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Guide to Lionfish Management in the Mediterranean

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The proliferation of the lionfish in the Mediterranean is a major threat to our sea's ecosystems. That is why it is important to do all we can to prevent, inhibit and limit it. This is what the solutions presented over the following pages very effectively set out, based on both sound scientific expertise and conclusive feedback.

Beyond these specific challenges, the lionfish also confronts us with broader issues, which concern our environment as a whole and call our responsibility into question.

A recent issue resulting from human negligence; a worrying development that threatens whole areas of our sea; a rapid scientific appraisal which in just a few years has enabled us to understand the risks and to identify solutions; the need to act quickly, together, in light of this appraisal; finally, the need to increase the awareness of the public and economic players, by proposing alternative consumption patterns... These phases, which are common to all environmental crises, confront us with our capacity to take action.

As such, our management of the lionfish will be indicative of our aptitude to deal with the major threats hanging over our environment. All the more reason to take action to address this threat, to protect the Mediterranean ecosystems!

Albert II Prince of Monaco

Executive Summary

Lionfish (*Pterois miles*) are spreading in the fastest fish invasion ever reported in the Mediterranean Sea where they are disrupting ecosystems and have the potential to impact livelihoods. First found in Lebanon in 2012, lionfish quickly became established throughout the eastern Mediterranean and are now spreading west. This management guide is based on lessons learnt during the European Union part-funded RELIONMED project which started in 2017.

Local citizen scientists, stakeholders, divers, fishers, researchers and managers worked together to tackle the lionfish threat to conserve biodiversity in priority habitats.

This Guide is designed to inform lionfish management in the Mediterranean region, key topics include (1) lionfish removals,
(2) development of markets, (3) outreach, (4) research and monitoring, and (5) regional cooperation.

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The Relionmed project...

Chapter 1

- **Monitored**

  the Mediterranean distribution of lionfish.

- **Modelled**

  the potential for lionfish to spread.

Chapter 2

- **Trained**

  divers and fishers to monitor and remove lionfish in priority areas.

- **Showed**

  that spearfishing with SCUBA can keep lionfish densities below levels that cause ecosystem damage.

Chapter 3

- **Raised**

  awareness of lionfish as an invasive but edible species.

- **Introduced**

  lionfish to Cypriot markets and increased its retail price.

Chapter 4

- **Built**

  social capital in invasive species management which can benefit coastal ecosystems.

Chapter 5

- **Assessed**

  the local biology of lionfish and their ecological and socio-economic impacts.

Chapter 6

- **Proposed**

  lionfish for inclusion in the list of invasive species that need management by all EU Member States.

- **Supported**

  collaboration with stakeholders in Mediterranean and western Atlantic countries.

Key Recommendations

- **Target lionfish quickly**

  to reduce the potential for ecological and socio-economic impacts.

- **Rapidly develop opportunities**

  for commercial and recreational fishers to target lionfish.

- **Focus on legal changes**

  needed to allow lionfish removals

- **Create a supply chain**

  for lionfish products.

- **Enthuse public interest**

  with opportunities to see, eat, and take part in activities to manage lionfish.

- **Set thresholds**

  for environmental, economic and social impacts and assess the performance of management activities.

- **Monitor**

  lionfish at sentinel locations.

- **Immediately put lionfish on the agenda**

  for regional cooperation. They need to be included on the EU list of invasive species of concern.

- **Support biosecurity**

  measures in the Suez Canal.

Chapter 1

A lionfish invasion is underway

Common lionfish *(Pterois miles)* are native to tropical areas of the Pacific and Indian Ocean basins, including the Red Sea. Enlargement and deepening of the Suez Canal in recent years has rapidly increased the introduction of Non-Indigenous Species into the Mediterranean [1; 2]. In 2012, two *Pterois miles* were recorded off Lebanon [3]. From 2015 to 2021 they spread rapidly (Figure 1) [4]. This is the fastest fish invasion ever reported in the Mediterranean Sea [5]. There is a need to monitor lionfish sentinel locations.

Figure 1

The Mediterranean spread of lionfish from 2013-21.

A threat to biodiversity

Lionfish threaten biodiversity, fisheries and human health, as shown in the western Atlantic where these invasive fish are now a major pest [6-8]. Lionfish reproduce quickly in the eastern Mediterranean and eat a wide range of native fishes (Figure 2). A population explosion of lionfish around Cyprus drew the attention of managers, scientists, and stakeholders [9;10]. That response forms the basis of this management guide.

Data from Bonaire and Curaçao in the western Atlantic show that quickly targeting lionfish reduces ecological and socio-economic impacts [11].

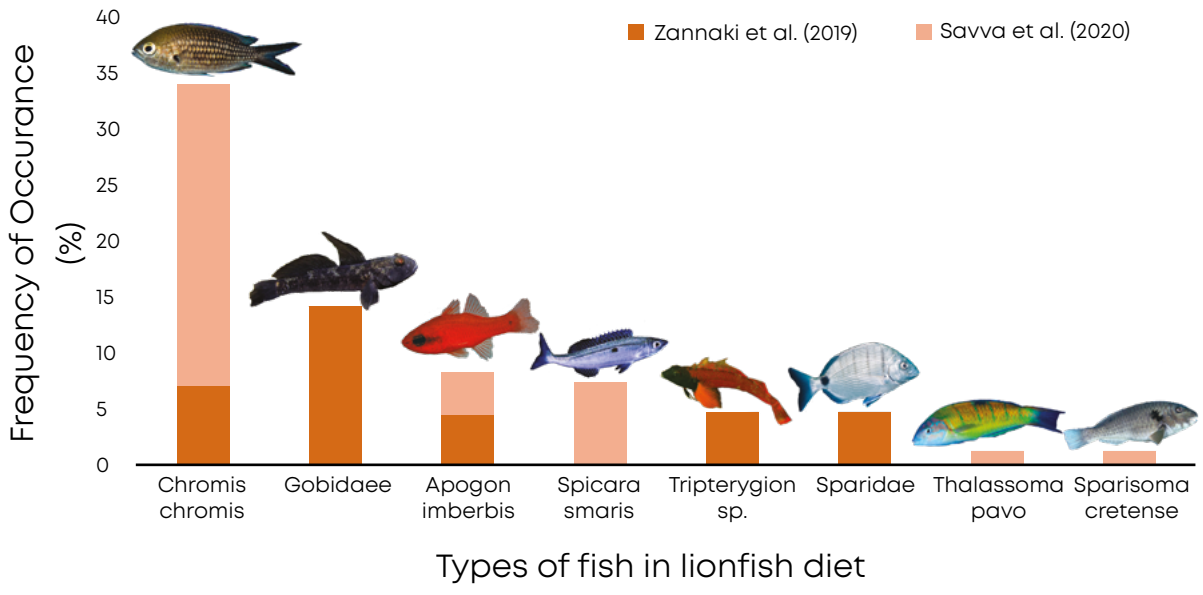


Figure 2

Five key traits make lionfish successful invaders of Mediterranean waters

1

Fast breeders, early maturity, high fecundity, and pelagic larvae

2

Few natural enemies as their predators are overfished

3

Venomous spines protect it from predators and can give people a painful sting

4

Lives in a wide range of temperatures, depths, and habitats; tolerates low salinity and turbid waters and can go months without food

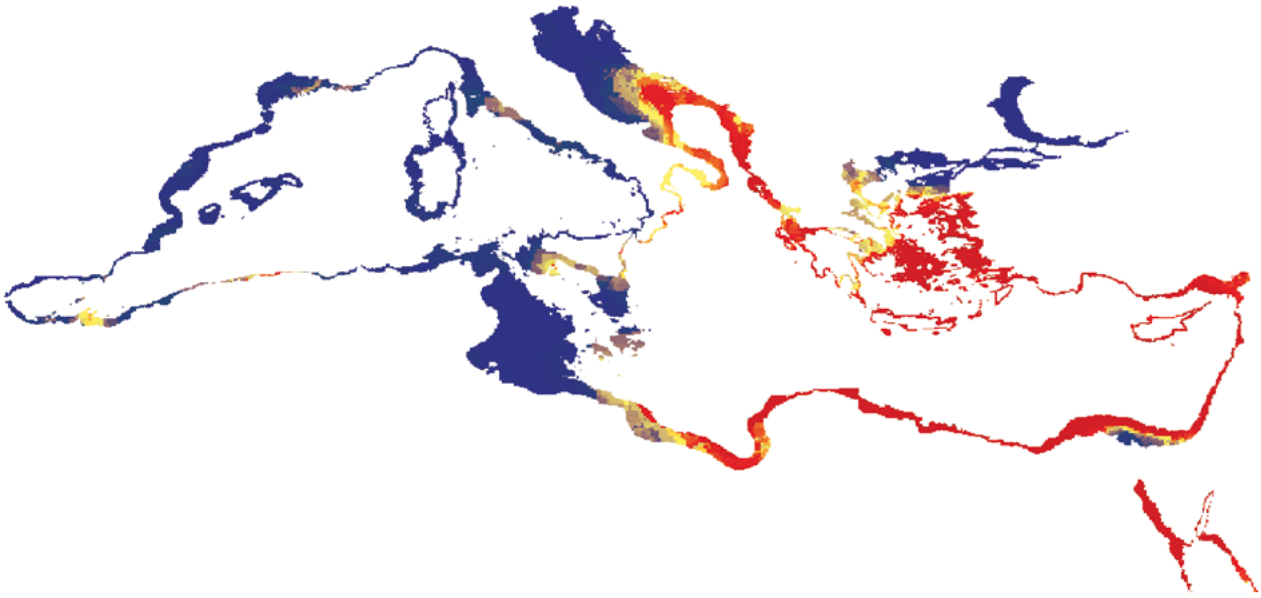
5

Eats native Mediterranean fish and crustaceans. Hides well, can hunt in groups, and sucks in its prey with a surprisingly large mouth.

Distribution Modelling

Projected lionfish distribution in the Mediterranean under Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathways 2.6 and 8.5 for 2040-2050. Based on a Species Distribution Modelling (SDM) approach was developed for waters to 300 m deep [10]. In present day climatic conditions, lionfish are expected to continue to spread into Italian and Algerian waters. With warming, lionfish are expected to spread into the south coast of France and all along the southern Mediterranean coast (Figure 3). This projected spread may be conservative because SDM modelling can underestimate the spread of invasive species [12].

