapper
Abundance
Date

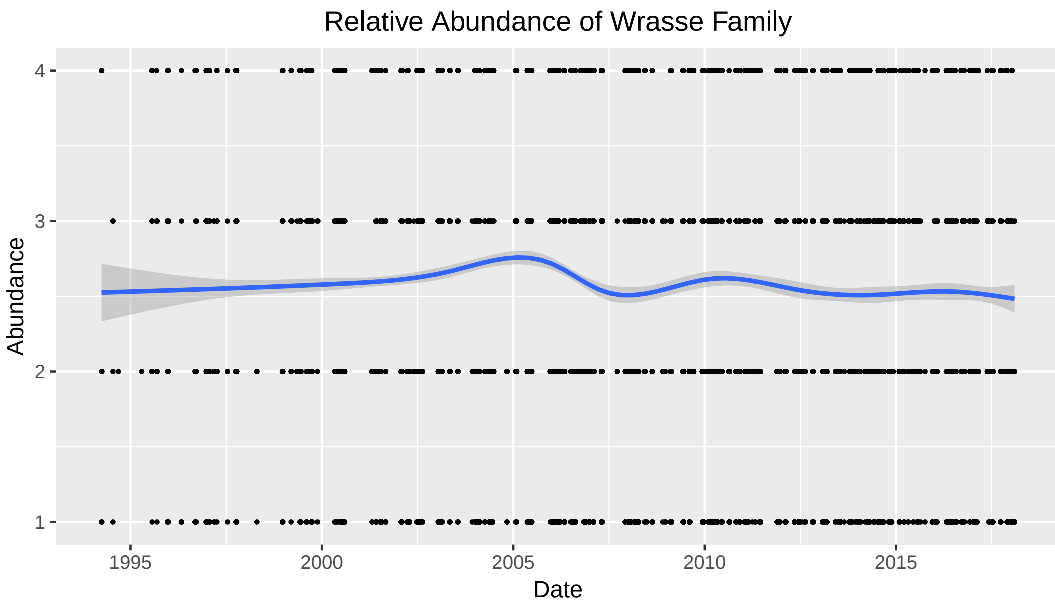


Figure 19: Relative Abundance of Species in the Snapper and Wrasse Families

10. Summary

According to reference 1, some areas have experienced a 90% reduction in fish populations as a result of the appetites of red lionfish. Elsewhere, a 65% decline in the biomass of the lionfish's 42 Atlantic prey has been noted (reference 2). These studies were completed in the early years of the red lionfish invasion before the harmful effect of their introduction was noticed. As mentioned in reference 5, studies of the red lionfish invasion in the Bahamas revealed the severity of the reduction in local fish populations.

Although many of the fish families display a negative trend of abundance, the trends appear to be very small (the slopes of the trendlines on the order of 10^{-4}). This suggests that there is no significant reduction of fish numbers as a result of the introduction of the red lionfish. The lack of a significant decline in the abundance of fish at Little Cayman may be explained by the success of local businesses and individuals in frequent culling events intended to reduce the onslaught of the non-native red lionfish[5].

The people of Little Cayman have taken an aggressive stance on combating the lionfish invasion. Their efforts have seemingly kept the lionfish at bay and prevented the same significant decline in fish populations as has been observed in the Bahamas.

11. Recommendations

A more detailed analysis of individual species could be performed in order to determine if there is a significant decline in their numbers. Species displaying the characteristics of primary lionfish prey, as stated in reference 4 would be ideal for analysis.

