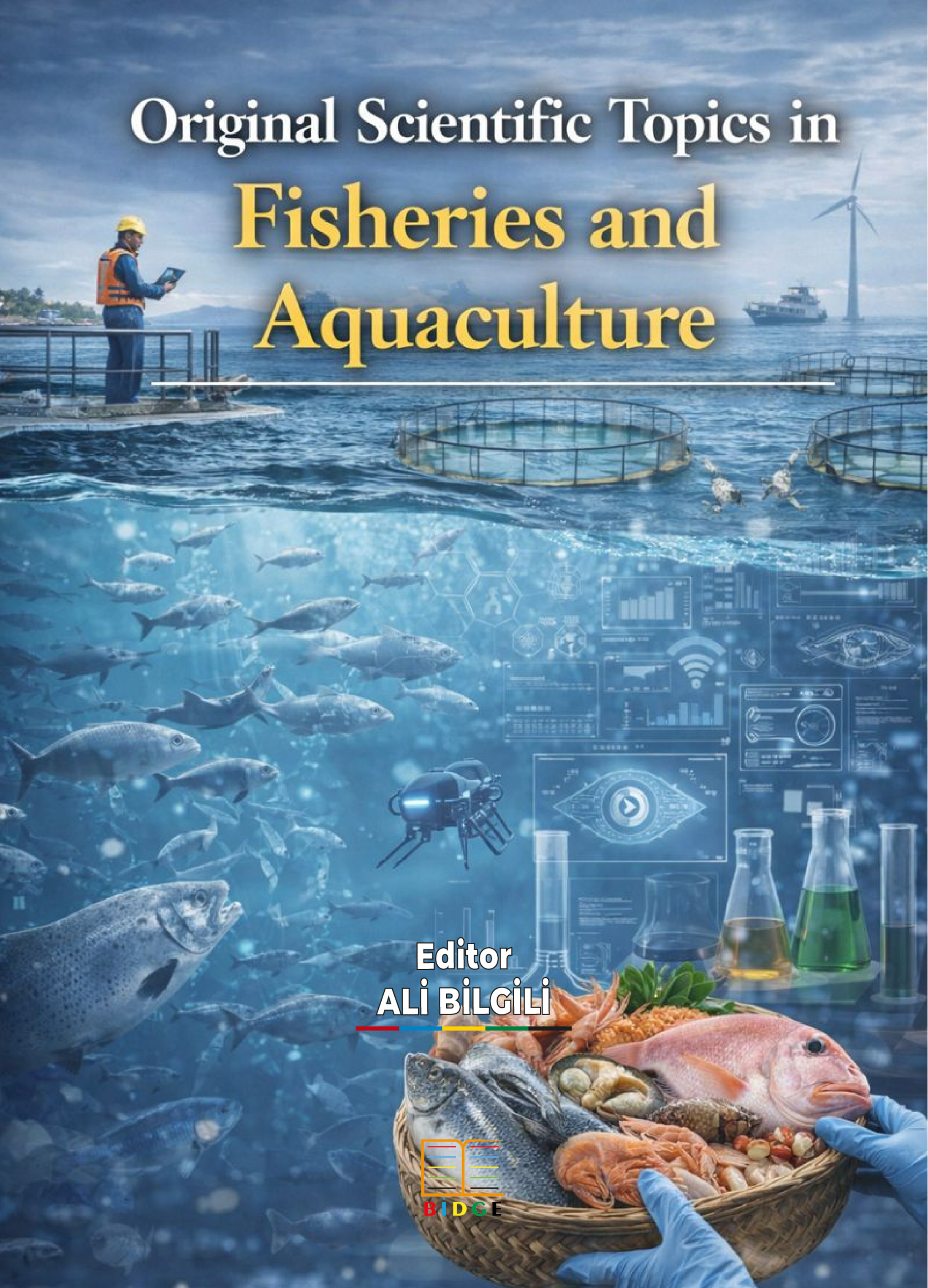

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Editor

ALİ BİLGİLİ

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PREFACE

From an ecological perspective, drift net fishing is more compatible with sustainable fishing approaches than other small-scale fishing methods, as it exerts limited physical pressure on habitats and allows for spatially controllable fishing activities. This section of the book provides information on the scientific realities of drift net fishing, highlighting that ensuring the sustainability of drift net fishing primarily requires the protection of fishing areas, systematic monitoring within fisheries management frameworks, and targeted support measures to enhance the resilience of this traditional fishing practice.

The study, which addresses the environmental problems of the Gulf of Iskenderun in the Eastern Mediterranean region and the measures taken, draws attention in detail to the need to show the necessary care and sensitivity towards the natural cleanliness of the Gulf of Iskenderun and our country's Mediterranean coastal ports.

In a separate chapter of the book, the opportunities and challenges of antimicrobial peptides in shrimp farming are evaluated. This chapter explains that antimicrobial peptides, with their broad-spectrum effects and immune-boosting roles, could play an important role in supporting responsible production that prioritizes animal welfare and consumer health in the future of shrimp farming.

Spearfishing in Turkey, current situation, regulations and management issues were evaluated.

Comprehensive information was provided on the use of mannan-oligosaccharides in responsible aquaculture, their mechanisms of action, feed utilization, and resistance to pathogens.

The effects of mycotoxins on gut health, immune function and disease susceptibility in aquaculture were discussed in detail based on information compiled from recent scientific sources.

Prof. Dr. ALİ BİLGİLİ

ANKARA UNIVERSITY

İÇİNDEKİLER

DONEK FISHING: A TRADITIONAL SMALL-SCALE FISHERY IN URLA, TÜRKIYE 1
AYTAÇ ÖZGÜL

OPPORTUNITIES AND CHALLENGES OF ANTIMICROBIAL PEPTIDES IN SHRIMP AQUACULTURE 17
PELİN BAĞLAN, ERCÜMENT GENÇ

ENVIRONMENTAL PROBLEMS AND PRECAUTIONS OF ISKENDERUN GULF IN EASTERN MEDITERRANEAN REGION 39
HİLAL KARGIN ERÖRS, HATİCE SÖNMEZ

SPEARFISHING IN TURKEY: AN OVERVIEW OF CURRENT STATUS, REGULATIONS, AND MANAGEMENT ISSUES 70
AYTAÇ ÖZGÜL

THE ROLE OF MANNAN-OLIGOSACCHARIDES IN RESPONSIBLE AQUACULTURE: IMPLICATIONS AS A DIETARY COMPONENT 84
AHMET GÜRLER, ERCÜMENT GENÇ

MYCOTOXINS IN AQUACULTURE : EFFECTS ON GUT HEALTH ,IMMUNE FUNCTION AND DISEASE SUSCEPTIBILITY 104
ULVİYE KARACALAR

BÖLÜM 1

DONEK FISHING: A TRADITIONAL SMALL-SCALE FISHERY IN URLA, TÜRKIYE

AYTAÇ ÖZGÜL[1]

Introduction

Fisheries play a critical role worldwide in economic, social, and cultural terms, contributing to human well-being and food security by providing employment through harvesting, processing, and marketing sectors (Dyck & Pontecorvo et al., 1980:208; Srinivasan et al., 2010:183). According to FAO data, global total aquatic products production reached 223.2 million tons in 2023, of which 92.3 million tons were obtained through capture fisheries and 130.9 million tons through aquaculture. Approximately 40% of capture fisheries production is provided by small-scale fisheries (FAO, 2025).

Small-scale fisheries are generally defined as day-trip fishing activities conducted in shallow, nearshore waters using fishing vessels not exceeding 12 meters in length, and employing fishing gears such as gillnets, longlines, lift nets, handlines, and traps. Compared to large-scale fisheries, this type of fishing requires and

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utilizes significantly lower levels of technology, capital, and labor. All fishers are members of local communities, and fishing is carried out using traditional methods (FAO, 2015:1; Ünal, 2003:165).

Small-scale fisheries play an important role not only in terms of production volume but also in generating employment, contributing to food security, and supporting the livelihood strategies of coastal communities (FAO, 2024:1). The vast majority of individuals who depend on fisheries for their livelihoods worldwide are engaged in small-scale fishing activities. Particularly in developing countries, small-scale fisheries serve a critical function in reducing both rural and coastal poverty. Moreover, small-scale fisheries are often characterized as family-based enterprises; fishing practices are shaped by local ecological knowledge, cultural values, and experiences passed down from generation to generation (Berkes, 2018:489; Johannes et al., 2000:257).

From an ecological perspective, small-scale fisheries generally stand out compared to industrial fisheries due to their lower environmental impact, more selective fishing practices, and relatively limited pressure on habitats (Pauly, 2006:1; Chuenpagdee et al., 2013:1). Although small-scale fisheries hold significant potential within the framework of sustainable fisheries management and ecosystem-based approaches, they face challenges such as limited capital structures, vulnerability to market fluctuations, insufficient inclusion in management processes, and difficulties in accessing resources (Jentoft & Chuenpagdee, 2015:1). For this reason, national and international policies aimed at supporting and protecting small-scale fisheries have increasingly been developed in recent years.

Small-scale fisheries play a vital role not only in production but also in job creation, food security, and the support of livelihood strategies in coastal communities (FAO, 2025:1). The majority of people worldwide who earn their living from fisheries fall within the classification of small-scale fisheries. Especially in developing countries, small-scale fisheries perform a critical function in alleviating rural and coastal poverty. These activities, often organized as family enterprises, are shaped by local ecological knowledge, cultural values, and experiences transmitted across generations (Berkes, 2018:489; Johannes et al., 2000:257).

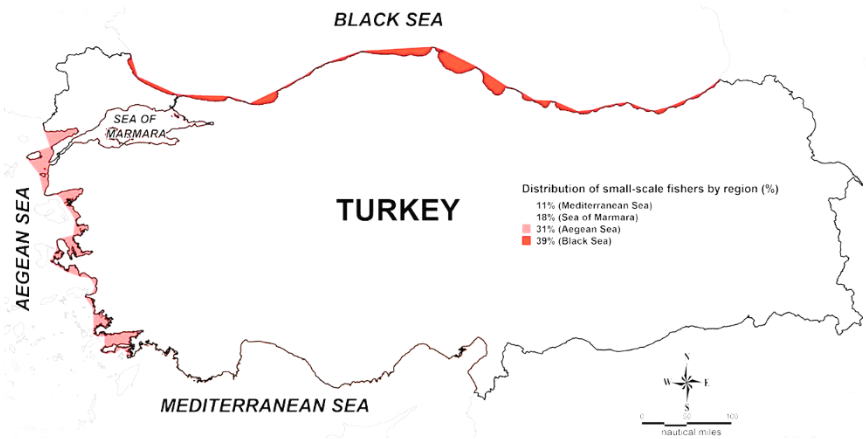
Due to their low environmental impact, more selective fishing methods, and limited pressure on habitats, small-scale fisheries are considered ecologically more sustainable than industrial fisheries. Nevertheless, they face challenges such as limited capital, vulnerability to market fluctuations, inadequate participation in management processes, and restricted access to resources (Jentoft & Chuenpagdee, 2015:1). Consequently, national and international policies aimed at supporting and conserving small-scale fisheries have been increasingly developed in recent years.

2. Small-Scale Fisheries in Türkiye

As of 2024, total aquatic products production in Türkiye amounted to 933,194 tons. Of this total, 356,070 tons were obtained through capture fisheries, while 577,124 tons were produced through aquaculture. Capture fisheries production declined by approximately 21.6% compared to the previous year, with marine capture fisheries recorded at 290,068 tons. Türkiye has a total of 13,773 active fishing vessels of various sizes, approximately 91% of which belong to the small-scale fisheries fleet. The production obtained using these vessels accounts for approximately 10% of total aquatic products production (TUIK, 2025:1).

In Türkiye, small-scale fisheries are conducted in coastal waters using vessels shorter than 12 meters in length with limited engine power, and employing passive fishing gears such as gillnets, handlines, longlines, and similar gear types (Fig.1). This form of fishing is predominantly based on day-trip operations, with a significant proportion of the catch sold fresh in local markets or directly consumed by fishing households (Ünal et al. 2009:394). With these characteristics, small-scale fisheries not only play a decisive role in the socio-economic structure of coastal settlements in Türkiye, but also contribute to the continuation of fisheries-related cultural practices, local ecological knowledge, and traditional fishing methods (Berkes, 2010:1; Ünal & Ulman, 2020:83).

Figure.1 Distribution of small-scale fishers along the Turkish coasts (Ünal & Ulman 2020:83)



Small-scale fisheries have a lower potential for environmental impact compared to industrial fisheries due to their use of more selective fishing gears and their operation within limited spatial areas. Nevertheless, environmental pressures such as intensive use of coastal zones, habitat loss, pollution, and climate change threaten the sustainability of this form of fishing. In addition, declines in fish stocks, fishing bans, and the implementation of management measures further increase the economic vulnerability of small-scale fishers (Sayın, 2003:957). Moreover, the largely centralized structure of fisheries management in Türkiye restricts the participation of small-scale fishers in decision-making processes (Ünal et al., 2015:1; Ünal & Ulman, 2020:83).

3. Small-Scale Fisheries in İzmir Bay

İzmir, one of the most important settlements along the Aegean Sea coast, has a coastline of 629 km and holds strategic importance for both the Aegean Sea and Turkish fisheries (Hoşsucu et al., 2001:1). Extending from the Dikili–Çandarlı Bay in the north and encompassing the Gülbahçe, Çeşme, and Sığacık bays, this biodiversity-rich ecosystem serves as a spawning, feeding, and nursery ground for numerous fish species (Sayın, 2003:957). In terms of its morphological structure and hydrographic characteristics, İzmir Bay is considered a semi-enclosed ecosystem composed of three main sections: The Inner, Middle, and Outer Bay. This structural configuration plays a decisive role in shaping hydrographic conditions, nutrient dynamics, and species distributions, and consequently influences the spatial and temporal patterns of fishing activities. The fact that the Inner Bay is largely closed to fishing has resulted in the concentration of fishing pressure in the Middle and Outer Bay.

Due to the availability of suitable fishing grounds and the presence of port infrastructure that accommodates a large number of fishing vessels, fisheries have become an important sector for the regional economy in İzmir. The main fishing centers in İzmir Province, listed from north to south, include Dikili, Çandarlı, Aliağa, Foça, Homa Lagoon and its surroundings, Güzelbahçe, Urla, Özbek, Mordoğan, Karaburun, Yeni Liman, Dalyanköy, Çeşme, Sığacık, and Gümüldür (Hoşsucu et al., 2001:1:). These fishing centers are organized through 50 fisheries cooperatives and 30 fishing ports operating within İzmir Province (Central Union of Fisheries Cooperatives, 2022:1; İzmir Provincial Directorate of Agriculture and Forestry, 2021:1). A total of 1,741 fishing vessels are registered to these cooperatives, comprising 72 trawl and purse seine vessels and 1,669 small-scale fishing vessels (İzmir Metropolitan Municipality, 2018:1).

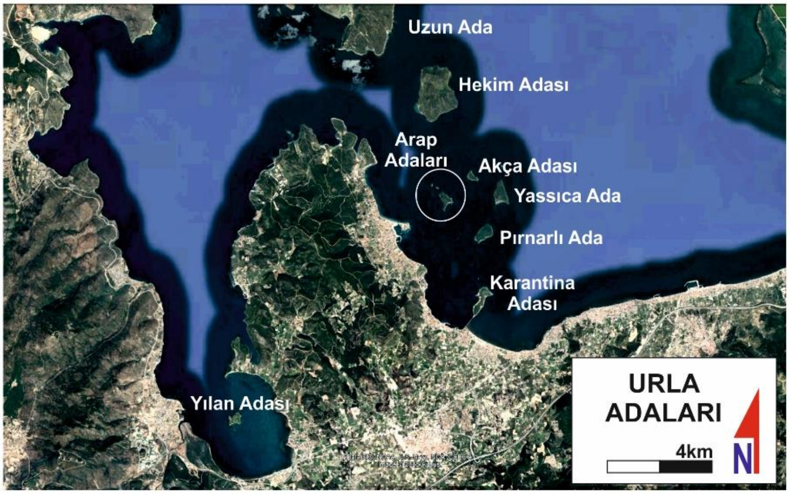
In İzmir Bay, small-scale fisheries are carried out as day-trip operations using fishing gears such as gillnets, handlines, and longlines. This type of fishing, generally characterized by demersal and semi-pelagic species, targets economically valuable species including red mullet, sparids (e.g., gilthead seabream, striped seabream, and white seabream), mullets, and common sole (Akyol 2017:99). Intensive use of coastal areas, urban and industrial pollution, habitat loss, and environmental changes driven by climate change exert pressure on fish stocks in the bay, leading to seasonal and spatial fluctuations in catch efficiency (Sayın, 2003:957).

4. Small-Scale Fisheries in the Urla Region

Urla is one of the coastal towns located in the southern part of İzmir Bay where small-scale fisheries have historically played an important role. Owing to its peninsula morphology, the presence of islets, and diverse seabed characteristics, small-scale fisheries are widespread along the Urla coast. Conducted mainly as day-trip operations and relying largely on passive fishing gears, fisheries in Urla represent a typical local-scale example of small-scale fisheries in the Aegean Sea and İzmir Bay.

Urla’s 40 km coastline along İzmir Bay, together with its surrounding islands, constitutes the main fishing grounds for local fishers. The Urla Islands located in the southern part of İzmir Bay include Hekim Island, Yassıca (Alman) Island, Pırnarlı Island, Akça Island, İncirli (Çiçek, Taş) Island, Karantina Island, and Uzunada (Fig.2). Uzunada and Hekim Island are designated as first-degree military zones with restricted access, and fishing is also prohibited within a 500 m buffer zone from the shoreline of Uzunada. These spatial restrictions and legal regulations have directly influenced the operational areas and fishing practices of small-scale fisheries in Urla. The prohibition of trawling, dredging, and similar active fishing gears has encouraged fishers to adopt more selective methods with relatively lower environmental impacts. In this context, various types of gillnets are among the most commonly used fishing gears in Urla, with the dönek method and nets being of particular importance to the local fishery (Tosunoğlu vd. 2022:1).

Figure.2. The Urla Islands located in the İzmir Bay



5. Dönek Fishing in the Urla Region

Dönek fishing is a fishing method that has been practiced for many years in the Urla region and has developed within the tradition of small-scale coastal fisheries. Fishing activities in the area are largely carried out in shallow, nearshore waters, primarily using gillnets. The dönek method, which represents a specific application of gillnets, has over time evolved into a fishing practice unique to the region. Shaped by fishers' observations based on local ecological knowledge—particularly regarding the seasonal movements and daily behavioral patterns of fish—dönek fishing has been practiced in the Urla İskele area for approximately 100 years (Per.Com with

İbrahim Temiztepe, S.S. Urla İskele Fisheries Cooperative). Transmitted from generation to generation, dönek fishing is regarded in Urla not only as a fishing technique but also as an integral part of local fishing culture.

Methodologically, dönek fishing is a passive fishing practice fundamentally based on the use of gillnets. In the Urla region, this fishing method is primarily carried out by members of the S.S. Urla İskele Fisheries Cooperative, although members of the S.S. Çeşmealtı Fisheries Cooperative and the S.S. Kalabak Fisheries Cooperative may also participate from time to time.

