Restaurant decision-maker perceptions of barriers and opportunities for invasive lionfish consumption

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Declarations of Interest: None

Financial Support: N/A

Abstract: Lionfish (*Pterois volitans*, *Pterois miles*), invasive coral reef fishes in the western Atlantic, cause extensive negative impacts to marine ecosystems. Following their introduction in Florida in the 1980's, lionfish colonized numerous coral reef ecosystems and have been documented at depths ranging from 1-300m. In addition to depleting native reef fish biomass and threatening macroalgae induced phase shifts on shallow reefs, the invasion of lionfish has caused severe economic damage in the form of reduced native fish yields for local fisher people and high costs of management. While few examples exist of successful management of marine invasive species, studies have shown that lionfish removal can decrease their density and increase prey species biomass. A critical component and challenge for any effective lionfish removal effort is to maintain consistently high levels of lionfish harvesting so as to reduce lionfish abundance to levels that mitigate their negative ecological impacts. One popular market-based option that may achieve this is increasing the demand for the consumption of lionfish. This management solution offers potential benefits to both human livelihoods and marine ecosystems. Our study focuses on Florida's consumptive lionfish market and fills a gap in understanding the lionfish supply chain for Florida's restaurant industry. Although lionfish are commercially available in Florida, they are not currently widely consumed with consistency. We conducted interviews with twenty restaurant decision-makers in FL to understand their perceptions of barriers and opportunities for increasing their use of invasive lionfish. The most commonly identified barriers were: price and consistency of supply, while the most prominent opportunities were: improved awareness and culinary potential to increase the demand for lionfish. Conservation managers and policymakers should leverage these findings to facilitate opportunities, address barriers, and promote public education about invasive lionfish and their impacts.

Keywords: aquatic invasive species, market-based options, coral reefs, culinary industry, marine conservation, seafood

Key findings:

1. Conservation and culinary decision makers should collaborate to optimize market based management options for controlling invasive lionfish.
2. Culinary industry professionals in Florida confirm known bottlenecks to the state's lionfish market such as harvest methods and public awareness.

3. Culinary industry professionals offer innovative solutions to these challenges as well as culinary opportunities.

1. Introduction

Invasive species are one of today's most pervasive conservation issues [1]. Invasives have been cited as a driver of recent species extinctions, biodiversity loss and degradation of ecological functions due to their ability to disrupt ecosystem and species population dynamics [2,3]. Biodiversity loss and ecosystem collapse pose major risks to human societies [4]; the cost of managing invasive species in the United States (U.S.) amounts to as much as \$120 billion each year [5]. Of particular concern are aquatic and marine invasive species, which, because of an environment that allows high levels of connectivity and dispersal, present very specific and complex management considerations [6].

Invasive lionfish (*Pterois volitans*) are particularly damaging to marine ecosystems due to their high fecundity, generalist diet, and ability to occupy diverse habitats [7]. Lionfish have colonized ecosystems ranging from coral reefs to mangroves [8], and have been documented at depths ranging from 1-300m [9], complicating management efforts that require going beyond recreational diving depths (1-30m) [10]. With no natural predators in their invaded range [11], and few examples of successful pathogens [12], lionfish have been mostly uninhibited in expanding their range [13]. Lionfish impact the marine ecosystem by depleting native reef fish biomass and threatening macroalgae induced phase shifts on shallow reefs, and similarly cause severe economic damage in the form of reduced native fish yields for local fisher people and high costs of management.

Physical removals by spearfishers have been the most effective method of lionfish control in the invaded range [14–16]. Several removal studies feature targeted removals by people spearfishing on SCUBA or while snorkeling, particularly through large scale events such as derbies and lionfish competitions. In the U.S., these are the most common and effective tools to remove a large number of lionfish from an area within a short time period [17]. These events, however, rely on public participation and are expensive, time consuming, present potential physical risks, and are hard to replicate on a larger scale [17]. In recent years, research has focused on creating traps to remove lionfish; to date, no traps have been fully approved for use with lionfish. Some states also have restrictions on using traps for finfish in general [71].

Lionfish removal studies have shown mixed results. Some have demonstrated decreased lionfish density while also significantly increasing reef fish species biomass [18–20], while others have failed to prevent native reef fish declines [21]. A critical

component of any removal effort is a consistently high level of lionfish harvesting, so a key challenge for managers and policy makers is how to achieve broader success across the invaded range [10,22].

A promising approach to incentivize improvement in the consistency of effective lionfish removals is the use of market-based options [23]. This strategy involves the creation of new markets or expansion of existing markets to increase removal of invasive lionfish to levels that would ecologically suppress the harmful effects of lionfish. In a fishery scenario, the focus is to limit lionfish's impact beyond the sustainable yield of the population so as to reduce its abundance to levels that mitigate their negative ecological impacts (see Bogdanoff et al., 2021 for modeling information of a lionfish fishery). Market based options have been suggested as viable management strategies for several invasive species, including Asian carp (*Hypophthalmichthys nobilis*) and nutria (*Myocastor coypus*) [24,25]. In the case of invasive lionfish, market-based options can increase the demand for lionfish, and offer the potential to benefit both human livelihoods and marine ecosystems.

To date, the creation of new markets, or the expansion of existing markets, have included demand-side interventions, such as promoting lionfish as food, as part of the curio trade (jewelry), as well as supply-side policies, such as establishing aforementioned lionfish derbies (catching competitions) or encouraging opportunistic harvest as bycatch or non target catch [17]. However, market-based approaches for invasive species have been criticized for several reasons: they may create economic dependency on the invasive species, make invasive species socially - and thus ecologically - acceptable, and fall short of having the desired positive ecological impact [24]. Increased demand for the invasive species could also cause an expansion of the species' range as harvesters try to meet consumer pressure and interest [26].

