Review

Adriatic Sea Fishery Product Safety, Prospective and Climate Change

Edmond Hala and Rigers Bakiu *

Posted Date: 25 March 2024

doi: 10.20944/preprints202403.1412.v1

Keywords: fishery product safety; climate change; fishery management; Adriatic Sea; Mediterranean Sea

Review

Adriatic Sea Fishery Product Safety, Prospective and Climate Change

Edmond Hala [1] and Rigers Bakiu [1,2,*]

[1] Department of Aquaculture and Fisheries, Faculty of Agriculture and Environment, Agricultural University of Tirana, Tirane 1000, Albania
[2] Albanian Center for Environmental Protection and Sustainable Development, Tirane 1000, Albania
* Correspondence: rigers.bakiu@ubt.edu.al

Abstract: This bibliographic study addresses key aspects related to fishing, product safety, and climate change in the Adriatic Sea region. The examination of product safety focuses on the assessment of contaminants originating from human activities such as industry, mining, agriculture, and household waste disposal. The contamination of the aquatic environment has emerged as a pressing global concern, extending to the Adriatic subbasin. Aquatic organisms, including fish, are prone to accumulating pollutants directly from polluted water sources and indirectly through the food web. The bio-accumulation of potentially hazardous substances, particularly heavy metals, pesticides, PCBs, PAHs, and antibiotic resistance in aquatic organisms, poses a significant threat to human health. Climate change effects will deplete our seafood supply in terms of quantity and safety owing to negative consequences such as higher levels of pollution, parasites, viruses, infections, acidification, and toxicities such as shellfish poisoning. Global food safety strategies should be developed to reduce greenhouse gas emissions and promote environmentally friendly technology, which indirectly affects seafood quality and microbiological safety, especially for Adriatic Sea, which is part of the Mediterranean Sea, characterized by the most polluted waters in the world.

Keywords: fishery product safety; climate change; fishery management; Adriatic Sea; Mediterranean Sea

---

1. Fishery Production and Management

1.1. Adriatic Sea Specificities

The Adriatic Sea is considered a hydrologically independent subsystem of the Mediterranean Sea [1]. The northernmost region of the Mediterranean Sea (excluding the Black Sea), it is generally divided into three subareas: North Adriatic, Central Adriatic, and South Adriatic (Figure 1). It is also different on the east and west coasts; the former is high, rocky, and inset with many islands, while the west coast is flat and alluvial, with raised terraces in certain areas [2]. Because of its many islands, the east coast is characterized by a rich coastal habitat. The depth decreases from south to north and in the northern Adriatic the depth never exceeds 100 meters. The greatest depth in the Central Adriatic region is 273 m in the Jabuka/Pomo Pit, while the South Adriatic has its deepest point in the Adriatic Sea (South Adriatic Pit) with a depth of 1,233 m. The average depth of the Adriatic is about 252 m [1].

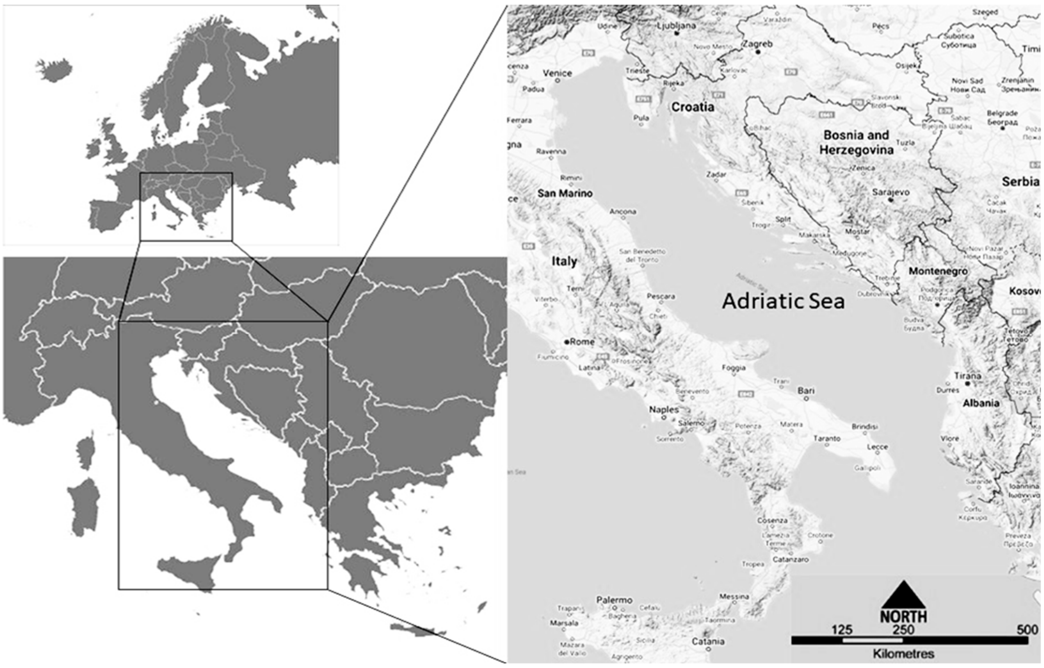

Figure 1. Location of the Adriatic sea in the European map.

Its thermohaline properties are primarily determined by sea-air interactions, river discharge, mixing, flow, water exchange through the Otranto Strait, and the general topography of the basin [1]. Surface water temperatures are around 18 °C in the south, but can reach up to 25 °C in the northern Adriatic Sea. Extreme surface temperatures range from 6°C to 29°C. Even in the deepest layers, average temperatures typically exceed 10°C. In winter, the southern Adriatic Sea is 8-10 °C warmer than the central and northern regions. In other seasons, the horizontal temperature profile is more uniform. Generally, open seas are warmer than coastal waters [3].

Salinity content is relatively high and varies considerably. The highest salinity is found in the southern Adriatic region (38.4–38.9), especially in the middle layer. Generally, salinity decreases from south to north and from the open ocean to the coast. The northern and western parts of the Adriatic Sea are more affected by river flooding (mainly the Po River), which affects the water cycle due to upwelling and the ecosystem dynamics due to the input of large amounts of nutrients [4].

The currents in the Adriatic Sea are highly complex and multilayered (surface, intermediate, and bottom layers) and are influenced by the overall circulation system of the Mediterranean Sea. Essentially, the surface circulation of the Adriatic Sea can be described as a large-scale meandering with northerly flow along the east coast and southerly flow (return) along the west coast [5]. However, specific geomorphology and significant seasonal variations elevate complexity of the Adriatic hydro-biological system making it rather difficult but interesting to study, as stated by Dragičević et al., [1].

One of the most important hydrological features that connects the Adriatic Sea with the rest of the Mediterranean through the Ionian Sea is the Bimodal Oscillating System (BiOS) mechanism. This mechanism changes the circulation of the North Ionian Gyre (NIG) from cyclonic to anticyclonic and *vice versa*, on decadal time scales [6]. In addition, this mechanism allows the influx of water from the Ionian Sea and/or the central Mediterranean Sea into the Adriatic Sea in response to low or high-pressure systems. Furthermore, this mechanism also affects the biodiversity of the Adriatic Sea, beside its influence on hydrology. Increased abundance or first appearance of some organisms in the Adriatic Sea has been shown to indicate a BiOS regime (influx of water from the Western Mediterranean/Atlantic or Eastern Mediterranean) [7].

Since 1953, Buljan [8] has indicated that some features influenced by BiOS mechanism have been attributed to a phenomenon of "Adriatic Ingressions", a theory which got updated with the description of BiOS [1]. Furthermore, the presence of various thermophilic species has been

 doi:10.20944/preprints202403.1412.v1

previously attributed to the phenomenon of "Adriatic Ingressions" [9]. In any case, the influx of warmer, more nutritious and saline Ionian waters not only contributes to the presence of several rare and exotic species in the Adriatic basin, but also to the overall biodiversity of the Adriatic Sea is also having a significant impact. The current flora and fauna of the Adriatic Sea is the result of numerous geological, geographical, climatic and biological processes that occur during its formation [1].

1.2. Fishery Production

The countries facing to the Adriatic Sea are represented by Italy in the Western part of the sea and Slovenia, Croatia, Bosnia and Herzegovina, Montenegro and Albania in the Eastern part, from the North to the South. Due to the limited production and coast of Bosnia and Herzegovina, we are not going to consider this country in this review. In the Adriatic Sea, most of the fishing fleet is represented by the small-scale fishing vessel (77.9%), while the large-scale fishing vessels are represented by trawlers and beam-trawlers (12.9%) and purse seiners and pelagic trawlers (2.8%) [10].

In terms of production, the "Purse seiners and pelagic trawlers" group is the fleet segment responsible for 58.8 percent of landings in the Adriatic Sea, while trawlers and and beam-trawlers account for 19.7 percent of landings and the small-scale fishing vessels provide a minimal contribution in landings (7.4%) [10]. Croatia and Italy represent the countries with the major contribution in average annual landings of 65 465 tones (45%) and 73 924 tones (50.9%), respectively [10]. Albania is positioned at the third place for the time period of 2020-2021, with 5 235 tones (3.6%) and the other remaining countries all together account for 7 735 tones (0.5%) [10].

European anchovy (*Engraulis encrasicolus*) (24 341 tones) and sardine (*Sardina pilchardus*) (57 890 tones) are the two predominant species in the Adriatic Sea contributing 20.1 percent and and 47.4 percent of total landings, respectively. The other most fished species are represented by spottail mantis squillid (*Squilla mantis*) (2 624 tones) and European hake (*Merluccius merluccius*) (3 550 tones) [10]. The European hake is one of those species, which landings in all the Mediterranea basin have decreased in recent years, because its landings decreased from 52 394 tones in 1994 to 17 824 tonnes in 2021 [10]. Some stocks under management plans show a larger than average reduction in fishing pressure, with notable examples including a 77 percent reduction since 2011 for common sole in the Adriatic Sea [10].

Regarding aquaculture production, Italy is one of the largest producers not only in the Adriatic basin, but all in all over Mediterranean basin and it represents the fourth largest producer, after Greece [10]. Anyway, Italy is grouped with other countries of Adriatic basin, like Montenegro and Slovenia, which showed a decrease of production from 2018 to 2021 [10]. In addition, the highest growth rates between 2018–2019 and 2020–2021 was recorded in Albania, with respective increases in production of 59.3 percent (+2 652 tones), though even Croatia represent one of those countries with a good growth rate of 22.4 percent (+3 826 tones) [10]. Similarly, to all over the Mediterranean basin, in the Adriatic basin the main species reared are represented by gilthead seabream (*Sparus aurata*), European seabass (*Dicentrarchus labrax*), Mediterranean mussel (*Mytilus galloprovincialis*), meagre (*Argyrosomus regius*), Atlantic Bluefin tuna (*Thunnus thynnus*), mullets (Mugilidae) and rainbow trout (*Oncorhynchus mykiss*) [10].