Within dönek fishing, an arrangement known among fishers as the "rotational system" is applied under unwritten rules. As of 2025, under this system, 15 fishers conduct fishing activities on a rotational basis across nine fishing grounds. These fishing grounds are locally named by fishers as Kayıkyatağı, PTT, Demirler, Kapı, Hastanealtı, Mezarlık Burnu, Gelinkaya, Polis Kampı, and Nebioğlu (Fig.3). Located along migration routes of different fish species, these fishing grounds are characterized by seagrass meadows or sandy and muddy seabed structures.

Figure.3. Fishing grounds used in dönek fishing in the Urla region

According to this fishing system, a fisher who begins setting the net at the first station (Area 4 in Fig. 3) continues fishing for nine consecutive days in accordance with the rotational order. After setting and hauling the dönek net at the final station (Area 12 in Fig. 3), the fisher then waits for six days before re-entering the cycle. Each fisher maintains the system by deploying their nets sequentially at these stations. Fishers who are not included in the rotation use other fishing grounds (Area 1, 2 and 3 in Fig. 3). Participation in this system is voluntary, and fishers may enter or leave the system at any time (Mermer, 2010:1; per.com. with Ertaç Akgün; S.S. Urla İskele Fisheries Cooperative).

Dönek fishing generally begins in April–May and continues until the end of the year (Mermer, 2010:1; Tosunoğlu vd. 2022:1). However, some fishers continue this activity between January and April at the six stations known to yield the highest catches.

The fishing gears used in this Urla–İskele–based fishery belong to the category of combined gillnets and are classified, in terms of operation, as bottom-set gillnets. Nevertheless, although these nets are categorized as bottom gillnets, they may locally extend from the seabed to the water surface, effectively covering the entire water column. In order to target both demersal and pelagic species simultaneously, the lower section of the net consists of trammel netting, while the upper section is composed of single-panel gillnets.

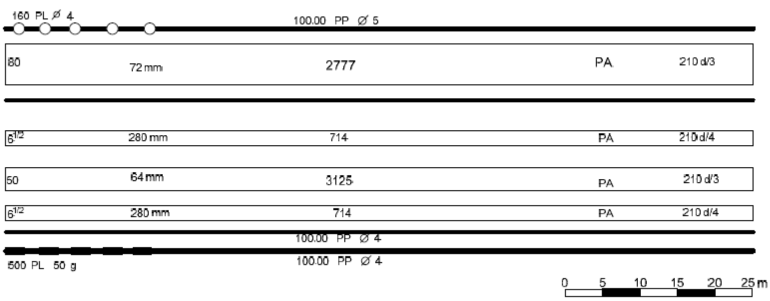
The upper part of the dönek nets is made of single-panel netting, whereas the lower section consists of trammel netting. Polyamide material is used in the trammel section, with a twine thickness of 210 d/4, a mesh size of 140 mm, and a net height of 6.5 meshes. The inner panel (tor) of this section has a twine thickness of 210 d/3, a mesh size of 32 mm, and a net height of 50 meshes. In the single-panel upper section, the twine thickness is 210 d/3, mesh size is 36 mm, and net height ranges between 60 and 160 meshes

(Mermer, 2010:1; Per.Com. with Ertaç Akgün; S.S. Urla İskele Fisheries Cooperative).

In the dönek method, maintaining the net in a near-vertical position is essential to increase catch efficiency. For this reason, floats numbered 4 and 5 are used in a configuration of three hollow floats and one solid float. As sinkers, bean-shaped lead weights of 50 g are employed, with each net unit (posta) equipped with approximately 500 sinkers. Polypropylene ropes of size No. 5 are used for the float line, while No. 3.5–4 polypropylene ropes are used for the lead line. (Mermer, 2010:1). No. 1.5 polypropylene twine is used to join the trammel net section to the single-panel net section (Fig. 4).

In dönek fishing, the nets are set before sunset by gradually deploying them from the shoreline toward offshore areas in a spiral pattern, forming an enclosure (kuzuluk). The nets remain in the water overnight and are hauled immediately after sunrise (Fig.5). This practice helps maintain the freshness of the catch while also limiting harm to non-target species and other organisms. In the nearshore section of the net, water depth ranges between 1 and 5 m, whereas the final section of the net extends to depths of up to 30 m

Figure.4. Technical characteristics of the nets used in dönek fishing in the Urla region (Mermer, 2010)



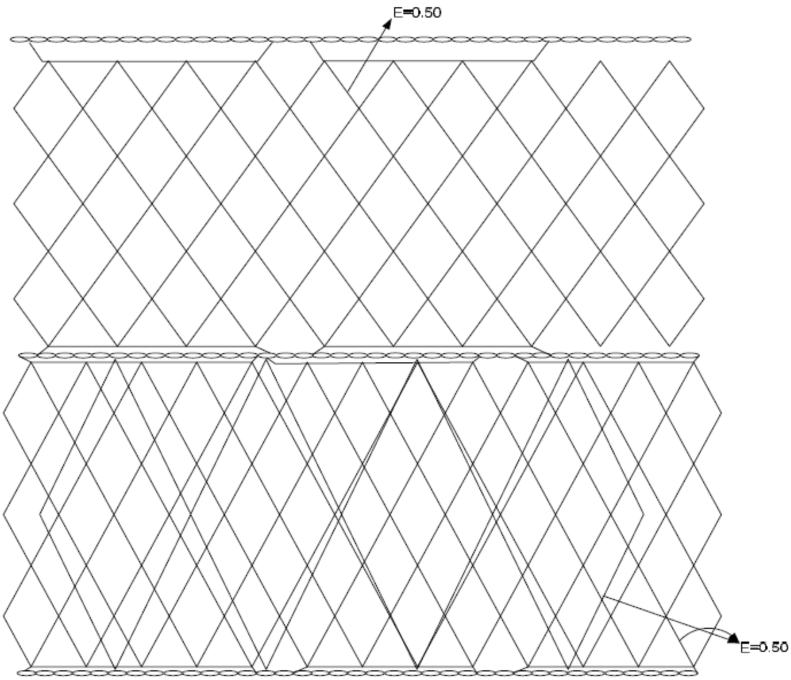


Fig. 7. Net-setting pattern used in dönek fishing

Using this method, gilthead seabream (*Sparus aurata*) is the most frequently caught species, followed by common sole (*Solea solea*), mullets (Mugil spp.), false scad (*Caranx rhonchus*), and common pandora (*Pagellus erythrinus*). The results indicate that the most productive period for dönek fishing is the autumn season (Table.1).

Table 1. Monthly species composition of catches obtained from dönek fishing in the Urla region in 2025

Species	January	February	March	April	May	June	July	August	September	October	November	December*	Total
Engraulis encrasicolus				75,0	7,5					1,5	3,0	1,5	**88,5**
Sardina pilchardus				54,0									**54,0**
Sarda sarda	19,5	15,0	165,0	217,5					118,5	412,5	667,5	33,0	**1648,5**
Auxis rochei									36,0	219,0			**255,0**
Scomber scombrus			1,5	9,0	1,5		10,5			64,5			**87,0**
Belone belone						6,0	4,5	7,5					**18,0**
Pomatomus saltatrix	1,5			7,5	27,0	6,0	15,0	9,0	12,0	12,0	22,5	19,5	**132,0**
Coryphaena hippurus									196,5	174,0	19,5		**390,0**
Mugil ssp.	985,5	625,5	1435,5	702,0	6,0	222,0	163,5	685,5	3075,0	1058,5	399,0	595,5	**9953,5**
Seriola dumerili				3,0			3,0				21,0	1,5	**28,5**
Dicentrarchus labrax	1116,0	54,0	45,0	1,5	4,5	27,0	3,0	10,5	9,0	58,5	4,5	7,5	**1341,0**
Caranx rhonchus	888,0	319,5	148,5	667,5	91,5	2062,5	2731,5	1003,5		25,5	37,5		**7975,5**
Sciaena umbra				1,5	6,0	4,5			1,5				**13,5**
Argyrosomus regius	3,0				357,0			6,0	1,5	15,0		213,0	**595,5**
Umbrina cirrosa	27,0	37,5	3,0			133,5	28,5	16,5	22,5	24,0		3,0	**295,5**
Boops boops								1066,5	183,0	73,5	25,5	6,0	**1354,5**
Sparus aurata	810,0	714,0	183,0	870,0	5214,0	1263,0	7104,0	726,0	1158,0	6456,0	13371,0	334,5	**38203,5**
Pagellus erythrinus	1623,0	1119,0	2748,0	766,5	10,5	18,0	7,5	90,0	4,5	1138,5	180,0	1,5	**7707,0**
Diplodus sargos	112,5	151,5	259,5	10,5	12,0	76,5	37,5	192,0	897,0	1356,0	286,5	75,0	**3466,5**
Diplodus vulgaris	18,0					15,0	66,0			54,0			**153,0**
Diplodus annularis	435,0	238,5	183,0	87,0		9,0							**952,5**
Dentex dentex	22,5		7,5	3,0	9,0	4,5	3,0			4,5	7,5		**61,5**
Lithognathus mormyrus	46,5	52,5	13,5	552,0	3321,0	664,5	108,0	100,0	54,0		7,5	6,0	**4925,5**
Sarpa salpa	237,0	150,0	172,5	51,0		30,0	562,5	417,0	142,5	136,5	6,0		**1905,0**
Oblada melanura	13,5	24,0	43,5	876,0		6,0	10,5	10,5	103,5	15,0			**1102,5**
Spicara maena	73,5	1,5											**75,0**
Sphyraena sphyraena	4,5		27,0	54,0	25,5	7,5	4,5	19,5	7,5	193,5	46,5		**390,0**
Mullus barbatus	456,0	259,5	96,0	120,0	9,0	3,0	3,0	3,0	718,5	997,5	238,5	343,5	**3247,5**
Mullus surmuletus									1,5				**1,5**
Solea solea	1,5	490,5	4713,0	5073,0	852,0	483,0	345,0	283,5	163,5	453,0	279,0	126,0	**13263,0**
Platichthys flesus		6,0	54,0	6,0	1,5					3,0	9,0	1,5	**81,0**
Scorpeana scrofa	6,0	1,5		97,5	114,0	1,5		9,0		1,5	4,5	3,0	**238,5**

* As the data for December are not yet fully available, only data from the first 15 days of the month were utilized."

6. Conclusions and Recommendations

This traditional fishing activity conducted using the dönek method in the Urla region reflects the characteristic features of small-scale fisheries in terms of species composition. The high economic value of the targeted species and the fact that these catches are offered for sale on the same day through cooperative-based auctions indicate that the marketing system employed is well aligned with the structure of traditional fisheries.

Although dönek fishing has been practiced in the region for approximately 100 years, there is no systematic data recording on species diversity or catch volumes. Monitoring and supporting this fishing practice therefore hold potential not only for fisheries management but also for contributing to the local economy through eco-tourism initiatives.

From an ecological perspective, dönek fishing demonstrates greater compatibility with sustainable fisheries approaches compared to other small-scale fishing gears, as it exerts limited physical pressure on habitats and allows for spatially controllable fishing activities. Nevertheless, the concentration of fishing pressure in specific areas, seasonal fluctuations in fish stocks, and environmental variability are among the key factors that require careful monitoring to ensure the long-term sustainability of dönek fishing in Urla.

Several factors influence the sustainability of dönek fishing. The prohibition of all fishing activities around Uzunada due to its military status, the designation of the areas surrounding Liman Tepe and Karantina Island as archaeological excavation sites, and restrictions resulting from intense maritime traffic in İzmir Bay significantly limit alternative fishing opportunities for local fishers. In this context, ensuring the sustainability of dönek fishing requires, first and foremost, the protection of fishing grounds, systematic monitoring within fisheries management frameworks, and targeted support measures to enhance the resilience of this traditional fishing practice.

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BÖLÜM 2

OPPORTUNITIES AND CHALLENGES OF ANTIMICROBIAL PEPTIDES IN SHRIMP AQUACULTURE

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Introduction

Aquaculture has turned into a strategic food production sector in parallel with the rising global demand for animal protein. As capture fisheries have reached their biological limits, for the first time in history, aquaculture production exceeded capture production in 2022 (FAO, 2024a; FAO, 2024b; AP, 2024). One of the clearest examples of this trend has been observed in shrimp farming. Over the past decade, penaeid shrimp production has shown remarkable exponential growth in terms of technology use, production intensity, and system design (Emerenciano et al., 2022: 236; Kaya, 2025: 232).

The shift to intensive and super-intensive systems has brought new production protocols supported by higher stocking densities and advanced engineering solutions. Closed-loop models such as biofloc and recirculating aquaculture systems (RAS) have emerged as alternative farming approaches in modern shrimp aquaculture by improving productivity and enabling better environmental control (Samocha, 2019; Rajeev et al., 2021: 238; Kaya et al., 2020: 735526;

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Kaya, 2025: 232). However, these systems also lead to increased organic matter accumulation and higher pathogen pressure, particularly from virulent agents like Vibrio species and white spot syndrome virus (WSSV), making biosecurity management more critical (Seethalakshmi et al., 2021: 1591).

The growing disease pressure in the sector has become a global concern, not only due to production losses but also because of the risks associated with antibiotic use. Intensive antibiotic application leads to the emergence of resistant bacteria, environmental contamination, and serious public health threats (Okeke et al., 2022: 69241; Mohammed et al., 2025: 598; Milijasevic et al., 2024: 2448). As a result, there has been increasing international policy pressure to regulate antibiotic use (Le & Munekage, 2004: 922; Kaya et al., 2020: 735526; Xiao et al., 2023: 9012; Yuan et al., 2023: 420; Luthman et al., 2024: 9253).

To ensure sustainability in intensive systems and manage disease more effectively, responsible farming practices have been introduced—particularly those supporting shrimp physiology and gut microbiota through functional feeding strategies. In recent years, compounds such as prebiotics, postbiotics, phytobiotics, polyhydroxybutyrate (PHB), and especially antimicrobial peptides (AMPs) have become key tools to reduce pathogen pressure and enhance host immunity (Shohreh et al., 2024: 37; Rodrigues et al., 2025: 156; Zhu et al., 2025: 4375783). These approaches are expected to become central components of next-generation biosecurity strategies in sustainable shrimp farming.

The Importance of Shrimp Farming in The Global Economy

Shrimp farming is one of the most economically valuable segments of global aquaculture trade. According to FAO data from 2024, total aquatic production has reached 223.2 million tons, and for the first time, aquaculture has surpassed capture fisheries in total output (FAO, 2024a; FAO, 2024b; AP, 2024). Within this production, shrimp stands out as one of the highest value-added product groups, and the volume of international trade continues to grow steadily. Asian countries, especially China, India, Vietnam, and Indonesia, are responsible for the majority of global shrimp production and have a strong influence on market dynamics worldwide (Rajeev et al., 2021: 238; Emerenciano et al., 2022: 236; Mandal & Singh, 2025: 1).

Because of its impact on export revenues, employment, and coastal economies, shrimp farming is defined as a strategic sector in the national development plans of many countries (FAO, 2024a; FAO, 2024b). As production capacity increases, functional feeds, advanced farming systems, and biosecurity applications have become key drivers of technological transformation in the sector.

In the case of Türkiye, shrimp farming is not yet as widespread as in Asia, but it is now seen as a fast-growing niche industry. Türkiye's geographical proximity to the European market, the demand for high value-added export products, and the availability of suitable coastal areas support the medium-term growth potential of shrimp aquaculture. New farming projects, system innovations, and research activities across the country continue to strengthen this outlook (Genç et al., 2007: 156; Kaya et al., 2019: 491; Kaya et al., 2020: 735526; Aktaş et al., 2022: 81; Kaya & Genç, 2024: 251; Genc et al., 2024a: e13086; Genc et al., 2024b: e13041; Kaya, 2025: 232).

The economic scale and global competitiveness of the sector require sustainable production models and effective disease management in shrimp farming. At this point, reducing antibiotic use, increasing the adoption of functional feed additives, and developing alternative approaches such as AMPs have become important. These steps are essential for both economic sustainability and the adoption of ethical practices in aquaculture (Mohammed et al., 2025: 598; Milijasevic et al., 2024: 2448).

Disease Challenges in Shrimp Farming

In intensive and super-intensive shrimp farming systems, the increase in organic load, disruption of microbial balance, and intensification of stress factors significantly raise the susceptibility of shrimp to pathogens (Rajeev et al., 2021: 238; Emerenciano et al., 2022: 236). Infectious diseases in shrimp aquaculture are commonly classified into three main categories: bacterial, viral, and parasitic.

Among bacterial pathogens, *Vibrio parahaemolyticus*, *V. harveyi*, *V. alginolyticus*, and *V. vulnificus* are the most frequently reported. Outbreaks caused by toxin-producing strains of *V. parahaemolyticus*, known to lead to acute hepatopancreatic necrosis disease (AHPND), have resulted in high mortality rates in Asia and Latin America (Okeke et al., 2022: 69241; Mohammed et al., 2025: 598). Viral diseases can cause devastating losses in shrimp production. White spot syndrome virus (WSSV) is one of the most aggressive viral infections, capable of causing high mortality within hours. Due to its rapid transmission capacity, WSSV remains a continuous threat to shrimp farming worldwide (FAO, 2024a). Other important viral agents include infectious myonecrosis virus (IMNV), yellow head virus (YHV), and Taura syndrome virus (TSV), all of which can lead to serious economic damage. Parasitic diseases are less common. However, infections such as gregarines and microsporidians like *Enterocytozoon hepatopenaei* (EHP) can lead to growth retardation, digestive disorders, and reduced production performance. Due to its rising prevalence, EHP is now closely monitored for biosecurity and production planning purposes (Seethalakshmi et al., 2021: 1591; Milijasevic et al., 2024: 2448).

The main causes of infections include high stocking density, poor water quality, organic matter accumulation, inadequate nutrition, and stress-related immune suppression (Rajeev et al., 2021: 238). A shift in gut microbiota composition is also considered an important mechanism that increases vulnerability to disease.

Traditionally, antibiotics have been used extensively in shrimp farming, often without clear evidence of disease. Although this provided short-term benefits, the long-term result has been an increase in pathogenic bacteria carrying antimicrobial resistance genes, posing significant risks for both aquaculture and public health (Yuan et al., 2023: 420; Mohammed et al., 2025: 598). Because of this, strict international regulations on antibiotic usage are now being implemented (Luthman et al., 2024: 9253). In light of these developments, the current approach to disease management is no longer focused solely on suppressing pathogens. It also includes strengthening immune responses, modulating the microbiota, and applying integrated biosecurity protocols (Wimley & Hristova, 2011: 27; Lee et al., 2015: 475062; Richter et al., 2022: 1710; Naiel et al., 2023: 691; Islam et al., 2024: 1542; Ma et al., 2024: 540; Zhou et al., 2025: e12986). Functional feed additives, probiotics, postbiotics, polyhydroxybutyrate (PHB), phytobiotics, and especially antimicrobial peptides (AMPs) are now recognized as promising tools for enhancing disease resistance, stabilizing gut microbiota, and limiting pathogen colonization (Rodrigues et al., 2025: 156; Shohreh et al., 2024: 37; Zhu et al., 2025: 4375783). As a result, disease management is shifting away from classical treatment methods and moving toward preventive and supportive biosecurity strategies.

