Using Markets to Control Invasive Species: Lionfish in the US Virgin Islands

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ABSTRACT

Invasive lionfish are affecting reef ecosystems along the Gulf Coast and Caribbean. By establishing commercial fisheries and harvesting lionfish in mass, it may be possible to reduce their ecological footprint in the region. Nonetheless, there has been little research assessing the viability of a consumer market for lionfish meat. Using data collected in the US Virgin Islands (USVI), this study examines individuals' willingness to participate in a hypothetical market for lionfish meat and their potential consumption levels. Consumer willingness to pay (WTP) for lionfish meat is also estimated. Findings suggest that individuals' market participation and consumption levels are correlated with concerns for food safety and the environment, and consumer WTP is compatible with dockside prices of other species of reef fish. These findings suggest that a latent demand structure for lionfish meat may already exist in the USVI and that the prospect of a commercial fishery is worth additional exploration.

Key words: Consumer preferences, contingent valuation, double hurdle Poisson, invasive lionfish.
JEL codes: C24, Q21, Q22.

INTRODUCTION

There is scientific consensus that Earth's coral reefs are under environmental threat. According to a 2008 study by the Global Coral Reef Monitoring Network, an estimated 19% of Earth's coral reef systems have been lost, with an additional 15% expected to disappear in the following 10–20 years (Wilkinson 2008). Marine resource scientists attribute these losses to several factors, including rising sea temperatures, overfishing, and pollutants. Invasive species are another threat. Lionfish are causing environmental and economic damage throughout reef systems in the Atlantic and Caribbean (Albins and Hixon 2008, 2013). A carnivorous species of fish native to the Indo-Pacific, lionfish (*Pterois volitans*) have no natural predators along the Atlantic coast, Caribbean, and Gulf of

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Mexico, and thus nothing to keep their numbers from rapidly expanding and consuming other fish species (Huth, McEvoy, and Morgan 2018). Invasive lionfish are changing native marine habitats by depleting the populations of herbivorous fish that otherwise keep the coral reefs from being overrun by seagrass and algae. Furthermore, invasive lionfish prey on commercially valuable reef species such as grouper, snapper, and lobster that are essential to Caribbean fishing economies (Rocha et al. 2015). An estimated 42 million people in the Gulf of Mexico and Caribbean coastal areas are directly dependent on coral reef systems for their food and livelihoods; thus if the lionfish invasion continues, it is likely to bring substantial economic losses to the region (Waite 2011). Fishing derbies and organized culling events have succeeded at temporarily reducing lionfish populations in limited areas, but they are expensive, ad hoc, and have no documented long-term impact to date (Malpica-Cruz, Chaves and Cote 2016; Frazer et al. 2012).

One proposed solution to the lionfish problem is for people to consume them on a mass scale (Morris et al. 2011). If economically feasible, commercial lionfish fisheries could dramatically reduce the lionfish population and restore balance to the region's native ecosystems. For a commercial lionfish fishery to be economically viable, however, there needs to be a sufficient and sustainable demand for lionfish meat. In addition, consumers' willingness to pay (WTP) needs to exceed the fishery's production costs to make it worthwhile to harvest lionfish and for there to be enough quantity harvested to make an ecological difference. Few peer-reviewed studies examining WTP for lionfish exist to date. Huth, McEvoy, and Morgan (2018) examined how the price that consumers are willing to pay for lionfish meat is a combination of WTP for both a private and a public good by conducting a series of experimental auctions at a seafood festival in Pensacola, Florida. The baseline WTP dollar value estimated for a three-ounce fillet was \$6.28, which could be increased by as much as \$1.66 (26%) through informing participants of the severity of the environmental threat (Huth, McEvoy, and Morgan 2018).

In a presentation at the annual Gulf and Caribbean Fisheries Institute Conference, Bethany Young, public relations and marketing assistant of Rainforest Seafood (Jamaica's largest seafood supplier), reported that lionfish cost her supply company about \$3.00 a fish, a price deemed high by Jamaican standards. Other presenters cited prices paid to suppliers ranging from \$6.00 a pound to \$16.00 a fish depending on the source (Bogdanoff, Akins, and Morris 2013). While these findings provide a glimpse of middle and end consumers' WTP in certain locations, they fail to provide the figures necessary to make a market feasibility assessment for the US Virgin Islands (USVI).

Since 2016, Whole Foods Market Inc. has offered lionfish at select southeastern US locations. The company's official blog includes a section describing lionfish and provides background on the lionfish problem, as well as links to instructional videos on how to make culinary dishes with lionfish (Myers 2016). Whole Foods markets its lionfish as a "green" item, displaying whole fish on ice that can be filleted by their seafood department's fishmongers. Whole lionfish sell at Whole Foods locations throughout the state of Florida for around \$7.00 per pound (lb), with usable fillets accounting for approximately one-third of total weight.

The use of economic research methods to address the lionfish issue is not limited to WTP estimates for lionfish meat. Moonsammy, Buddo, and Seepersad (2011) used the contingent valuation method (CVM) to estimate the aggregate economic cost of invasive lionfish on Jamaica's reef systems by first calculating a mean estimate of individuals' WTP to protect the reef and then extrapolating to the population level. They conclude that lionfish have resulted in a loss of \$11 million in economic value to residents because of reduced marine biodiversity (Moonsammy, Buddo, and Seepersad 2011).

The USVI were selected for this study because various economic, ecological, and cultural characteristics of the territory appear favorable to the establishment of a commercial fishery for lionfish. Lionfish lead mostly solitary lives as ambush predators and cannot be consistently harvested through scalable methods such as angling and netting, but rather are primarily harvested through spearfishing by trained divers (Myers 2016). Recreational and commercial spearfishing are already widespread in the territory, and seafood features prominently in local cuisine (Goedeke et al. 2016; Stoffle et al. 2009; Crosson and Lia 2017). Given the abundance of divers already frequenting the reefs in pursuit of commercially valuable species in the USVI, there exists a culture and infrastructure in place to support large-scale harvesting, should sufficient demand materialize. Perhaps more importantly, fishermen would benefit from the availability of a new target species as stocks of other valuable reef fish species have declined in recent years (Albins and Hixon 2013). To help assess the demand side of the market, this study seeks to determine the WTP of potential consumers in different markets in the USVI.

Essential to assessing a latent demand structure for lionfish in the USVI is identifying the conditions and characteristics that contribute to consumers being willing to purchase lionfish, and the extent to which they will participate in the market. Just as consumers may not participate in certain markets (e.g., nonsmokers in the tobacco market or vegetarians in meat markets), there is good reason to suspect that a portion of those who live in and frequent the USVI will never participate in a market for lionfish meat. The factors that determine whether consumers would be willing to participate in a market for lionfish may be related first and foremost to whether they eat fish and, if so, whether they will consider eating lionfish. As lionfish is not yet a popular food item, we can assume that potential consumers have little idea of its palatability. Additionally, lionfish possess negatively perceived characteristics, including being a transmitter of *ciguatera* (a toxin harmful to humans present in many reef species) and possessing venomous spines (Robertson et al. 2014; McDermott 2017).

In this study, we apply nonlinear estimation techniques to two groups of potential consumers of lionfish meat, USVI residents and tourists. First, a double hurdle Poisson (DHP) model is estimated for the resident group. This allows for the identification of individual consumer preferences and characteristics that increase both the likelihood of participation in a market for lionfish meat and the potential frequency of purchase. Second, a logit regression is applied to the tourist group to model the individual tourists' likelihood of participating in a market for lionfish meat; only the first hurdle is estimated for the tourist group as a small sample size and lack of variability in the data on consumption frequency prevented the estimation of the second hurdle. Another part of our analysis of latent market structures focuses on prices. The Turnbull lower bound of consumer mean WTP is calculated for both the tourist and the resident groups and for both restaurant entrées and lionfish meat fillets purchased from the dockside market for home preparation. Consumer WTP is then estimated as a linear function of individual characteristics and preferences through the application of maximum likelihood estimation to double-bounded contingent valuation data. Results from our analyses are used to assess the viability of a new commercial fishery for lionfish in the USVI.

