Evaluating consumption as a management strategy for the invasive lionfish (*Pterois miles*) in Crete

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Abstract

The introduction of non-indigenous marine species to the Mediterranean Sea has increased significantly since the opening of the Suez canal. Many of these species could potentially become invasive, impacting local ecosystems and population dynamics. The lionfish, which is endemic to the Indian Ocean and the Red Sea, is a non-indigenous species that has become highly invasive in the Mediterranean. Its large venomous spines, high fecundity and few natural predators have facilitated its rapid spread all throughout the region. The lionfish represents a major threat to biodiversity and population dynamics in this already fragile ecosystem. Ecological control measures implemented by researchers have so far been unsuccessful in managing lionfish populations. Alternative population control strategies remain understudied. One approach in managing invasive species that has been gaining academic interest is the promotion of consumption. Evaluating this option could assist identifying key elements in managing its populations. To investigate this topic, this study utilizes a framework on sustainable food sources by the FAO and applies this to the case of lionfish consumption in Crete. The framework consists of three dimensions; an economic, ecological, and social dimension. Results show that there are several sustainability issues regarding lionfish consumption. First, the market price of lionfish is relatively low compared to other seafood species, therefore, an economic incentive for fishermen to target the lionfish is not present. Additionally, the most efficient fishing method to catch lionfish, spearfishing, is not permitted for commercial use. Finally, the views of locals on the lionfish as a food source differ. There is still a stigma surrounding the lionfish due to its venomous spines and its status as an invasive species. Addressing these issues should be a priority in successfully managing the lionfish invasion. Examples from other marine invasive species have demonstrated that it is possible to turn an invasion from a nuisance towards a benefit.

KEYWORDS: INVASIVE SPECIES, SUSTAINABLE FOOD SOURCE, LIONFISH (*Pterois miles*), MANAGEMENT STRATEGY, CONSUMPTION

1. Introduction

The lionfish (*Pterois miles*) has entered the Greek Mediterranean Sea over the past decade (Phillips & Kotrschal, 2021). Being endemic to the Indian Ocean and the Red Sea, the lionfish is considered a non-indigenous species (NIS) that has become invasive. Rising temperatures due to climate change, combined with the opening of the Suez Canal, have facilitated the introduction of approximately 800 NIS into the now warmer Mediterranean (Samourdani et al., 2024). NIS have the potential to impact multiple aspects of both nature and socio-economic structures by affecting biodiversity, human health, infrastructure, tourism, and other ecological aspects (Katsanevakis et al., 2018). Native species are at a disadvantage when compared to the better-adapted invasive species (Samourdani et al., 2024), which is also the case for the lionfish. Its diet is that of an opportunistic generalist predator. This type of predator will feed on many different fish species, including reef fish species (Batjakas et al., 2023). In addition to a wide variety of possible prey, the lionfish also has few natural predators in the Greek Mediterranean. Species such as several grouper species (*Epinephelus marginatus* & *E. costae*) have been identified as natural predators and could be used to biocontrol the lionfish population through predation. However, due to high fishing pressure these predators are being overfished and densities have declined drastically (Hüseyinoğlu et al., 2018). On top of that, the composition of local fish communities is likely to change drastically in areas that have been heavily invaded (Samourdani et al., 2024). One such area is the island of Crete, where the lionfish has established itself in large numbers. Natural options to mitigate the ecological impact of the lionfish invasion are limited due to the lack of natural predators, high resistance to parasites, high fecundity, and a high adaptability to many different environmental conditions (Ulman et al., 2022). Overall, the lionfish invasion represents a major threat to the biodiversity and population dynamics in the Greek Mediterranean Sea.

In addition to ecological impacts, invasive species may also have socio-economic impacts on local stakeholders such as fishermen, fishmongers, and restaurant owners. Fishing practices have traditionally always played a big economic role in the life of many Greek citizens. In 2020, the Greek fishing fleet consisted of 14,000 vessels, the most out of any EU country, employing over 18,000 people (AGRERI, 2024). Therefore, impacts on ecological systems could have much greater impacts on socio-economic aspects. As described by Christidis et al. (2024), the pufferfish species (*Lagocephalus sceleratus*), which has also heavily invaded Crete, can have an economic impact on fisheries in three different ways: i. depredation of fishing gear, ii. increase in labour costs for fishing and, iii. change in catch composition. The results of this study show that local fishermen can have thousands of euro's in damages due to the invasion of this species. However, very little is known about the socio-economic impact of the invasive lionfish species on local stakeholders. Kleitou et al. (2019) suggest that lionfish could potentially reduce local fish recruitment by up to 95%. As lionfish also prey on commercially valuable fish, a change in catch composition could be a possibility (Kleitou et al., 2019). Furthermore, loss of ecosystem services, loss of tourism, monetary benefits through trade, and the cost of controlling and managing the invasion are all viable ways the lionfish could have a socio-economic impact in Crete. The combination of evolutionary benefits, the ecological, and socio-economic impacts of the lionfish invasion in Crete make it a complex problem that requires coordinated management by a diverse group of stakeholders (Ulman et al., 2022).

