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# Appendix 1: Belize's MPAs

Table 1: Names and sizes of Belize's 14 marine protected areas, their management organisations, and IUCN categories (where applicable).

| Protected Area | Government Body | Co-manager | Area (acres) | IUCN Category WHS |
|---|---|---|---|---|
| **Bacalar Chico Marine Reserve & National Park** | Fisheries Dept. | - | 15,766 | II (National Park) |
| **Blue Hole Natural Monument** | Forest Dept. | BAS | 1,023 | II (Natural Monument) |
| **Caye Caulker Marine Reserve** | Fisheries Dept. | FAMRACC | 9,670 | - |
| **Corozal Bay Wildlife Sanctuary** | Forest Dept. | SACD | 180,509 | - |
| **Gladden Spit and Silk Cayes Marine Reserve** | Fisheries Dept. | SEA | 25,978 | - |
| **Glover's Reef Marine Reserve** | Fisheries Dept. | - | 86,653 | IV (Habitat/Species Management Area) |
| **Half Moon Caye Natural Monument** | Forest Dept. | BAS | 9,771 | II (Natural Monument) |
| **Hol Chan Marine Reserve** | Fisheries Dept. | - | 102,400 | - |
| **Laughing Bird Caye National Park** | Forest Dept. | SEA | 10,119 | II (National Park) |
| **Port Honduras Marine Reserve** | Fisheries Dept. | TIDE | 100,000 | - |
| **Sapodilla Caye Marine Reserve** | Fisheries Dept. | - | 38,594 | IV (Habitat/Species Management Area) |
| **South Water Caye Marine Reserve** | Fisheries Dept. | - | 117,875 | IV (Habitat/Species Management Area) |
| **Swallow Caye Wildlife Sanctuary** | Forest Dept. | FOSC | 8,972 | - |
| **Turneffe Atoll Marine Reserve** | Fisheries Dept. | TASA | 325,412 | - |

# Appendix 2: SEF

Link to complete SEF (large image file): here

# Appendix 3: Lionfish Dissections

Simplified lionfish dissection method, data sheet and link to data entry template. All can be found here.

# Appendix 4: Lionfish Focused Search Method

Lionfish Focused Search Method 2016.pdf can be found here

# Appendix 5: Lionfish Ecological Threshold Model

Author: S. Green

Green et al. (2014) [1] estimate prey biomass production and lionfish biomass consumption rates in order to calculate threshold densities at which lionfish begin to deplete the standing biomass of their prey on invaded marine habitats. Specifically, individual prey fish biomass production (P) is estimated via the relationship:

$$Z \approx \frac{P}{B} = \frac{jB^q}{e^{E/kT}}$$

(Equation 4 in Green et al. [2014])

where the scaling exponent (*q*) has been theoretically proposed as -0.25, and *j* empirically validated as $e^{26.25}$ (Brown et al. 2004 [2]; Table 2). The equation $e^{E/kT}$ describes the effect of environmental temperature on prey fish production rates, where *E* is the activation energy, *k* Boltzmann's constant and *T* is ambient water temperature, expressed in degrees Kelvin. The body mass (*B*) of each prey fish species *i* was estimated using the allometric scaling function:

$$B = a_i L^{b_i}$$

(Equation 5 in Green et al. [2014])

Individual biomass production rates (*P* from Equation 4) were summed across prey sizes and species, and averaged across transect surveys at each study site to give average site-specific prey productions rates:

$$\bar{P} = \frac{1}{z} \sum_{\forall_z} \sum_{\forall_i} \sum_{\forall_v} P_{v,i,z}$$

(Equation 2 in Green et al. [2014])

This method for estimating individual prey fish biomass production was used to model threshold lionfish densities ($\bar{d}$) at which prey consumption equals prey production as, which can be used as targets for lionfish suppression:

$$\bar{d} = \frac{\frac{1}{z} \sum_{\forall_z} \sum_{\forall_i} \sum_{\forall_v} \left( \frac{j(a_i L_{v,i,z}{}^{b_i})^q}{e^{\frac{E}{kT}}} \right) a_i L_{v,i,z}{}^{b_i}}{\frac{1}{m} \sum_{\forall_m} (a_l L_m{}^{b_l})\, \bar{p} \left( 9\text{x}10^{-22}\, e^{0.16T}\, \frac{1}{m} \sum_m (a_l L_m{}^{b_l})^h \right)}$$

(Equation 9 in Green et al. [2014])

Where $L_m$ is the total length of each of *m* lionfish (in cm) observed at the site, and $a_l$ and $b_l$ are lionfish-specific allometric length-weight scaling constants. The function $9\text{x}10^{-22}\, e^{0.16T}$ describes the scaling relationship between lionfish mass-specific prey consumption rate (g prey$^{-1}$ g lionfish$^{-1}$

[1] Green, S.J., et al. (2014) Linking removal targets to the ecological effects of invaders: A predictive model and field test. Ecological Applications. 24: 1311-1322.

[2] Brown, J.H. et al. (2004). Towards a metabolic theory of ecology. Ecology. 85(7): 1771- 1789.

day$^{-1}$) and body weight (g) derived by Côté and Green (2012)[3] from two field studies of lionfish prey consumption at different water temperatures (Côté and Maljković 2010[4], Green et al. 2011[5]; Table 2). The scaling constant *h* has a value of -0.29 for lionfish (Côté and Green 2012).

Importantly, Green et al. (2014)'s model of $\bar{d}$ assumes that prey fish populations at a reef could remain stable if lionfish consumption exactly balances prey production. However, prey are undoubtedly subject to stochastic mortality and recruitment from other sources (Freckleton et al. 2006[6]) and hence a precautionary 'buffer' of excess production may generally be necessary to ensure that these mortality events do not further reduce prey standing stock. As calculations do not include this buffer, estimates of 'sustainable' lionfish densities represent the *maximum* lionfish densities at which further declines in prey fish biomass may be averted.

**Model simulations**

A model of $\bar{d}$ was created for each study reef, with variation in our parameter estimates incorporated through Monte Carlo simulation to generate a distribution of reef-specific 'threshold' lionfish densities at which lionfish prey consumption matches prey production rates (Equation 9; see Table 2 for a summary of parameter sources). Figure 1 shows a hypothetical distribution of $\bar{d}$ for a generic site.

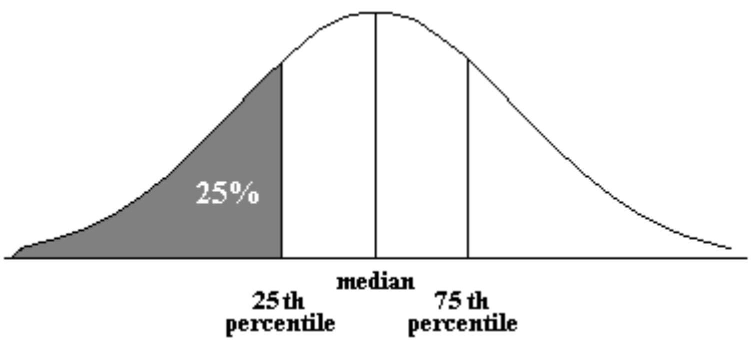


Figure 1: Hypothetical distribution of threshold lionfish densities ($\bar{\boldsymbol{d}}$) for a generic site, with the 25$^{th}$,50$^{th}$ (median) and 75$^{th}$ percentiles displayed.

Specifically, the median from 1,000 iterations of each model was calculated and the simulation was repeated 500 times, generating a distribution for the median of $\bar{d}$. This procedure was repeated for each of the 50 sites. For each model a log-normal distributions for lionfish body mass ($\bar{W}$) was specified because the assumption of normality for log-transformations of these data was not rejected (Kolmogorov-Smirnov tests, $p > 0.13$ for all tests). Normal distributions for water temperature and for the proportion of diet composed of fish prey were specified (*T* and *p* respectively; Table 2).

Empirical 95% confidence intervals of the median were constructed by taking the 2.5 and 97.5 percentiles of the resulting distributions as confidence limits for $\bar{d}$ for each site (Vose 2008[7]). For the Belize Lionfish Management Strategy, the 25$^{th}$ percentile of this distribution was used, providing a conservative estimate of lionfish threshold densities $\bar{d}$ for each site. All simulations were done in the statistical software R (R Core Development team 2008[8]).