Antimicrobial Peptides (AMPs)

Definition and general properties of AMPs

Antimicrobial peptides (AMPs) are described as some of the most ancient and universal defense molecules in the innate immune system. These short peptides are positively charged and amphipathic, meaning they have both hydrophobic and hydrophilic parts, and they can act quickly against a wide range of pathogens including bacteria, viruses, fungi, and protozoa (Rodrigues et al., 2025: 156; Shohreh et al., 2024: 37).

Since there is still no strong scientific evidence of adaptive immunity in shrimp and other invertebrates, AMPs are believed to play a central role in the early response to infections and in regulating inflammatory processes. They usually consist of 6 to 100 amino acids and contain both hydrophobic and cationic regions, which help them to recognize microbial membranes and maintain low toxicity to host cells (Zhu et al., 2025: 4375783). In shrimp, the most studied AMP groups are penaeidins, crustins, anti-lipopolysaccharide factors (ALF), and lysozyme-like peptides. In addition to their antimicrobial functions, these molecules can also influence immune processes such as phagocytosis, melanization, activation of the prophenoloxidase (proPO) system, and hemocyte differentiation (Rajeev et al., 2021: 238). AMPs are attractive because they can be produced quickly, are stable under environmental stress, and have broad-spectrum effects. These features make them promising tools for modern biosecurity strategies, especially in combating antibiotic resistance (Mohammed et al., 2025: 598; Milijasevic et al., 2024: 2448).

Structural classification and modes of action

AMPs can be grouped into four main classes based on their biophysical properties. These include alpha-helical AMPs, beta-sheet (disulfide-bridged) AMPs, loop or coil-structured AMPs, and amino acid-rich AMPs. This classification is directly related to the stability of the peptides and their ability to kill pathogens (Shohreh et al., 2024: 37; Rodrigues et al., 2025: 156). Alpha-helical AMPs are the simplest form. They usually do not contain disulfide bonds and can form alpha-helices when they bind to membranes. Thanks to their amphipathic nature, they can quickly penetrate bacterial membranes. Some helical peptides in penaeid shrimp have shown strong activity against *Vibrio* species. Beta-sheet AMPs such as crustins and ALFs are very common in shrimp and contain one or more disulfide bridges. These bridges increase their ability to bind lipopolysaccharides (LPS), making them particularly effective against Gram-negative bacteria. They are also more heat stable, which is useful for feed formulation (Zhu et al., 2025: 4375783). Loop or coil AMPs have loop-like structures that are stabilized by disulfide bonds or metal ions. These peptides are energy-efficient and often act against specific targets. Many of them bind to viral envelope proteins and stop the infection process. Amino acid-rich AMPs contain high levels of certain amino acids like arginine, proline, histidine, or glycine. These peptides can block specific microbial targets. For example, histidine-rich peptides are more active at low pH and are effective against gastrointestinal pathogens. Thanks to this structural diversity, AMPs can provide a wide and adaptable range of defence responses.

Antimicrobial mechanisms of AMPs

Among the antimicrobial effects of AMPs, the most studied and rapid mechanism is their action on the cell membrane. Cationic AMPs bind electrostatically to negatively charged phospholipids on bacterial membranes. This leads to the formation of pores or the disruption of the membrane surface, which can cause ion imbalance, leakage of cell contents, and eventually cell death (Shohreh et al., 2024: 37). Another mechanism involves targeting inside the cell.

Some AMPs can pass through the membrane and bind to DNA, RNA, or ribosomal structures. This blocks DNA replication, transcription, protein synthesis, and enzymatic activity. This effect is especially important in shrimp AMPs that suppress viral replication (Rodrigues et al., 2025: 156). AMPs are not only killer molecules. They also regulate the host immune system. For example, in shrimp, ALF and crustins can increase hemocyte activation, boost phagocytosis, stimulate the proPO system, and strengthen antiviral responses (Rajeev et al., 2021: 238). Because of these effects, when AMPs are used as functional feed ingredients, they not only suppress pathogens but also help activate the whole immune system.

The Immune System of Shrimp

Unlike vertebrates, shrimp and other arthropods do not develop adaptive immune responses. This means their defense against infections depends entirely on the innate immune system. This system is composed of both cellular and humoral components. In aquaculture environments, where environmental stress factors are common, the immune system is considered a key determinant of survival and growth performance (Rajeev et al., 2021: 238). Shrimp immunity works through fast and energy-efficient mechanisms, giving them the ability to respond flexibly and dynamically to high pathogen loads under intensive farming conditions.

The immune response generally follows three steps: recognition, neutralization, and clearance. Key molecules involved in these processes include pattern recognition receptors (PRRs), the prophenoloxidase (proPO) system, phagocytic mechanisms, antimicrobial peptides (AMPs), lysozyme, and hemolin (Dawood, 2021: 642; He et al., 2021: 710845; Emerenciano et al., 2022: 236; Rajendran et al., 2022: 17).

Cellular immune mechanisms in shrimp

Hemocytes are central to cellular immunity. These immune cells circulate in the hemolymph and respond quickly to pathogens. There are three main types of hemocytes: hyaline, semi-granular, and granular hemocytes. These cells are responsible for important tasks such as phagocytosis, encapsulation, nodule formation, and the release of antimicrobial molecules. During infection, the number and activity of hemocytes can change rapidly. Phagocytosis involves the recognition and internalization of pathogens by hemocytes. This process is triggered by the interaction between PRRs and pathogen-associated molecular patterns (PAMPs). It is one of the fastest and most effective defense mechanisms against bacterial and fungal infections. When environmental stress reduces phagocytic activity, shrimp become more vulnerable to disease. For example, suppressed phagocytosis during *Vibrio* infections has been linked to higher mortality rates (Okeke et al., 2022: 69241; Mohammed et al., 2025: 598). Encapsulation and nodule formation involve the clustering of hemocytes around large or multicellular pathogens, often working together with melanization. This leads to the accumulation of toxic reactive oxygen or nitrogen species on the pathogen surface.

Humoral immune mechanisms in shrimp

The prophenoloxidase (proPO) system is one of the best-known humoral defense mechanisms in crustaceans. Once a pathogen is recognized, proPO is activated and converted into the enzyme phenoloxidase. This leads to melanin formation, which helps isolate the pathogen and produce toxic oxidants. If the proPO system is suppressed during viral infections, mortality rates can increase significantly (Milijasevic et al., 2024: 2448).

Pattern recognition receptors (PRRs) are essential for detecting pathogens in shrimp. They recognize molecules like LPS, peptidoglycan, beta-glucan, and viral envelope proteins and activate all immune defenses. Important PRR subtypes include C-type lectins, beta-glucan binding proteins, LPS-binding proteins, and Toll-like receptor-like structures. Reduced PRR activity, especially under intensive farming conditions, can increase susceptibility to infections (Rajeev et al., 2021: 238).

Antimicrobial peptides (AMPs) are among the most important non-cellular immune components. ALF, crustin, penaeidin, and lysozyme-like peptides are central to the rapid response against pathogens. The fact that AMP gene expression can increase within minutes of infection highlights their critical role in the immune system (Zhu et al., 2025: 4375783; Rodrigues et al., 2025: 156). Lysozyme is another humoral molecule, especially effective against Gram-positive bacteria through peptidoglycan hydrolysis. Other humoral defenses include reactive oxygen species (ROS), anticoagulant factors, and various protease inhibitors.

Interaction between microbiota and immunity in shrimp

Shrimp immunity is not limited to recognizing and killing pathogens. The stability of gut microbiota is also important for both the strength and consistency of immune responses. A balanced microbiota can increase phagocytic capacity, block pathogen colonization, enhance AMP and proPO activity, and protect the integrity of the gut barrier. In intensive systems, disruptions in microbial balance can lead to rapid pathogen growth and immune suppression (Rajeev et al., 2021: 238).

Therefore, feed additives such as probiotics, PHB, postbiotics, and AMPs should be considered important tools at the intersection of immunity and microbiota regulation. It is also known that environmental factors like stress, ammonia accumulation, poor nutrition, sudden temperature changes, and high stocking density can suppress the immune system (Emerenciano et al., 2022: 236). Since traditional treatment methods are no longer effective due to antibiotic resistance problems, immune support is now seen as an essential part of sustainable shrimp farming (Luthman et al., 2024: 9253; Mohammed et al., 2025: 598).

Applications of Antimicrobial Peptides (AMPs)

Antimicrobial peptides (AMPs) are seen as a strong alternative to deal with key problems in shrimp aquaculture, such as increasing antibiotic resistance, rising pathogen pressure in intensive systems, and microbiota instability. As core components of the natural immune response, AMPs have wide-ranging effects. They help improve growth performance, strengthen immune activity, and increase resistance to pathogens (Rodrigues et al., 2025: 156; Shohreh et al., 2024: 37; Zhu et al., 2025: 4375783). For this reason, using AMPs directly as feed additives, combining them with probiotic or postbiotic platforms, or applying strategies that stimulate their gene expression are current research topics.

Effects of AMPs on growth performance

In shrimp, growth depends strongly on digestion efficiency, gut integrity, and microbial balance. AMP applications can help reduce pathogen colonization in the gut and create a more stable microbial environment. This may lead to better digestion, improved feed conversion ratio, and lower metabolic stress. Previous studies have shown that dietary AMPs improved feed efficiency and significantly increased weight gain in species like *Litopenaeus vannamei* (Rajeev et al., 2021: 238). In addition, beta-sheet AMPs that contain disulfide bridges are more heat-stable. This allows them to remain active during feed processing steps like extrusion, which increases their practical use in feed formulation (Zhu et al., 2025: 4375783). These features make AMPs a promising functional ingredient in commercial feed development.

Effects of AMPs on immune response

AMPs have a clear advantage in modulating the shrimp immune system quickly and effectively. When shrimp are fed with natural AMPs such as ALF, crustin, and penaeidin, several positive changes have been observed. These include increased hemocyte count, improved phagocytic capacity, higher proPO activity, optimized ROS production, and faster antiviral responses (Milijasevic et al., 2024: 2448; Rodrigues et al., 2025: 156). These findings show that AMP applications may help prevent stress-related immune suppression, especially in intensive systems. The immune-stimulating effect of AMPs is not limited to infection conditions; they may also enhance immunity under normal farming conditions.

Effects of AMPs on microbiota modulation

The shrimp gut is one of the most important immune-related organs. Instability in the gut microbiota can cause critical problems such as pathogen overgrowth, digestion issues, and slow growth. AMPs have been shown to support the stability of beneficial bacteria, reduce attachment and growth of opportunistic pathogens, protect intestinal epithelial integrity, and help maintain microbial diversity at optimal levels (Rajeev et al., 2021: 238). These effects can be strengthened when AMPs are combined with probiotics or postbiotics. Some recent studies even suggest AMP–probiotic combinations as a new biotechnological approach to target the shrimp microbiota more effectively.

AMPs are especially valuable because they provide broad-spectrum protection against both bacterial and viral pathogens. Various *in vivo* studies have shown that AMPs reduce disease severity, increase survival rates, and suppress viral load in infections caused by *Vibrio* *parahaemolyticus*, *V. harveyi*, *V. alginolyticus*, WSSV, and IMNV (Okeke et al., 2022: 69241; Mohammed et al., 2025: 598). The role of AMPs in pathogen resistance works at two levels. First, they act directly by damaging membranes, binding to viral capsid proteins, or inhibiting DNA/RNA activity. Second, they have indirect effects by boosting hemocyte activation, speeding up the proPO system, and increasing expression of antiviral genes. Because of this dual action, AMPs are considered useful not only for treatment but also for prevention.

AMPs as feed additives

AMPs are quickly gaining interest as alternatives to antibiotics in both fish and shrimp farming. However, some opportunities and challenges exist for commercial use. The opportunities include broad-spectrum action, low risk of resistance development, fast antimicrobial effects, immune modulation, microbiota stabilization, easy inclusion in feed, and safe use for public health (Luthman et al., 2024: 9253). The challenges include low stability of some AMPs against digestive enzymes, still high production costs in some regions, rare but possible toxicity at high doses, the need for standardization in industrial-scale production, and limited long-term performance data for AMP-feed combinations (Zhu et al., 2025: 4375783). Current studies are focusing on making AMPs more stable through nanoencapsulation, microencapsulation, recombinant production, and genetic stimulation techniques. In particular, feeding strategies that enhance natural AMP gene expression in crustaceans such as PHB, MOS, ginseng, or beta-glucan are seen as future hybrid solutions with growing application potential.

General Evaluation and Conclusion

Shrimp aquaculture is a rapidly growing industry worldwide and holds strategic importance for food security. However, the transition to intensive and super-intensive farming systems has created a more complex production ecosystem, both environmentally and in terms of biosecurity. The most vulnerable point in this system is the high infection pressure caused by bacterial, viral, and parasitic pathogens. These agents are the leading cause of economic losses in global shrimp production (Emerenciano et al., 2022: 236; Milijasevic et al., 2024: 2448). But while effective control of viral and parasitic pathogens remains limited, the overuse of antibiotics against bacterial infections has led to rising resistance and serious public health risks. This makes antibiotics an increasingly unsustainable solution (Yuan et al., 2023: 420; Luthman et al., 2024: 9253). Although some research has attempted vaccination in shrimp, current knowledge suggests that these animals do not develop immune memory like vertebrates. Therefore, attention has shifted toward alternative biological protection strategies. Among these, antimicrobial peptides (AMPs), microbiota modulators, prebiotics, probiotics/postbiotics, synbiotics, PHB, and phyto-biotics are seen as promising new-generation functional tools in aquaculture (Hersi et al., 2023: 739391; Kaya, 2025: 232). AMPs, with their broad antimicrobial and immunomodulatory roles, including direct bactericidal/virucidal activity, stimulation of immune responses, and stabilization of gut microbiota, are positioned as central components in modern shrimp biosecurity (Rodrigues et al., 2025: 156; Shohreh et al., 2024: 37; Zhu et al., 2025: 4375783).

Recent studies have focused on the ability of AMPs to provide early and fast immune defense, supporting both cellular and humoral immunity even in the absence of adaptive responses. Their structural diversity such as α-helical, β-sheet, loop-type, and amino acid–rich classes offers a broad and flexible antimicrobial defense system. This wide spectrum, not limited to a single pathogen group, provides layered protection and is a key advantage of AMP-based strategies. It is expected that future research will focus on integrating AMPs into shrimp farming practices as essential components of next-generation health management.

However, the use of AMPs as feed additives has certain limitations. Some AMPs are easily degraded by digestive enzymes, reducing their stability in the gut. Technologies such as nanoencapsulation, polymer coating, microencapsulation, and lipid-based delivery systems offer strong potential to improve their stability (Zhu et al., 2025: 4375783). In the future, it is expected that these technologies will be standardized in the feed industry. Natural AMP production can be expensive, but recombinant DNA methods using microorganisms for AMP synthesis could reduce costs and increase production volumes. Additionally, synthetic design optimization (e.g., reducing toxicity or improving target specificity) is emerging as another promising area.

Modulating gut microbiota may produce even stronger effects than AMP application alone. It is believed that this approach could reshape new-generation feed formulations, improving both immune responses and microbial stability. Functional additives such as mannan oligosaccharides (MOS), fructo-oligosaccharides (FOS), galacto-oligosaccharides (GOS), β-glucan, polyhydroxybutyrate (PHB), and plant-based extracts are expected to enhance AMP gene expression naturally. Thus, feeding strategies that boost natural AMP production in shrimp may become more common. Although AMPs are thought to have a low risk of inducing resistance, more long-term ecological studies are needed. Understanding their lasting effects on the shrimp genome and microbial ecosystems is essential before widespread commercial use (Mohammed et al., 2025: 598).

AMPs are likely to be especially beneficial in high-density systems like recirculating aquaculture systems (RAS) and biofloc models.

For this reason, more research is needed on AMP dose optimization, water parameter interactions, and microbial community dynamics. As the FAO 2024 data show, global shrimp farming continues to grow rapidly. For this growth to remain sustainable, antibiotic use must be nearly eliminated and replaced with functional and biotechnological approaches. AMPs, with their broad-spectrum effects and immune-enhancing roles, may play a key role in supporting responsible production that prioritizes animal welfare and consumer health in the future of shrimp aquaculture.

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BÖLÜM 3

ENVIRONMENTAL PROBLEMS AND PRECAUTIONS OF ISKENDERUN GULF IN EASTERN MEDITERRANEAN REGION

HILAL KARGIN ERÖRS[1]

HATICE SÖNMEZ[2]

Introduction

Marine pollution could be defined as the direct or indirect abandonment of the marine environment by people, as it harms the marine ecosystem, disrupts human health, hinders activities in the sea, affects the quality of marine use, and reduces its value (Yiğit, 2006:172). Although it has damaging effects on humans in various ways, marine pollution is particularly damaging to organisms living in the sea. The decreasing number of living species and the already extinct number of species in our seas is a direct result of the increase in sea pollution and the growth of coastal structures resulting from urban, industrial, and agricultural wastes. Marine pollution from various ways is of great importance in terms of the sustainability of natural resources and the future of human welfare. Most of the sources of marine pollution originate from land and human activities. Sea pollution is affected directly by an excessive rate of nutrient discharge. Eutrophication on water surfaces occurs by increasing algal growth because of overabundant nutrients in the environment, such as nitrogen and phosphorus. The rate of polluting elements within the entire pollution is shown in Figure 1 (Satır, 2007:137).