1.3. Fishery Management

This section aims to provide an overview of the main regulations that have affected and currently affect the Adriatic small pelagic and demersal fisheries [11], though there are available several multilateral environmental agreements, which indirectly impact fisheries in almost all the countries of the Adriatic basin.

Initially as part of the European Economic Community (ECC) and subsequently the European Community (afterwards absorbed into the European Union), Italy and Slovenia need to follow EU regulations: Member States can take measures for the conservation of the stocks in waters under their sovereignty, as long as these are not less restrictive than the EU regulations in place [11].

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

In 2001, Croatia signed the Stability and Association Agreement with the EU, a formal commitment to integrate the EU *Aquis* binding countries to the adoption of the Common Fisheries Policy (CFP). This agreement did not prevent Croatia from carrying out a significant fleet renewal since 2004 with the construction of new fishing vessels and a net increase in fleet capacity [11]. Furthermore, the Croatian government sought to establish an Ecological Fisheries Protection Zone (EFPZ), which would somehow contradict the CFP agreement and could lead to the exclusion of EU fishing within the Croatian zone. The EFPZ was approved after several years of discussion and negotiation and came into force in 2008 with special exemptions for EU vessels [11]. Although there have been improvements in recent years, especially after Croatia's accession to the EU, Croatia remains heavily influenced by domestic politics and circumstances [12]

Italy's national regulatory framework, in conjunction with EU regulations, has historically helped to manage various aspects of fishing, including the number of issued licenses, gear characteristics, technical features of the fishing vessels, spatial and temporal restrictions. A similar approach has been taken in Croatia, where the main legislative instruments were drafted in 2000 and 2006, and have been developed in terms of fishing gear, time and space limitations, and species protection, through fishing effort and catch capacity, which in conclusion, regulates fishing areas [13]. In line with these legislations, following the directives included in the reformed CFP, as well as the pressure from the scientific community and the worries of the fishers themselves, recent measures have been enforced for both small pelagic and demersal fisheries [11].

A series of measures stemming from GFCM recommendations have been adopted: a reduction of the number of fishing days for both anchovy (*E. encrasicolus*) and sardine (*S. pilchardus*) to a maximum of 144 days; the closure, in Italy, of the 6 mile strip along the entire coast for 6 months from 1st July to 31 December and a closure in Croatia of the inner seas for 6 months in 2016 and again in 2017, from 1 April to 30 September; extra temporal closures between 1 October and 31 March for sardine and between 1 April and 30 September for anchovy; as well as the imposition of catch and fishing capacity limits for both species [11].

Further, an area of the Pomo/Jabuka Pit, which is an important nursery area for European hake (*M. merluccius*) and hosts a resident population of Norway lobster (*Nephrops norvegicus*) —was closed to the trawl fishery for 15 months in 2015/2016 [11]. Since October 2016 it is open to a limited number of authorized bottom trawlers and closed to bottom longliners. This measure, which mainly affected Italian vessels, was associated with the development of a specific monitoring program that started in 2015 and it is carried out every year [14].

The main players of the management of marine stock in the Mediterranean Sea can be divided in four big entities: (i) the Food and Agriculture Organization (FAO) with its own Regional Fisheries Management organization (RFMO), the GFCM, as well as its Scientific Advisory Committee on Fisheries (SAC) and regional projects, (ii) the European Commission (EC) and its bodies (i.e., STECF and JRC), (iii) the national authorities and iv) fisheries associations coordinated by the MEDiterranean Advisory Council (MEDAC) [11].

Established in 1949, GFCM is the official RFMO for the Mediterranean and Black Sea and is part of FAO. The main objective of the GFCM was to promote the development, conservation and rational management of marine fisheries resources in the Mediterranean and Black Seas and to provide a common basis for discussions between European and non-European countries. Furthermore, GFCM became a Commission in 1997 and has since played an important role in the region's fisheries policy, with the power to adopt binding recommendations on the protection and management of fisheries within its scope, while GFCM recommendations become binding on individual Member States after notification [11]. The GFCM receives scientific input from the SAC and its mission is to provide independent advice on the technical and scientific basis of decisions regarding fisheries conservation and management. The Directorate-General for Maritime Affairs and Fisheries (known as DG-MARE) is the right arm of the European Commission when it comes to the implementation of the CFP and the Integrated Maritime Policy. DG-MARE receives scientific inputs to implement the common fisheries policy from International Council for the Exploration of the Sea (ICES), whose competence area is Northern Europe, and the Scientific, Technical and Economic Committee for Fisheries

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

(STECF), an EC body that is meant to be the EC scientific forum and operate in all the areas under EU control, including the Mediterranean [11].

The national authorities (such as ministries and port authorities) have the main role of implementing the regulations established by the GFCM and the EU. In Italy, Croatia, Albania, Slovenia and Montenegro, the fisheries directorates under the Ministry of Agriculture are responsible for carrying out this task. These are the competent authorities for Monitoring, Control, and Surveillance (MCS). The governments regularly convene the sector to inform them of the resolutions and changes that affect or may affect the fishery.

The fisheries sector participates in the MEDAC [11]. MEDAC is comprised of European and national organizations representing the entire fishing sector and other stakeholders (e.g. environmental organizations, consumer organizations, sport/recreational fishing associations) operating under the CFP in the Mediterranean region. MEDAC's mandate includes providing advice on fisheries management and socio-economic aspects to support the Mediterranean fisheries sector. Generally, such opinions will be submitted to Member States and European institutions in order to facilitate the achievement of the objectives of the CFP [11].

1.4. Historical, Social and Political Context

To understand the context and issues related to the fishery management and product safety of such a complex environment, it is important to set the fisheries in their historical, social and political context. Firstly, analogous to what is now happening in several of the coastal Mediterranean countries (e.g., North Africa and Turkey), the recent past political situation in the Balkan areas has been harsh, with the management of the fishery being irrelevant compared to other problems [11].

Furthermore, like other parts of the Mediterranean, Croatia's accession to the European Community is recent. Previous relations between these two main actors in the Adriatic, Croatia and Italy, were therefore plagued by a lack of easy agreement to make this policy possible, according to Carpi et al. [11]. This situation is further exacerbated by the fact that fishers still play an important role in political decisions. Furthermore, the Italian situation is characterized by a history of indiscriminate license allocation, a weak data collection system until the early 2000s, and a general lack of political interest in the issue (often reflected in a lack of control and conflict). Generally, it is even more complicated due to the conflicts between fishers (northern *vs*. southern, Italian *vs*. Croatian and even between categories). This situation undermined the possibility of a joint agreement or full cooperation [11].

In the Adriatic Sea, the two main countries contributing to total catches are Italy, targeting mainly anchovy, and Croatia, targeting mainly sardine. Both species are fished all year round by pelagic trawlers and purse seiners covering great part of the basin, but mostly concentrated in the Northern part [11]. The Croatian fishing industry went through a phase of forced closure in the 1990s due to the wars in the former Yugoslavia. After the end of the war, the fleet was updated with the introduction of large purse seiners, which now form a major part of the fleet in the fishing industry. Regarding, the other biggest fishery producer in Adriatic basin, Italy, its share of anchovies and sardines accounts for 30% of the total national catch [11]. In Croatia, small pelagic fish account for approximately 80% of the total national catch [15].

Anchovy landings have fluctuated cyclically over the years, reaching very high levels in the late 1970s and early 1980s, partly due to the availability of European Community subsidies, and again in the late 2000s. Generally, the number of landings has increased, while both peaks were followed by more or less significant declines [11]. Meanwhile, the amount of sardines landed has plummeted from around 90,000 tons in the early 1980s, reaching a historic low of 1,900 tons in 2005. Landings subsequently increased again, with a sharp increase in 2007. This is mainly due to a significant increase in Croatian fishing, with landings reaching 82,000 tons in 2014, the second highest value in the entire series [11,16] associated the increase and successive decline of sardine before 2000 to changes in the advection of Levantine Intermediate Waters (LIW) due to climatic fluctuations [11].

During and after both events, little or no action was taken by the competent authorities to regulate effort to allow the stock to recover, or to minimize potential losses in fishing opportunities

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

in hypothetic future situations of impaired recruitment. The consequences of this apathy are now evident: the Italian sector, whose fishery has always focused on anchovy, is now suffering, with a decrease in the number of vessels and a general feeling of dismay [11]. The Croatian fleet, targeting mainly sardine for tuna farms, is still stable [11]. However, the use of low-value (in marketing terms) whole feed-fish species for the growing and fattening of tuna in Croatian waters with locally caught sardines, is a practice that is unlikely to be sustainable in the long term, with a food conversion ratio that, at best, is equal to 12.5:1 [17,18].

Due to the amount of data available, to the high value of the fisheries and the high political interest for the shared nature of these resources, the EU has, lately, focused a lot of attention and invested plenty of resources on these stocks. According to Carpi et al. [11] this has surely had some positive effects; however, this effort has not always been properly channeled, and would have been more effective with the constant involvement of the right parties and a continuous collaboration with the bodies involved.

2. Fishery Product Consumption and Potential Hazards

2.1. General Considerations

Fish are renowned for being an exceptionally abundant reservoir of essential nutrients that greatly contribute to the overall well-being of the human body (Figure 2).

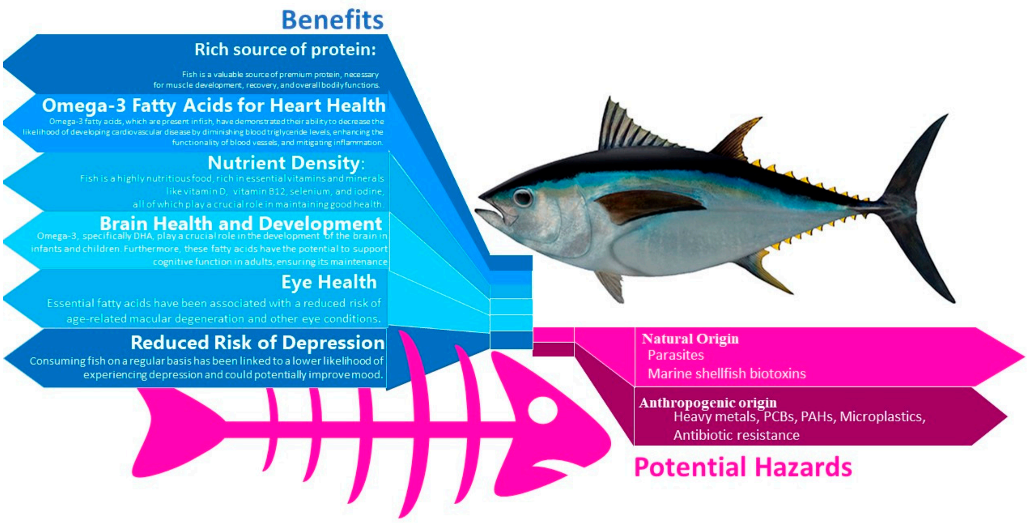

Figure 2. Benefits and potential hazards due to seafood consumption.