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[3] Côté and Green (2012)
[4] Côté and Maljković 2010
[5] Green et al. 2011
[6] Freckleton et al. 2006
[7] Vose 2008
[8] R Core Development team 2008

Table 2: Sources used to parameterise the lionfish predation threshold model for coral reef study sites off Belize

| Model component | Parameter | Meaning | Value | Data source |
|---|---|---|---|---|
| Prey fish production ($\bar{P}$) | $L_{v,i,z}$ | *prey fish length | 1 -13cm (individual-specific) | ++Field survey |
| | j, q | *metabolic biomass-production scaling constants | *q* =-0.25; *j* = $e^{26.25}$ | Brown *et al.* 2004 |
| | $a_i$, $b_i$ | species-specific length-weight scaling constants | Species-specific | www.fishbase.org |
| | E | activation energy | 0.65eV | Brown *et al.* 2004 |
| | k | Boltzmann's constant | 8.06 x $10^{-5}$ | |
| | T | *water temperature | 299.25 ± 3 $^{o}$K (26 ± 3°C) | NOAA 2015 |
| Lionfish prey consumption ($\bar{C}$) | $a_l$, $b_l$ | lionfish-specific length-weight scaling constants | $a_l$ = 0.00497;$b_l$ = 3.291 | Green et al. 2012 |
| | $L_m$ | *lionfish length | 6-390mm (individual-specific) | ++Field surveys |
| | h | *prey consumption scaling constant | 0.29 | Côté and Green 2012 |
| | x | scales daily rate to annual rate | 365.4 days $year^{-1}$ | |
| | p | *proportion of diet composed of fish | 0.7± 0.07 | ++Stomach contents |
| | T | *water temperature | 299.25 ± 3 $^{o}$K (26 ± 3°C) | NOAA 2015 |
| | r | *radial distance of the area over which lionfish forage | Radius of reef area | ++Field surveys |
| | y | constant scaling daily to annual consumption | 365.4 days/year | |

## Appendix 6: Fisher Semi-Structured Interview Guide

Authors: J. Sabattis, J. Solomon

**Informed consent:**

*For translator, as required: Hello, my name is [translator's name]. I am assisting in translating your interview with Julie Sabattis, a researcher with Colorado State University.*

Hello, my name is Julie Sabattis and I am a researcher with Colorado State University. I am conducting a study to understand your sentiments towards catching lionfish. Specifically, I am interested in the thoughts, knowledge, beliefs and experiences of fishers in Belize on lionfish. The information from this study may be used by Blue Ventures to understand the potential for a market for lionfish. I will record this interview for the purpose of going back to review our conversation. You have the right to not answer any questions you choose and can stop the interview anytime you wish. This interview is to understand your ideas and opinions. There are no wrong answers. Depending on how much you would like to share, the interview could take approximately one hour. Your participation is voluntary and your responses will remain completely confidential. Your name, contact information, and any other personally identifying information will never in any way be released or associated with your responses in reporting of the data. In addition, there are no known risks associated with your participation in this study.

Keep in mind that, according with federal regulations in the United States, the Colorado State University Institutional Review Board has reviewed and approved this study. If you have questions about your rights as a participant in this research, you may contact the principal investigator of this study, Jennifer Solomon, Assistant Professor at Colorado State University by email at [email] or by phone at [phone].

Do you understand what I just said?
Do you have any questions?
Considering the information I just told you, are you willing to participate in this interview?

**Interview Questions**

**(1) FISHING BACKGROUND**

First I will ask you a couple of questions about your background with fishing. This is to understand what has influenced you as a fishermen throughout the years.

**As a fisherman, could you tell me about why you choose to become a fishermen. (Objective: to understand why fishing is important - as they perceive it - in order to compare between fishermen)**

a. How old are you?
b. What is your place of residence?
c. How long have you been fishing?
d. How long have you been in the current role?
e. What other (fishing-related) roles have you been in since you started fishing?
f. Does anyone else in your family fish?
g. Why did you decide to become a fisher?
h. What aspects of being a fisher are important to you?
i. What are difficult aspects associated with fishing as a job?

**As a fisherman, could you tell me what your typical schedule looks like for the year? (Objective: to understand the parameters to their work life)**

a. Do you fish consistently as a year round job or do you work at another job during part of the year?
    i. Can you describe a year in your life in terms of your work? (Ask if interviewee would prefer to use paper to draw out the seasonal components of the work. If so, provide paper.)
b. On an average trip, how long are you out at sea?
c. How far do you travel?
d. Do you go to the same region everytime, or visit another region?
e. How many people are on your boat?
e. What equipment is needed for these trips that you need to provide? (determines economic investment for current practices)
f. What are reasons you would cut a fishing trip short? (determines some of limitations/barriers for their type of fishing)

**(2) GENERAL FISHING CATCHES**

**Now I'm going to ask you a few questions about what you typically catch as a fishermen and the differences between catching various varieties of seafood.**

a. What kind of seafood do you fish for? (fish types, conch, lobster)
b. Why do you fish for that type of seafood? (are there seasonal influences to what is available, economic drivers-demand, determined by captian)
c. Do you see a change in what being caught from the sea?
d. Do you see a change in the amount of fishermen going out to fish? Are there a lot of other fishing boats where you fish? Are they from your community or other communities?
e. Who do you sell your catch to?
    i. in Belize
    ii. in San Pedro/Caye Caulker/elsewhere
f. how much does lobster/conch/finfish sell for?
g. does that change if you sell to market/restaurant ?

**Thinking about what you catch in the places you go fishing, I'd like to get some idea of how you think the fisheries are being managed.**

a. Do you know who manages the areas you fish?
b. How often do you see them patrolling?
c. Could you tell me what you know about managed access.
    i. will it affect where you can fish?
    ii. what effects do you think it will have on what/how much you catch?
    iii. Will you be able to apply to change areas to fish each year?
d. Do you see illegal fishing in your areas?
    i. do you think managed access address illegal fishing?
e. Do other people fish in the same areas as you? Are they from the same or other communities?

**(3) UNDERSTANDING PERCEPTIONS OF LIONFISH**

**Now I would like to ask you some questions about what you know about lionfish and how much (if any) interaction you have had with the fish.**

a. Could you explain to me what you know about lionfish?
b. Do you think lionfish are bad for the reefs?
c. Do you see lionfish when you are out fishing?
    i. Have they always been around?
        1. When did you first start seeing them?
    ii. do you think lionfish are a threat to Belize's fishing industry in any way?
    iii. do you think that people can die from lionfish stings?
    iv. do you think lionfish are spreading into other areas in Belize?
    v. do you think lionfish is safe to eat then?

If yes to question b: how often do you see lionfish?

d. Have you ever speared lionfish?
e. Why (or why not) have you caught (or not caught) lionfish?
f. Have you ever been stung by lionfish?

**(*If they catch lionfish*) Since you said you have caught lionfish before I would be interested in hearing more about your experiences.**

a. How long have you been spearing lionfish?
b. Why did you start spearing lionfish (major reasons)?
c. What do you do with the lionfish once you have speared them?
d. Do you own equipment that is specially used to catch lionfish? If so, what is it?
e. Where there any hesitations or barriers for you to catch lionfish?
g. How did you overcome them?
h. Where did you learn about them/how to handle them?
i. What would encourage you to catch more lionfish?
j. (If they have sold lionfish) How much do you get for lionfish per pound?
    1. Is this whole or fillet?
k. Who do you sell to? (middleman/captain/restaurant/co-op/other?)

**(*If they don't catch lionfish*) Since you said you have *not* caught lionfish before, I would be interested in understanding why not.**

a. If training was offered to show how to catch and prepare lionfish, would you be interested in learning?
b. What is the main reason you have never fished for lionfish? (lack of equipment, lack of knowledge, no interest)
c. Have you heard of other fishers targeting lionfish?
    1. If so, do you know what communities he/she is from?

**Barriers ranking exercise**

Ask people to rank their main barriers to lionfish fishing – you can use index cards to do so.

What would you say were/are the BIGGEST barriers for you to catch lionfish

Are there other barriers that other fishermen have?

**(4) DETERMINING PRICE POINT**

**The next few questions are aimed trying to understand how important the cost of fish is to you as a fishermen.**

a. If other fish/lobster/conch become less available, would you consider catching lionfish?
b. What is the lowest price you would receive per pound for lionfish you bring in?
    1. Would that be whole or fillet of lionfish?
c. What would it take for you to go out and begin catching lionfish? (more training, equipment, higher selling point?)
d. What do you think it would it take for more fishermen to start or catch more of lionfish?
e. Are you concerned about lionfish in any way? (affect other fish/lobster populations, harmful to habitat)
f. In your opinion, is it better to sell at market, to a co-op or straight to a restaurant/resort?

Thank you so much for your time and sharing your fishing experiences with me. Is there anything else you would like to talk about that I haven't covered? If you have any questions or would like follow up from this study on results, please feel free to contact me. [Provide with contact information]. If you would like to enter into a raffle to win a fishing-related prize, you can provide me with your telephone number and/or address. Prizes to win include a lionfish speargun, gloves, knife/scissor, etc. The raffle information will be kept separate from this interview and I will hold the drawing on [date]. This is optional and you don't have to participate if you don't want to. Also, if you do or are interested in catching lionfish, here is contact information to get in touch with Blue Ventures who can get you in touch with individuals looking to purchase lionfish.