Representative Concentration Pathway 2.6



Representative Concentration Pathway 8.5

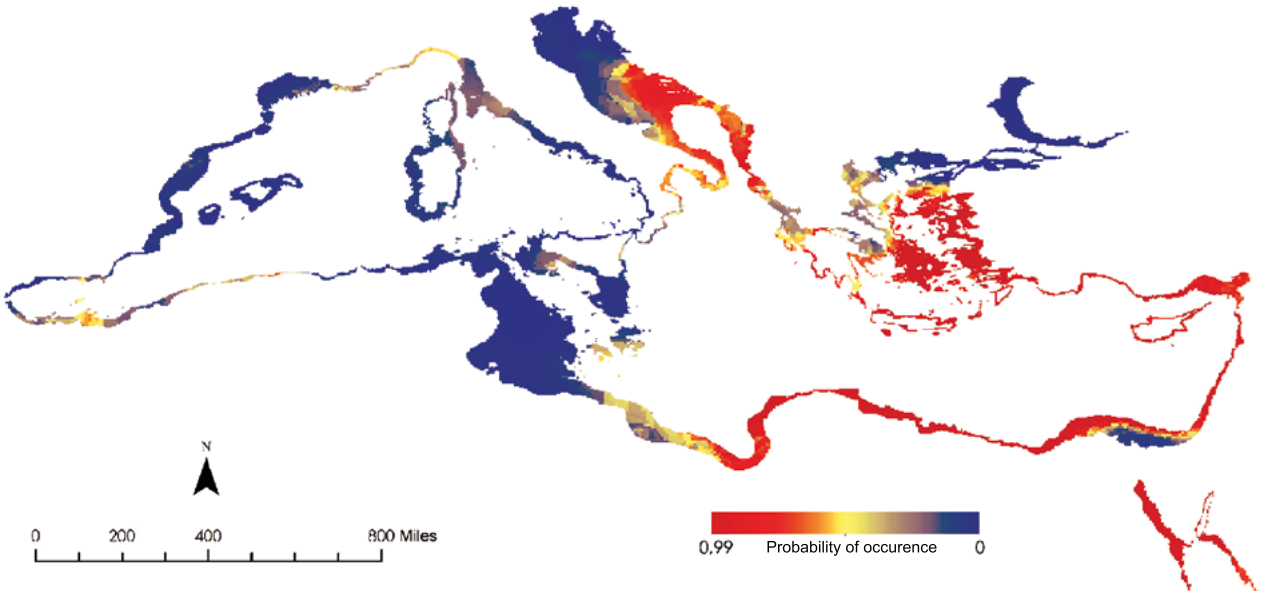


Figure 3

Potential range of *P. miles* in the decade 2040 – 2050 with conservative (Representative Concentration Pathway 2.6) and business as usual (Representative Concentration Pathway 8.5) IPCC climate change scenarios. In both scenarios lionfish are set to spread widely across the Mediterranean Sea.

The Cyprus project

The RELIONMED project ran in Cyprus from 2017 to 2022 and brought together local citizens, divers, fishers, researchers and managers to detect and control lionfish. Lionfish biology was studied, their impacts monitored and management tools were evaluated. These included a lionfish reporting system, training of SCUBA and free divers; training of fishers, and the promotion of new markets for lionfish products.

RELIONMED showed that lionfish removals by pole spear fishing was highly effective in marine protected areas. However, lionfish could soon re-invade and so coordinated monitoring and further targeted removal events are needed. Cypriot restaurateurs and jewellery makers had a strong interest in using lionfish products.

The project provided an educational platform for better management of the marine environment using public collaboration to raise awareness and tackle the lionfish invasion. RELIONMED proposes that lionfish are included on the EU list of invasive species of concern (EU Regulation 1143/2014) needing regional management.

Lionfish are beautiful as well as tasty, but they bristle with venomous spines

Chapter 2

Lionfish control

Recreational spearfishing events were the main method used to control lionfish around Cyprus. Commercial fishers also caught and landed lionfish from the area as incidental bycatch. In the Caribbean, lionfish were kept under control in areas with high stocks of native groupers [13]. RELIONMED assessed the benefits and risks of using divers to remove lionfish, compared with removals with fisheries and natural ecosystem control (Annex Table 1)
N.B. All tables are at the end of this guide.

Spearfishing

Lionfish are sedentary by day and the adult fish are easily caught by trained SCUBA divers in shallow (<30 m depth) waters using hand-held spears. At these shallow depths, spearfishing reduced lionfish numbers, biomass and size in Marine Protected Areas off Cyprus [14]. Tournaments and regular removals were monitored by citizen scientists [14]. Teams of 2-3 divers were awarded prizes for the smallest, largest, and/or most lionfish caught. Some harvested lionfish were given to the divers for consumption, to raise market awareness of the product, while the rest were kept for research into lionfish biology and ecology [15-17].

In most Mediterranean countries spearfishing is only allowed while free diving. EU Regulation EC/1967/2006 prohibits the use of spearfishing using underwater breathing apparatus. The Cyprus Government issued RELIONMED a permit for spearfishing within Marine Protected Areas as this was a scientific investigation intended to reduce impacts on native biodiversity

This permit approach could be effective in other countries. As spear fishers often target large, top-predator 'trophy' fish [18] we needed to have educational activities that demonstrated the need to leave native fish alone. Licences for spearfishers to sell lionfish may also encourage this sector as would lifting daily catch restrictions for lionfish [19].

Lionfish removal teams were able to control lionfish in Marine Protected Areas around Cyprus (31/05/2021 off Green Bay, Ammochostos) [14].

Lionfish removals

We set up Removal Action Teams (RATs) and hosted tournaments where SCUBA and free divers could participate. From March 2019 to November 2021, there were 82 removal events, eight tournaments and 74 RATs removals. The number of participants averaged 5 in the RAT removals and 34 in the tournaments and a total of 4767 lionfish were removed. Free divers were more efficient where large shallow areas could be covered slowly, while SCUBA divers were more efficient at quickly removing lionfish from small areas, such as wrecks.

Removal toolkits had wooden pole spears, specialized containment units, puncture-resistant gloves, and heat packs.

During removal events, divers were not allowed to catch other species or damage the environment using the pole spears. In case of infringement, they would be banned from future activities and be reported to the authorities (no such incidents occurred). All participants first attended a workshop where they were trained in the safe use of removal toolkits and lionfish biology.

The Ministry of Cyprus allowed **RELIONMED** to recruit 100 volunteer divers in the RATs under a permit which set the following rules:

The permit was valid only in the presence of RELIONMED staff members

Before each removal, the RELIONMED team had to inform the relevant authorities

The RELIONMED team ensured the safety of each participant

During removals, the boats displayed a RELIONMED flag and license number

Removals were prohibited from sunset until dawn

Only pole spears were allowed

Lionfish removed could not be used for commercial purposes

Reporting used a standard data sheet to collect information on the lionfish removals (Figure 4). During tournaments, an ambulance was on standby.

RAT removal/Derby:			Region:				Date:
Participants	Team's code	Time in	Time out	Dive time	Depth range	Area dived	Area details

Temperature °C	Boat (Y/N)	Gases (air, mixed, nitrox)	Lionfish missed	Lionfish caught

Figure 4

Data sheet to record lionfish removal dives.

In the three years of the RELIONMED project, no spearfishing license infringements occurred and the events enhanced public education and motivation to participate in marine conservation. Participants said they would be happy to pay a small fee to participate in future events [14] to foster long-term commitment and frequency of removals.

1

Amend legislation to permit removals with SCUBA gear

2

Assess divers' qualifications, request waivers, and a medical fitness declaration

3

Educate about invasive species and train on using removal toolkits and how to safely handle lionfish

4

Equip divers with removal toolkits

5

Utilize a participatory approach to monitor lionfish and identify priority sites for removals

6

Organize, coordinate, and participate in removal events and tournaments

7

Use the events for research and scientific information, and to promote the commercial exploitation of lionfish

Steps used to organise lionfish removals around Cyprus

Lionfish control in Marine Protected Areas

Between 2018-2020 there was around a 400% increase in numbers and biomass of lionfish in areas off Cyprus where fishing was restricted within Marine Protected Areas but there was around half this increase in areas where commercial fishing was allowed. Where frequent lionfish removal activities were allowed there was a 64% decrease in lionfish numbers (Figure 5) and a 250% decrease in lionfish biomass. Average lionfish size reduced from around 20 to 18 cm in length in areas with frequent culling events but increased in all other monitoring sites.