Researchers have now agreed that the lionfish has fully established around the island of Crete (Samourdani et al., 2024), prompting a shift in focus of research from mitigation towards controlling and understanding the problem (Kleitou et al., 2019). From a socio-economic

perspective, major challenges arise in the understanding of the problem around Crete. A lack of data on the commercial value of the lionfish, public awareness, catch composition, and tourism all add to this. Spearfishing has been identified as the main fishing technique used to catch lionfish around Crete. The Greek law P.D. 373/85 on recreational fishing states that all spearfishers are not allowed to sell or trade any caught fish (Spearzen, 2024), creating problems in regulating and controlling the lionfish population. However, the lionfish has the potential to play a beneficial role in the economy of Crete if trading fish caught using spearfishing was made legal. Locals could reap the benefits by profiting in both socio-economic and ecological ways. Therefore, this research aims to identify both the official market and the black market for lionfish in Crete. Quantifying data would allow for an analysis of the potential socio-economic role of the lionfish in Crete. The following research questions have been constructed.

1.1 What are the socio-economic benefits of the lionfish being part of the fishing industry, both for the official and the black market, as a source of food for the local people of Crete?

I predict that the lionfish has the potential to play a big role in the local economy of Crete. The potential positive socio-economic impact is big as the lionfish is very abundant and can be eaten. The availability of lionfish to restaurants and locals is currently inconsistent and informal. Supply and demand dynamics are unstable and heavily dependent on supply from spearfishers. Since spearfishing is the main fishing technique used, the black market for lionfish is much larger than the official market. If made legal, spearfishers may become specialised in lionfish hunting in the future. It is difficult to quantify supply and demand as there is very little data available. Catches of lionfish are not always recorded.

1.2. Which stakeholders play a role in the official and black market?

I predict that relevant stakeholders include spearfishers, fisheries, fishmongers, restaurant owners, locals, researchers (HCMR), and government initiatives such as Lionhare.

2. Methods

The study will focus on the socio-economic impact of the lionfish on the island of Crete by identifying market dynamics through the economic concepts of supply, demand and price. I aimed to speak to as many restaurant owners, fishmongers, and spearfishers as possible. They provided me with information on the market dynamics. To accomplish this, I went to the island of Crete from the 6th of January to the 8th of March. I planned on traveling around the whole island, which I did by car. During my study, I did not perform any experiment on animals. The current research design aims to gather knowledge on the role the lionfish plays in the both the official and the black market of Crete. As of now, there is no clear indication of what, if any, socio-economic role the lionfish plays. See figure 1 for an overview of the methods.

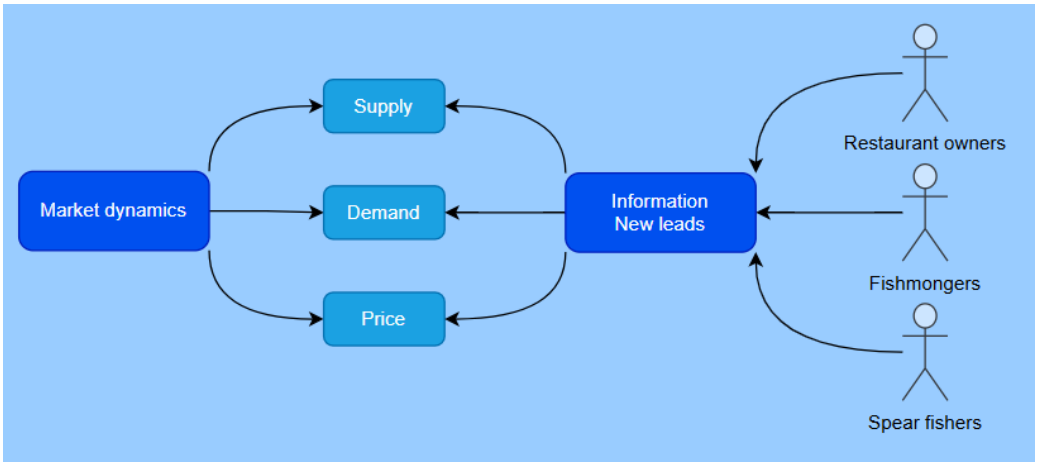


Figure 1: *schematic overview of the methods. The market dynamics were identified using the concepts of supply, demand and price. The information on these three factors was collected through informal talks with restaurant owners, fishmongers, and spearfishers.*