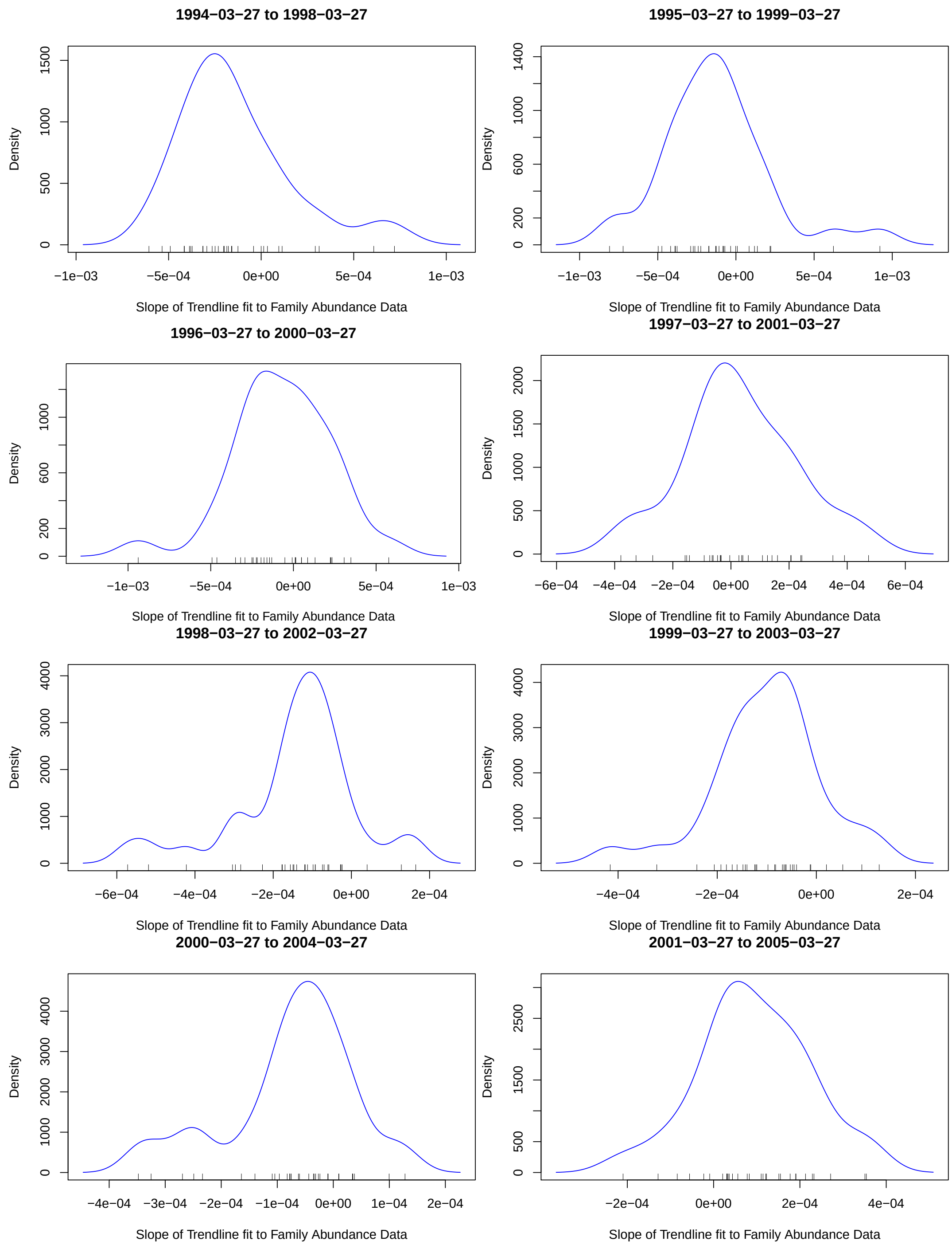
This analysis could be performed on other REEF data sets to examine the health of local fish populations during the time that REEF surveys have been recorded. As mentioned in reference 2, the red lionfish have the ability to seriously harm local ecosystems and cause significant changes that may be irreversible. Governments and organizations all around the Tropical Western Atlantic may want to begin regular culling events as a means to reduce lionfish numbers, if they have not already done so and assuming that it is not too late.

