Marine Policy 183 (2026) 106903

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Impacts of invasive algae from the perspective of fishers in the Lagoon of Venice, Northern Italy

Jimlea Nadezhda Mendoza [a,f], Baiba Prūse [b], Giulia Mattalia [c], Sophia Kochalski [d], Julia Prakofjewa [a], Alessandro Buosi [a], Aimee Ciriaco [e,f], Francesco Primavera [g], Agnese Martini [a], Maria Viktoria Bittner [h], Renata Sõukand [a,*], Adriano Sfriso [a]

[a] Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice, Italy
[b] University College Cork, Ireland
[c] Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona (ICTA-UAB), Cerdanyola del Vallès, Barcelona, Spain
[d] Center for Ocean and Society, Kiel University, Kiel, Germany
[e] Kabulusan Integrated National High School, Pakil, Laguna, Philippines
[f] Tagalog Fisher Community of Mabato Asufre Pangil, Pangil, Laguna, Philippines
[g] Agenzia Regionale per la Prevenzione e Protezione Ambientale – Veneto (ARPAV), Venice, Italy
[h] Department of Asian and North African Studies, Ca Foscari University of Venice, Italy

ARTICLE INFO

Keywords:
Local ecological knowledge
Fishers' knowledge
Invasive algae impacts
Invasion mechanisms
Venice lagoon
Lagoon biodiversity

ABSTRACT

Invasive alien species are generally considered a cause of biodiversity decline globally, and studying their evolution could provide valuable insights about their invasion mechanism and impacts to new habitats. The Lagoon of Venice (LV) is a significant gateway for invasive algae introduction into the Adriatic Sea. This work aims to address the pressing need to enhance research on the perceptions of local resource users, especially fishers, on invasive algae impacts on marine resources in the Mediterranean setting. The study conducted between February 2022 and April 2024 involved 31 people, most of whom had been engaged in fishing activities for up to over 60 years, who were interviewed during boat trips and algae collection. Interviewees reported knowledge components, complemented by scientific expertise, related to the invasion mechanisms of algae. Of the 26 identified algae recorded, eight taxa have not yet been reported with their scientific names in surveys on the impact of algae in the LV. Together with perceived reasons and related challenges, environmental impacts, solutions proposed by local fishing experts, and adaptations along with their positive uses are socio-economic impacts which are lacking in the LV scientific surveys. The findings reveal perceptions on the direct and indirect impacts of invasive macroalgae in the LV environment affecting its coastal ecosystem functions. Local fishers' knowledge (LFK) offers many ecologically relevant perspectives, which based on the long-lasting practice could complement scientific knowledge (SK) about the impacts of invasive algae and local stressors related to climate change. Hence, it is vital to integrate the broader knowledge of fishers and include them as equal stakeholders in conservation initiatives.

1. Introduction

The significant ecological, economic, and societal importance of marine algae, their complex nature, and the potential threats that could disrupt their ecology and distribution support their continued research, as identified in the objectives of the Agenda 2030 and more specifically the UN Decade of Ocean Science for Sustainable Development [1–4]. Marine algae provide a wide range of external and internal benefits which are being negatively affected by human activities and more broadly climate change, consequently modifying the ecology and distribution of marine species [5]. Moreover, some marine algae are invasive alien species, which generally are widely recognized as the primary direct cause of global biodiversity decline [6–8].

Among other coastal users (such as scuba divers and beachgoers), local fishers represent key observers of such impacts, who with proper guidance can support the investigation and surveillance of marine algae, e.g. citizen science helping to find new knowledge about algae [9–11]. We acknowledge the citizen science efforts to document marine alien

* Corresponding author.
E-mail address: renata.soukand@unive.it (R. Sõukand).

https://doi.org/10.1016/j.marpol.2025.106903
Received 5 September 2024; Received in revised form 2 September 2025; Accepted 9 September 2025
Available online 16 September 2025

fishes and mollusks in European marine waters (see [12]). However, the knowledge of local resource users such as fishers is understudied and declining worldwide despite their long-term perceptions on aquatic plants and algae, which are fundamental to better understanding the complex ecosystem of a region [13]. Incorporating local ecological knowledge (LEK) on invasive algal species into resource management programs can complement our understanding of the structure and function of marine ecosystems in future, climate-altered systems [14].

In order to contribute to the identified knowledge gap, we have chosen as a case study the Lagoon of Venice (LV), a hotspot of marine biodiversity, yet it faces a significant threat from non-indigenous species (NIS) introduction. This is due to its environmental instability, limited species diversity, aquaculture activities, and the presence of unsaturated benthic communities [15–17]. This risk is particularly high in the LV, which serves as a major gateway for NIS introduction into the region [18,19]. The LV is also linked to numerous marinas and coastal areas that are popular among tourists [20] especially on the eastern shore of the Adriatic Sea [21,22]. The LV functions as a hub for several sources of NIS introduction, such as shipping, recreational boating, shellfish aquaculture, and the trade of live seafood, making it both a reservoir and a dispersal point [16,19,23–25]. Four primary vectors are responsible for the introduction of NIS through shipping activities in the Adriatic Sea, including (1) ballast water and (2) hull fouling (biofouling) (BHF). For macroalgae in transitional water systems (TWS) the main vectors are (3) aquaculture and (4) fish markets [16,25]. Of these, ballast water has become the most significant vector in the past 20 years, according to Gollasch et al. [26] and Katsanevakis et al. [27].

Although there have been numerous studies examining the impacts of harmful invasive algae (e.g. [28–29]), there are few investigations that have evaluated the interconnectedness of the invasion mechanisms of these harmful algae in coastal ecosystems, on the basis of the perceptions of local resource users, especially fishers. This work aims to show the complex connections among knowledge components regarding invasion mechanisms of macroalgae and changes in the environment, based on the knowledge of fishers. The LEK of fishers on invasion mechanisms of algae and their impacts on the fishing communities of Venice Lagoon, Italy are crucial for understanding the harmful effects of invasive species on marine resources in the Mediterranean region. Specifically, this study documents the perceptions of fishers regarding invasive algae, analyses their narratives, and maps the knowledge components related to the invasive algae in the Lagoon of Venice, Italy.

2. Methods

2.1. Study region

The Lagoon of Venice is an enclosed coastal ecosystem covering approximately 550 km^2, which has an average depth of approximately 1.2 m and a tidal range of approximately 0.62 m. It is linked to the Adriatic Sea via three port-entrances (Lido, Malamocco, Chioggia) [30,31]. The lagoon is the most expansive transitional ecosystem within the Mediterranean Sea [32], comprising islands, fishing ponds, and tidal areas [33]. The lagoon is partitioned into three primary hydrological basins, namely the southern, central, and northern basins. These basins are demarcated by the Lido and Pellestrina watersheds, whose boundaries are influenced by tide movements and wind [32]. The salinity of the LV varies from 18.5 ‰ to 35.9 ‰, with the exception of choked areas and river mouths. Salt levels in the canals of Chioggia and the Venice Islands range from 28 ‰ to 33 ‰. Tidal currents in the canals change direction every 6 h. The speed of the currents is 100–120 cm s^{-1} in the inlet, 20–40 cm s^{-1} in the main canals of the city, and 0–10 cm s^{-1} in the smaller canals [30,31]. The lagoon, which exhibits a highly heterogeneous environment with varying depths, was formed approximately 12, 000 years ago during the Würm period [33] as a result of melting glaciers, which caused flooding of the lands located behind the sand dunes in the Po River valley. The current form of the lagoon is mostly the result of hydraulic alterations designed to mitigate the deposition of sediments carried by the river and erosion caused by the sea.

2.2. Methodology

Ethnographic field work and algae collection took place between February 2022 and April 2024. The fishing communities in some stations close to Lido Malamocco, Lido Faro and Punta Sabbioni, Murano, Burano, Sant'Erasmo, Sant'Elena, and Chioggia around the LV were visited (Fig. 1). The team purposely selected participants who were local experts in the fishery, i.e., local fishers and resource users who were recognized as having substantial knowledge on this topic by local people. The interviewees were asked about their knowledge of the invasive macroalgal species affecting their fishery activities in the LV. Field notes were taken and interviews were voice-recorded. Thirty-one people were interviewed: 13 were interviewed individually and the remaining took part in six group interviews consisting of 2–6 people. Interviews were conducted in Italian and ranged from 30 min to three hours. All interviewees were local resource users and fishers engaged in fishing activities, the latter of which had been doing fishing activities for 6 to more than 60 years. Four boat trips were arranged for macroalgae collection with local fishers. All interviewees provided written informed consent to participate in this study. The study was approved by the Ethics Committee of Ca' Foscari University of Venice.

The macroalgal taxa were identified, when possible, on the basis of the collected samples by AS and AB. These samples are stored dried in the Ca' Foscari herbarium (UVV) bearing identification numbers UVVETBOTALG01–16. The algae nomenclature follows AlgaeBase [35] and the recent literature [24,25]. When a macroalgal sample was not available, it was identified on the basis of the combination of description and local name provided by local fishers, as often done in ethnobotanical research [36,37]. Some taxa remain unidentified either because they have disappeared or were not available for sampling and neither name nor description was enough to identify them at least to family level.