400%

Increase in lionfish densities and biomass in areas off Cyprus

64%

Decrease in numbers where lionfish removal activities were allowed

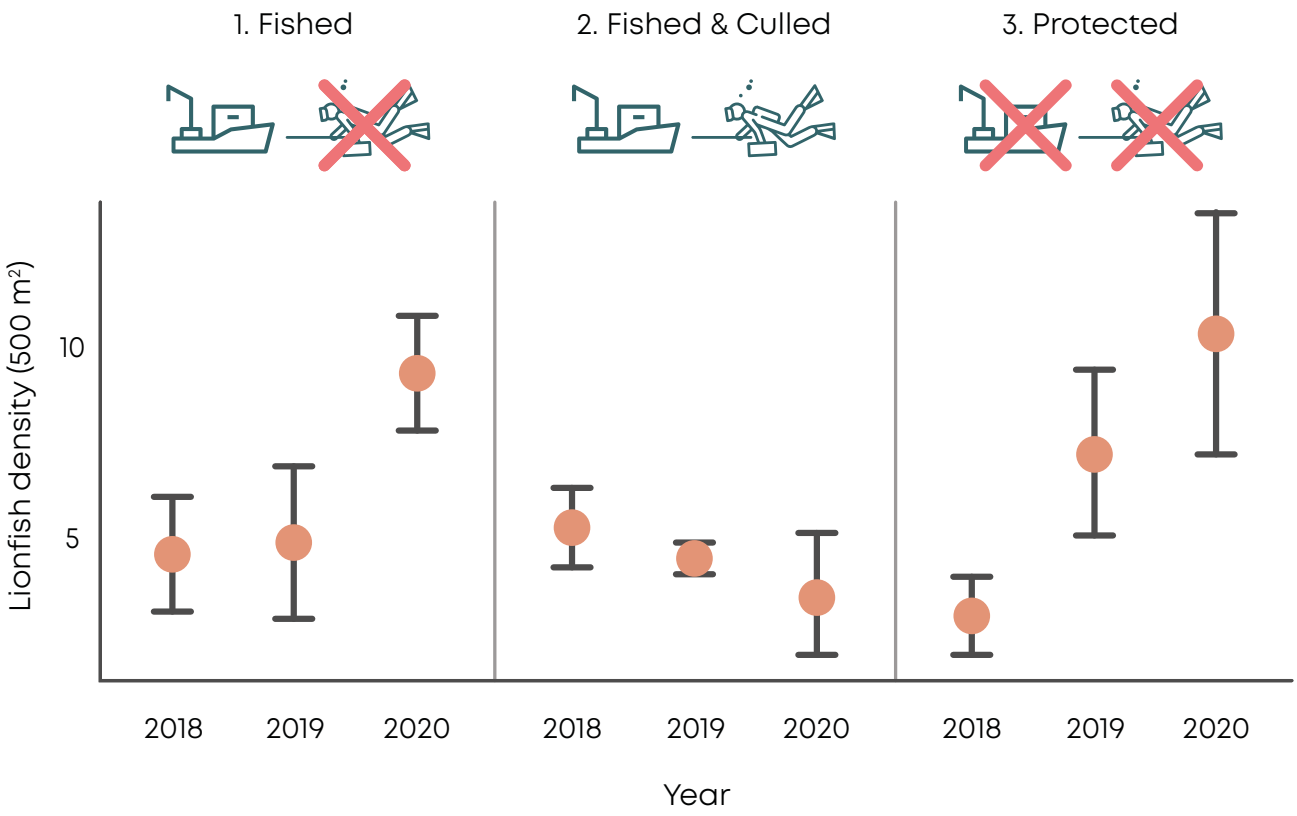


Figure 5

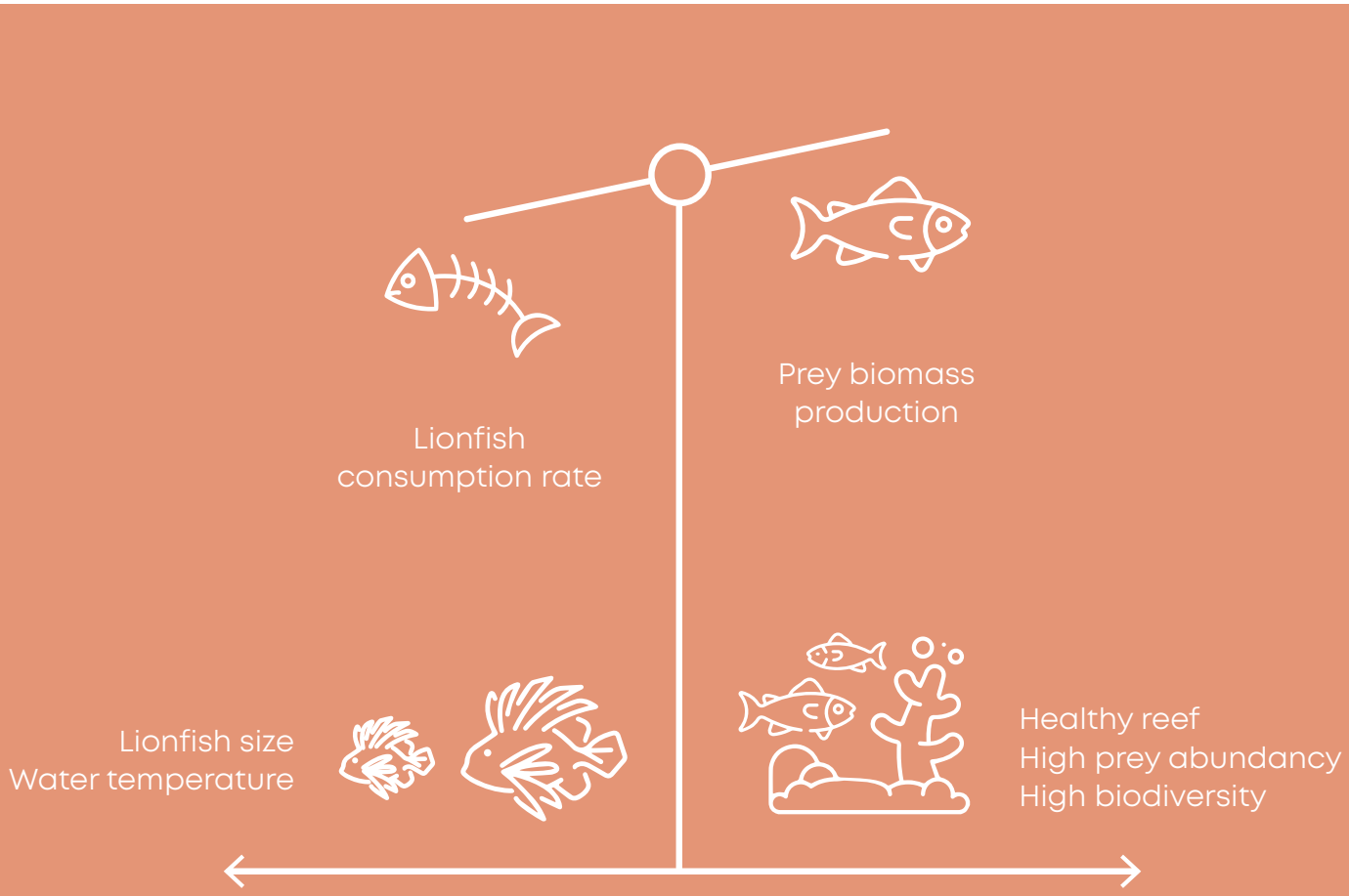
Lionfish densities from 2018 to 2020 in

1. Commercially fished areas.
2. Commercial fishing plus frequent culling events with SCUBA divers.
3. Restricted fishing areas around Cyprus.

Density thresholds to inform removal targets

The level at which lionfish densities cause damage to native fish can be calculated based on the rate at which lionfish consume prey (which is related to their size and seawater temperature) and the rate at which new prey biomass is created.

Research in the Bahamas has shown that reducing lionfish numbers can allow native fish to recover [20]. The vulnerability of sites depends on fish community composition, lionfish body size and consumption rates, and seawater temperature. A model using these parameters predicts densities at which lionfish start damaging native fish communities [20].



We applied this model at 22 sites around Cyprus under three scenarios:

(i) using data on the current lionfish sizes and observed densities of their prey,

(ii) increasing average lionfish length by 10 cm, which is likely if the population structure shifts towards older individuals,

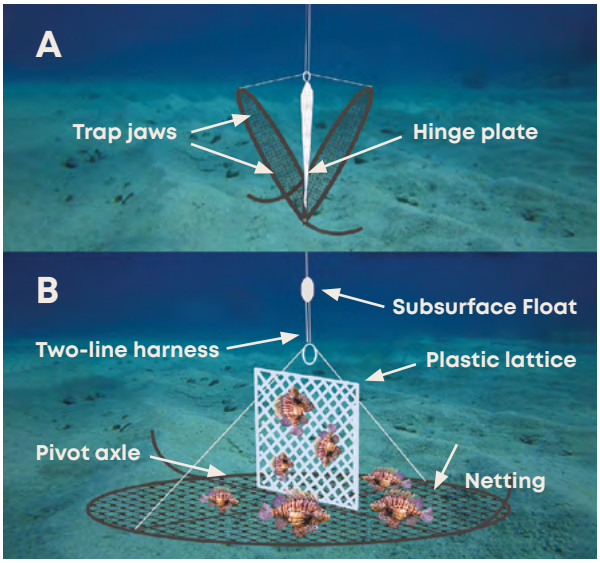
(iii) a reduction in average lionfish body length by 10 cm, to simulate management shifting size distribution towards younger individuals. In 2020 average densities of lionfish (170 per hectare) at nine sites were high enough to cause significant ecological effects, highlighting the importance of targeted removals.

Commercial fishing

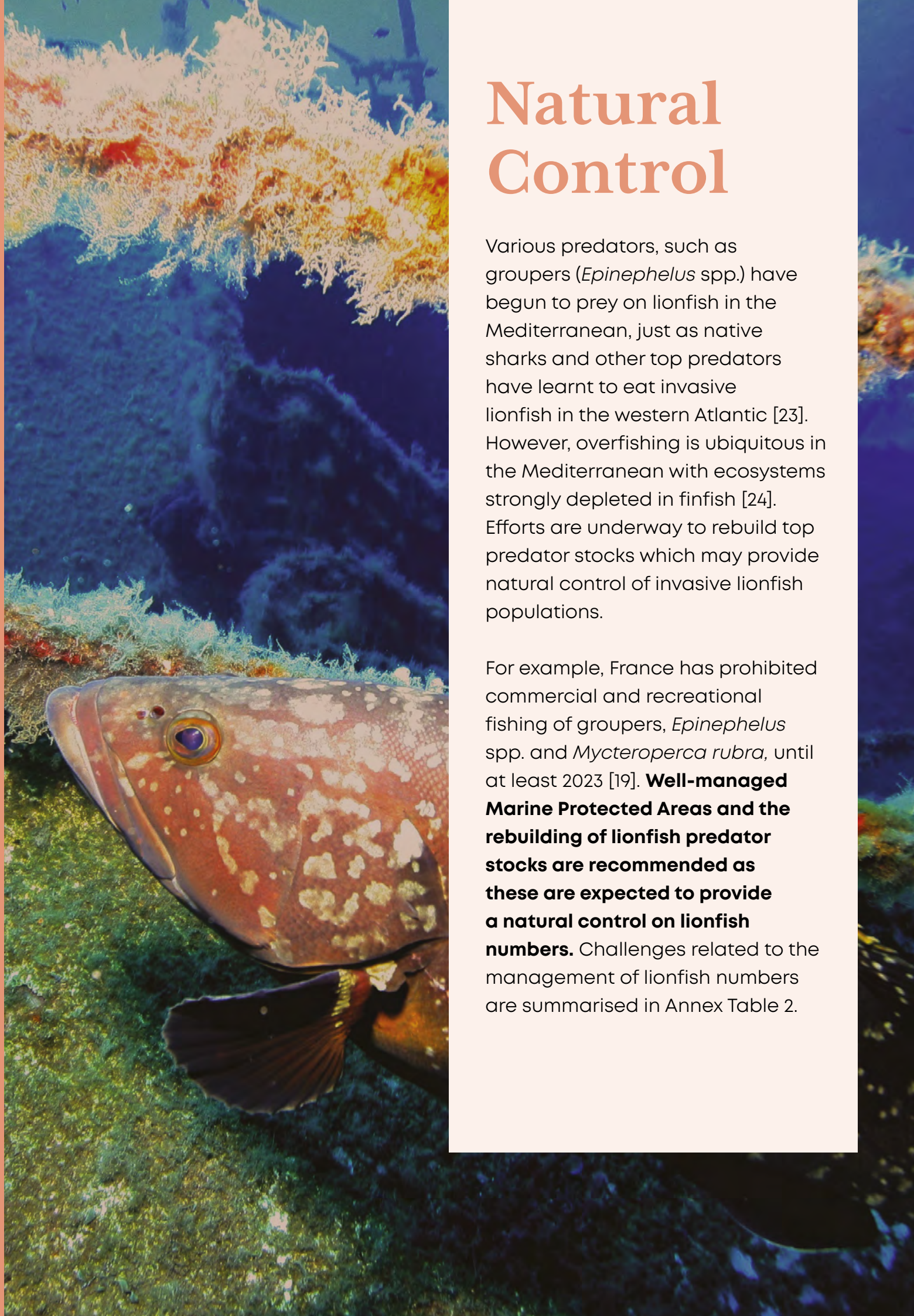
RELIONMED trained commercial static net fishers how to handle lionfish and provided them with safety gloves. There was some initial resistance amongst these fishers to target lionfish, as they were not an established commercial species, they initially had low market prices and required more time and effort to disentangle from nets than preferred target species.