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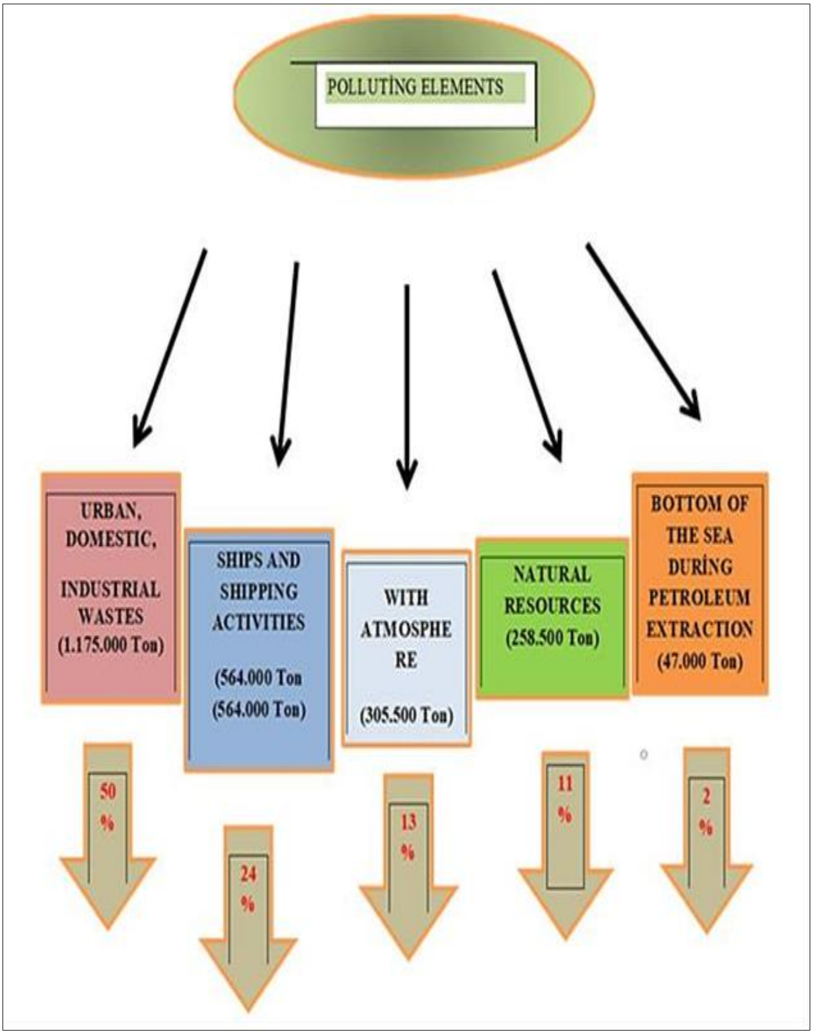
Main Causes of Marine Pollution

The effluents created by the cities, the industrial facilities located along the seaside, the oil platforms and pipelines installed in the sea and the oceans, the vehicles using air and sea way, the ship accidents (especially oil carrying vessels) are specifically an intentional or unintentional sources of marine pollution. In Turkey, as in the whole world, problems related to marine pollution and coasts are of great importance. Due to their high capacity in maritime transportation, tankers and the crude oil they carry play a significant role in marine environmental pollution (Aşan et al., 2020: 1). Not only ships but also offshore platforms engaged in drilling activities and seabed storage activities for nuclear and chemical waste should be considered as sources of pollution (Tütüncü, 2004: 2). Past marine accidents have led to legal regulations that grant states the authority and responsibility to save human lives at sea and the necessity of international cooperation (Töz & Olgaç, 2020: 46). Pollution of the marine environment, both from ship accidents and other activities, and the resulting damages suffered by coastal countries, necessitate the implementation of a series of measures in this area. The process of protecting the marine environment, which began with the 1954 International Convention for the Protection of the Seas against Oil Pollution (1954 OILPOL), has evolved with numerous international regulations and has introduced various rights and responsibilities to states. Turkey has established domestic law to protect its rights and interests arising from international law and to fulfill its obligations within the scope of preventing and responding to loss of life and property at sea, as well as marine pollution. In this context, in 2005, it enacted the implementing regulations related to Law No. 5312 on Emergency Response and Compensation for Damages in Pollution of the Marine Environment by Oil and Other Harmful Substances. It published its Response Plan (UAMP) and designated "Marine Pollution Emergency Response Responsibility Areas" in the surrounding seas.

Figure 1. *Polluting elements and their rate in pollution according to 1990 data*



Source: (Satır, 2007:137)

In addition to industrial, maritime transport, urbanization, tourism, and waste disposal, Turkish seas started to become more polluted every day by sea accidents. However, Turkish waters are also contaminated with domestic and industrial wastes because of their geographical position, which is surrounded by three major seas. Much of the wastes generated by industrial and household sewage are directly discharged to the waterbeds without any treatment, and the solid wastes are left irregularly in the receiving environment. The seas are also becoming polluted due to the unconscious agricultural pesticide application and fertilization practices carried out throughout the country. As well as its direct harmful effects on the marine environment, it is known that liquid wastes generated by industrial activities also cause pollution on the soil and vegetation, which results in the destruction of nature. Residue from spraying pesticides for agricultural pest control and the wastes generated as smoke from industrial factories could pollute the water sources due to the wind-water transferring of the dangerous chemical particles in the air. On the other hand, unconscious and excessive use of chemical fertilizers over time also makes the soil debilitated, which results in the deterioration of both soil fertility and water pollution due to infiltration of groundwater and surface water flows and superficial water contamination. Overall, the use of seas for transportation and tourism, the discharge of domestic and industrial wastes to the sea without being treated or partially purified, the oil flows from the aftermath of sea accidents, and the agricultural wastes reaching the waters from the rivers are the main factors that cause pollution marine environment. The waters that cause marine pollution affect human health and the environment negatively at certain times, depending on the concentration of pollution in a certain area.

Other factors that cause marine pollution could be listed as follows

Wastes are discharged from the city centers and industrial facilities on the seashore and discharged to the sea without treatment; Soil and other contaminants that enter the sea with erosion after being used in agricultural areas. The soil is transported to the sea by erosion in considerable quantities every year from agricultural areas; Therefore, wastes generated by agricultural activities, mainly chemical wastes such as pesticides and fertilizers, are transported into the marine environment through a series of rivers and their tributaries; Leaks consisting of platforms and pipelines installed in the seas.

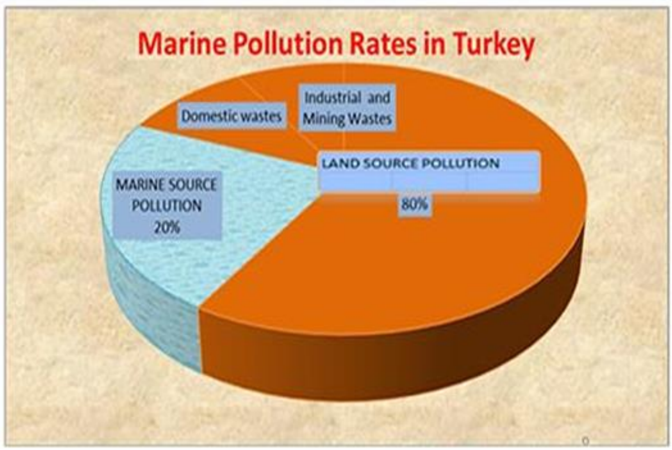
Pollution from ships and other sea vessels is mainly oil, oil waste, toxic liquids, sewage, garbage, etc. Because of sea accidents, a considerable amount of oil spillage accumulates in the water and threatens the marine habitats. Especially large oil tankers' accidents cause thousands of tons of crude oil to spill into the sea. Crude oil transportation, petrochemical industries, and developments in the organic chemistry industry have increased the amount of pollution in land, air, and seas. The release of plastic materials from land and from ships to the sea could create serious damage to the beaches and the natural life of the seas.

In conclusion, Sea route transportation, oil refinery in Mersin, and two oil pipeline terminals in Iskenderun Bay are important pollutants in the Eastern Mediterranean. However, the pollution rate in the Mediterranean Sea is lower than that of the Marmara and the Aegean Sea. Moreover, the rapid development of industrial and technological infrastructure in the region in recent years has resulted in an increase in migration from rural to urban areas, leading to rapid and irregular urbanization. On the other hand, the ever-decreasing number of living species in our seas is a result of the increase of marine pollution resulting from urban, industrial, and agricultural wastes and the growth of coastal formations. Marine pollution from various ways is of great importance in terms of the sustainability of natural resources and the future of people.

Marine Pollution in Turkish Seas

Turkey is exposed to intense sea traffic due to its geographical location, surrounded by three major seas. The major sources of marine pollution consist of pollutants released from land and freshwater river systems into the marine environment. There is also pollution originating from the atmosphere or formed through the atmosphere (Fig. 2; Baykal & Baykal, 1999:9).

Figure 2. *Percentage of marine pollution in Turkey*



Source: (Baykal et al., 1999:9).

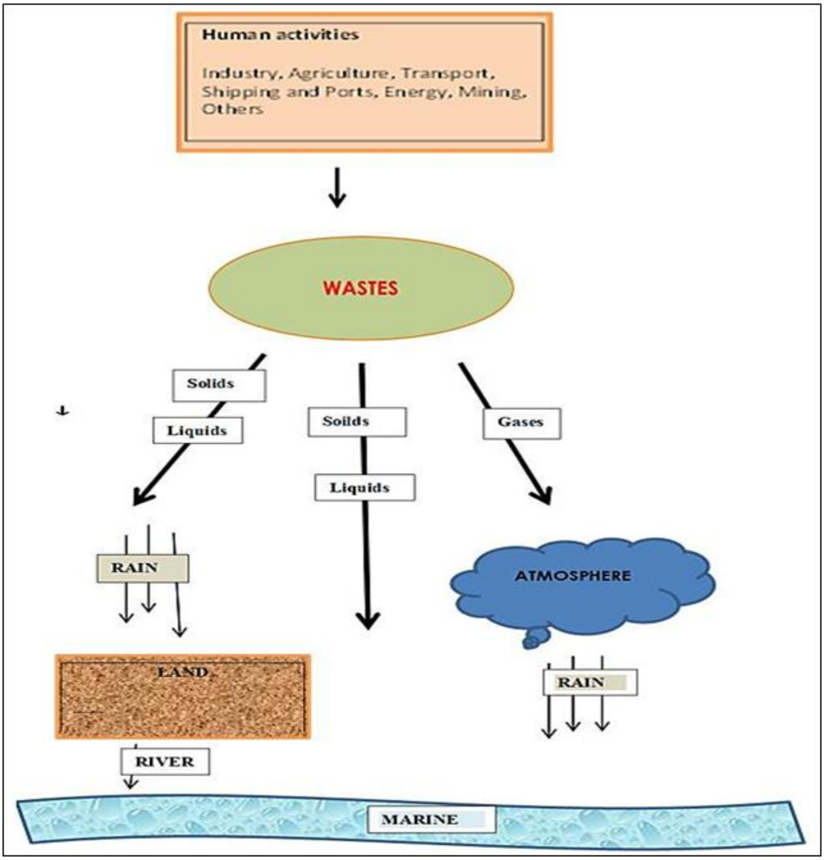
Marine Pollution Sources in the Mediterranean Region

The sources of marine pollution are very different and can be classified according to the characteristics of the pollutants as follows (Table 1) (Artüz, 1992:90). The sources of water pollution in Part XII of 1982 Convention on the Sea Law as to "protection and preservation of the marine environment" have been provided in six items (Fig. 3):

- Pollution originating from land-based sources.
- Pollution originating from activities made within the sea bed of the national jurisdiction.
- Pollution originating from activities carried out in the region (area).
- Pollution originating from agricultural and industrial discharge to water (dumping).
- Pollution originating from or through the atmosphere,

- Pollution originating from shipping vessels.

Figure 3. *Pollution sources*



Source: (Keskin, 2006:191)

Water that constitutes the source of life on Earth is also an important element of pollution on Earth. Today, sea pollution causes a decrease in oxygen in seawater, which is considered a sign of poisoning of marine organisms living in the sea.

1. Land-based pollution sources

One of the most important indicators of environmental pollution is sea pollution. Half of the world's population lives near the oceans and seas. For this reason, sea pollution is a vital issue for the countries connected to the sea. Wastes dumped from land to sea are classified into two categories as domestic and industrial wastes. From industrial facilities to marine water, wastes such as soluble salts, gases, chemical substances, and organic molecules that cannot be otherwise purified by natural means are being considered seriously all over the world due to the high pollution impact that they could create. Industrial wastes also contain toxic heavy metals such as cadmium, mercury, and lead. As a result of the production technology, the chemical substances used rapidly disrupt the marine environment. This problem, which is more prevalent in developed countries, causes damage affecting all countries. The fact that the Mediterranean has a very important role in the delivery of human food supply and transportation for the region, its integrity is greatly affected by human movements (Küçük & Topçu, 2012:4). Wastewater received from the coastal cities is one of the basic pollution aspects of the Mediterranean coast. The impact thereof on marine life is reflected in the health of humans living in the coastal zone as well as the stability of the water ecosystem and economy (effects on tourism and aquaculture), directly or indirectly. Rapid urban growth in the southern coasts of the Mediterranean aggravates the issue in particular. The wastewater collection system is furnished to a certain part of the urban population in general. And this leads to the release of much of the untreated wastewater directly into the sea by virtue of other systems.

- **The primary pollutants in urban wastewaters are as follows**

Organic matter (measured as BOD5 and COD), suspended solid materials, nutrients (nitrogen and phosphorus), and pathogenic microorganisms. Other pollutants, including heavy metals, petroleum, and chlorinated hydrocarbons, also exist in sewage water (Anonymous, 2009:65).

The amount of solid waste produced in city centers along the Mediterranean coast poses a serious threat to human health, in addition to the marine and coastal environment. Besides disposal of uncontrolled waste as garbage, solid wastes are dumped into dumping areas with minimum or no sanitary treatment in many countries. Such uncontrolled garbage disposal sites are mostly located within the city borders or along the water coasts. Such uncontrolled wastes pose a risk of illness and waste to the areas in their vicinity. Generally, no measures are taken for leakage water originating from garbage collection areas and polluting the underground waters or marine environment due to the organic pollutants and heavy metals they contain. Moreover, the health of cities in the vicinity is also affected seriously due to fires and pollution caused by car accidents. Smoke particles release polycyclic aromatic hydrocarbons (PAHs) and dioxins. Domestic solid wastes are collected improperly in most of the coastal areas and generally are mixed with industrial solid wastes and thrown into open waste areas without suitable management. The most important dumping areas located directly along the water coasts are Tripoli (3 hectares), Beirut (Borj Hammoud, 15 hectares), Normandy (10 hectares), and Saida. These dumping areas along the water coasts are sources of leakage waters loaded with metals and organic compounds, which directly affect the marine and coastal ecosystem.

Waste waters received from Alexandria province are poured into the Mediterranean Bay, Abou-Abou-Qir Bay, and Maryut Lake. This situation is a serious indicator of degradation occurring within the environment (oxygen deficiency, discoloration, and an increase in algae). Dumping of land-based heavy metal leads to an increase in metal concentrations in seawater close to the shore.

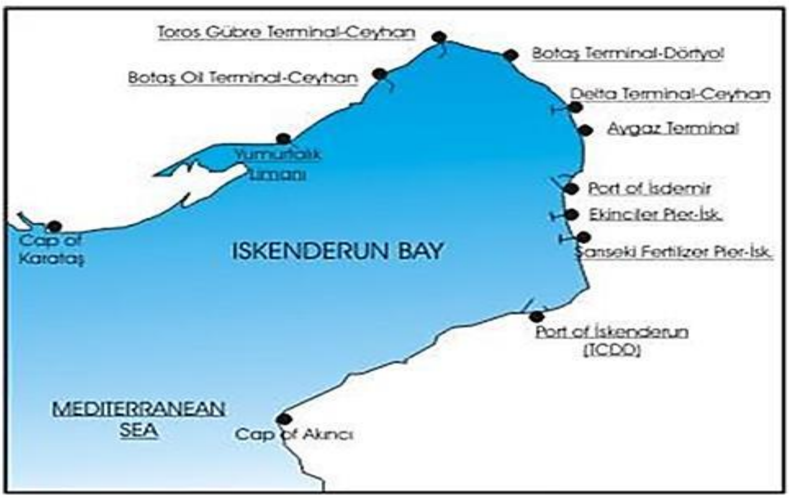
Coasts of Alexandria

Have a critical wastewater problem because of high population growth and leading to rapid industrial development; total BOD5 loads in the Mex Gulf and Abu-Qir related to urban and industrial waste waters are 219,000 and 91,700 tonnes per year, respectively. There are high metal concentrations in sediments in the gulfs and Lake Maryut, which receives industrial wastewater water and in addition to severe eutrophication (anaerobic conditions, hydrogen supplied odors), there is a significant accumulation of heavy metals (mercury, cadmium, lead, zinc).

Land-based nutritional salts could positively affect the increase of productivity to a specific extent in oligotrophic environments such as the eastern Mediterranean. But neritic areas in the Mediterranean are becoming increasingly polluted. Giving nutritional salts to coastal areas leads to eutrophication in shallow and confined spaces, in particular. Such environments occur in the Northeast Mediterranean from time to time (Demirel, 2011:152). One of the most concrete examples in Turkey on this issue is the eutrophication, which has taken place in the Gulf of İzmir (Polat et al., 2006:4; Koray, 1994:14). Harmful algae increases are also related to eutrophication (Richardson, 1997: 83). Eutrophication can be observed more frequently in polluted regions. Excessive algae productions cause effects such as a decrease in water quality, fish deaths due to toxicity issues and losses in cultural fishing areas, adverse effects on public health, and aesthetic loss of aquatic environments due to bad smell and appearance problems. Frequency in production of harmful algae, defined as a sudden and excessive increase of one or several phytoplankton species seen locally in seas (red-tide), has increased in recent years (Mann, 2000: 406). An increase in the amount of nutrients (nitrogen and phosphorus) in the water ecosystem increases primary production and may cause water eutrophication. This incident has the following adverse effects: proliferation of planktonic biomass, discoloration of water, reduction of water transparency, reduction of dissolved oxygen in deep waters, and emergence of toxic algae in extreme cases. Urban waste has a substantial nutrient burden, especially when treatment is not applied to water. As a consequence, all cities or coastal areas around large cities that do not have operational wastewater treatment plants effectively receive high nutrient loads. Turkey has a total coastline length of 8,333 km. The Mediterranean shoreline is divided into two as: the Aegean and the Eastern Mediterranean.

Urban and industrial centers, oil facilities, agricultural and social facilities on the coast are among the most important land-based pollution sources in both regions. There is a rapid housing development on the Turkish coast due to the construction of recreational facilities on the Aegean and Eastern Mediterranean coastline, as well as the widespread secondary (summer) housing constructions. This is a serious destruction of nature. Coastal erosion is also a significant issue. Gulf of İskenderun: Industrial activity including petroleum pipeline terminal (de ballasting and pollution due to operational oil spills); Mersin: urban and industrial waste waters and heavy shipping activity (Fig. 4; Subaşı, 2010:96).

Figure 4. *Quantity of waste discharged to Mediterranean yearly*



Source: (Anonymous, 1987:3; Anonymous, 2009:65)

Gulf of İskenderun is one of the regions where the continental entrances are most concentrated in the Northeastern Mediterranean. The Gulf is subject to intensive environmental impacts because of industrial establishments, residential units, river discharges, and ship traffic around it. Furthermore, large-scale mariculture activities have been carried out in the bay recently. All these activities increase the content of nutrients in the water, creating an environment suitable for the growth of phytoplankton (Priority environmental issues in the Mediterranean region, 2006:92).

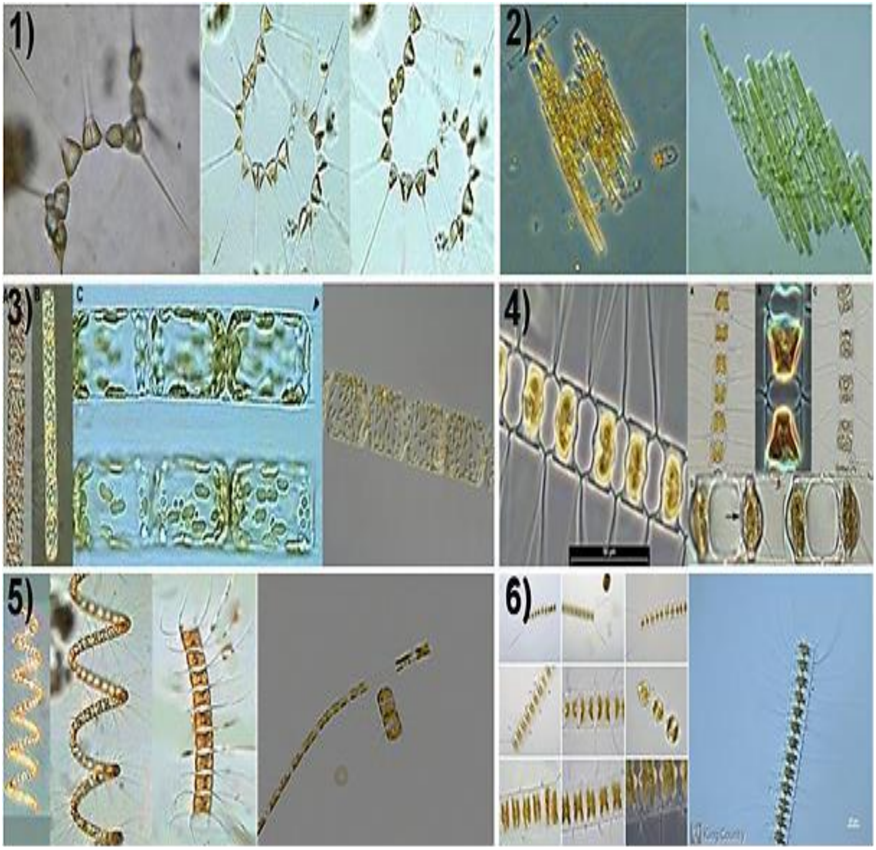
Household wastewaters, which constitute a significant pollution in the marine environment, are very important in terms of forming organic substances, nutrients, suspended solids, oil, and coliforms. Organic matters do not always have a direct effect on the environment. Most of the organic materials are biodegradable and use dissolved oxygen in this process. This situation creates an undesirable situation for natural life in the marine environment, while leading to a lack of oxygen. The situation becomes even more serious when organic substances are mixed into semi-enclosed and warmer receiving water environments. In this case, besides the damage caused by natural life, also bad odors are created in the environment due to anaerobic conditions caused by toxic and explosive gases.

