A COMPUTATIONAL PROFILE OF INVASIVE LIONFISH IN BELIZE

A New Insight on a Destructive Species

Abstract

Since their discovery in the region in 2009, invasive Indonesian-native lionfish have been taking over the Belize Barrier Reef. As a result, populations of local species have dwindled as they are either eaten or outcompeted by the invaders. This has led to devastating losses ecologically and economically; massive industries in the local nations, such as fisheries and tourism, have suffered greatly. Attempting to combat this, local organizations, from nonprofits to ecotourism companies, have been manually spear-hunting them on scuba dives to cull the population. One such company, Reef Conservation Institute (ReefCI), operating out of Tom Owens Caye outside of Placencia, Belize, has dissected their caught lionfish for the past three years and kept logs of results. With little to no studies reliably indexing the Belizean lionfish population, this data set provides a priceless opportunity to take a first look and probe further questions about this relatively unstudied population. This project accomplished this by computing various population statistics using these records, including the differences in sex ratio, presence of supraorbital tentacles, length, age, and more. The results and combinations of these factors provide new insight on current theories surrounding lionfish and their anatomy, but more importantly it opens new questions, the answers to which can shed light on new techniques to more efficiently cull the population for the future.

Keywords

lionfish, reef, conservation, computing, scuba, dissection, Belize

https://doi.org/10.7771/2158-4052.1583

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INTRODUCTION

Lionfish (*pterois volitans*) are native to Indonesian regions of the Great Barrier Reef. There, they have natural predators and are a healthy part of the natural ecosystem and food chain. Today, however, lionfish have been found in a variety of environments in Atlantic waters ever since the early 2000s and have since invaded waters from the United States to the shores of Venezuela. Originally introduced in Florida coasts due to aquarium dumping, almost all lionfish can be genetically traced back to 10 original females that were dumped (NOAA, para. 9). Their numbers quickly spread to the Belize Barrier Reef, where they have an abundance of prey and very few predators. Today, lionfish are an overpopulated danger to the health of reefs in several ways. On top of their inherent disruption of the natural food chain, they destroy populations of keystone species, such as small herbivores (e.g., the native parrotfish) who feed on reef-competing algae. Without these species, the reef's light source gets overtaken by the algae and is choked out (Belize Lionfish Project, 2020, para. 3). Additionally, lionfish often prey on stock fish, the catching of which is the basis of over 64,000 people's income in the Caribbean (CANARI, 2020, p. 1).

With all this damage, many organizations have been searching for a solution, yet surprisingly few in the region document their efforts. Rather, most nonprofit organizations as well as ecotourism companies simply scuba dive and conduct spear hunts, manually attempting to cull the population. Although this has been somewhat effective in managing the invasion, few academic, documented studies have taken place in the Belizean region, unlike in the Bahamas or United States, which have much more recorded information. However, Reef Conservation International (ReefCI), an ecotourism company operating out of Tom Owens Caye, Belize, has attempted to archive their observations. Like other local organizations, they harness the power of volunteer divers to go on spear hunts, but they differ in that they conduct dissection studies measuring a variety of general diagnostic information about their catch, as described in the data collection section of this report. This project seeks to interpret their cache of dissection logs to suggest new correlations to provide new insights into and provoke new questions regarding this largely unstudied sector of the lionfish population.

Anatomically, lionfish have orange and black scales, and they range from 15 to 40 centimeters in length. Each lionfish possesses 18 total venomous spines: 13 on the dorsal fin, 2 on each pelvic fin, and 1 on the anal fin. Lionfish are rarely found alone; they instead prefer to live and hunt in packs, much like the mammals they are named for. They tend to live in different forms of tube coral, sponges, caves, or other places in which they can hide, especially during the day as they follow nocturnal hunting patterns; this may sometimes pose a hurdle to hunting efforts as the location of some "dens" could cause stray spear shots to damage surrounding corals (Belize Lionfish Project, 2020, para. 7).