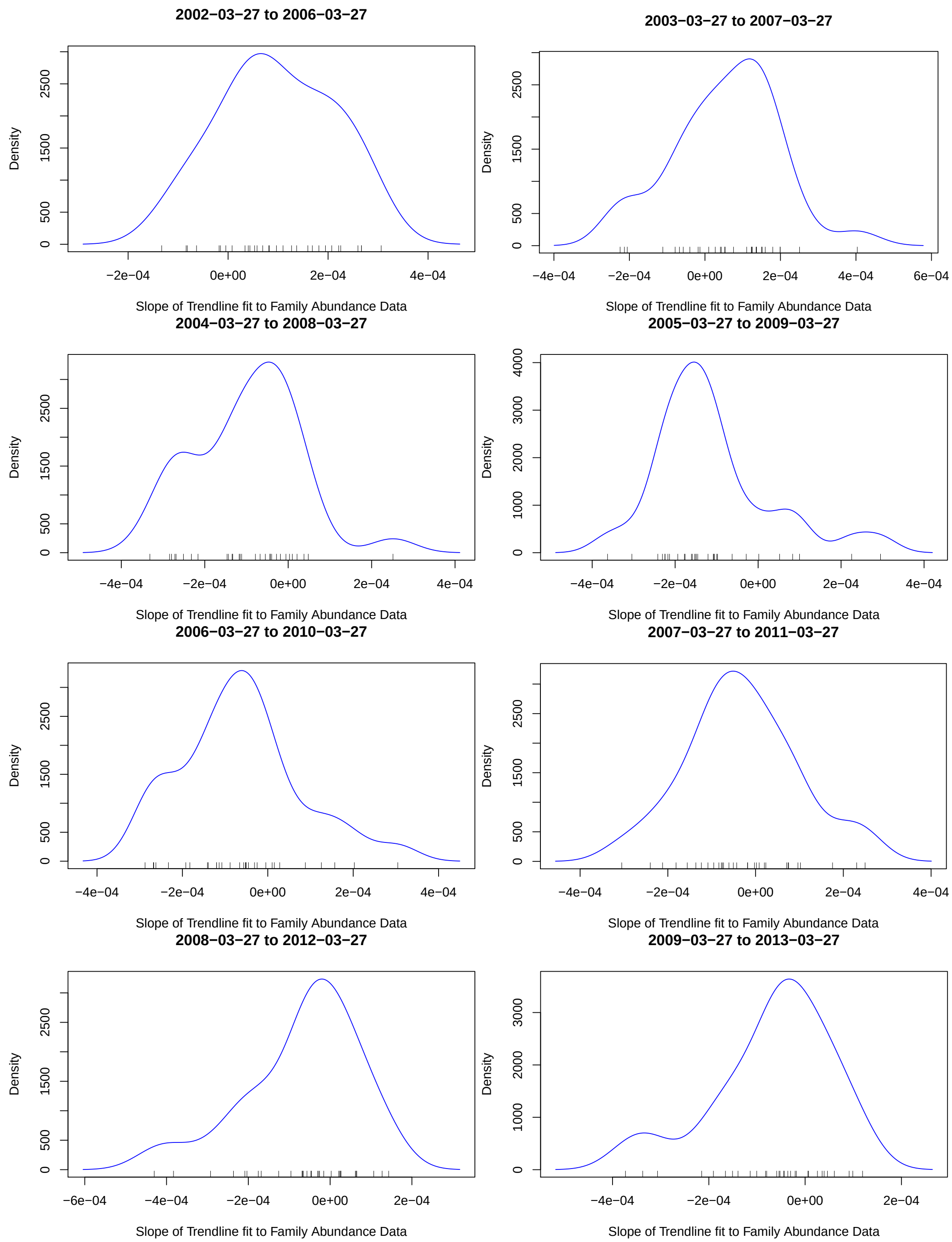
12. Acknowledgements

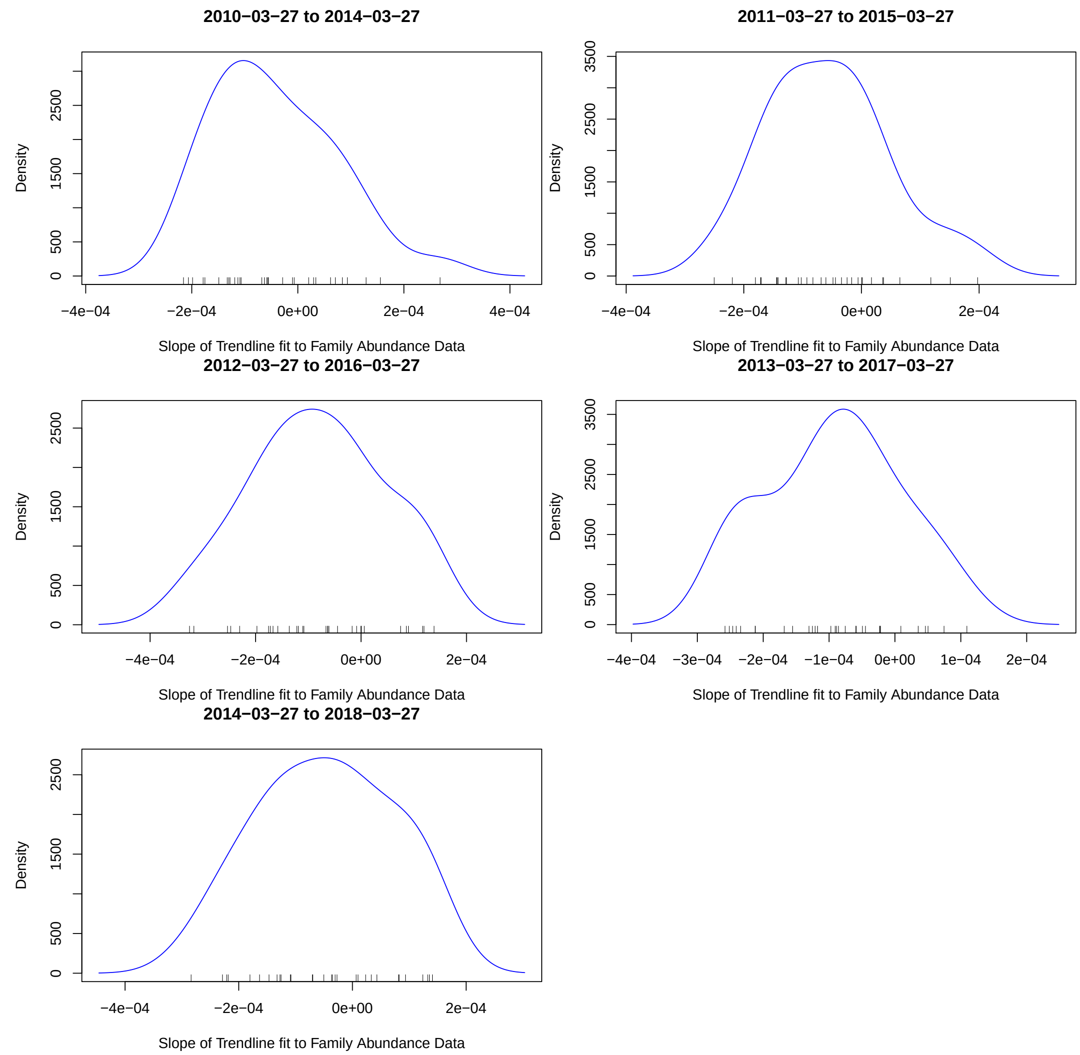
Many thanks to Christy Pattengill-Semmens of REEF for providing the data for this project. Many, many thanks to Ryszard Czerminski, my mentor during the class, for his unending patience, understanding and many helpful tips and code snippets.