Bad smell affects people more due to the negative impact caused thereby in the marina where they have come to rest. Nutrients denote substances such as nitrogen and phosphorus required for the growth of organisms in the marine environment. Nutrients are the materials required for the sustainability of life within the marine environment. However, if they are too much in the environment, they increase primary production. This situation, which is called eutrophication, creates more important problems in water areas such as lakes, gulf, and bays where there is not much water flow and circulation. If nutrient discharges are not controlled, the mass of water fills quickly, depending on the growth of this uncontrollable organism and shallowing starts, and the water area turns into a swampy environment over time. Because of the serious problems caused by nutrients found in domestic wastewater of ships, it should be acted upon carefully, and necessary measures should be taken in these environments to avoid eutrophication. Types of potentially harmful phytoplankton detected in the Gulf of İskenderun are provided below (Fig. 5A, B, C).

2. Pollution from marine bed activities

In Turkey, waterways are generally polluted by domestic and industrial waste. The fact that these wastes are delivered to the waterbeds without being treated, the solid wastes are left irregularly in the receiving environment. It is also known that liquid wastes cause pollution on the soil and vegetation, destroying natural habitats. Moreover, the rapid development in the industrial and technological infrastructure in recent years has increased migration from rural to urban areas, leading to rapid and irregular urban structuring. Chemicals used in agriculture involve substances that create wastes containing pesticides and fertilizers. Wastes are polluted because the waste of medicine in the air is carried to the waters by the wind, or the waste of the manufacturers of agrochemicals is supplied to the water resources without treatment. On the other hand, the unconscious and excessive use of chemical fertilizers also leads the soil water pollution due to the infiltration into groundwater, depleting over time, which results in both soil fertility and surface water flows with surface water.

Figure 5A. *Potentially Harmful Phytoplankton in the Gulf of İskenderun*



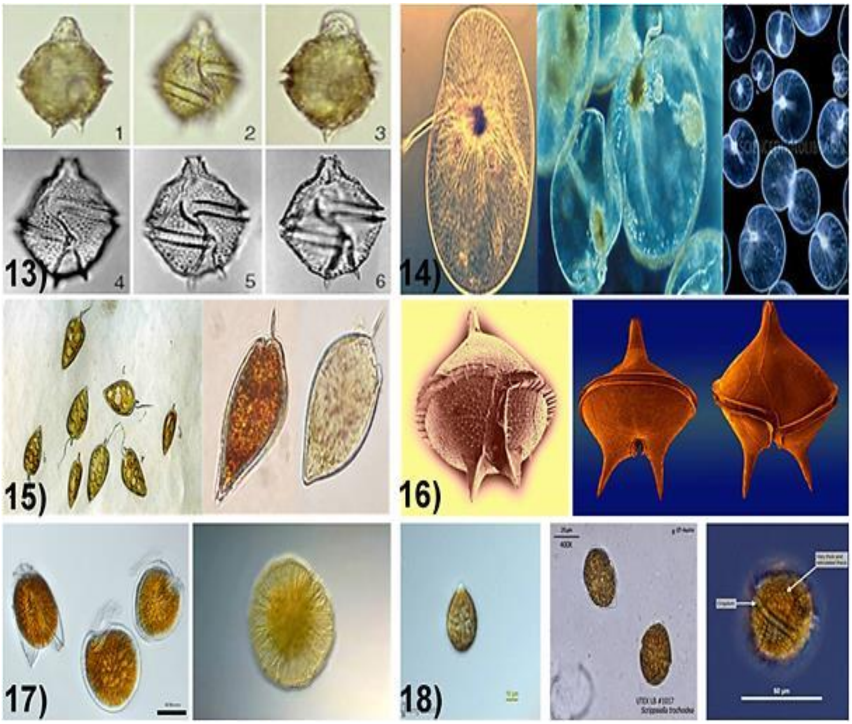
Source: (1) Asterionellopsis glacialis (Castracane) (Round, Crawford & Mann, 1990), (2) Basillaria paxillifera (Marsson, 1901), (3) Cerataulina pelagica (Hendey, 1937), (4) Chaetoceros brevis (Schütt, 1895), (5) Chaetoceros atlanticus (Cleve, 1873) and (6) Chaetoceros didymus (Ehrenberg, 1844).

Figure 5B. *Potentially Harmful Phytoplankton in the Gulf of İskenderun*

Source: (7) Pseudonitschia pudens (Hasle, 1993), (8) Rhizosolenia hebetata (Bailey, 1856), (9) Rhizosolenia setigera (Brightwell, 1858), (10) Thalassionema nitschioides (Mereschkowsky, 1902), (11) Ceratium furca (Claparede & Lachmann, 1859) and 12) Gonyaulax polygramma (Stein, 1883).

The use of seas for transportation and tourism, the supply of domestic and industrial wastes to the sea without being treated or partially purified, the oil flows from the aftermath of sea accidents, and the agricultural wastes reaching the waters from the rivers are the main factors that cause pollution.

Figure 5C. *Potentially Harmful Phytoplankton in the Gulf of İskenderun*



Source: (13) Gonyaulax spinifera (Diesing, 1866), (14) Noctiluca scintillans (Kofoid & Swezy, 1921), (15) Prorocentrum micans (Ehrenberg, 1844), (16) Protoperidinium pellucidum (Bergh, 1881), (17) Pyrophacus steinii (Wall & Dale, 1971) and (18) Scrippsiella trochoidea (Loeblich, 1976).

3. Petroleum hydrocarbons resulting from maritime activities

Petroleum hydrocarbons from shipping activities. Maritime transport is one of the major causes of pollution of petroleum hydrocarbons (petroleum) and polycyclic aromatic hydrocarbons (PAH) in the Mediterranean.

Transport of Invasive Species

Invasive species are organisms transported by various means, unintentionally, from one natural water ecosystem to another. One way of transporting these organisms is by fouling. Invasive species can pose a great risk ecologically and economically. They can lead to the disappearance of economically important species, reduction of biological diversity, as well as the transport and spread of various diseases in the region they are transferred to (Keskin, 2006:191; Anonymous, 2009:65).

4. Water from immersion (drain) results in pollution

Leaks consisting of platforms and pipelines installed in the seas. Pollution from ships and other marine vehicles. As a result of sea accidents, a considerable amount of oil spillage accumulates in the water, threatening life in the marine environment. Thousands of tons of crude oil are spilled into the sea, especially because of accidents involving the big oil tankers. Crude oil transport, petrochemical industries, and organic chemical industry developments are increasing the amount of pollution in land, air, and seas. Leaving plastic items on land and ships in the sea causes serious damage to the beaches and the natural life of the sea. Suspended solid materials lead to various issues in the sea environment. First and foremost most they create unwanted situations in terms of aesthetics. Collapsible solid materials can precipitate to the bottom over time, reducing depth. These precipitated solids cover the benthic organisms while suspended solids cause turbidity and discoloration. Coliform is particularly important in terms of public health. Coliform in the marine environment is used as an indicator of pathogenic microorganisms (pathogenic). Millions of coliforms are excreted through feces. Even though these pathogenic organisms are not pathogenic on their own, they are a good indicator of diseases transmitted by water. Coliform is particularly important for the quality of the water where people swim. If swimming cannot be restricted in such areas, it must be controlled very carefully (Keskin, 2006:191).

5. Marine Pollution Caused by the Airborne Pollutants

The wastes of air vessels are usually dumped into the open sea. However, the damages caused by these wastes have not yet reached very important levels. The most important reason for the pollution of the sea is the pollution of the air created by the industries or the residences. Air pollutants, along with rainwater, land on the ground and cause a large increase in the pollution load (Küçük & Topçu, 2012:4).

- **Air pollution**

CO_2, SO_2, and NOx levels of gases released to the atmosphere increase due to excessive fuel consumption. The solvents used during the removal of anti-fouling paints from the vessel can also cause mixing of toxic chemicals into the atmosphere. Following is the list of the pollutants that could cause sea pollution generated specifically by ship transportation

Petroleum products, radioactive substances, toxic liquid substances carried in bulk, packed or portable tanks, containers, wastes transported in wagons, bilge water, ballast and tank washing waters of vessels, domestic wastewater from ships (waters from toilets, washbasins, showers and kitchens), garbage of the ships. The release of plastic materials from land and from ships to the sea creates serious damage to the beaches and the natural life of the sea.

- **Fuel consumption**

Even very small quantities of fouling on a ship can cause a considerable increase in fuel consumption. It can also cause to 50% increase in the fuel consumption of the ship. Anti-fouling Agents in Ship Paints: Fouling is the layer consisting of live microorganisms as crustaceans, shellfish, algae and etc. adhere to the surface of vessels in water and grow there. There are many negative effects of fouling. The most important ones thereof can be listed as below (Keskin, 2006: 191; Anonymous, 2009:65).

- **Marine litter**

Mediterranean coasts are frequently polluted with plastic waste. However, the degree of the effect due to the pollution is not known yet. Increasing evidence shows each and every day that plastic wastes have an adverse impact on the environment when they are inconsiderately dumped, thrown, or left into the sea environment. Environmental pollution causes costly cleaning processes as well as aesthetic disturbances. Environmental effects are caused by sea creatures that wrap around plastic waste and swallow it. Such wastes cause a major risk to human health when divers, ships, or boats are exposed to them. The coastal area near Alexandria Province (Lake Manzala, Abu-Qir Bay, and Mex Bay, Alexandrian coast) and Port Said is the most important area of environmental threat in Egypt. Major environmental issues arise from untreated urban and industrial wastewater, and intense urbanization has led to coastline degradation (Özdemir, Yılmaz & Başer, 2016:6).

- **Sea Pollution Caused by an Accident**

One of the most important substances causing sea pollution is fuel oil. Pollution; Shipping accidents generally result in the large amount of fuel pumped out into the sea creating a huge environmental catastrophe (Küçük & Topçu, 2012:4). Coasts of Alexandria have a critical wastewater problem because of high population growth and led to the rapid industrial development; total BOD5 loads in Mex Gulf and Abu-Qir related to urban and industrial waste waters are 219,000 and 91,700 tonnes per year, respectively. There are high metal concentrations in sediments in the gulfs. Lake Maryut receives industrial wastewater, and when this is combined with severe eutrophication (anaerobic conditions, hydrogen sulphide odors), a significant accumulation of heavy metals (mercury, cadmium, lead, zinc) occurs in the water.

Turkey has a total coastline length of 8,333 km. The Mediterranean shoreline is divided into two as: the Aegean and the Eastern Mediterranean. Urban and industrial centers, oil facilities, agricultural and social facilities on the coast are among the most important land-based pollution sources in both regions. There is a rapid housing development on the Turkish coast due to the construction of recreational facilities on the Aegean and Eastern Mediterranean coastline, as well as the widespread secondary (summer) housing constructions. This is a serious destruction of nature. Coastal erosion is also a significant issue in the region (Küçük & Topçu, 2012:4).

Gulf of İskenderun

Industrial activity, including petroleum pipeline terminal (de ballasting and pollution due to operational oil spills); Mersin: urbanization and industrial waste waters, and heavy shipping activity. Maritime transportation and accidents, the widespread production and use of petroleum and its derivatives, and their subsequent discharges all play a role in industrial marine pollution (Subaşı, 2010:96). The substances causing the ships to pollute the seas were collected under five headings according to MARPOL (İncaz, Alkan & Bakırcı, 2005:13).

These are as follows

Petroleum and petroleum-derived substances, toxic liquids, packaged hazardous materials, waste waters, and garbage. The facilities and equipments which have to be kept in ports according to MARPOL are as treatment facilities, facilities to destroy dry waste by grinding, laboratories and measuring devices follows: facilities to receive oily materials, facilities to receive wastes which contain toxic liquids, water, loading and unloading devices and facilities and devices suitable for pipes and fitting assemblies of ships. Another important issue related to the acceptance and treatment of wastes is the presence of waste acceptance and treatment facilities with appropriate capacity in ports.

Protocol for the Protection of the Mediterranean Sea against Pollution (RG 12.6.1981-17368)

It was approved in 1980 and signed to prevent environmental pollution caused due to wastes from ships, airplanes, petroleum platforms, and facilities built at sea. Substances that are forbidden for discharge or that require a special permission certificate are listed in the lists that are annexed to the protocol. For example, mercury, cadmium, permanent plastic materials, acid and alkali compounds, in addition to biological and chemical warfare agents, are all considered prohibited substances for discharging to the Mediterranean (İncaz, Alkan & Bakırcı, 2005:13; Öğüt, 1999:192).

The main cause of marine pollution arising from vessels is the discharge of ship waste into the sea. The ships are either discharging the waste into the sea or destroying it by processing (burning, separating, etc) and disposing of residues or storing the waste during the sail or discharging it to waste acceptance facilities in the ports (Öğüt, 1999:192). Ships are obliged to store residues that are forbidden to be discharged into the sea and residues resulting from the processing of their wastes according to MARPOL. Since a national policy has not been created in Turkey in the field of waste acceptance facilities, there are not enough waste acceptance facilities in ports operated by various institutions, organizations, and companies. The majority of ports, including private ports, do not have any waste acceptance facilities (Court of Accounts, 2002:14; Köseoğlu, Töz & Şakar, 2016:24).

Most of the waste acceptance facilities in Turkey are aimed at taking bilge and ballast water. Facilities for destroying and grinding solid wastes are scarce. In the survey made at the ports, it was seen that the treatment systems either did not exist or operated improperly. Bilge water is separated by the method of stilling because the treatment is not done. Therefore, the tanks to collect the bilge water from the vessels to be separated from are insufficient in terms of capacity, and this insufficiency causes undesirable results. Besides, plastic pollution in marine areas has become a worldwide concern, leading to environmental, socioeconomic, and health consequences (Jang et al., 2014:5; Gall & Thompson 2015:9; Geyer et al., 2017:5; Karbalaei et al., 2018:17; Beaumont et al., 2019:6; Galgani et al., 2019:208). Abandoned, discarded, lost, or transported plastics from various sources can enter the marine environment and drift across aquatic areas, causing transboundary pollution and reaching great distances where they are not normally found (Browne et al., 2015:12; Turrell 2019:11; Stanev & Ricker 2019:660).

Measures

Parliamentary Assembly of the Council of Europe, has taken numerous decisions of recommendation for the improvement of the Mediterranean environment (Environmental Protection Magazine, 1986:1). Countries which have signed the Barcelona convention for the protection of the Mediterranean Sea have taken decisions in the meeting held in Genova; both to prevent sea pollution and to protect marine mammals, which are becoming extinct increasingly. The precautions to be taken for this purpose are;

Works for to protection of the Mediterranean coastline; improvement of the wastewater treatment along the coastal strip and presence of wastewater acceptance and treatment facilities with appropriate capacity at the ports, and an increase in supervision have to be ensured.

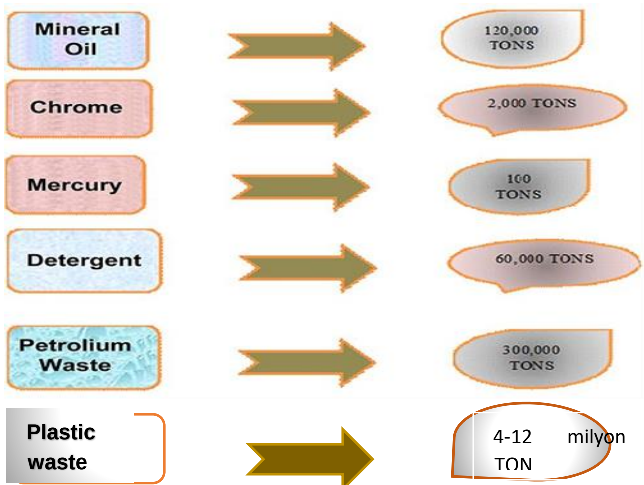
- The transport conditions of toxic substances should be under control.
- Establishment of treatment facilities in cities with a population of over 100,000 people.

Combating air pollution.

- Taking necessary measures against desertification due to fires.
- Tourism activities are also interrupted due to the pollution risk. Countries that generate a big income from tourism are concerned about this.

Ship emissions compose a major, and so far, poorly regulated, source of air pollution (Jonson et al., 2020:23). Shipping activity can pollute the atmosphere through routine operations. In particular, carbon dioxide (CO_2), carbon monoxide (CO), sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM) are released due to the operation of the ship's machinery and the incineration of waste, which contributes to global warming and acid rain (Potters, 2013: 231; Aygül & Baştuğ, 2020:14). As a result of the burning of fossil fuels used in ship machinery, exhaust emissions are harmful to the environment and human health (Aygül & Baştuğ, 2020:14). The oil tankers as well as trade and freight ships of numerous countries visit the Gulf of İskenderun. There are no measures taken to prevent them from polluting the sea (Environmental Protection Magazine, 1986:1) (Fig. 6).

Figure 6. *Quantity of waste discharged to Mediterranean yearly*



Source:(Anonymous, 1987:3; Anonymous, 2009:65)

Diesel and lubricating oil remain in bilge waters discharged into the sea, polluting the sea and causing the following damages to the sea creatures (Table 2).

Table 2. *Damages of motorine and petroleum wastes in ecosystem*

Damages	Effects of Precautions
Single-Cell Live and Ecosystem	Oils such as diesel oil and etc. density which are lighter than water form a film of oil on the surface of the water and prevent the utilization of sunlight by unicellular vegetal organisms (phytoplankton) in water. These organisms constitute the first link of the food chain in water and enable the water to have dissolved oxygen by virtue of photosynthesis, due to pollution and lack of light, and die and accumulate on the bottom of the sea. Bacteria that break them down use the oxygen in water.
All Marine Ecosystem	When diesel and other oils dissolve, many substances, like lead or other similar substances, are released. These substances threaten the microorganisms in the sea and cause them to die (Figure 25). The density of the detergent dilutes when various oils and motor oils are mixed with the detergent in the sea. In this way, they become easily absorbed by organisms. They pass to other living organisms, which eat detergent-loaded organisms through the food chain and affect all living things. If required measures are not taken, the marine ecosystem may vanish in a very short time.
Atmospheric Pollution	Iron-steel plants established in Iskenderun province and the surroundings thereof release gases such as SO_2, CO_2, CO, NO_X, and NO_2 daily to the atmosphere. SO2 and NO2 gases are transformed into H_2SO_4 and HNO_3 and fall as acid rain into the sea and surroundings. Filters can be placed on the gas outlet chimneys of iron-steel plants, and thus, contamination can be prevented partially.
Mediterranean Gulf and Ecosystem	Petroleum hydrocarbons from shipping activities: Maritime transport is one of the major causes of pollution of petroleum hydrocarbons (petroleum) and polycyclic aromatic hydrocarbons (PAH) in the Mediterranean.