## Appendix 7: Restaurant Questionnaire Outline

Author: M.L. Fruitema

Surveyor Initials: ________

Restaurant Name: ________ Location (district): ________

**Survey Respondent Information**

Q1. Sex: Male / Female

Q2. Age category:
A. 18-24 B. 25 -34 C. 35-44 D. 45-54 E. 55+

Q3. What is your position at this restaurant? Owner / Manager / Chef / Other: ________

Q4. Where are you from? Belize / USA / Other: _________

Q5. How long have you owned or worked at this restaurant?
A. 0 – 1 years B. 1 – 2 years C. 2 - 4 years D. 4 – 6 years E. 6 – 10 F. 10 +

**Restaurant Information:**

Q6. What is the seated capacity of the restaurant?
A. <10 B. 10-20 C. 21-40 D. 41-60 E. 61-80 F. >80

Q7. How would you characterize your target clientele?
100% tourist / tourist & expatriate / expatriate & Belizean / 100% Belizeans / Other: ______

Q8. How would you characterize the cuisine?
Caribbean/ Indian/ Chinese/ Western/ Vegetarian / Fast Food / Other: ______

Q9. Do you serve seafood dishes? Y / N
a. If Yes, what kind of seafood:
b. If No, why not:

Q10. What is the average price of a main dish (BZD)?
A. 10 – 15 B. 16 – 20 C. 21 – 25 D. 26 -30 E. 31 – 35 F. >35

Q11. What is your most expensive dish? ________________________________
a. Its price (BZD)?
A. 10-15 B. 16-20 C. 21-25 D. 26-30 E. 31-35 F. >35

**LF Questions:**

Q12. Have you heard of lionfish before? Y / N

Q13. Have you eaten lionfish before? Y / N
→ IF NO: Jump to Q17.
→ IF YES: continue below

Q14. On a scale of 1 to 5, how much did you like it?
1. 1 2 3 4 5

Q15. What does lionfish taste like to you? (select all that apply)
a. Snapper b. Grouper c. Lobster d. Hogfish e. Other: ______

Q16. Would you choose lionfish instead of:
a. Snapper: Y/ N
b. Grouper: Y/ N
c. Lobster: Y/ N
d. Hogfish: Y/ N
→ Jump to Q18

Q17. Why have you not eaten lionfish before?
a. It is unsafe to eat
b. I am afraid to try it
c. never had an opportunity
d. somebody I know did not like it
e. other: ______

Q18. Have you ever served lionfish at this restaurant? Y / N
→ IF NO: Jump to Q30.
→ IF YES: continue below

Q19. How often have you served lionfish?
a. Don't anymore
b. irregularly (< 5 x / year)
c. only during tourist high season (Nov – April)
d. consistently (at least once every month)
e. regularly (at least twice every month)
f. I keep it on my main menu

Q20. When was the last time you served lionfish?
A. Less than 1 month
B. Last 6 months
C. 6 months – 1 year
D. 1 – 2 years
E. 2 - 3 years
F. 3 years +

Q21. When did you first start serving lionfish?
A. Less than 1 month
B. Last 6 months
C. 6 months – 1 year
D. 1 – 2 years
E. 2 - 3 years
F. 3 years +

Q22. Why did you first start serving lionfish? (select all that apply)
A. Good for the environment
B. Sell at a high price
C. Good quality fish
D. Popular with customers
E. Other: ______

Q23. How popular were the lionfish dishes with your customers on a scale of 1-5, with 1 being very unpopular and 5 being very popular?
1 2 3 4 5

Q24. How do you buy the lionfish? Filleted / Whole

Q25. Do you buy all sizes? Y / N

Q26. How many pounds of lionfish, on average, did/do you buy?
Week / Month: ______ lbs

Q27. How do you acquire the lionfish?
A. Directly from fisher
B. Fishing cooperative
C. Seafood distributor / middleman
D. Other: ______

Q28. How much do you pay per pound?
Filleted:______
Whole: ______

Q29. How much do you sell a lionfish dish for?
A. 10 – 15 B. 16 – 20 C. 21 – 25 D. 26 -30 E. 31 – 35 F. >35
→ Jump to Q35

Q30. Why have you never served lionfish at this restaurant (select up to three answers)
A. Unsafe to eat
B. Too expensive
C. Don't know where to buy
D. Can't supply enough
E. Customers won't buy it
F. Doesn't match our cuisine
G. Other: ______

Q31. Do you know of other restaurants serving lionfish? Y / N

Q32. Would you be interested in trying to serve lionfish as a specials dish? Y / N

Q33. Why are you interested in trying lionfish as a specials dish? (select all that apply)
A. Good for the environment
B. Sell at a high price
C. Good quality fish
D. Popular with customers
E. Other:

Q34. Why are you not interested in trying to serve lionfish as a specials dish? (select up to three answers)
A. Unsafe to eat
B. Too expensive
C. Don't know where to buy

D. Can't supply enough
E. Customers won't buy it
F. Doesn't match our cuisine
G. Other: ______

Q35. For each of the following statements, select the response that is closest to how you feel.
A. Strongly Disagree B. Disagree C, Undecided D. Agree E. Strongly Agree

- I want to include lionfish on my standard menu
- I only want to serve lionfish as a special (<2 x month)
- I could easily include lionfish in our menu/cuisine
- I am not interested in changing my menu
- Customers will pay more for a lionfish special than my standard dishes
- I would sell lionfish dishes at the same price or higher than lobster
- Restaurants should only serve sustainable seafood
- Local fishermen are an important aspect of Belize's culture
- My customers care about responsible social and environmental practices
- My business will increase by promoting sustainable practices
- Belizeans will never eat lionfish
- The abilities of my waiting staff is crucial in the success of 'specials' dishes
- My waiting staff are trained to promote and sell 'specials' dishes

Q36. Would you be interested in marketing materials to help you further promote lionfish? Y / N
→ If yes, go to Q37

Q37. What is the most reliable form of communication?
a. Phone: ______
b. Email: ______

Thank you for participating in our survey!

# Appendix 8: Consumer Questionnaire Outline

Authors: J.L. Sabattis, P. Krening, J. Solomon

**Screening Questions-**

*Screening Q1.* Are you 18 years of age or older?
[if yes continue; if no thank respondent for their time]

*Screening Q2.* Are you a resident of Belize? (1 year or more)
[if yes continue; if no thank respondent for their time]

**Metadata-**

Date________
[dd/mm/yyyy]
Researcher_________
[0:JS 1:PK 2:other]
Location_________
[0:Belize City, 1:Belmopan, 2:Benque, 3:Corozal, 4:Dangriga, 5:Orange Walk, 6:Punta Gorda, 7:San Ignacio, 8:San Pedro, 10: Santa Elena 11:Sarteneja]
Time start_________
[hh:mm]
Time end_________
[hh:mm]

**Seafood Consumption-**

***I'm going to ask you a series of questions about seafood***

Q1. Do you eat seafood? (This includes fish, lobster or conch) (*Screening question*)
[select one]
No [0]
Yes [1] (if no continue to Q8.)

Q2. How often do you eat seafood at home?
[select one]
Three or more times in one week [0]
Once or twice in one week [1]
Once or twice in one month [2]
Once every 2 to 3 months [3]
Never [4]

Q3. How often do you consume seafood at a restaurant?
[select one]
Three or more times in one week [0]
Once or twice in one week [1]
Once or twice in one month [2]
Once every 2 to 3 months [3]
Never [4]

Q4. What are the reasons you choose to eat seafood? [Select 'primary' one]

Because I believe it is healthy [0]
Because I like the way it tastes [1]
Because it is a more environmentally friendly choice than other meats [2]
Because of cultural reasons [3]
Because it is commonly available [4]
Other________ [open ended response; coded]

Q5. What type of fish do you eat the most?
[open ended; coded]

Q6. Why do you eat [said fish] the most?
[open ended; coded]

Q7. Have you heard of lionfish?
[if yes continue; if no skip to Q23]
No [0]
Yes [1]

Q8. Have you ever tried eating lionfish?
No [0]
Yes [1] (skip to Q10)

Q9. Could you tell me why you have not tried lionfish?
[open ended] (skip to Q21)

Q10. Have you eaten lionfish more than once?
[select one]
No [0]
Yes [1]

Q11. Have you ever purchased lionfish?
[select one]
No [0]
Yes [1]

Q12. Where did you first eat lionfish? (frequency)
[Select one]
Home [0]
Restaurant [1]
Sponsored event [2]
Party [3]
Other________ [open ended response; coded]

Q13. In what year did you first try lionfish?
[Open ended]

Q14. When thinking about the first time you tried Lionfish, were you…
[Select one]
One of the first to try it [0]
You tried it after SOME friends/family tried it [1]
You tried it after MANY friends/family tried it [2]
Were you very reluctant to try it [3]

Q15. How much would you pay for a pound of lionfish at the market?
[open ended amount]

Q16. How much would you pay for a bowl of lionfish ceviche?
[open ended amount]

