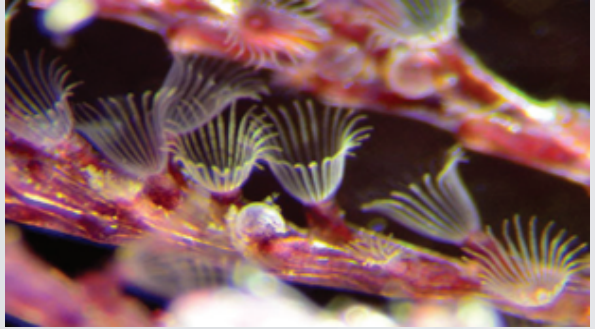


MARINE AND FRESHWATER ADVANCES: ECOLOGY, NUTRITION, AND TECHNOLOGY

Editors

Prof. Dr. Aysun KOP

Assist. Prof. Dr. Boran KARATAŞ



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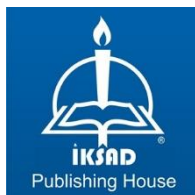
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DOI: <https://dx.doi.org/10.5281/zenodo.14251843>



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Iksad Publications – 2024©

ISBN: 978-625-367-959-0

Cover Design: İbrahim KAYA

December / 2024

Ankara / Türkiye

Size = 16x24 cm

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PREFACE

In recent decades, the importance of aquaculture and fisheries has grown significantly as global demand for seafood continues to increase. These fields have seen remarkable advancements, combining traditional practices with cutting-edge innovations to tackle critical global challenges such as food security, climate change, and sustainable development.

This book brings together 14 chapters written by leading experts, offering an in-depth exploration of key topics in aquaculture, fisheries, and aquatic research. The chapters cover a wide range of subjects, including the health benefits of seaweed and marine-derived bioactive compounds, the environmental impacts of aquaculture, and the integration of smart technologies to improve efficiency and sustainability. Each contribution provides a comprehensive analysis of current research and innovations, showcasing the transformative potential of these industries.

By focusing on the intersection of sustainability and innovation, this book not only highlights scientific progress but also emphasizes its practical applications in addressing real-world challenges. Together, these chapters aim to inform, inspire, and contribute to the sustainable growth of aquaculture and fisheries. We hope this book serves as a valuable resource for researchers, professionals, and anyone interested in the future of aquatic sciences.

EDITORS

CHAPTER 1

ARSENIC IN BROWN SEaweEDS: BIOACCUMULATION, SPECIATION, AND HEALTH IMPLICATIONS

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INTRODUCTION

Seaweeds are necessary bioactive additives in various industries, including pharmaceuticals, cosmetics, and food. In culinary applications, they can be utilized in several forms, like fresh, dried, dissolved, fermented, or cooked, and frequently enhance products that combine these preparation methods (Kumar et al., 2023). Seaweed is a functional food because it contains higher levels of proteins, fatty acids, secondary metabolites, vitamins, and bioactive compounds than other edible plants. Various vitamins, such as L-ascorbic acid, thiamine, riboflavin, cobalamin, folic acid, and their derivatives, as well as tocopherols and carotenoids, have been identified in seaweeds (Pereira & Kraan, 2023). Due to their rich mineral content, seaweeds are suggested as dietary additions to enhance the consumption of trace elements essential for human metabolism (Taş & Ak, 2023). Attention has also focused on the polysaccharides and polyphenols from seaweed for their antibacterial, antiviral, and antifungal effects and for potential use in managing chronic conditions, including heart disease, obesity, diabetes, and cancer (Ghaliaoui et al., 2024). The significance of their role in human health and their global use as food additives continues to grow (Wells et al., 2017).

Over the last two decades, there is an eruption in the production of marine seaweed, from 10.6 million tonnes in the year 2000 to 32.4 million tonnes during 2018. China remains the top producer, with a harvest of 11.5 million tonnes, followed by South Korea at 444.3 thousand tonnes (Khan et al., 2015). In 2021, the global market for seaweed and related products reached a valuation of USD 17 billion (FAO, 2023).

Around 145 seaweed species are used for human consumption, including 79 red, 38 brown, and 28 green (Pereira, 2011). Seaweed is a common dietary component globally, particularly in parts of Asia where it is a staple food. However, its consumption is much less common in Europe and North America (Taylor & Jackson, 2016). Aside from their nutritional benefits, seaweeds are also widely employed as feed supplements and fertilizers in agricultural and aquaculture settings. Edible seaweeds are recognized as dietary supplements that can help adults achieve the advised daily intake of specific nutrients (Rupérez, 2002). While seaweeds serve as a valuable source of essential minerals, they also can accumulate substantial levels of toxic metals from the marine environment because of their metal-binding properties, which can

present health risks. One of the most concerning toxic elements is arsenic, primarily recognized for its high toxicity (Almela et al., 2006; Lin et al., 2024). Brown seaweeds absorb arsenic from seawater, resulting in higher concentrations of arsenic than terrestrial plants (Ma et al., 2018).

Arsenic concentrations in algae were first reported in 1922 by Jones AJ at the British Pharmaceutical Conference (Geiszinger et al., 2001). Brown seaweeds have a reputation for their ability to accumulate high levels of arsenic, attributed to their efficient absorption mechanisms. This capability is primarily linked to compounds such as alginic acid, alginate, and their salts (Muñoz & Díaz, 2022). Consequently, brown seaweeds notably impact arsenic intake in humans (Yu et al., 2024). Therefore, comprehending the arsenic metabolism in brown macroalgae is crucial as it directly influences the arsenic contamination in algae-based substances.

Arsenic (As) has an atomic weight of 74.92 and is categorized as a metalloid, possessing characteristics of both metals and non-metals. Arsenic was initially documented by Albertus Magnus around 1250, and its name likely derives from the Persian term "az-zarnikh," or related words stemming from the root "zar," meaning yellow or golden orpiment (Chen et al., 2013). Arsenic exists in various chemical forms: it can be found in its elemental state, as a gas (arsine), and in both organic and inorganic compounds.