DATA AND METHODS

The data for this research were collected via a survey of 308 tourists and residents on the island of St. Croix in the USVI. Surveys of the resident population were collected during May 22–28, 2016, while surveys of tourists were collected throughout the summer of 2016. Participants were approached outside of every major grocery retail outlet ($n = 10$) on the island of St. Croix. To ensure representation by tourists, surveyors also canvassed three additional locations: the airport, the Christiansted Pier, and the Frederiksted tourist district. To randomize the selection of participants, surveyors were instructed to stand equal distance apart and then approach every third adult that passed next to them. The first question asked was whether they were a resident of St. Croix in order to determine which questionnaire to use. Most questions were designed to extrapolate consumer preferences and attitudes, and were asked in the form of Likert scales.

One purpose of the survey was to assess public perceptions and knowledge of lionfish to serve as a baseline for future outreach programs. Therefore, following several questions about fish and seafood in general, participants were presented with a picture of a lionfish and asked if they knew nothing, a little, somewhat, or a lot about lionfish (a four-point Likert scale). No additional information was shared with regards to lionfish biology or their ecological impact on the region. If survey participants had individual questions about lionfish these were not answered by the researcher until after the survey. Then the respondent was asked about their potential interest in eating lionfish using the same Likert scale before being presented with the following hypothetical market scenario:

> Several companies are interested in developing a local market for locally caught lionfish, which currently isn't sold in very large quantities because they are a new species in local waters. In July, they will be buying lionfish from fishermen directly and bringing it to local markets and to local restaurants. If the program were in place now, and the price was reasonable to you, would you have bought this local fish to cook at home, from a restaurant, or neither?

This question was followed by six others: (1) how many times they would buy (during a month for residents and during their trip for tourists), (2) whether they would buy more fish or buy this lionfish instead of other species, (3) whether they would still buy given a price, and then (4) a follow-up with a different price (higher or lower) depending on their answer, (5) a Likert question on how sure they were that they would actually do what they just said (not at all, somewhat, or very sure), and regardless of their responses, (6) whether they thought the companies could sell enough to be successful. Collectively, these questions allow an assessment of the share of the sample interested in the program, potential participation in the program, estimated frequency of purchase by venue (grocery stores and restaurants), responses to two bid levels, and a surety response to derive a more credible estimate of WTP.

Because of the difference in proposed consumption time frames, separate regression models were estimated for the tourist and resident groups during the market participation and consumption portions of the analysis. For each group, consumption frequencies were grouped into five categories based on the distribution of responses: 0, 1, 2, 3, or at least 4 (figure 1). These values correspond to the number of times individual residents indicated that they would consume lionfish during a typical calendar month, or the number of times that tourists would consume lionfish during their trip. Because of the sparseness of the data, tourist consumption frequency was ultimately recoded to a dichotomous variable to simply indicate whether they would consume lionfish at least once during their trip.

Greene (2018, 885) states that "the Poisson regression model is the fundamental starting point for the analysis of count data." Our review of the empirical literature on count data models suggests that the Poisson and its variant regressions (zero-inflated Poisson, etc.) are the most

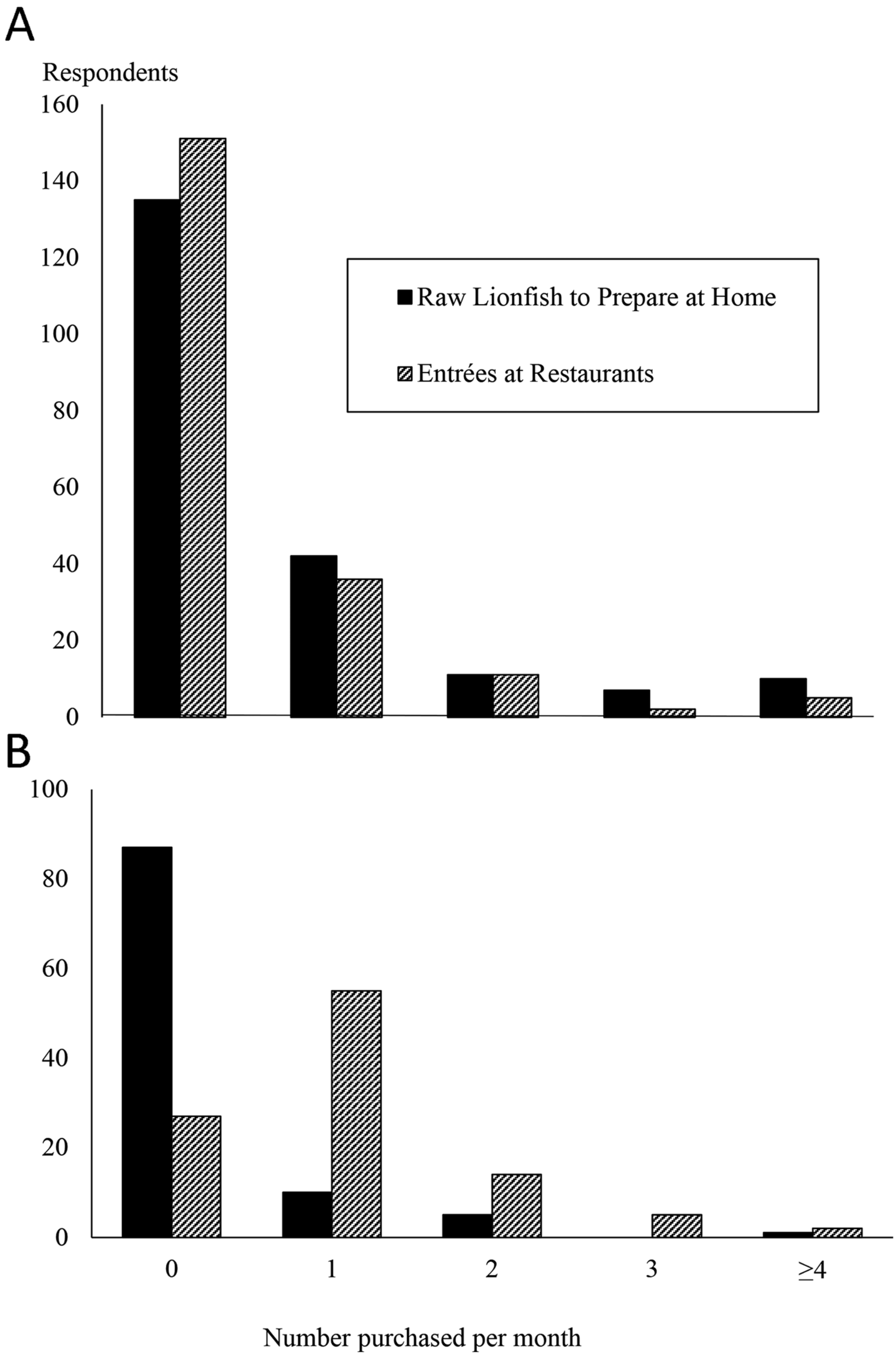

Figure 1. Monthly Calculated Frequency of Purchase by Venue and Respondent Type. Panel A shows results for residents; panel B, for tourists.

commonly estimated count models (e.g., Greene 1994; Lambert 1992; Cameron and Trivedi 2013). Less prevalent, although also represented in this literature, are the negative binomial, ordered discrete, and geometric regression models (e.g., Gardner, Mulvey, and Shaw 1995; Kockelman and Kweon 2002). Because the geometric and Poisson are nested within the negative binomial, comparison of these three models is straightforward (Mullahy 1986). In this research, we employ a test for overdispersion as suggested by Cameron and Trivedi (1990) to determine between the Poisson and the less restrictive negative binomial model.