Omega-3 fatty acids found in fish have been shown to reduce the risk of cardiovascular disease by lowering blood triglycerides, improving blood vessel function, and reducing inflammation [19]. Also, are essential for brain development in infants and children and may help maintain cognitive function in adults [20]. Also, omega-3 fatty acids in fish are beneficial for eye health and may help reduce the risk of age-related macular degeneration and other eye conditions [21]. Fish provides high-quality protein, essential for muscle growth, repair, and overall body function [22]. Fish is a nutrient-dense food, containing vitamins and minerals such as vitamin D, vitamin B12, selenium, and iodine, which are important for overall health [23,24]. Regular consumption of fish has been associated with a reduced risk of depression and may have mood-enhancing effects [25].

Due to the growing levels of contaminants associated with human activity such as industry, mining, agriculture, and household waste production, pollution of the aquatic environment has become a serious problem worldwide [26] (Figure 2). Aquatic organisms, including fish, accumulate pollutants directly from contaminated water and indirectly *via* the food chain, while bio-concentration of potentially harmful substances, mainly represented by heavy metals, pesticides,

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in aquatic organisms present a major threat to human health. Since fish occupy the top of the aquatic food chain, they are widely used as a bio-indicator to evaluate the health of aquatic ecosystem [27].

2.2. Heavy Metal Pollution in the Adriatic Sea

Heavy metals have been used by humans for many different types of activities for thousands of years. Although most of their toxic effects are now known, exposure to these elements continues, especially in developing countries. The Mediterranean Basin is a semi-occlusive ocean, and is characterized by low water circulation. It is being all these factors add both anthropogenic and natural metals to the basin, making the Mediterranean Sea one of the most polluted waters in the world [28]. Furthermore, the Mediterranean basin is considered to be a hotspot for contamination of sediments, water, and biota by several elements [28,29]. In the forthcoming decade, it is imperative to examine whether the Adriatic Sea, as an integral component of the Mediterranean basin, will witness any changes in the state of pollution in its waters caused by heavy metals, PCBs, and PAHs. This review will solely concentrate on the presence of these elements in biota, disregarding their presence in sediment or water. This approach is directly relevant to the assessment of human consumption of these products.

At the first sight, the Adriatic Sea, is inevitably impacted by pollution in its marine and coastal ecosystems due to human activities, including resource exploitation, agricultural practices leading to land runoff, urban development along the coast, and various maritime transport activities such as harbor operations and ballast water management. Heavy metal pollution in the Adriatic region can be traced back to sources like oil refinery plants [30], metallurgic industries like the Taranto industrial plants [31], land mining activities, such as the mercury mine in Idrija, Slovenia [32], municipal-sewage outflows [33], oil and gas extraction plants [34]. This pollution is of particular concern due to the high concentration of heavy metals in biota, which are a significant food source for humans.

Contamination of bivalve shellfish, such as mussels, clams, and oysters, through filtration is a significant fact due to their filter-feeding behavior, which makes them vulnerable to accumulating various contaminants present in the water.

The examination of heavy metals led to the discovery that the contamination level of bivalve molluscs across the Adriatic Sea's coastlines remained below the European Union's established standards. Nevertheless, it is important to acknowledge that for some exeptions Cr, Pb, Cd, and total Hg that slightly exceeded the permissible limits [35,36]. The evaluation of the risk linked to the utilization of molluscs, for human health indicated that there is no apparent risk for individuals who consume these mussels moderately. From these studies results that, it is crucial to regularly and carefully monitor the concentrations of heavy metals in order to ensure the safety of consumers' health [35]. However, it is important to note that there may still be a potential risk for vulnerable groups, such as women of childbearing potential and children, as well as for individuals who regularly consume shellfish or consume them at high levels. This potential risk is particularly relevant for those who frequently consume species like murex [36]. Additionally, wild shellfish samples exhibited higher concentrations of Cd, Hg, and Pb, while mussels from cultivated areas showed higher levels of As [37]. According to Tanaskovski et al, the risk assessment of these elements through mussel consumption indicated that weekly intake of 250 g of mussels over a human lifetime is unlikely to have adverse health effects, considering the element concentrations in M. galloprovincialis from the Bay, except for Zr concentration. According to medical literature, high levels of Zr were detected in farmed mussels harvested from the Bay suggest that consuming more than 140 g per week could pose health risks over a human lifetime [38].

The levels of Pb, Cd, and total Hg in Two species of squids, Loligo vulgaris and Todarodes sagittatus, from the northern Adriatic Sea in Italy were analyzed [39]. The results indicated that flying squids displayed Hg concentrations that were three times greater and Cd concentrations that were one hundred times greater than those observed in European squids. This disparity was significant to the extent that more than 6% and 25% of the samples exceeded the maximum limits for Hg and Cd, respectively, as established by the current legislation [39].

 doi:10.20944/preprints202403.1412.v1

The contamination with hevy metals is present also in many fish species in the Adriatic subbasin. Thus, in a separate investigation on the two most cultivated fish species in the Adriatic, *Dicentrarchus labrax* and *Sparus aurata*, to analyze the majority of metal concentrations in commercial fish did not pose any issues for human consumption [40].

Again in a separate study from the Albanian Adriatic coast was assessed the bioaccumulation levels of various heavy metals in fish sourced from the Ishmi river discharge into the Adriatic Sea, Albania. Heavy metal concentrations (Hg, Pb, Cd) were analyzed in the muscle tissues of approximately thirty different fish species. The heavy metal concentrations detected in the fish muscles in this study complied with the international regulatory limits, indicating that they are safe for human consumption [41].

From an Italian study conducted by Di Lena and colleagues in 2017 emphasize the presence of total mercury levels among many fish species both marine and freshwater species from intensive and extensive aquaculture systems, including crustaceans captured along the Central Adriatic and Tyrrhenian coasts of Italy. The specimens of large-size, pelagic and demersal species occupying high trophic levels species were found to exceed the limits set by the European Commission. These authors suggest the importance to diversify seafood consumption and making informed choices, including crustaceans, by opting for less mercury-accumulating species [42].

In the South Adriatic Sea near Montenegro involved the examination of metals (Pb, Cd, Cu, Fe, Mn, Ni, Cr, Zn) and radionuclides (137Cs, 40K, 214Bi, 228Ac). Six fish species were used to analyse the levels of metals three mullet species along with *Merluccius merluccius, Dicentrarchus labrax,* and *Sparus aurata*. None of the muscles exceeded the limits set by EU regulations for toxic trace elements Pb and Cd [43].

In Croatia was conducted a study in white and blue sea fish, and to determine if the recorded levels of heavy metals analyzed could pose a threat to consumer health. The analysis revealed that the levels of heavy metals, such as lead (Pb) and cadmium (Cd), in both groups were below the legal limits set by the European Union. For few samples Hg levels exceeded the permissible threshold and also it was noted that arsenic (As) was present in almost all samples. Considering the dietary patterns and frequent consumption of fish in Croatia, it can be concluded that there is no significant risk of adverse health effects [44].

From another study were investigated the concentrations of total Hg and mineral element Se in the muscle tissue of 12 commercially significant fish species obtained from 48 sites located in the eastern Adriatic Sea. The findings suggest that consuming two meals a week consisting of small pelagic-neritic and bento-pelagic fish. can serve as a valuable source of essential Se without posing a risk of toxic Hg exposure for children and women during their vulnerable reproductive period [45].

The levels of Hg, Cd, Pb, and As through the ingestion of *Umbrina cirrosa* and *Sciaena umbra* fish species were analised among the high-level fish consumers. In general, the detected levels generally falling below the maximum permissible limits for human consumption, except for Cd. Non-carcinogenic risks were generally not a cause for concern, except for Hg. From this study is strongly advised to conduct regular monitoring of metal(loid) levels in these fish due to the identified health risks, particularly among high-level fish consumers, stemming from the presence of Hg and Cd [46].

The levels of heavy metal Hg were analysed based on the analysis of sediments, water, and organisms in the Marano and Grado Lagoon in the northern Adriatic Sea, Italy. From this study the biota sediment accumulation factor (BSAF) values indicate a low bioavailability of Hg for transfer from sediment to biota. Furthermore, the Target Hazard Quotient (THQ) calculated suggests that there are no immediate concerns regarding adverse effects on human health, at least in the Marano basin [47].

2.3. Contamination of Biota with POPs, OCPs PCBs

Contamination of biota with Persistent Organic Pollutants (POPs), including Organochlorine Pesticides (OCPs) and Polychlorinated Biphenyls (PCBs), is a significant environmental concern due to their persistence, bioaccumulation, and potential adverse effects on ecosystems and human health. POPs are organic compounds that resist degradation, persist in the environment, bioaccumulate

 doi:10.20944/preprints202403.1412.v1

through the food web, and pose risks to human health and the environment. OCPs and PCBs are two major classes of POPs [48].

From one research conducted to a tuna farm located in the Croatian Adriatic were analysed the concentrations of PCBs and OCPs in different tissues of farmed Bluefin tuna (*Thunnus thynnus*). Based on the results can be concluded that the farmed tuna from the Adriatic Sea, exhibited moderate contamination with persistent organic pollutants (POPs), primarily PCBs. However, the levels detected were below the legal limits and do not pose a risk to humans who consume tuna meat in moderate amounts [49]. In another research six PCBs and twenty-three OCPs were discovered in anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) samples collected in the Herceg Novi Bay area of the Adriatic Sea. The levels of OCPs in all samples were found to be relatively low, indicating no immediate negative effects. However, it is important to note that potential adverse effects may become apparent as these pollutants accumulate in higher trophic levels. Among the PCBs detected, congeners 153, 138, 180, and 101 were the most prevalent, indicating a higher level of toxicity [50].

This study aimed to assess the concentrations of organochlorine pesticides (DDTs, HCHs, Heptachlors, Aldrins, and Endosulfanes), as well as their residues PCB and PAH, in water samples collected from the Albanian part of the Adriatic Sea. The degradation products of pesticides and volatile PCBs were found to be present at elevated levels in all analyzed samples. In certain cases, the concentrations of specific organochlorine pesticides exceeded the limits set by both the EU and Albanian regulations, particularly in the Semani and Shkumbini rivers that dischage in the Adriatic Sea [51]. Various organic pollutants, such as PCBs and PAHs, were identified on the surface of the collected microplastics, in a study conducted in the Central Adriatic Sea in Italy. The total concentration of PCBs was higher in microplastics from nearshore waters (64.72 ng/g plastic) compared to those from offshore waters (greater than 6 nautical miles) (10.37 ng/g plastic) [52].