Despite criticisms and the lack of robust bioeconomic research, region-specific consumptive markets already exist for lionfish, and some studies have sought to understand the opportunities for expanding demand for lionfish consumption and reducing the impact of lionfish invasions [27]. Research in Belize, for example, has demonstrated that development of a lionfish fishery (as a market based option) has the potential to provide a cost-effective, or at least cost-neutral, means of controlling the invasive population [7]. Similarly, a recent study in the U.S. Virgin Islands confirmed that the latent demand for lionfish as food could make the expansion of commercial lionfish harvesting an effective tool for reducing the negative impacts of lionfish invasions [28].

In Florida, research on invasive lionfish has focused mainly on lionfish biology, ecological impacts, and the efficacy of removals. A few surveys have been administered to the general public, anglers, and recreational divers regarding their awareness of lionfish, involvement in removals, and willingness to pay for lionfish [29, 30]. Additionally, lionfish have been shown to be nutritious and desirable to consumers for its

taste [31]. In the U.S., no study has examined the perspectives of an important stakeholder group in this discussion: restaurant decision makers. Chefs, managers, and owners are influential actors in restaurant sustainability because their knowledge, values, and leadership contribute to menu design and overall product sustainability [32, 33]. As tastemakers and agents of cultural change, culinary professionals have been highlighted as important participants in solutions for invasive species, and lionfish specifically [34]. Furthermore, the invasivore movement - a culinary ethos devoted to consuming invasive species for the benefit of native species - is gaining ground as more chefs experiment with including invasives on their menu [35]. Considering these factors, and the fact that culinary professionals in Florida are already utilizing lionfish to some extent [36], analyzing the perceptions of these individuals can yield important insights about how to optimize market-based management efforts to increase lionfish consumption in order to reduce lionfish abundance to levels that mitigate their negative ecological impacts.

In this study, we explore the perceptions of culinary decision-makers in Florida's restaurant industry in regard to creating and expanding existing markets for lionfish as a food product. We sought to understand: (1) What barriers exist for restaurant decision-makers to work with lionfish? and (2) What opportunities exist for restaurant decision-makers to address and overcome these barriers? Recent literature has called for a study of this nature, and our research fills this gap [34].

2. Study Area and Methodology

2.1 Study context

Florida, with its 8,436 miles of coastline, is home to the U.S.' largest sport-fishing community, important commercial fisheries, vast areas of protected marine resources, a highly active recreational diving industry, and the third largest barrier reef in the world [37–41]. Florida's seafood sector alone brought in a dockside value of \$237 million in 2016, or 4.5% of the U.S. total seafood value [42], and "on-reef" tourism in Florida has been estimated to bring in over \$300 million annually [43]. Even relatively low levels of damage to competing fish species and the resilience and functioning of coral reefs due to lionfish invasions could incur high economic costs. Increasing lionfish harvesting for consumptive use may be an important market based option to manage lionfish populations and reduce their negative impacts on marine ecosystems and economic welfare.

In Florida, commercial landings of lionfish peaked in 2017 at more than 120,000lbs and \$600,000 in value [44]. A 2015 public awareness survey reported that

less than 1% of the general public had ordered lionfish at a restaurant [29]. These factors, in addition to estimates of consumer willingness to pay for lionfish meat that are compatible with prices fishers are willing to accept for supplying lionfish - make growing the commercial and culinary market a viable option for consistent impactful lionfish management in Florida [28].

2.2 Data collection and analysis

From June to August 2020, we carried out semi-structured interviews with culinary decision makers (n=20) in the restaurant industry in the state of Florida who currently serve or previously served invasive lionfish on their menu. This group consisted of chefs, restaurant managers and restaurant owners. We developed a semi-structured interview guide (see: Interview Guide) based on literature and the co-authors' experience doing research on the human dimensions of invasive lionfish [45]. Interview questions focused on interviewee experiences with lionfish as well as research topics and gaps identified in the literature on invasive species management/invasive lionfish literatures. Our project was approved by Colorado State University's Research Integrity & Compliance Review Office Internal Institutional Review Board (IRB protocol #19-8890H).

To identify restaurants (N=37) who sold lionfish in Florida, we used two lists acquired from the Florida Fish and Wildlife Conservation Commission (FWC)[36], and REEF [46]. Restaurants must request to be added to the FWC list, and individuals can submit tips to REEF's email line. We contacted all 37 restaurants at least twice, and reached saturation with 20 interviews [47]. As we spoke with participants, we employed a snowball sampling approach [47], where individuals would typically recommend one or two other culinary decision-makers who they knew, and we would follow up with these individuals until we exhausted the calling pool. We spoke with six restaurants from the FWC list, four from REEF's, and 10 that were suggested.

Our analysis followed an inductive grounded theory approach [48]. We transcribed interviews using the automatic online transcription tool Otter.ai, and coded the interviews using eclectic coding, memoing, and axial coding techniques to connect categories found within the data [49].

To ensure intercoder reliability, two authors coded each interview twice to extract overarching and sub themes across interviews and to incorporate ideas from the first coding round. We applied constant comparative analysis as new themes within the data arose [50]. Using Dedoose's intercoder reliability test, we achieved Cohen's Kappa value of (.8) using two test codes across six excerpts.

Throughout the collaborative coding process, the code regime was refined to communicate themes and subthemes more accurately, with 33 initial parent codes and 115 child codes. Data rich excerpts, alongside the proportion of code application illustrated the most prevalent perceptions amongst the culinary decision makers. Further separation of barriers and opportunities into subcategories allowed for greater understanding of the nuances of these perceptions.

3. Results

3.1 Interviewee Socio-demographics

Of 20 interviewees, 12 were chefs, four were managers, and four were exclusively restaurant owners. Of the 12 chefs, eight were also restaurant owners. On average, respondents had been in the restaurant industry for 16.2 years. The least time reported spent in the industry was 1.5 years, while the most time reported was 30 years. The earliest reported year as one's first year serving lionfish in their restaurant was 2008; the most recent year was 2019.