Economists have long theorized that as rational individuals consume goods, each inadvertently makes a series of decisions: (1) whether to consume at all, (2) how much to consume, and (3) how often. Whether this sequence of decisions is made simultaneously or in succession is still a matter of debate. Nonetheless, there is broad consensus that econometricians estimating consumption models from consumer survey data must control for these different decision stages or otherwise suffer the fate of biased parameter estimates.

Numerous econometric methods have been proposed to control for the interplay of the decisions of whether to participate in a market and the quantity to consume. Cragg (1971, 829) introduced an extension of the "multiple probit analysis model" wherein the magnitude of the positively valued dependent variable is also dependent on different variables or parameters from when the dependent variable is zero. Mullahy (1986) was among the first to apply Cragg's double hurdle approach to models with count data, introducing hurdle specifications for the Poisson and geometric models. We present the probability mass functions (PMFs) for the binary and count portions of the hurdle model used in our application. Best recommended practices suggest that one can model the participation decision in the DHP with a probit, logit, or complementary log-log link (clog-log) function (Greene 2012). While we also tested probit and complementary log-log link functions for the binary portion of the hurdle analysis, we ultimately settled on the logit. Estimated results were similar across these different link functions, and the logit was deemed to be most consistent with the literature on market participation and to provide for a more straightforward comparison with our binary analysis of the tourist group.

These PMFs of the binary and count portions of the hurdle model are depicted in equation sets 1 and 2, respectively, where equation 1 represents the PMF for a logit model, and equation 2 depicts the PMF of the zero truncated Poisson:

$$\Pr(Y = y) = \begin{cases} \dfrac{e^{-\lambda_1}}{1 + e^{-\lambda_1}}, y = 0 \\ \dfrac{1}{1 + e^{-\lambda_1}}, y = 1, 2, 3, \ldots \end{cases}; \tag{1}$$

$$\Pr(Y = y | y > 0) = \begin{cases} \dfrac{\lambda_2^y}{\left(e^{\lambda_2} - 1\right) y!}, y = 1, 2, 3 \ldots \\ 0, \text{ otherwise} \end{cases}. \tag{2}$$

In these equations y is the discrete dependent variable, λ_1 is the parameter of a logit distribution governing the probability of observing a positive, and λ_2 is the parameter of a Poisson truncated at zero. Equation set 3 depicts the unconditional PMF for y, wherein both the binary and the count portions of the model are combined:

$$\Pr(Y = y) = \begin{cases} \dfrac{e^{-\lambda_1}}{1 + e^{-\lambda_1}}, y = 0 \\ \left(\dfrac{1}{1 + e^{-\lambda_1}}\right) \dfrac{\lambda_2^y}{\left(e^{\lambda_2} - 1\right) y!}, y > 0 \end{cases}. \tag{3}$$

If we use the log link to model λ_1 and λ_2, this renders these parameters $e^{X_i\beta_1}$ and $e^{X_i\beta_2}$, respectively. The log likelihood equation for the hurdle model can thus be expressed as the following:

$$\ln L = \ln\left\{ \prod_{i\in\Omega_0} \left(\frac{e^{-e^{X_i\beta_1}}}{1 + e^{-e^{X_i\beta_1}}} \right) \prod_{i\in\Omega_1} \left(\frac{1}{1 + e^{-e^{X_i\beta_1}}} \right) \prod_{i\in\Omega_1} \frac{e^{y_i X_i \beta_2}}{\left(e^{e^{X_i\beta_2}} - 1\right) y_i!} \right\}, \tag{4}$$

or

$$\begin{aligned} \ln L = & \left\{ \sum_{i\in\Omega_0} - e^{X_i\beta_1} - \sum_{i\in\Omega_0} \ln\left(1 + e^{-e^{X_i\beta_1}}\right) - \sum_{i\in\Omega_1} \ln\left(1 + e^{-e^{X_i\beta_1}}\right) \right\} \\ & + \left\{ \sum_{i\in\Omega_1} y_i X_i \beta_2 - \sum_{i\in\Omega_1} \ln\left(e^{-e^{X_i\beta_2}} - 1\right) - \sum_{i\in\Omega_1} \ln(y_i!) \right\} \end{aligned} \tag{5}$$

The first set of brackets corresponds to the binary portion of the model (hurdle 1), while the second set corresponds to the count portion (hurdle 2). As depicted, we assume that the decision to participate in the market (binary) is separate from the consumption quantity decision (count), thus these two portions are independent. The same set of explanatory variables is included at both hurdles, as indicated by repetition of the vector X_i (McDowell 2003; Zeileis, Kleiber, and Jackman 2008). Although we do not expect the same effect of these variables across both stages of the model (e.g., seafood safety and income), their repetition permits comparison across the decision process and provides guidance in the development and targeting of education and outreach materials.

The DHP is preferred to the standard Poisson regression model if consumers do indeed go through a two-stage decision process. A good indication that market participants are distinct from nonparticipants in the sample is the presence of excess zeros. An examination of the reported consumption frequency of residents (figure 1) corroborates the notion that these data contain an abundance of zeros.

One can compute the Vuong statistic to test for goodness of fit between two non-nested models (e.g., the DHP with logit link, and the standard Poisson). Vuong z-statistics were computed to provide a comparison between the DHP and the standard Poisson regressions in both the restaurant and home consumption models for the resident group. Statistically significant z-values of 2.46 and 1.93, respectively, provide evidence that the DHP fits the data better than the standard Poisson in both the restaurant and home consumption models.

As described earlier, data were collected on consumer WTP using the standard double-bounded contingent valuation method, an estimation technique commonly used in environmental economics where there is a lack of established markets to observe actual consumption at given price levels (Hanneman 1994). The technique has the surveyor propose a value (or "bid") for the hypothetical good and record a yes or no response. In the double-bounded method, considered statistically superior to single-bounded, the surveyor follows up with a second bid value that is either higher or lower than the initial bid depending on the participant's first response. In this analysis, participants who indicated that they were "not at all" interested in eating lionfish were excluded as this group was also highly correlated with those who answered similarly on all questions related to eating fish or seafood (i.e., non-seafood eaters); this comprised 32.5% of the sample. As part of standard CVM methodology, the remaining participants were under no obligation to accept either bid value and in fact a nonnegligible number rejected both bid values (i.e., 20% in the home model and 12% in the restaurant model).

Bid values were framed as a per pound price in the case of lionfish for home consumption and as a per entrée price in the case of restaurant consumption. Secondary bids differed from the initial bids (either higher or lower) by a factor of \$2. All bid values were in 2016 US dollars. The starting bid values for restaurant consumption ranged from \$16 to \$25. These values spanned the price range of similar fish entrées offered at restaurants on the island at that time. The starting bid values for raw fillets ranged from \$6 to \$15. Given the estimated number of interviews that could be completed during the survey period, it was determined that only four starting bid values could be used. We were unable to test for any anchoring effect. Given that this study is examining the willingness to participate in a market for a market good, and that initial prices were varied, we believe that the analysis conducted serves our purpose, which is primarily to analyze latent consumer demand.