Source: (Anonymous, 1987:3; Anonymous, 2009:65)

Conclusion

In conclusion, we urge that the necessary attention and sensitivity be given to the natural cleanliness of İskenderun Bay and our country's Mediterranean coast ports. Otherwise, protozoa and their ecosystems, all marine ecosystems, atmospheric pollution, and the Mediterranean Gulf and its ecosystems could suffer irreversible damage.

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BÖLÜM 4

SPEARFISHING IN TURKEY: AN OVERVIEW OF CURRENT STATUS, REGULATIONS, AND MANAGEMENT ISSUES

AYTAÇ ÖZGÜL[1]

Introduction

Spearfishing is a fishing method that has been widely practiced worldwide, particularly in the Mediterranean and Southeast Asian regions, for both recreational and commercial purposes. Although the precise period during which humans first began using spears to harvest fish and other aquatic resources remains unknown, it is generally assumed that spearfishing predates many other fishing techniques. Archaeological evidence indicates that the earliest records of spearfishing originate from ancient Mesopotamia. Historical findings suggest that the Babylonians and Sumerians employed spears of various designs and sizes to capture

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a range of fish species in riverine and lagoon environments (Saggs, 1988:1). In contemporary times, similar spear designs continue to be utilized by indigenous tribes in Africa as well as by Aboriginal communities in Australia (Jawad, 2006:1).

Following the Second World War, the transfer of military technologies to the underwater domain led to rapid advancements in spearfishing, alongside the development of equipment-based diving. After the 2000s, the expansion of the internet, specialized publications, and social media platforms contributed significantly to the global dissemination of spearfishing practices. This widespread adoption has necessitated the regulation of this form of recreational fishing through a series of laws and administrative frameworks. In many countries, spearfishing is classified as a form of recreational fishing and is governed under recreational and leisure fishing regulations (Özgül & Ulaş, 2009: 108; Sbragaglia et al., 2023:1199).

Globally, spearfishing is classified into three main categories: recreational, sport, and commercial spearfishing (Coll et al., 2004:97).

1. Recreational Spearfishing: Recreational spearfishing refers to fishing activities conducted primarily for leisure and hobby purposes, in which the captured fish are not commercially exploited. Recreational spearfishing is further divided into amateur and professional categories.

a) Amateur Recreational Spearfishing: This group generally consists of individuals who practice spearfishing during the summer season, when water temperatures are relatively high. The equipment and fishing techniques employed are relatively basic and amateur in nature. Fishing activities are typically conducted at shallow depths ranging from 0 to 10 meters.

b) Professional Recreational Spearfishing: Professional recreational spearfishers engage in spearfishing activities throughout the year for leisure purposes. They can be readily distinguished from amateur practitioners based on the sophistication of their equipment, the depths they reach, and the species and sizes of fish they capture. These individuals are highly experienced and capable of diving to depths exceeding 20 meters. Despite their advanced skills, they do not commercialize their catch; rather, they experience spearfishing as a social and cultural practice, sharing their knowledge and experiences within the spearfishing community.

2. Sport Spearfishing: Sport spearfishing is primarily practiced by individuals who participate in national and international competitions. In many countries, spearfishing is recognized as an official sport discipline, and competitive events are organized at various times throughout the year. In Türkiye, spearfishing is officially recognized as a sport under the authority of the Turkish Underwater Sports Federation, who representing the country at the national team level.

3. Commercial Spearfishing: Commercial spearfishing involves the harvesting of fish using spears for commercial purposes. Practitioners engage in diving activities throughout all seasons and under a wide range of sea conditions. However, commercial spearfishing is considered illegal in many countries due to its potential ecological impacts.

In this study, a general assessment of the current status of spearfishing in Türkiye is provided, with a particular focus on existing regulations and management issues. The demographic characteristics of spearfishers in the country, the fishing techniques they employ, and their perspectives on current regulatory frameworks, as well as the challenges they encounter, are systematically evaluated.

2. Material and Methods

The material of this study consists of individuals engaged in spearfishing in Türkiye, as well as the laws and regulations governing spearfishing activities. Initially, a structured questionnaire was developed based on an extensive review of the relevant literature. Subsequently, the questionnaire was administered through face-to-face interviews with individuals practicing spearfishing (n = 120).

During the interviews, participants were first asked questions regarding their demographic characteristics, including gender, age, educational background, and diving experience. In addition, their opinions on the current regulations governing spearfishing and the challenges they face were solicited. The questionnaire also collected information on whether the licensing of fish caught by spearfishing should be required, the characteristics of diving equipment used, fishing techniques employed, and the target species harvested. Data obtained from the questionnaires were analyzed using the SPSS 15.0 statistical software package.

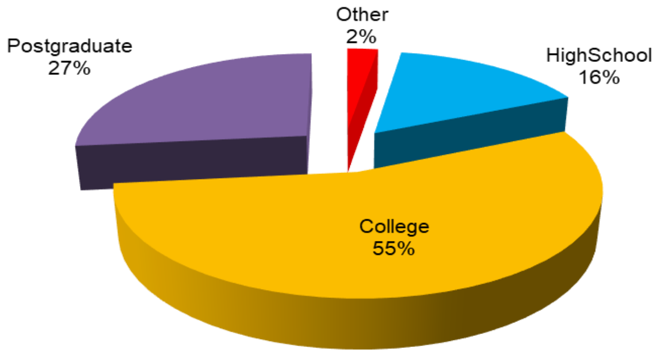
3. Results

Spearfishing is classified as a form of recreational fishing and is regulated under the Fisheries Law No. 1380 in Türkiye. According to the fisheries circulars, a spearfisher is defined as an individual who harvests fish underwater using a speargun and auxiliary equipment, without the use of any additional air supply other than their own breath (TÜİK, 2024:1).

3.1 Demographic Characteristics of Spearfishers

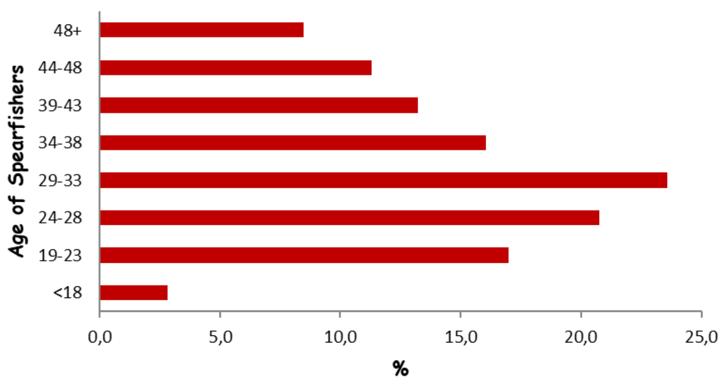
According to the findings of this study, the vast majority of spearfishers are male (88.4%). Nevertheless, it is acknowledged that an increasing number of women have become involved in spearfishing in recent years. Of the participants, 68% were married. Spearfishers generally exhibit a high level of educational attainment, with 82% holding a university degree (Fig. 1).

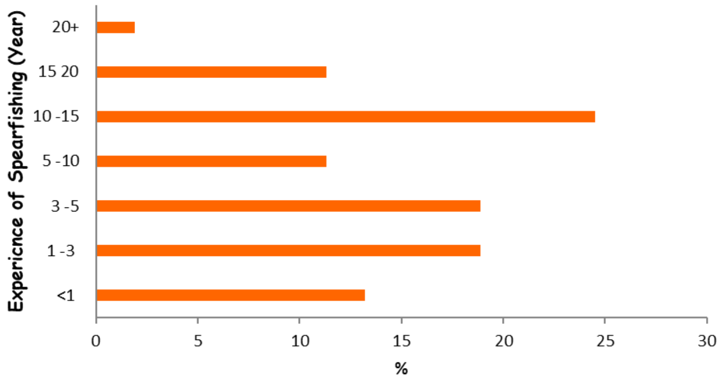
Fig.1 Education level of spearfishers in Turkey



The ages of spearfishers ranged from 16 to 67 years, with a mean age of 34.2 ± 6.6 years. More than half of the participants (52.6%) were over 30 years old, and 38.3% reported having over 10 years of spearfishing experience (Fig. 2).

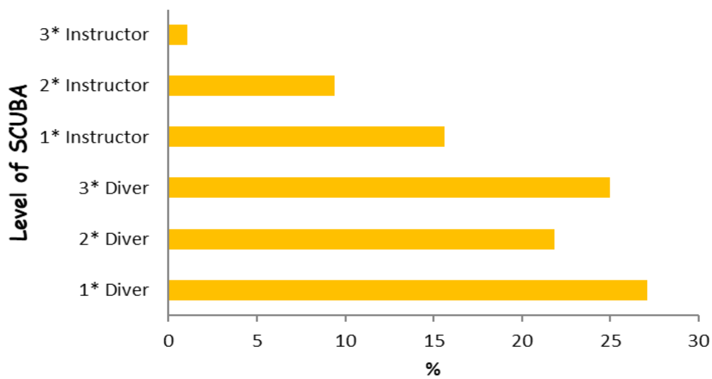
Fig.2 Age distribution and experience of spearfishers in Turkey





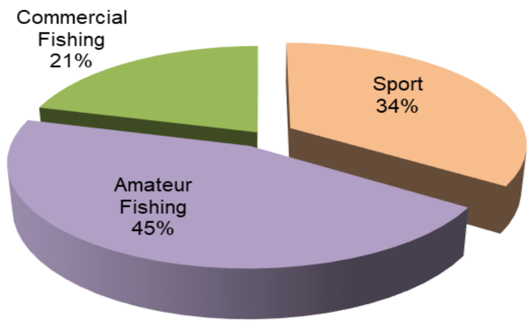
The majority of spearfishers (80%) hold scuba diving certifications from various organizations such as PADI, CMAS, or SSI. Among these certified divers, 25% are classified as experienced divers, while 26% hold instructor-level certifications (Fig. 3).

Fig.3 Scuba certificate levels of spearfishers in Turkey



In countries such as Greece, Egypt, Morocco, the USA, and Australia, obtaining a Recreational Fishing License is required to engage in spearfishing as an amateur, whereas in Algeria, Portugal, and Spain, an Underwater Fishing License is mandatory. In Türkiye, an "Amateur Fisherman License" is required for recreational fishing. Although spearfishing is classified as a form of recreational fishing, spearfishers are not legally obliged to obtain any license (Coll et al., 2004:97; Cacaud, 2005:1; Özgül & Ulaş, 2009:108). In this study, 45% of participants classified spearfishing as a recreational fishing activity, while 86% emphasized the need for licensing this activity (Fig. 4).

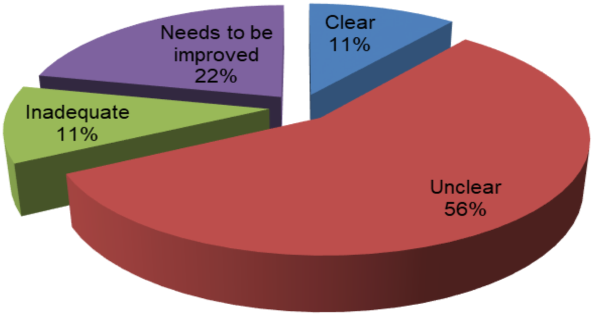
Fig.4 Classification of spearfishing by fishing methods



3.2. Regulations on Spearfishing

The Ministry of Agriculture and Forestry regulates recreational fishing, including spearfishing, through circulars issued every four years. These circulars define the permitted fishing gear and establish procedures for harvesting aquatic resources for non-commercial purposes, ensuring that recreational fishing is conducted within a structured legal framework. The current regulations, effective from 01/09/2024 to 31/08/2028, provide detailed definitions and provisions for recreational fishing activities (TÜİK, 2024:1). Within this framework, 56% of spearfishers indicated that the recreational fishing regulations (circulars) are unclear (Fig. 5).

Fig.5 Spearfishers' Views on Recreational Fishing Regulations



Within the framework of sustainable fisheries management in Türkiye, several restrictions apply to recreational fishing, including daily catch limits, minimum size regulations, and bans on harvesting certain species. Key regulations relevant to spearfishing are outlined below.

In Türkiye, the use of scuba gear, hookah systems, or any auxiliary air supply is strictly prohibited in spearfishing. Additionally, the use of artificial light sources during spearfishing is not permitted. Spearfishing is also prohibited in inland waters and lakes, around aquaculture facilities, in lagoons, marine protected areas, beaches, ports, and in areas where equipment-based diving is not allowed (TÜİK, 2024:1).

According to the results of this study, 50% of participating spearfishers stated that species-specific restrictions in recreational fishing regulations are inadequate (Fig. 6). Regarding the harvesting of groupers (Epinephelus spp.), one of the most popular target species in Mediterranean spearfishing, 46% of respondents indicated that spearfishing for groupers should be permitted. In addition, 85% of participants agreed that spearfishing using scuba equipment should remain prohibited, while 60% stated that the use of flashlights during dives should be allowed.

Current recreational fishing regulations in Türkiye allow spearfishing only during daylight hours; however, 58% of spearfishers participating in this study reported that they do not comply with this restriction. According to the fisheries circulars, the daily catch limit for spearfishing is set at 5 kg (TÜİK, 2024:1). In this study, 43% of respondents stated that they do not adhere to the 5 kg/day bag limit (Fig. 7).

Fig.6 Comments on Forbidden Species by Spearfishers.

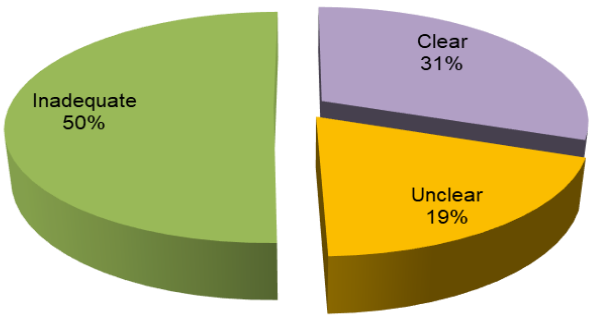
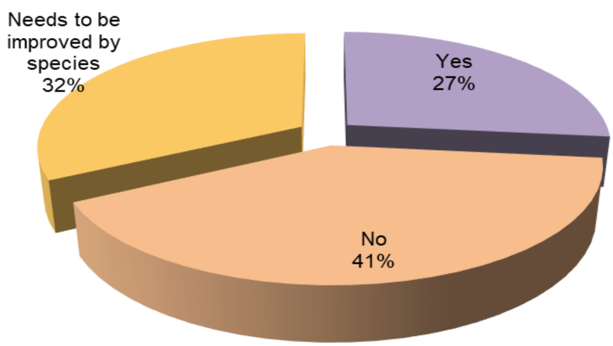


Fig.7 Comments on Daily Catch Limits by Spearfishers



The commercial sale of spearfished fish is prohibited in most countries, except for certain Pacific island nations (Gillett & Moy, 2006:1; Gaudin & Young, 2007:1). Similarly, the sale of fish caught through recreational fishing is also prohibited in Türkiye (TÜİK, 2024:1). In this study, 55% of spearfishers indicated that the commercial trade of spearfished fish should be permitted.

3.3 Issues in Spearfishing

Conflicts exist between spearfishers and other maritime sectors, which can be categorized as follows:

Conflicts with Fishers: Spearfishers often experience disputes with small-scale fishers using hook and line, longlines, or gillnets. High-value target species for spearfishing, such as parrotfish, dentex, gilthead seabream, white seabream, and sea bass, are also targeted by small-scale fishers. This overlap in target species and fishing areas can lead to tensions between spearfishers and fishers, including harassment of spearfishers from boats and complaints filed with the gendarmerie or coast guard.

Conflicts with Scuba Divers: Issues with scuba divers are particularly observed in regions with intensive underwater tourism, such as Bodrum, Marmaris, and Antalya. In these areas, maintaining the underwater ecosystem for tourism purposes is important, and spearfishing is perceived as a factor that reduces marine biodiversity. Similar conflicts occur, including harassment of spearfishers and complaints to law enforcement or coast guard authorities.

Conflicts with Sea-cage Fish Farms: Aquaculture facilities attract various fish species in the surrounding area (Akyol et al., 2019:271). Moreover, escaped fish from marine cages make these areas highly attractive for spearfishing. Although fishing is prohibited within 100 meters of aquaculture facilities, spearfishers often disregard this regulation, leading to conflicts with aquaculture operators.

Issues Related to Fisheries Circulars: Misunderstandings regarding specific provisions in fisheries circulars regulating spearfishing also create conflicts between spearfishers and enforcement authorities. For example, the circular limits the daily catch to 5 kg. If a diver captures a single fish weighing 5 kg, it is considered within the legal limit. However, because the limit applies to the total weight of a species, whether caught individually or as a mixture, divers must stop fishing once they reach 5 kg, which can create confusion and tension.

4. Discussion and Conclusion

Spearfishing is highly popular in Mediterranean countries such as Spain, France, Italy, Greece, and Türkiye, and it is generally classified as a form of recreational fishing (Özgül & Ulaş, 2009:108; Sbragaglia et al., 2023:1199). Regulations governing spearfishing in Türkiye largely resemble those of other Mediterranean countries. However, because spearfishing is regulated together with other recreational fishing methods, these regulations are not always fully understood or are interpreted differently by spearfishers. Including a representative of spearfishers in the commissions that draft fisheries circulars could help prevent misunderstandings and misapplications.

Since spearfishers visually select their targets, bycatch of non-target species or undersized individuals is negligible. Additionally, this method has minimal negative impacts, such as bait use, gear loss (ghost fishing), or damage to the seafloor and seagrass beds (Frisch et al., 2008:1; Diogo et al., 2020:536; Giglio et al., 2018:17). Therefore, when conducted according to regulations, spearfishing can be considered the most selective fishing method among coastal fishing techniques (Smith & Nakaya, 2002:19; Sbragaglia et al., 2023:1199). Nevertheless, illegal practices, such as excessive or night diving and the use of scuba, can exert fishing pressure on certain species (Nevill, 2006:1; Barbosa et al., 2021:105988; Sbragaglia et al., 2023:1199).

The definition of "underwater fisher" in the fisheries circulars should be revised, as divers often enter the water before sunrise to reach their fishing grounds, which may be misinterpreted under the current wording. Thus, the term should be updated to "person fishing during daylight hours." Furthermore, equipment used in spearfishing should be listed clearly, specifying which items are mandatory and which are optional.

Restrictions on protected and catchable species, as well as minimum size limits, should not be uniform across all Turkish seas, given the substantial variability in faunal composition. Spatial and seasonal restrictions should be implemented, and fishing bans during reproductive periods should also apply to spearfishing.