Year of first lionfish use	City	Position	Years in Industry	Diver	Dive for own lionfish	Interview #
2008	Marathon	Owner	21	Yes	Yes	12
2011	North Palm Beach	General Manager	10	Yes	Yes	11
2013	Destin	Chef/Owner	20	Yes	Yes	5
2014	Destin	Chef/Owner	10	No	No	2
2014	Port Canaveral	Manager	4.5	Yes	Yes	3
2014	Pensacola	Chef	21	No	No	4
2014	Sarasota	Chef/Owner	30	No	No	13
2014	Cortez	Chef	20	Yes	No	14
2015	Vero Beach	Chef/Owner	10	No	No	7
2015	St Augustine	Owner	8	No	No	20
2016	Vero Beach	Chef/Owner	12	Yes	Yes	6
2017	Grant	General Manager	30	Yes	No	9

2018	Destin	Manager	Unreported	No	No	15
2019	Pensacola	Chef/Owner	1.5	Yes	No	1
2019	DeLand	Owner	Unreported	Yes	No	8
Unreported	Sarasota	Owner	Unreported	Unreported	Unreported	16
Unreported	Sarasota	Chef	Unreported	Unreported	Unreported	17
Unreported	Sarasota	Chef	Unreported	Unreported	Unreported	18
Unreported	Sarasota	Chef/Owner	Unreported	Unreported	Unreported	19
Unreported	Destin	Chef/Owner	29	No	No	10

Table 1. Demographic Information.

Figure 1. Barriers and Opportunities: Interviewee counts of perceived barriers and opportunities to working with invasive lionfish

3.2 Barriers

The three most commonly reported perceived barriers to serving lionfish in restaurants in Florida (in order of prevalence) were: high dock (i.e., ex-vessel) price,

consistency of supply, and difficulty of fishing effort (Figure 1). Below, we illustrate in detail the types of perceptions that shape these supply side barriers to the market for lionfish (see Figure 2 below for exemplary quotes).

BARRIER	EXEMPLARY QUOTE
High Price	<i>"People think trash fish and invasive (fish) should be cheap, but, you know, there's a lot of effort in diving for them. There's a lot of cost, there's a lot of risks for the diver so you know they justifiably want to be paid a premium for it. And, you know, they have a really poor yield. Gigantic heads and small bodies. So you know, you pay \$5 a pound for lionfish, and by the time you sell it you're...\$15 a pound, or even higher. In some cases, when it gets on the menu, it's a \$28-30 plate of food. People are hesitant to pay that kind of money for something they've never heard of." (I10)</i>
Lack of Consistent Supply	<i>"It's an easy fish to sell. So, you know, the restaurants and chefs in my mind will have no problem selling it. The problem is getting a regular supply." (I2)</i> <i>"If you only get something every once in a while and people don't get in the habit of seeing it, it stays a novel item." (I10)</i>
Difficulty of Harvest	<i>"It's a commitment to go down, and shoot these things and you know they're not that big. Two to three pounds is average and I see I've seen one as big as a football but that was just one. And so, it's, it's, it's hard to get. It's like, you know, guys in Italy trying to find truffles. It's a commitment. There's not, it's not like it's coming out of a factory. You've got to work to get these things." (I7)</i>

Figure 2. Barriers: Exemplary quotes of the three most commonly reported perceived barriers for Florida's culinary lionfish market.

3.2.1 High Dock Price

All but two interviewees reported facets of price as a significant barrier to working with lionfish. Compared to grouper (*Mycteroperca bonaci* / *Epinephelus morio*) or snapper (*Lutjanus campechanus*), two popular fish that some reported selling, lionfish were reported as "not affordable" for purchasing or serving (Interviewee, or "I" 9). Of the six that reported knowing the ex-vessel price, (hereafter referred to as dock price), off hand, the average stated price was USD\$6.60/lb for whole fish. Taking into account the average butchering yield of a whole lionfish, interviewees reported a 26% yield of usable meat on average for lionfish. Interviewee 15 remarked that "the yield is of course

not the same as you would get on a grouper or snapper.” Grouper and snapper both have a butchering yield of roughly 40% [51], almost twice that of the reported lionfish yield. Average dock prices for these fish are much lower - USD\$4.50/lb for red snapper and USD\$4.20/lb for grouper [52]. This implies a significant comparative price difference for deboned fish meat: \$25.38/lb for lionfish compared to \$10.50/lb for red snapper and grouper. The higher dock price and lower yields makes lionfish meat relatively expensive to purchase for culinary use, and interviewees perceive this high relative price of lionfish meat to be an important factor determining whether or not to purchase lionfish to serve in their restaurants.

3.2.2 Lack of Consistent Supply

Consistency of supply was a major barrier to serving more lionfish reported by all but three interviewees. Interviewee 2 expressed that while lionfish is “an incredibly easy fish to sell,” they explained further that the “problem is getting a regular supply.” The lack of well-established supply chains within the lionfish market reportedly affects the consistency in which restaurants can offer the product, making it difficult to keep lionfish on the menu year round, and maintain and grow consumer knowledge and interest. One chef explained: “I can't get it consistently... I don't have it always on the menu, it's just a supply issue” (I5).

The reliability of availability of lionfish to restaurants depends on the suppliers. Twelve interviewees reported receiving lionfish from divers, three from independent fisherpeople, eight from wholesalers, and one chef exclusively harvested their own lionfish. Five interviewees reported that they dive and harvested their own lionfish, or had done so in the past. Interviewed divers tended to harvest recreationally or as a conservation/clean-up effort, while independent fisherpeople and wholesalers harvested opportunistically, catching lionfish in addition to their typical commercial fish products like lobster (*Panulirus argus*), grouper (*Epinephelidae*), or snapper (*Lutjanidae*). Many of the divers from whom chefs were receiving lionfish were reportedly part of that interviewee's circle of friends/acquaintances as well, and sometimes, chefs explained, that no money was exchanged. Eight sourced exclusively from divers, four exclusively from wholesalers, and four from both divers and wholesalers.