Average WTP can be calculated from CVM data using both parametric and nonparametric methods. In this study, we calculate consumers' mean WTP with the nonparametric Turnbull lower-bound method to obtain a conservative estimate of the price that suppliers can expect to receive. The Turnbull (1976) method requires combining participants' responses to the questions on WTP at given prices.[1]

In addition to calculating mean WTP via the Turnbull method, we use the CVM data with a parametric approach to determine what factors are correlated with the stated WTP via maximum likelihood as detailed by Hanneman, Loomis, and Kanninen (1991). This approach requires the assumption that an individual's WTP is a linear function of the individual's attributes, such that WTP takes the following functional form:

$$WTP_i = X_i\beta + \varepsilon_i, \tag{6}$$

where X_i is a matrix of individual characteristics and ε_t is a stochastic error term. The β coefficients derived through maximum likelihood estimation can be interpreted as explaining how each control variable affects individual WTP. The associated log-likelihood function of the double-bounded CVM is as follows:

$$\begin{aligned}\ln L = \Sigma\Bigg[& I_i^{nn}\ln\left(1-\Phi\left(X_i'\cdot\frac{\beta}{\sigma}-\frac{A_L}{\sigma}\right)\right) + I_i^{ny}\ln\left(\Phi\left(Xi'\cdot\frac{\beta}{\sigma}-\frac{A_L}{\sigma}\right)-\Phi\left(X_i'\cdot\frac{\beta}{\sigma}-\frac{A}{\sigma}\right)\right)\\ & + I_i^{yn}\ln\left(\Phi\left(X_i'\cdot\frac{\beta}{\sigma}-\frac{A}{\sigma}\right)-\Phi\left(X_i'\cdot\frac{\beta}{\sigma}-\frac{A_H}{\sigma}\right)\right) + I_i^{yy}\ln\left(\Phi\left(X_i'\cdot\frac{\beta}{\sigma}-\frac{A_H}{\sigma}\right)\right)\Bigg].\end{aligned} \tag{7}$$

As this study posed two bids to each individual, yes (y) or no (n) responses fall into one of four possible categories: (1) no, no; (2) no, yes; (3) yes, no; and (4) yes, yes. These are represented by

1. For a comprehensive description of how to perform Turnbull's estimation process, we recommend that the reader consult Turnbull's original paper (1976) or see Haab and McConnell's somewhat condensed version (1997).

the symbols I_i^{nn}, I_i^{ny}, I_i^{yn}, and I_i^{yy}, respectively, as seen in equation 7. The symbol Φ denotes the cumulative distribution function of the standard normal. A_L and A_H represent the lower and higher of the two bids offered, respectively, while A (without subscript) represents the initial bid value. X_i' denotes a vector of explanatory variables, with β a corresponding vector of parameters. Vector X_i' includes many of the same consumer preference and characteristics variables included in the demand portion of the analysis. Willingness to pay for home consumption was calculated for the resident group alone. Tourists were excluded from this model because of relatively small sample size ($n = 17$ individuals) and lack of variation in bid values. Willingness to pay for restaurant consumption was estimated for the pooled sample of residents and tourists.

RESULTS

This section begins by summarizing statistics for the research sample, including demographic and preference variables used in the analyses. This discussion of summary statistics is followed by a subsection presenting results from the double hurdle Poisson and logit regression models used to estimate latent demand for lionfish meat. The section concludes with a discussion of the willingness-to-pay estimates derived through Turnbull and maximum likelihood methods.

SUMMARY STATISTICS

Demographic characteristics such as gender, age, educational attainment, and income for the resident and tourist groups are displayed in table 1 alongside statistics for St. Croix from the 2010 US Census. The sampled residents have a higher proportion of males with a higher education but lower household income than the population. The age profile is similar between the resident survey and census data. Overall, these differences do not appear to be at a level to compromise findings. Not surprisingly, the tourists in the survey reported more education and a higher household income than the local residents. The majority of survey participants (67%) reside in the USVI; for comparison, during the month of the survey, the share of the adult population that were residents was 75% (i.e., there were 12,851 adult tourists in June 2016, according

Table 1. Descriptive Statistics of USVI Census Data and Comparable Sample

	Residents		Tourists
Variable	Sample (%)	Census (%)	Sample (%)
Gender			
Male	51	46	52
Education			
High school graduate	85	75	99
College graduate	36	36	76
Income			
> median	52	50	89
Age			
18–24 years	8	8	6
25–54 years	43	48	68
55–64 years	23	18	17
> 65 years	26	25	9

Note: NA = not applicable. Median annual household income for USVI and US was $34,600 and $43,500, respectively.

to the Bureau of Economic Research, United States Virgin Islands, 2017, compared with 50,601 residents from the 2010 Census, of which 24% are minors on average). Ninety-two percent of the tourists in the sample were visiting from the US mainland, with the remainder coming from Puerto Rico, another island in the USVI, or a foreign country.

Prior research demonstrates that consumers' perceptions regarding the safety of fish and seafood affects their consumption levels (Roheim, Kline, and Anderson 1996; Grunert 2005; Fonner and Sylvia 2015; Aruga and Makamatsu 2018), thus the survey included several questions (19 in total) designed to measure participants' general levels of interest, knowledge, and concern about topics related to this study and questions related to the safety of eating lionfish in particular. Nearly all of these questions were framed in terms of a four-point Likert scale indicating their level of agreement with statements; responses were coded from 0 indicating "not at all," 1 indicating they agreed "a little," 2 indicating they "somewhat" agreed, to 3 indicating they agreed "a lot." These questions and results related to safety concerns are summarized in figure 2. Mann-Whitney U tests were conducted on the data for each statement to detect statistically significant differences between the mean responses of tourists and residents; results are indicated in the figures.

By design, one of these statements used to assess participants' level of safety concern was false: "Lionfish meat is poisonous." Although this statement is inaccurate, as lionfish meat is edible, we found that consumer responses are directly correlated with responses to the other safety questions and thus the statement appears to be a consistent indicator of individuals' overall level of concern about seafood safety.

Mean tourist and resident responses were statistically different for all of the questions regarding seafood safety. This difference is especially pronounced for the statements regarding ciguatera and fish poisoning, which is not surprising given that these issues in seafood are unique to coral reef systems (especially in the Caribbean Sea, Hawaii, and coastal Central America) such that the US tourists, on average, are likely to be unfamiliar with these concerns. Tourists' mean Likert response to the statement that "people can get sick with fish poisoning from eating seafood like amberjack or barracuda from the USVI" (0.80) is 1 point lower than that of residents. Similarly, the mean Likert value for tourists' response to the statement that "people can get sick with ciguatera from eating seafood like amberjack or barracuda from the USVI" (0.58) is 1.14 points lower than the average Likert value of residents (1.72). Additionally, tourists' mean response to the statement that "people can get sick with fish poisoning from eating lionfish" (0.41) is 0.65 points lower than the residents' mean response.

Figure 2 also displays participants' mean Likert scales in response to statements indicating their level of accurate knowledge about lionfish. The mean Likert responses were statistically different for the resident and tourist groups in the case of the following: "Lionfish harm the marine environment" and "It is safe for people to eat lionfish." In both instances the mean score of residents was higher than that of tourists, which is unsurprising given that residents live in communities directly affected by lionfish.