In order to talk to as many stakeholders as possible, I took the following steps: prior to the fieldwork, I distributed a message (Appendix A – Facebook message) to several Facebook spearfishing groups (Appendix B – Supplementary Excel file) in order to find leads that may be useful for gaining information. I constructed this list using the Facebook search bar and entering the following search terms: “spearfishing”, “Crete”, “lionfish”, “Greece”, “Kríti”, “fisheries”, and “hunters”. Depending on the responses, I scheduled meetings with spearfishers who were willing to share their knowledge. Furthermore, I compiled a list of fish markets before going to Crete using Google with the search term ‘’fish markets Crete’’ (Appendix B – Supplementary Excel file). Finally, I also compiled a list of fish restaurants using Google with the search term “fish restaurants Crete” (Appendix B – Supplementary Excel file). While in Crete, I used the application Google Maps to identify fish restaurants and fish shops. I used the same search terms for every city I visited to avoid search bias. The search terms were “fish restaurant”, “fish shop”, and “fish market”. By zooming in on a city/region of Crete and using these search terms the restaurants and fish markets were shown. I then added these places to “My Favourites” in Google Maps, after which I visited them the next day. I gathered the data through an informal conversation with the person that was present at that time.

The following topics were covered in the talks with stakeholders.

1. Location (city and North or South in Crete)
2. In contact with lionfish (yes/no)
3. Way of getting lionfish (Official or black market)
4. Price of lionfish / kg
5. Quantity delivered (supply) to fish markets and restaurants
6. Quantity sold (demand) in the markets and restaurants
7. View on the lionfish as food
8. Price of other seafood species
9. New leads

I put all data collected during the fieldtrip in an Excel file (Appendix C – Excel file Data) and used Rstudio version 4.4.0 to perform basic statistics in order to analyse this dataset. The R script can be found in Appendix D – R script. Firstly, I constructed a Generalized Linear Model (GLM) to explain the variable price. The independent variables consisted of location, city, and seafood species as linear predictor.

$$Y = Price\ in\ euros\ per\ kg$$
$$Linear\ predictor = \eta = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$$

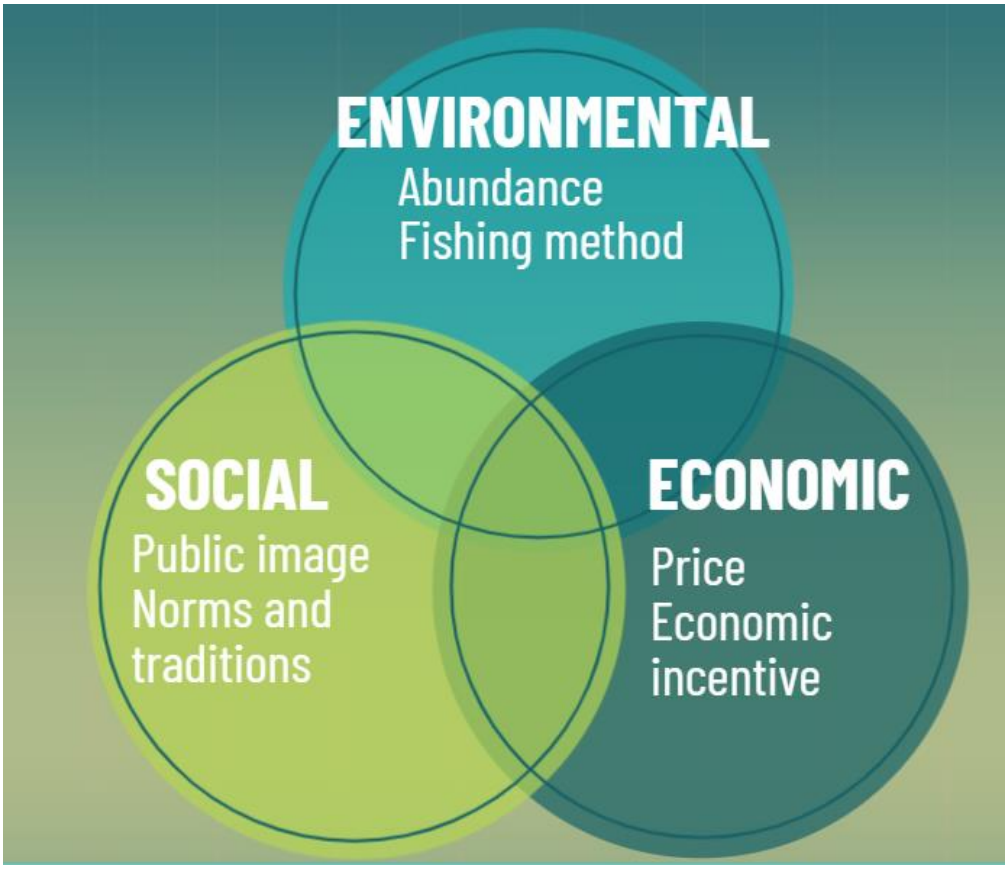
Where X_1, X_2, and X_3 are variables that influence the dependent variable price.
X_1= location
X_2= city
X_3= species