The licenses used by interviewees were inconsistent. Despite diving for their own lionfish, only three of the five divers interviewed had Saltwater Products Licenses (SPL), the state license required to harvest and sell seafood products. Despite twelve sourcing directly from divers, only six restaurants had the wholesale licenses needed to purchase seafood products harvested by a SPL holder. Several others reported that their sourcing

was less controlled. Interviewee 13 spoke about their restaurant's criteria for accepting lionfish:

"I don't have a wholesale license to just buy fish and sell it whole, or anything, we're just a restaurant. For me to buy from a diver who just is Joe and Jennifer Schmo, whoever they are - if they go diving and come to my back door and say here's a whole bunch of lionfish, legally they frown on that, with the programs that are out there for food and sanitation safety and all that stuff, but it's daily routine in this state."

The reliability of supply of lionfish was also found to be associated with different seasonal events. For example, eight indicated that lionfish supply was seasonal because of factors such as lobster season, weather, or lionfish tournaments with one stating, "when the diving conditions were really bad it was tough to get, but anytime - especially during lobster season for us, which is the beginning of August [into] the early fall timeframe - when they were diving for lobster, they were able to grab some lionfish as well. And that really, really let us get a lot of numbers and get some good volume" (I3). In addition, lionfish tournaments were reported to enhance supply available to restaurants. Tournaments are typically held several times a year between May and October (Florida Fish and Wildlife, 2020). Most tournaments allow and sometimes encourage divers to sell their catch once they've weighed in. At the 2019 Lionfish Removal and Awareness Day Festival and Tournament, over 19,000 lionfish were removed in just one weekend [53]. The above quote and tournament data are evidence of three seasonal factors - one that decreases supply (poor conditions), and two that increase supply (lobster season and tournaments).

3.2.3 Difficulty of Harvest

Dive effort and difficulty of harvest was also a significant barrier, affecting the supply of lionfish. The majority of those interviewed emphasized that divers must exert considerable effort and incur heavy financial costs to harvest lionfish. Divers either pay for a charter boat or pay for their own boat operating costs to venture out to reefs to harvest lionfish. The difficulties associated with lionfish harvest place an additional constraint on the supply of lionfish to the market.

Of the five who dive for their own lionfish, four regarded difficulty of harvest as a barrier. One reported that since "lionfish can't be netted with a fishing hook, you gotta go down there and spear them one by one. And that is just not timely...it's hard to get. It's

like, you know, guys in Italy trying to find truffles. It's a commitment. There's not, it's not like it's coming out of a factory. You've got to work to get these things" (I7).

In addition to the above identified barriers, personal risk was also noted to be an important barrier by a few restaurant decision-makers. Diving is inherently risky, and lionfish's 17-18 venomous spines also pose a risk, as those handling them need to have the know-how to safely handle and de-spine them not only to avoid getting stung themselves, but also to avoid any potential risk to a consumer.

In summary, the interviewees reported that difficulty associated with harvest was a limiting factor in getting the "volume you need of the fish" in order to have enough to sell consistently/put on the menu at a restaurant (I5). With 26% as the average reported butchering yield (the portion of the whole fish that is consumable) and the high dock price, the overwhelming sentiment expressed was that the barriers to harvesting, purchasing, and serving lionfish were prohibitive.

3.3 Opportunities

Despite the supply-side barriers described above, interviewees identified numerous demand-side opportunities to increase lionfish consumption in the restaurant sector in Florida. Five prevalent themes emerged. These are: improved awareness; culinary potential; chefs as conservationists/trusted educators (i.e. chefs can be instrumental in communicating about lionfish threats and the conservation issues therein); processing opportunities; and innovations in harvesting methods (Figure 1). Figure 3 summarizes excerpts from interviews that express opportunities identified or commented on by participants.

OPPORTUNITY	EXEMPLARY QUOTE
Improved Awareness	<i>"I would say, it's been 10 years since I've heard about lionfish and...people are significantly more aware of it today. It's all trending in the right direction. We just have to fix the supply issue." (I2)</i>
Culinary Potential	<i>"So I've brought some in, and I was stunned. It is still to this day the best tasting fish I've ever come across in my life. Easily not even close."(I7)</i>
Chefs as Trusted Educators	<i>"Our primary motivation is to educate people about lionfish, and to also try and be on the front end of driving a market for lionfish because if you can teach people that a lionfish tastes just as good as a hog snapper, or red snappers, then there will be a demand and if we have a demand for the fish in the restaurants, it's going to be a lot easier for me to pay higher prices, and then put that on the menu."(I15)</i>
Processing Opportunities	<i>"You got to get the spines off properly. And there's some work to be done and I'm not sure the regular consumer is prepared to do all that work, and so less likely to purchase it. But if it's sold in fillet form, already filleted and ready to cook like most other seafoods are in a deli case at a grocery store or a fresh market type of a store, then I think they're more apt to use it." (I3)</i>
Innovations in Harvesting Methods	<i>"It's just so sad that we don't have a trap and the ability to, you know, massively harvest these fish so we can get them to be affordable for not just chefs, everybody should have access to these things."(I13)</i>

Figure 3. Opportunities: Opportunities for Florida's lionfish market with exemplary quotes from interviewees about various opportunities associated with serving lionfish.

3.3.1 Improved Awareness

The majority of interviewees indicated consumer awareness concerning invasive lionfish was "good" or improving, and that this increased the demand for consuming lionfish in restaurants. Five noted that their customers regularly asked if lionfish was available, signaling that some consumers were not only aware, but had developed an affinity for lionfish consumption. At one restaurant, about "25% of [the chef's] customers...come looking for lionfish" (Interview 12). Interviewee 5 remarked, "When it's on the menu, we sell all of it." Nine explained that their local customers had high levels of awareness, and four believed that, overall, awareness was increasing. Interviewees attributed this increase in awareness to certain chefs (local and celebrity) having played a role in outreach efforts, as well as "lionfish cooking competitions...that would sell out, and so people are aware of it" (Interview 7). Six suggested that more awareness could

drive demand, with Interviewee 3 attributing current declines in lionfish populations to consumer demand.