Q17. How much would you pay for a lionfish fillet with a plate of rice and beans?
[open ended amount]

Q18. If you were offered a free sample of lionfish at the market, would you try it?
[select one]
No [0]
Yes [1]
Undecided [2]

Q19.Could you tell me why you would not try lionfish?
[open ended]

**Level of Knowledge-**

***Now I want to ask you a few questions about lionfish…***

Q20. How much do you know about lionfish?
[select one]
None [1]
A little bit [2]
Some [3]
Quite a bit [4]
A lot [5]

Q21. I am going to give you 7 statements, please tell me whether you think they are "***True*** *" OR "* ***False*** *".*
[select one]
True [2]
False [0]
Uncertain [1]

Lionfish have always been in Belize's waters (F)
Lionfish are bad for the reefs (T)
Lionfish are moving to new areas (T)
Lionfish can't be handled (F)
People die from lionfish stings (F)
Lionfish threaten Belize's fishing industry (T)
Lionfish meat is safe to eat (T)

**Attitudes and Perceptions-**

Q22. Please state how much you AGREE or DISAGREE with the following statements about lionfish.
[select one]
Strongly disagree [1]
Somewhat disagree [2]
Undecided [3]
Somewhat agree [4]
Strongly agree [5]

I would purchase lionfish if I knew it had a benefit for the reef…
I like other fish too much to buy lionfish…
Belizeans will never eat lionfish…
I would purchase lionfish if I knew it benefited local fishermen…
Even if lionfish was commonly available I probably wouldn't buy it…
Lionfish is currently too expensive...
I would purchase lionfish if it was regularly available…
I would pay more for a Belizean product than for a similar, but less expensive one from somewhere else...
I am worried about lionfish…

[if they somewhat or strongly agree] ask the following statement
Q 22a. Since you agreed, could you tell me why you are worried? [open ended]

Q23. Please state how much you AGREE or DISAGREE with the following statements about your eating habits....
[select one]
Strongly disagree [1]
Somewhat disagree [2]
Undecided [3]
Somewhat agree [4]
Strongly agree [5]

I do not trust new foods… (attitude)
I will eat almost anything...
When considering what food to buy my main consideration is how much it costs… (attitude)
Fish is too expensive… (attitude)
I am curious to try new foods… (attitude)
I like to try new recipes

**Information Networks-**

Q24. What source of media to you get MOST of your information from?
[select one]
Social media (fb, twitter, etc.) [0]
Radio [1]
TV News [2]
Newspaper [3]
Internet news (other than social media) [4]
Word of mouth [5]
School [6]
Other [open ended response; coded]

**Sociodemographic-**

***Finally, I would like to ask you some questions about yourself...***

[researcher selects]
Female [0]
Male [1]

Q25. What is your age?
[Select range]

Q26. What is your cultural identity?
[Select one]
Mestizo/Latino [0]
Creole [1]
Mayan [2]
Garifuna [3]
East Indian [4]
Caucasian [5]
Other [open ended; coded]

Q27. What is the name of your community?
[open ended response; coded]

Q28. What district is that in?
[open ended response; coded]
Corozal [0]
Orange Walk [1]
Belize [2]
Cayo [3]
Stann Creek [4]
Toledo [5]

Q29. Please tell me YES or NO if you have the following in your house...
No [0]
Yes [1]

[select all that apply]
1 Vehicle (inc. motorcycle)
2 Vehicles (inc. motorcycle)
3 Vehicles (inc. motorcycle)
A bicycle
A cell phone
TV
Microwave
Refrigerator
Washing machine
Computer

***I am going to ask you a few questions about your house...***
Q30. What is your roof made of
[Select one]
metal [3]
concrete [2]
thatch [1]
other

Q 31. What are your walls made of
[Select one]
concrete [2]
wood [1]
other

Q32. What are your floors made of
[Select one]
concrete [3]
wood [2]
dirt [1]
other
What was the “other” you mentioned?

Q33. What is your occupation?
[open ended response; coded]

Q34. What is the primary job that provides income for your household?
[open ended response; coded]

Q35. What is the highest level of formal education you have achieved?
[choose one]

Pre-school [0]
Primary school [1]
Secondary/high school [2]
6th form/Jr. college/ associate's degree [3]
Bachelors [4]
Masters/Ph.D. degree [5]

# Appendix 9: Lionfish Population Model Description

Author: A.K. Bogdanoff

This section describes the development of an age-structured population model designed to estimate the abundance and biomass of lionfish under different management scenarios. The objectives of this modelling exercise were to provide the Belize Fisheries Department with a baseline population dynamics model to begin managing lionfish as a fishery resource and to identify data gaps and needs for developing and performing more sophisticated population dynamic and stock assessment models.

Since lionfish are not currently managed as a fishery resource in Belize, neither a formal monitoring and research program nor the associated data currently exist. The model was therefore developed using data specific to lionfish in Belize where available, but drew heavily on information from other locations as a matter of necessity. While this inevitably creates some limitations to the accuracy of the model, the creation of a lionfish model that can later be improved upon as data become available is an important first step in the effective management of the lionfish fishery.

## Data sources

Data used to estimate population demographics and model parameters were sourced from a five-year dataset of lionfish sightings in BCMR. This dataset contains 5,528 estimates of lionfish size between 2011 and 2015, recorded during research and recreational dives by field staff and trained volunteer SCUBA divers[9]. The size structure was then converted to an age structure using an age-length key constructed from age-length data of lionfish from North Carolina (unpublished data via J. Potts of NOAA).

Initial (year 0/current) abundance was estimated from lionfish focussed search (LFS) surveys (see Chapter 3, Belize Lionfish Management Strategy), estimated per reef type and then scaled using a detailed reef map of Belize produced by Coastal Zone Management Authority & Institute. As atolls were not represented in LFS surveys, one estimate has been made for the main barrier (including backreef areas) and one estimate has been made for the total reef area of Belize (including atolls).

- Estimate for the main barrier and backreef areas only (36678.792 ha, 427201 lionfish)
- Estimate for Belize's total reef area (main barrier, backreef areas and atolls, 60703.913 ha, 733257 lionfish)

---

[9] Anderson LG, Chapman JK, Escontrela D, Gough CLA (2017) The role of conservation volunteers in the detection , monitoring and management of invasive alien lionfish. Management of Biological Invasions 8(4): 589-598

## Model description

An age-structured population model was developed for lionfish in Belize. This type of model was deemed appropriate because it can be easily updated and will provide higher quality output as new data become available in Belize.

The model was structured to predict age-specific abundance and biomass through time. The number of recruits in each time step of the model was calculated using the Beverton-Holt stock-recruitment function:

*(eq. 1)* $$\text{Number of recruits} = (0.8 * R0 * h * S) / (0.2 * R0 * Phi.0 * (1 - h) + S * (h - 0.2))$$

where *R0* is the asymptotic recruitment for age 1's in the population, *h* defines the steepness of the relationship curve, *S* is the number of spawners (eggs), and *Phi.0* is the number of spawners per recruit in an unfished population.

*R0* is a scaling factor used to estimate recruitment rate to an unfished population. This number is rarely known. We used the two initial (year 0/current) abundance estimates described above to back calculate R0 for each scenario (see Scenario Planning table below).

*h* defines the steepness of the Beverton-Holt spawner-recruit relationship. This number typically does not have empirical data to define it so it is commonly assumed in population models. We assumed a value of 0.75, which is similar to other reef fishes including rock fish and scorpionfish (Scorpaenidae) on the U.S. West Coast.

*S* defines the number of eggs per female at each age in each year. Values of *S* were assumed based on a linear increase between two bounds. The bounds used were 1,024,000 eggs for age-1 and 3,924,000 eggs for age-4+. These estimates of fecundity were derived from J. Morris' fecundity study (unpublished) from North Carolina and the Bahamas. *Phi.0* is the number of spawners per recruit in an unfished population and was calculated for each age in each time step.