Secondly, I analysed the price of different seafood species by plotting the mean and its spread, and by performing post-hoc pairwise comparison tests. Before doing so, I checked the normality of the data using the Shapiro-Wilk test, which is suitable for small sample sizes (King & Eckersley, 2019). The outcome of the test determined which test for pairwise comparison I used. If the p-value is below 0.05, the null-hypothesis (H_0) is rejected and the sample is not normally distributed. Next, I plotted the mean price of each seafood species, including the spread and highlighted the lionfish in green. I swapped the axis to increase readability of the plot. Finally, I performed post-hoc pairwise comparison tests where I included every seafood species with $n \geq 3$. I compared the price of each seafood species to the lionfish using two different tests depending on the distribution of the sample. For the normally distributed data I used a Welch two sample t-test and for the species that were not normally distributed I used the Wilcoxon rank-sum test.

During my field trip, it became evident that gathering enough data to quantify the market dynamics of the lionfish in Crete was not feasible. This was mainly due to the winter season, during which a lot of restaurants and fish shops were closed. Additionally, I found that the lionfish is not abundant in the winter, resulting in a very low availability. Lastly, many spearfishers were inactive due to the cold ocean temperatures. As a result, I decided to change the research topic to fit the data that I did manage to collect. I set up the following research question: *What are the key elements that explain why the lionfish could potentially become a sustainable food source in Crete?* Using the quantitative data I collected on the price of different seafood species and the qualitative data I collected during the talks with fishermen, fish mongers, and spearfishers, I had enough data to identify key elements that determine the sustainability of the lionfish as a food source and to assess consumption as a viable management strategy. Furthermore, I used a framework from the Food and Agriculture

Organisation (FAO) on sustainable food systems as a concept, which is illustrated in figure 2 (FAO, 2018). This framework consists of three dimensions based on economic, social, and environmental elements that determine the sustainability of a food source. Only when all dimensions are considered sustainable, a food system can be described as sustainable. The economic dimension focuses on the added value of the lionfish consumption towards the local economy by for example providing job opportunities or economic incentives. The environmental dimension focuses on the environmental impact of consuming a specific food source. Two elements that play a key role in determining sustainability of any fishery, are the abundance of the fish and the fishing method used. The social dimension focuses on the lionfish as a food source enhancing cultural values. A key element in this is whether lionfish consumption aligns with Greek cultural norms and traditions. In order to fit the data I collected and the specific case of the lionfish, I researched only a few elements of each dimension.

Figure 2: the sustainable food system framework adjusted for the lionfish. Concept adopted from FAO, 2018. SFS is an abbreviation for Sustainable Food System. A food system is described as sustainable when all three dimensions meet its sustainability goals.



3. Results

The price of seafood was collected from 4 fish shops, 2 in the north and 2 in the south of the island. As can be deducted from table 1, all seafood species are roughly normal distributed, except for horse mackerel and sea bass. Therefore, a Wilcoxon rank-sum test will be performed for these two species during the pairwise comparison test. Furthermore, in figure 3 a large variety in the price range of different seafood species is presented. The mean price of lionfish showed similar results to that of dorade (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*), while species such as red mullet (*Mullus barbatus & surmuletus*) and red snapper (*Lutjanus campechanus)* showed a higher price.

*Table 1: the normality for each of the seafood species with n ≥ 3. If p-value>0.05 the data is roughly normal distributed. *p-value<0.05 **p-*

	Shapiro p
Cuttlefish (*Sepia officinalis*)	0.952
Dorade	0.087
Horse mackerel (*Trachurus trachurus*)**	0**
Lionfish	0.200
Red mullet	0.409
Red snapper	0.363
Saddled Seabream (*Oblada melanura*)	0.161
Sea bass**	0.009**

Figure 3: mean price of different seafood species in euro/kg with spread. The mean of each species is shown as a black dot. Species are ordered from high to low price. Lionfish is highlighted in green.