Lionfish could in the future also be caught commercially using traps, hook and line, or by trawling. Traps are well worth exploring in the Mediterranean context because they do not cause the habitat damage associated with other fishing gears. In the western Atlantic, lionfish traps have been developed [21; 22] and can be especially useful at depths out of the reach of SCUBA divers.

Lionfish in a set net aboard a commercial Cypriot fishing boat (24/10/2021 off Limassol, Cyprus).



The Gittings lionfish trap lays open on the seabed attracting fish to a vertical lattice. No bait is needed and the trap closes when it is lifted. These traps have never been used in the Mediterranean [22].



Natural Control

Various predators, such as groupers (*Epinephelus* spp.) have begun to prey on lionfish in the Mediterranean, just as native sharks and other top predators have learnt to eat invasive lionfish in the western Atlantic [23]. However, overfishing is ubiquitous in the Mediterranean with ecosystems strongly depleted in finfish [24]. Efforts are underway to rebuild top predator stocks which may provide natural control of invasive lionfish populations.

For example, France has prohibited commercial and recreational fishing of groupers, *Epinephelus* spp. and *Mycteroperca rubra,* until at least 2023 [19]. **Well-managed Marine Protected Areas and the rebuilding of lionfish predator stocks are recommended as these are expected to provide a natural control on lionfish numbers.** Challenges related to the management of lionfish numbers are summarised in Annex Table 2.

Chapter 3

Developing markets

Lionfish seafood, handicraft products, and opportunities in volunteer/adventure tourism can all help with lionfish control offering benefits such as:

Better fishery yields

Raised awareness of invasive lionfish threats

New business skills and jobs related to tourism and handicrafts

Diversification of fisheries, making them more resilient to change

Market opportunities

The seafood market seeks large specimens since small individuals are more difficult to prepare. Restaurants collaborating with RELIONMED were unwilling to work with lionfish smaller than 25 cm total length but these small fish were amenable for use in handcrafts using the patterned spines, rays, skin, and tails to make jewellery [40]. Lionfish handcrafts could be made using 100% locally available and abundant materials that stimulated public interest and substantially increased awareness about the threats posed by invasive lionfish.

Lionfish jewellery created by the Neldi art gallery in Cyprus, 2021.

Lionfish are palatable and attractive for the seafood industry.

Lionfish provide tasty white fillets that are rich in omega-3 fatty acids [25]. Consumption is widely promoted as the primary control strategy in the western Atlantic [26-28] so that targeted removals endure. In that region, there is now a high-end reef fish price for lionfish [29] and a fishery that has significantly reduced lionfish populations [27; 30].

Picture iSea

Lionfish market timeline

In 2016-17, at the start of the initial expansion of lionfish populations in Cyprus, fishers were discarding lionfish (or keeping them for themselves / friends). Stemming from outreach activities, lionfish entered the fish markets in 2019 and are now also available in restaurants. Fishmonger prices range from 5-17 € per kg. In Cypriot restaurants in 2021 lionfish ranged from 12-22 € per dish.

The main challenge to selling lionfish dishes, reported by restaurants, was a lack of a steady supply of lionfish. Conventional fishing gears are not effective in targeting lionfish which are usually obtained as bycatch in areas where lionfish have become very common. Developing a specialized fishery for lionfish could secure reliable supply and increase demand as consumers become familiar with the product.

In Mexican Atlantic fisheries, lionfish are captured commercially using spearfishing. At their peak in 2014, landings matched the number of lionfish caught in removal events across the entire Caribbean that year [30]. Commercial food harvest for lionfish in the north-east Gulf of Mexico has reached 20,000 kg per year.

Connecting fishers, retailers, wholesalers and restaurateurs with each other can substantially improve the supply chain of lionfish. RELIONMED trained people in how to handle and cook lionfish after removal tournaments and encouraged attendees and bystanders to sample dishes such as lionfish ceviche, soup, sushi rolls, and fried fillets. In the western Atlantic, websites such as 'Lionfish Hunting' offer lists of restaurants serving lionfish (https://lionfish.co/eat-lionfish-here/) and in Greece the organisation iSea has been organising events to share lionfish information and recipes. Such events and outreach activities (see Chapter 4) aid market development and substantially increase public awareness and so they are strongly recommended in Annex, Table 3.

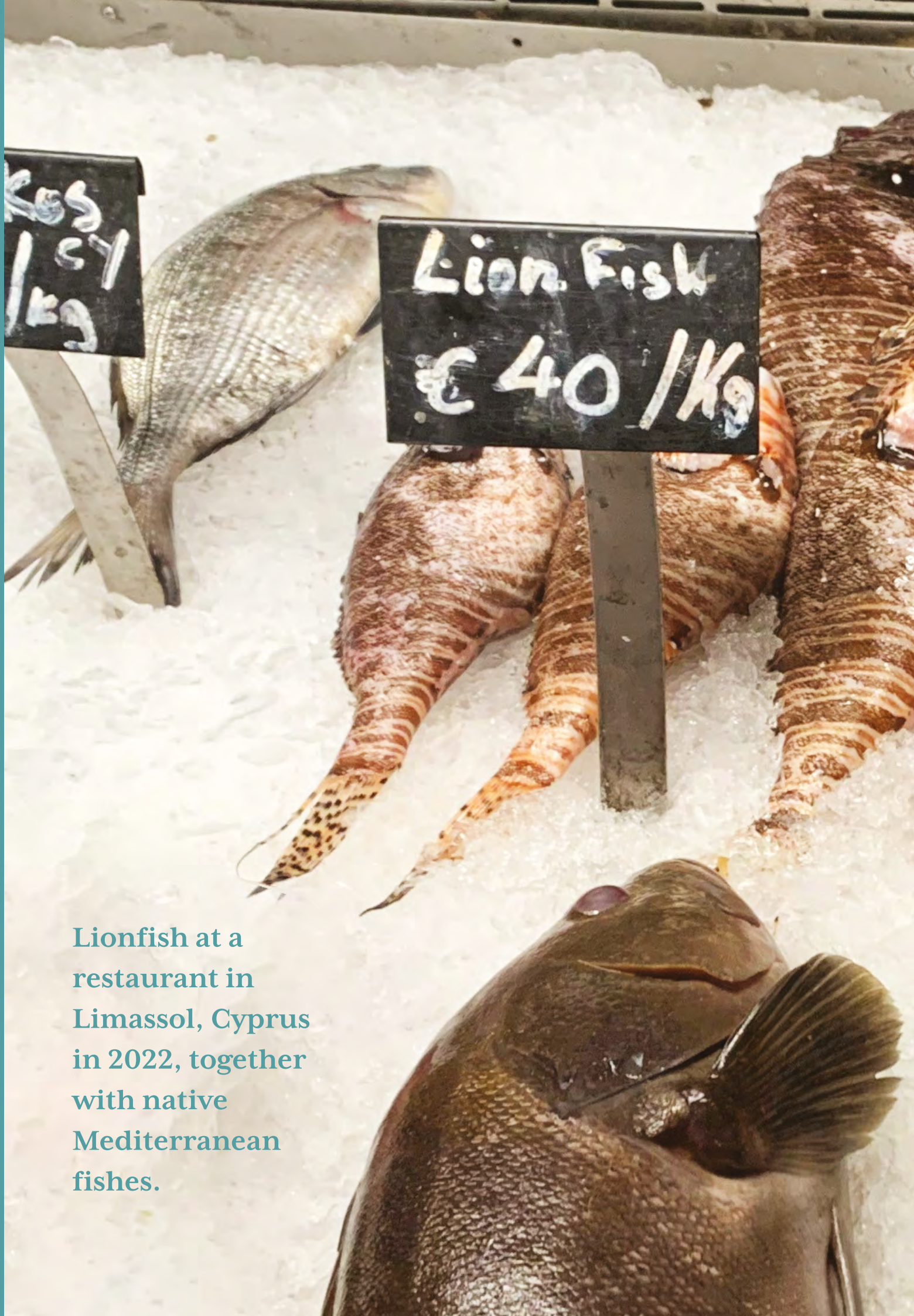
Getting lionfish into restaurants

Restaurants shift cultural views about food, its sourcing, consumption, and environmental impacts, allowing people to learn about and taste lionfish. RELIONMED did a series of surveys to understand lionfish inclusion in restaurants. Issues included a lack of lionfish awareness, the need for venomous fish handling skills and a lack of reliable supplies.

The promotion of lionfish on a dedicated restaurant menu increased customer demand, and customers' willingness to pay increased after they were provided with tasters. The restaurant had a lucrative demand for lionfish >30 cm in length.

Annual surveys of 30 restaurants from Ammochostos district from 2018-20 showed an increase from one to four in the number of venues serving lionfish. Only about half of these restaurant's chefs knew how to prepare lionfish and most restaurateurs stated that they did not include lionfish dishes since customer demand was low.

Surveys of 60 restaurants that served fish, from all over the island in 2020-21 showed that 18% used lionfish in their menus in 2020 and 23% did in 2021. About half of these restaurants were unwilling to serve lionfish because of a lack of reliable supply, possibilities of envenomation of their chefs, the need for more time to process lionfish, lack of knowledge on how to prepare a lionfish dish, a lack of demand (including some customers being fearful of eating lionfish), and a general preference (restaurant owner and customer) to serve local species that are already on the menu. Surveyed restaurant owners were positive but wanted a more consistent supply. The main factors that would motivate them to add lionfish to their portfolio were the environmental benefits, diversification of menu, and profits.



Lionfish at a restaurant in Limassol, Cyprus in 2022, together with native Mediterranean fishes.