Arsenic occurs naturally in the Earth's crust and may enter the environment via volcanic eruptions, mineral weathering, and biological processes. Historically, industrial activities have significantly contributed to air, water, and soil arsenic levels. Inorganic arsenic compounds were commonly utilized in pesticides, wood preservatives, herbicides, and paint formulations; however, their use in agriculture has been discontinued due to environmental concerns.

However, organic arsenic compounds such as disodium methyl arsenate (DSMA), cacodylic acid, and monosodium methyl arsenate (MSMA) are still utilized in agricultural pest control (Chen et al., 2013). Since arsenic occurs naturally in the environment, humans may encounter it in small amounts through food, drinking water, or inhalation of air (Chen et al., 2013). Arsenic biomagnification refers to increased chemical concentrations across the food web, from algae to top predators, due to heightened dietary exposure (Goessler et al., 1997). It is hypothesized that rooted aquatic macrophytes, including some

within the seaweed group, contribute to arsenic toxicity due to their direct interaction with sediments (He et al., 2024). As a result, not only contaminated waters but also arsenic-bearing fish and other seafood and brown algae, which are generally consumed as human food, can become possibly hazardous to human health. Therefore, monitoring of high-arsenic foods like seaweed becomes an important aspect of the lack of comprehensive toxicity studies against organic arsenic species in it, especially due to their sometimes elevated concentration (Taylor & Jackson, 2016).

This chapter deals with the complex relationship of seaweeds primarily brown algae and their arsenic salt content in the aquatic system. It discusses the arsenic metabolism in brown algae and estimates the capability of different seaweed species in relation to the accumulation of arsenic and the potential health effects associated with its consumption.

BROWN SEAWEEDS

Brown algae represent a rather diverse group of multicellular algae that are generally marine, with the largest number of species appearing in the cooler waters of both temperate and polar regions. They constitute a vital component of aquatic ecosystems and are major contributors to the structure and function of marine coastal environments. The characteristic brown or olive-green color of brown algae results from the pigment fucoxanthin, which masks the green color of chlorophylls *a* and *c* (Cirik & Cirik, 2017).

Class Phaeophyceae includes more than 1,800 brown algae distributed in three common orders: Fucales, Laminariales, and Ectocarpales within the phylum Ochrophyta. Members of the class Phaeophyceae come in a wide range from simple filamentous forms to giant kelps with some species known to reach up to 60 meters in length. These are among the structurally most complex of all algae; the degree of specialization in tissues and organs is very high, especially in the order Laminariales (Guiry & Guiry, 2023).

The algae are very crucial in the marine ecosystem's food chain because of the role they play as primary producers in many coastal environments (Yılmaz & Ak, 2023). Large brown species like kelps create expansive underwater forests that offer shelter and habitat for marine life, including other algae, invertebrates, and fish. Kelp forests rank among the highly productive and dynamic ecosystems globally. Their levels of biodiversity and productivity

have few rivals on Earth, other than tropical rainforests (Steneck et al., 2002). Besides their ecological functions, these algae play a crucial role in the global carbon cycle; they have the capability of capturing atmospheric carbon dioxide through photosynthesis, transforming it into organic matter, which feeds other organisms up the food web. This process also mitigates the impacts of climate change as carbon is sequestered in the ocean (Pessarrodona et al., 2023).

Besides their ecological importance, these algae have been used by humans for many centuries. They are collected for food, fertilizer, and industrial purposes. Among the key products derived from brown seaweeds is alginate, a polysaccharide applied in food production as a thickening and stabilizing agent. It also finds its place in the textile industry for printing on fabrics and, particularly, in medical items: from wound dressings to dental molds. For example, Ak (2015) and Cirik & Cirik (2017) discussed it in detail. Moreover, the economic attainments of brown algae are also related to their biotechnological application. Recent studies have focused on the extraction of these algae for bioactive compounds used in pharmaceuticals, cosmetics, and nutraceuticals. These include fucoidan, phlorotannins, and fucoxanthin, exhibiting diverse biological activities such as antioxidant effects, thereby enhancing the culinary and economic value of brown seaweed (Table 1).

ARSENIC IN AQUATIC ECOSYSTEMS

Natural sources of arsenic include hot springs, thermal springs, volcanic rocks, sedimentary rocks (organic and inorganic clays), metamorphic rocks, seawater, and mineral deposits (US EPA, 2003). Volcanic eruptions release arsenic into the atmosphere, dispersing it across air, water, and soil via wind-blown dust. This arsenic eventually mixes with water through runoff and leaching (Chen et al., 2013). Arsenic, stemming from the planet's crust, acts as a common environmental contaminant and appears in four oxidation states: [As(V)] arsenate, [As(III)] arsenite, elemental arsenic (As), and [As(-III)] arsine (Sharma & Sohn, 2009) (Figure 1).

Table 1. Culinary uses of commonly eaten seaweed species containing arsenic

Latin Name	Common Name	Commonly Used In	References
<i>Saccharina japonica</i>	Kombu	dashi, soups, broths	McHugh (2003); Tanaka et al. (2020)
<i>Undaria pinnatifida</i>	Wakame	soups, salads	Figueroa et al. (2023); Tanaka et al. (2020)
<i>Sargassum fusiforme</i>	Hijiki	cooked with soy sauce	Tanaka et al. (2020)
<i>Eisenia bicyclis</i>	Arame	salads, stir-fries	Tanaka et al. (2020)
<i>Fucus vesiculosus</i>	Bladderwrack	European traditional foods and medicine	Pereira (2022)
<i>Cladosiphon okamuranus</i>	Okinawa Mozuku	salads	Tanaka et al. (2020)
<i>Nemacystis decipiens</i>	Mozuku	salads	Tanaka et al. (2020)
<i>Ecklonia kurome</i>	Kurome	soups	Tanaka et al. (2020)
<i>Durvillaea antarctica</i>	Cochayuyo	empanadas, stews	Montecino (2004)
<i>Undaria pinnatifida</i>	Wakame	salad, soup	Cwierotka (2008); Mouritsen (2013)