Hunting is conducted using a spear, which has barbs on the end that meets the lionfish and an elastic band on the other end that stretches and releases to produce a controlled jabbing motion. Once a lionfish is speared, it is met by a "zookeeper," a specially designed containment vessel with a one-way door, which pulls the lionfish off the spear and into the containment unit for safekeeping until the hunting team surfaces. Although lionfish hunters are found all along the affected region, the ones on small islands ("cayes") are largely disconnected from each other; this is a problem this project seeks to remedy, as these remote hunters often yield the greatest catch.

Isolated hunters have no way of reliably recording observations of the fish they catch, due to both their secluded location as well as the sheer number of lionfish they catch, which could be in excess of hundreds per week. Because of this, no academically published dissection studies have been conducted in Belize that this project could find, but similar operations have been recorded in both the Flower Garden Banks Marine Sanctuary off the southern coast of the United States in 2015, as well as in the Bahamas in 2009. These studies are used for comparison in the commentary section.

MATERIALS AND METHODS

Data Collection

Data collection began long before this project and will continue long after its conclusion. This project uses the data collected by ReefCI in the way they have been doing for years and had no control over its collection, only over its processing. Potential modifications to this procedure are listed in the commentary section. Although ReefCI catches lionfish by the hundreds weekly, only 10 randomly chosen fish are dissected from the first fruitful hunting dive of each week. These pseudo-random selections occur from the entirety of the batch laid out on the table, much like the lionfish measured for dissection pictured in Figure 1. In these dissections, the length of the fish is first recorded, once with the tail attached and once when removed. Then the sex of the fish is identified using outside characteristics; for example, if a

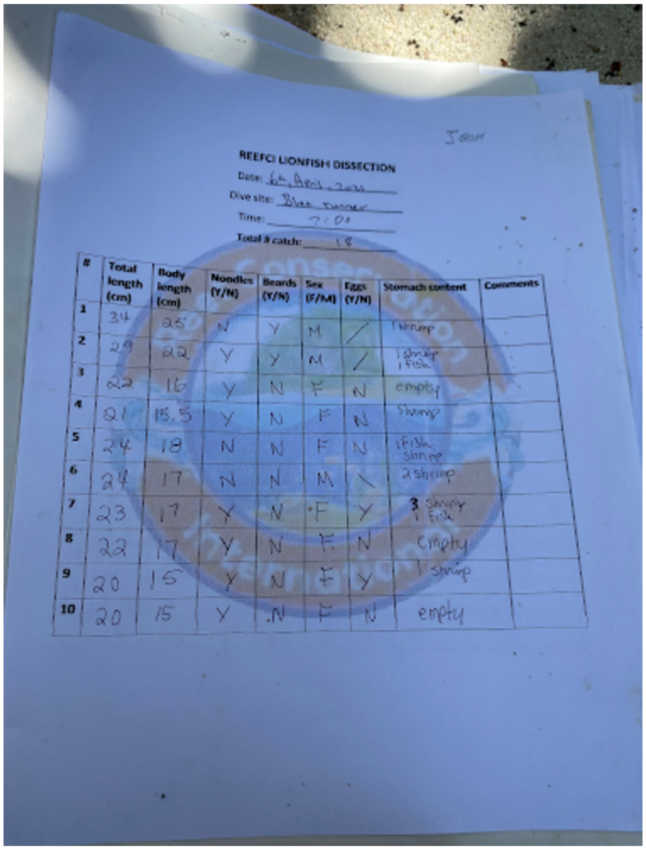
FIGURE 1. A lionfish on the dissection table. In this instance, we can see that the length would be ~24 cm, ~17.5 cm without the tail; the fish is male (no egg sac) and with tentacles present.

fish has roughness under its chin (hereafter referred to both here and by ReefCI as a “beard”), it is a male, and the absence of that trait denotes a female fish, which is then confirmed by the presence of egg sacs. Next, the presence of supraorbital tentacles (hereafter referred to both here and by ReefCI as “noodles”) is recorded. Finally, the fish is cut open, its stomach contents are emptied and visually identified, and paper records are archived. Additionally, the total catch is recorded on a tally, reported yearly, which this project also had access to.