Lionfish aging studies have not been conducted in Belize. As such, Belize-specific length-at-age data do not exist. The age structure of the population in Belize was determined by converting size structure to age structure using an age-length key. The age-length key was constructed using lionfish length-at-age data from North Carolina, USA, which was kindly provided by J. Potts of NOAA. The North Carolina length-at-age data was binned into 25 mm size bins from 0 – 500 mm, and the proportion of fish at ages 1, 2, 3, and 4+ years that fell into each size bin was determined. Lionfish in North Carolina, and elsewhere in the Caribbean, become sexually mature at age 1. Based on the age-length key, all individuals ≤75 mm were not included in the model as they were not considered to be sexually mature (i.e., were considered age 0). A plus group (e.g., 4 +) was used because few fish in North Carolina were aged at 5 years and above. Combining these age classes into a plus group increased the range of sizes within the group.

| |
|---|
| Lionfish aging studies are needed in Belize to obtain a Belize-specific age-structure of the population. Once an aging study has been completed, the model can be updated. |

Sizes were pooled across years (e.g., 2011-2015) and categorised into 25 mm size bins from 0 – 500 mm. Using the age-length key from North Carolina (

Table 3), the proportionate number of individuals in each size bin was aged accordingly (Figure 2). Sizes were pooled across years to account for annual variability in age structure and to simplify the model.

| |
|---|
| As the commercial market for lionfish expands, fishery-dependent and fishery-independent surveys of lionfish size will be required. Once the Belize-specific age data become available, lionfish sizes can be converted to age using a Belize-specific age-length key. |

Fish sex data were available for (n=375) individuals that were collected and sexed between 2011 – 2016. These individuals were captured in the BCMR[10], GSSCMR[11], and SCMR[12]. Population sex structure was determined by pooling all available data on lionfish sex in Belize. Of the 375 individuals,

[10] Raw data provided by Blue Ventures (Anderson et al., 2017, ibid)
[11] Raw data collected at annual Placencia Lionfish Tournament, provided by Blue Ventures
[12] Raw data provided by ReefCI

49% (n=184) were females and 51% (n=191) were males. The sex ratio observed in Belize is similar to other areas in the Caribbean[13].

Table 3: Age-length key used to convert annual lionfish size structure in Belize to annual age structure.

| | Proportion of fish in each age class | | | |
|---|---|---|---|---|
| TL (mm) | 1 | 2 | 3 | 4+ |
| 0-25 | 0.00 | 0.00 | 0.00 | 0.00 |
| 26-50 | 0.00 | 0.00 | 0.00 | 0.00 |
| 51-75 | 0.00 | 0.00 | 0.00 | 0.00 |
| 76-100 | 1.00 | 0.00 | 0.00 | 0.00 |
| 101-125 | 1.00 | 0.00 | 0.00 | 0.00 |
| 126-150 | 1.00 | 0.00 | 0.00 | 0.00 |
| 151-175 | 1.00 | 0.00 | 0.00 | 0.00 |
| 176-200 | 1.00 | 0.00 | 0.00 | 0.00 |
| 201-225 | 0.82 | 0.18 | 0.00 | 0.00 |
| 226-250 | 0.43 | 0.51 | 0.05 | 0.00 |
| 251-275 | 0.06 | 0.84 | 0.10 | 0.00 |
| 276-300 | 0.01 | 0.81 | 0.17 | 0.01 |
| 301-325 | 0.01 | 0.73 | 0.24 | 0.02 |
| 326-350 | 0.00 | 0.45 | 0.47 | 0.08 |
| 351-375 | 0.00 | 0.17 | 0.53 | 0.30 |
| 376-400 | 0.00 | 0.05 | 0.46 | 0.49 |
| 401-425 | 0.00 | 0.00 | 0.28 | 0.72 |
| 426-450 | 0.00 | 0.00 | 0.09 | 0.91 |
| 451-475 | 0.00 | 0.00 | 0.00 | 1.00 |
| 476-500 | 0.00 | 0.00 | 0.00 | 0.00 |

[13] Edwards MA, Frazer TK, and Jacoby CA. (2014) Age and growth of invasive lionfish (Pterois spp.) in the Caribbean Sea, with implications for management. Bulletin of Marine Science 90(4): 953-966.

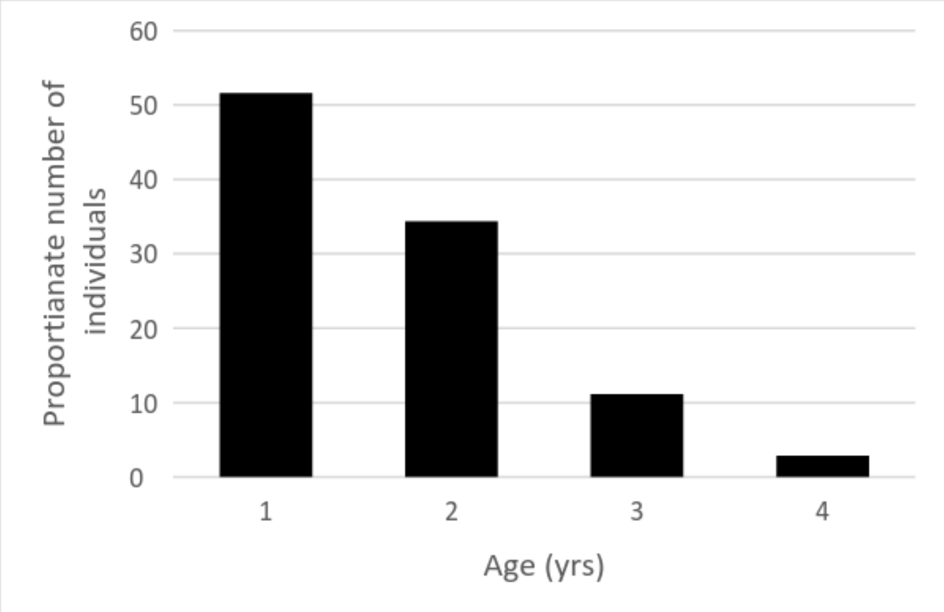


Figure 2: Age structure of the population used to initialize the model.

Growth parameters for lionfish have been estimated in North Carolina[14], The Cayman Islands[15], and Mexico[16], but not in Belize. Growth parameters used to initialize the model were those from North Carolina (Belize-specific length-weight relationships (e.g., parameters “a” and “b”) were determined using length-weight data from lionfish captured in the BCMR and GSSCMR. Length and weight data was available for (n=352) individuals of both and unknown sexes. Length-weight parameters used to initialize the model were with both sexes and unknown sexes combined (**Table 4**, **Figure 3**). The relationship between length and weight was determined by fitting a power function to the relevant data:

*(eq. 3)* $$\textit{Total weight (g)} = a * \textit{Total length (mm)}^{b}$$

[14] Unpublished data of J. Potts (NOAA)
[15] Edwards et al. 2015 (ibid)
[16] Rodriguez-Cortes KD, Aguilar-Perera A and Bonilla-Gómez JL (2015) Growth and mortality of red lionfish, Pterois volitans (Actinopterygii: Scorpaeniformes: Scorpaenidae), in the Parque Nacional Arrecife Alacranes, southern Gulf of Mexico, as determined by size-frequency analysis. Acta Ichthyologica et Piscatoria 45(2): 175.

**Table 4**). This was done so that the growth parameters aligned with the age-length key used. Age and length data from North Carolina were used to model growth by estimating the parameters in the von Bertalanffy growth equation:

*(eq. 2)* $$L_t=L_\infty(1-e^{-K[t-t_0]})$$

where Lt= length at age (t), L∞= asymptotic maximum length, K = the Brody growth coefficient of growth toward L∞, and t0 = the theoretical age at which a fish would be 0 mm in length. Growth in North Carolina was estimated with males, females, and unknown sexes combined. In addition to initializing the model with growth estimates from North Carolina, we have coded the population model so that the user may choose which growth characteristics to use, or all can be used separately to model a range of estimates. Growth parameter estimates from the Cayman Islands and Mexico were derived from the original studies. Belize-specific lionfish growth rates can be derived from aging studies[17].

Belize-specific length-weight relationships (e.g., parameters "a" and "b") were determined using length-weight data from lionfish captured in the BCMR[18] and GSSCMR[19]. Length and weight data was available for (n=352) individuals of both and unknown sexes. Length-weight parameters used to initialize the model were with both sexes and unknown sexes combined (**Table 4**, **Figure 3**). The relationship between length and weight was determined by fitting a power function to the relevant data:

*(eq. 3)* $$\text{Total weight (g)} = a * \text{Total length (mm)}^b$$

[17] E.g. Edwards et al. 2015 (ibid)
[18] Raw data provided by Blue Ventures (Anderson et al., 2017, ibid)
[19] Raw data collected at annual Placencia Lionfish Tournament, provided by Blue Ventures

Table 4: Parameters used to initialize the model

| Parameters | Description | Value | Data Source |
|---|---|---|---|
| Recruitment | | | |
| *R0* | average annual unfished recruitment | Varies by scenario | Estimated from initial abundance surveys |
| Natural Mortality | | | |
| M | instantaneous natural mortality (yr-1) | 0.2 | Estimated from catch curve analysis |
| Fishing Mortality | | | |
| F | Instantaneous fishing mortality (yr-1) | 0.173 | Estimated from catch curve analysis and fisher survey data |
| Growth | | | |
| $L_\infty$ | asymptotic length (mm) | 441.5 | J. Potts raw data |
| K | metabolic coefficient (yr-1) | 0.45 | J. Potts raw data |
| $t_0$ | theoretical age at size 0 (mm) | -0.31 | J. Potts raw data |
| Length-Weight | | | |
| a | Length-weight coefficient | 0.000007 | This study |
| b | Length-weight exponent | 3.11 | This study |