A series of questions were included in the survey to capture individuals' interest in seafood; per a factorial analysis, two of these variables are grouped under the category "interest in seafood." Participants' mean responses disaggregated by tourists and residents are also displayed in figure 2. Statistically different mean responses occur between tourists and residents for both of the following statements: "I am interested in eating lionfish" and "I am interested in trying new kinds of seafood." Tourists' mean response to the statement that "I am interested in trying new kinds of seafood" (2.29) indicates relatively strong agreement with the statement, while

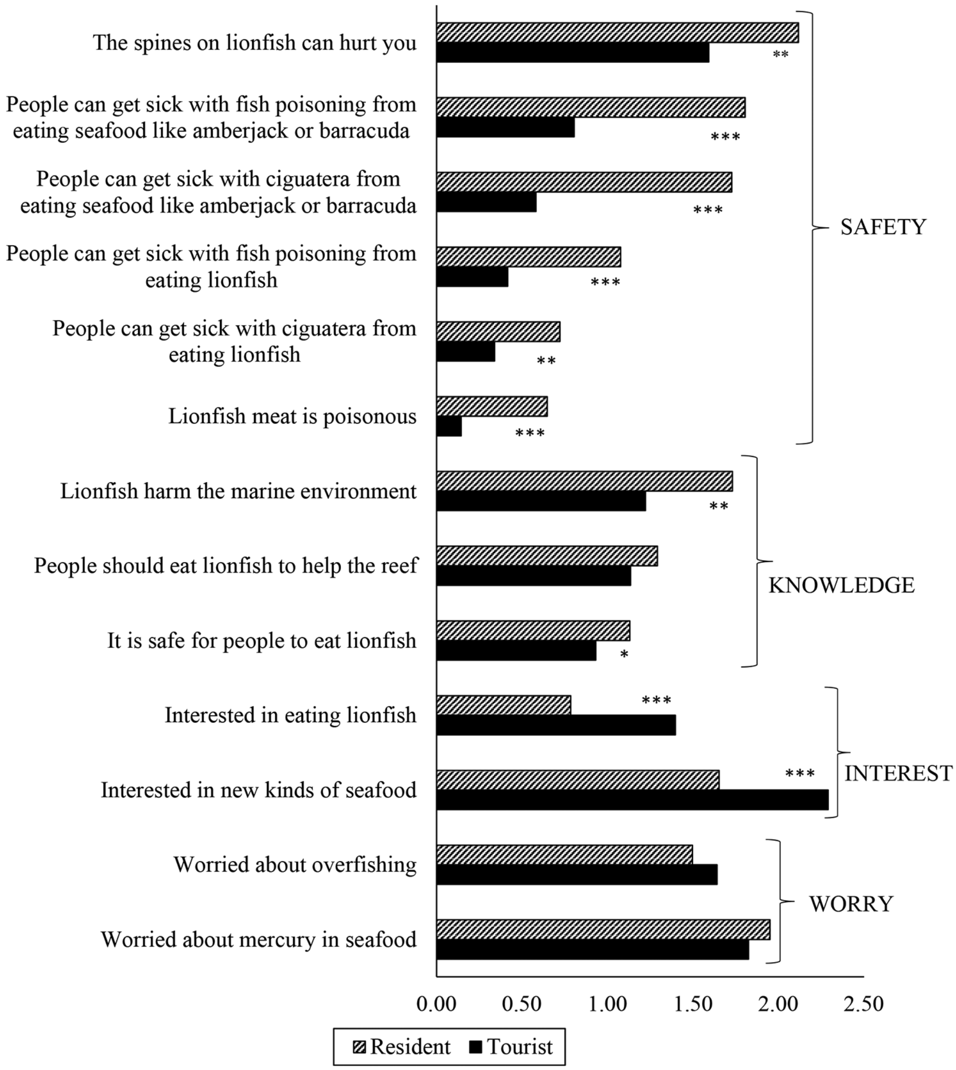

Figure 2. Mean Responses to Agreement with Statements by Category and Respondent Type. Agreement ranges from 0 (not at all) to 3 (a lot). ***, **, and * indicate statistical significance of difference between respondent types at the 1%, 5%, and 10% levels, respectively.

USVI residents' mean response (1.65) falls between the categories "agree a little" and "somewhat agree."

Figure 2 further displays participants' mean Likert scales in response to statements gauging their levels of concern about the two topically unrelated issues of overfishing and mercury levels in seafood. The mean resident and mean tourist responses are not statistically different for these two statements, suggesting that all participants are on average "a little" to "somewhat" concerned about overfishing and mercury.

We expect participants' Likert responses to many of the aforementioned statements to be correlated with the probability of individual participation in a market for lionfish meat and subsequent consumption frequencies. Thus, while the inclusion of all variables makes intuitive sense, data constraints must be considered. First, best recommended practices suggest having 10–20 observations per parameter to be estimated in a regression model (Harrell 2001). Our complete datasets contain 205 observations for the resident group and 103 observations for the tourist group. Thus the inclusion of all 19 Likert response variables among the model regressors would use up too many degrees of freedom. Second, the Likert response variables (especially by category) will likely lead to multicollinearity in the regression model. As such, tests were performed to determine whether statistically significant correlation exists among the variables falling within the following topical categories: knowledge about lionfish, concerns about the environment, safety concerns about eating fish and seafood, and interest in eating new fish and seafood.

Cronbach's alpha scores calculated for variable groupings indicated a significant amount of correlation only among the variables in the category "safety concerns" (score of 0.74). A factorial analysis was conducted for all the remaining variables, and three additional statistically significant groupings were identified; the hypothesis test that three variables are sufficient, where variables with loadings greater than 0.50 were combined, had a chi-square value of 53.27 (42 df, p-value 0.114). Variables were summed within each of the identified categories, creating four composite variables: "seafood safety concerns" (SAFETY), "knowledge about lionfish" (KNOWLEDGE), "interest in seafood" (INTEREST), and "level of worry" (WORRY).

There is a robust literature examining how individual characteristics and preferences, as well as policies and education campaigns, affect environmental concern at both the micro and macro levels (Buttel 1979; Dietz, Stern, and Guangnano 1998; Brulle, Carmichael, and Jenkins 2012), including those specific to seafood products (Nauman et al. 1995; Onozaka, Hansen, and Sorvig 2014; Aruga and Makamatsu 2018). Relevant findings from this literature suggest that individuals' concerns about environmental issues are largely contingent on personal and societal factors that can develop and change over time. Thus, for example, if the variable WORRY is correlated with individual willingness to consume lionfish, this suggests that efforts aimed at influencing societal attitudes towards overfishing and mercury in seafood could affect consumer demand.

Mean consumption frequencies and market participation rates for the resident and tourist groups are reported in table 2. Table 2 also includes summary statistics for several of the independent variables used in the analyses. The mean number of times that resident participants indicated they would purchase lionfish from a restaurant over a 30-day period was 0.41, whereas the mean number of times they indicated they would purchase from a market for home preparation was 0.61. Although these values appear relatively small (less than 1), recall that they represent per capita consumption calculated over all respondents, and not aggregate consumption. A majority of tourists indicated they would purchase lionfish at least once from a restaurant (74%) while on vacation in the USVI. A smaller percentage of tourists (16%) indicated they would purchase for consumption at their place of lodging while on vacation.

RESIDENTS' DOUBLE HURDLE MODEL

To begin the econometric estimation of the models for residents, the Cameron Trivedi tests for overdispersion were calculated and returned relatively small values of 1.35 and 1.11 for the restaurant consumption and home consumption models, respectively. These statistics have limiting chi-square distributions with one degree of freedom; therefore, we failed to reject the null of equidispersion and proceed with estimation of the double hurdle Poisson as opposed to a double hurdle negative binomial or some other double hurdle variant of the geometric (Greene 2012).