Onboarding and Indexing

Because all records were kept on paper, as shown in Figure 2, this project was forced to manually transcribe each one into a digital medium. In doing so, the records were written in a comma-separated-value format for easier computing, as shown in Figure 3. In the process, other values were added to each dissection:

1. Sample representativeness index [SRI]: This is a calculated value of representativeness of the given lionfish for the sample from which it was taken. This is necessary because there are only 10 fish whose stomachs are cut open and recorded at any given time, regardless of how many lionfish were present in the batch. For instance, suppose on a given dissection day there were 25 fish on the table when all the dive teams have resurfaced, and dissections have begun. Because only 10 out of these will be dissected, the sample only represents 40% of the total caught during that dive, so each fish from that set is given an SRI of 0.40, such that during all stages of analysis sampling bias is outwardly apparent, not just upon vigorous inspection.
2. Juvenile status: This is a calculated Boolean variable surrounding the age of the fish. According to ReefCI’s marine biologist, Willie R. Caal, a lionfish may be identified as a juvenile both if the length of the fish is less than

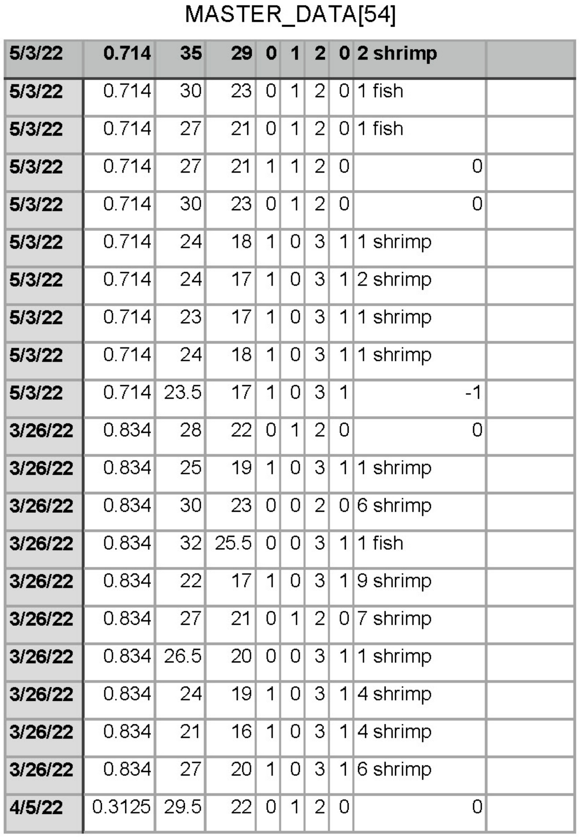


Josh

REEFCI LIONFISH DISSECTION
Date: 6th, April, 20[illegible]
Dive site: Blue [illegible]
Time: 7:00
Total # catch: 18

#	Total length (cm)	Body length (cm)	Noodles (Y/N)	Beards (Y/N)	Sex (F/M)	Eggs (Y/N)	Stomach content	Comments
1	34	25	N	Y	M	/	1 shrimp	
2	29	22	Y	Y	M	/	1 shrimp 1 fish	
3	22	16	Y	N	F	N	empty	
4	21	15.5	Y	N	F	N	Shrimp	
5	24	18	N	N	F	N	1 fish shrimp	
6	24	17	N	N	M	\	2 shrimp	
7	23	17	Y	N	F	Y	3 shrimp 1 fish	
8	22	17	Y	N	F	N	empty	
9	20	15	Y	N	F	Y	1 shrimp	
10	20	15	Y	N	F	N	empty	

FIGURE 2. A paper dissection log. This was 1 of 64 logs transcribed, which dated back to late 2020.