In its elemental form, arsenic is insoluble in water. However, when combined with other elements (such as salts), its solubility varies depending on the presence of different chemicals and the environment's acidity (Flora, 2015). Many common arsenic compounds are water-soluble, allowing arsenic to dissolve in rain or snow and enter lakes, rivers, groundwater, and eventually the oceans through industrial discharges (Chen et al., 2013). The type and distribution of arsenic in the aquatic environment are determined by pH, metal complex ions, and redox potential (Başkan & Pala, 2009). Arsenic is primarily found in inorganic forms, specifically arsenite (As(III)) and arsenate (As(V)) (Cutter & Cutter, 1995; Šlejkovec et al., 2006).

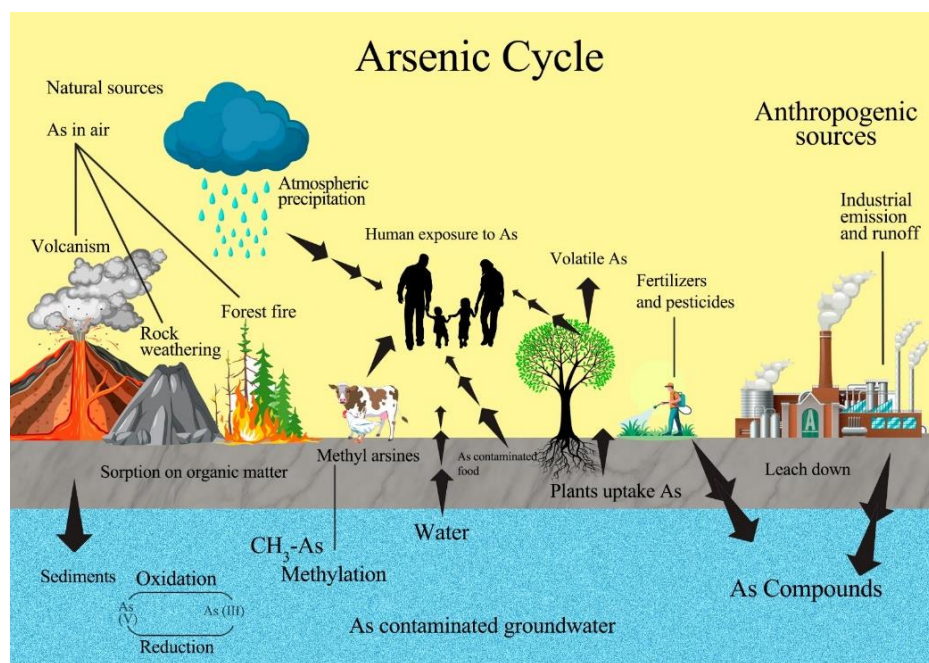


Figure 1. Natural arsenic sources and their pathways

Aquatic organisms can absorb different arsenic forms from contact with polluted food, water, sediments, and particles (Saidon et al., 2024). These organisms can also convert arsenic species into organic forms that are less toxic or harmless (Murthy et al., 2024), resulting in arsenic concentrations that are three to four times higher than those found in seawater (Šlejkovec et al., 2006). Marine algae, particularly those in the Phaeophyceae, are known to absorb large

amounts of arsenic, exhibiting a greater capacity to accumulate this element compared to other algal groups (Ma et al., 2018).

In seaweeds, there are several forms in which arsenic exists: inorganic arsenic includes As(III) and As(V), and organic arsenic compounds like MMA (monomethyl arsenic acid), DMA (dimethyl arsenic acid), AsB (arsenobetaine), and AsC (arsenocholine) (Li et al., 2024; Sadee et al., 2024). Arsenic is normally absorbed via the pathway for phosphorus and can be transferred into different chemical species with arsenic (Li et al., 2024; Sadee et al., 2024). Lower levels of environmental phosphorus, therefore, increase the accumulation of arsenic in seaweed at higher levels of iAs (inorganic arsenic), which may be potentially toxic to human health through seaweed consumption (Lin et al., 2021).

These studies on arsenic speciation in marine organisms have indicated that primary arsenic compounds in seaweeds and terrestrial plants are arsenic sugars (Šlejkovec et al., 2006). The studies have also established that while the said organisms contain arsenic sugars, they do not contain arsenic betaine (Goessler et al., 1997).

ARSENIC METABOLISM IN BROWN ALGAE

In aquatic systems, biochemical speciation and cycling of arsenic are controlled by pH, iron/manganese oxides, redox potential, and microorganisms. For instance, these factors have an important effect on the interaction of brown algae with arsenic and its metabolism (Hussain et al., 2019). The chemistry of arsenic in marine environments is quite diverse because of various types of chemical and biological-mediated reactions, such as oxidation, reduction, methylation, and de-methylation, which occur in seawater (Mamun et al., 2019). While all these processes are well documented, the particular contribution of algal species to the arsenic biotransformation deserves much more investigation and exploration. In seawater, the main form of arsenic is As(V), which represents the thermodynamically stable form of oxygen-rich surface waters (Shchukin et al., 2023). Carboxylates within the cell wall structure of brown algae, including alginate and fucoidan, contribute to their strong capacity for metal chelation (Ghimire et al., 2008). Brown algae readily take up arsenate, mistaking it for a structural analog of phosphate, especially in environments where phosphate is scarce. As a result of the metabolic activity

of marine organisms, other arsenic compounds, including arsenite (As(III)), monomethyl arsenic acid (MMA(V)), and dimethyl arsenic acid (DMA(V)), are also found (Matschullat, 2000) (Figure 2).