Penalties for commercial spearfishing should be increased and monitored at points of sale; not only the fishers but also vendors or restaurants selling the catch should be subject to the same penalties. All individuals engaging in spearfishing—whether professional or amateur, or using nets, lines, or spearguns—should be required to obtain a license. Applicants should undergo specific training or at least pass an examination to receive the license.

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BÖLÜM 5

THE ROLE OF MANNAN-OLIGOSACCHARIDES IN RESPONSIBLE AQUACULTURE: IMPLICATIONS AS A DIETARY COMPONENT

AHMET GÜRLER[1]
ERCÜMENT GENÇ [2]

Introduction

Aquaculture has become one of the most significant components of global food production and, for the first time in history, surpassed capture fisheries in total output in 2022 (FAO, 2024). Despite this rapid progress, the sector continues to face several important challenges. These include the excessive use of antibiotics, the growing frequency of disease outbreaks, increasing environmental pressures, and the wider consequences of climate change (Luthman et al., 2024: 9253). As concerns about antimicrobial resistance and sustainability intensify, the industry has accelerated its search for alternative approaches that can support animal health and production efficiency. Within this context, functional feed additives such as mannan oligosaccharides have received considerable scientific interest.

Mannan oligosaccharides are complex carbohydrates primarily obtained from the cell walls of yeast species such as *Saccharomyces cerevisiae*. They are regarded as promising dietary supplements in

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aquaculture because they demonstrate prebiotic activity, modulate immune responses, and contribute to gut health (Abdel Gayed et al., 2021:40; Dawood, 2021: 642; Kango et al., 2022: 100883). Through these properties, MOS can enhance animal welfare while reducing dependence on chemical treatments, which supports a more sustainable production model. Unlike antibiotics, MOS do not generate resistance pressure. They also influence interactions between the host and its microbiota in ways that contribute to physiological stability. Studies conducted on a wide variety of aquatic organisms, including finfish, shrimp, crayfish, lobsters, crabs, sea cucumbers, and ornamental species, have reported notable improvements in growth, survival, disease resistance, and intestinal condition following MOS supplementation (Ringø et al., 2010: 117; Song et al., 2014: 40; Kaya, 2025: 232; Li et al., 2025: 102958; Zhou et al., 2025: e12986). These advantages are particularly valuable in intensive culture systems where stress and pathogen exposure remain constant concerns (Ringø et al., 2016: 219; Emerenciano et al., 2022: 236).

Advances in molecular biology and omics technologies have recently provided deeper insight into how MOS influence host physiology. Current evidence shows that MOS can regulate immune related gene expression, strengthen the structural integrity of the intestinal barrier, and reduce pathogen adhesion through specific molecular mechanisms (He et al., 2021: 710845; Wang et al., 2024: 740097). This chapter explores the functional roles of MOS in aquaculture, their biological and physiological impacts, species specific applications, and their potential contribution to the development of more sustainable production systems.

Use of MOS: Historical Background

Mannan oligosaccharides were first introduced in the 1990s as an alternative to antibiotics in terrestrial livestock, particularly in poultry production. The positive outcomes obtained in these animals soon encouraged their adoption in aquaculture as well (Staykov et al., 2007: 153; Ringø et al., 2016: 219; Abdel Gayed et al., 2021:40). Although the most common form of MOS is derived from yeast, there are also bacterial and plant-based derivatives. Production generally involves the mechanical or enzymatic breakdown of yeast cell walls and the isolation of the mannan rich fraction. In recent years, advances in biotechnology have increased MOS yield, improved purity, and facilitated its incorporation into feed formulations. Legal restrictions on antibiotic use and growing market demand for antibiotic free production have further accelerated the interest in functional additives such as MOS (FAO, 2024; Luthman et al., 2024: 9253). In addition, the combined use of MOS with probiotics, organic acids, and enzymes has enabled the development of more complex and synergistic feed formulations (Hersi et al., 2023: 739391).

The effectiveness of MOS has been demonstrated across a wide range of aquatic species in studies conducted from Europe to Asia and Latin America. These findings have led commercial feed manufacturers to integrate MOS into standard feed formulations. Although MOS increases feed costs, the gains in growth performance and health make the investment highly favorable when evaluated in terms of economic return (Dawood, 2021: 642). Ongoing research is now examining alternative MOS sources derived from fungal and algal biomass. These sources contain different mannan structures, which may offer species specific or more targeted physiological effects.

Mechanisms of Action

The effects of mannan oligosaccharides in aquaculture are mediated through several interconnected biological mechanisms. The most widely recognized mechanism is the prebiotic effect of MOS. Since

MOS are non-digestible carbohydrates, they suppress harmful bacteria in the gut and promote the growth of beneficial microbial populations. Notably, increases in *Lactobacillus* and *Bifidobacterium* species have been consistently documented following MOS supplementation (Dimitroglou et al., 2009: 3226; Wang et al., 2022: 550).

MOS also activates immune cells located in the intestinal mucosa, enhances cytokine production, stimulates macrophage activity, and strengthens nonspecific immunity (Ding et al., 2022: 856409; Do-Huu et al., 2023). Another important mechanism is the so-called decoy effect, through which MOS block pathogen attachment to the intestinal epithelium. By increasing mucus secretion, MOS protect epithelial cells and reduce toxin transfer into the bloodstream (Torrecillas et al., 2011: 1373). Through these actions, MOS create both a physical and immunological barrier within the digestive tract. This protective effect is particularly valuable in fast growing species exposed to high levels of environmental stress, such as pompano and tilapia (Hoang, Ky & Thi, 2023: 101720; Eissa et al., 2024: 740453).

At the molecular level, MOS have been shown to regulate the expression of several immune related genes (Wang et al., 2024: 740097). This observation suggests that long term immune priming, often described as trained immunity, may also occur in aquatic species. MOS additionally affect energy metabolism. Studies report improved lipid metabolism, decreased hepatic fat accumulation, and increased production of short chain fatty acids in the intestinal lumen of animals fed MOS enriched diets (Li et al., 2025: 102958; Lu et al., 2020: 344).

Growth Performance and Feed Efficiency

One of the main reasons for using MOS in aquaculture is their ability to improve growth performance and feed utilization. Many studies have reported that diets supplemented with MOS lead to faster growth, lower feed conversion ratios and higher specific growth rates in both fish and crustaceans (Genc et al., 2006: 37; Genc et al., 2007a: 156; Genc et al., 2007b: 10; Yilmaz, Genc & Genc, 2007: 182; Staykov et al., 2007: 153; Ringø et al., 2010: 117; Zhang et al., 2012: 673; Gelibolu et al., 2018a: 817; Gelibolu et al., 2018b: 229; Genc et al., 2024a: e13086; Genc et al., 2024b: e13041). These improvements are especially clear when MOS is provided during the juvenile stage, where growth curves show a noticeable acceleration.

Although the magnitude of the response varies between species, the overall trend indicates that MOS supplementation produces consistently positive outcomes. For example, in pompano, MOS feeding resulted in an increase in body protein content together with a reduction in lipid levels (Hoang, Ky & Thi, 2023: 101720). Similar findings have been reported in various tilapia species, where MOS improved feed efficiency and enhanced digestive enzyme activity (Wang et al., 2022: 550; Eissa et al., 2024: 740453). These results suggest that MOS contribute to better nutrient absorption and more efficient use of dietary energy.

Several studies also show that MOS enlarge the absorptive surface of the intestine by increasing intestinal length and villus height (Dimitroglou et al., 2009: 3226). Effects on growth have likewise been documented in crustaceans. In biofloc systems, for example, MOS enriched diets produced significant increases in both growth and survival compared with unsupplemented feeds (Genc et al., 2007a: 156; Genc et al., 2024a: e13086; Genc et al., 2024b: e13041; Kaya, 2025: 232). These findings demonstrate that MOS remain effective not only in fish but also in a broad range of crustacean species (Torrecillas et al., 2011: 1373; Zhang et al., 2012: 673; Wang et al., 2022: 550; Li et al., 2025: 102958).

Additionally, healthier liver histology has been observed in MOS fed individuals, with reduced lipid deposition in hepatocytes (Lu et al., 2020: 344). This indicates that MOS do not simply promote weight gain but also support tissue quality and overall animal welfare. Taken together, studies across different species provide strong evidence supporting the use of MOS as a functional additive in aquaculture.

Immune System and Pathogen Resistance

The immune enhancing effects of MOS are evident in both innate and adaptive immune parameters of aquatic animals (Dawood, 2021: 642; Abdel Gayed et al., 2021: 40). Diets supplemented with MOS lead to increases in several key immune indicators, including leukocyte counts, lysozyme activity, phagocytic capacity and serum bactericidal properties (Ding et al., 2022: 856409; Eissa et al., 2024: 740453). For example, in the Japanese sea cucumber (*Apostichopus japonicus*), MOS supplementation produced significant increases in the activity of immune related enzymes (Gao et al., 2023: 380).

One of the most important defensive mechanisms associated with MOS is their role as pathogen binding agents. MOS prevent harmful bacteria such as *Salmonella*, *E. coli* and *Vibrio* from attaching to the intestinal epithelium, thereby reducing the likelihood of infection. This mechanism is often described as competitive exclusion, where pathogens lose their ability to compete for nutrients and attachment sites (Meng et al., 2019: 497; He et al., 2021: 710845). Studies conducted on turbot have shown that MOS supplementation supports balanced increases in inflammatory cytokines while reducing oxidative damage in liver tissue (Wang et al., 2024: 740097).

The effect of MOS on the immune system varies with age, species and environmental conditions. Supplementation during the larval and juvenile stages can be particularly effective because the immune system has not yet reached full maturity at these early life stages.

Moreover, the immune enhancing effects of MOS become more pronounced under stressful environmental conditions, including high salinity, elevated temperature and increased ammonia levels (Do-Huu et al., 2023: 977; Hersi et al., 2023: 739391). Although invertebrates have immune systems that function differently from those of fish, MOS have also shown clear benefits in these organisms. In brown shrimp, for instance, MOS supplemented diets increased both hemocyte counts and phenoloxidase activity (Genc et al., 2024a: e13086; Genc et al., 2024b: e13041).

Intestinal Microbiota and Health

The intestinal microbiota plays essential roles in digestion, immunity and overall metabolic balance. One of the most valuable features of MOS in aquaculture is their ability to shape the gut microbiota in a beneficial way (Dimitroglou et al., 2009: 3226; Dawood, 2021: 642). The influence of MOS on the intestinal flora includes promoting the growth of beneficial bacteria such as *Lactobacillus*, *Bacillus* and *Bifidobacterium*, while suppressing pathogenic microorganisms through competitive interactions. Reductions in harmful bacterial populations, particularly *Escherichia coli*, *Aeromonas hydrophila* and *Vibrio* species, have been reported in several studies (He et al., 2021: 710845; Li et al., 2025: 102958).

Multiple investigations show that MOS supplementation increases villus height, reduces crypt depth and enhances mucus production in the intestine (Dimitroglou et al., 2009: 3226; Torrecillas et al., 2011: 1373). MOS can also improve epithelial barrier function by increasing the expression of tight junction proteins, which helps limit paracellular permeability and may reduce inflammation (Zhou et al., 2025: e12986). As MOS reshape the microbiota, the production of microbial metabolites that stimulate the immune system, such as short chain fatty acids, also increases. These metabolites contribute to stronger mucosal and systemic immunity in the host (Lu et al., 2020: 344; Wang et al., 2022: 550).

The impact of MOS on the microbiota is influenced by environmental conditions. Studies conducted on species cultured at different salinity levels indicate that MOS related shifts in microbial communities become more pronounced under variable environmental regimes (Hersi et al., 2023: 739391). It is also well established that species differ in their baseline microbial composition. Herbivorous and carnivorous species, for example, exhibit distinct intestinal communities, which leads to variation in how they respond to MOS. For this reason, developing species specific MOS application strategies is essential for optimal microbiota management.

Antioxidant Activity and Physiological Effects

Previous studies have shown that MOS not only strengthen the immune system but also enhance the organism’s ability to cope with oxidative stress. The antioxidant defense system plays a central role in preventing cellular damage caused by free radicals. By modulating this system, MOS have the potential to protect animal health and contribute to long term production success (Lu et al., 2020: 344; Wang et al., 2024: 740097). The antioxidant effects of MOS are most evident in liver and intestinal tissues. Research demonstrates that animals receiving MOS supplementation show increased activity of key antioxidant enzymes such as superoxide dismutase, glutathione peroxidase and catalase (Ding et al., 2022: 856409; Do-Huu et al., 2023: 977). These increases are important because they help neutralize free radicals and preserve cellular integrity.

A reduction in malondialdehyde levels has also been reported, indicating lower lipid peroxidation and improved protection against oxidative tissue damage. Healthier liver histology, characterized by reduced lipid accumulation and better-preserved cellular structure, has been observed in MOS fed individuals. There is also evidence that MOS may influence the secretion of gastrointestinal hormones, which can contribute to a more stable digestive process (Wang et al., 2024: 740097).

In stressful environmental conditions, such as high temperature or low oxygen, individuals supplemented with MOS tend to show lower levels of stress related biomarkers (Hersi et al., 2023: 739391). It is important to note that physiological responses to MOS vary according to factors such as sex, age and species. Supplementation during the juvenile stage often results in more pronounced physiological benefits because the organism is still undergoing rapid development (Meng et al., 2019: 497; Eissa et al., 2024: 740453). For this reason, age specific MOS application strategies are essential to maximize physiological improvements.

Reproductive Physiology and Gene Expression

Research on MOS has traditionally focused on growth and immune function, but recent studies have begun to examine their influence on reproductive performance, endocrine regulation and molecular level responses. Although the extent of these effects varies across species and life stages, most findings suggest that MOS can enhance overall reproductive quality. Supplementation has been associated with improved regulation of key reproductive hormones in both males and females. Increases in luteinizing hormone, follicle stimulating hormone, estradiol and testosterone have been reported in several studies (Eissa et al., 2024: 740453).

Gene expression analyses further indicate that MOS can modulate the transcription of many genes related to immunity, stress response and metabolism. Significant regulation has been observed in genes encoding cytokines, antioxidant enzymes and immune receptors (Wang et al., 2024: 740097; Li et al., 2025: 102958). In MOS fed groups, the expression of interleukin 1 beta, tumor necrosis factor alpha and various heat shock proteins increased, suggesting a more responsive and better primed immune system. Other studies show that MOS can also influence genes associated with intestinal health by enhancing the expression of tight junction proteins, including zonulin, claudin and occludin, which are critical for maintaining epithelial integrity (Zhou et al., 2025: e12986).

Despite these promising findings, the genetic level impacts of MOS remain an expanding field of research. There is a clear need for more comparative studies across species and for the use of high-resolution analytical tools such as RNA sequencing. Similarly, the epigenetic effects of MOS, including potential influences on DNA methylation or histone modification, have not yet been examined in detail. Understanding how MOS shape genomic and epigenomic responses will be an important part of future research and will help clarify their broader biological significance.

The Role of MOS in Sustainable Aquaculture

Sustainability has become one of the fundamental principles of modern aquaculture (Dawood, 2021: 642; FAO, 2024). The contribution of MOS to sustainable aquaculture begins primarily with their potential to reduce antibiotic use. As antibiotic resistance becomes a major global threat, there is growing interest in alternative agents that can support immunity and help stabilize the gut microbiota (Luthman et al., 2024: 9253; Mohammed et al., 2025: 598). Through their prebiotic activity, MOS help maintain a balanced intestinal microbiota and prevent pathogen colonization, which reduces the need for prophylactic antibiotic treatments (Ringø et al., 2016: 219). This outcome is considered highly valuable for both product safety and environmental health.

The combined use of MOS with biofloc technology also creates new opportunities for sustainable aquaculture. Biofloc systems support environmentally friendly production by enabling the microbial recycling of waste. MOS contribute to the development of microbial communities in these systems, which helps maintain water quality and improve waste management efficiency (Kaya & Genc, 2024: 251; Samocha, 2019: 1; Kaya et al., 2021: 569; Genc et al., 2024a: e13086; Genc et al., 2024b: e13041; Kaya, 2025: 232). As a result, water resources can be used more efficiently over longer periods.

Sustainability encompasses not only environmental aspects but also economic and social dimensions. By improving animal health and reducing mortality, MOS decrease production risks. This leads to healthier and higher quality products reaching consumers, which strengthens consumer confidence and provides broader social benefits (FAO, 2024). Integrating MOS into sustainable aquaculture policies may also support the transition toward ecosystem-based production models. Future research should examine in greater detail how MOS influence sustainability indicators such as life cycle assessments and carbon footprints.

Conclusion and Evaluation

Although the current literature on the use of mannan oligosaccharides in aquaculture has made significant progress, there are still many areas that require deeper investigation. Most available studies are short term and often limited to specific species. For this reason, more comprehensive research that evaluates the long term effects of MOS and examines different species and life stages is needed. It is also important to understand species specific sensitivity and determine optimal dosage levels in order to achieve greater standardization in practical applications (Abdel Gayed et al., 2021:40).

Another major research gap concerns the genetic, epigenetic and metabolomic effects of MOS. Although gene expression studies have revealed certain responses, these findings are not yet fully understood at the mechanistic level. Future work should explore whether MOS trigger epigenetic modifications and how these modifications influence immune or metabolic pathways through changes in DNA methylation or histone structure. Metabolomic analyses are also essential for mapping the biochemical changes induced by MOS in body fluids and tissues (Wang et al., 2024: 740097; Zhou et al., 2025: e12986).

While the effects of MOS on the microbiota are clearly positive, the functional consequences of these changes remain insufficiently described. The impact of increased microbial diversity on digestive enzyme activity, immune performance and even behavioral traits should be examined in a more systematic manner. With the use of next generation sequencing and metagenomic tools, researchers can better identify which microbial groups are influenced by MOS and what roles these microbes play. In addition, newly recognized biological interactions, such as the gut brain axis, may provide fresh perspectives for future evaluations of MOS.

Environmental impacts of MOS production also require closer examination. From a sustainability perspective, it is important to assess indicators such as carbon footprint, water consumption and energy use associated with MOS production. The ecological effects of the raw materials used in manufacturing should likewise be considered. Optimizing industrial production processes through environmentally friendly technologies will strengthen the ecological sustainability of MOS (FAO, 2024). Moreover, there is limited information regarding synergistic or antagonistic interactions between MOS and other feed additives. The combined use of MOS with probiotics, enzymes, organic acids and other prebiotics should be explored in more detail. Understanding these interactions will support the development of more effective formulations that offer both biological and economic advantages.

A further consideration is the influence of MOS on consumer health and the quality of final aquaculture products. Future studies should examine how MOS affect the textural, nutritional and sensory characteristics of fish and shrimp intended for human consumption. It is also important to evaluate potential residue levels and any possible allergenicity risks. These points indicate that MOS should be considered not only in terms of production performance but also from the perspective of food safety and public health.

Looking ahead, MOS show considerable potential for broader use in aquaculture. To make full use of this potential, the research gaps outlined above should be addressed. Collaborative work and multidisciplinary approaches will be essential for strengthening our understanding of MOS and improving their application across different aquaculture production systems.