In a study in European hake were ascertained the levels of six marker PCBs congeners and four trace elements in European hake specimens obtained from the Mediterranean Sea. The findings indicated that the levels of contaminants in all samples were below the recommended international limits. However, it is worth noting that samples from the Ligurian and Adriatic Sea exhibited higher concentrations of PCBs. The results revealed that the total health risk index (HRI) value was low (< 1) in cases of chronic consumption, despite the presence of notable mercury concentrations [53].

In this study, 16 elements, 24 POPs, and 14 fatty acid contents were analyzed in six pelagic species suitable for human consumption. The diet centered around chub mackerel and round sardinella exhibited a lower daily intake (DI) of POPs and a higher DI of essential omega-3 fatty acids compared to the other species studied. Consumption of anchovy and round sardinella resulted in lower exposure to toxic elements. The analysis of POP concentrations did not reveal any non-carcinogenic (HI) or carcinogenic (CR) risks for consumers [54].

2.4. Contamination of Biota with PAHs

Polycyclic Aromatic Hydrocarbons (PAHs), are a significant class of pollutants that contaminate aquatic environments. These compounds are known for their persistence and ability to cause harm to cells, induce mutations, birth defects, and even cancer in both humans and wildlife. The Northern Adriatic Sea, in particular, can be considered a PAH-sensitive marine area due to the heavy shipping traffic and the substantial inputs from Italian rivers that pass through the highly industrialized areas of Europe [55]. Fish in marine environments can be exposed to PAHs through various sources such as atmospheric pollution, industrial and domestic sewage, and oil spills. The primary sources of PAHs in the environment are anthropogenic, arising from the incomplete combustion of fossil fuels, wood, oil spills, and ship discharges. It is important to note that PAHs can exhibit different physicochemical properties and characteristic patterns, which can influence their toxicity, uptake, distribution, metabolism, and elimination in organisms [56].

Frapiccini et al. [57] conducted varies studies to evaluate the concentration of PAHs in different fish species. Thus, in a study was investigated the relationship between PAH concentrations and mRNA expression profiles of antioxidant genes (CAT, GST, and SOD), in the muscle of sexually

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

inactive female red mullet (*Mullus barbatus*) during different seasons. The downregulation of certain oxidative stress biomarkers during the winter season suggests that red mullets may be more susceptible to the effects of PAHs during this winter season [57]. In another styd the same authors analysed 16 PAHs, which have been designated as priority pollutants by both the EU and the United States Environmental Protection Agency (US EPA) due to their carcinogenic and mutagenic properties. The research delves into the levels and distribution of PAHs in various tissues of two fish species (*Solea solea* and *Mullus barbatus*) from a significant fishing area in the Northern and Central Adriatic Sea. This PhD thesis offers fresh insights into the primary biological, chemical, and environmental factors influencing PAH levels in fish tissues, including those that are edible. Additionally, it explores the correlation between PAH levels and the mRNA expression levels of certain antioxidant enzymes, along with lipid peroxidation, providing novel and valuable information on the biological responses of wild Adriatic fish exposed to PAH pollution [58]. Another studu of the same collaborators involved the examination of edible fillets from 380 specimens of *Mullus barbatus* to determine the levels of individual PAHs, total PAHs, as well as low, medium, and high molecular weight (MW) PAHs. The results indicate the presence of a significant detoxification mechanism, primarily affecting the heavier PAHs, during the spawning and post-spawning phases. Reproductive stage and seasonality were identified as key factors influencing the accumulation of heavier PAHs, while total lipid content and age had a limited impact, and body size showed no effect at all [59]. The last investigation of Frapiccini et al, represents the study conducted on *S. solea* in the Adriatic Sea, shedding light on the potential correlation between MPs and PAHs. Initial findings indicate that MPs do not serve as carriers for PAHs. Moreover, the primary source of PAH contamination in fish originates from the surrounding environment, specifically marine sediments where the sole species resides. These conclusions are substantiated by the strong association observed between PAH concentration in marine sediments and fish, the absence of a relationship between PAH fish concentration and MPs, and the varying PAH concentration across the three different fish tissues examined. Additional field studies have already been planned to further enhance our comprehension of the interplay between MPs and PAHs in marine ecosystems [60].

This study aimed to assess the concentrations of organochlorine pesticides (DDTs, HCHs, Heptachlors, Aldrins, and Endosulfanes), as well as their residues PCB and PAH, in water samples collected from the Albanian part of the Adriatic Sea. The highest levels of these pollutants were observed near the Shkumbini and Semani estuaries that discharge in the Adriatic. The degradation products of pesticides and volatile PCBs were found to be present at elevated levels in all analyzed samples. Given the significance of the Adriatic Sea in terms of fishing, tourism, recreation, and the overall economy of Albania, continuous monitoring of organic pollutants in its waters is crucial [51].

2.5. Antibiotic Resistance in Fish Farming

The use of antibiotics in fish farming is primarily aimed at preventing and treating bacterial infections that can spread rapidly in crowded fish populations. However, the overuse and misuse of antibiotics in this industry have contributed to the development and spread of antibiotic-resistant bacteria. These bacteria can then be transmitted to humans through the consumption of contaminated fish or through environmental contamination [61].

The emergence of antibiotic resistance bacteria (ARB) and the rise of multi-drug resistant bacteria (MDR) are direct consequences of the selective pressure imposed by antibiotics. These MDR bacteria have become increasingly challenging to control and eliminate. However, in the salmonid farming industry in Europe and America, the development of effective vaccines has proven beneficial. These vaccines have significantly reduced the need for antimicrobial agents in combating bacterial diseases [62]. Notably, antibiotic resistance has been frequently observed against Tetracyclines, Fluoroquinolones, Sulfonamides, Penicillins, and Macrolides [63,64]. The Vibrio species exhibit a broad geographical distribution and possess the capability to cause disease in aquatic organisms. In order to investigate this further, a comprehensive study was undertaken wherein gill and skin swabs were obtained from 110 European seabass that were being farmed. The objective was to determine the presence of Vibrio in these samples. The research team successfully

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

isolated *Vibrio* spp. from a range of environmental samples that were collected over a span of three years from a fish farm situated in the Adriatic Sea, specifically in Croatia. The analysis indicated that *V. alginolyticus* was the most prevalent species in European seabass, followed by *V. anguillarum*. Upon analysis, these two isolates were found to differ genetically and in terms of antibiotic resistance. The results of the study confirm the seasonal nature of vibriosis incidence and the presence of pathogenic *V. anguillarum*, which heightens the risk of vibriosis [65]. Also, the cultivable microbiota linked to plastic debris gathered by commercial fishing trawlers in the south-eastern Adriatic Sea was object of a study conducted by Kapetanovića et al [65]. The prevalence of Vibrio was notably higher on plastic debris compared to the adjacent seawater and sediment. All identified *Vibrio* strains exhibited resistance to ampicillin and vancomycin, with resistance to other antibiotics varying depending on the specific species [66].

Another research presents compelling evidence that the exclusive reliance on primary treatments in urban wastewater management leads to significant contamination of marine coastal waters with microbial pollutants. Conversely, conventional treatments fail to completely eradicate antibiotic resistance genes (ARGs) in treated wastewater. By incorporating molecular techniques, the assessment of depuration efficiency can be enhanced, paving the way for innovative approaches in urban wastewater treatment [67].

Also, the presence of antimicrobial resistance genes can be observed in the aquatic environment. In this particular investigation, a combination of phenotypical, biochemical, and molecular techniques were employed to examine a group of marine strains that were isolated from aquaculture farms in Italy. By comparing the phylogeny of enzymes and the clustering of strains based on sampling locations and dates, it was determined that certain clones of Multi Drug Resistant (MDR) *Shewanella* algae have spread along the Italian Adriatic coast [68].

Pavlinec et al recently conducted a study on *Vibrio harveyi*, a major cause of vibriosis in fish aquaculture. The objective of this study was to provide a comprehensive description of the biochemical, physiological, and genetic characteristics of three serologically distinct strains of V. harveyi that were isolated from farmed European Sea bass in the Adriatic Sea. The analysis revealed a significant number of nonsynonymous variations among the sequences of the three strains. Furthermore, six virulence genes, which were previously not associated with vibrio virulence, were detected in all three strains under investigation [69]. The Vibrio abondance was detactd using the AqADAPT dataset, which aids in the creation of management and adaptation tools through the provision of microbial parameters of seawater and biochemical analysis of culturable bacteria in two sites adjacent to floating cage fish farms in the Adriatic Sea. This dataset encompasses the assessment of various physicochemical parameters of seawater and serves as a valuable resource for monitoring water quality at varying depths surrounding aquaculture operations [70].

The digestive gland of Mytilus galloprovincialis has been identified as a key component in the detoxification of various emerging pollutants, including antibiotics, herbicides, and insecticides. Palladino et al. conducted a study that highlighted the ability of this sentinel species to naturally resist exposure to xenobiotics of both natural and anthropogenic origins. The findings suggest that the microbiome associated with the digestive gland of M. galloprovincialis plays a crucial role in the detoxification process, especially in environments with high levels of anthropogenic pressure. This underscores the potential of mussel systems as effective tools for bioremediation efforts [71]. In another research using as sample bivalve molluscs intendet for human consumption, was conducted to investigate the occurrence and susceptibility of potentially harmful bacteria, such as Salmonella spp. and Vibrio spp. The findings revealed that one strain of S. typhimurium exhibited multidrug resistance (MDR) to sulfamethoxazole, trimethoprim, tetracycline, gentamicin, and ampicillin. Additionally, 41.3% of the Vibrio strains displayed MDR, primarily against sulfonamides, penicillin, and cephem. However, all the tested Vibrio isolates demonstrated susceptibility to azithromycin, chloramphenicol, tetracycline, amoxicillin/clavulanic acid, gentamicin, streptomycin, amikacin, and levofloxacin [72].

This research study presents novel findings regarding the culturable skin bacteria associated with healthy European seabass in both antibiotic-treated and antibiotic-free culture conditions.

Notably, certain pathogenic microbiota known to affect fish health were identified, including *V. alginolyticus*, *V. anguillarum*, and *V. harveyi*. It is worth mentioning that the Vibrio strains exhibited a higher level of resistance to specific antibiotics when compared to previous studies conducted in similar contexts [73].

3. Effects of Climate Change on Fishery Products

Climate is one of the most important abiotic factors that shapes the distribution of plants and animals on Earth through a combination of direct and indirect effects [1]. In organisms whose body temperature varies according to the environmental temperature (poikilotherms) such as fishes, the temperature may shape population and community structures through its influence on the survival, reproduction and patterns of resource use of single individuals [74]. Indirect effects are exhibited for example through modification in water circulation which can influence larval dispersal and recruitment [75].