One form of educational marketing about which we asked chefs concerned whether or not they use the term “invasive” on their menu when speaking with customers. While seven reported using “invasive” in their marketing or on their menu, three were only using the term sometimes and three reported that they never used the term in association with lionfish. For the chefs that had used the word “invasive,” there were varying perceptions around why they used it and what impact they think it may have had on consumer attitude and awareness. Interviewee 5 noted that, while they have used the word “invasive” in marketing, they believe it’s “not a very good word to put on a menu... that’s an alarming word...it might also be an unappetizing word... invasive is a powerful word that can strike an emotion of alarm or danger.” Interviewee 6 noted that while they had used invasive as a marketing term, “just getting it in people’s mouths was the best form of education, and after they ate it, then I would come over and describe it more. It’s proven to be successful; sell them on the flavor and the price and then educate them as they’re eating the last bite.”

3.3.2 Culinary Potential

The majority also indicated that lionfish had creative culinary potential. A few interviewees noted that lionfish was a versatile product and in all, a total of 24 different methods of preparation were reported. Taste was identified to be a motivating factor to include lionfish on menus (n=7), as well as why consumers selected lionfish dishes (n=8). One reported: “I was stunned. It is still to this day the best tasting fish I’ve ever come across in my life. Easily. Not even close.” (I7). Interviewee 5 added, regarding the texture, that lionfish is “a good white mild flaky fish that does lend itself to being really popular because it does taste good” (I5).

Two spoke of taste and price point together, indicating that the culinary potential can help to alleviate price concerns. One explained that informing consumers about the taste of lionfish can make a higher price point more acceptable: “If you can teach people that a lionfish tastes just as good as a hog snapper or red snappers, then there will be a demand and if we have a demand for the fish in the restaurants, it’s going to be a lot easier for me to pay higher prices, and then put that on the menu” (I15).

3.3.3 Chefs Are Trusted Educators

The majority of chefs perceived that culinary professionals can play a role in combating invasive lionfish and conserving Florida’s marine ecosystems. Six stated

that social connections play an important part in increasing the market demand for lionfish. Several communicated they were aware of or had a personal relationship with lionfish researchers and marine conservation organizations in the region, whereas others said that their source for information about lionfish was attributable to a specific researcher. Half considered themselves to be educators, as capable of having a big impact, or that the restaurant industry can play a critical role in conservation efforts regarding the lionfish invasion. Interviewee 1 remarked that they are on the “frontline” of this issue. As one (I13) explained: “It went back to us just being teachers and saying, well as a chef, [lionfish] was one of the best fish I’ve ever had, and you know, you gotta trust me. The success of most restaurants is usually that the chef is finally trusted by the community.” Speaking to the broader impacts of chefs, one mentioned: “If you look at a lot of upper echelon chefs, especially the top guys in the world, like the Chef’s Table...in every single episode, the chef’s doing something with helping the world....I have an offer standing to everyone and anyone who comes to my doorstep: if I’m not busy, I will literally clean it and cook it for you whenever you want. I love to do that stuff” (I6).

Participation in lionfish events and collaboration was also common, with nine having been involved with an event in the past, three stating involvement with non-profits on the issue, and six having explicitly participated in active education or research about lionfish.

3.3.4 Processing Opportunities

Processing or processed items is an opportunity for increasing the use of lionfish in restaurants. In terms of what is possible with processed lionfish products, one noted seeing lionfish dumplings “at [their] local Whole Foods,” adding that they thought it was “cool to see how everyone else has done that” (I3). Another, having purchased a de-boning machine:

“I can use the processed product in ceviche or tacos just as easily as I can use a fillet because now I can segment that product...I can use fishmeal for something ...and then I can sell that fillet [at a] premium price....So I don't think it's an issue if you have the infrastructure to process it properly” (I1).

Three reported receiving frozen lionfish while ten reported using exclusively fresh lionfish. Interviewee 11 reported using both fresh and frozen. Interviewee 13, who exclusively used frozen lionfish, stated, “Lionfish freezes very good, which is a good aspect of that fish, a good property of that fish.”

3.3.5 Innovations in Harvest Methods

Considering the challenges inherent in spearfishing lionfish, many divers, chefs, and culinary industry professionals reported the promise of alternative and more scalable harvest methods. Although trapping of finfish is currently illegal in Florida, four indicated that traps may alleviate dock price concerns and harvest difficulties. One interviewee explained: “You need a coordinated harvesting effort that can really only come from adoption of a trapping technique” (I1). The risk associated with diving at great depth was perceived to be mitigated by the promise of traps. Interviewee 12 remarked:

“I know people who have been trying to build traps and stuff...deep diving is never going to be an option. One of my personal dive buddies got the Bends. He got out [of the hospital] three weeks ago and he can’t feel his legs. He’s 34 years old. So deep diving for lionfish, it’s really impractical and definitely not for someone who’s not skilled at deep diving and doesn’t have many years of experience...no one is harvesting those [lionfish] beyond 200 feet.”

Another spoke of how trapping may alleviate price barriers. “It’s just so sad that we don’t have a trap and the ability to, you know, massively harvest these fish so we can get them to be affordable for not just chefs...everybody should have access to these things” (I13, Figure 3).

Additionally, anecdotal evidence from our interviews pointed to alternative methods for lionfish removals. I12 indicated they received lionfish from deep water lobster trappers, and I15 reported lionfish being caught on hook and line by fishers fishing for snapper. Finally, one commented on another alternative associated with the tourism industry. Another (I2) shared that they had encountered divers who are paid by charter boat captains to clean the reefs of lionfish to make recreationally important fish more abundant for their clients.