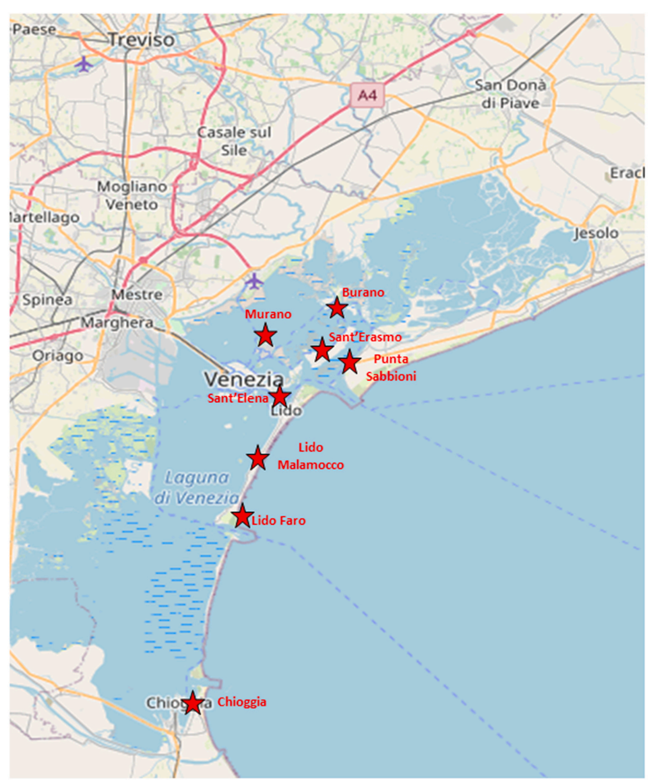

Fig. 1. Map of the Lagoon of Venice, Italy (from the OpenStreetMap resource: [34]).

2.3. Data analysis

The interviews were transcribed and translated into English before being coded in a codebook generated using the Atlas.ti 23 software. The analyses followed an inductive (data-driven) approach as outlined by Bernard et al. [38]. The exported codebook from the software had an organizing table that contained codes derived from the categories and subcategories identified in the transcripts. Every segment of the encoded transcripts was meticulously examined to ascertain the categories and subcategories (Appendix 1).

Results were then analyzed using Atlas.ti 23 software, then organized, summarized, and pivoted in MS Excel. RAWgraphs was used for data visualization.

3. Results and discussion

Local resource users including fishers reported 33 invasive macroalgal ethnotaxa, referring to 26 algae, based on characteristics, uses, and impacts. Ethnotaxa were formed on the basis of the local name or description. They consisted of 11 families and seven genera; five taxa remained unidentified (Table 1). Among those identified, 11 taxa were previously recorded by Sfriso et. al [24] and 1 taxon was recorded by Sorokin et al. [39], while 8 taxa had not yet been reported in surveys about the impacts of algae in the LV. This shows that information from interviewees can complement scientific studies on the current composition of invasive algae and their impacts in the region.

On the basis of the descriptions given by the interviewed local resource users, macroalgae can be divided into several conceptual categories, which are summarized in Fig. 2. The fishers explained the differences in names within LV fishing communities, as there exists a particular nomenclature among local resource users that refers to physical characteristics of algae: "*For example, pelo rosso [literally: red hair] [Gracilaria sp.pl.] could be related to many different species of algae unless they have some other specific characteristics*" (BUF21).

The knowledge components on the mechanisms of invasions reported by the local resource users in the Lagoon of Venice (Italy) include the origins of invasive macroalgae and related challenges (179 mentions), environmental (181) and socio-economic (105) impacts to the Lagoon of Venice, solutions proposed by experts (41), and adaptations reported by local resource users (Figs. 3 and 4).

3.1. Perceived reasons for the invasion mechanisms of algae

According to the perception of local resource users, one of the most cited problems in the lagoon is the proliferation of invasive algae (48 mentions) and related challenges on invasion mechanisms (41 mentions), which are mostly associated with the decline of anthropogenic impacts and climate change-related stressors, including higher temperatures in the lagoon that impact the growth of species and no longer allow the lagoon to freeze, and movement-related factors, such as currents and wind. This is followed by consequences caused by clam harvesting, MoSE (Modulo Sperimentale Elettromeccanico) construction (28), the movement of navigation vessels (12), and waste coming from agriculture, domestic, and industrial activities (16). Interviewees also reported water-related issues (12) such as bad water quality, less fresh water coming into the lagoon, and nutrient overabundance. Lagoon development projects (9), including the digging of canals, the diversion of rivers, and urbanization in the lagoon, as well as aquaculture activities (8), such as the growing and harvesting of clams, were cited as well. Sedimentation rates, the establishment of artificial salt marshes, and the impacts of herbicide use were among the least mentioned (Figs. 3 and 4).

The building of artificial salt marshes also affects the presence of aquatic angiosperms and sensitive macroalgae, lagoon water mixing, water/current/water cycle flow (also due to MOSE), and flow for fish. This changes biodiversity in the area, including the disappearance of native aquatic angiosperms (mostly *Ruppia cirrhosa* and *Nanozostera*

Table 1
Invasive algae in the Lagoon of Venice, Italy.

Latin name, (herbarium nr.), (family)	Local name/ description	No. of people that cited	Characteristics/Uses/ Impacts (No. of mentions)
Agardhiella subulata (C. Agardh) Kraft & M.J. Wynne 1979, (ALG01), (Solieriaceae)	veleta	2	grows everywhere (1), habitat for shrimp and "acquadelle" [*Atherina boyeri* (Risso)] (1), suffocates other species (3), affects "seppie" [*Sepia officinalis* (Linnaeus)], "rombo" [*Scophthalmus rhombus* (Linnaeus)], "calamaro" [*Loligo vulgaris* (Lamarck)] fishing (2), blocks nets (1), creates problems for boats (1), discomfort to fishers (1)
Chaetomorpha linum (O. F.Müller) Kützing 1845, (ALG02), (Cladophoraceae)	sea/cea	4	cooking (1), disappearance of seagrasses (1), problem for fishing (3)
Chaetomorpha sp.pl., (ALG03), (Cladophoraceae)	pe(l)o oglio, pe(l) o ojo pe(l)o verde, pettole, form like a green carpet	6	covers the algae "salata" [*Ulva australis/Ulva rigida*] (1), disturbs the growth of "moeche" [*Carcinus mediterraneus*] (1), creates problems for clam growth (1), sticks to nets (6), makes the soil muddy, sterile, anoxic (1)
Codium fragile (Suringar) Hariot 1889, (ALG04), (Codiaceae)	algae brought from another place by current to the canal	1	proliferation (1)
Dictyopteris polypodioides (De Candolle) J.V. Lamouroux	toxic seaweed	2	toxic to mussel farming (2)
Ectocarpus sp.pl., (ALG05), (Ectocarpaceae)	pe(l)o vischio verde, pe(l)o oglio	6	covers the algae "salata" [*Ulva australis/Ulva rigida*] (1), disturbs the growth of "moeche" [*Carcinus mediterraneus* (Nardo)] (1), problem for clam growth (1), sticks to nets (6), makes the soil muddy, sterile, does not breath (1)
Gongolaria barbata (Stackhouse) Kuntze 1891, (ALG06), (Sargassaceae)	barba di frati	1	proliferation (1)
Gracilaria sp.pl., (ALG07), (Gracilariaceae)	pe(l)o rosso, barba di frati	8	hiding place (1), medicine (1), natural banks of clam seeds, oysters (2), use in pharmaceuticals (1), habitat for giant seabass (1), proliferation (4)
Gracilaria bursa-pastoris S.G.Gmelin) P.C.	barba di frati, razioni, found	1	sticks to nets (1)

(continued on next page)

Table 1 (*continued*)

Latin name, (herbarium nr.), (family)	Local name/ description	No. of people that cited	Characteristics/Uses/ Impacts (No. of mentions)
Silva, 1952, (ALG08), (Gracilariaceae)	with seaweed that forms like a ball		
Osmundea oederi (Gunnerus) G. Furnari, (ALG09), (Rhodomelaceae)	forms like a ball	1	sticks to nets (1)
Picocyanobacteria	Cyanobacteria	1	disappearance of seagrasses (1), fish kills (1)
Polysiphonia sp.pl. (including *P. morrowii* Harvey), (ALG10), (Rhodomelaceae)	alga rossa, alghe americane	3	makes the soil muddy, causes the death of juveniles (2), hinders the reproduction of juveniles, clams, and crustaceans (1), sticks to nets (1)
Polysiphonia sp.pl.; *Chondria capillaris* (Hudson) M. J. Wynne; *Kapraunia schneideri* (Stuercke & Freshwater) Savoie & G.W.Saunders; *Acanthosiphonia echinata* (Harvey) Savoie & G.W. Saunders; *Melanothamnus japonicus* (Harvey) Díaz-Tapia & Maggs; (Rhodomelaceae)	pe(l)o vischio rosso, pe(l)o oglio	6	[are within] the algae "salata" [*Ulva australis/Ulva rigida*] (1), disturbs the growth of "moeche" [*Carcinus mediterraneus* (Nardo)] (1), problem for clam growth (1), stick to nets (6), makes the soil muddy, sterile, anoxic (1)
Sargassum muticum (Yendo) Fensholt 1955, (ALG11), (Sargassaceae)	alga giapponese, (Cold-loving species of North Atlantic origin)	1	floating algae problem (1)
Spyridia filamentosa (Wulfen) Harvey 1833, (ALG12), (Callithamniaceae)	forms like a ball, barba di frati	1	sticks to nets (1)
Ulva australis Areschoug 1854; *Ulva rigida* C. Agardh 1823, (ALG13), (Ulvaceae)	salata, veli	13	cream (2), fertilizer (3) but increased salt content in fields (1), for sauna (1), hiding place for fish/shrimp (2), decomposition - makes the water rot (2), produces a bad smell (5) and takes away oxygen (2) causing the death of other species leading to their decline (7), makes the soil muddy, sterile (1), disappearance of seagrasses (2), harms clam growth (3), suffocates the growth of mussels (1) and juvenile "*acquadelle*" [*Atherina boieri* (Risso)] (2), sticks to nets (10)
Ulva sp.pl. (filamentous-tubular), (ALG14), (Ulvaceae)	algae found on the bottom of the boat, baro	1	problem for boats (1)
Undaria pinnatifida (Harvey) Suringar 1873, (ALG15), (Alariaceae)	radicio, (cold-loving species of Korean, Japanese origin)	2	grows at Chioggia, Lido, and the historical center of Venice (1), problem for boats (1)
Valonia aegagropila C. Agardh 1823 (Valoniaceae)	alga palla (it has disappeared from the free lagoon since the '80 s.)	1	releases a bad smell (1)
Vaucheria submarina (Lyngbye) Berkeley, (ALG16), (Vaucheriaceae)	pe(l)o oglio, pe(l) o ojo pe(l)o verde, pettole, form like a green carpet	6	covers the algae "salata" [*Ulva australis/Ulva rigida*] (1), disturbs the growth of "moeche" [*Carcinus mediterraneus* (Nardo)] (1), creates problems for calm growth (1), sticks to nets (6), makes the soil muddy, sterile, and anoxic (1),
Unidentified	alga beretta	1	sticks to nets (1)
Unidentified	alga marrone, alga palle da calcio	1	sticks to nets (1)
Unidentified	peo riccio, barba di frati	2	cosmetics (1), problem forming balls (1), sticks to nets (1)
Unidentified	red algae look like dragon's tail (in our fishing areas it no longer exists)	1	problem for boats (2)
Unidentified	alga marroncina	2	annoying (1), stick to nets (1)
Microalgae related	mucillagine	5	suffocates everything, less oxygen in the soil, affects Posidonia [*Cymodocea nodosa* (Ucria) Asch., *Zostera marina* (Linnaeus), Nanozostera noltei **(Hornem.) Toml. & Posl.**] (5)