Chapter 4 Outreach

Many fishers and divers were aware of lionfish from the spread of the species from 2017 onwards [31]. RELIONMED activities raised wider public awareness of lionfish in Cyprus. Lionfish are now available in local food markets, and their price has been steadily increasing. Removal tournaments raised awareness amongst participants, onlookers and through coverage on TV, radio, social media and the internet. Other communication events included workshops and food festivals, exhibitions and information boards. Training videos and educational pamphlets covered the lionfish invasion, its impacts and management efforts. Challenges related to outreach are summarised in Annex, Table 4.

Removal events were a great opportunity for meeting objectives of 1) lionfish removals, 2) fisher engagement, 3) market development, and 4) public education.

Public perceptions

Between 2018 and 2022, RELIONMED published articles about the lionfish invasion and its management in more than 100 local and international media articles, covered by over 20 television and 10 radio shows, published over 10 articles in scientific journals, posted numerous stories on social media and the internet, and organised numerous consultation, gastronomic, and removal events. Questionnaires were used involving a representative cross-section of the adult general public (via telephone) (n~300) and stakeholders (fishers, divers and managers) in Cyprus (n~100) in 2017, 2019, and 2021. Almost all stakeholders were aware of lionfish and expressed unanimous support for management measures [14]. Only 26% of the public was aware of lionfish in 2017 which increased to 61% in 2021. Only 14% were aware in 2017 that lionfish are edible and this increased to 31% in 2021.

Most of the public learnt about lionfish through television and/or radio (40%), the internet (23%), friends (17%), and social media (9%). Fishers and divers learnt about lionfish mainly from personal observations.

Chapter 5

Biology and ecology

RELIONMED used a range of metrics to understand lionfish biology in the Mediterranean (Annex, Table 5). These lionfish have an opportunistic diet, fast growth, high fecundity, early maturity, an absence of predators, naïve prey [15; 16; 23; 32], and they mainly eat native species of fish [31; 33]. The Mediterranean lionfish spawn mainly during the warmest months (June – November) [16; 34]. Mediterranean lionfish are genetically diverse indicating that large numbers were introduced through the Suez Canal (Bernardi et al. under review), in contrast to western Atlantic lionfish where the invasion originated from a few individuals [35].

We assessed the options for monitoring lionfish (Annex, Table 6) and chose visual census surveys and citizen science surveys to guide management efforts. Fishery-dependent data were not useful since lionfish were frequently misidentified or misreported, but structured interviews with fishers helped fill this gap [18].

Monitoring lionfish

To monitor lionfish and surrounding fish populations, we recommend visual-census surveys at sentinel locations complemented with fishery and citizen-science data. Environmental DNA could also be useful for early detection, but was not tested in our project. Depth, habitat, date and time of sampling, bottom temperature, weather conditions (i.e. currents and waves) were recorded. To assess changes in seaweed and sessile invertebrate communities, photoquadrats were taken (e.g. once a year) from the sampling stations. A set of ecological indicators that can be monitored is shown in Annex, Table 7. RELIONMED compared belt transects (25 x 5 m) with detailed lionfish searches along 25 x 20 m transects. In the first technique, trained divers monitored all fish species' density and size using a standard protocol [36]. In the second technique observers only monitored lionfish, paying special attention to overhangs, crevices, and cracks, using a torch when needed (Figure 6). The searches detected significantly more lionfish than the conventional technique.

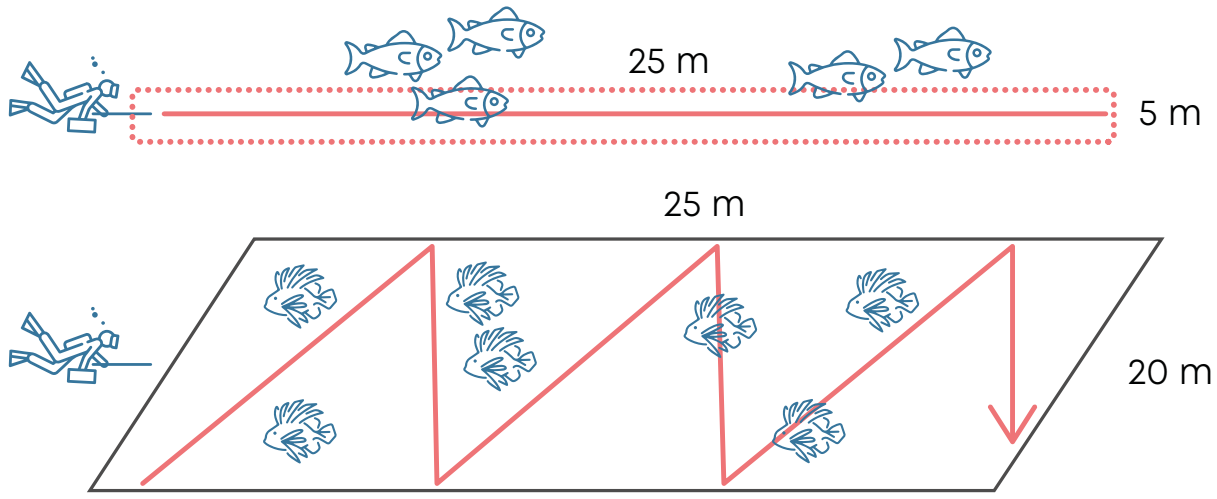
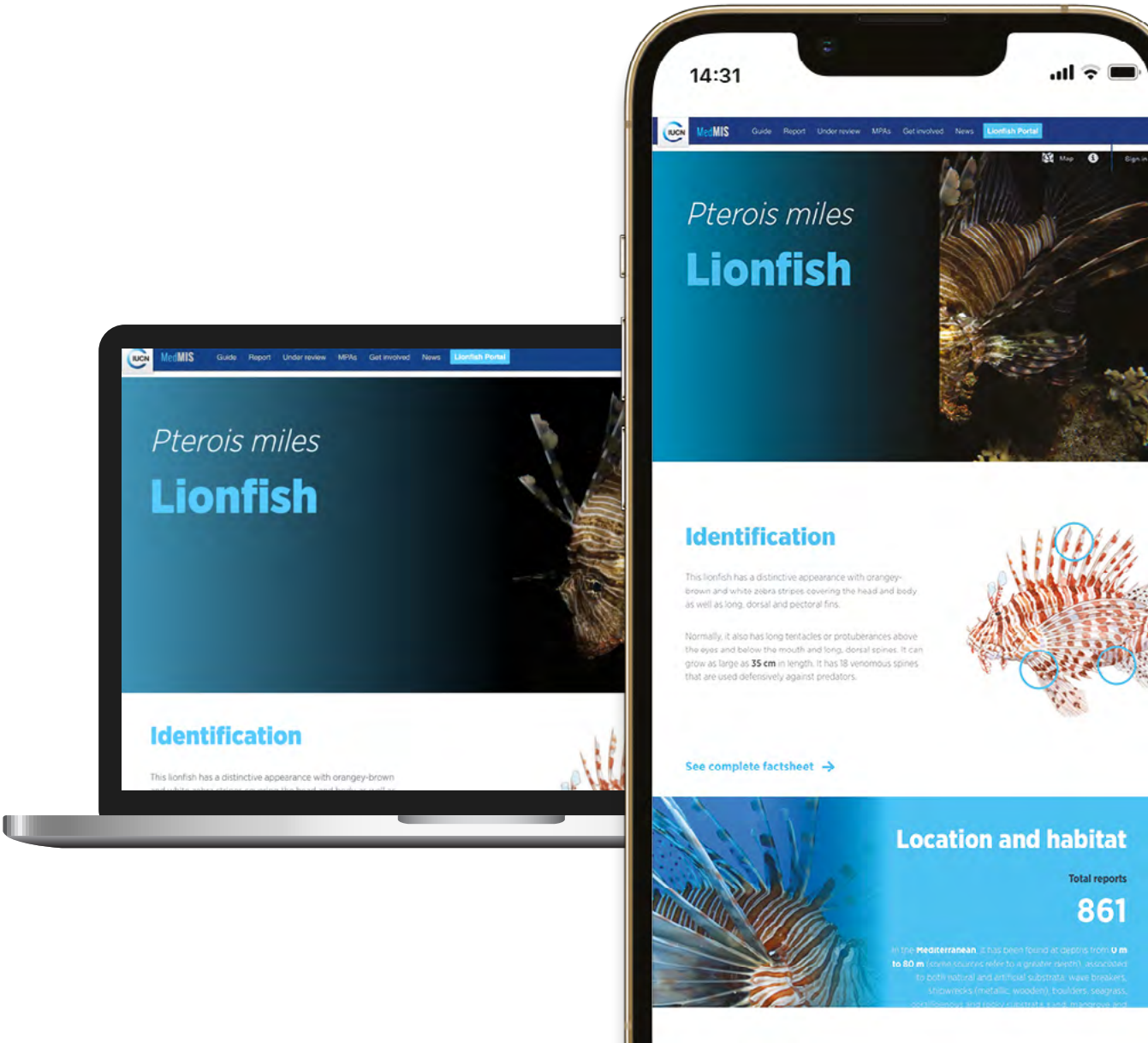


Figure 6

Standard belt transect (upper) and modified method (lower) used to monitor lionfish off Cyprus in 2018-2020.

Citizen science

Lionfish-removal events were conducted at a shipwreck off Larnaca, Cyprus, and divers were asked to report via email, phone or social network platforms their lionfish sightings [14]. A total of 870 records of lionfish were received from 104 reports; most records (88%) were sent via email with filled data logbooks, followed by communication via social networks (10%), and (3%) via telephone. This showed lionfish abundance trends, and divers' logbooks guided the timing of removals.



The RELIONMED project upgraded the IUCN MedMIS platform to include lionfish surveillance combined with educational material. A heat-map setting (allowing display of sighting concentrations) and new filters (filter by time, depth, habitat type) were incorporated. The system now allows posts of sightings for the whole of the Mediterranean. New records are displayed after scrutiny by experts. RELIONMED created a leaflet and an educational video (Video: Use of MedMIS guidelines), both in Greek and English, explaining how to use MedMIS. The platform is now available in Spanish, French, Greek, and English. This is providing data on the current spread of lionfish in the Mediterranean.

IUCN MedMIS is a guide, reporting and monitoring platform on Marine Invasive Species in the Mediterranean. Lionfish specific platforms are available on the website and mobile phone application, helping to map the abundance and spread of lionfish to inform management action.