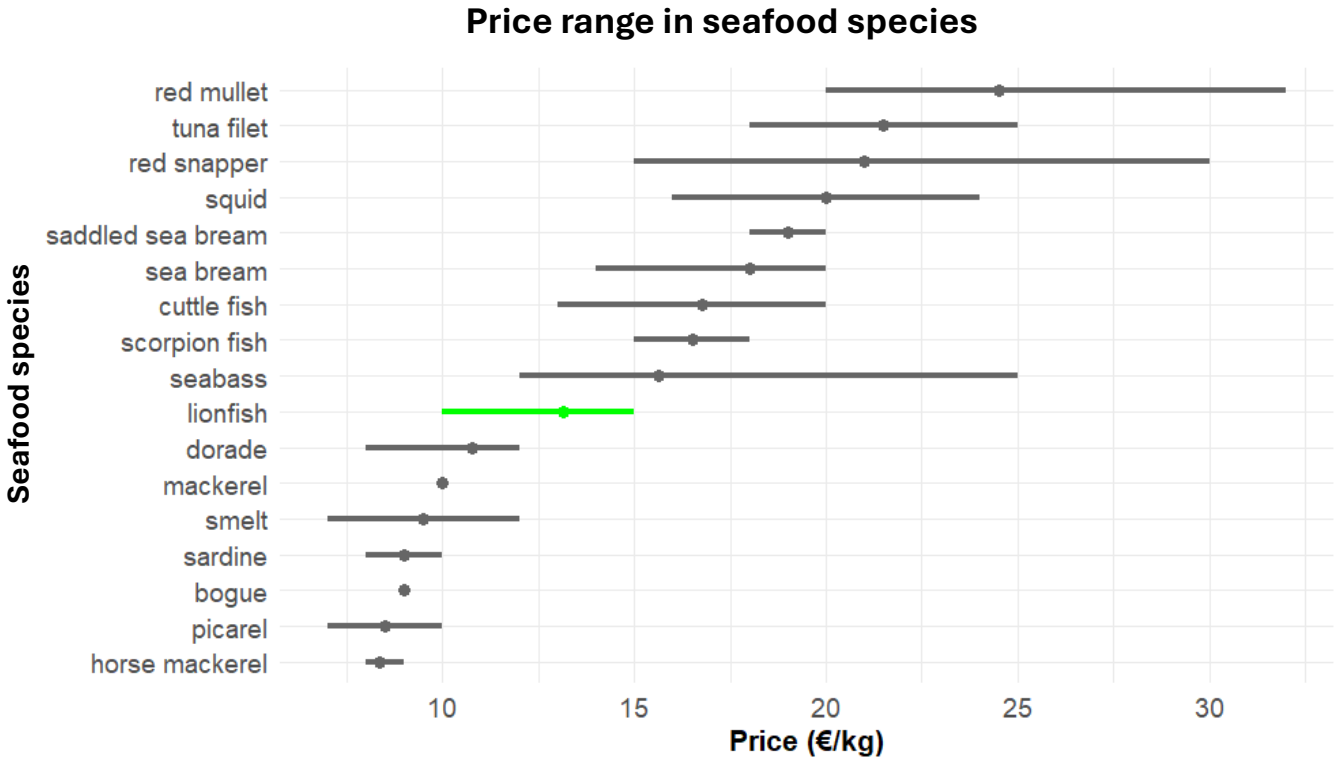


*Table 2 shows the pairwise comparison in price between the lionfish and other seafood species. Only species with n>=3 are included. *p-value<0.05 **p-value<0.01*

	Type of test	t/w	df	p
Cuttlefish	Welch two sample t-test	2.166	4.5	0.089
Dorade	Welch two sample t-test	-1.994	6.54	0.089
Red mullet**	Welch two sample t-test	-5.99	6.76	0.001**
Red snapper	Welch two sample t-test	-1.69	2.10	0.226
Saddled Sea bream*	Welch two sample t-test	-3.05	4.68	0.031*
Sea bass	Wilcoxon rank-sum test	14.5	-	1

As can be deducted from table 2, only two species differ significantly in price when compared to the lionfish. These species are the red mullet and the sea bream; both are significantly more expensive than the lionfish. The price of other species do not differ significantly from the lionfish. Although statistically not always significantly different, it is reasonable to conclude, based on figure 3, that the price of the lionfish is relatively low compared to many popular seafood species. Following the price of the lionfish, fishing as a job opportunity was analysed. Manthos, a fishermen in Agia Galini stated: "*The aging of the fishermen is a big problem in Greece, almost all fishermen are above 60 years old and have no successor for their fishing vessels. Furthermore, fishing yields continue to decrease due to overfishing which does not encourage the young adults to partake in fishing activities.*"

During the fieldwork in Crete, I identified two main fishing methods with which lionfish is caught. Through talks with commercial fishermen I identified small-scale fisheries using static gill nets to be the first. Fishing vessels of up to 12 meters are used, mostly fishing in coastal waters. Multiple fishermen stated that static gill-nets are not the most efficient way to catch lionfish. However, during the winter, these gill-net fisheries were able to catch lionfish, as they were sold in 4 different locations. In summer, 20 out of 32 fresh fish shops mentioned that they sell lionfish. Out of those 20 fish shops, 19 stated the seafood they sold was caught using small-scale fisheries. The second fishing method I identified is spearfishing. After the distribution of the Facebook message (Appendix A – Facebook message), 8 spearfishers messaged back. All stated to catch fish only for their own consumption and that spearfishing was an efficient method to catch lionfish. Average catch quantities ranged from 4 kg of lionfish per trip to 22.5 kg of lionfish per trip depending on which species was targeted.