noltei), which can be found where water is clearer, and nutrients are lower. Fishery in the lagoon is also negatively impacted as the growth of clams, the movement of fish, fishes like gobies "*Go*" (*Gobius niger, Zosterisessor ophiocephalus*) and eels (*Anguilla anguilla*) (which require "*staissa*" water that is neither too salty nor too fresh), shrimp, snails, crabs, mollusks, and mussels. Recreational fishers from Sant'Erasmo island said: "*The fresh water is unfortunately polluted. Land erosion and herbicides and pesticide spraying generate problems. Arsenic is all over the land if it rains a lot, salinity increases if it rains little, therefore some plants don't grow and others grow*" (SEF23, SEF24).

The fishers' insights resonate with a study from 2018 which showed that invasive macroalgae have strong tolerance to a wide range of temperatures and high salinity [40]. Fishers perceived that the lagoon environment, including its morphology, has changed. For instance, fishers in Chioggia observed: "*Salinity has also changed lagoon life. Instead of 24, we now have a salinity of 34 or 36. Because they blocked all the lagoon's freshwater outflows and other things*" (CHF03). "*In the past, the decline of aquatic angiosperms reduced the presence of shrimp. They have changed their position since artificial salt marshes were made, which changed the flow of water affecting fish and feed flow*" (CHF08).

Local resource users mentioned that the diffusion of macroalgae in the lagoon is caused by climatic changes, seasonal changes, and movement-related variables like currents and wind locally known as "*bora*". Regarding *salata* (*Ulva australis/Ulva rigida*), recreational fishers in Sant'Erasmo added: "*it accumulates, settles down, and dies* [releasing high amounts of nutrients, pollutants previously accumulated in the biomass, increasing water turbidity]. Moreover, their luxuriant growth

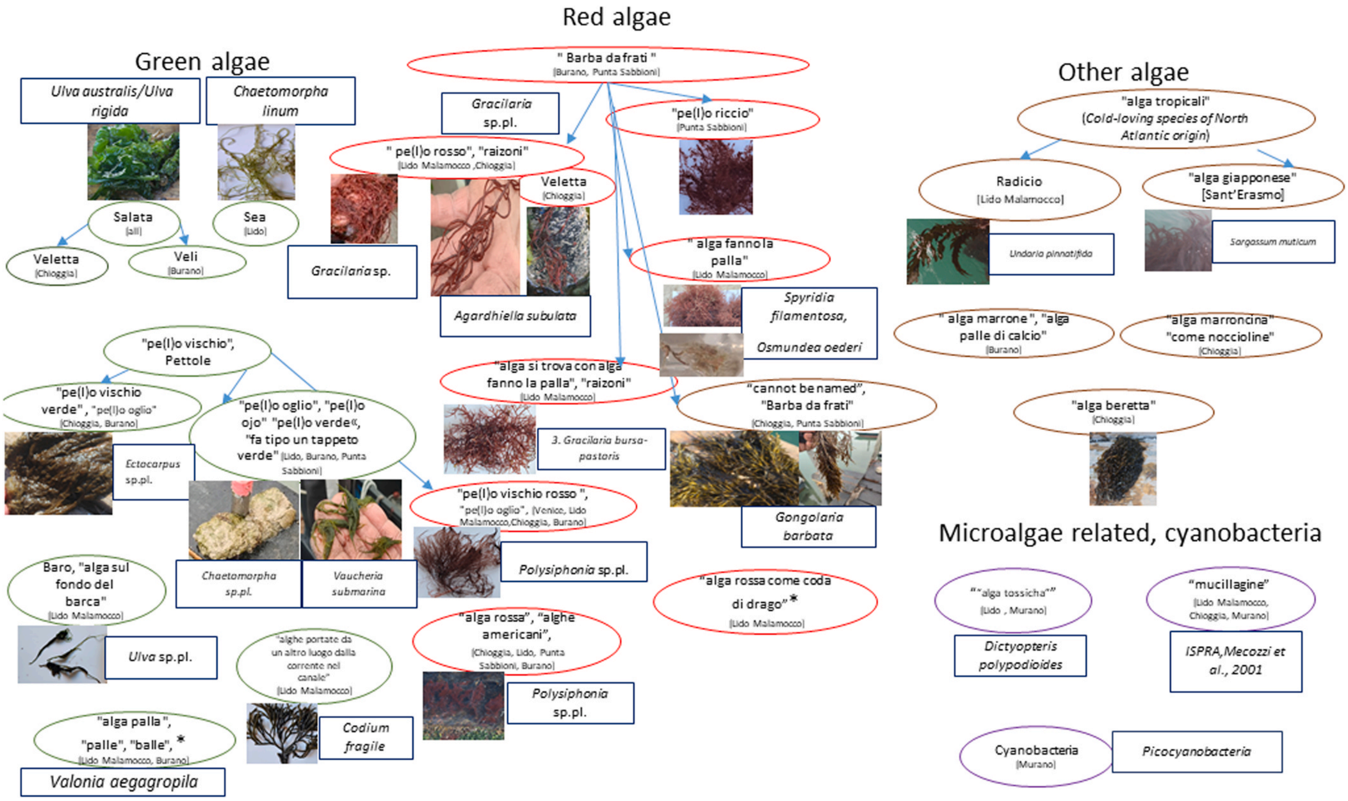

Fig. 2. Mind map of invasive macroalgae in the LV based on local resource users perception.

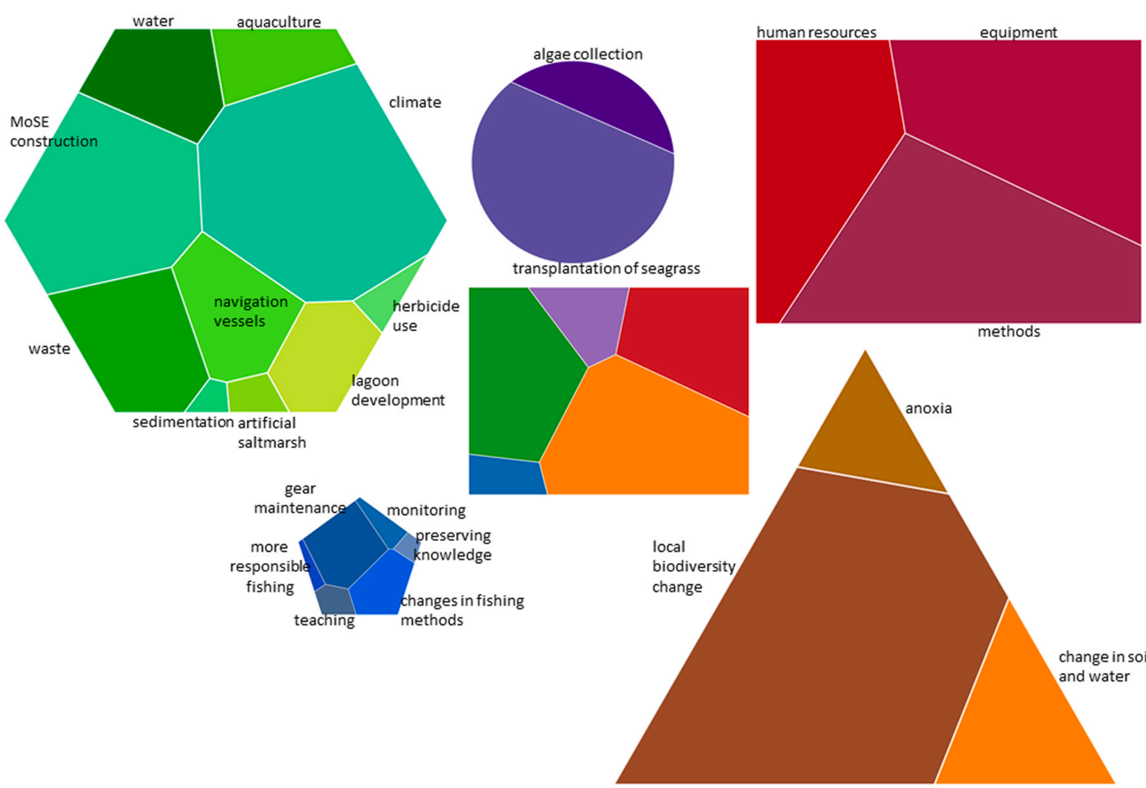

Fig. 3. Knowledge components on algae invasion mechanisms in the LV.