Fish has been used as indicators of environmental changes for a long time [76,77]. Their high dispersal ability, ecological differentiation, temperature sensitivity, typically large size, and ease of identification make them excellent indicators of the effects of climate change. Additionally, climate change is known to negatively impact the biology, fertility, growth, and biodiversity of aquatic, terrestrial, and aerial animals [78]. Furthermore, Pörtner and Peck suggested that climate change has an effect on individual organisms during all life stages hence affecting populations of a species, communities and the functioning of the ecosystem [1,79].

More specifically, local athmospherical conditions significantly influence hydrological properties of Adriatic Sea. For instance, Ferrarese et al. [80] pointed out that the Adriatic Sea circulation and temperature patterns change abruptly at onset and growth of strong winds [1]. Indeed, highest seasonal variability of sea surface temperature (SST) in the Mediterranean has been documented for the area of North Adriatic [81]. In addition, weakening of thermohaline circulation in the Adriatic Sea due to climate change can potentially affect deep pelagic and benthic organisms especially biodiversity in niches, such as those found in the nearby Jabuka Pit [82]. In recent decades, many publications have also acknowledged the impact of climate change on hydrological and biological processes in the Adriatic Sea [83–85].

Potential responses to climate warming include a wide array of taxa seeking cooler environments by shifting toward poles and higher latitudes, higher global extinction rates and reorganization of local communities resulting from local extinctions and expansion of thermophilic species [86]. There are few theoretical consequences that can be experienced by the mobile fauna (especially fishes) of the Adriatic Sea [1]. It can happen through several mechanisms, like the extension of the northern limit of species distributions which usually affects thermophillic species (northward expansion) and the reduction of distribution of species of cold water affinity with subsequent northward shift of center of population distribution, while the relative species are seeking refuge in northern areas of the Adriatic Sea [1]. Beside the phenomenon of shift in population distribution (usually northward) by native Mediterranean species, which is usually termed "meridionalization", a process of "tropicalization" (arrival of alien species of tropical origin) also plays an important role in carving of the faunal assemblages of the Mediterranean and Adriatic Sea [87].

Numerous northward shift records came from the Adriatic Sea [88,89], where even juveniles of some previously rare or absent, thermophilic fishes have been recently registered. The occurrence or increase of certain thermophilic species in the Adriatic Sea is usually attributed to rising water temperatures, but distinguishing them from other potential causes is a very complex task.

However, it is very likely that most of the possible causes are essentially related to rising average sea temperatures. In the last 25 years numerous thermophilous fish species have been recorded for the first time in the Adriatic Sea and their presence might be related to climate change [89,90], while climate change effects are responsible for facilitating the migration of lessepsian fish species. Heavy fishing increases the success of non-commercial species by reducing competition from commercial species for the same resources, thereby allowing previously rare species to form larger and more

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

resilient populations [85]. Secondly, since Adriatic Sea is not isolated from the rest of the Mediterranean, changes occurring in other areas have consequences for the Adriatic ecosystem [84]; [85]. This is especially important for the presence of lessepsian fish species whose arrival in the Adriatic is not only facilitated by climate change but also by the presence of already established populations in the southern regions which probably act as recruitment areas for subsequent northward spreading [91], while the presence of lessepsian species in the Adriatic Sea is probably facilitated if not a consequence of periodic influx of water originating from the eastern Mediterranean Sea (BiOS) [1].

Beside arrival and spreading of non-native species there are also certain changes affecting populations of native fishes. This is evident through either increased abundances, northward extension or decline in occurrence of some species. It is very likely that some cold water species will be negatively affected by the water warming while thermophilious species will benefit from it. This issue is of particular importance for the Adriatic Sea since the impacts of the global warming are particularly critical in semi-enclosed seas (Pozdnyakov et al., 2007). There are already indications that some cold-water fish species, particularly European sprat (*Sprattus sprattus*) or cold-water species whiting (*Merlangius merlangus*) are in decline in the last 30 years [16,92].

Among the most interesting examples are increases in abundances, possibly due to distributional shift, of species like yellow barracuda (*Sphyraena viridensis*), flying gurnard (*Dactylopterus volitans*), ornate wrasse (*Thallasoma pavo*), grey triggerfish (Balistes carolinensis), white trevally (*Pseudocaranx dentex*), Mediterranean parrotfish (*Sparisoma cretense*) and fangtooth moray (*Enchelycore anatine*) [89].

Species of the Serranidae family, previously dominant in the southern Adriatic Sea, have also experienced a northward migration. This is especially important for white grouper (*Epinephelus aeneus*) and mottled grouper (*Mycteroperca robra*). After first being recorded in the southern Adriatic Sea in 1999 and 2000, respectively, these groupers have undergone northward expansion and are now occasionally reported from these waters, southern and central Adriatic Sea [89,93].

4. Future Prospective and Conclusions

Climate induced changes are expected to affect services provided by the ecosystem including important fishery sectors, like aquaculture and fisheries [87,94]. The impact of climate change on the marine fisheries sector is particularly complex, due to the fact that the effects can be both positive and negative in economic terms [94,95]. The effects of climate change on fishing communities will be determined by their exposure to change, the vulnerability of essential species and ecosystems to climate change, and fishers' capacity to adapt to new situations [96].

Fisheries should be influenced by both "meridionalization" and "tropicalization" of catch, i.e., a rise in warmer-water species in comparison to colder-water ones, because variations in distribution are predicted to alter their availability to fisheries (Cheung et al., 2013). Landings may change in relation to global warming and this may induce changes in the intensity and spatial distribution of fishing effort [97], like it has been shown for European Lobster (*Homarus gammarus*) in the eastern Adriatic Sea. A fishery's sensitivity to climate is determined by previously caused changes in fish stocks, which impact species composition and consequently abundance in commercial captures [85]. It means that climate change will have more or less marked effects on all the fishery sectors, even if it is not yet clear whether the diversity of the Mediterranean fleet in terms of catches and vessels will contribute to the adaptive capacity of these regions [98].

Small pelagic fish are important ecological indicators of the state of the ecosystem due to their sensitivity to climate forcing that influences their distribution and abundance [99], which suggest that purse-seine fisheries could be particularly vulnerable to climate change [84]. Additionally, fishing activities can lead to a reduction in habitat complexity and changes in the structure of the benthic community, which can in turn affect fish abundance and distribution of important commercial fishes, such as hake (*Merluccius merluccius*), mackerel (*Scomber scombrus*), and blue whiting (*Micromesistius poutassou*) [100].

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

A potential displacement of native species by alien species is expectable according to Dragičević et al. [1] due to the fact that alien species are usually more successful in competition for space, shelter and food. Displacement of native mullets (*Mullus* sp.) by the alien goatfishes (Upeneus spp.) (Bianchi, 2007), of salema, *Sarpa salpa* by spinefoot species (*Siganus* spp.) and/or anchovy, *Engraulis encrasicolus* by round-eye herring *E. golanii* (Kallianiotis and Lekkas, 2005) is on the way in certain areas.

Furthermore, among commercially significant species that have the potential to develop or have already established populations in the Adriatic Sea are tripletail *Lobotes surinamensis* and spinefoots, *Siganus luridus* and *S. rivulatus* [1]. In the Adriatic Sea nations, it is vital to increase their worth through public awareness initiatives. These might be used to educate consumers about their nutritional worth, develop new processed items, and promote both fresh and processed products on the market. The best way to reduce the pressure of the populations of alien species like spinefoots and cornetfish species (Langeneck et al., 2023) is to stimulate the commercial fishery to target these species. For the Adriatic basin fisheries, Dragičević et al. [1] suggested that this shouldn't include only alien species but also other (thermophilic) species, whose populations are experiencing significant increase like *Pomatomus saltatrix, Sphyraena viridensis* or *Balistes carolinensis*.

Understanding how climate change affects fisheries income is an important step toward developing successful socioeconomic policies and food sustainability measures in adaption efforts [101]. Lam et al. [101] suggest the need to conduct full-fledged economic analyses of the potential economic effects of climate change on global marine fisheries. While aquaculture appears to be a plausible alternative approach to alleviate the financial burden of fishing losses and increase food security under climate change, [101] imply that aquaculture may drive down seafood prices, resulting in additional drops in fisheries earnings [1]. In the Adriatic basin, many coastal communities rely on living marine resources for livelihoods and food security [1,89]. These resources are already under significant stress from overfishing, pollution, coastal development and habitat degradation, while climate change could be an additional stressor impacting coastal systems and communities [102]. For instance, warming waters will facilitate mercury methylation and increase the methylmercury uptake in fish by about 3-5% when the temperature rises by 1°C [103] Contaminants transmitted from the environment pose a significant hazard not only to fish life, but also to consumer health [104]. In addition, climate change effects are expected to bring out an increase in toxic algae in waters, while particularly in marine environment [105], it will be possible an adaptation of harmful algae [104]. Like, it is expected to happen worldwide [104] shellfish poisoning outbreaks are predicted to be even more frequent due to the future climate scenario in the Adriatic Sea and relative lagoons, mostly due to its peculiarities [102,106] *please read fishery sections*). [104] suggest hazardous algae will possibly lead to the formation of Paralytic (PSP), Amnesic (APS), Diarrhetic (DSP), Neurotoxic (NSP), and Azaspiracid (AZP) Shellfish Poisonings, and negatively affect human health, as a result of global climate change.

An increase in temperature and changes in precipitation patterns will increase the resistance and incidence of bacteria, viruses, parasites, and fungi, which will cause rises in foodborne diseases, while a minor increase in water temperature broadens the geological range of nematodes and boosts their proliferation in the infective stages in many habitats. [104]. Particularly in the Adriatic basin countries, it should be paid attention in the farming of rainbow trout and Mediterranean mussel, especially on detection and prevention of the disease's outbreaks. Another important issue induced by climate change is the increased presence of harmful bacteria in water and aquatic species. As a result, climate change-induced temperature increases are expected to expand globally in the future. Shellfish are expected to be the main pathogen transmission route to humans, as they are filter-feeders and are generally consumed raw [104], especially in Mediterranean Sea and Adriatic Sea, which are considered as the most valuable touristic destinations worldwide [94]. Acidification is the other adverse effect of climate change on water resources, because crustaceans and mollusks may not form shells due to the reduction of calcification, and the availability of these foods on our tables will come to an end [103]

In conclusion, climate change effects will deplete our seafood supply in terms of quantity and safety owing to negative consequences such as higher levels of pollution, parasites, viruses,

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

infections, acidification, and toxicities such as shellfish poisoning. Global food safety strategies should be developed to reduce greenhouse gas emissions and promote environmentally friendly technology. Strategies must be devised to address emerging concerns such as climate change, which affects seafood quality and microbiological safety.