Table 2. Descriptive Statistics of Model Variables by Respondent Type

		Residents ($n = 205$)		Tourists ($n = 103$)	
Variable	Description	Mean	Std. Dev.	Mean	Std. Dev.
REST_PARTIC	Respondent would order a lionfish entrée at a restaurant at least once during the month (0 = no, 1 = yes)	0.26	0.44	0.74	0.44
HOME_PARTIC	Respondent would buy raw lionfish to cook at home at least once during the month (0 = no, 1 = yes)	0.34	0.48	0.16	0.36
REST_FREQ	Frequency of restaurant entrées purchased per month (range 0–4)	0.41	0.84	1.03	0.88
HOME_FREQ	Frequency of raw liofsh purchases for home per month (range 0–4)	0.61	1.07	0.23	0.63
SAFETY	Concerns about eating seafood and lionfish (range 0–18)	8.10	4.27	3.88	3.71
KNOWLEDGE	Agreement with accurate statements about lionfish (range 0–9)	4.16	2.99	3.29	3.27
INTEREST	Level of interest in seafood (range 0–6)	2.44	1.93	3.69	1.66
WORRY	Concerns about mercury and overfishing (range 0–6)	3.45	1.99	3.47	1.85
WHITE	Respondent identified their race as being white (0 = no, 1 = yes)	0.21	0.41	0.67	0.47
AGE	Age of respondent in years (range 18–84)	51.60	16.63	44.59	14.32
CHILDREN	Number of children under 18 living in the home (range 0–16)	0.77	1.63	0.48	0.86
MALE	Respondent was male (0 = no, 1 = yes)	0.51	0.50	0.52	0.50
HIGH_EDU	Respondent was a college graduate (0 = no, 1 = yes)	0.36	0.48	0.76	0.43
HIGH INC	Household income was higher than median (0 = no, 1 = yes)	0.52	0.50	0.89	0.31

Note: The 0 level of concern, knowledge, or interest is lowest. NA = not applicable.

Marginal effects were calculated for each independent variable in the analysis. The effect was averaged over all individuals in the sample group. These effects are reported alongside the coefficients in table 3.

Several variables were found to be significant predictors of resident participation in the market for home consumption (table 3, top right): safety concerns, knowledge about lionfish, interest in seafood, race (white), age, and being a college graduate. Two variables were found to be significant in the count portion of the model estimating frequency of home consumption (table 3, bottom right): interest in seafood and race (white).

The estimated marginal effect of seafood safety concerns on resident participation in a market for home consumption suggests that an increase of one standard deviation corresponds to a decrease in the probability of an individual purchasing raw lionfish by 12%. This finding is consistent with much of the literature on perceived risk and consumption of meat, poultry, and seafood (Senhui, Flether, and Arbindra 2003; Shim and You 2015). Yeung and Morris (2001) found that as individuals' level of perceived danger related to consuming a meat item increases, they often cope by reducing or eliminating consumption altogether.

The probability that a resident participates in a market for lionfish meat for home consumption increases with her knowledge about lionfish. A one standard deviation increase in a resident's level of knowledge corresponds to an increase in the probability of consuming lionfish

Table 3. Estimation Results of the Double Hurdle Models for Residents by Venue

	Restaurant				Home			
Variable	Coeff.	Std. Error	M.E.	Std. Error	Coeff.	Std. Error	M.E.	Std. Error
Hurdle 1: Participation								
constant	0.34	0.990	NA	NA	–2.14***	0.605	NA	NA
SAFETY	–0.07	0.326	–0.02	0.071	–0.45**	0.205	–0.12**	0.058
KNOWLEDGE	0.46	0.286	0.10*	0.060	0.43**	0.187	0.12**	0.052
INTEREST	0.95***	0.275	0.21***	0.079	0.68***	0.196	0.18***	0.061
WORRY	–0.08	0.296	–0.02	0.063	0.02	0.164	0.01	0.044
WHITE	0.53	0.582	0.11	0.128	–0.84**	0.377	–0.23**	0.107
AGE (10 YRS)	–0.30	0.181	–0.06*	0.004	0.36***	0.104	0.10***	0.003
CHILDREN	–0.39	0.247	–0.08	0.051	0.05	0.131	0.01	0.035
MALE	–0.95**	0.477	–0.21*	0.116	–0.01	0.313	0.00	0.084
HIGH_EDU	0.21	0.475	0.05	0.106	–0.66*	0.356	–0.18*	0.105
HIGH_INC	0.95*	0.523	0.21*	0.107	–0.30	0.394	–0.08	0.110
Hurdle 2: Consumption								
frequency constant	–0.30	1.062	NA	NA	–0.72	0.691	NA	NA
SAFETY	0.69*	0.396	0.14	0.090	–0.05	0.273	–0.01	0.065
KNOWLEDGE	0.00	0.296	0.00	0.058	0.17	0.190	0.04	0.039
INTEREST	0.59*	0.343	0.12	0.083	0.75***	0.238	0.19***	0.053
WORRY	–0.25	0.265	–0.05	0.050	0.03	0.171	0.01	0.042
WHITE	–0.98	0.603	–0.19	0.158	–0.71**	0.353	–0.17**	0.084
AGE (10 YRS)	0.14	0.250	0.00	0.005	0.14	0.122	0.00	0.003
CHILDREN	–0.32	0.646	–0.06	0.111	0.01	0.104	0.00	0.026
MALE	–0.31	0.697	–0.06	0.139	–0.40	0.346	–0.10	0.088
HIGH_EDU	0.06	0.535	0.01	0.105	0.51	0.327	0.13	0.096
HIGH_INC	–0.74	0.920	–0.14	0.218	–0.44	0.410	–0.11	0.105

Note: M.E. = marginal effect. NA = not applicable. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

in the home by 12%. This finding may imply that stakeholders can increase market participation through sharing accurate information to USVI residents about lionfish.

The marginal effect for interest in seafood suggests a positive relationship between interest in eating seafood and the probability of purchasing lionfish for consumption in the home. A one standard deviation increase in a resident's stated level of interest corresponds to an 18% increase in their probability of market participation.

According to these results, white residents have a 23% lower probability of participating in a market for lionfish for in-home consumption than their nonwhite counterparts. This relationship between race and lionfish consumption is consistent with studies reporting that non-Hispanic white Americans tend to consume certain seafood items at lower quantities than their black and Hispanic counterparts (Cheng and Capps 1988; Jahns et al. 2014).

The marginal effect of age suggests that for every additional 10 years of age, the probability of an individual consuming lionfish in the home increases by 10% (table 3, top right). This finding can be interpreted to mean that younger individuals are less likely to participate in a market for lionfish destined for consumption in the home. This inverse relationship with age is consistent with the notion that younger individuals may lack the culinary knowledge to prepare fish in the home and may be less likely to cook in general.

The marginal effect for higher education suggests that college graduates have an 18% lower probability of participating in a market for lionfish for in-home consumption. This finding suggests that lionfish for in-home consumption is more appealing to non–college graduates, and may reveal different underlying preferences between less and more educated segments of the population for preparing and cooking wild-caught reef fish in general.

The marginal effects of variables predicting consumption frequency can be interpreted as the unit increase in the average number of times consumed. As expected, interest in seafood is a positive predictor of consumption frequency in the home, with the estimated marginal effect suggesting that a standard deviation increase in interest corresponds to an increase in the average number of times that a resident consumes in the home by 0.19. Being white is also negatively correlated with the frequency of individual home consumption. The estimated marginal effect suggests that on average white individuals in the consuming group will purchase lionfish 0.17 fewer times than their nonwhite counterparts ceteris paribus.

Results from the DHP regression model for the restaurant resident group (table 3, top left) suggest that four variables are statistically significant predictors of market participation: interest in seafood, knowledge about lionfish, and high income are positively correlated with being a restaurant consumer, while being a male and age are negative predictors of market participation. Two explanatory variables were also shown to be statistically correlated with consumption frequency in the normal count-generating portion of the DHP model for restaurant consumption (table 3, bottom left): interest in seafood and safety concerns. Although the coefficients were found to be significant for these two variables, the corresponding marginal effects are not, limiting the interpretability of these results.

As in the previous model, knowledge is also a significant predictor of market participation in the restaurant model. The estimated marginal effect of knowledge suggests that a standard deviation increase in an individual's level of knowledge corresponds to a 10% increase in their probability of participating the restaurant market.

Interest in seafood is also statistically significant and positively correlated with a resident purchasing a lionfish entrée at a restaurant. The marginal effect of interest in seafood suggests that an increase in the interest variable by one standard deviation corresponds to an increase in the probability of participating in the market by 21%.