Socioeconomic impacts of lionfish

Socioeconomic data can be combined with ecological data to assess the impacts of lionfish on economy and society. There needs to be a good understanding of evolving relations between local communities and lionfish, the factors, perceptions, knowledge and the values that influence their behaviour. Lionfish can reduce landings for both commercial and recreational fisheries. Loss of biodiversity can reduce the attractiveness of sites for tourists. Dense populations of lionfish are also likely to affect the seafood market, diving and tourism industry. Divers may selectively avoid reefs, caves and wrecks with high lionfish densities due to risks of venomous stings. Dive instructors have already reported to RELIONMED that they do not visit favourite dive sites with customers due to an abundance of lionfish.

A set of indicators of the impacts of lionfish on stakeholders were developed (Annex, Table 8). In Cyprus, we combined semi-structured interviews with fishery-dependent data, and envenomation records from medics, lifeguard, fishery, and dive associations. This helped assess the effects of the lionfish invasion and the impact of RELIONMED activities. For example, surveys in the Ammochostos district showed that in 2018, 42% of the commercial fishers discarded lionfish but in 2019, following RELIONMED communication activities, none of them did. The percentage of beach users that knew that lionfish are edible increased from 14% to 28%, and of recreational fishers from 70% to 80%. Challenges related to lionfish research and monitoring are summarised in Annex, Table 9.

Chapter 6

Regional cooperation

Lionfish management is more effective when policies and research activities are regionally consistent [37] which requires coordination and collaboration. RELIONMED strengthened local cooperation, in ways that can be scaled-up to the Mediterranean level.

RELIONMED members are now working with experts on lionfish management across its global invasion range (western Atlantic and the Mediterranean Sea). This group shares experiences of failures and best practices to help manage lionfish invasions cost-effectively [27]. Standardised survey methods for lionfish control and their incorporation into monitoring programmes promote a coordinated response to the lionfish problem.

Corridor is the principal pathway of introduction for around half of the non-indigenous species in the Mediterranean, among which is the Suez Canal. This figure exceeds 60% in the Eastern Mediterranean, but when we proceed west and north to other regions Lessepsian species migrate via natural dispersion.

Mediterranean countries and politicians recognize the urgency and work together. In 2003 they adopted the Regional Action Plan concerning introduction of invasive species in the Mediterranean and, in 2016, the Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and Related Assessment Criteria (IMAP). Mediterranean EU countries have adopted Regulation (EU) 1143/2014 on invasive alien species (the IAS Regulation), fulfilling Action 16 of Target 5 of the EU 2020 Biodiversity Strategy, as well as Aichi Target 9 of the Strategic Plan for Biodiversity 2011-2020 under the Convention of Biological Diversity. Challenges related to regional cooperation are summarised in Annex, Table 10.

Including lionfish on the EU list of Invasive Alien Species

RELIONMED has put forward lionfish (*Pterois miles*) for inclusion on the list of concern under Regulation EC/1143/2014 which has provisions for prevention, detection and management of Invasive Alien Species. To do this the EU was provided with a risk assessment of the Mediterranean invasion and an analysis of the cost of management versus the cost of inaction.

Our risk assessment concluded with high confidence that there is a high degree of social, ecological, and economic risk associated with the spread of lionfish in the Mediterranean. The magnitude of impacts on biodiversity, ecosystem services, economy, and human health are large (Figure 7).

These findings were submitted to the European Commission in February 2019 and following peer-revisions, comments by stakeholders, reviews by the EU Scientific Forum, and public consultations were deemed robust and fit-for-purpose. RELIONMED identified challenges for listing Marine Invasive Alien Species [10] which relate to insufficient monitoring, absence of proactive response and the high environmental connectivity and dispersion capacity of marine species. A decision for inclusion is expected from the EU in March 2022.

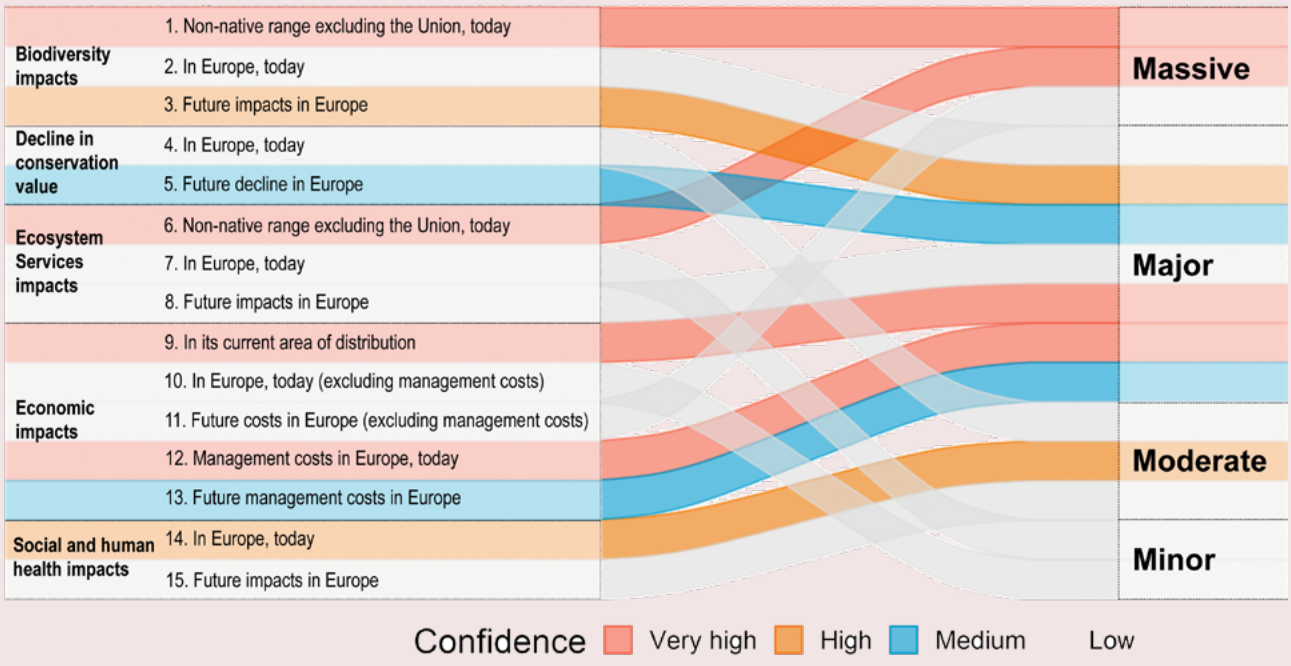


Figure 7

Assessment of lionfish current and future impacts on (i) biodiversity, (ii) conservation value, (iii) economy, (iv) ecosystem services, and (v) society and human health. The evaluation scheme, methodology, and results are explained in Kleitou et al. [15].

DO'S AND DON'TS OF LIONFISH MANAGEMENT

ALLOW HARVEST VIA SCUBA AND POLE SPEARS

Noncompliance can be mitigated by gear use restrictions and working with stakeholder groups.

PROMOTE LIONFISH HUNTING TOURISM

Helps support dive operators and tourism; divers need training and proper equipment.

ENCOURAGE RECREATIONAL TOURNAMENTS

Derbies provide a participatory approach to conduct removals, research, and public education.

ENCOURAGE COMMERCIAL MARKETS

Develop market-based solutions to control lionfish densities and diversify fishers' catches.

ENCOURAGE PARTICIPATORY MANAGEMENT

Stakeholder engagement can support removals, market building, and strategic planning.

DON'T RELY ON "BOUNTY" PROGRAMS

Funds can be quickly exhausted. Sustainable control is better achieved by improving education, stakeholder engagement, and lionfish fisheries.

COORDINATE REGIONAL MANAGEMENT

Biological invasions require rapid and strategic management approaches with multinational cooperation.

DON'T "TRAIN" NATIVE PREDATORS

Feeding speared lionfish to predators results in aggressive behavior by them towards divers.

Ulman et al. (2022) Lessons from the Western Atlantic lionfish invasion to inform management in the Mediterranean. Frontiers in Marine Science

Annex

Table 1

The benefits and risks of three ways to control lionfish populations: spearfishing events, traditional fishing, and natural control

Spearfishing	Benefits	Risks
	Effectively reduces lionfish populations at priority locations. Can remove lionfish from no-take (no fishing) marine protected areas. Increases awareness about lionfish. Promotes consumption and removes the misconception that lionfish meat is poisonous. Target lionfish of all sizes. Increases social cohesion and community participation. Engagement and collaboration of a large stakeholder network. Lionfish removal tours could create economic opportunities. Participation fees could be levied and reinvested in conservation and management.	Geographically limited to a small area. Many sites are far from shore or boat access points (expensive to reach). Resource intensive (money and time). Lack of access to lionfish culling equipment. Risks of injury (being stung). Tourists with minimal diving experience might damage reefs. Risks of illegal or unregulated activities. Divers against killing an animal, even if invasive. Low participation.
Traditional fishing	**Benefits**	**Risks**
	Cost effective. Covers large areas. Direct commercial benefits to the fishers. Benefits other market sectors including restaurants, fish markets, and retailers. Effectively reduces lionfish populations.	Cannot remove lionfish from no-take (no fishing) marine protected areas. Small-scale fishing is mostly concentrated in shallow waters. Limited catch and/or destruction of benthos. Only large lionfish are commercially attractive. Value of lionfish in the market does not motivate fishers. Might not provide a steady supply for a market to be developed. Risks of injury (being stung). Untangling lionfish from gear might cost fishing time and effort.
Natural control	**Benefits**	**Risks**
	Covers large areas. Control lionfish populations. Ensures healthy and resilient ecosystem.	Mediterranean ecosystems are heavily overfished and depleted. Many marine protected areas are not resilient enough to prevent lionfish proliferation without targeted removal measures. Stakeholder might be opposed to protection measures.

Table 2

Challenges and recommendations related to the different mechanisms to control lionfish

Mechanism(s)	Challenge(s)	Recommendation(s)
Lionfish control with tournaments and targeted removal events with SCUBA divers and spearfishing	The ecological characteristics of lionfish make the possibility of eradication through removal events extremely unlikely.	• Use models and set targets for sustainable thresholds.
	To counter fast reproductive, growth rates, and population recovery rates, a large proportion of the lionfish population needs to be removed at regular intervals.	• Prioritise removal efforts spatially and temporally (e.g. tourism areas, marine protected areas, and nursery and spawning sites of commercially important species). Increase the frequency of removals.
	Juvenile lionfish are not easily removed using pole spears and other conventional fishery gear.	• Use of alternative equipment such as handheld nets. • Tournaments offer prizes for smallest lionfish.
	Tournaments and targeted removals can be costly.	• Introduction of a registration fee for tournaments. • Identify funding sources and sponsors. • Allow dive shops to advertise removal events as part of a dive package experience.
	Illegal, unreported and unregulated fishing activity.	• Strict legislation for fishing with SCUBA gear. • Preventive measures to dissuade illegal activities such as prohibitive penalties, membership termination, and obligatory reporting. • Behavioural management approach to increased awareness of IUU and voluntary compliance. • Nominate a responsible authority (e.g. MPA authority, diving association) for the coordination and implementation of the removal events. • Only allow removal events (using pole spears <95 cm in length) during the daytime hours to avoid by-catch.