In the future, a key aspect would be to assess the vulnerability of natural ecosystems before the arrival of new species [85] and probably new diseases [106]; but in the Adriatic Sea, similarly to the Mediterranean marine environment, relatively little effort has been made to improve predictions about the spatial distributions of these species under different climate scenarios [107,108]. Nowadays, this knowledge is of primary importance not only for the Mediterranean Sea (as one of the most invaded marine regions in the world [109], but also for the Adriatic Sea, as a very particular ecosystem of the Mediterranean Sea, which is warming faster than the global average [110].

Author Contributions: Conceptualization, R.B.; writing—original draft preparation, E. H. and R.B.; writing—review and editing, R.B and E.H.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Dragičević, B.; Matić-Skoko, S.; Dulčić, J. Fish and Fisheries of The Eastern Adriatic Sea in The Light of Climate Change. Trends in Fisheries and Aquatic Animal Health, **2017**,1-22.
2. UNEP-MAP-RAC/SPA. Status and Conservation of Fisheries in the Adriatic Sea. 2014.
3. Zore-Armanda, M.; Grbec, B.; Morović M. Oceanographic properties of the Adriatic Sea-A point of view. Acta Adriat **1999**; 40 (Suppl.): 39-54.
4. Marini, M.; Campanelli, A., Sanxhaku, M.; Kljajić, Z.; Grilli, F. Late spring characterization of different coastal areas of the Adriatic Sea. Acta Adriat **2015**; 56(1): 27-46.
5. Orlić, M.; Gačić, M.; La Violette, PE. The currents and circulation of the Adriatic Sea. *Oceanol Acta* **1992**; 15(2): 109-24.
6. Civitarese, G.; Gačić, M.; Lipizer, M.; Eusebi Borzelli, GL. On the impact of the Bimodal Oscillating
7. Batistić, M.; Garić, R.; Molinero, JC. Interannual variations in Adriatic Sea zooplankton mirror shifts in circulation regimes in the Ionian Sea. *Clim Res* **2014**; 61: 231-40.
8. Buljan, M. Fluctuations of salinity in the Adriatic, Institut za Oceanografiju i Ribarstvo – Split (Croatia),*Reports*.**1953**; 2(2): 64.
9. Pallaoro, A. On the possibilites of the occurrence of certain fish species in the Middle Adriatic connected with the Adriatic ingressions in years 1986/1987. *Morsko Ribarstvo* **1988**; 3: 82-7. [In Croatian].
10. FAO. The State of Mediterranean and Black Sea Fisheries 2023 – Special edition. General Fisheries Commission for the Mediterranean. Rome. **2023**, https://doi.org/10.4060/cc8888en
11. Carpi, P.; Scarcella, G.; Cardinale, M. The Saga of the Management of Fisheries in the Adriatic Sea: History, Flaws, Difficulties, and Successes toward the Application of the Common Fisheries Policy in the Mediterranean. *Front. Mar. Sci.* **2017**,4:423. doi: 10.3389/fmars.2017.00423
12. Mackelworth, P., Holcer, D., Jovanovic, J., and Fortuna, C. (2011). Marine conservation and accession: the future for the croatian adriatic marine conservation and accession: the future for the croatian. Environ. Manage. 47, 644–655. doi: 10.1007/s00267-010-9460-z
13. AdriaMed. General Outline of Marine Capture Fisheries Legislation and Regulations in the Adriatic Sea Countries. FAO-MiPAF Scientific Cooperation to Support Responsible Fisheries in the Adriatic Sea. GCP/RER/010/ITA/TD14 (rev. 2). *AdriaMed Technical Documents* **2007**, 14, 70.
14. Colloca, F.; Garofalo, G.; Bitetto, I.; Facchini, M. T.; Grati, F.; Martiradonna, A.; et al. The seascape of demersal fish nursery areas in the North Mediterranean Sea, a first step towards the implementation of spatial planning for trawl fisheries. PLoS ONE 10:e0119590. **2015** doi: 10.1371/journal.pone.0119590
15. EU. Facts and Figures on the Common Fisheries Policy. Publications Office of the European Union, **2016**.
16. Grbec, B.; Dulčić, J.; Morović, M. Long-term changes in landings of small pelagic fish in the eastern Adriatic - possible influence of climate oscillations over the Northern Hemisphere. *Clim Res* **2002**; 20: 241-52. [http://dx.doi.org/10.3354/cr020241]

17. Allan, G. "Fish for feed vs fish for food," in Fish, Aquaculture and Food Security: *Sustaining Fish as Food Supply Conference*. **2004,** (Canberra, ACT).
18. Muñoz-Benavent, P.; Andreu-García, G.; Martínez-Peiró, J.; Puig-Pons, V.; Morillo-Faro, A.; Ordóñez-Cebrián, P.; Atienza-Vanacloig, V.; Pérez-Arjona, I.; Espinosa, V.; Alemany, F. Automated Monitoring of Bluefin Tuna Growth in Cages Using a Cohort-Based Approach. *Fishes* **2024**, 9, 46. https://doi.org/10.3390/fishes9020046
19. Mozaffarian, D. and Rimm, E.B.,. Fish intake, contaminants, and human health: evaluating the risks and the benefits. *Jama*, **2006**, *296*(15), 1885-1899.
20. Innis, S.M., Essential fatty acids in growth and development. *Progress in lipid research*, **1991**, *30*(1),39-103.
21. SanGiovanni, J.P.; Chew, E.Y. The role of omega-3 long-chain polyunsaturated fatty acids in health and disease of the retina. *Progress in retinal and eye research*, **2005**,*24*(1),87-138.
22. Lees, M.J.; Carson, B.P. The potential role of fish-derived protein hydrolysates on metabolic health, skeletal muscle mass and function in ageing. *Nutrients*, **2020**, *12*(8), p.2434.
23. Nakamura, K., Nashimoto, M., Okuda, Y., Ota, T. and Yamamoto, M., Fish as a major source of vitamin D in the Japanese diet. *Nutrition*, **2002**, *18*(5), 415-416.
24. Watanabe, F. Vitamin B12 sources and bioavailability. *Experimental biology and medicine*, **2007**, *232*(10), pp.1266-1274.
25. Grosso, G.; Galvano, F.; Marventano, S.; Malaguarnera, M.; Bucolo, C.; Drago, F.; Caraci, F. Omega-3 fatty acids and depression: scientific evidence and biological mechanisms. *Oxidative medicine and cellular longevity*, **2014**.
26. Briffa, J., Sinagra, E. and Blundell, R., 2020. Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon, 6(9).
27. Telli-Karakoç, F.; Tolun, L.; Henkelmann, B.; Klimm, C.; Okay, O.; Schramm, K.W. Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) distributions in the Bay of Marmara sea: Izmit Bay. *Environmental Pollution*, **2002**, 119(3),383-397.
28. Capodiferro, M.; Marco, E.; Grimalt, J.O. Wild fish and seafood species in the western Mediterranean Sea with low safe mercury concentrations. *Environmental Pollution*, **2022**, 314, 120274.
29. Copat, C.; Conti, G.O.; Fallico, R.; Sciacca, S.; Ferrante, M. Heavy metals in fish from the Mediterranean Sea: potential impact on diet. In *The Mediterranean Diet. Academic Press*. **2015**, 547-562
30. Traven, L.; Furlan, N.; Cenov, A. Historical trends (1998–2012) of nickel (Ni), copper (Cu) and chromium (Cr) concentrations in marine sediments at four locations in the Northern Adriatic Sea. *Marine pollution bulletin*, **2015**, 98(1-2), pp.289-294.
31. Di Leo, A.; Annicchiarico, C.; Cardellicchio, N.; Spada, L.; Giandomenico, S. Trace metal distributions in Posidonia oceanica and sediments from Taranto Gulf (Ionian Sea, southern Italy). *Mediterranean Marine Science*, **2013**, 14(1), pp.204-213.
32. Gallmetzer, I.; Haselmair, A.; Tomašových, A.; Stachowitsch, M.; Zuschin, M. Responses of molluscan communities to centuries of human impact in the northern Adriatic Sea. *PLoS One*, **2017**, 12(7), 0180820.
33. Joksimović, D.; Perošević, A.; Castelli, A.; Pestorić, B.; Šuković, D.; Đurović, D. Assessment of heavy metal pollution in surface sediments of the Montenegrin coast: a 10-year review. *Journal of Soils and Sediments*, **2020**, 20, 2598-2607.
34. Igwe, C.O.; Saadi, A.A.; Ngene, S.E. Optimal options for treatment of produced water in offshore petroleum platforms. *J Pollut Eff Cont*, **2013**, 1(2), pp.1-5.
35. Spada, L.; Annicchiarico, C.; Cardellicchio, N.; Giandomenico, S.; Di Leo, A. Heavy metals monitoring in mussels Mytilus galloprovincialis from the Apulian coasts (Southern Italy). *Mediterranean Marine Science*, **2013**, 14(1),99-108.
36. Bille, L.; Binato, G.; Cappa, V.; Toson, M.; Dalla Pozza, M.; Arcangeli, G.; Ricci, A.; Angeletti, R.; Piro, R. 2015. Lead, mercury and cadmium levels in edible marine molluscs and echinoderms from the Veneto region (north-western Adriatic Sea–Italy). *Food Control*, **2015**, 50,362-370.
37. Bogdanović, T.; Ujević, I.; Sedak, M.; Listeš, E.; Šimat, V.; Petričević, S.; Poljak, V. As, Cd, Hg and Pb in four edible shellfish species from breeding and harvesting areas along the eastern Adriatic Coast, Croatia. *Food chemistry*, **2014**, 146,197-203.
38. Tanaskovski, B.; Jović, M.; Mandić, M.; Pezo, L.; Degetto, S.; Stanković, S. Elemental analysis of mussels and possible health risks arising from their consumption as a food: the case of Boka Kotorska Bay, Adriatic Sea. *Ecotoxicology and environmental safety*, **2016**, 130,65-73.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 25 March 2024 doi:10.20944/preprints202403.1412.v1