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BÖLÜM 6

MYCOTOXINS IN AQUACULTURE : EFFECTS ON GUT HEALTH ,IMMUNE FUNCTION AND DISEASE SUSCEPTIBILITY

ULVİYE KARACALAR

Introduction

The rapid global expansion of aquaculture, which now supplies over 50% of the world's aquatic protein, has led to a shift in feed formulations from fishmeal to plant-based alternatives rich in cereals and oilseeds.. While this transition has undoubtedly had economic and ecological benefits, it has also inadvertently introduced a new biosafety hazard in the form of mycotoxin contamination. Mycotoxins are defined as secondary metabolites produced by fungal species that contaminate aquaculture feeds, posing significant challenges to fish health and production efficiency.[1] The most prevalent mycotoxins in aquaculture ingredients include aflatoxins (AFB1, AFB2), trichothecenes such as deoxynivalenol (DON), zearalenone (ZEN), fumonisins (FB1, FB2), and ochratoxin A (OTA) (Koletsi et al., 2021; Oliveira & Vasconcelos, 2020). Surveys indicate that more than 75% of

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commercial aquafeeds contain detectable levels of one or more mycotoxins (Marijani et al., 2019). Despite the fact that concentrations frequently fall below individual regulatory thresholds, the concomitant occurrence and synergistic toxicity of substances can significantly amplify biological risks (Puvača et al., 2024).

In contrast to terrestrial livestock, fish exhibit distinct vulnerabilities to mycotoxin exposure due to their unique physiological characteristics. Their lower body temperature, aquatic environment, and specialized digestive systems result in patterns of mycotoxin absorption and metabolism that differ from those of mammalian species. In fish, the gastrointestinal system, which functions as both a digestive and immune organ, is particularly susceptible to mycotoxin-induced damage. The gastrointestinal tract (GIT) constitutes the primary interface, as it is home to the largest immune organ system and a complex microbiota that is essential for nutrient assimilation and immune modulation. Chronic exposure to mycotoxins has been demonstrated to interfere with this delicate gut–immune axis by inducing oxidative stress, tight-junction disruption, altered cytokine signalling, and dysbiosis (Guerre, 2020; Liew & Mohd-Redzwan, 2018).

Recent mechanistic studies have revealed that mycotoxins not only disrupt digestion but also fundamentally reshape gut immunophysiology. For instance, Aflatoxin B_1 has been observed to reduce villus height and goblet cell density in *Oreochromis niloticus*, while Deoxynivalenol (DON) has been shown to damage enterocytes and promote apoptosis via MAPK pathway activation (Yu et al., 2025). This structural disruption has been shown to increase inflammation and compromise systemic immunity by allowing the translocation of microbial products such as lipopolysaccharide (LPS)(Claudino-Silva et al.,2018). These pathologies render fish susceptible to opportunistic infections by viral agents such as Aeromonas, Vibrio, and Cyprinid Herpesvirus 2 (Xue et al., 2023). In addition to direct toxicity, the immunosuppressive properties of mycotoxins have been demonstrated to impair vaccine efficacy and alter disease outbreak dynamics in dense systems. A decline in growth rates, an increase in mortality rates, and compromised product safety have been shown to result in economic difficulties. Nevertheless, despite the accumulation of evidence, a comprehensive synthesis focusing particularly on the gut-immune interface in fish is still lacking. The present study aims to review the prevalence and mechanisms of key mycotoxins affecting fish health. In addition, the study will analyse their effects on gut morphology, microbiota, and immune responses.

1.Mycotoxin Contamination in Aquaculture Feeds

1.1 Prevalence of Mycotoxins in Fish Feed

The primary mycotoxins that are a cause for concern in the context of aquaculture are listed below:

Aflatoxins (AFs), which are produced primarily by Aspergillus flavus and Aspergillus parasiticus, are among the most potent naturally occurring carcinogens. Aflatoxin B_1 (AFB_1) is the most prevalent and toxic form. These compounds have been found to accumulate in feed ingredients, particularly maize, peanut meal, and other legumes, when stored in warm, humid conditions.(Chen et.al.,2021)

Ochratoxins (OTs), primarily ochratoxin A (OTA), are produced by Aspergillus and Penicillium species and are particularly prevalent in cereals stored in cool, damp environments. OTA has been demonstrated to possess both nephrotoxic and immunosuppressive properties.

Fumonisins (FBs), which are produced by Fusarium species, are structurally diverse molecules. (Adeyemo et al., 2018) The most common and toxic variant is fumonisin B1 (FB1). Fumonisins have been demonstrated to disrupt sphingolipid synthesis pathways, thereby affecting membrane integrity and cellular signalling.

Table* . *Major mycotoxins and their documented intestinal and immunological effects in fish

Mycotoxin	**Principal Fungal Source**	**Target Tissue(s)**	**Key Gut Effects**	**Immunological Consequences**	**Representative Species / Study**
Aflatoxin B₁ (AFB₁)	*Aspergillus flavus*, *A. parasiticus*	Liver, Intestine	Villus atrophy, goblet-cell depletion, epithelial apoptosis	↓ Lysozyme, ↓ IgM, ↑ IL-10, oxidative stress	*Oreochromis niloticus* (Yu et al., 2025)
Deoxynivalenol (DON)	*Fusarium graminearum*	Intestine	Tight-junction disruption, increased permeability	↓ IFN-γ, ↓ TNF-α, ↑ IL-8; leukocyte apoptosis	*Oncorhynchus mykiss* (Koletsi et al., 2021)
Zearalenone (ZEN)	*Fusarium roseum*	Gut, Reproductive tissue	Epithelial disorganization	↓ Lymphocyte proliferation, endocrine modulation	*Cyprinus carpio* (Puvača et al., 2024)
Ochratoxin A (OTA)	*Aspergillus ochraceus*, *Penicillium verrucosum*	Kidney, Intestine	Lipid peroxidation, microvilli damage	↓ Complement activity, immunosuppression	*Clarias gariepinus* (Guerre, 2020)
Fumonisins (FB₁, FB₂)	*Fusarium verticillioides*	Liver, Gut	Sphingolipid disruption, mitochondrial stress	↓ Macrophage activity, ↑ apoptotic signaling	*Ictalurus punctatus* (Oliveira & Vasconcelos, 2020)

1.2 Prevalence in Feed Ingredients

Mycotoxin contamination rates in feed ingredients vary geographically and seasonally. Research has demonstrated that between 20 and 80 percent of feed samples from tropical and subtropical regions contain mycotoxin residues, with the presence of multiple mycotoxins being a prevalent occurrence. It is evident that the co-exposure phenomenon frequently engenders toxic effects that are either additive or synergistic in nature. These effects frequently exceed predictions derived from single-toxin models.

1.3 Bioavailability and Accumulation

A species-specific difference in mycotoxin absorption has been demonstrated in fish. It is evident that aquatic species generally exhibit elevated bioavailability of aflatoxins, a consequence of their aquatic lifestyle and the efficiency of their intestinal absorption mechanisms. Aflatoxins, being lipophilic compounds, are known to accumulate readily in fish tissues, particularly the liver. This bioaccumulation poses to the health of the fish population and a potential food safety concern for consumers.

2.Mechanisms of Mycotoxin-Induced Intestinal Barrier Disruption

2.1 Epithelial Damage

Mycotoxins, such as aflatoxins and fumonisins, have been observed to exert a direct cytotoxic effect on intestinal epithelial cells. Aflatoxin B1, following hepatic metabolism to its reactive epoxide form, has been shown to form DNA adducts (Jones et al., 2022). The resulting mutations, apoptosis and cell cycle arrest are key factors in the toxicological effects of the substance (Smith et al., 2019). The histological examination of fish exposed to aflatoxins has demonstrated that the exposure results in a dose-response relationship with respect to the epithelium hyperplasia (increased cell number), necrosis at the villous tip and loss of epithelial integrity. Fumonisins, by inhibiting ceramide synthase, disrupt sphingolipid metabolism, leading to the accumulation of toxic sphinganine bases. Ochratoxin A has a nephrotoxic (harmful to the kidneys) effect and can also cause damage to the intestinal epithelium through oxidative stress by producing reactive oxygen species (ROS) in excess of the capacity of cellular antioxidants (compounds that protect against oxidative stress).

2.2 Mucus Layer Compromise

The intestinal mucus layer, a product of goblet cells, functions as a pivotal physical and chemical barrier against noxious pathogens and antigens present within the gastrointestinal tract. Mycotoxins can compromise goblet cells, leading to their destruction and a reduction in mucus production. This decline is manifest in reduced levels of periodic acid-Schiff (PAS) staining in the intestinal tissues of fish exposed to mycotoxins.A reduction in the thickness of the mucus layer signifies a decrease in the distance between the epithelial cells and deleterious bacteria within the gastrointestinal tract, thereby elevating the risk of these bacteria penetrating the body.Moreover, a decrease in the synthesis of mucin glycoproteins curtails the availability of sustenance for beneficial bacteria that ordinarily facilitate the breakdown of mucin.This alteration has the potential to precipitate a shift in the bacterial equilibrium within the gastrointestinal tract towards harmful species.

2.3 Oxidative Stress and Antioxidant Depletion

When fish metabolize mycotoxins, they end up producing a flood of reactive oxygen species—far more than their natural antioxidant defenses like superoxide dismutase, catalase, and glutathione peroxidase can handle. This spike in oxidative stress doesn’t just stay in the background; it actively breaks down cell membranes through lipid peroxidation, damages proteins, and even hits DNA. In the intestines, the overproduction of reactive oxygen species can be particularly harmful (.Yu et al.,2025).It damages the mitochondria in epithelial cells, which are crucial for generating ATP—the energy currency of the cell. This energy is vital for maintaining tight junctions and actively transporting nutrients. When oxidative stress remains high over time, it can trigger inflammatory responses and lead to further cell death in the epithelial layer.

3. Mycotoxin-Induced Dysbios

3.1. Selective Pressure on Microbial Communities

Mycotoxins have selective antimicrobial properties and are differentially toxic to various bacterial species. Aflatoxins and ochratoxins reduce the growth of beneficial commensal bacteria like Lactobacillus and Bifidobacterium species while favoring the growth of opportunistic pathogens that are more resistant to mycotoxins, like some species of Vibrio, Aeromonas, and Clostridium. This selective pressure results in a dysbiotic microbiota composition, represented by reduced microbial diversity, reduced abundance of commensals, and predominance of pathogens. These dysbiotic conditions lead to an imbalanced microbial ecological homeostasis and reduce resistance to invading pathogens due to decreased exclusion pressure.

3.2 Functional Loss in Dysbiotic Microbiota

Dysbiosis, which refers to an imbalance in the microbial community, not only alters the types of microbes present but also leads to a decline in their ability to perform important functions. For the dysbiotic microbiome, there is a decrease in levels of SCFAs (short-chain fatty acids), specifically butyrate, and its effects on the intestinal health of fish. In addition to SCFA synthesis dysfunctions, the dysbiotic microbiome also produces lower levels of essential amino acid and vitamin synthesis; therefore, fish with a dysfunctional microbiome will have a deficiency of essential nutrients and thus further impact the overall health and immunity of fish.

3.3 Loss of Microbiota-Derived Immunomodulation

Commensal bacteria provide crucial immunoregulatory cues to the immune system through recognition receptors. A lack of specific bacteria resulting from a disbiositic state abolishes these immunoregulatory cues, leading to a reduction in regulatory T cell differentiation and instead promoting a pathologic Th17 response, thus potentiating inflammation.

4. Immunosuppression and Immune Dysfunction

4.1 Innate Immune Suppression

Exposure to mycotoxins significantly weakens various aspects of innate immunity in fish. Aflatoxin exposure lowers the number and effectiveness of phagocytic cells, such as neutrophils and macrophages (Matejova et al., 2017). It also diminishes the activity of natural killer (NK) cells and decreases the production of antimicrobial substances like lysozyme and complement proteins.

4.2 Adaptive Immune Suppression

Mycotoxins affect both T cell-mediated immunity as well as B cell-mediated immunity. Exposure to aflatoxin causes suppressed lymphocyte proliferation after mitogenic challenge, reduced antibody output, with significant suppression of IgM, as well as impaired T cell response against specific antigens. These findings are therefore linked with impaired delayed-type hypersensitivity reactions as well as reduced protection after immunization.

4.3 Mucosal Immune Dysfunction

The mucosal immune system, which focuses on the tissues in the intestines and mucosa-associated lymphoid tissue (MALT), is especially vulnerable to mycotoxins. When exposed to aflatoxins, the number of plasma cells that produce secretory IgA (sIgA) in the intestinal area decreases, leading to lower levels of sIgA in the mucus of the intestines. This drop in sIgA weakens the body's first line of defense against harmful germs. sIgA plays a crucial role in stopping pathogens from sticking to cells, neutralizing harmful bacteria, and helping the body clear out these germs. Without enough sIgA, the risk of harmful germs taking hold in the body increases.

5. The Cascade to Disease Susceptibility

5. 1 Periods of Weakness

Immunosuppression caused by mycotoxins creates intervals of susceptibility to pathogens, which would normally be eradicated by immune systems functioning normally. The immune system suppression intervals are dependent upon the level and period of mycotoxin exposure. The higher the level of exposure, the greater the immune system suppression that occurs, but temporarily. However, low exposure levels result in immune system suppression, which could potentially be even more detrimental in intensive aquaculture, as pathogens are constantly encountered.

5.2 Increasing Bacterial Translocation and Sepsis

When the intestinal barrier becomes compromised as a result of impaired structural integrity, bacterial translocation (the transfer of viable bacteria or bacterial products through a mucosal membrane) can occur. In cases of dysbiosis, the type of bacteria that are translocated from the gut is usually opportunistic pathogens rather than the normal commensal bacteria; thus, these translocated bacteria are able to spread and cause systemic infection and sepsis.

5.3 Opportunistic Pathogenic Infections

In aquaculture, it has been proven that the virulence of certain pathogens, particularly Vibrio anguillarum, Aeromonas hydrophila, Edwardsiella ictaluri, and Flavobacterium columnare, increases when fish are exposed to mycotoxins (Pietsch,2025). These findings can be explained by various factors. For example, it has been found that an imbalance in the gut flora, also known as dysbiosis, reduces the ability of commensal bacteria to regulate the growth of pathogenic bacteria, thus leading to increased growth of these pathogens in the gut flora of fish. It has also been observed that the reduction of intestinal mucus defenses, especially immunoglobulin A (IgA), lysozyme, and antimicrobial peptides, also supports the proliferation of these pathogens. Finally, a decrease in both innate and acquired immunity has also contributed to a decrease in the ability of fish to eliminate pathogens. Furthermore, increased epithelial permeability has created an effective environment for these pathogens to easily penetrate.

5.4 Synergistic Stress Effects

In intensive aquaculture, multiple stressors occur at any one time within fish in addition to their exposure to mycotoxins; these include overcrowding stress, high water temperature and/or fluctuations, poor quality of water, immunization, and other factors that negatively affect the immune system. All of these stressors will suppress the immune system independently as well as in combination with the effects of mycotoxins. When mycotoxins are combined with other stresses, this results in a multiplicative effect on the susceptibility of fish to disease. This is why there are instances where significant disease outbreaks have occurred in aquaculture systems with inadequate management and poor quality feed for fish.

6. Diagnostic & Analytical Approaches

6.1 Feed Analysis and Mycotoxin Detection

Accurate mycotoxin detection in feeds has become critical for risk assessment in aquaculture. Traditional methods are high-performance liquid chromatography with fluorescence detection for aflatoxins and ochratoxins, while those for general multi-mycotoxin screening are carried out by using liquid chromatography tandem mass spectrometry. However, point sampling of feed might become misleading for mycotoxin risk assessment, particularly due to the heterogeneous mycotoxin distribution in many feed types. A more realistic assessment for mycotoxin risk can therefore be achieved through sampling of various feed lots.

6.2 Fish Health and Immune Markers

The assessment of mycotoxin-induced effects in fish can be approached in a number of ways. Intestinal histopathology, as determined by histological examination, reveals epithelial damage, changes in villous structure, and immune cell infiltration. Immunohistochemistry is a technique that can be used to visualise the expression and localisation of tight junction proteins. The analysis of microbiota using 16S ribosomal RNA gene sequencing provides a comprehensive characterisation of microbial community composition and diversity. The estimation of metabolic capacity in dysbiotic communities is facilitated by the utilisation of functional prediction tools. The quantification of immune cell populations and activation status is achieved by measuring immune markers using flow cytometry. RT-qPCR or RNA-sequencing is utilised for the assessment of the expression of immune-related genes, cytokines, and tight junction proteins. Functional immune assays are used to measure phagocytic capacity, antibody responses, and T cell proliferation.

7. Mitigation and Management Strategies

7.1 Feed Quality Control and Source Selection

The most effective way to prevent mycotoxin contamination is by carefully selecting and managing feed ingredients. At this stage, the most economical mitigation strategy can be determined using several methods. These include the sourcing of raw materials from quality-certified suppliers with established methods for testing feed raw materials, the storage of feed raw materials under conditions that protect them from spoilage and the conducting of routine tests of all feed raw materials to determine the presence of mycotoxins.

7. 2 Mycotoxin Binders and Adsorbents

Mycotoxin binders, such as activated charcoal, bentonite clay, and yeast-derived β-glucans, can help lower the absorption of mycotoxins in the intestines when mixed into animal feed. However, their effectiveness depends on the type of mycotoxin, the type of binder used, and how much is added. It is important to use these binders alongside reducing the sources of mycotoxins instead of relying on them as the main solution.

7. 3 Dietary Supplements and Functional Ingredients

Dietary supplements like probiotics, prebiotics, and immune-boosting additives can help lessen the harmful effects of mycotoxins in several ways. Prebiotics that act as precursors to short-chain fatty acids (inulin and fructooligosaccharides) can selectively promote butyrate-producing bacteria Specific probiotic strains that are known for their resistance to mycotoxins and their immunomodulatory effects hold potential as a future strategy.

7.4 Management and Environmental Optimization

The reduction of overall stress loads from cumulative mycotoxin-induced immunosuppression can be achieved through water quality optimization, temperature management, and stocking density management. Vaccination schedules should anticipate when an animal will be exposed to feed mycotoxins and vaccination should take place when feed mycotoxin levels are anticipated to be lower if possible.

Conclusion

Mycotoxin infections in fish feed pose a complex risk to fish health, as they act through the loss of integrity and functional properties of the intestinal barrier, as well as significant impairment to both innate and adaptive immune systems. The process provoked by mycotoxin infection, including loss of cellular integrity and functional properties of the tight junction, as well as immunosuppression, results in increased susceptibility to disease, as indicated by decreased growth, reduced feed efficiency, and ultimately increased fish death resulting from opportunistic infections.

Currently, measures to reduce mycotoxin exposure from feed include the use of probiotics, antioxidants/additives, and organic minerals as adsorbents, but a comprehensive and integrated feed safety assurance (from feed raw material to final product) is lacking. Advances in molecular diagnostic methods and the ability to engineer the gut microbiome of fish may provide future opportunities to achieve sustainable mycotoxin control through a biologically based approach. Future research should focus on multiple mycotoxin interactions as well as immune transcriptomic responses in farmed fish, and the development of functional feeds aimed at supporting mucosal immunity should be targeted. The goal of ensuring toxin-free nutrition extends far beyond an industry's quality control assurance and is ultimately a necessary condition for the successful development of a healthy aquaculture industry.

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