4. Discussion:

4.1 Addressing Barriers Through Opportunities

Based on a review of the academic literature, culinary professionals have yet to be consulted regarding barriers and opportunities to growing the consumptive market for lionfish in Florida, despite the impacts they can have on lionfish control and public perception. Understanding their perspectives of existing barriers and opportunities that exist can shed light on how to boost the consumption of lionfish in the restaurant sector.

Considering the rate of invasive spread, consistent removals of lionfish are likely essential in many locations to mitigate the long-term ecological, social, and economic impacts [20,54,55]. Facilitation of consistent removals, then, is contingent on the ability of restaurant decision-makers to overcome the supply-side barriers and enhance the demand-side opportunities identified in this study. Opportunities to mitigate or eliminate these barriers exist and are evolving.

We identified barriers and opportunities perceived by culinary professionals associated with the culinary market for invasive lionfish in Florida, as well as other significant findings relevant for managers and policy makers. The barrier mentioned by the most culinary decision makers was the dock price for lionfish, while the opportunities most mentioned were public awareness and culinary potential. Ideally, the opportunities mentioned would marry neatly with the most prominent barriers. There was, however, both, dissonance and harmony, between the most common barriers mentioned and the most prominent opportunities (Figure 4). Solutions may also vary based on restaurant characteristics such as location, price-point, and management.

In this section, we link potential barrier-opportunity connections based on our study's results and the literature. This bridging is an effort to enhance intervention points that address the most prominent underlying barriers that restaurant decision-makers face.

Figure 4. Barriers and Opportunities: Barriers to serving lionfish are matched with opportunities highlighted by interviewees.

4.1.2 Opportunities associated with high dock price: addressing value concerns

The high dock price for whole lionfish and subsequently reported low butchering yields (~26%) makes processed lionfish relatively expensive (i.e. \$25/lb) compared to other fish meats (i.e. \$20.50/lb for red snapper and group), and deters restaurant

decision makers from purchasing and serving lionfish. Based on these interviews, this barrier can be reduced in two ways: altered value proposition and improved processing.

Findings concerning the variety of culinary applications for lionfish provide solutions for cost versus benefit problems. Communicating to consumers that the value of lionfish is tied to its novelty or conservation value is a way to cut through price concerns on the menu. A study in Pensacola, FL found that consumers are willing to pay (WTP) upwards of USD\$33/lb for prepared lionfish fillets and even more if they are educated about the ecological impacts [30]; whereas, Pelican Point Seafood, a seafood market in Tarpon Springs, FL, currently lists both red snapper and grouper prepared fillets at \$21.99/lb [56]. The average reported post-processing price for lionfish was \$19.50/lb, well under the WTP figure found by Huth et al. Although research regarding the average weight of lionfish is inconclusive [57], one study demonstrating the nutritional properties of lionfish reported average weight of 637g, or around 1.4lbs [31], meaning that with a yield of 26%, the estimated usable meat from a lionfish is only 0.36lbs and costs \$7.90 per fish. Even with a post-processing price of \$19.50/lb, the small size of fillets is a challenge when finding culinary applications. However, the opportunity to offer lionfish as a premium or specialty item is worth exploring, i.e. offering lionfish as an appetizer paired with another product, such as relatively low-cost shrimp as was found in this study.

Chefs' status as educators is also an important aspect of awareness for consumers. Providing education about the ecological aspects of lionfish, and using terminology such as the word "invasive," which only some chefs used, can increase the value proposition by capitalizing on consumer motivations to eat sustainably [34]. This word, however, along with interchangeable terms like "alien," "non-native," and "introduced" can carry negative, and even racist social connotations, and careful consideration of terminology and communication strategy is critical, and leveraging consumer willingness to consume sustainably is a viable option [58–61].

Additionally, campaigns to promote whole fried lionfish as a premium novelty item (i.e. something new/unusual) or promoting ceviche, which can utilize processed lionfish meat, may also make the current average dock price more transferable to a viable menu price. Within culinary opportunities, chefs expressed creative ideas involving processed lionfish products like dumplings or fish sticks.

Next steps for increasing the capacity of restaurants to serve lionfish include engaging with restaurant decision makers in Florida about 1) how to communicate the invasiveness of lionfish and how consumption can help fight a harmful invasion, 2) how to use creative preparation methods, and 3) the potential for increased profit. Increasing the value proposition for lionfish, regardless of a change in harvest methods or processing, could help to alleviate price concerns.

Processing technologies were identified in this study as promising. Increasing the yield by way of deboning machines can increase yield by 10-15%. For example, if the current average yield of deboned lionfish meat of 26% is increased to 40%, then this improvement in meat extraction would bring the price of deboned lionfish meat down from \$25/lb to \$16.50/lb. This is relatively more competitive with alternate deboned fish meat such as grouper and red snapper, which comes in at around \$10.50/lb. This could make the dock price much more palatable. This is an opportunity that exists regardless of lionfish size and one that is promising to promote removals of smaller lionfish. Cost versus benefits is an oft cited topic of debate regarding the commercial lionfish market, and processing techniques could be a means of making the effort worth the return [18]. Further research into the viability and accessibility of processing technologies is necessary to discern if this opportunity is scalable within Florida's restaurant industry.

In terms of harvest innovations, the current harvest method, spear hunting, is time consuming and costly, but is still the most efficient method of harvest for diver-accessible areas, as neither hook and line nor traps have yet to be largely successful [14]. Increasing the volume of landings is one way that the price for lionfish could decrease, assuming divers are motivated by profit. Increased catch per unit effort (CPUE), that is, the volume in pounds or kilograms of the catch divided by the hours or trips needed for the harvest, effectively reduces the per unit cost of harvesting. Considering that lionfish have been observed in abundance, at larger sizes and on reefs beyond diving depths, innovations such as a deep water lionfish trap could increase the CPUE, at least initially [14]. An increased CPUE can then tackle the high cost of lionfish harvesting, which is a major barrier to management [10,14,18]. It should be mentioned that the level of success of a trap fishery for lionfish may vary geographically based on the underwater topography and regional features for a given area.