is favored by *domestic waste, animal waste,* [whereas it is hampered] *by herbicides"* (SEF23, SEF24). Also, some Rhodophyceae, i.e. *Polysiphonia* sp.pl. and similar taxa, might have entered the lagoon through various means, such as the excavation of canals or through ports, i.e. aquaculture, commercial and tourist ships, and proliferated because of the reduction of trophic level and anthropogenic impacts and low water

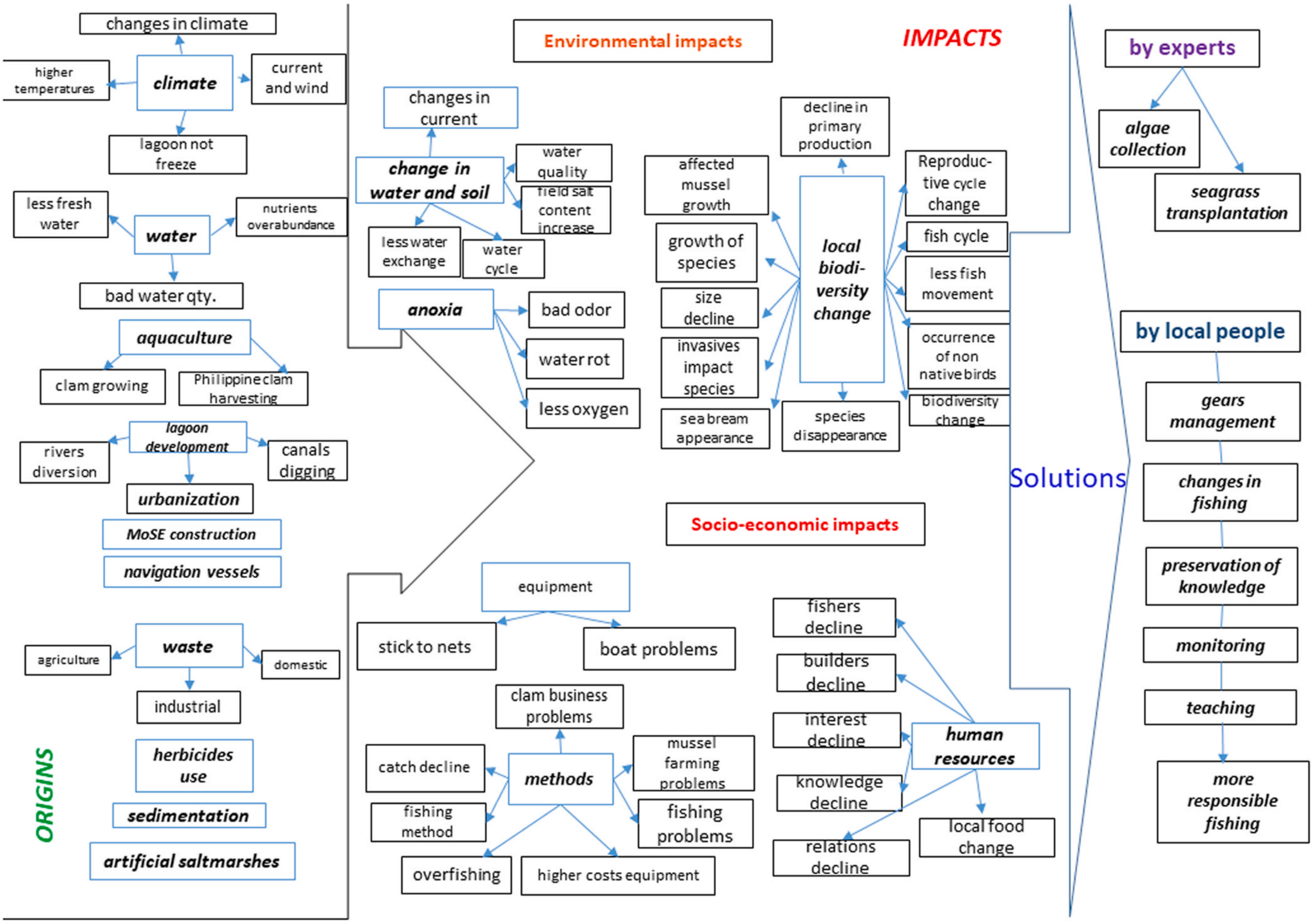

Fig. 4. Invasive algae invasion mechanisms and impacts in the LV.

exchange. However, other species are favored by this and pollution from domestic waste, including detergents enriched with phosphorus on Lido island, agriculture waste, and industrial effluents (CHF04, LMF09, SEF23, SEF24).

The decline of primary production of macroalgae was due almost exclusively to trophic level reduction and climate change [41]. In relation to this, climate change-related stressors are considered responsible for local algae proliferation by 11 interviewees (who could have been influenced by media communication). In relation to increasing temperature, a fisher, referring to *Ulva rigida*, explained: *"Salata are green ones, like lettuce…until '93-'94 there was the cursed triangle of the three islands, Poveglia, Sacca Sessola, and Santo Spirito, where making the Petroli canal* [Malamocco-Marghera Canal] *occurred 15 years before, the channels no longer discharge as they used to. So, these algae multiplied because of climate-related stressors,* [the reduced water exchange in the Lido watershed] *and began to proliferate"* (LMF09).

Four interviewees observed the negative impact of MoSE in the LV ecosystem and especially on algae proliferation. In particular, an interviewee in Punta Sabbioni explained:

"MoSE has done its damage and is still doing it, changing the waterways. For instance, alga rossa [*Polysiphonia* sp.pl.] *is new, it arrived when the stones for MoSE were brought here* [then it colonized the stones afterwards]." (PSF16)

Previous studies in the LV demonstrated that human activities have significantly altered the lagoon over the past century by artificially manipulating its hydraulic dynamics, which involved constructing canals to improve navigation [42–45]. According to Marchini et al. [16], the LV is a hub for the introduction of marine NIS through shipping, recreational boating, shellfish cultivation, and live seafood commerce. Historical changes have affected submerged aquatic plants for a long time [46–48]. However, current rapid environmental changes have fostered the arrival of NIS and real invasions [49]. NIS from the Indo-Pacific were already affecting the Mediterranean basin when recent climate changes and rising temperatures allowed these species to find numerous suitable sites [50]. Ocean warming and acidification affect the ecophysiology, lifecycle, zonation, and biogeographic distribution of marine algae [51], while pollution changes water pH and undermines settlement, photosynthesis, growth, and other biological processes [52].

3.2. Environmental impacts of invasive algae on the Lagoon of Venice

Most of the environmental impacts mentioned by the interviewees were changes in local biodiversity (136 mentions), followed by changes in water and soil (29) and anoxia-related impacts (16). The changes in local biodiversity include species disappearance (86), invasive species impacting local species and other invasive species (23), the reduction in biodiversity (8), and the decline in macroalgal primary production (7). Among the least mentioned changes were the decline in species size, the reduced movement of fish, the occurrence of non-native birds, the appearance of predator species such as sea bream and alterations in the life cycle of species and impacts to their growth. Water and soil related-impacts include changes in water quality, currents, and cycles, and a decrease in water exchange. Fishers also reported that anoxia decreases oxygen levels in the lagoon and creates a bad odor, as water rot, especially during algae decomposition.

According to the interviewees, the proliferation of the invasive algae *"pelo vischio"* (Ectocarpaceae, Rhodomelaceae, Vaucheriaceae, Cladophoraceae and filamentous Ulvaceae) disturbs the growth of crab "*moeche*" (*Carcinus mediterraneus*). *Salata* (*Ulva australis/Ulva rigida*) and mucilage, along with clam harvesting and nurseries, affect seagrass meadow areas causing their reduction and/or disappearance. According to interviewees, seagrasses "*Posidonia*" (*Cymodocea nodosa*, *Zostera marina*, Nanozostera noltei) in the LV were very abundant before the 1980s and important for a variety of reasons, such as preventing erosion processes, retaining sediments, as a food source for migratory bird species, providing oxygen in the lagoon, habitat for fish and shrimp, and serving as fish spawning areas (e.g. cuttlefish). In subsequent years, aquatic angiosperms declined during *Ulva* overgrowth and the harvesting of the manila clam *Ruditapes philippinarum*, which has returned to colonize the lagoon since 2014 [53].

A previous investigation on the occurrence of mucilage in marine waters can lead to significant environmental and economic issues [54] allowing negative impacts on the tourism and fishery sectors of the Adriatic Sea [55]. In addition to this, fishers, hunters, and amateur fishers mentioned that in the LV, mucilage suffocates everything, allowing less oxygen into the sediment impacting the seagrasses (CHF05, CHF06, CHF07).