Once inside the algae, most absorbed arsenate is reduced to arsenite, which is then converted by oxidative methylation into various organic arsenic compounds such as MMA(III) , MMA(V) , DMA(III) , DMA(V) , trimethylarsine (TMA(III)), and trimethylarsine oxide (TMAO(V)) (Kalia et al., 2015). In brown algae, the methylation of arsenic compounds is facilitated enzymatically via methylcobalamin or S-adenosylmethionine, leading to the formation of these less toxic forms (Shchukin et al., 2023). Further reactions, such as the reduction of dimethyl arsenic acid (DMA) by adenosylmethionine, can produce even more complex compounds like dimethyl arsenyladenosine and trimethyl arsenoribosides, which are typically stored in cells in safer forms (Shchukin et al., 2023).

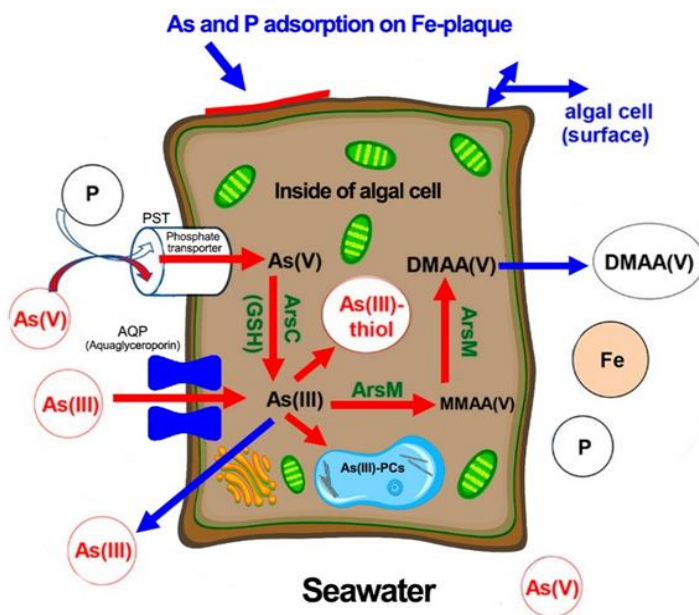


Figure 2. Arsenic metabolism in a brown alga cell

These finally result in the formation of arsenosugars, with more than 20 individual types identified in seaweeds to date (Taylor et al., 2017). In brown algae, organic arsenic species like arsenosugars are usually the major constituent of arsenic, composing up to more than 85% of the total arsenic in brown seaweed (MacMonagail & Morrison, 2019). Generally, detoxification occurs in most brown algae when in seawater that contains relatively low arsenic content (Shchukin et al., 2023). But in highly arsenic-polluted conditions, brown algae contain higher levels of arsenate over the other organic forms; this has recently been noted in species like *Hizikia fusiforme* (Taylor et al., 2017). This would therefore mean that different brown seaweeds have different ways through which they handle arsenic and cannot detoxify it satisfactorily. The knowledge of these metabolic processes in brown algae is important for better understanding the detoxification mechanisms in organisms and assessing the overall impact of arsenic toxicity in marine ecosystems, including possible effects on human health.

ARSENIC CONTENT IN BROWN SEAWEEDS

Species of arsenic include inorganic forms such as As(III) (arsenite) and As(V) (arsenate), as well as organic compounds with As-C bonds, including As-sug (arsenosugars), AC (arsenocholine), AB (arsenobetaine), AsL (arsenolipids), MMA (monomethylarsonic acid), and DMA (dimethylarsinic acid) (Camurati & Salomone, 2019).

In algae, arsenic exists in organic forms, usually known as arsenic sugars and inorganic. Certain species of algae can naturally amass arsenic to levels that exceed the threshold of regulatory health (Verdehlo, 2023). Among all the most sensitive living organisms, toxicity from iAs affects freshwater and marine algae (He et al., 2024). Bioavailability and bioaccumulation of arsenic depend largely on the species of arsenic concerned (Obuekwe and Ajuzie, 2024). Thus, the presence of inorganic and organic arsenic forms may be necessary to account for variations in bioaccumulation across marine algae (Mamun et al., 2019).

Variations in the classification of macroalgae impact arsenic accumulation levels. Indeed, research has shown total arsenic concentrations were 1,000 to 50,000 fold higher in the algal tissues compared to seawater (Mamun et al., 2019). The brown algae accumulate more arsenic than other

algae divisions (Almela et al., 2006; Muñoz & Díaz, 2022; Obuekwe and Ajuzie, 2024). Overall, brown algae were found to contain significantly higher levels of total arsenic at 230 mg/g dw, compared to green algae at 23.3 mg/g dw and red algae at 39 mg/g dw (Francesconi & Edmonds, 1993).

Alginate, the primary polysaccharide in brown algae cells, can bind to metals and metalloids present in marine environments to varying degrees (Jeon et al., 2002). For this reason, a listing of brown seaweed species whose tissues tend to accumulate arsenic would be a useful reference for the consumers (Table 2).

Whereas inorganic arsenic could reach about 0.3 mg/kg d.w. in algae, the total organic arsenic exceeded more than 50 mg/kg dwt, especially in *Laminaria* species (Verdehlo, 2023). *Laminaria digitata*, a key brown seaweed in agriculture, food, and health products, contains high levels of iAs and the NSFA (Norwegian Food Safety Authority) to advise against its use due to health concerns (NFSA, 2020). In brown seaweed, iAs concentrations ranged from 0.02 to 0.24 mg/kg in *Saccharina japonica*, *Undaria pinnatifida* and *Padina australis* species and from 15.1 to 83.7 mg/kg in different *Sargassum* species (*S. fusiforme*, *S. horneri*, *S. hemiphyllum*, *S. henslowianum*), highlighting significant differences in iAs concentrations compared to other algal groups (green and red) (Huang et al., 2022). In a study of several species of algae, *Hizikia fusiforme*, a brown alga, was found to have an exceptionally high arsenic content (68.3-149 mg/kg dw) compared to other species. However, many literature sources indicate that the high levels reported for this species, which can reach up to 179 mg/kg dw, are typical for this type of algae and should not be considered abnormal (Almela et al., 2006).