MASTER_DATA[54]

5/3/22	**0.714**	**35**	**29**	**0**	**1**	**2**	**0**	**2 shrimp**	
5/3/22	0.714	30	23	0	1	2	0	1 fish	
5/3/22	0.714	27	21	0	1	2	0	1 fish	
5/3/22	0.714	27	21	1	1	2	0	0	
5/3/22	0.714	30	23	0	1	2	0	0	
5/3/22	0.714	24	18	1	0	3	1	1 shrimp	
5/3/22	0.714	24	17	1	0	3	1	2 shrimp	
5/3/22	0.714	23	17	1	0	3	1	1 shrimp	
5/3/22	0.714	24	18	1	0	3	1	1 shrimp	
5/3/22	0.714	23.5	17	1	0	3	1	-1	
3/26/22	0.834	28	22	0	1	2	0	0	
3/26/22	0.834	25	19	1	0	3	1	1 shrimp	
3/26/22	0.834	30	23	0	0	2	0	6 shrimp	
3/26/22	0.834	32	25.5	0	0	3	1	1 fish	
3/26/22	0.834	22	17	1	0	3	1	9 shrimp	
3/26/22	0.834	27	21	0	1	2	0	7 shrimp	
3/26/22	0.834	26.5	20	0	0	3	1	1 shrimp	
3/26/22	0.834	24	19	1	0	3	1	4 shrimp	
3/26/22	0.834	21	16	1	0	3	1	4 shrimp	
3/26/22	0.834	27	20	1	0	3	1	6 shrimp	
4/5/22	0.3125	29.5	22	0	1	2	0	0	

FIGURE 3. A CSV formatted sample of dissection log data after transcription and correction.

15 centimeters without its tail, as well as in the absence of sex-determining traits (such that the fish has neither a "beard" nor an egg sac). This variable was automatically calculated by the computer during data onboarding using these conditions. More information and reasoning regarding the treatment of data on juvenile fish may be found in the results section.

3. Length of tail: This is simply the difference between the length of the fish with its tail attached and the length of the fish without its tail.

Techniques of Analysis

This project utilized the C and Java programming languages in order to build a tool for data set processing. After all onboarding, the paper data was turned into a .csv file for this program to read, process information, and output needed files for further manual analysis. This was done by creating a custom data structure, wherein each line's information (as well as the automatically calculated additional figures detailed in the onboarding and indexing section) were stored in one cohesive unit. These structures were then stored in a sorted tree-like table with optimizations for robustness. Using the sorted nature of these tables, algorithms could quickly access data and detect simple patterns, such as male-female ratio, stomach contents, and so on. From there, output is written to a new .csv file. This formatted final file creates the figures seen in this paper. All programming operations in this project have been made such that it may be implemented for the standardization of data collection across isolated islands in Belize, as detailed in the commentary section.

RESULTS

General Data Set Statistics

After all onboarding, the data set consisted of 638 dissections representing 1,297 out of 14,500 total lionfish caught over the tally-recorded period mentioned earlier. Of these, there were 601 adults and 37 juveniles; of the adults, 338 were female and 263 were male. Juvenile data was largely ignored in the calculation of most of the following statistics (see "Comments on Juveniles"). The dissections span from late 2020 through early May 2022, when this project's transcription occurred, although logs are still being taken through the present. This project focuses mostly on the size, presence of supraorbital tentacles, sex distribution, and stomach contents, as detailed in the following sections.

Size Distribution

The most notable observation one may find upon first inspection of the data is that the size of a lionfish follows, at least when split by sex, an approximately normal distribution across the set, and in general males are longer than females (Figure 4). Without tails attached, the average male was 22.06 centimeters in length, with the minimum and maximum being 15.3 and 30 centimeters, respectively. Females, however, were on average 17.99 centimeters long, with the minimum and maximum being 15.5 and 26.5 centimeters, respectively. This is a key difference that holds for other parts of this project.