Many eutrophic marine and freshwater habitats with harmful algal blooms (HABs) already encounter severe temperatures, low oxygen levels, and acidic conditions [14]. The disappearance of aquatic angiosperms has also been noted to be caused by the proliferation of picocyanobacteria [39]:

"*In July* [2001], *these plants disappeared everywhere; because of a strange green color that the waters of the northern LV had, which led to the death of many fish species, all the plants, mollusks, mussels, and so on and allowed seagrasses disappearance. From that year all the fish disappeared there also benthic species. The first to notice were the fishers, but the first interventions were made by the hunters and amateur fishers to try to restore these prairies that had disappeared* [see also, [56] Life12 NAT/IT/000331; [57] Life 16 NAT/IT/000663] (MUF20).

Indeed, the proliferation of invasive macroalgal changes the fish life cycle, but it could also affect other eutrophic species, like *"pelo vischio"* (Ectocarpaceae, Rhodomelaceae, Vaucheriaceae, Cladophoraceae and filamentous Ulvaceae) which cover or replace *salata* (*Ulva australis, Ulva rigida*) during the summer.

Our interviewees have observed toxic algae in Trieste during the summer season, which according to Facca et al. [58] are phytoplanktonic species including Dinophysis, Pseudonitzschia, Prorocentrum, and Alexandrium. For instance, one fisher observed: "*When there is a certain water temperature. They come out in September and release stuff* [such as neurotoxins, hepatotoxins, gastrointestinal toxins]." (LIF14)

Interviewees spoke about changes in the chemistry of the lagoon sediments because of algae proliferation and the consequences to other native species; for instance, "*alga rossa*" [*Polysiphonia* sp.pl.], "*peo oglio*" [Ectocarpaceae, Rhodomelaceae, Vaucheriaceae, Cladophoraceae, and filamentous Ulvaceae], and *salata* [*Ulva australis/Ulva rigida*] make the soil muddy and sterile. According to interviewees: "*This is one way they impact the seagrass* "*Posidonia*" [*Cymodocea nodosa*], *as it requires sandy sediments. This causes the death of juveniles, therefore preventing or hindering other species (e.g. clams and crustaceans) from reproducing – which then impacts the fishing activities of seppie* [*Sepia officinalis*], *rombo* [*Scophthalmus rhombus*], *and calamaro* [*Loligo vulgaris*], *due to algae "pelo rosso"* [Gracilariaceae, Solieriaceae] (PSF18, MUF19, LIF14).

Ulva rigida proliferation in the LV triggered widespread anoxia, degrading the environment and affecting fishing, aquaculture, and recreation [59,60]. The loss of substrata for egg deposition [61], preferred food and habitat [62,63] might have adverse effects on organisms that depend on seagrasses, which offer a complex habitat matrix including cyanobacteria [64].

The findings of this study based on the long-term perceptions of local resource users on invasion mechanisms and impacts, complemented by previous scientific studies in the LV, demonstrate that the primary reasons for the past decline of seagrasses in the LV was the rise of nutrient concentrations that favored Ulvaceae overgrowth and water turbidity resulting from clam-harvesting, embankment reconstruction or reinforcement, and the use of unsuitable sandy sediments which hindered the growth of seagrasses [65] that affected the numerous fish species dependent on it [66] and its ability to improve water clarity [67]. Sfriso et. al. [68] and Zi-Min and Lopez-Bautista [69] reported that *G. vermiculophylla* affected marine ecosystems by modifying interspecific competition (also [70]), altering community dynamics, transforming biogeochemical cycles, changing estuarine food webs, e.g. in the Mediterranean Sea and intertidal coastlines in southeast Australia [71,72], and causing a rise in the populations of small native invertebrates and epiphytic algae that are likely to have cascading effects on higher trophic levels [73]. Tweedley et al. [74] found that algae like *S. muticum* successfully colonize oyster shells in soft sediments, while seagrasses such as *Z. marina* and *Z. noltei* enhance this colonization allowing algae to settle on them, thereby posing ecological challenges and disrupting linked food webs [75].

The findings show the integrated perspectives of local resource users in the LV which provide information on the impacts of successful invasion mechanisms of macroalgae on native species in the coastal environment of the LV with a potential reduction of biodiversity.

3.3. Socio-economic impacts of invasive algae on the Lagoon of Venice

According to the interviewees, the socio-economic impacts of invasive algae in the LV include effects on their fishing methods and activities (42), equipment (35), and human resources (28).

Impacts on fishing methods and activities include a decline in catch (13), changes in fishing methods (10), and problems with their activities (5). Among the least mentioned impacts were challenges to clam and mussel farming, overfishing, and higher equipment costs. Impacts on equipment mainly include problems with invasive macroalgae entangling nets and creating issues for boat engines. The reported human resource-related impacts were mostly the decline in fishers (17) and builders (2), while the decline in knowledge, interests, and relationships between current and future generations of fishers, as well as a change in local food diversity, were among the least mentioned.

In regard to the decline in knowledge from previous generations including the reduction in boat builders and net makers, one fisher in Lido-Malamocco mentioned: *"Fishers, the old ones disappeared and finally everything practically ends. There is no turnover. unlike 50 years ago"* (LMF09). Additionally, fishers in Chioggia stated: *"It is a profession either by choice or by necessity. Those who do it by choice are few left."* (CHF05, CHF06).

Considering the decline in fish, a fisher mentioned: *"I had made the largest catch of my life in December 1992—these fish, "Go" [Gobius niger, Zosterisessor ophiocephalus], which was basically my work. It is vital to preserve historical memory, it would be good if I also put something in writing. The network marketers from my dad's era and those who provided information to boat and nets builders are disappearing. So, the quality is not as good as it was previously"* (LMF09).

Sixteen interviewees from Chioggia, Sant'Elena, Burano, Lido, and Punta Sabbioni mentioned algae that come with warm temperatures, like *salata* [*Ulva australis/Ulva rigida*], "*peo oglio*" (Rhodomelaceae, Vaucheriaceae, and Cladophoraceae), *barbe da frate* (*peo riccio*), and "*alga rossa*" (*Polysiphonia* sp.pl.), cause problems for fishing as floating algae fill the nets even in bad weather and blocks them from catching fish.

As Lido and Chioggia fishers remembered: *"pelo rosso"* [*Gracilaria sp. pl.*]*, macroalgae* [like *Sargassum muticum, Undaria pinnatifida*]*, and red algae like dragon's tail block nets and ruin boat engines, creating difficulties for fishing seppie* [*Sepia officinalis*]*, rombo* [*Scophthalmus rhombus*]*, and calamaro* [*Loligo vulgaris*]*"* (LMF09, CHF05, CHF06, CHF07).

These basic findings are consistent with research showing that both of these species found on the hard substrata of Venice's historical center create significant navigational difficulties [24]. However, their impact is minimal when compared to other algae such as *Ulva rigida* and *Ulva australis* which can trigger anoxic events [65].

For example, regarding the impact of the decline in fishers and fish catch, thus resulting in a decline in fish diversity, one interview from Lido explained: *"The lagoon had more fish in my dad's time from the 1950s. Venice's market was once full of fish…If you want to eat fried food, you can't anymore.because there isn't a large quantity…Because now if you go to a local restaurant, they offer the one that they can prepare. Then, if you expect to eat squid, they are not ours, they are likely American."* (LMF09).

Previously, Nunes et al. [76] reported the decline of LV fisheries and their vulnerability to climate change [77]. In relation to this, another person in Lido added that clam farmers had to move to the sea to fish because of algae proliferation: "*I had a clam farm in the lagoon, but these algae reproduced excessively, so I stopped and went to the sea."* (LIF14).

The remaining impacts to human resources include the decline in fishers' relationship with other fishers and the reduction in income, also considering the higher costs of equipment and fuel.

The above findings demonstrate that the integrated perspectives of local resource users in the LV provide information on the impacts of successful invasion mechanisms of algae on society and the economy in LV fishing communities which disrupt the traditional knowledge system and fishing culture practices. This could erode the cultural significance and long understanding of this coastal ecosystem, potentially leading to the loss of the cultural heritage and identity of its local resource users and cause the loss of the undocumentable Dark Local Knowledge that may hold yet undiscovered knowledge [78].

3.4. Solutions proposed by experts and adaptations by local people

During interviews, local resource users reported that the solutions proposed by experts were the transplantation of aquatic angiosperms and the collection of algae. The adaptations of local people included gear maintenance (9) including the cleaning and pulling up of nets, bait repositioning, the recasting of rods, and fishing gear retrieval; as well as changes in fishing practices (6) including changes in fishing methods, farm fencing, and lagoon to sea fishing conversion. Teaching, monitoring, and preserving knowledge were among the least mentioned, but crucial adaptation strategies to be considered.

Many local resource users from Punta Sabbioni, Lido, Sant'Erasmo, Chioggia, and Murano described the transplantation of seagrass in the lagoon. For example, amateur fishers and hunters in the lagoon helped in the transplanting project with experts of the Ca' Foscari University of Venice project SERESTO. One interviewee in Murano said: *"This transplantation raised awareness among fishers, who have begun seagrass restoration. Several sods were left near the sea, so we asked the authorities* [Interregional authority for Veneto, Trentino Alto Adige, Friuli Venezia Giulia (OOPP)] *for permission to plant hundreds of 23-cm-diameter sods of seagrasses where they existed before. Thus, they developed from there. We presented this initiative to Ca' Foscari, and an expert saw the success of these activities and proposed a European project, which was financed, and now the northern lagoon is back to how it once was, with "Go" fish and eels back, but the "passarini" [Platichthys flesus] are not as many as cormorants, ichthyophagous have preyed on them. Thanks to these initiatives, a whole ecosystem that had disappeared since 2002 has been restored"* (MUF20).

Previous studies reported that the lagoon is still affected by considerable anthropogenic impacts, but the decrease in trophic levels has enabled the natural recolonization of seagrasses. As a result, several places are moving towards the restoration of their pristine conditions [65]. Two interviewees shared some positive changes in the lagoon, for instance, less pollution compared to 30 years ago and the lower abundance of *salata* (*Ulva australis/Ulva rigida*).