Age is a negative predictor of market participation, with the marginal effect suggesting that each additional 10 years of age corresponds to a 6% decrease in the probability of an individual purchasing lionfish at a restaurant. This finding can be interpreted to mean that younger individuals are more likely to participate in a restaurant market for lionfish (by all accounts, an exotic menu item) and is consistent with the psychology literature suggesting a negative correlation between age and openness to new experiences (Costa et al. 1986).

Male residents have 21% lower probability of participating in a market for lionfish meat at restaurants than their female counterparts. It is unclear from the analysis whether this difference reveals more about gender preferences regarding eating out at restaurants, consuming seafood in general, or gender differences in attitudes towards exotic menu items.

If we consider a lionfish restaurant entrée as a normal good in economic terms, it is unsurprising that we observe a positive relationship between income and participation in the market. This conforms to prevailing notions of income and willingness to eat out at restaurants as well as purchasing seafood items that are relatively expensive compared with other protein sources (Saad 2017). Interpretation of the marginal effect for income suggests that residents from households who earn above $34,600 have a 21% higher probability of participating in a restaurant market for lionfish than their lower-earning counterparts.

Although two of the explanatory variables in the count portion of the restaurant model were found to be statistically significant, seafood safety concerns and interest in seafood, neither of their marginal effects is significant. As expected, interest in seafood is positively correlated with restaurant consumption frequency; seafood safety concerns, however, defy expectation, being positively correlated with consumption frequency. This finding is counterintuitive assuming that individuals who are especially concerned about the safety of seafood are likely to consume at lower rates; however, it may reveal nuances in how potential consumers perceive risk related to how their seafood is sourced. Potential resident consumers of lionfish may feel that lionfish is safer to eat in restaurants compared with home or other venues, given the perception that restaurants face more stringent safety regulations than open-air markets and other venues. Market participants that are particularly concerned about seafood safety may therefore actually consume at higher rates in restaurant settings.

These results from the double hurdle Poisson models for the resident group, for both home and restaurant consumption, conform to the underlying assumption that individuals undergo a two-stage decision process when confronted with the opportunity to consume lionfish. First, they decide whether to participate in the market at all; second, if they are a consumer, they decide how much to consume. More specifically, these models indicate that knowledge about lionfish, interest in seafood, and age are positively correlated with market participation. Seafood safety concerns are negatively correlated with being a consumer, in the case of home consumption. With regards to the count portion of the model, interest in seafood is also statistically significant and positively correlated with consumption frequency, while being white is negatively correlated with both market participation and consumption frequency of lionfish in the home

TOURIST PARTICIPATION MODEL

Results for the logit regression of tourist participation in the lionfish market suggest that safety concerns are a negative predictor of participation in the restaurant model for this new potential group of consumers (table 4, left); the marginal effect suggests that an increase of one standard

Table 4. Estimation Results of Participation Models for Tourists by Venue

	Restaurant				Home			
Variable	Coeff.	Std. Error	M.E.	Std. Error	Coeff.	Std. Error	M.E.	Std. Error
Participation constant	1.70	1.385	NA	NA	–2.37	1.466	NA	NA
SAFETY	–1.18***	0.411	–0.13***	0.045	–0.10	0.408	–0.01	0.046
KNOWLEDGE	0.60	0.368	–0.07	0.041	–0.09	0.338	–0.01	0.038
INTEREST	1.97***	0.485	0.22***	0.053	0.38	0.406	0.04	0.046
WORRY	–0.39	0.345	–0.04	0.038	0.19	0.359	0.02	0.040
WHITE	–0.89	0.733	0.10	0.087	–0.40	0.755	–0.05	0.090
AGE (10 YRS)	–0.03	0.026	0.00	0.003	0.46*	0.241	0.05*	0.003
CHILDREN	0.84**	0.397	0.09**	0.044	–1.42	0.951	–0.16	1.067
MALE	–0.96	0.699	–0.10	0.070	–0.50	0.659	–0.06	0.075
HIGH EDU	–0.34	0.748	–0.04	0.080	–0.65	0.701	–0.08	0.091
HIGH_INC	–0.35	1.248	–0.04	0.130	–0.58	1.116	–0.07	0.152

Note: M.E. = marginal effect. NA = not applicable. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

deviation in the variable seafood safety concerns corresponds to a decrease in the probability of a tourist consuming lionfish at a restaurant by 13%. In contrast, tourists that have an interest in eating new seafood are more likely to buy a restaurant entrée; a single standard deviation increase in interest corresponds to a 22% increase in probability of market participation (table 4, left).

The number of children in the home is also a positive predictor of tourist participation in a restaurant market for lionfish meat. For each additional child residing in the home, the probability of an individual participating in the market increases by 9% ceteris paribus (table 4, left). The reason for this positive relationship between family size and restaurant consumption is counterintuitive given that household budgets generally experience greater constraints with additional children in the home (Cheng and Capps 1988).

The variable age is the only statistically significant predictor of an individual tourist's participation in a market for lionfish for home consumption. This finding is consistent with the assumption that preparation of finfish requires prerequisite knowledge that older individuals are more likely to have and is directionally consistent with the resident sample as discussed previously. The accompanying marginal effect suggests that for each additional 10 years of age the probability of a tourist buying lionfish to cook increases by 5% (table 4, right).

WILLINGNESS TO PAY

Results for the mean WTP calculation from using the Turnbull lower-bound method are shown in table 5. Residents' estimated mean willingness to pay for lionfish for home consumption is $11.80/lb compared with $10.09/lb for tourists. Tourists' estimated mean WTP for a lionfish entrée at a restaurant is $22.83 compared with $17.70 for residents. This is to be expected given that tourists are overrepresented among the high-earning group and, as basic microeconomic theory dictates, WTP is positively correlated with income (Mankiw 2016). Both estimates of mean WTP are within the price range of comparable finfish restaurant items in the territory, such as mahi-mahi, groupers, and snappers, which lends support to the idea of market feasibility.

Residents' mean WTP for lionfish destined for home preparation ($11.80/lb) exceeds that of tourists' WTP by $1.70/lb, or 16.8% (table 5). Compared with residents, we expect that tourists are generally less interested in cooking and frequently lack access to kitchens during their vacations in the USVI. While no data were collected on the type of cooking facilities tourists had access to during their stay, one can assume that many stay-in hotels and other rented rooms lacked these amenities. Furthermore, we assume that tourists lack the seafood-specific culinary knowledge of their island resident counterparts, which means they have a higher opportunity cost of preparing a lionfish meal. Thus, it follows that despite tourists being overrepresented in the higher-earning group, they are willing to spend less on raw lionfish than USVI residents. Regardless of this difference, both resident and tourist WTP for lionfish purchased fresh from a

Table 5. Turnbull Lower-Bound WTP Estimates by Venue and Respondent Type

Status	Venue	Mean WTP	Var.
Resident	Home (raw lionfish to cook at home)	$11.80/lb	8.12
Resident	Restaurant entrée	$17.70	6.33
Tourist	Home/place of lodging	$10.09/lb	1.66
Tourist	Restaurant entrée	$22.83	0.69

retail market are within the price range of similar reef fish species, according to a report by Kojis (2014).