Like the length of the bodies, the tails on their own were consistently longer on the male fish than the females. On average, a male tail was 6.65 centimeters long, while a female tail on average was 5.57 centimeters. However, some sizes had an incredibly large range, wherein the longest tail on a male was 15 centimeters and the shortest was 2 centimeters. Neither of these are outliers, proven by the fact that the mean and range stayed largely the same when either of those points were removed from the set. This incredibly large range is why this study focused on the length of the fish without tails for standardization. Further, this difference in sizes compounds the differences found above, a significance that is further explained in the commentary section.

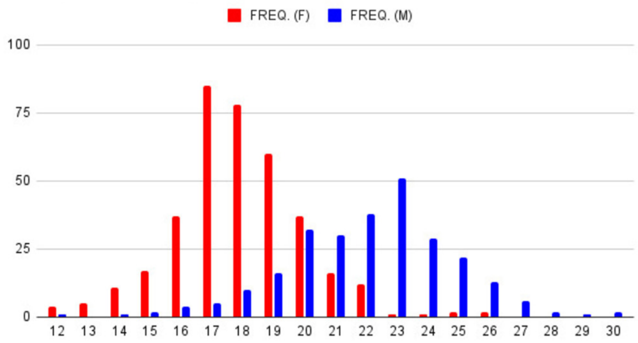


FIGURE 4. Histogram of the (tailless) length data, split by sex. Male lionfish are denoted in blue and female lionfish are denoted in red. It is clear that the male lionfish are more frequent at larger lengths.

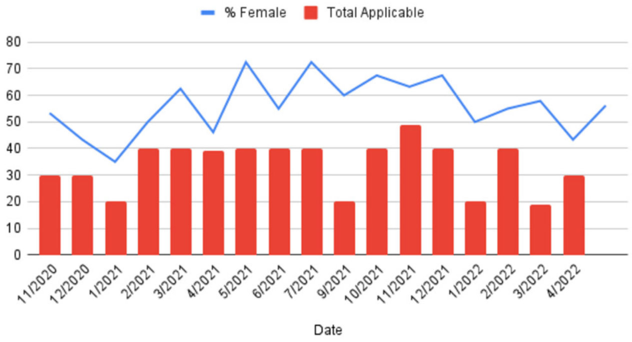


FIGURE 5. Sex distribution over time, with the line being the percent female and the bars being the total lionfish caught in that interval. The population stays majority female over time, except when the sample size is smaller.

Sex Distribution

The second factor this project considered was the distribution between sexes of the fish. Upon counting and averaging, it was found that the population had approximately a 6:4 female to male ratio. This was relatively consistent over time, as shown in Figure 5, which shows the percentage of the dissections that were of female fish, with bars on the bottom representing the total dissected in that interval as a metric of confidence. It is immediately apparent that on most occasions males are more prevalent than females; the confidence is lower and the inverse is true for the female-dominated majority of the timeline.

Stomach Contents

Because the stomach contents were only identified visually, there are only four major identifications of stomach contents. First, the stomach can be empty, but if it is not, it may contain any number of fish or shrimp (not mutually exclusive), or contents that are digested beyond visual recognition. Using basic string analysis, Table 1 shows the contents that were found.

TABLE 1. The stomach contents of the lionfish, split among the 4 groups recognized visually.

Diet item	Percent of set containing that item
Shrimp	45.6113
Fish	22.884
-1: Digested beyond recognition	3.1348
0: Empty stomach	37.6176

Comments on Juveniles

Although the breakdown of juvenile vs. adult status was an interesting factor to consider, juvenile data often had to be thrown out due to lack of confidence and consistency. According to Mr. Caal, a juvenile is characterized as a lionfish that is both less than 15 centimeters long, as well as lacking either form of an outside sex-determining characteristic. For example, the sex distribution of the total population was quickly restricted to adults; although the juvenile fish are listed as one sex or the other, this is inherently unreliable by virtue of their definition as lacking the telling traits needed to perform this identification. For this reason, their assigned sexes were deemed unreliable and were not included in such distributions.