According to surveys conducted recently in the LV, ecological conditions continue to improve, leading to an increase in both biodiversity and the growth of macroalgae and aquatic angiosperms [25,53].

Fishing nets are brought to the shore and then cleaned by fishers, manually and with a pressure washer, to deal with the issue of nets being filled with invasive algae. Similarly, in the case of recreational fishing, fishers recast rods and reposition the bait.

Because of the abovementioned challenges, for example, the decline in fish affecting local food diversity, fishers tend to change their fishing methods, as mentioned by recreational fishers from Sant'Erasmo. Fishing practice changes such as shifting from fishing in the lagoon to fishing in the sea have occurred. As young people have less interest, teaching-related adaptations, such as the encouragement of future fishers and the introduction of fishing in schools, could help. Fishers reported the possibility of learning from previous generations within the family and also from other fishers.

3.5. Positive contributions of invasive macroalgae in the Lagoon of Venice

The positive uses of invasive macroalgae in the LV are reported few. For example, "sea" could also be used for cooking, *Ulva* sp.pl. can be used to make medicine, creams, and fertilizers, provide hiding places for shrimp and fish, and serve as bioindicators of the abundance of nutrients. For instance, a fisher in Chioggia shared: *"Veletta" [Agardhiella subulata] could be habitat for shrimp and fish like "acquadelle"* [*Atherina boieri*]*"* (CHF08).

A fisher from Chioggia mentioned: *Salata* [*Ulva australis/Ulva rigida*] *could be used as fertilizer"* (CHF03). However, another interviewee added: *"its dried waste could increase the salt content in agricultural fields as well"* (CHF06). Invasive macroalgae could serve as a spawning area; but not all, because one fisher from Chioggia observed: *"But now that there are no more macroalgae there, the fish come and don't know where to stick. It's all sand or the alga "veletta"* [*Agardhiella subulata*]*, but they can't stick the eggs there"* (CHF01).

Previous studies have shown that macroalgae have been significant in coastal communities for centuries. For instance, historically, they have been collected and procured from coastlines worldwide for traditional purposes but currently, macroalgae are utilized in various fields, including the growing global industries of hydrocolloids, cosmetics, and food supplements. Additionally, they hold promise as a possible source of biofuel [79]. *G. vermiculophylla*, *S. muticum*, *U. pinnatifida*, *A. subulata*, and *Solieria filiformis* have shown potential as species suitable for the manufacture of phycocolloids and antioxidants and cosmetic purposes [24]. Additionally, *S. muticum* offers a new and additional habitat for the native epifauna [80]. In this case, invasive species could also play a significant role in preserving species richness and variety, providing food and habitat for higher trophic levels [70].

4. Future implications

Our study supports the agencies and previous investigations, such as that conducted by Ferreira et al. [81], which explore the capacity of various stakeholders to actively engage coastal users in the examination, preservation, and administration of marine resources. This fosters stronger connections between individuals and the ocean through the promotion of Ocean Literacy [82]. Moreover, Kelly et al. [83] focused on enhancing knowledge on Ocean Literacy by examining public perceptions of marine resources, support for research and monitoring, and the influence of coastal use on these beliefs. The authors would like to recommend moving in the direction of involving local resource users, such as amateur and professional fishers and their cooperatives, as well as hunter associations, in monitoring invasive macroalgae in the Lagoon of Venice in collaboration with local organizations and scientists.

Previous study emphasizes the importance of assessing the methods through which invasive marine species are introduced for effective control strategies and prevention measures [27]; and thus every EU Member State is required to monitor and assess the ways in which non-indigenous species (NIS) are introduced [84–86]. The significance of promptly identifying NIS in ports and transitional waters must be considered in every environmental management plan [23]. Our results show the importance of long-term perceptions on the invasion mechanisms of macroalgae and how they have impacted the LV ecosystem in the last few decades. This could complement scientific studies and be integrated into local ecological efforts facilitating co-management. This could increase their engagement and compliance towards biodiversity conservation and restoration of the LV ecosystem.

5. Conclusions

On the basis of the perceptions of local resource users, enhanced and complemented by scientific knowledge, the LV faces several challenges created by the proliferation of invasive algae. Of the approximately thirty-three ethnotaxa reported, which refer to 26 algae, eight of those identified have not yet been reported with their scientific names in surveys about the impact of algae in the LV. This proliferation was connected to alterations in the local environment. Previous environmental impacts of invasive macroalgae included changes in local biodiversity (composition, behavior, and productivity), changes in the water and soil, and anoxia-related effects. These impacts favored the disappearance of sensitive species, the presence of invasive NIS which impacted local species, the decline in seagrass coverage, and changes in the life cycle of species. Socioeconomic impacts, however, included declines in fishing methods, equipment, and human resources. The social and economic impacts of invasive algae could erode the cultural significance and long understanding of this coastal ecosystem, potentially leading to a loss of cultural heritage and identity in the LV. Given the abovementioned impacts, fishing experts we interviewed have proposed solutions, and shared positive uses of invasive macroalgae in the lagoon.

This research demonstrates that the perceptions of local resource users such as fishers, enhanced with scientific knowledge (SK) on macroalgal invasion mechanisms and their impacts, show the complex connection among the abovementioned knowledge components and related environmental changes, with climate as a co-stressor. This knowledge is crucial for developing co-management strategies and impact mitigation policies in conjunction with local experts, such as local resource users, to safeguard fisheries, aquaculture, and aquatic ecosystems in the LV. This could aid the native fish community, micro/macro-invertebrates, and aquatic angiosperm populations. Integrating LEK with SK on invasive macroalgal species management programs that consider climate change-related stressors will offer more ecologically relevant perspectives on invasion mechanisms of macroalgae in the LV, as well as in the Adriatic Sea and other ecosystems experiencing similar challenges. This could provide a basis for the sustainable development of inclusive marine biodiversity maintenance and conservation. Therefore, it is crucial to integrate the local fishers knowledge and include them as equal stakeholders in conservation initiatives.

CRediT authorship contribution statement

Alessandro Buosi: Investigation. **Julia Prakofjewa:** Writing – review & editing, Data curation. **Sophia Kochalski:** Writing – review & editing, Methodology. **Maria Viktoria Bittner:** Writing – review & editing, Investigation, Data curation. **Agnese Martini:** Writing – review & editing, Investigation, Data curation. **Francesco Primavera:** Writing – review & editing, Methodology, Data curation. **Aimee Ciriaco:** Writing – review & editing, Methodology. **Giulia Mattalia:** Writing – review & editing, Methodology. **Baiba Prūse:** Writing – review & editing, Methodology. **Jimlea Nadezhda Mendoza:** Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Adriano Sfriso:** Writing – review & editing, Validation, Investigation. **Sõukand Renata:** Writing – original draft, Supervision, Methodology, Conceptualization.

Funding

This research is through Phd scholarship in Environmental Science 37th cycle from Ca Foscari University of Venice Italy under the Biocultural Diversity Lab. It did not receive any grant from funding agencies in the commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank the local experts - the local resource users such as fishers, hunters, amateur fishers of Lagoon of Venice including from *Laguna Venexiana Onlus*, *I Vagantivi*, *Cacciatori Italiani, Cooperativa San Marco – Pescatori di Burano* associations, Chef Lorenzo Barbasetti di Prun of prometheus_open food lab, organizations such as TBA21–Academy's Ocean Space and We are Here Venice island walking tours, masters students of Ca' Foscari University of Venice Italy including also Tiziana Floridia for their collaboration when they serve as research guides among local resource users, their moral support in the beginning up to the field interviews (also with Mr. Nonon Malinay and Mr. Joey Esteban from The Filipino Community of Venice Italy, El Shaddai Venice) and algae collection. Harvey Ciriaco as student volunteer from Laguna Philippines for additional scientific support for this research work.

Data availability

Data will be made available on request.