Table 2 Continued

Challenges and recommendations related to the different mechanisms to control lionfish

Mechanism(s)	Challenge(s)	Recommendation(s)
Lionfish control using commercial and recreational fisheries.	Commercial fishers do not currently target lionfish.	• Develop awareness campaigns to increase consumers' demand for lionfish, and favour the development of lionfish fisheries. • Orchestrate the establishment of a special fishing fleet that targets only lionfish. The efficiency of new gears (e.g. traps) could be tested in the Mediterranean Sea.
	Non-destructive lionfish extraction by fishers can only occur in areas physically or legally accessible to fishers – i.e. relatively shallow water environments outside of highly protected MPAs (no-take zones).	• Orchestrate the establishment of a special fishing fleet that targets only lionfish. • Develop innovative technologies to target lionfish in deeper areas; e.g. robots and traps.
	Risk of injury.	• Train fishers on safe handling and first aid procedure in case of an accident and equip them with safety tools such as puncture resistant gloves.
	Fishers are not motivated to target lionfish.	• Challenge norms, feelings and moral obligations through awareness and market campaigns. • Create a commercial price point for lionfish that will motivate fishers to change target species.
	Fishers' catch is restricted by legislation, such as daily bag restrictions, activity limits, etc.	• Amend legislation to allow fishers to legally remove as many lionfish individuals as possible with non destructive gear.
Natural control	Marine ecosystems are depleted and overfished.	• Establish marine protected areas and enable fishers to target lionfish. • Protect native predators of lionfish, such as groupers. • Enhance harvest control measures to protect lionfish predators.

Table 3

Challenges and recommendations related to the market exploitation of lionfish.

Mechanism(s)	Challenge(s)	Recommendation(s)
Market exploitation can add long-term pressure on lionfish populations and offer socioeconomic benefits; support income generation, and contribute to social wellbeing and skill acquisition.	Low price of lionfish products or high volatility in price.	• Foster domestic market growth through fishers-restaurant partnerships. • Develop partnerships between fishers. • Develop awareness and promotion campaigns through events, media and social networks to increase awareness, demand, and willingness to pay for lionfish products.
	Economic dependence on lionfish harvest could develop perverse incentives. Unknown long-term impacts associated with the creation of a commercial market for lionfish meat, and other products.	• Prioritise removal efforts spatially and temporally (e.g. tourism areas, marine protected areas, and nursery and spawning sites of commercially important species). Increase the frequency of removals. • Communicate and inform fishers about the impacts of lionfish and how their removals can augment other commercial fish stocks.
	Low demand for small lionfish individuals from the seafood market.	• Train culinary art students and chefs on lionfish handling and cooking • Develop technology, knowledge, and markets (e.g. jewellery) that will utilize both lionfish meat and its by-products to optimize the use and avoid waste. • Establish an authority/cooperation that will pay a fair price to fishers and coordinate the wholesale of lionfish to multiple markets.
	Perceived risk of envenomation by lionfish spines deters users such as fishers, chefs, and consumers.	• Conduct lionfish outreach, safe-handling, and first-aid demonstrations. • Equip fishers with safe handling tools such as puncture-resistant gloves.
	Local markets are in their infancy without satisfactory lionfish supply.	• Conduct lionfish outreach, safe-handling, and first-aid demonstrations. • Equip fishers with safe handling tools such as puncture-resistant gloves.
	Lionfish caught mostly as a by-catch with low efficiency using the conventional gears and unsatisfactory lionfish supply.	• Establish partnerships between actors of the market value chain to improve consistency of supply and reliable sales.
	Lack of knowledge on how to utilise lionfish.	• Facilitate access to professional business advice and tailored training courses. • Develop open access material to guide and mentor new businesses on methods to cook and prepare lionfish.

Table 4

Challenges and recommendations related to lionfish educational and communication activities.

Mechanism(s)	Challenge(s)	Recommendation(s)
Lionfish provides a unique opportunity for communication, education, and stakeholder participation.	A lack of education and awareness can limit public support for the management of lionfish as an invasive species.	• Empower communities and utilise a participatory approach to ensure control and management of lionfish. • Use lionfish to exemplify the problem of invasive species through education and outreach activities including communication through media, workshops and seafood promotion events. • Use removal events to increase awareness, engagement and public participation for lionfish management and related conservation issues, such as invasive species, overfishing, marine litter and climate change.
	Communication and educational activities can be costly.	• Identify funding sources and sponsors. • Combine activities with other events, such as removal tournaments. • Utilise cost-effective means of communication, such as the internet and social media.
	Inaccurate information.	• Ensure the accuracy of the communication material; correct species, data on the biology of the species, details of the venomous spines, etc.
	Inappropriate method of communication.	• Use image-rich, captivating and appropriate material for the targeted audience.
	Static communication and outreach activities.	• Be creative and diverse to ensure engagement of the public.

Table 5

Biological information that was collected through the RELIONMED project.
NA: Not Available.

Body part	Type	Metric	RELIONMED application	RELIONMED insights
External	Measurement	Total length (TL)	Growth, body condition, population structure: Used to calculate the length-weight relationship (useful for stock assessment models, biomass estimation, estimation of fish condition, life-history and comparisons of populations from different locations)	NA
		Standard length (SL)		NA
		Wet weight		The weight changes as the specimen dries.
		Gape width	Feeding ecology: relationship with prey size	Resistance in opening the mouth might differ according to size.
		Gape height		

Body part	Type	Metric	RELIONMED application	RELIONMED insights
Internal	Measurement	Gonad weight	Assessment of reproductive condition (calculation of the GSI index)	The weight changes as the specimen dries. Only indicative results are produced.
		Stomach weight	Feeding ecology	
		Gonad - macroscopic	Gender ratio, reproductive dynamics	The macroscopic examination was prone to error and required microscopic validation. Shortcomings in understanding reproductive phases, ovarian dynamics, onset and cessation of spawning periods.
		Gonad analysis - microscopic / histology		Expensive, time-demanding, requires experienced personnel and equipment.
		Otoliths	Age determination, growth rate, feeding ecology through stable isotope analysis	Accurate age reading requires cross sectioning and specialised equipment.
		Stomach contents	Feeding ecology	Requires extensive knowledge of the prey. Might miss many species that are rapidly digested, genetic tools could be useful.

Table 6

Advantages and disadvantages of popular monitoring techniques for monitoring fish populations, and their suitability to monitor lionfish.

Tech-nique	Advantages	Disadvantages	Suitability for lionfish
Underwater visual census (UVC)	Non-destructive. Rapid and cost-effective. Able to provide abundance and biomass estimations. Traditional technique with standardized protocols in place.	Prone to bias towards larger fish. Difficulty in assessing large numbers/ schools of individuals. Potential for error in length estimations or in identifications, especially relevant to small-bodied and juvenile fish from closely related species which can be difficult to identify and require collection. Potential adverse effect of diver presence on fish behaviour. Less suitable for detecting "cryptic" species. Less suitable for pelagic species due to fish behaviour response to divers. Can be costly if long time-series data are needed.	**Unsuitable for early detection.** **Partially suitable for monitoring populations with traditional UVC** Underestimates lionfish populations. Can be prone to error due to the cryptic behaviour of lionfish, especially during inactive periods. **Suitable for monitoring populations if a detailed lionfish search method is used**
Baited remote underwater video (BRUV)	Non-destructive. Simple and reliable. Accurate measurements and identifications. Power to detect changes such as richness. Allows for post-hoc species identification and re-evaluation.	Selectivity for shallow-dwelling and for mobile benthopelagic species. Dependable on bait and selective to predators. Poor ability to observe immobile species or species with cryptic behaviour. Selectivity for shallow-dwelling and for mobile benthopelagic species. Video does not work well in murky waters. Footage analysis is labour-intensive. Stereo BRUVs require calibration and potentially expensive software. Can be costly if long time-series data are needed. Potential for wrong identification, especially of small-bodied and juvenile fish from closely related species which can be difficult to identify and require collection.	**Unsuitable** Can significantly underestimate lionfish populations since lionfish usually exhibit high site fidelity, primarily move during low light dawn and dusk, and have cryptic behaviour.
Environmental DNA (eDNA)	Non-destructive. Lack of selectivity. Ability to identify more taxa per sample than other techniques. Suitable for rapid early detection and response.	Public reference sequence databases lack data for many Mediterranean fish species. It has a non-quantitative nature which prevents implementation of indices that require the relative abundances of fish. Might be affected by DNA traces from surrounding areas/habitats. Factors affecting eDNA degradation rates are not clear. Can be costly if long time-series data are needed.	**Suitable for early detection and presence/absence** Not suitable for areas where lionfish populations have already expanded.

Tech-nique	Advantages	Disadvantages	Suitability for lionfish
Fisheries-dependent data	Can acquire long time-series in a cost-effective manner. Wide spatial and temporal coverage. Information on a large variety of target species. Ability to "capture" rare and cryptic species, and their susceptibility to variations in environmental conditions. Able to accurately identify species, and estimate their abundance and biomass.	Destructive. Results strongly influenced by the gear used. Biased on species traits depending on the gear, bait, technique used. The probability of catching fish of different sizes varies with mesh size. Issues with bias and misreporting. Lacks particular details such as the location of fishing grounds and species identity (catches are mostly identified to a higher taxonomic level). Preferential and commercially driven sampling.	**Unsuitable unless there is a major improvement in the quality of reporting data to underpin an ecosystem-based approach to fisheries management (EFBM).** Destructive, therefore, not suitable for monitoring at protected sites. Fisheries-dependent data lack the resolution for EFBM and there are issues with the catch being wrongly identified and misreported in fishers' log books and sales reporting. Lionfish are not easily caught with existing fishing gears.
Fisheries-independent data	Biological information or target species can be taken into consideration during the survey design. Potential to gather information on a large variety of target species. Ability to "capture" rare and cryptic species, and their susceptibility to variations in environmental conditions. Able to accurately identify species, and estimate their abundance and biomass.	Destructive. Relies on expensive research programmes at sea carried out over relatively short periods of time. Limited coverage in space and time (in terms of seasonality), as well as the number of years of available data, which could lead to biased and imprecise estimations. Not suitable to understand the effectiveness of targeted removals.	**Unsuitable.** Expensive. Low coverage. Lionfish are not easily caught with existing fishing gears.
Citizen Science	Non-destructive. Suitable for rapid early detection and response. Cost-effective and opportunistic. Relies on a participatory process with engagement of volunteers; potential for wider social benefits.	Most citizen science projects do not monitor densities and biomass of species. Data might be hardly sufficient to understand abundance trends. Lack of standardized protocols for data collection, storage, and processing. Prone to bias towards larger species or specific taxa. Some existing projects might be prone to inaccuracies in identifications if records are not validated by experts.	**Suitable for early detection and presence/absence.** Not suitable for areas where lionfish; populations have already expanded except if significant improvements in existing programmes.