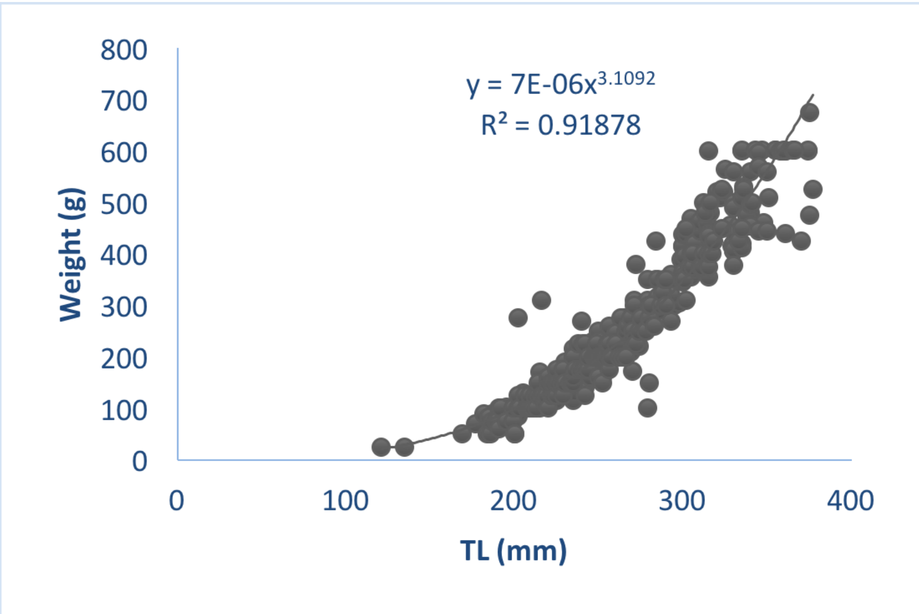


Figure 3: Length-weight relationship with males, females, and unknown sexes combined (n=352)

Instantaneous natural mortality (M) and fishing mortality (F) are unknown for lionfish in Belize and elsewhere in the Caribbean. The parameter (M) in this model was assumed to equal to 0.2, which is a value that has been used in other published lionfish models[20]. A catch curve analysis was then performed using data from Belize[21]. The catch curve analysis provided an estimate of total morality (Z), which was found to equal 0.4. Since Z = M + F, we estimated F to equal 0.2. Blue Ventures also estimated F (see Chapter 3, Belize Lionfish Management Strategy), which was close to the estimate of 0.2. As such, F was initialized in the model to equal 0.2. A range of values for M and F can be used in the model if desired.

More robust and long-term catch data is needed to obtain more accurate estimates of F.

[20] E.g. Barbour AB, Allen MS, Frazer TK and Sherman KD (2011) Evaluating the potential efficacy of invasive lionfish (Pterois volitans) removals. PloS one 6(5): e19666

[21] Raw data provided by Blue Ventures (Anderson et al., 2017, ibid)