4.1.3 Opportunities associated with supply consistency

The issue of supply consistency is multifaceted. First, opportunistic harvest during lobster season is one aspect that was identified in this study. According to Bogdanoff et al., lobster catch is significantly reduced (by more than half) when invasive lionfish are present within a trap, and as a result, lobster fishers may only pocket \$3.50-\$6.00 USD₂₀₁₃ per pound of lionfish, compared to approximately \$10.69/lb for lobster [17]. Results for other key products are similar such as grouper and snapper. This tradeoff could be ameliorated by financial incentives (e.g. 'conservation bonuses') effectively subsidizing harvesting to motivate continued opportunistic harvesting, even if income per trip in relation to the lobster catch is negatively impacted. Subsidies for bycatch have been proposed by researchers [26], and opportunistic harvest has been

shown to drive extinction of non-target species [62]. Given that lionfish impacts to reef fish biomass and recruitment are economically significant [22], such a program may be worth exploring. This could be funded through government allocations for aquatic invasive species management that, in essence, compensate fisherpeople for lionfish bycatch. This sort of incentive program is already taking place in the region, and has the potential to be effective on a large scale. Bounties, subsidy payments, and contractor payments, among others, exist in programs for other aquatic invasive species, but are designed around intentional removal, not bycatch [26,63]. Regulations in Florida would need to be altered slightly to allow for this differentiation.

In addition to incentivizing harvest via existing fishing gear and methods, the adoption of a deepwater lionfish trap could allow fishers to access lionfish during times when diving is difficult due to weather concerns [14]. The potential for traps to increase catch volumes via simultaneous trap deployments may also make lionfish more consistently available for use by the culinary industry [14].

Some restaurant decision makers experience lionfish supply as seasonal based on a lack of willingness of divers to target lionfish at certain points of the year. This places pressure on demand, in that if lionfish is then only being *offered* seasonally, customer demand may shift as well. This can then lead to further proliferation of lionfish populations in the “off-season.” Lionfish reproduce year-round, so continuous removals are essential [64,65].

In Belize, Chapman et al. similarly determined in part that seasonality and opportunistic harvest were supply-related barriers preventing the growth and success of a culinary lionfish market [7,66]. Our research suggests that both do in fact impact the success of Florida’s lionfish market. Maximizing lionfish supply, and ecological benefits, requires serious consideration of the temporal aspects of lionfish harvest. While most commercial fish markets have a regular season, the capriciousness of the lionfish market makes it difficult for restaurant decision makers to predict and include on their set menus. The opportunities that can address this aspect of seasonality are tied to those related to the difficulty of harvest, with alternative and diverse harvesting methods reducing the burden on divers, and possibly helping to maintain more sustainable trends of supply and demand.

In addition to harvest opportunities, post harvest processing opportunities could also improve supply consistency by sustaining supplies of lionfish beyond any given seasonal parameters. While few chefs in this study reported using frozen lionfish, a growth in this practice could be a promising development. Frozen seafood inventories could allow restaurants to serve lionfish beyond seasonal constraints [67], and are also more resilient to shocks within the seafood sector [68].

Without harvest and post harvest opportunities, there has yet to be an example in the literature of a successful and consistent lionfish market or harvest program.

Sustaining lionfish harvest for ecological benefit will require creative solutions that address the challenges of invasive commercial fisheries.

4.1.4 Opportunities associated with harvest difficulty

Traps, an opportunity identified by a few interviewees, could make harvesting easier, and thus cheaper, and less reliant on favorable diving conditions. Additionally, traps that target lionfish could displace the lionfish being caught as by-catch in lobster traps, increasing revenues for the lobster trap fishery [17]. Current efforts in trap development are underway, but have yet to realize impactful and scalable results [14,69]. Currently, there exists no reliable method for lionfish removals beyond diving depth and recent research has shown higher lionfish densities beyond these depths [10]. The opportunity herein exists in the further development of trap research, which could address the issue of lionfish occupying deeper depths. In order to offer traps as a mass-eradication tool, section 370.1105 of the 2005 Florida Statutes would need to be altered, as it currently prohibits the trapping of finfish without exemption for lionfish [70]. In addition, greater social science research on lobster trappers and the potential for coordination stands to be explored in greater depth.

In addition to trapping, greater processing opportunities, could allow for scalable uses for lionfish meat. It may open up the possibility of using lionfish that are too small for some restaurant purposes such as whole and filleted preparations, widening the scope of culinary applications for fish of all sizes. Current processing capabilities effectively place a size restriction on lionfish harvests. In this study, eight chefs expressed this opportunity, with processing options such as “lionfish fishsticks” for kids, ravioli, and other dishes to help justify the difficulty of harvest (I13).

4.1.5 The importance of networks

A key finding from this study was the strong network connecting a variety of stakeholders. Interviewees reported personal relationships with other restaurant industry professionals, researchers, and divers. They also felt deeply involved in educational and promotional efforts to spread awareness and improve understanding about the threats and possibilities regarding lionfish. While uneducated is not equivalent to unaware, the information available about lionfish is still a major hurdle to overcome, especially for tourists or out of town consumers. The wide network of restaurant industry professionals and scientific researchers allows for bi-directional transmission of

information [71]. These connections are important because researchers can disseminate new information to restaurant decision-makers that can then be communicated to consumers [71]. These networks can assist policy makers and managers in advancing awareness and education about lionfish. Managers and policy makers should leverage these networks in order to expedite and evolve solutions to the barriers that prevent Florida's lionfish fishery from scaling up.