COMMENTARY AND SIGNIFICANCE

In Contrast to Other Studies

Although this is all but the only large dissection study conducted in Belize, similar operations have happened elsewhere. Most notably, the National Oceanic and Atmospheric Association (NOAA) performed a study of 317 lionfish in the Flower Garden Banks Marine Sanctuary near Houston, Texas. In that study, NOAA executed their dissections by splitting the fish along the bottom, then after determining weight and length, examining the otolith bones in the lionfish's head to determine age. Additionally, the stomach was emptied and its contents recorded.

In comparison to this study, shrimp and fish are still the two most identifiable contents in the stomach, but NOAA had more tools to determine which species were eaten specifically. However, when generalized to simply shrimp and fish, some of NOAA's results are shockingly close to this project's findings. In this project, 45.6113% of dissected lionfish contained shrimp, while NOAA found that 48.75% did the same. This pattern continues for other metrics. This study found that 3.1348% had stomach contents digested beyond recognition vs. 6.20% found by

NOAA; differences begin afterward as it was found that 22.8840% contain various fish vs. 36.31% found by NOAA, and 37.6176% had an empty stomach vs. 8.08% found by NOAA. These differences are in part due to equipment differences as well as differences in level of training of those doing the dissecting to recognize eaten fish, especially small ones. The empty stomach statistic is too significant a difference to be simply an error, however, which provokes further questions discussed later.

NOAA mentions a tangential study that uses the otolith data from the University of Southern Mississippi, which has a different purpose but takes similar basic population statistics. For example, as opposed to NOAA, they displayed their length distribution of their caught lionfish. This project re-created their graph for easier comparison:

It is immediately apparent that the lionfish in this study are significantly smaller. This is not due to any confusion regarding whether tails are attached or not—both sets are total length, or length with tail included in this case. Because their fish are bigger (theirs are from the same estuary as the NOAA study), it makes significantly more sense that they eat more fish than the ones observed in this study: Their larger size allows them to eat a wider variety of fish, compensating for that extra 15 or so percent over this study. This also explains why shrimp percentages are so similar—shrimp are small enough for the size of the predator not to matter as much.

In the Bahamas, however, a different study exists by James A. Morris Jr. and John L. Akins (2009). Once again, using more sophisticated methods, they were able to analyze the stomach contents of lionfish caught over the course of a year, about 111 per month (Morris Jr. & Akins, p. 390). With their more specialized equipment, they were able to analyze stomach content with such certainty that no content was ever marked as unidentifiable, hence there is no mention of unidentifiable content on the graph in Figure 6, which compares all three projects.

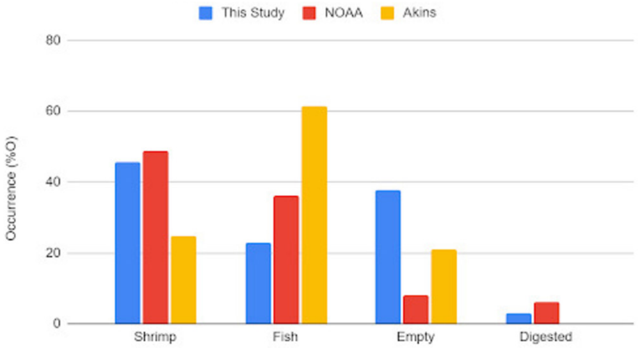


FIGURE 6. Comparison of stomach contents across studies. Included also is data from Morris Jr. and Akins (2009), a study of similar proportions in the Bahamas. They used precise genetic sequencing on the stomach contents of the lionfish, so they had no unidentifiable content recorded, hence their absence in that column.