39. Varrà, M.O.; Husáková, L.; Patočka, J.; Ianieri, A.; Ghidini, S.; Zanardi, E. Cadmium, lead, and mercury in two commercial squid species from the north Adriatic Sea (central Mediterranean): contamination levels and health risk assessment. *Italian Journal of Food Safety*, **2023**, 12(2).
40. Dolenec, T.; Baždarić, B.; Karamarko, V.; Kniewald, G.; Dolenec, M. Element levels in cultured and wild sea bass (Dicentrarchus labrax) and gilthead sea bream (Sparus aurata) from the Adriatic Sea and potential risk assessment. *Environmental Geochemistry and Health*, **2013**, 36(1),19-39.
41. Kucaj, E.; Abazi, U.; Abazi, E.Z. Bioaccumulation of heavy metals in Bass fish (Morone Saxatilis) at Rodoni Cape, in Adriatik sea, Albania. *IOSR Journal of Engineering* (IOSRJEN). **2015**, 5(8), 28-31.
42. Di Lena, G.; Casini, I.; Caproni, R.; Orban, E. Total mercury levels in crustacean species from Italian fishery. *Food Additives & Contaminants: Part B*, **2018**, 11(3), 175-182.
43. Antović, I.; Šuković, D.; Andjelić, S.; Svrkota, N. Heavy metals and radionuclides in muscles of fish species in the South Adriatic-Montenegro. In *RAP Conference Proceedings* Vol. **2019**, 4, 96-102.
44. Brkić, D.; Bošnir, J.; Bošković, A.G.; Miloš, S.; Šabarić, J.; Lasić, D.; Jurak, G.; Cvetković, B.; Racz, A.; Ćuić, A.M. Determination of heavy metals in different fish species sampled from markets in Croatia and possible health effects. *Med. Jadertina*, **2017**, 47, 89-105.
45. Grgec, A.S.; Kljaković-Gašpić, Z.; Orct, T.; Tičina, V.; Sekovanić, A.; Jurasović, J.; Piasek, M. Mercury and selenium in fish from the eastern part of the Adriatic Sea: A risk-benefit assessment in vulnerable population groups. *Chemosphere*, **2020**, *261*,127742.
46. Barone, G.; Storelli, A.; Garofalo, R.; Mallamaci, R.; Storelli, M.M. Residual levels of mercury, cadmium, lead and arsenic in some commercially key species from Italian coasts (Adriatic Sea): Focus on human health. *Toxics*, **2022**, 10(5), 223.
47. Bettoso, N.; Pittaluga, F.; Predonzani, S.; Zanello, A.; Acquavita, A. Mercury Levels in Sediment, Water and Selected Organisms Collected in a Coastal Contaminated Environment: The Marano and Grado Lagoon (Northern Adriatic Sea, Italy). *Applied Sciences*, **2023**, *13*(5), p.3064.
48. Walker, C.H.; Hopkin, S.P.; Sibly, R.M.; Peakall, D.B. *Principles of Ecotoxicology*. Taylor & Francis, London, UK, **1996**.
49. Klinčić, D.; Romanić, S.H.; Katalinić, M.; Zandona, A.; Čadež, T.; Sarić, M.M.; Šarić, T.; Aćimov, D. Persistent organic pollutants in tissues of farmed tuna from the Adriatic Sea. *Marine Pollution Bulletin*, **2020**, 158, 111413.
50. Krivokapić, M. Assessment of PCBs and OCPs in anchovy (Engraulis encrasicolus) and sardine (Sardina pilchardus) from theAdriatic Sea, Bay of Herceg Novi (alongside Kumbor Marine Channel). Acta Adriatica: *International Journal of Marine Sciences*, **2020**, 61(1), pp.27-38.
51. Nuro, A.; Murtaj, B., October. Levels of Some Priority Substances on Adriatic Sea, Albania. In Fourth International Scientific Conference on Recent Advances in Information Technology, Tourism, Economics, Management and Agriculture **2020**, 277.
52. Capriotti, M.; Cocci, P.; Bracchetti, L.; Cottone, E.; Scandiffio, R.; Caprioli, G.; Sagratini, G.; Mosconi, G.; Bovolin, P.; Palermo, F.A. Microplastics and their associated organic pollutants from the coastal waters of the central Adriatic Sea (Italy): Investigation of adipogenic effects in vitro. *Chemosphere*, **2021**, 263, p.128090.
53. Spognardi, S.; Bravo, I.; Rea, R.; Cappelli, L.; Papetti, P. A perspective on the potential health risks from PCBs and heavy metals contamination of M. merluccius from Mediterranean Sea. *International Journal of Food Safety, Nutrition and Public Health*, **2021**,6(2), pp.85-103.
54. Milićević, T.; Romanić, S.H.; Popović, A.; Mustać, B.; Đinović-Stojanović, J.; Jovanović, G.; Relić, D. Human health risks and benefits assessment based on OCPs, PCBs, toxic elements and fatty acids in the pelagic fish species from the Adriatic Sea. *Chemosphere*, **2022**, 287, p.132068.
55. Campanelli, A.; Grilli, F.; Paschini, E.; Marini, M. The influence of an exceptional Po River flood on the physical and chemical oceanographic properties of the Adriatic Sea. *Dynamics of Atmospheres and Oceans*, **2011**, 52(1-2), pp.284-297.
56. Zhang YanYan, Z.Y.; Dong SiJun, D.S.; Wang HongOu, W.H.; Tao Shu, T.S.; Kiyama Ryoiti, K.R. Biological impact of environmental polycyclic aromatic hydrocarbons (ePAHs) as endocrine disruptors, **2016**.
57. Frapiccini, E.; Cocci, P.; Annibaldi, A., Panfili, M., Santojanni, A.; Grilli, F.; Marini, M.; Palermo, F.A.. Assessment of seasonal relationship between polycyclic aromatic hydrocarbon accumulation and expression patterns of oxidative stress-related genes in muscle tissues of red mullet (M. barbatus) from the Northern Adriatic Sea. Environmental Toxicology and Pharmacology, **2021**, 88,103752.

58. Frapiccini, E. Polycyclic Aromatic Hydrocarbon (PAH) pollution in wild Adriatic fish-from the main determining factors of PAH accumulation to some biological responses of fish, **2021**.
59. Frapiccini, E.; Panfili, M.; Guicciardi, S.; Santojanni, A.; Marini, M.; Truzzi, C.; Annibaldi, A. Effects of biological factors and seasonality on the level of polycyclic aromatic hydrocarbons in red mullet (Mullus barbatus). **Environmental Pollution**, **2020**, 258, 113742.
60. Frapiccini, E.; Pellini, G.; Gomiero, A.; Scarcella, G.; Guicciardi, S., Annibaldi, A.; Betti, M.; Marini, M.. Microplastics and Polycyclic Aromatic Hydrocarbons Occurrence in a Demersal Fish (Solea solea) in the Adriatic Sea. In Proceedings of the 2nd International Conference on Microplastic Pollution in the Mediterranean Sea. *Springer International Publishing*, **2020**, 226-233.
61. Hansen, P.K.; Lunestad, B.T.; Samuelsen, O.B. Effects of oxytetracycline, oxolinic acid, and flumequine on bacteria in an artificial marine fish farm sediment. *Canadian Journal of Microbiology*, **1992**, 38(12),1307-1312.
62. Alderman, D.J.; Hastings, T.S. Antibiotic use in aquaculture: development of antibiotic resistance–potential for consumer health risks. *International journal of food science & technology*, **1998**, 33(2),139-155.
63. Depaola, A.; Peeler, J.T.; Rodrick, G.E. Effect of oxytetracycline-medicated feed on antibiotic resistance of gram-negative bacteria in catfish ponds. *Applied and environmental microbiology*,**1995**, 61(6), 2335-2340.
64. Mog, M.; Ngasotter, S.; Tesia, S.; Waikhom, D.; Panda, P.; Sharma, S.; Varshney, S. Problems of antibiotic resistance associated with oxytetracycline use in aquaculture: A review. *J. Entomol. Zool. Stud*, **2020**, 8,1075-1082.
65. Kapetanović, D.; Vardić Smrzlić, I.; Gavrilović, A.; Jug-Dujaković, J.; Perić, L.; Kazazić, S.; Mišić Radić, T.; Kolda, A.; Čanković, M.; Žunić, J.; Listeš, E. Characterization of Vibrio Populations from Cultured European Seabass and the Surrounding Marine Environment with Emphasis on V. anguillarum. *Microorganisms*, **2022**, 10(11), 2159.
66. Kapetanović, D.; Smrzlić, I.V.; Kazazić, S.; Omanović, D.; Cukrov, N.; Cindrić, A.M.; Rapljenović, A.; Perić, L.; Orlić, K.; Mijošek, T.; Redžović, Z. A preliminary study of the cultivable microbiota on the plastic litter collected by commercial fishing trawlers in the south-eastern Adriatic Sea, with emphasis on Vibrio isolates and their antibiotic resistance. *Marine Pollution Bulletin*, **2023**, 187,114592.
67. Fonti, V.; Di Cesare, A.; Šangulin, J.; Del Negro, P.; Celussi, M. Antibiotic resistance genes and potentially pathogenic bacteria in the central Adriatic Sea: are they connected to urban wastewater inputs? *Water*, **2021**, 13(23), p.3335.
68. Zago, V.; Veschetti, L.; Patuzzo, C.; Malerba, G.; Lleo, M.M. Shewanella algae and Vibrio spp. strains isolated in Italian aquaculture farms are reservoirs of antibiotic resistant genes that might constitute a risk for human health. *Marine Pollution Bulletin*, **2020**, 154, 111057.
69. Pavlinec, Ž.; Zupičić, I.G.; Oraić, D.; Lojkić, I.; Fouz, B.; Zrnčić, S. Biochemical and molecular characterization of three serologically different Vibrio harveyi strains isolated from farmed Dicentrarchus labrax from the Adriatic Sea. *Scientific Reports*, **2022**, 12(1), 7309.
70. Purgar, M.; Kapetanović, D.; Gavrilović, A.; Hackenberger, B.K.; Kurtović, B.; Haberle, I.; Pečar Ilić, J.; Geček, S.; Hackenberger, D.K.; Djerdj, T.; Bavčević, L. Dataset AqADAPT: Physicochemical Parameters, Vibrio Abundance, and Species Determination in Water Columns of Two Adriatic Sea Aquaculture Sites. *Data*, **2023**, 8(3),55.
71. Palladino, G.; Rampelli, S.; Scicchitano, D.; Nanetti, E.; Iuffrida, L.; Wathsala, R.H.G.R.; Interino, N.; Marini, M.; Porru, E.; Turroni, S.; Fiori, J. Seasonal dynamics of the microbiome-host response to pharmaceuticals and pesticides in Mytilus galloprovincialis farmed in the Northwestern Adriatic Sea. *Science of The Total Environment*, **2023**, 887, 63948.
72. Mancini, M.E.; Alessiani, A.; Donatiello, A.; Didonna, A.; D'Attoli, L.; Faleo, S.; Occhiochiuso, G.; Carella, F.; Di Taranto, P.; Pace, L.; Rondinone, V. Systematic Survey of Vibrio spp. and Salmonella spp. in Bivalve Shellfish in Apulia Region (Italy): Prevalence and Antimicrobial Resistance. *Microorganisms*, **2023**, 11(2), 450.
73. Ramljak, A.; Vardić Smrzlić, I.; Kapetanović, D.; Barac, F.; Kolda, A.; Perić, L.; Balenović, I.; Klanjšček, T.; Gavrilović, A. Skin Culturable Microbiota in Farmed European Seabass (Dicentrarchus labrax) in Two Aquacultures with and without Antibiotic Use. *Journal of Marine Science and Engineering*, **2022**, 10(3),303.
74. Azzurro E. The advance of thermophilic fishes in the Mediterranean Sea: overview and methodological questions. In: Briand F, Ed. Climate warming and related changes in Mediterranean marine biota. In: No:35. *CIESM Workshop Monographs*; **2008**; 39-46.