Table 7

Ecological indicators that could be used to monitor lionfish populations, impacts on the ecosystems, and success of control measures.

#	Indicators	Justification
1	Mean fish length of lionfish	The length can be an indication of lionfish status in the area and help to quantify depletion after control efforts.
2	Proportion/biomass of predatory fish in the surveyed community	Predatory fish are all surveyed fish species that are piscivorous or feed on invertebrates that are larger than 2 cm. The role of predators is important in an ecosystem as they regulate the abundance of the lower trophic level species and they dampen the effects of environmental variability.
3	Macroalgae (Multimetric index using species number, evenness, and diversity)	Macroalgae are effective in assessing the ecological quality of coastal rocky communities and they have been found to be affected by lionfish in other invaded regions.
4	Margalef Species Richness	Total number of fish species was assessed for a given number of individuals per station and was used as a measure of biodiversity on each sampling occasion.
5	Biomass and abundance of the species	Abundance and biomass, for selected species (e.g. favourite prey) or all species altogether, are needed to identify and monitor changes caused by the lionfish invasion and control efforts.
6	Biodiversity indices (Pielou's evenness, Simpsons, Shannon, Brillouin)	These indices are simple mathematical measures that characterise species' diversity in a community.
7	Vulnerability index	The FishBase vulnerability index can be used to explore effects on less resilient species.
8	Trophic group	Trophic groups of species can be identified (planktivores, detritivores, low and middle- carnivores, top predators, and herbivores). Particular interest are the interactions with top predators/lionfish-competitive species.

Table 8

Indicators that were developed by the RELIONMED project to assist assessment of lionfish socioeconomic impacts and management actions.

Stake-holder group	Impacts	Indicators
Commercial fishermen	• Change of catches. • Change of revenues. • Increase of time/effort due to interference with lionfish catch. • Force fishers to change their fishing grounds. • Force fishers to reduce their fishing trips. • Increase fishing effort due to interference with lionfish. • Health risk implications.	• Change in the wet weight of landings/harbour; • Change in the value of landings/harbour; • Change in the number of fishing trips; • Change in the number of lionfish stinging accidents; • Perceptions of fishers to elucidate the impact of lionfish in terms of the quantity of the catches, conflicts and interferences of lionfish with fishing gear/activities, and alteration of fishing grounds due to the presence of lionfish; • Lionfish sales.
Dive businesses	• Loss of available dive sites. • Change of revenues related to the reduction of the biodiversity or attraction of lionfish. • Health risk implications and impact on dive tourism.	• Change in the dive sites due to lionfish infestation or because lionfish acts as an attraction; • Change in the number of divers per annum; • Change in the annual turnover; • Perception of divers and dive shop owners regarding the lionfish impact on the quality/biodiversity of the dive sites and the lionfish as an attractant for the divers or as a deterrent if considered a safety hazard.
Recreational fishermen	• Reduction of catches and interest. • Health risk implications.	• Change in the wet weight of catches; • Change in the number of lionfish stinging accidents; • Perception of different groups of recreational fishers to elucidate the impact of lionfish in terms of the quantity of the catches, conflicts and interferences of lionfish.
Beach visitors	• Health risk implications.	• Change in the number of envenomation incidents; • Change in the number of people not entering the water because they are afraid of the lionfish; • Perception of beach visitors regarding the invasion of lionfish and potential impacts on their beach choice due to safety issues.
Pet/ aquarium owners	• Reduction of lionfish price/sales due to high availability.	• Change in the sales of lionfish; • Change in the selling price of lionfish; • Incorporation of lionfish if not previously sold.
Restaurants (fish taverns)	• Change of available fish. • Change of fish prices and sales. • Revenues and new job opportunities due to exploitation and serving of lionfish.	• Incorporation of lionfish dishes in seafood menus; • Change in the annual turnover; • Number of new jobs; • Perception of restaurant owners regarding the lionfish impact on restaurants' profitability and attractiveness.
Jewellery and artwork shops	• Revenues and new opportunities derived from the exploitation of lionfish.	• Number of lionfish jewellery made and sold; • Change in the annual turnover; • Number of new jobs; • Perception of shop owners regarding the lionfish impact on shops' profitability and attractiveness.

Table 9

Challenges and recommendations related to lionfish research and monitoring.

Mechanism(s)	Challenge(s)	Recommendation(s)
Research is essential to acquire a better understanding of the biology, ecology, potential impacts, and design appropriate tools and targets for control, based on the best available science.	Lack of long-term data.	Develop strategic and coherent long-term monitoring in key locations.
	Absence of standardized protocols and methods.	• Develop and share standardized survey methods and protocols.
	Monitoring and research can be costly.	• Integrate cost-effective and opportunistic techniques (e.g. citizen science and fisheries data) in monitoring programmes. • Collaborate with other stakeholders and transparency to increase spatial coverage and avoid duplication of efforts. • Mobilize resources for further studying lionfish biology, ecology, impacts, and management options. • Identify funding sources and sponsors
	Lack of information to support lionfish markets.	• Research on the nutritious value of lionfish to support marketing campaigns. • Exploration of new markets and valorisation opportunities for lionfish products.

Table 10

Challenges and recommendations related to regional cooperation.

Mechanism(s)	Challenge(s)	Recommendation(s)
Facilitate collaboration among managers, researchers and stakeholders, by providing mechanisms for coordination of efforts across political and geographical boundaries.	Absence of a convening mechanism to facilitate political consensus and represent the region.	• Create a transnational advisory group to promote coordination of control and management of lionfish in the Mediterranean Sea, and sharing of experience, best practices, and strategies.
	Lack of concerted management approaches.	• Develop best-practice guidelines to promote responsible lionfish-culling tourism activities. • Establish synergies with established regional legally binding instruments. • Promote the adoption of standardized survey methods for lionfish control mechanisms and incorporate them into relevant monitoring programmes. • Explore possibilities for biosecurity measures at the Suez Canal.

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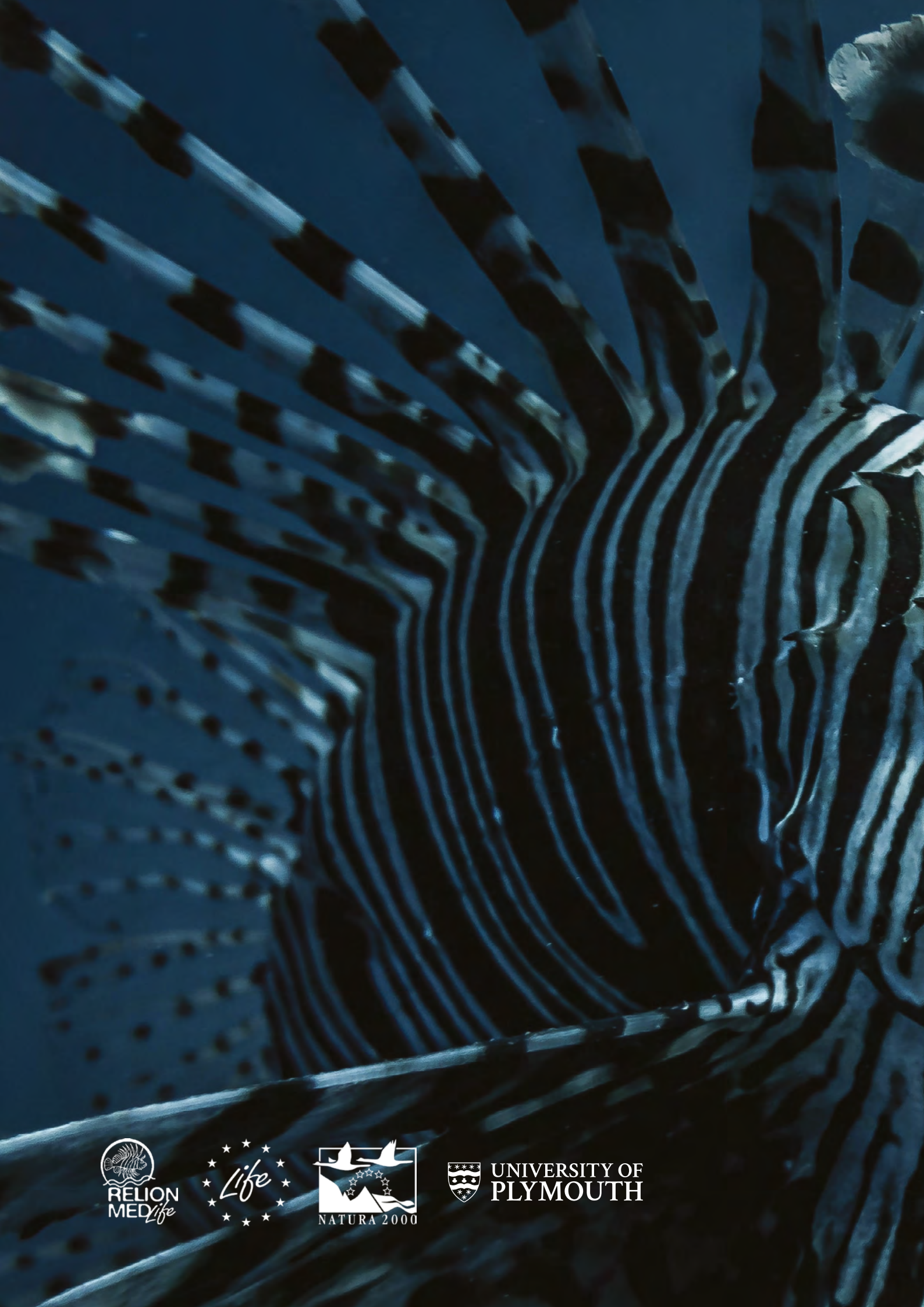
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