Table 2. Total Arsenic, Inorganic Arsenic Contents in brown seaweed species. Results expressed in ppm

Brown Seaweed Species	Description of Product	Total As (ppm)	Inorganic As (ppm)	References
<i>Palmaria palmata</i>	Atlantic dulse (dried seaweed)	7.56	0.44	Almela et al., 2002
<i>Eisenia bicyclis</i>	aramé (dried seaweed)	23.8 30.0	- 0.15 – 1.35	Almela et al., 2002; Almela et al., 2006
<i>Undaria pinnatifida</i>	wakame (dried seaweed)	0.29-63.8	0.15 - 1.06	Almela et al., 2002, 2006; Khan et al., 2015; Huang et al., 2022
<i>Laminaria japonica</i>	kombu (dried seaweed)	0.52- 116.0	0.254 - 1.44	Almela et al., 2002; Almela et al., 2006; Khan et al., 2015
<i>Laminaria digitata</i>	fresh seaweed (Ireland)	59 - 114	30 - 62	Ronan et al., 2017
<i>Fucus vesiculosus</i>	fucus (dried seaweed)	40.4 53.1	- 0.291 - 0.34	Almela et al., 2002; Almela et al., 2006; Huang et al., 2022
<i>Hizikia fusiforme</i>	hiziki/hijiki (dried seaweed)	0.746 149	- 2.35 - 117	Almela et al., 2002; Almela et al., 2006; Khan et al., 2015
<i>Himanthalia elongata</i>	dried seaweed (Spain)	31.2	0.202	Almela et al., 2006
<i>Durvillaea antarctica</i>	dried seaweed (Chile)	15.2	0.318	Almela et al., 2006
<i>Ascophyllum nodosum</i>	fresh seaweed (Ireland)	98 - 111	0.007 - 0.703	Ronan et al., 2017
<i>Sargassum fusiforme</i>	fresh seaweed (Chinese coastal)	49.6	-	Huang et al., 2022
<i>Sargassum fulvellum</i>	different packaging (South Korea)	0.14	5.347	Khan et al., 2015
<i>Sargassum horneri</i>	fresh seaweed (Chinese coastal)	57.8	-	Huang et al., 2022
<i>Sargassum hemiphyllum</i>	fresh seaweed (Chinese coastal)	72.6	-	Huang et al., 2022
<i>Sargassum henslowianum</i>	fresh seaweed (Chinese coastal)	150.0	-	Huang et al., 2022
<i>Padina australis</i>	fresh seaweed (Chinese coastal)	15.3	-	Huang et al., 2022

HUMAN HEALTH AND REGULATIONS

Today, people are more concerned about food safety. This has increased interest in understanding the arsenic content and potential toxicity of the seaweed species they consume and seaweed-based dietary supplements. Arsenic has been identified as an essential food safety hazard in seaweeds and has been reported to require careful monitoring and regulation to protect human health (Camurati & Salomone, 2019; Banach et al., 2020). However, even with the expanding international market for seaweed and its rising applications, there is currently no specific Codex standard or guideline addressing seaweed food safety (FAO, 2022). In the absence of Codex guidelines and regulations, several countries have implemented initiatives to manage food safety risks related to seaweeds. However, countries' thresholds for total and iAs in seaweed-derived human food and animal feed vary (Pétursdóttir et al., 2015).

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) and the European Food Safety Authority (EFSA) have issued recommendations for the provisional safe weekly intake of total inorganic arsenic based on body weight. JECFA recommends a value of 0.015 ppm, while EFSA has set a value of 2 ppm (Khan et al., 2015).

France is the earliest European nation to conduct a targeted evaluation of macroalgae as a non-traditional food for human consumption (CEVA, 2019). In its recommendation on trace elements in edible seaweeds, France has proposed a maximum limit of 3 mg/kg dw for inorganic arsenic (Ficheux et al., 2023).

The European Union has started a standardization project for seaweed and its products, whether in the development of standards for the missing methods in analyses of seaweed. In the Philippines, BAFS (the Bureau of Agriculture and Fisheries Standards) issued GAP-Seaweed (the Code of Good Aquaculture Practices for Seaweed) in 2021, along with guidelines for dried seaweed (FAO, 2022). The Australia New Zealand Food Standards Code has set seaweed's maximum level of iAs at 1 mg/kg (Ashmore et al., 2019; FSANZ, 2020). In addition, standardization based on estimated iAs and total As content is included in Chinese regulations (Shchukin et al., 2023). According to the Chinese National Food Safety Standards, the limit of iAs in infant complementary foods containing seaweed has been set at 0.3 mg/kg (Huang et al., 2022). It is 0.5 mg/kg for iAs in edible seaweed, according to Lin et al.

(2021) about the National Food Safety Standard - Limits of Pollutants in Food (GB 2762-2017).

Commonly consumed seaweeds are known to have high levels of arsenic, primarily in organic forms (Taylor et al., 2017). Arsenic's harmful effects vary based on its chemical type or species, with iAs compounds generally regarded as more toxic than organoarsenic (orgAs) compounds (EFSA, 2024). Inorganic arsenic acts as a carcinogen and thus requires attention from a public health standpoint (WHO, 2011). As(III) is generally more toxic than As(V) and more harmful than its significant compounds, dimethyl arsenous acid (DMAA(III)) and monomethyl arsenous acid (MMAA(III)) (Davydiuk et al., 2023). Some inorganic contaminants are specific to certain algal species, with particular attention drawn to natural arsenic levels in brown seaweed, which may exceed health limits (Verdehlo, 2023). The global regulatory framework governing the legal upper limit of iAs in seaweeds as a food source is limited (Huang et al., 2022). Furthermore, there is currently no standardized limit for the total arsenic content.