During the two months in Crete, 42 fish shops were visited, of which 36 were open. Almost every major town in Crete had a fish shop or local market selling seafood. In total 141 restaurants were visited, of which 108 restaurants were closed 26 described themselves as a fresh fish restaurant. This indicated that fish plays a big role in the diet of many locals. However, it became apparent that locals are still divided in their opinion on the lionfish as a food source. Of the 42 fish shops visited, 22 fish shops did not sell lionfish in summer nor in winter. When asked why, common responses included concerns about the lionfish as an edible fish species. A similar trend was observed in restaurants, particularly those specialized in seafood. One restaurant owner said: "*Lionfish is a bad eating fish, it is a fish of low quality and it is trash of the sea.*" Others indicated it was due to the venomous spines, difficult in preparation, or because

they were not familiar with the fish. On the other hand, fish mongers who did sell lionfish were positive about the fish as a food source. One fish monger in Heraklion said: "*The flesh of the lionfish is as good as any other white fish. It can be used in a variety of dishes. It is good for soup, grilling or even as sushi or ceviche (figure 4). You just need to know how to prepare it.*"

Figure 4: the lionfish prepared as ceviche in a restaurant in Heraklion

Discussion

The three dimensions of the framework for sustainable food sources have provided insight into the sustainability of lionfish as a food source. For the economic dimension, the elements of price and job opportunities were identified, which helped explain the economic value added to the local economy of Crete. The price of lionfish is relatively low compared to that of other seafood species. Important to note, the statistical significance of this comparison was not always present due to the low number of data entries. A low price has resulted in the lionfish as an affordable fish species, however, there is little economic incentive for fishermen to specialise in catching it. Furthermore, talks with fishermen showed that the fishing industry in Crete continues to play a big role in the livelihood of many inhabitants by providing jobs and food. However, until now, the lionfish has not significantly contributed to this. Regarding the environmental dimension, the lionfish consumption has a relatively low environmental impact. The fishing methods used to catch lionfish, spearfishing and gill nets, are considered to have a lower environmental impact than other fishing methods. However, gill-net fisheries are not efficient at catching lionfish, and while spearfishing is efficient, it is not legal to do so commercially. Lastly, regarding the social dimension, consuming fish is a long-standing tradition in Greek culture and thus aligns well with the lionfish as a food source. However, lionfish is not yet widely accepted across the population as a good food source. Results indicated that there is still a stigma surrounding the fish due to its venomous spines and it being invasive.

Overall, this study shows that the lionfish has the potential to become a sustainable food source for the people of Crete. However, the three main problems mentioned before, currently hinder this potential. The current available literature on the lionfish in the Mediterranean does not provide enough information to develop a strategy to increase consumption. Several crucial elements are either understudied or completely unknown. Previous government initiatives such as the project Lionhare, focused primarily on understanding the ecological impacts of the lionfish and on assessing tools to control their population (Lionhare, 2021). Therefore, literature from the lionfish invasion in the Caribbean and other marine invasive species in the Mediterranean should be taken as an example to develop a management strategy. Huth et al., (2018) conducted a series of experiments in Florida to test customers willingness to pay for a prepared lionfish dish with varying levels of information. They found that willingness to pay increased significantly when customers were informed about the ecological problems caused by the lionfish. A recent example of an invasive species in the Mediterranean is the invasive blue crab (*Callinectes sapidus*), which experienced a massive outbreak in 2023 across the Northern Adriatic Sea (Marchesseux et al., 2022). This species heavily impacted Italy's shellfish industry, causing damages of up to €100 million (Azzurro et al., 2024). According to Azzurro et al., (2024), the main strategy to manage the invasion of the blue crab is through its consumption. Although measures were taken by the Italian government to compensate the economic losses of shellfish farms and not to promote the consumption of the crab, the management of this invasion has been highly successful (Ministerial Decree No. 587931 on October 23, 2023 & No. 628456 on November 13, 2023). Their study highlighted that spikes in media attention increased consumption and availability of the blue crab, and that it has now become part of the fishing industry in several Mediterranean countries (Marchessaux et al., 2023). Furthermore, there have reports of market prices going up after spikes in media attention, creating an economic incentive to commercialise this species (Azzurro et al., 2024). Another study on the blue crab, this time in France, demonstrated that public awareness and willingness to consume invasive