75. Dulčić, J.; Grbec, B. Climate change and Adriatic ichthyofauna. *Fish Oceanogr* **2000**, 9: 187-91 [http://dx.doi.org/10.1046/j.1365-2419.2000.00128.x]
76. Stephens, JS.; Hose, JH.; Love, MS. Fish assemblages as indicators of environmental change in nearshore environments.Marine Organisms as Indicators. New York: Springer-Verlag **1988**; 91-105. http://dx.doi.org/10.1007/978-1-4612-3752-5_5]
77. Bakiu, R.; Santovito, G.; Hoda, A.; Shehu, J.; Durmishaj, S.; Irato, P.; Piccinni, E. Metallothionein (MT): a good biomarker in marine sentinel species like sea bream (Sparus aurata). *Albanian Journal of Agricultural Sciences*, **2013**, 12, 247-253.
78. Eissa, AE.; Zaki, MM. The impact of global climatic changes on the aquatic environment. *Procedia Environ Sci* **2011**; 4: 251-9. [http://dx.doi.org/10.1016/j.proenv.2011.03.030]
79. Pörtner, HO.; Peck, MA. Climate change effects on fishes and fisheries: towards a cause-and-effect understanding. *J Fish Biol* **2010**; 77(8): 1745-79. [http://dx.doi.org/10.1111/j.1095-8649.2010.02783.x] [PMID: 21078088]
80. Ferrarese, S.; Cassardo, C.; Elmi, A.; et al. Air-sea interactions in the Adriatic basin: simulations of Bora and Sirocco wind events. *Geofizika* **2009**; 26(2): 157-70.
81. Shaltout, M.; Omstedt, A. Recent sea surface temperature trends and future scenarios for the Mediterranean Sea. Oceanologia **2014**; 56(3): 411-43. [http://dx.doi.org/10.5697/oc.56-3.411]
82. Vilibić, I.; Šepić, J.; Proust, N. Weakening thermohaline circulation in the Adriatic Sea. *Clim Res* **2013**; 55: 217-25.
83. Bakiu, R.. Innovation towards the sustainability of Mediterranean blue economy - *New Technologies for Marine Aquaculture*. European Week, Brussels, **2017.**
84. Hidalgo, M.; El-Haweet, AE.; Tsikliras, AC.; Tirasin, EM.; Fortibuoni, T.; Ronchi, F.; Lauria, V.; Ben Abdallah, O.; Arneri, E.; Ceriola, L.; Milone, N. Risks and adaptation options for the Mediterranean fisheries in the face of multiple climate change drivers and impacts. *ICES Journal of Marine Science*. **2022,** 79(9):2473-88.
85. Cavraro, F.; Anelli Monti, M.; Mati´c-Skoko, S.; Caccin, A.; Pranovi, F. Vulnerability of the Small-Scale Fishery to Climate Changes in the Northern-Central Adriatic Sea (Mediterranean Sea). *Fishes* **2023**, 8, 9. https://doi.org/10.3390/fishes8010009
86. Ben Rais Lasram, F.; Guilhaumon, F.; Albouy, C.; Somot, S.; Thuiller, W.; Mouillot, D. The Mediterranean Sea as a 'cul-de-sac' for endemic fishes facing climate change. *Glob Change Biol* **2010**, 16(12): 3233-45. [http://dx.doi.org/10.1111/j.1365-2486.2010.02224.x
87. Bakiu, R.; Kamberi, E.; Expected Climate Change Effects on Gilthead Seabream and European Seabass Abundance and Catch in Albanian Waters –*Albanian j. agric. sci*. **2021**;20 (2): 1-1
88. Dulčić, J.; Grbec, B.; Lipej, L.; Beg Paklar, G.; Supić, N.; Smirčić, A. The effect of the hemispheric climatic oscillations on the Adriatic ichthyofauna. *Fresenius Environ Bull***, 2004**; 13(3b): 293-8.
89. Glamuzina, B.; Cukteras, M.; Dulcic, J. (2012, July). Present changes and predictions for fishery and mariculture in the eastern Adriatic (Croatia) in the light of climate change/cambiamenti attuali? Previsioni per la pesca? La maricoltura nell'Adriatico Orientale (Croazia) alla luce del cambiamento climatico. In Annales: Series Historia Naturalis *Scientific and Research Center of the Republic of Slovenia*, **2012**, 22, 2, 105.
90. Kamberi, E.; Beqiri, K.; Luli, K.; Bakiu, R. Tracking changes in fish diversity in the South-eastern Adriatic Sea (Albania) based on local ecological knowledge. *Croatian Journal of Fisheries*, **2022**, 80, 17-25. 1. DOI:10.2478/cjf-2022-0003.
91. Crocetta, F.; Al Mabruk, S.A.; Azzurro, E.; Bakiu, R., Bariche, M.; Batjakas, I.E.; Bejaoui, T.; Ben Souissi, S.J.; Cauchi, J.; Corsini-Foka, M.; Deidun, A. 2021. *New alien Mediterranean biodiversity records*, **2021**.
92. Calì, F.; Stranci, F.; La Mesa, M.; Mazzoldi, C.; Arneri, E.; Santojanni, A.Whiting (Merlangius merlangus) Grows Slower and Smaller in the Adriatic Sea: New Insights from a Comparison of Two Population with a Time Interval of 30 Years. *Fishes* **2023**, 8, 341. https://doi.org/ 10.3390/fishes8070341
93. Dulčić J, Tutman P, Ćaleta M. Northernmost occurrence of the white grouper, Epinephelus aeneus (Perciformes: Serranidae), in the Mediterranean area. *Acta Ichthyol Piscat* **2006**; 36: 73-5. [http://dx.doi.org/10.3750/AIP2006.36.1.10]
94. Bakiu R. Climate Change Effects to Aquaculture Production Based on Social and Economic Indicators of the Albanian Marine Aquaculture. *Albanian j. agric. sci.* **2023**, 21 (1):37-42.
95. Agnetta, D.; Badalamenti, F.; Colloca, F.; Cossarini, G.; Fiorentino, F.; Garofalo, G.; Patti, B.; Pipitone, C.; Russo, T.; Solidoro, C.; Libralato, S. Interactive effects of fishing effort reduction and climate change in a

central Mediterranean fishing area: Insights from bio-economic indices derived from a dynamic food-web model. *Front. Mar. Sci.* **2022**, 9:909164. doi: 10.3389/fmars.2022.909164
96. Gamito, R.; Costa, MJ.; Cabral, HN. Fisheries in a warming ocean: trends in fish catches in the large marine ecosystems of the world. *Reg Environ Change* **2015**; 15: 57-65 [http://dx.doi.org/10.1007/s10113-014-0615-y]
97. Matic´-Skoko, S.; Pavicic´ M.; Sepic´ J.; Janekovic´ I.; Vrdoljak, D.; Vilibic´ I, Staglicic´ N.; Segvic´-Bubic´ T.; Vujevic´ A. Impacts of Sea Bottom Temperature on CPUE of European Lobster Homarus gammarus (Linnaeus, 1758;Decapoda, Nephropidae) in the Eastern Adriatic Sea. *Front. Mar. Sci.* 9:891197.doi: **2022**, 10.3389/fmars.2022.891197
98. Hidalgo, M.; Mihneva, V.; Vasconcellos, M.; Bernal, M. Climate change impacts vulnerabilities adaptations: Mediterranean Sea the Black Sea marine fisheries. In Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options; Barange, M., Bahri, T., Beveridge, M.C., Cochrane, K.L., Funge-Smith, S., Poulain, F., Eds.; *FAO:* Kanagawa, Japan, **2018**; 630.
99. Valencia-Gasti, JA.; Baumgartner, T.; Durazo, R. Effects of ocean climate on life cycles and distribution of small pelagic fishes in the California Current System off Baja California. *Cienc Mar* **2015**; 41(4): 315-48. [http://dx.doi.org/10.7773/cm.v41i4.2571]
100. Valente, S.; Moro, S.; Di Lorenzo, M.; Milisenda, G.; Maiorano, L.; Colloca, F. Mediterranean fish communities are struggling to adapt to global warming. Evidence from the western coast of Italy. *Mar Environ Res*. **2023** Oct;191:106176. doi: 10.1016/j.marenvres.2023.106176. *Epub* 2023 12. PMID: 37716279.
101. Lam, VW.; Cheung, WW.; Reygondeau, G.; Sumaila, UR. Projected change in global fisheries revenues under climate change. *Sci Rep* **2016**; 6: 32607. [http://dx.doi.org/10.1038/srep32607] [PMID: 27600330]
102. Bakiu R. Albania: Climate change impacts become ever more obvious. Eurofish Magazine 5 **2022**.
103. Kibria, G.; Nugegoda, D.; Rose, G. Climate change impacts on pollutants mobilization and interactive effects of climate change and pollutants on toxicity and bioaccumulation of pollutants in estuarine and marine biota and linkage to seafood security, Marine Pollution Bulletin, **2021**, 167,112364.
104. Mol, S.; Coşansu, S. Seafood safety, potential hazards and future perspective. Turkish Journal of Fisheries and Aquatic Sciences, **2022**, 22(6).
105. Tirado, M.C.; Clarke, R.; Jaykus, L.A. Climate change and food safety: A review. Food Research International, **2010**, 43(7), 1745-1765.
106. FAO. Climate Change Adaptation Roadmap and Implementation Action Plan of the Agriculture Forestry and Other Land Use (AFOLU) sector of Albania, 2022, 1- 93.
107. Coro, G.; Vilas, L.G.; Magliozzi, C.; Ellenbroek, A.; Scarponi, P.; Pagano, P.F. Forecasting the ongoing invasion of Lagocephalus sceleratus in the Mediterranean Sea. *Ecol. Model*. **2018**, 371, 37–49. [CrossRef]
108. Melo-Merino, S.M.; Reyes-Bonilla, H.; Lira-Noriega, A. Ecological niche models and species distribution models in marine environments: A literature review and spatial analysis of evidence. *Ecol. Model*. **2020**, 415, 108837. [CrossRef]
109. Katsanevakis, S.;Wallentinus, I.; Zenetos, A.; Leppäkoski, E.; Cinar, M.E.; Oztürk, B.; Grabowski, M.; Golani, D.; Cardoso, A.C. Impacts of marine invasive alien species on ecosystem services and biodiversity: A pan-European review. *Aquat. Invasions* **2014**, 9, 391–423.
110. Giorgi, F. Climate change hotspot. *Geophys. Res. Lett*. **2006**, 33, L08707. [CrossRef]