It has been clear according to the United States Pharmacopeia that organic forms of arsenic are nontoxic; hence, setting a limit of 2.0 mg/kg only for inorganic arsenic, iAs content (Shchukin et al., 2023). Substances with organic arsenic have been identified as nontoxic many times. This is because they omit arsenobetaine and arsenosugars, the main species in brown algae and warm-blooded organisms (Shchukin et al., 2023). Furthermore, a study on seaweed consumption in adults demonstrated that exposure to inorganic arsenic (averaging 0.002 µg/kg body weight per day) accounted for no more than 0.7% of the total dietary intake of iAs. This evidence conclusively shows that seaweeds contribute little to dietary exposure to this contaminant (Ficheux et al., 2023). A study on the consumption of various packaged edible brown seaweeds sold in South Korean markets showed that the iAs contents were within the permissible limits of EFSA and JECFA for inorganic arsenic (Khan et al., 2015).

The International Agency for Research on Cancer has classified the total arsenic and inorganic arsenic forms as Group 1 carcinogens for humans (IARC, 2004). Arsenic accumulates primarily in the kidneys, liver, lungs, and heart, and secondarily in the brain and muscles (Shchukin et al., 2023). Arsenic compounds have been proven to affect human health, even at low

concentrations adversely (Figure 3). They can lead to various diseases, including diabetes and cancer (Luvonga et al., 2020). The harmful effects of inorganic and organic arsenic compounds are a global concern. They have been proven to play a role, along with other heavy metals, in promoting lung, bladder, skin, prostate, and kidney cancers in humans (Tsai et al., 1998; Bernstam & Nriagu, 2000; Peralta-Videa et al., 2009). Scientists from various countries have definitively proven that pregnant women exposed to arsenic experience high levels of spontaneous abortion, stillbirth, and premature birth (Kwok et al., 2006).

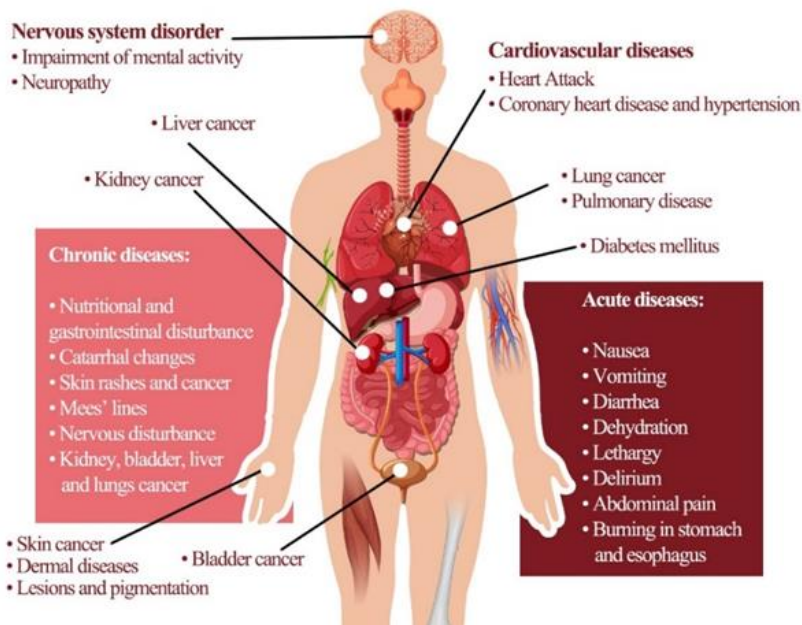


Figure 3. The diagram illustrates the various health impacts associated with arsenic exposure in humans.

Regarding inorganic arsenic, BMDL01 values for lung, skin, and bladder cancers, besides skin lesions, have been estimated to lie in the range between 0.3-8 $\mu\text{g/kg}$ body weight/day. However, MoE indicating risks excluding have not been specified so far (EFSA, 2009).

The standardization of only inorganic arsenic forms needs to be improved. This is because it does not consider possible impacts of organic arsenic metabolites on human health. It is, therefore, necessary that total arsenic content and inorganic forms of arsenic should be standardized separately since

this will help reduce risks associated with arsenic compounds in the products or supplements derived from brown algae. It is currently not feasible to assess the exposure risk of organic arsenic due to insufficient information on the concentrations and distributions of various species in seafood and a major gap in toxicity research and studies on human populations (Taylor et al., 2017). Health risk from exposure to organic arsenic cannot be evaluated due to insufficient data on toxicity and long-term exposure in humans or other mammals. Consumption of seaweed has also been linked in another study to arsenic exposure, thus posing a possible health hazard to humans. This, overall, is low except at high dosages or sensitive individuals (Taylor et al., 2017). Therefore, there is an urgent need for a collaborative global standardization and regulatory framework to guarantee the safety of seaweed products for consumers. The monitoring and control of arsenic content in seaweeds are of paramount importance to ensure consumer health safety by limiting the potential toxic effects that consumption might cause. Additionally, there is a need to create consumer awareness, and information on safe practices regarding seaweed consumption should be provided to help minimize arsenic exposure risks.

CONCLUSION

In other words, while seaweeds are health foods because of their high yields and nutritional bioactive useful food ingredients, they are also associated with the intake of arsenic and other potential risks. Arsenic, mainly inorganic, is an established carcinogen, and diet ingestions represent the most important route of arsenic exposure for the general population. The levels of arsenic in commonly consumed seaweed, the absorption rate after consumption, and its formation and bioaccumulation in the human body should be assessed when the risks from the consumption of seaweed due to arsenic exposure will be comprehensively checked. Arsenic metabolism in brown algae and its transformation to various chemical species is a key factor flowing into the toxicity of these seaweeds and linked health risks. Awareness must be raised about the consumption of seaweed and detailed analysis, together with strict regulatory action concerning the sale of various seaweed-derived products. Establishment and enforcement regarding standardized limits of the quantities of arsenic in seaweeds at both levels, global and local, are thus absolutely

crucial to ensuring the health of consumers. Further research is seriously considered necessary for fuller understanding of exposure, bioavailability, and possible long-term health consequences of arsenic. This will ensure that from a holistic point of view, the health benefits accruable from seaweed will be enjoyed safely without compromising public health.