References

[1] R.L. Chapman, Algae: the world's most important "plants"—an introduction, Mitig. Adapt. Strateg. Glob. Change 18 (2013) 5–12.
[2] J. Claudet, L. Bopp, W.W. Cheung, R. Devillers, E. Escobar-Briones, P. Haugan, J. J. Heymans, V. Masson-Delmotte, N. Matz-Lück, P. Miloslavich, L. Mullineaux, A roadmap for using the UN decade of ocean science for sustainable development in support of science, policy, and action, One Earth 2 (1) (2020) 34–42.
[3] M. Cornish, A. Critchley, A. Hurtado, D. Largo, N. Paul, L. Pereira, Seaweed resources of the world: a 2020 vision. Part 3, Bot. Mar. 63 (1) (2020) 1–3.
[4] D. Largo, A. Critchley, A. Hurtado, N. Paul, L. Pereira, M. Cornish, Seaweed resources of the world: a 2020 vision. Part 4, Bot. Mar. 63 (4) (2020) 299–301.
[5] S. Lucrezi, Support for the research and monitoring of marine algae: a study of Italian coastal users, Mediterr. Mar. Sci. 23 (2) (2022) 374–388.
[6] CBD, 2016. Convention on Biological Diversity, Programme of Work on Invasive Alien Species, 〈https://www.cbd.int/invasive/.Accessed?〉 6 January 2024.
[7] Lucy, F.E., Roy, H., Simpson, A., Carlton, J.T., Hanson, J.M., Magellan, K., Campbell, M.L., Costello, M.J., Pagad, S., Hewitt, C.L. and McDonald, J., 2016. INVASIVESNET towards an international association for open knowledge on invasive alien species.
[8] H. Seebens, N. Schwartz, P.J. Schupp, B. Blasius, Predicting the spread of marine species introduced by global shipping, Proc. Natl. Acad. Sci. 113 (20) (2016) 5646–5651.
[9] A.G. Jacquin, S. Brulé-Josso, M.L. Cornish, A.T. Critchley, P. Gardet, Selected comments on the role of algae in sustainability, Adv. Bot. Res. 71 (2014) 1–30 (Academic Press).
[10] L.M. Grattan, S. Holobaugh, J.G. Morris Jr, Harmful algal blooms and public health, Harmful algae 57 (2016) 2–8.
[11] Stockholm University. n.d. The citizen science algae project. Available at: 〈https://www.su.se/english/research/research-projects/the-citizen-science-algae-project?open-collapse-boxes=research-project-members〉.
[12] V. Kousteni, K. Tsiamis, E. Gervasini, A. Zenetos, P.K. Karachle, A.C. Cardoso, Citizen scientists contributing to alien species detection: the case of fishes and mollusks in european marine waters, Ecosphere 13 (1) (2022) e03875.
[13] J.N. Mendoza, N. Hanazaki, B. Prūse, A. Martini, M.V. Bittner, S. Kochalski, E. Macusi, A. Ciriaco, G. Mattalia, R. Sõukand, Ethnobotanical contributions to global fishing communities: a review, J. Ethnobiol. Ethnomed. 19 (1) (2023) 57.
[14] A.W. Griffith, C.J. Gobler, Harmful algal blooms: a climate change co-stressor in marine and freshwater ecosystems, Harmful Algae 91 (2020) 101590.
[15] C. Munari, M. Mistri, Biodiversity of soft-sediment benthic communities from Italian transitional waters, J. Biogeogr. 35 (9) (2008) 1622–1637.
[16] A. Marchini, J. Ferrario, A. Sfriso, A. Occhipinti-Ambrogi, Current status and trends of biological invasions in the Lagoon of Venice, a hotspot of marine NIS introductions in the Mediterranean Sea, Biol. Invasions 17 (2015) 2943–2962.

[17] C. Munari, N. Bocchi, M. Mistri, *Grandidierella japonica* (Amphipoda: Aoridae): a non-indigenous species in a Po Delta Lagoon of the Northern Adriatic (Mediterranean Sea), Mar. Biodivers. Rec. 9 (2016) 1–8.
[18] L. Mizzan, Le specie alloctone del macrozoobenthos della Laguna di Venezia: il punto della situazione, Boll. Del. Mus. Civ. di Stor. Nat. di Venezia 49 (1999) 145–177.
[19] A. Occhipinti-Ambrogi, A. Marchini, G. Cantone, A. Castelli, C. Chimenz, M. Cormaci, C. Froglia, G. Furnari, M.C. Gambi, G. Giaccone, A. Giangrande, Alien species along the Italian coasts: an overview, Biol. Invasions 13 (2011) 215–237.
[20] M. Slišković, H. Ukić Boljat, I. Jelaska, G. Jelić Mrčelić, Review of generated waste from cruisers: Dubrovnik, Split, and Zadar port case studies, Resources 7 (4) (2018) 72.
[21] M. Kovačić, L. Silveira, Nautical tourism in Croatia and in Portugal in the late 2010's: issues and perspectives, Pomorstvo 32 (2) (2018) 281–289.
[22] J. Nikčević, Strengthening the role of local government to ensure sustainable development of the cruise sector: the case of Kotor, Mar. Policy 109 (2019) 103693.
[23] M. Orlando-Bonaca, L. Lipej, G. Bonanno, Non-indigenous macrophytes in adriatic ports and transitional waters: trends, taxonomy, introduction vectors, pathways and management, Mar. Pollut. Bull. 145 (2019) 656–672.
[24] A. Sfriso, A. Buosi, M.A. Wolf, A.A. Sfriso, Invasion of alien macroalgae in the Venice Lagoon, a pest or a resource? Aquat. Invasions 15 (2) (2020).
[25] A. Sfriso, M.A. Wolf, A. Buosi, K. Sciuto, A.A. Sfriso, Alien macroalgal rearrangement in the soft substrata of the Venice Lagoon (Italy): impacts, threats, time and future trends, Sustainability 15 (10) (2023) 8256.
[26] S. Gollasch, C.L. Hewitt, S. Bailey, M. David, Introductions and transfers of species by ballast water in the Adriatic sea, Mar. Pollut. Bull. 147 (2019) 8–15.
[27] S. Katsanevakis, A. Zenetos, C. Belchior, A.C. Cardoso, Invading european seas: assessing pathways of introduction of marine aliens, Ocean Coast. Manag. 76 (2013) 64–74.
[28] F.P. Mancuso, R. D'Agostaro, M. Milazzo, F. Badalamenti, L. Musco, B. Mikac, S. L. Brutto, R. Chemello, The invasive seaweed *Asparagopsis taxiformis* erodes the habitat structure and biodiversity of native algal forests in the Mediterranean Sea, Mar. Environ. Res. 173 (2022) 105515.
[29] H. Li, Y. Geng, H. Shi, C. Wu, Z. Yu, H. Zhang, L. Chen, R. Xing, Biological mechanisms of invasive algae and meta-analysis ofecological impacts on local communities of marine organisms, Ecol. Indic. 146 (2023) 109763.
[30] F. Costa, R. Ruggeri, F. Salviati, F. Simionato, R. Zonta, Misure correntometriche in canal grande, Comune di Venezia Consiglio Naz. delle Ric. Venezia (1991) 53.
[31] Consiglio Nazionale delle Ricerche, Acquisizione dei valori delle variabili chimico-fisiche in un sistema campione di rii del Centro Storico di Venezia (Febbraio–Dicembre 1997), Venezia (1998) 145.
[32] A. Zuliani, L. Zaggia, F. Collavini, R. Zonta, Freshwater discharge from the drainage basin to the Venice Lagoon (Italy), Environ. Int. 31 (7) (2005) 929–938.
[33] E. Miozzi, Venice in the centuries: the Lagoon (in Italian), Libeccio Venezia (1980) 545.
[34] Open street map, ⟨https://www.openstreetmap.org/#map=10/45.3647/12.1756⟩).
[35] Guiry, M.D. & Guiry, G.M. 03 September 2024. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. ⟨https://www.algaebase.org⟩.
[36] D.M. Zocchi, N. Sulaiman, J. Prakofjewa, R. Sõukand, A. Pieroni, Local wild food plants and food products in a multi-cultural region: an exploratory study among diverse ethnic groups in Bessarabia, Southern Moldova, Sustainability 16 (5) (2024) 1968, https://doi.org/10.3390/su16051968.
[37] M. Alrhmoun, N. Sulaiman, S.M. Haq, S. Abidullah, J. Prakofjewa, N. Krigas, A. Pieroni, R. Sõukand, Is boiling bitter greens a legacy of ancient Crete? Contemporary foraging in the Minoan refugium of the Lasithi Plateau, Foods 13 (22) (2024) 3588, https://doi.org/10.3390/foods13223588.
[38] H.R. Bernard, G.W. Ryan, Analyzing qualitative data: systematic approaches, Sage, Thousand Oaks, CA, 2016.
[39] P.Y. Sorokin, Y.I. Sorokin, R. Boscolo, O. Giovanardi, Bloom of picocyanobacteria in the Venice Lagoon during summer–autumn 2001: ecological sequences, Hydrobiologia 523 (1) (2004) 71–85.
[40] L. Thouvenot, G. Thiébaut, Regeneration and colonization abilities of the invasive species elodea canadensis and elodea nuttallii under a salt gradient: implications for freshwater invasibility, Hydrobiologia 817 (2018) 193–203.
[41] A. Sfriso, A. Marcomini, Decline of ulva growth in the Lagoon of Venice, Bioresour. Technol. 58 (3) (1996) 299–307.
[42] A.A. Orio, R. Donazzolo, Toxic and eutrophicating substances in the lagoon and the gulf of Venice, Ist. Veneto di Sci. Lett. Ed. Arti 11 (1987) 149–215.
[43] A. Sfriso, B. Pavoni, A. Marcomini, A.A. Orio, Macroalgae, nutrient cycles, and pollutants in the Lagoon of Venice, Estuaries 15 (4) (1992) 517–528.
[44] M. Dalla Valle, A. Marcomini, A. Sfriso, A.J. Sweetman, K.C. Jones, Estimation of PCDD/F distribution and fluxes in the Venice Lagoon, Italy: combining measurement and modelling approaches, Chemosphere 51 (7) (2003) 603–616.
[45] C. Facca, N. Pellegrino, S. Ceoldo, M. Tibaldo, A. Sfriso, Trophic conditions in the waters of the Venice Lagoon (Northern Adriatic Sea, Italy), Open Oceanogr. J. 5 (1) (2011).
[46] Battiston, L., Giommoni, A., Pilan, L. and Vincenzi, S., 1983. Salinity exchange induced by tide in the Venice Lagoon. In Conference Proceedings on Five Centuries of Water Management in the Venice Territory, pp. 1-7.
[47] D. Curiel, A. Rismondo, G. Bellemo, M. Marzocchi, Macroalgal biomass and species variations in the lagoon of Venice (Northern Adriatic Sea, Italy): 1981-1998, Sci. Mar. 68 (1) (2004) 57–67.
[48] A. Sfriso, D. Curiel, Check-list of marine seaweeds recorded in the last 20 years in Venice Lagoon and a comparison with the previous records. Botanica marina 50 (2007) 22–58.
[49] A. Occhipinti-Ambrogi, Biotic invasions in a Mediterranean lagoon, Biol. Invasions 2 (2000) 165–176, https://doi.org/10.1023/A:1010004926405.
[50] M.A. Wolf, A. Sfriso, I. Moro, Thermal pollution and settlement of new tropical alien species: the case of *Grateloupia yinggehaiensis* (Rhodophyta) in the Venice Lagoon, Estuar. Coast. Shelf Sci. 147 (2014) 11–16.
[51] F.P. Mancuso, E.M.A. Strain, E. Piccioni, O. De Clerck, G. Sarà, L. Airoldi, Status of vulnerable Cystoseira populations along the Italian infralittoral fringe, and relationships with environmental and anthropogenic variables, Mar. Pollut. Bull. 129 (2) (2018) 762–771.
[52] L. Contreras-Porcia, A. Meynard, C. López-Cristoffanini, N. Latorre, M. Kumar, Marine metal pollution and effects on seaweed species, Syst. Biol. Mar. Ecosyst. (2017) 35–48.
[53] A. Sfriso, A. Buosi, K. Sciuto, M. Wolf, Y. Tomio, A.S. Juhmani, A.A. Sfriso, Effect of ecological recovery on macrophyte dominance and production in the Venice Lagoon, Front. Mar. Sci. 9 (2022) 882463.
[54] G.G. Leppard, The characterization of algal and microbial mucilages and their aggregates in aquatic ecosystems, Sci. Total Environ. 165 (1-3) (1995) 103–131.
[55] M. Mecozzi, R. Acquistucci, V. Di Noto, E. Pietrantonio, M. Amici, D. Cardarilli, Characterization of mucilage aggregates in Adriatic and Tyrrhenian sea: structure similarities between mucilage samples and the insoluble fractions of marine humic substance, Chemosphere 44 (4) (2001) 709–720.
[56] www.lifeseresto.eu. Life12 NAT/IT/000331 -SERESTO- Habitat 1150* (Coastal lagoon) recovery by SEagrass RESTOration. A new strategic approach to meet HD & WFD objectives.
[57] www.lagoonrefresh.eu. Life 16 NAT/IT/000663 -LAGOON REFRESH- Coastal Lagoon habitat (1150*) and species recovery by REstoring the salt gradient increasing FRESH water input.
[58] C. Facca, D. Bilaničovà, G. Pojana, A. Sfriso, A. Marcomini, Harmful algae records in Venice Lagoon and in po river delta (Northern Adriatic Sea, Italy), Sci. World J. 2014 (2014) 1–11.
[59] A. Sfriso, A. Marcomini, B. Pavoni, Relationships between macroalgal biomass and nutrient concentrations in a hypertrophic area of the Venice Lagoon, Mar. Environ. Res. 22 (4) (1987) 297–312.
[60] E. Runca, A. Bernstein, L. Postma, G. Di Silvio, Control of macroalgae blooms in the Lagoon of Venice, Ocean Coast. Manag. 30 (2–3) (1996) 235–257.
[61] S. Wikström, L. Kautsky, Invasion of a habitat-forming seaweed: effects on associated biota, BiolInvasions 6 (2004) 141–150.
[62] I. Gestoso, C. Olabarria, J.S. Troncoso, Effects of macroalgal identity on epifaunal assemblages: native species versus the invasive species *Sargassum muticum*, Helgol. Mar. Res 66 (2011) 1–8.
[63] C. Buschbaum, A.S. Chapman, B. Saier, How an introduced seaweed can affect epibiota diversity in different coastal systems, Mar. Biol. 148 (4) (2006) 743–754.
[64] R. Novak, A study in Ultra-Ecology: microorganisms on the seagrass *Posidonia oceanica* (L.) Delile, Mar. Ecol. [Internet]. 1984 Jun. 1 5 (2) (1984) 143–190. Available from: ⟨http://resolver.scholarsportal.info/resolve/01739565/v05i0002/143_asiumotspod.xml⟩.
[65] A. Sfriso, C. Facca, Distribution and production of macrophytes and phytoplankton in the Lagoon of Venice: comparison of actual and past situation. Lagoons and Coastal Wetlands in the Global Change Context: Impacts and Management Issues: Selected papers of the International Conference "CoastWetChange", Venice, 26–28 April 2004, Springer Netherlands, 2007, pp. 71–85.
[66] L. Scapin, M. Zucchetta, A. Sfriso, P. Franzoi, Local habitat and seascape structure influence seagrass fish assemblages in the Venice Lagoon: the importance of conservation at multiple spatial scales, Estuaries Coasts 41 (2018) 2410–2425, https://doi.org/10.1007/s12237-018-0434-3.
[67] A. Sfriso, C. Facca, A. Marcomini, Sedimentation rates and erosion processes in the lagoon of Venice, Environ. Int. 31 (7) (2005) 983–992.
[68] A. Sfriso, M.A. Wolf, S. Maistro, K. Sciuto, I. Moro, Spreading and autoecology of the invasive species *Gracilaria vermiculophylla* (Gracilariales, Rhodophyta) in the lagoons of the north-Western Adriatic sea (Mediterranean Sea, Italy), Estuar. Coast. Shelf Sci. 114 (2012) 192–198.
[69] H. Zi-Min, J. Lopez-Bautista, Adaptation mechanisms and ecological consequences of seaweed invasions: a review case of agarophyte *Gracilaria vermiculophylla*, Biol. Invasions 16 (2014) 967–976.
[70] E. Jones, C.S. Thornber, Effects of habitat-modifying invasive macroalgae on epiphytic algal communities, Mar. Ecol. Prog. Ser. 400 (2010) 87–100.
[71] M. Vázquez-Luis, P. Sanchez-Jerez, J.T. Bayle-Sempere, Changes in amphipod (Crustacea) assemblages associated with shallow-water algal habitats invaded by *Caulerpa racemosa* var. *cylindracea* in the Western Mediterranean Sea, Mar. Environ. Res. 65 (5) (2008) 416–426.
[72] M. Lutz, A.R. Davis, T.E. Minchinton, Non-indigenous macroalga hosts different epiphytic assemblages to conspecific natives in southeast Australia, Mar. Biol. Int. J. Life Oceans Coast. Waters 157 (5) (2010) 1095–1103.
[73] C.D. Nyberg, M.S. Thomsen, I. Wallentinus, Flora and fauna associated with the introduced red alga *Gracilaria vermiculophylla*, Eur. J. Phycol. 44 (3) (2009) 395–403.
[74] J.R. Tweedley, E.L. Jackson, M.J. Attrill, Zostera marina seagrass beds enhance the attachment of the invasive alga sargassum muticum in soft sediments, Mar. Ecol. Prog. Ser. 354 (2008) 305–309.
[75] J.F. Valentine, K.L. Heck, A.M. Cinkovich, Impacts of seagrass food webs on marine ecosystems: a need for a broader perspective, Bull. Mar. Sci. 71 (3) (2002) 1361–1368.