Consumer willingness to pay for lionfish is also estimated via maximum likelihood estimation as proposed by Hanneman, Loomis, and Kanninen (1991). This method assumes that WTP is a linear function of individual consumers' preference and characteristics, which we include in the independent variable vector X_i (equation 6). The results for models estimating WTP for restaurant and home consumption are displayed in table 6. Estimates of mean WTP accompanied by lower and upper bounds for the home resident and pooled restaurant models are also presented in table 6. For the home consumption residents-only model, estimated mean WTP is $10.61. This value is about $1.20 lower than the estimate derived through the nonparametric Turnbull method ($11.80). Mean WTP estimated for the restaurant model (pooling both residents and tourists) is $23.90, about $1 higher than the Turnbull estimate of tourist WTP for a restaurant entrée. This value is nearly $5 more than estimated resident WTP for a restaurant entrée as calculated via the Turnbull method. The lower and upper bounds of these mean willingness-to-pay values were computed via bootstrapping, with confidence levels of 99%. The only variable that appears significant in both versions of the model is bid price, as expected; the higher the price, the lower is the willingness to pay.

Few variables were found to be significant predictors of willingness to pay for lionfish meat in the double-bounded contingent valuation models estimated through maximum likelihood. This lack of significant predictors may be partially due to the small size of the samples in both CVM models estimated ($n = 134$ for the restaurant model and $n = 71$ for the home model). One curious finding is that male residents have a lower WTP for raw lionfish meat than their female counterparts, with a corresponding marginal effect of –$2.06. This observed effect of gender may conform to gender stereotypes that men are less likely to participate in grocery shopping and food preparation in the home, which may reflect in lower WTP values. Income is a significant

Table 6. Contingent Valuation WTP Estimation Results by Venue

	Home (residents only)		Restaurant (pooled)	
Variable	Coeff.	Std. Error	Coeff.	Std. Error
Constant	4.78***	1.142	5.84***	1.100
SAFETY	–0.55	0.340	–0.17	0.285
KNOW	0.47	0.363	0.03	0.239
INTEREST	0.00	0.320	0.21	0.248
WORRY	–0.04	0.312	–0.24	0.216
WHITE	0.53	0.669	0.02	0.431
AGE	0.01	0.015	–0.01	0.013
CHILDREN	–0.02	0.170	–0.17	0.225
MALE	–0.95*	0.553	0.09	0.394
HIGH EDU	–0.64	0.651	0.46	0.444
HIGH_INC	0.41	0.601	0.92*	0.489
RESIDENT	NA	NA	0.44	0.488
BID	–0.46***	0.066	–0.29***	0.037
Mean WTP	10.61		23.90	
Lower-bound WTP	8.77		21.68	
Upper-bound WTP	13.34		25.76	

Note: NA = not applicable. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

predictor of willingness to pay for lionfish in restaurant settings, with a marginal effect of $3.22. This finding suggests that individuals in the high-income group are willing to pay more for lionfish as a restaurant entrée, suggesting that it is a normal good.

SUMMARY AND CONCLUSION

The underlying motivation of this research is to find a sustainable way to combat the proliferation of invasive lionfish in the Caribbean region. If a market for lionfish meat in the USVI is feasible, it would also be the most cost-effective means (from a policy perspective) of combatting the spread and population growth of the species. This study focused on the demand side of a potential market for lionfish in the USVI. We analyzed survey data from potential end consumers (residents and tourists) on the island of St. Croix and modeled residents' willingness to participate in a potential market for lionfish along with their potential consumption levels via a double hurdle Poisson (DHP) regression model. Tourists' willingness to participate in a potential market for lionfish meat was modeled via a logit regression. Two separate DHP regressions were performed in this analysis, one for restaurant consumption and another for home consumption. Similarly, restaurant consumption and home consumption were modeled for the tourist group with two separate logit regressions. We determined that individuals' willingness to participate in a market for lionfish (whether they are a resident or a tourist) is correlated with a number of individual preference and demographic characteristics. We likewise find that residents' potential consumption frequencies are correlated with a number of control variables. Stakeholders hope to establish and maintain commercial fisheries for lionfish meat in the USVI. Such an endeavor, however, will be contingent on sufficient consumer demand for locally sourced lionfish as a seafood product. If sufficient demand exists, there is reason to believe that such a fishery could reduce the population of lionfish to more manageable levels, allowing for the restoration of native ecosystems and more abundant diversity of reef fish (for consumption or for viewing).

Furthermore, estimates of mean consumer willingness to pay for lionfish meat both for home consumption and at restaurants are compatible with prices fisherman are willing to accept; that is, they are higher than dockside prices of other targeted reef species (Kojis 2014). It is our hope that increased education and outreach programs targeting residents and tourists in the USVI can increase market participation and potential consumption levels. The WTP and consumption estimates derived in this research provide evidence that a viable market for lionfish in the USVI may be an achievable goal. If so, a market for lionfish would create a positive externality for the USVI, as benefits would extend beyond the suppliers and consumers directly participating in the market. Such a market would suppress the population of lionfish without additional expenditure of public funds. Additionally, it would reduce the predation of human harvesters and lionfish on other native ecologically important species. This is critical because invasive lionfish are unlikely to officially become a managed species, as such an action would require public expenditures on stock status determinations. Because of the species' extraordinary rate of reproduction, we find it unlikely that future demand for lionfish in the USVI is ever going to exceed supply. Thus, even while reducing their numbers to more manageable levels, commercial fisheries are unlikely to fully extirpate the species from the region, although complete elimination of the species would be ideal for the ecosystem.

The most substantial findings from this analysis from a policy perspective are that accurate knowledge about lionfish and seafood safety concerns are both significant predictors of market participation. As these variables are related to individuals' level of knowledge, stakeholders may be able to increase market participation through targeted education programs and outreach. Materials oriented towards dispelling misinformation about the inherent risks of seafood consumption and informing about the lionfish problem may be beneficial in increasing the potential consumer base. Previous studies have shown that consumers' food safety concerns can be influenced by media reports and public information (Cao et al. 2015; Zhou et al. 2016). Additionally, it has been demonstrated that potential consumers are willing to pay more for seafood items that are certified safe under regulated programs (Wessells and Anderson 1995), ecolabeled (Fonner and Sylvia 2015), or locally sourced (Ropicki, Larkin, and Adams 2010). Thus, there exists an incentive for stakeholders to address potential consumers' safety concerns about lionfish through targeted information and outreach campaigns.

The potential ecological contribution of a robust local market for lionfish in the USVI merits further consideration. In an effort to encourage additional research and discussion on this issue, we conclude by proposing a rough estimate of the potential impact of a lionfish market on the invasive fish's population. Although we suspect the sample of St. Croix residents is fairly representative of grocery shoppers on the island, it is not statistically random, thus some skepticism is warranted. Multiplying the percentage of St. Croix residents willing to buy lionfish per the survey data by population estimates for the island, we estimate that monthly demand for lionfish meat among residents may be as high as 38,400 pounds. Although we are less confident that the tourists sampled in this study are representative of all tourists on the island, we can similarly estimate aggregate demand for lionfish on the tourist side. Through multiplying mean consumption frequency for the tourist sample by the population of adult tourists on the island in June 2016, we derive the value 16,192 pounds of lionfish to be consumed by tourists.

As of 2016, there were 141 registered commercial fishers on the island of St. Croix, with another 119 commercial fishers licensed in St. Thomas and St. John (Kojis, Quinn, and Agar 2017). Based on the participatory observation of this study's data collection team, the true number of active commercial fishers in the territory may be closer to 400. While these numbers of commercial fishers are below those required to meet all estimated consumer demand on the island of St. Croix, fishers can still make a significant ecological contribution by consistently harvesting the species. Data from the geographically similar Cayman Islands suggest lionfish densities of 233 to 650 fish per hectare (Frazer et al. 2012). With a total submerged area in the USVI territory of 485 km squared up to 20 meters in depth, there is reason to believe that sufficient lionfish exist to meet demand. Furthermore, research on the impact of culling efforts in the Cayman Islands also indicates that consistent removal of lionfish from targeted areas significantly reduces the presence of the invasive species, albeit temporarily (Frazer et al. 2012). If a dedicated consumer base were to be established in the USVI, then there is promise for a sustainable commercial fishery.

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