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CHAPTER 2

SEAWEED SALADS BE A GOOD ALTERNATIVE FOR OBESITY

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INTRODUCTION

Seaweeds, also known as marine macroalgae, are very important group of aquatic plants found in oceans and coastal waters around the world. They have been a staple food in many coastal cultures for centuries and are increasingly recognized for their nutritional value (Hefft and Fornaciari, 2024). Seaweeds and seaweed-derived bioactive materials have been used for centuries in countless applications, from the production of glass and gunpowder to their use in high cuisine and molecular gastronomy (Hayes et al., 2015). They are often consumed in small proportions as a source of iodine, as dried snacks, savory spices, and hydrocolloids are found in desserts, cakes and jams. Given the nutritional benefits of seaweeds such as *Kappaphycus*, *Pyropia*, *Sargassum*, *Gelidium*, *Gracilaria*, and *Ulva* species can be promoted for the commercialization of seaweed-based food products (Darko et al., 2024). They could potentially contribute to future global security in functional foods and nutraceuticals, and be an important compound in the pharmaceutical and biotechnology industries for drug development, among other uses (Salido et al., 2024). Seaweeds are also very good source of dietary fiber and antioxidants. They contain unique compounds called fluorotanins, which have been indicated to have not only anti-inflammatory, but also anticancer properties (Hefft and Fornaciari, 2024). Apart from this, bioactive compounds of seaweeds have also been related to various biological activities such as prebiotic, antiviral, hypocholesterolemic, anticoagulant, antimicrobial, antioxidant, anticancer, anti-inflammatory, immunomodulatory

and antidiabetic. Due to their richness in highly valuable compounds and their balanced composition, seaweeds have become a promising and innovative source of new functional ingredients that can be used in the development of new novel food products as well as nutraceuticals, thereby improving human health, well-being and quality of life and also stimulates to the prevention and treatment of diseases (Matos et al., 2024). Seaweeds are effective as therapeutic pharmacological assets for various disorders, including cancer, dyslipidemia, hypertension, diabetes and obesity (Pradhan et al., 2022). For example, *Sargassum fusiforme*, a brown seaweed widely consumed as a culinary delicacy and medicinal plant in East Asian countries, contains a large number of bioactive materials with anti-inflammatory, antioxidant and anti-obesity properties (Bai et al., 2024). Another example can be given for brown algae *P. tetrastomatica* bioactives eliminated adipogenesis and lipogenesis in 3T3-L1 adipocytes. Therefore, *P. tetrastomatica* and barley-based functional foods could have potential applications in obesity management (Sharma et al., 2022). More than 90% of all cases of diabetes are commonly type 2 diabetes, a disease exacerbated by sedentary behaviour, poor eating habits and an increase in obesity (Pillay et al., 2024). Obesity have been highlighted to be one of the most important cardiovascular risk factors and its prevalence is increasing in industrialized populations. Obesity appearance rates in the United States have approximately doubled in the past 20 years, reaching about 34% of the population, and that includes children. In Europe, the percentage reduces to 15%, with big differences between several countries. In addition to being a very important risk factor for obesity, diabetes mellitus, cardiovascular diseases, dyslipidemia and hypertension. It also leads to a very important increase in the incidence of bone and joint, biliary, gastrointestinal, dermatological, neoplastic, respiratory diseases. Therefore, it was indicated as an important to explore alternative ways in dietetics (Leonetti et al., 2016). The Korean diet has attracted great attention due to the very low prevalence of metabolic disorders and obesity in this country. Although the Korean diet has been indicated to have a good health benefits, these effects have been examined by analyzing individual nutrients or food compositions. Additionally, the Korean diet was reported to be prevented obesity and improved insulin resistance. Consequently, it is also reported that the Korean

diet could be very healthy as a therapeutic diet to control many metabolic disorders (Choi et al., 2017).

An increasing population is demanding more and more food for their nutrition. In addition, people around the world have become health-conscious, demanding foods with fewer calories and high fiber content. For this purpose, seaweeds have an important potential to meet this demand, as they are rich in various nutrients and fiber, as well as they can grow very quickly. At the same time, their calorie index is low (Shukla et al., 2023). In this study conducted in the light of the above mentioned information, the introduction of consumable seaweeds and the effects of seaweeds on human health, seaweed salads have been produced from different types of seaweed in different formulations.

SEAWEED CULTIVATION, ENVIRONMENTAL CONDITIONS AND HARVESTING

Algae, which is a very important food to meet the increasing food needs in some parts of the world, are produced in large quantities worldwide. Asia, in particular, provides the largest production with 99.5% of the world's seaweed production. (Chopin, 2018). Algae that develop using organic matter in their environment clean the water and increase its quality. Seaweed production is one of the fastest growing industries in the world, covering an area of 48 million km² and having production facilities in 132 countries worldwide. Production is concentrated in 37-45 countries (Froehlich et al., 2019).

While the amount of seaweed obtained from natural sources remained at 1.1 million tons, production in seaweed farms increased to 35.8 million tons in 2019, accounting for 97% of global seaweed production (FAO, 2021b).

Cultured *Gracilaria* constitutes 10.7% of this production. *Gracilaria verrucosa* has a branched thallus and is 5-30 cm long on average. The optimum temperature of *Gracilaria* is 16°C, while the optimum temperature range is between 4°C-37°C. The optimum salinity range is between 0-15% and 0-50%, while the optimum salinity range is between 0-20%-035%. (Düsedau et al., 2023) (Picture 1).