[76] P.A. Nunes, S. Silvestri, M. Pellizzato, V. Boatto, Regulation of the fishing activities in the Lagoon of Venice, Italy: results from a socio-economic study, Estuar. Coast. Shelf Sci. 80 (1) (2008) 173–180.

[77] F. Pranovi, A. Caccin, P. Franzoi, S. Malavasi, M. Zucchetta, P. Torricelli, Vulnerability of artisanal fisheries to climate change in the Venice Lagoon, J. Fish. Biol. 83 (4) (2013) 847–864.

[78] R. Sõukand, Dark local knowledge: the yet-to-be scientifically discovered and locally acknowledged aspects of local knowledge systems, J. Ethnobiol. Ethnomed. 20 (2024) 50.

[79] M. Mac Monagail, L. Cornish, L. Morrison, R. Araújo, A.T. Critchley, Sustainable harvesting of wild seaweed resources, Eur. J. Phycol. 52 (4) (2017) 371–390.

[80] I. Gestoso, C. Olabarria, J.S. Troncoso, Variability of epifaunal assemblages associated with native and invasive macroalgae, Mar. Freshw. Res. 61 (6) (2010) 724–731.

[81] J.C. Ferreira, L. Vasconcelos, R. Monteiro, F.Z. Silva, C.M. Duarte, F. Ferreira, Ocean literacy to promote sustainable development goals and agenda 2030 in coastal communities, Educ. Sci. 11 (2) (2021) 62.

[82] M. Mokos, E. De-Bastos, G. Realdon, D. Wojcieszek, M. Papathanasiou, P. Tuddenham, Navigating ocean literacy in Europe: 10 years of history and future perspectives, Mediterr. Mar. Sci. 23 (2) (2022) 277–288.

[83] R. Kelly, K. Evans, K. Alexander, S. Bettiol, S. Corney, C. Cullen-Knox, C. Cvitanovic, K. de Salas, G.R. Emad, L. Fullbrook, C. Garcia, Connecting to the oceans: supporting ocean literacy and public engagement, Rev. Fish. Biol. Fish. (2022) 1–21.

[84] EC Regulation (E.U.) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species J. Eur. Union, 57, pp. 35-55. ⟨http://eurlex.europa.eu/legalcontent/EN/TXT/?qid=1417443504720&uri=CELEX:32014R114⟩.

[85] B.S. Galil, A. Marchini, A. Occhipinti-Ambrogi, East is east and west is west? Management of marine bioinvasions in the Mediterranean Sea, Estuar. Coast. Shelf Sci. 201 (2018) 7–16.

[86] A. Petrocelli, E. Cecere, M. Verlaque, Alien marine macrophytes in transitional water systems: new entries and reappearances in a Mediterranean coastal basin, BioInvasions Rec. 2 (3) (2013).