Appendix

The following is the full set of density plots for the 4-year moving window.


1994−03−27 to 1998−03−27
Density
0
500
1000
1500
−1e−03
−5e−04
0e+00
5e−04
1e−03
Slope of Trendline fit to Family Abundance Data
1995−03−27 to 1999−03−27
Density
0
200
600
1000
1400
−1e−03
−5e−04
0e+00
5e−04
1e−03
Slope of Trendline fit to Family Abundance Data
1996−03−27 to 2000−03−27
Density
0
200
600
1000
−1e−03
−5e−04
0e+00
5e−04
1e−03
Slope of Trendline fit to Family Abundance Data
1997−03−27 to 2001−03−27
Density
0
500
1000
1500
2000
−6e−04
−4e−04
−2e−04
0e+00
2e−04
4e−04
6e−04
Slope of Trendline fit to Family Abundance Data
1998−03−27 to 2002−03−27
Density
0
1000
2000
3000
4000
−6e−04
−4e−04
−2e−04
0e+00
2e−04
Slope of Trendline fit to Family Abundance Data
1999−03−27 to 2003−03−27
Density
0
1000
2000
3000
4000
−4e−04
−2e−04
0e+00
2e−04
Slope of Trendline fit to Family Abundance Data
2000−03−27 to 2004−03−27
Density
0
1000
2000
3000
4000
−4e−04
−3e−04
−2e−04
−1e−04
0e+00
1e−04
2e−04
Slope of Trendline fit to Family Abundance Data
2001−03−27 to 2005−03−27
Density
0
500
1500
2500
−2e−04
0e+00
2e−04
4e−04
Slope of Trendline fit to Family Abundance Data


2002−03−27 to 2006−03−27
2003−03−27 to 2007−03−27
2004−03−27 to 2008−03−27
2005−03−27 to 2009−03−27
2006−03−27 to 2010−03−27
2007−03−27 to 2011−03−27
2008−03−27 to 2012−03−27
2009−03−27 to 2013−03−27
Density
Slope of Trendline fit to Family Abundance Data



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(1) Lionfish Quickfacts: (http://www.reef.org/reef_files/Lionfish%20quickfacts.pdf)

(2) Green SJ, Akins JL, Maljković A, Côté IM (2012) Invasive Lionfish Drive Atlantic Coral Reef Fish Declines. PLoSONE 7(3): e32596. https://doi.org/10.1371/journal.pone.0032596

(3) Global Invasive Species Database (http://www.iucngisd.org/gisd/)

(4) Lionfish analysis reveals most vulnerable prey as invasion continues (24 November 2014), Phys.org, (https://phys.org/news/2014-11-lionfish-analysis-reveals-vulnerable-prey.html)

(5) Staff (August 17, 2012), Managing invasion of lionfish, https://www.caymancompass.com/2012/08/17/Managing-invasion-of-lionfish/