Errors and Unresolved Questions

Not all trends found in this project have clean explanations. For example, the female-dominated sex ratio of the sample defies predictions, especially when considering the findings regarding size differences between the sexes. Because male lionfish are approximately 20% larger, one would predict a bias in the sample toward them, as a larger target theoretically would be easier for a volunteer to hit with a spear. Instead, the opposite is found, making this population even more unique and destructive; this is because a single virile male can fertilize many, many eggs, while female lionfish may only release a certain number of eggs at a time. Thus, a female bias in the population, which is likely even larger than 6:4 due to the probable male bias mentioned above, allows this population to spread even faster and further overpopulate the reef.

On the other hand, some hypotheses have definitive answers in the light of this data. For example, the presence of supraorbital tentacles (“noodles”) in the lionfish are in some circles thought to be a sign of sexual maturity. The data collected in this study definitively proved that claim incorrect, as the presence of these tentacles is correlated with the youth of the fish, and even more definitively inversely correlated with length. Considering these findings, future experimentation is required to definitively determine their purpose, as detailed in the next section.

Further Questions and Experimentation

When put in juxtaposition to other studies, it is apparent that due to their generalist nature, there is a vast

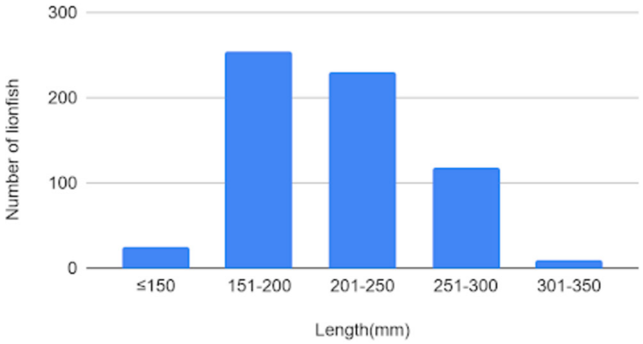


FIGURE 7. Our data formatted to match Blakeway et al. (2021). This means that tail length is included and data is from both sexes.

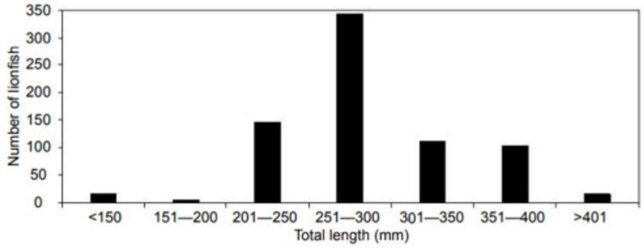


FIGURE 8. Original length histogram (both sexes, tails included) from Blakeway et al. (2021). This is data from the same NOAA study mentioned prior.

disparity in the observed traits in these lionfish between diet characteristics and even size. This means that a study in one region cannot accurately predict the characteristics of lionfish in another, especially as time goes on and they adapt to their varying environments more and more. Thus, not only is future experimentation required to determine the environmental conditions that are causing these permutations, but also to expand the archive by probing more locations in the affected region.

Another avenue for which more work needs to be done is in the dissections themselves—these dissections need to have more factors recorded, such as using better tools for stomach analysis (even if just a magnifying glass on unidentifiable or empty stomachs), or even analysis on otolith bones to determine relative age.

The first step to accomplishing these tasks is simply to utilize and streamline the resources already present to gather data. All the computational techniques used to garner usable statistics from the sea of dissections has been streamlined into one program, which will be distributed to the individual islands throughout Belize to begin recording the lionfish they catch in a manner consistent with the surrounding islands, which establishes a strong footnote trail for the scientific community to use as it analyzes this problem. In partnership with the Belize Lionfish Working Group, a collective of hunters and agencies from across the country, this project hopes to brighten the future for the Belize Barrier Reef as a whole.

ACKNOWLEDGMENTS

This author would like to acknowledge the support of his mentor, Dr. Greg Michalski, for his guidance and assistance in this project. We would also like to thank Reef Conservation International for their cooperation and sharing of their data, as well as the students of the 2022 Coral Reef Research in Belize study abroad trip for their assistance in transcribing it.

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