# Appendix 10: Lionfish Population Model Code

Author: A.K. Bogdanoff, K. Shertzer

```
#Appendices
#Appendix 1: Lionfish Population Model Code for R
########################################################################################
###################################################

#Lionfish Age-Structured Population Model
#Written: 7 June 2017
#F values updated by JKC based on updated estimates as presented LF Strategy in Nov 2017
#Added model output as csv file fname3 for population size structure
#Set to 10 years

########################################################################################
####################################################

#Clear existing code
graphics.off()
rm(list=ls(all=TRUE))

########################################################################################
####################################################

#Beverton-Holt (B-H) Stock-Recruitment (S-R) Function
BH.fcn<- function(S,h,R0,Phi.0)
{
  recruits=(0.8*R0*h*S)/(0.2*R0*Phi.0*(1-h) + S*(h-0.2))
  return(recruits)
}
#Beverton-Holt S-R model gives the expected number of individuals in time-step t + 1 as
a function of the number of individuals in the previous time step.
#S is spawners (in eggs).
#h parameter defines the steepness of the curve (how quickly it asymptotes).
#R0 parameter is asymptotic recruitment for age 1's in the population.
#Phi.0 is number of spawners per recruit in an unfished population.
#The numbers in the above function are part of the function itself.

########################################################################################
####################################################

##### THIS IS THE "KNOB" TO TURN. SEE "SCENARIO INPUT VALUES" FOR
VALUES###############################################
########################################################################################
###############################

#Set fishing mortality (F), initial abundance (R0), and the number of recruits in year 1
(N1.init) values based on scenario of interest (see "Scenario Input Values").
F.init=0.2 #This is the F value used to initialize the population in year 0 (i.e., an
unfished population). We estimated total mortality (Z) to equal 0.4 using a catch curve
analysis of lionfish captured in Bacalar Chico. F.init=Z-M.

F.large.1=0.230 #F for age 2+ in years 1 and 2
F.small.1=0.048 #F for age 1 in years 1 and 2

F.large.2=0.230 #F for age 2+ in years 3+
F.small.2=0.048 #F for age 1 in years 3+

F.1=F.large.1 # Defines variable F.1 to be used in the selectivity below
F.2=F.large.2 # Defines variable F.2 to be used in the selectivity below

R0=252558     #Average annual unfished recruitment. This number helps scale the size of
the population. The number that is used here will vary based on the estiamted unfished
abundace. Obtain the R0 values from the "R0 May 4 2017" code that optimizes the values
of R0 based on the set initial abudance. A range of values (based on a range of intial
abundance estiamtes) can be used if desired.
N1.init=226815 #Recruits in year 1. Solved using the R0 estimation code.
```

```
####################################################################################
################################
####################################################################################
################################

#Additional Population Parameters
M=0.2  #Age-independent natural mortality. This value is unknown for lionfish. A range
of estimates can be used.
h=0.75 #Defines the steepness of the Beverton-Holt spawner-recruit relationship. This
number typically does not have empirical data to define it so it is commonly assumed in
population models. We assumed a value of 0.75, which is similar to other reef fishes
including rock fish and scorpionfish (Scorpaenidae) on the U.S. West Coast .
fec.scale=1e9 #Scaler. Scales population fecundity. Is really only for plotting purposes
as it helps reduce the scale of the figures.
fec.scale.txt=as.character(fec.scale) #Text string used for labeling plots.
AL.dat=read.csv(file="size-age.csv", header=T)#Tells R to read-in a csv file titled
"size-age".
AL.key=t(t(AL.dat[,2:5])/colSums(AL.dat[,2:5]))#Data table containing length-at-age data
for Belize. Length-at-age was estimated using an age-length key constructed from length-
at-age data from North Carolina. AL stands for age-length. This should be updated when
length-at-age data for Belize become available.

####################################################################################
###############################################

#Choose Growth Characteristics
Area="Bel"    #Options have been given so a wider range of scenarios can be modeled. The
location choice should be written here and in "quotes" to designate it as a character
string. Growth characteristic options are "NC"=North Carolina (estimated from Jennifer
Potts raw data), "CI"=Cayman Islands (derived from Edwards et al. 2013), "Mex"=Mexico
(derived from Rodriguez-Cortez et al. 2015), and "Bel"=Belize (uses length-weight
relationship from Belize (this study) and the other growth parameters are from NC (J.
Potts data)). The If/else statements below identify which location has been chosen.
if (Area == "Bel")
{
  Linf=441.5  #Asymptotic length from North Carolina length-at-age data
  K=0.45      #Growth coefficient from North Carolina length-at-age data
  a0=-0.31    #Theoretical age at size 0 from North Carolina length-at-age data
  a=0.000007   #Length-weight coefficient estimated for lionfish in Belize in this study
  b=3.11       #Length-weight exponent estimated for lionfish in Belize in this study
} else if (Area == "NC")
{
  Linf=441.5  #Asymptotic length in mm
  K=0.45      #Growth coefficient
  a0=-0.31    #Theoretical age at size 0
  a=7.97e-6   #Length-weight coefficient
  b=3.12      #Length-weight exponent
} else if (Area == "CI")
{
  Linf=349.0  #Asymptotic length in mm
  K=0.42      #Growth coefficient
  a0=-1.01    #Theoretical age at size 0
  a=0.000003  #Length-weight coefficient
  b=3.24      #Length-weight exponent
} else if (Area == "Mex")
{
  Linf=420.0  #Asymptotic length in mm
  K=0.88      #Growth coefficient
  a0=-0.107   #Theoretical age at size 0
  a=0.000005  #Length-weight coefficient
  b=3.33      #Length-weight exponent
} else
{
  print ("Error: Area not specified correctly.")
}

####################################################################################
################################################

#Create and fill matrices to be used in the population model
```

```
nyrs=10 #Choose any number of years you would like the model to run for
ages=1:4 #Choose the age structure of the population to be modeled. Modeled ages in this model are 1, 2, 3, 4+. This is fixed for the current model, but can be updated with future age data from Belize
nages=length(ages) #Calculates the number of ages based on "ages"
sizes= AL.dat$bin #Lets the model know that the csv file "AL.dat" contains length-at-age data that has been binned into 25 mm size bins
nsizes=length(sizes) #Calculates the number of sizes in AL.dat
N.age.size<-C.age.size<-array(data=NA, dim=c(nyrs, nages, nsizes),dimnames=list(1:nyrs, ages, sizes)) #Creates two 3-dimensional arrays with number of years, ages, and sizes
N.age<-C.age<-C.kg<-matrix(data=NA, nrow=nyrs, ncol=nages, dimnames=list(1:nyrs, ages))
#Creates three matrices with the number of ages by year
N.size<-C.size<-matrix(data=NA, nrow=nyrs, ncol= nsizes, dimnames=list(1:nyrs, sizes))
#Creates two matrices with number of sizes by year

N.age.size.F0<-matrix(data=NA, nrow=nages, ncol=nsizes) #Creates a matrix containing sizes at age in an unfished state
N.size.F0<-rep(NA, nsizes) #Creates a vector of the size structure of the unfished population
N.tot.knum<-C.tot.knum<-C.tot.mt<-rep(NA,nyrs) #Creates three vectors to store total abundance and catch in a given year by summing abundance and catch across each age

TL=Linf*(1-exp(-K*(ages-a0))) #Calculates the von Bertalanffy growth function
M.age=rep(M,nages) #Applies the value for "M" across all ages. "M" is assumed to be constant at 0.2 across all ages
fec.age=seq(1024000, 3924000, length=4)/fec.scale #Defines the number of eggs per female at each age in each year. We assumed a linear increase between the bounds. The bounds of 1,024,000 and 3,924,000 were derived from J. Morris' fecundity study from the Bahamas (unpublished) and assumed here to represent fecundity in age 1 fish and age 4+ fish
mat.age=rep(1, nages) #Defines at what age lionfish become mature in the model. In this model, all fish at age 1 and above are considered mature

W.g=a*TL^b  #Weight-length relationship. Weight is in grams and total length is in mm
W.kg=W.g/1000 #Weights converted to kilograms

##########################################################################################
################################################

#Define the selectivities for the different size/age classes
if (F.1>0) {
  selex.1=c(F.small.1/F.large.1,1,1,1) #Means that age 1 selectivy = (F.small.1/F.large.1), age 2 = 1, age 3 = 1, and age 4+ = 1
} else {(selex.1=rep(1,4))}
if (F.2>0) {
  selex.2=c(F.small.2/F.large.2,1,1,1)
}

##########################################################################################
##############################################

#Compute the number of spawners per recruit at time 0 (i.e., in an unfished population)
N.pr=rep(1,nages)#Defines the number of spawners per recruit

for (a in 1:(nages-1))
{
  N.pr[a+1]=N.pr[a]*exp(-M.age[a])
}             #Calculates the number of spawners per recruit in each age
N.pr[nages]=N.pr[nages]/(1-exp(-M.age[nages])) #Tells the model that the last age is a plus (+) group
Phi.0=sum(N.pr*0.49*mat.age*fec.age) #Calculates the number of spawners per recruit. We chose a value of 0.49 for females here based on the estimated sex ratio of the population in Belize

for (a in 1:nages)
{
  N.age.size.F0[a,1:nsizes]=N.pr[a]*AL.key[,a]
}             #Unfished abundance at size for each age
N.size.F0=colSums(N.age.size.F0)#Defines unfished abundance-at-length in 25 mm bins. This vector gets re-normalized later to sum to one
```

```
###########################################################################################
##############################################

#Compute the number of spawners per recruit at year 1 (i.e., initializes a "fished"
population)
N.init=rep(NA,nages)#Initialize vector of initial abundance
N.init[1]=N1.init #Set initial recruits
Z.init=F.init*selex.1 + M #Set initial total mortality

for (a in 1:(nages-1))
{
  N.init[a+1]=N.init[a]*exp(-Z.init[a])
}             #Compute initial abundance at each age
N.init[nages]=N.init[nages]/(1-exp(-Z.init[nages]))#Plus (+) age group correction
N.age[1,]=N.init#Set initial abundance at age equal to the initialization values
computed above

for (a in 1:nages)
{
  N.age.size[1,a,1:nsizes]=N.age[1,a]*AL.key[,a]
}             #Abundance at size at each age
N.size[1,]=colSums(N.age.size[1,,])#Abundance at size
C.age[1,]=F.init*selex.1/Z.init*N.age[1,]*(1-exp(-Z.init))#Compute catch using the
Baranov catch equation
C.kg[1,]=C.age[1,]*W.kg#Calculates the total weight of the catch at each age

for (a in 1:nages)
{
  C.age.size[1,a,1:nsizes]=C.age[1,a]*AL.key[,a]
}             #Calculate catch at size for each age
C.size[1,]=colSums(C.age.size[1,,]) #Calculates the number of fish caught at each size

###########################################################################################
########################################

#Compute the number of spawners per recruit for each subsequent year in the model
SSB=rep(NA,nyrs)#Initialize SSB vector over projection years
for (y in 1:(nyrs-1))
  {
  if (y<=2) {F=F.1; selex=selex.1;
  } else {F=F.2; selex=selex.2} #this if/else statement hardwires the change in F
starting in year 3. The code can be modifed to implement a switch in mortality at any
defined year in the model.

  SSB[y]=sum(N.age[y]*0.49*mat.age*fec.age)#Compute SSB as total population fecundity
(49% female population absed on Blue Ventures data)
  N.age[(y+1),1]=BH.fcn(S=SSB[y],h=h,R0=R0,Phi.0=Phi.0)#Compute next year's age-1
recruits based on Beverton Holt S-R model
  Z.age=F*selex + M#Total mortality at age

for (a in 1:(nages-1))
  {
    N.age[(y+1),(a+1)]=N.age[y,a]*exp(-Z.age[a])#Abundance at age in each year
    N.age.size[(y+1),a,1:nsizes]=N.age[(y+1),a]*AL.key[,a]#Abundance at size for each
age in each year
  }

  N.age[(y+1),nages]=N.age[(y+1),nages] + N.age[y,nages]*exp(-Z.age[nages]) #Plus group
correction
  N.age.size[(y+1),nages,1:nsizes]=N.age[(y+1),nages]*AL.key[,nages]#Abundance at size
for the plus group
  N.size[(y+1),]=colSums(N.age.size[(y+1),,])#Abundance at size summed across ages
  C.age[(y+1),]=F*selex/Z.age*N.age[(y+1),]*(1-exp(-Z.init))#Catch at age
  C.kg[(y+1),]=C.age[(y+1),]*W.kg#Calculates the total weight of the catch at each age

for (a in 1:nages)
  {
    C.age.size[(y+1),a,1:nsizes]=C.age[(y+1),a]*AL.key[,a]
  }           #Catch at size for each age
  C.size[(y+1),]=colSums(C.age.size[(y+1),,])
```

```
  }           #Catch at size summed across ages
SSB[nyrs]=sum(N.age[nyrs]*0.49*mat.age*fec.age)#SSB in the last year of the simulation
C.tot.knum=rowSums(C.age)/1000#Total catch in each year, in units of 1000 fish
C.tot.mt=rowSums(C.kg)/1000#Total catch in each year, in units of metric tons
N.tot.knum=rowSums(N.age)/1000#Total abundance in each year, in units of 1000 fish

#####################################################################################

#For graphical display, compute S-R relationship
SSB.dum=seq(1,1.5*max(SSB))
rec.dum=BH.fcn(S=SSB.dum,h=h,R0=R0,Phi.0=Phi.0)

########################################################################################
################################################################

##Plot model output

#1) Stock-recruitment curve
yrs=1:nyrs
windows(width=8, height=10, record=T)
par(mfcol=c(3,2), las=0)
plot(SSB.dum, rec.dum/1000, main=paste("Beverton-Holt SR Curve"), xlab=paste("Population
fecundity (",fec.scale.txt, " eggs)",sep=""), ylab="Recruits per 1000 age-1 fish",
type="l", lwd=2, col="blue")

#2) Annual fecundity
points(SSB[1:(nyrs-1)], N.age[2:nyrs,1], cex=1.5, col="blue")
plot(yrs, SSB, xlab="Year", ylab=paste("Population fecundity (",fec.scale.txt, "
eggs)",sep=""), type="o", lwd=2, col="blue")

#3) Annual age-1 recruitment
plot(yrs, N.age[,1]/1000, xlab="Year", ylab="Recruits (1000 age-1 fish)", type="o",
lwd=2, col="blue")

#4) Annual population abundance
plot(yrs, N.tot.knum, xlab="Year", ylab="Abundance (1000 fish)", type="o", lwd=2,
col="blue")

#5) Annual Catch in #
plot(yrs, C.tot.knum, xlab="Year", ylab="Catch (1000 fish)", type="o", lwd=2,
col="blue")

#6) Annual catch in weight
plot(yrs, C.tot.mt, xlab="Year", ylab="Catch (mt)", type="o", lwd=2, col="blue")

#7) Annual population size structure
windows(width=8, height=10, record=T)
par(mfcol=c(3,2), las=1)
barplot(N.size.F0/sum(N.size.F0), main="Unfished population size structure",
names.arg=sizes+12.5, xlab="Length (mm)", ylab="Proportionate number of individuals")
#Provides estimates as proportions
for (i in 1:nyrs)
{
    barplot(N.size[i,], main=paste("Population size structure in year ", i, sep=""),
names.arg=sizes+12.5, xlab="Length (mm)", ylab="Number of individuals")
}

#8) Annual (F) values
windows(width=8, height=10, record=T)
par(mfcol=c(3,2), las=1)
plot(1:nages, F.1*selex.1, xlab="Age", ylab="Fishing Mortality (F)", type="o", lwd=2,
pch=1, col="blue", ylim=c(0,0.3))
lines(1:nages, F.2*selex.2, lwd=2, col="green", lty=2)
points(1:nages, F.2*selex.2, pch=2, col="green")
legend("topleft",legend=c("Yrs 0,1,&2", "Yr3+"), lwd=2, pch=1:2, col=c("blue","green"))

#9) Annual catch size structure
for (i in 1:nyrs)
{
```

```
    barplot(C.size[i,], main=paste("Catch size structure in year ", i, sep=""),
names.arg=sizes+12.5, xlab="Length (mm)", ylab="Number of individuals")
  }

#########################################################################################
############################################################
#Provides model output as csv file
fname=paste("out.",Area,".csv",sep="")
out=data.frame(yrs,SSB,N.tot.knum, C.tot.knum, C.tot.mt)
write.csv(out, file=fname, quote=FALSE)

fname2=paste("catch.",Area,".csv",sep="")
write.csv(C.size, file=fname2, quote=FALSE)

fname3=paste("pop.",Area,".csv",sep="")
write.csv(N.size, file=fname3, quote=FALSE)
```