4.2 Limitations of the study

The global COVID-19 pandemic severely limited our ability to contact participants for the study, as we were restricted to virtual contact only. COVID impacts on restaurants were noticeable as well, with many businesses having closed during the time we called, or having stopped serving lionfish altogether. Some restaurants reported an increase in demand for comfort foods, and with take-out as the dominant dining option, both interviewees and customers seemed less likely to purchase products like lionfish, which are 1) novel (meaning, a food they've never tried), 2) impractical to reheat and serve at home, and 3) may even be unappetizing to reheat at home.

4.3 Conclusion

In order to address the presence of invasive lionfish, maintaining consistently high levels of lionfish harvesting can reduce their abundance to levels that mitigate their negative ecological impacts. This paper has explored the supply- and demand-side constraints and opportunities that impact the market for lionfish consumption in the restaurant sector, which in turn determines the rates of lionfish removals.

While this research is the first to account for the perceptions and experiences of restaurant decision makers, our findings suggest that additional research into the barriers and opportunities of other stakeholders in the supply chain, such as divers and wholesalers, could yield further insights. Studies by Carrillo-Flota & Aguilar-Perera make similar conclusions [72,73]. Additionally, future studies that explore novel and efficient harvest methods, lionfish ecology beyond diving depths, and bioeconomic modeling are needed to fully understand the optimal management responses for invasive lionfish in the different regions of Florida. Our research suggests that the main policy opportunities are those that increase funding towards research and awareness, address harvesting difficulties and support market success. While policy and legislation can play a role in addressing some of the barriers and opportunities identified in our research, the role of restaurants and the supply chain in general is nested within a complex social and ecological system and therefore a combination of stakeholders

working at different levels and in various fields are necessary to successfully mitigate the invasion's deleterious ecological effects. The significance of this research extends beyond the WA to the more recent lionfish invasion in the Mediterranean, where research and management has in part explored a market-based approach [74]. A multidimensional understanding of the supply, demand, opportunities, and barriers that lionfish markets face in Florida can help inform research questions and management in areas where the lionfish invasion is still emerging.

Acknowledgments

We thank Phil Karp, Fadilah Ali, Jen Chapman, and the culinary industry professionals who donated their time and expertise to this research.

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Interview Guide

Hello [name], thank you for making the time to speak with us today. This interview will touch on a few topics and themes regarding the commercial lionfish market in Florida. We encourage you to answer as honestly and candidly as you can. Feel free to decline to answer any questions, or stop this interview at any time. Results of this recorded interview will be used towards the completion of our Master's program requirements in the form of a report on perceptions about invasive lionfish. Do we have your permission to record this conversation? [answer]. Ok great. Any questions before we begin recording? [answer]

1. What is your role at your restaurant?
 - a. How long have you been there and worked in the industry?
 - b. How would you describe your restaurant?
 - c. Ask how many aspects of lionfish each chef is. Are they also a diver, supplier?
 - d. What motivated you to spearfish?
 - e. How did you promote it?
2. Has the present Coronavirus pandemic impacted your business? If so, how?
3. When did your restaurant start serving lionfish?
 - a. Has it served it consistently?

- b. When did you first hear about lionfish?
 - c. When did you first consider selling?
 - d. What motivated you to add lionfish to the menu?
 - e. How do you advertise it when it's on the menu?
 - f. Who do you get your lionfish from?
- 4. Describe your typical consumer base.
 - a. How informed do you suppose are your patrons about lionfish?
 - b. Have there been any trends in lionfish demand at your restaurant?
 - c. *Why do you think people don't want to buy it?*
 - d. How many lionfish dishes are served per day when on the menu?
 - e. What is your favorite way to prepare it?
 - f. What do you do with the spines?
 - g. Nutritional value? (kind of irrelevant but could be a motivator for purchase)
 - h. Why do you think your customers order lionfish?
- 5. What is your biggest barrier to selling lionfish?
 - a. Is ciguatera an issue? Is filet size an issue?
 - b. Are supply and demand seasonal for lionfish?
- 6. Do you perceive market growth or reduction?
 - a. Do your competitors also sell lionfish?
 - b. Have you noticed a price fluctuation?
 - c. What do you think will happen with lionfish in the future?
 - d. How do you think consumer perceptions of lionfish could modify demand in regards to what is healthy for Florida ecosystems?
 - e. Does your menu price affect consumer purchases?
- 7. Who makes decisions about procurement?
 - a. Who do you get lionfish from?
 - b. Are your suppliers consistent? If not, how have they changed?
 - c. Do you know how/where your lionfish is caught?
 - d. How are you receiving lionfish, fresh or frozen?
- 8. Do you see your role as being involved in a conservation effort?
 - a. What are the impacts, if at all, for conservation?
 - b. Do you see restaurants as part of the solution?
 - c. What role *can* chefs have in local conservation efforts?
- 9. Would you be interested in advertising sustainability programs/certification programs, similar to a Fair Trade type program, Marine Stewardship Council, or the Seafood Watch certification?
 - a. If such programs existed do you think you would include them in your marketing?
 - b. Would your customers react to such marketing?
 - c. Do you think consumer perceptions could modify demand?
- 10. How do you market your lionfish dishes?
 - a. Do you see opportunities in value added/processed versions (eg fish sticks)
 - b. Do you include the word "invasive" in your marketing or on your menu?
 - c. Where do you go for information about lionfish?

11. Do you have any insights into the licensing process?
 - a. Saltwater license - small scale wholesale - chefs who are also divers have this
 - b. What is your role in that?
 - c. Are lionfish covered in your HACCP plan? - Hazard Analysis and Critical Control
12. Are you a diver?
 - a. Do you know divers who are involved in lionfish removals?
 - b. How do you know these individuals?
13. Would it be okay to contact you with follow-up questions?
 - a. What is a good email/phone number?

Thanks again for making the time to speak with us today. We greatly appreciate your perspective on this important issue! Please feel free to contact us at any time if you have further questions or comments.