species can function as a form of environmental protection and can contribute in managing invasive species effectively (Marchessaux et al., 2024). These examples should be utilized to create a management strategy for the lionfish in Crete. Azzurro et al., (2024) identified that public awareness is the main driver of consumption. The current study highlighted that the public image surrounding the lionfish is bad as locals are not yet familiar with the lionfish as a food source. Initiatives to increase the consumption of lionfish in Crete are crucial to improve the public awareness. Cooking shows such as MasterChef Greece could serve as an inspiration for many Greek home cooks to and establish the lionfish as an edible food source. Other initiatives such as "Pick the Alien" have informed over 7000 consumers in Greece about the consequences of invasive species (iSea, 2025). Local government support for such initiatives could increase public awareness and increase consumption. Widespread media attention would provide information to consumers on a regular basis, creating a positive image around lionfish consumption. Similar to the situation of the blue crab before its boom, the lionfish is not harvested efficiently. An increase in market prices could see increased interest from fishermen to target the lionfish. Government subsidies could provide an incentive for fishermen to target the lionfish and create innovative methods to catch it (Skeerritt & Sumaila, 2021). Another possibility is to emphasize creating higher value products from lionfish such as ceviche or sushi, which is already done by some restaurants. Additionally, legalising the commercial trade of fish caught via spearfishing would likely increase catch numbers. Setting up a pilot in which spearfishing on invasive species is made legal could provide a great opportunity to test if lionfish catches go up. Implementing these measures as a management strategy for the lionfish invasion is crucial for the future. However, more research is needed to determine whether these specific measures and consumption are a viable way to manage invasive species in general (Seaman et al., 2021).

This research has attempted to apply a multi-dimensional framework to identify and analyse various elements that describe the lionfish as a sustainable food source. For each dimension, multiple elements were examined, leading to a conclusion regarding the sustainability of the lionfish as a food source and regarding consumption as a viable way to manage invasive species. Limitations of this study are present due to the lack of statistical significance, explained by the low number of observations and data entries. This study was conducted during the winter months, strongly reducing the number of open fish shops and lionfish availability. Future research should prioritize the use of quantitative data and statistical analysis to assess the sustainability of lionfish consumption. Furthermore, only a limited number of elements from the FAO framework were analysed in this study due to time and data constraints. Therefore, future studies should aim to analyse a complete overview of the framework in a quantitative manner. A comprehensive summer study on the lionfish and other fish species should give more insight into the lionfish as a sustainable food source in Crete.

Statement on the use of generative AI

Generative AI (ChatGPT-4o) has been used to generate and solve code in Rstudio and check spelling. It has NOT been used to generate written text in this Msc thesis report.

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1. Appendix

Appendix A – Facebook message

Γεια spearfishers,

Thank you for sharing all the beautiful pictures and videos of the fish you have caught. I am Bart, 23 years old and new to spearfishing. I will be visiting Crete In January and February and would like to learn more about spearfishing. I am particularly interested in talking to divers who are hunting for lionfish. It would be great to get in contact with each other. Feel free to send me a message. Let's meet in January or February

αντίο

Photos by Davide Bottacini

Appendix B – Supplementary Excel file

This file includes the sheets 'ReadMe', 'Restaurants', 'Facebook groups', 'fish markets' and, 'Dataset'.

Appendix C – Excel file Data

This file includes the sheets 'ReadMe', 'Spearfishers', 'Fish markets winter', 'Fish markets summer', 'Restaurants', 'Fish prices'.

Appendix D – Rstudio code

The following lines show the script used in Rstudio to analyse the data.

```
#Set working directory

setwd("~/WUR/BHE thesis/Msc Thesis")


#Packages

library(broom)

library(readxl)

library(ggplot2)

library(dplyr)

library(carData)

library(car)

library(Hmisc)

library(ggpubr)

library(tidyr)

library(purrr)

library(tibble)

library(stringr)


#Read data

Data <- read_excel("Data.xlsx", sheet = "Fish prices", range = "N1:Q54")


#Plot mean fish price per species with spread

fish_data <- tribble(

 ~ID, ~Species, ~Region, ~Location, ~Price,

 1, "bogue", "South", "Agia Galini", 9.0,

 2, "bogue", "North", "Rethymnon", 9.0,

 3, "cuttle fish", "North", "Rethymnon", 13.0,

 4, "cuttle fish", "South", "Agia Galini", 16.0,

 5, "cuttle fish", "South", "Mires", 18.0,

 6, "cuttle fish", "North", "Heraklion", 20.0,
```