# Appendix 11: R0 Model Code

Author: A.K. Bogdanoff, K. Shertzer

```
#################################################################################
#  Lionfish Compute initial N age 1 and for R0
#  This is simply a separate "semi-optimization" code to calculate initial abundance of
age 1s and R0. Estimated R0 values here should be entered into the Model code. The
estimated R0 values are APPROXIMATIONS BASED ON THE ESTIMATED ABUNDANCE
#  Written: 4 May 2017
#  Last updated: 7 June 2017
#################################################################################

#Clear existing code
graphics.off()
rm(list=ls(all=TRUE))

#################################################################################

#Observed abundance
N.obs=733257 #set this = 427201 for "main barrier and back reef" and to = 733257 for
"total reef area"


#Define Mortality Parameters
M=0.2  #Age-independent natural mortality. This value is unknown for lionfish. A range
of estimates can be used.
F.large=0.230 #F ages 2-4.
F.small=0.048 #F age 1.

#################################################################################
#Create and fill matrices to be used in the population model
ages=1:4      #Choose the age structure of the population to be modeled. Modeled ages in
this model are 1, 2, 3, 4+. This is fixed for the current model, but can be updated with
future age data from Belize
nages=length(ages) #Calculates the number of ages based on "ages"
h=0.75 #Defines the steepness of the Beverton-Holt spawner-recruit relationship.
M.age=rep(M,nages) #Applies the value for "M" across all ages. "M" is assumed to be
constant at 0.2 across all ages
fec.scale=1 #1e9     #Scaler. Scales population fecundity.
fec.age=seq(1024000, 3924000, length=4)/fec.scale#Defines the number of eggs per female
at each age in each year. We assumed a linear increase between the bounds. The bounds of
1,024,000 and 3,924,000 were derived from J. Morris' fecundity study (unpublished) and
assumed here to represent fecundity in age 1 fish and age 4+ fish
mat.age=rep(1, nages) #Defines at what age lionfish become mature in the model. In this
model, all fish at age 1 and above are considered mature
selex=c(F.small/F.large,1,1,1) #Defines the selectivity in period 1 of a fish at a given
age. In this model, all fish age 1 and above are considered vulnerable to fishing
Z.init=F.large*selex + M.age #Set initial total mortality
#################################################################################

N1.solve<-function(x, N.obs, nages, Z){ #This is the function used in the optimization,
to calculate initial age 1 fish (recruits)
  #N.obs=total abundance observed, nages=number of ages, Z=total mortality at age
  N.age=rep(NA,nages)#Initialize vector of abundance at age
  N.age[1]=x #Set initial recruits, the estimated parameter
  for (a in 1:(nages-1)) #Compute initial abundance at each age
    {N.age[a+1]=N.age[a]*exp(-Z[a])}
  N.age[nages]=N.age[nages]/(1-exp(-Z[nages]))#Plus group correction

  N.pred=sum(N.age) #Total abundance
  SSE=(N.obs-N.pred)^2 #Sum of squares error term to be minimized
  return(SSE)
}
#################################################################################
#Compute initial age 1 fish (recruits) using an optimization routine and assuming
equilibrium age structure
fit<-optimize(f=N1.solve,interval=c(1,N.obs), N.obs=N.obs, nages=nages, Z=Z.init)
R.eq=fit$minimum #equilibrium recruitment
```

```
#####################################################################################
#Compute R0

#First compute the number of spawners per recruit of an unfished population (Phi.0)
N.pr=rep(1,nages)#Defines the number of spawners per recruit
for (a in 1:(nages-1)) #Calculates the number of spawners per recruit in each age
  {N.pr[a+1]=N.pr[a]*exp(-M.age[a])}
N.pr[nages]=N.pr[nages]/(1-exp(-M.age[nages])) #The last age is a plus (+) group
Phi.0=sum(N.pr*0.49*mat.age*fec.age) #Calculates the number of spawners per recruit. We
chose a value of 0.49 for females here based on the estimated sex ratio of the
population in Belize

#Next compute the number of spawners per recruit of a population fished at the rate
(F.large and F.small) defined above (Phi.F)
N.pr=rep(1,nages)#Defines the number of spawners per recruit
for (a in 1:(nages-1)) #Calculates the number of spawners per recruit in each age
{N.pr[a+1]=N.pr[a]*exp(-Z.init[a])}
N.pr[nages]=N.pr[nages]/(1-exp(-Z.init[nages])) #The last age is a plus (+) group
Phi.F=sum(N.pr*0.49*mat.age*fec.age) #Calculates the number of spawners per recruit. We
chose a value of 0.49 for females here based on the estimated sex ratio of the
population in Belize

#R0 is a function of equilibrium recruitment, h, Phi.F, and Phi.0
scale=(4*h*Phi.F-(1-h)*Phi.0)/((5*h-1)*Phi.F)
R0=R.eq/scale

text1=paste("The estimate of R0 is ", round(R0,0), sep="")
print(text1)
text2=paste("The estimate of initial recruits (N1.init) is ", round(R.eq,0), sep="")
print(text2)
```

## Appendix 12: Social Marketing Campaign

Author: M. Fruitema

To better understand peoples' perceptions of lionfish and identify the social-emotional drivers upon which a campaign could be built, semi-structured interviews were conducted with community members. Topics covered tourism on the island, development trends and the island way of life, fishing culture and the branding & marketing of lionfish. Purposive sampling was used to interview individuals that represented three distinct groups in Caye Caulker:

1. Restaurant owners and chefs not serving lionfish (n= 4)
2. Fishers, seafood suppliers and consumers (n = 8)
3. Restaurant owners / chefs who had served lionfish at some point (n = 4)

Following these interviews, three campaign design concepts were developed and piloted individually with four separate restaurant managers in Caye Caulker who served lionfish. Each concept was designed to draw on the strongly held values uncovered in pre-campaign assessments and interviews.

**<u>Semi-Structured Interview Outline</u>**

**Caye Caulker**
What is unique about this destination? Why do people come here? What do you try to offer them that they can't get anywhere else in Belize? Why do you stay here over any other location?

**Lionfish**
Is lionfish a unique product / Y→how so / N→what are competitors

Why have you not served lionfish before (ranking, get at #1 barrier, emotional barrier, if this barrier was addressed, would you start serving lionfish?)

What would it take for you to start?
What do you not like about lionfish?
Are you aware that others serve lionfish? Has this made you consider it?

How do you see the market for lionfish? How do you see lionfish consumption in Belize? Will this change? (primary consumers, markets, sales points, necessary points for development) Do you think restaurants can play an important role in this?

**Functional/emotional benefits**
Do you think there are any benefits to serving lionfish?
How does the competition fare?
How important are emotional values to you as a restaurateur
    Do you value sustainability, or just in it to win it?

**Brand essence of lionfish**
Is there anything that makes lionfish stand out? Is there anything that makes it Belizean?
Is there anything that makes it Caye Caulker?

## Appendix 13: Promotional Materials for Community Consultations

PCC Flyer.pdf in here