7, "dorade", "North", "Heraklion", 8.0,

8, "dorade", "South", "Agia Galini", 11.0,

9, "dorade", "North", "Rethymnon", 12.0,

10, "dorade", "South", "Mires", 12.0,

11, "horse mackerel", "South", "Agia Galini", 8.0,

12, "horse mackerel", "North", "Heraklion", 8.0,

13, "horse mackerel", "North", "Rethymnon", 9.0,

14, "lionfish", "South", "Agia Galini", 10.0,

15, "lionfish", "North", "Rethymnon", 11.0,

16, "lionfish", "South", "Mires", 13.0,

17, "lionfish", "North", "Heraklion", 14.0,

18, "lionfish", "North", "Rethymnon", 14.0,

19, "lionfish", "North", "Heraklion", 15.0,

20, "lionfish", "North", "Heraklion", 15.0,

21, "mackerel", "South", "Agia Galini", 10.0,

22, "mackerel", "South", "Agia Galini", 10.0,

23, "picarel", "South", "Agia Galini", 7.0,

24, "picarel", "North", "Heraklion", 10.0,

25, "red mullet", "South", "Mires", 20.0,

26, "red mullet", "South", "Agia Galini", 22.0,

27, "red mullet", "North", "Rethymnon", 22.0,

28, "red mullet", "South", "Agia Galini", 25.0,

29, "red mullet", "North", "Heraklion", 26.0,

30, "red mullet", "North", "Heraklion", 32.0,

31, "red snapper", "South", "Mires", 15.0,

32, "red snapper", "South", "Agia Galini", 18.0,

33, "red snapper", "North", "Heraklion", 30.0,

34, "saddled sea bream", "South", "Agia Galini", 18.0,

35, "saddled sea bream", "North", "Heraklion", 20.0,

36, "sardine", "South", "Agia Galini", 8.0,

37, "sardine", "North", "Heraklion", 10.0,

```
  38, "scorpion fish", "South", "Agia Galini", 18.0,
  39, "scorpion fish", "North", "Heraklion", 15.0,
  40, "sea bream", "North", "Heraklion", 14.0,
  41, "sea bream", "South", "Mires", 18.0,
  42, "sea bream", "South", "Agia Galini", 20.0,
  43, "sea bream", "North", "Rethymnon", 20.0,
  44, "seabass", "South", "Agia Galini", 12.0,
  45, "seabass", "North", "Rethymnon", 12.5,
  46, "seabass", "South", "Mires", 13.0,
  47, "seabass", "North", "Heraklion", 25.0,
  48, "smelt", "South", "Agia Galini", 7.0,
  49, "smelt", "North", "Heraklion", 12.0,
  50, "squid", "South", "Agia Galini", 16.0,
  51, "squid", "North", "Rethymnon", 24.0,
  52, "tuna filet", "South", "Agia Galini", 18.0,
  53, "tuna filet", "South", "Mires", 25.0
)

# Summarize
summary_df <- fish_data %>%
  group_by(Species) %>%
  summarise(
    min_price = min(Price),
    max_price = max(Price),
    mean_price = mean(Price),
    .groups = "drop"
  ) %>%
  arrange(mean_price) %>%
  mutate(Species = factor(Species, levels = Species),
         color = ifelse(Species == "lionfish", "lionfish", "other"))
```

```
# Plot: Species on x-axis, Price on y-axis
ggplot(summary_df, aes(x = Species, ymin = min_price, ymax = max_price)) +
 geom_linerange(aes(color = color), size = 1.5) +
 geom_point(aes(y = mean_price, color = color), size = 3) +
 scale_color_manual(values = c("lionfish" = "green", "other" = "gray40")) +
 labs(
  title = "Price Range of seafood Species",
  x = "Fish Species",
  y = "Price (€/kg)"
 ) +
 coord_flip() +
 theme_minimal(base_size = 14) +
 theme(
  axis.text.y = element_text(size = 14),
  axis.text.x = element_text(size = 14),
  axis.title.x = element_text(size = 16, face = "bold"),
  axis.title.y = element_text(size = 16, face = "bold"),
  plot.title = element_text(size = 18, face = "bold", hjust = 0.5),
  legend.position = "none"
 )

#####Pairwise comparison

# List of unique species (excluding lionfish)
species_list <- unique(Data$species)
species_list <- species_list[species_list != "lionfish"]

# Loop through species
for (sp in species_list) {
 cat("\nComparing lionfish to", sp, ":\n")
```

```
# Subset the data for lionfish and current species
temp_data <- Data %>% filter(species %in% c("lionfish", sp))

# Check if both groups have at least 3 observations
lionfish_prices <- temp_data$price[temp_data$species == "lionfish"]
 sp_prices <- temp_data$price[temp_data$species == sp]

 if (length(lionfish_prices) < 3 | length(sp_prices) < 3) {
   cat("Not enough data (less than 3 samples), skipping...\n")
   next}

# Shapiro-Wilk normality tests
shapiro_lion <- shapiro.test(lionfish_prices)$p.value
shapiro_sp <- shapiro.test(sp_prices)$p.value

# Decide which test to use
 if (shapiro_lion > 0.05 & shapiro_sp > 0.05) {
# If both are normal
   result <- t.test(price ~ species, data = temp_data)
   cat("Using t-test:\n")} else {
# If not normal
   result <- wilcox.test(price ~ species, data = temp_data)
   cat("Using Wilcoxon test:\n")}

# Print the result summary
 print(result)}
```