Ulva lactuca var. *rigida* C. Agardh has a thick thallus and lettuce-like structure (Picture 1). Due to the expected demand for ulva snack seaweed products, salinity between 15% and 30% and temperature between 10°C and

35°C have been studied for large-scale ulva production in India. Optimum growth of *Ulva lactuca*, which loves eutrophic brackish water, was found at 0.15% salinity and temperature 10°C (Malta, E. J., et al., 1999; Chin, et al., 2023) (Picture 2)

Codium fragile is a striking green alga with spongy, thick, finger-like branched leaves. It is native to Asia and has been introduced around the world, including North America, South America, Greenland, Europe, Africa, Australia, and New Zealand. It grows attached to hard surfaces in a wide variety of habitats. *Codium fragile* is tolerant to a wide range of temperatures (-2-30°C) and salinities (12-42 PSU) (Malinowski ve Ramus 1973; Hanisak 1979) (Picture 4).

Enteromorpha, accepted in the genus *Ulva*, are simple or branched species with tubular talus, intestine-like, single cell layer, showing a hollow center (Starmach, 1972). The leaves are usually unbranched. The leaves are usually 10–30 cm long with rounded tips and can be 6–18 mm in diameter. *Enteromorpha intestinalis* has an optimum temperature of 20 to 25° C and an optimum salinity of 25 to 30‰. Light has an important effect on initial growth, but is not essential. Optimum development in waters where the salinity ranges from 15 to 30 PSU (Bermejo, R., et al., 2022) (Picture 3).

Algae are cultured in open air tanks with an initial density of 1 kg fresh weight per m². In macroalgae production, 10 mL/lit F2 Culture Medium is applied to seawater weekly. Vegetatively produced algae are harvested.



Picture 1. *Gracilaria verrucosa* (Hudson) Papenfuss (Original)



Picture 2. *Ulva rigida* C. Agardh, 1823 (Original)



Picture 3. *Enteromorpha intestinalis* (Linnaeus) Nees, 1820 (Original)



Picture 4. *Codium fragile* subsp. *fragile* (Suringar) Hariot, 1889 (Original)

THE EDIBLE SEAWEEDS USED AS SALAD

The dominant species under cultivation include: Rhodophyceae or red algae (*Porphyra* spp, *Rhodomenia* spp, *Aeodes orbitosa*, *Notogenia stiriata*), Chlorophyta or green algae (*Ulva*, *Enteromorpha*, *Monostroma* spp.) and Phaeophyceae or brown algae (*Fucus*, *Laminaria*, *Zonaria*, *Ascophyllum*, *Macrocystis*), mainly divided according to its pigment accumulation (Benelhadj et al., 2016). In the lights of above sentences. Edible aquatic seaweeds are divided into three important groups according to their composition of the available photosynthetic pigments: red seaweed (Rhodophyta) (R), brown seaweed (Ochrophyta, Phaeophyceae) (P) and green seaweed (Chlorophyta) (C). (Ganesan et al., 2019). The scientific and common name of seaweeds, together with the type of salad or vegetable product produced, is indicated as follows. *Sargassum fusiforme* (P) (*Hiziki*) is cooked with curd and vegetables such as beans and carrots. *Cladosiphon okamuranus* (P) (*Mozuku*) is consumed fresh with soy sauce in a salad. *Caulerpa lentillifera* (C) (*Sea grapes* or *green caviar*) is used in fresh salads. *Chondrus crispus* (R) (*Irish moss* or *carrageenan moss*) is added to salads. *Gracilaria* spp. (R) (*Ogo*, *ogonori* or *sea moss*) is added to vegetable salad. *Durvillaea Antarctica* (P) (*Cochayuyo*) is consumed as salad (Raja et al., 2022). Although it is not a complete protein, some types of seaweed such as dulse, laver and nori are good sources of protein. Seaweeds can be eaten fresh, dried or as a powder or extract and they can be also preferred in a variety of different dishes such as soups, sushi, and salads (Hefft and Fornaciari, 2024).

Red seaweed alone (Rhodophyta), *Kappaphycus* / *Eucheuma*, *Gracilaria* (warm water genus) and *Porphyra* (cold water genus) are the main cultivated species, respectively. Among them, *Porphyra*, popularly known as *Nori*, is mainly used as an ingredient in sushi wraps, soups and snacks. *Palmaria palmata*, or dulse, is increasingly becoming an ingredient in home cuisine and snacks, while *Gracilaria* and *Kappaphycus/Eucheuma* are often consumed as salads and pickles. In addition to being consumed directly, other species are also used in the manufacture of carrageenan (*Kappaphycus* / *Eucheuma*) and agar (*Gracilaria* and *Gelidium*) (FAO, 2021a). *Ulva lactuca* is a green macroalgae widely grown on the Mediterranean coast, belongs to the phylum Chlorophyta and is commonly known as “Sea lettuce”. *U. lactuca* contains about 13.6% protein on a dry weight basis. Nutrient-dense *U. lactuca*

is used as a salad, as well as in kimchi preparations (Mohan et al., 2023). In many countries, sea lettuce has been widely consumed by humans as food since the beginning of time. Sea lettuce contains a significant amount of nutrients that are necessary for the human body (Kim et al., 2011). This seaweed is a type of green seaweed that it has also received significant attention due to its remarkable potential as a prolific source of bioactive compounds (Putra et al., 2024). *Ulva* species have not only attracted interest as a protein source due to their high production potential and high proportion of essential amino acids, lipid, fatty acid, mineral and vitamin content (Juul et al., 2024), but also dietary fiber can be extracted from algae *Ulva lactuca* (Yaich et al., 2015). Brown algae (Phaeophyceae or Phaeophyta) and its derivatives products have already used in food products (Roohinejad et al., 2017). The integration of algae as an ingredient into food products can contribute to flavor characteristics in addition to providing nutritional requirements. Nine macroalgae species were selected from three sections, namely Phaeophyta (brown algae): *Laminaria japonica*, *Undaria pinnatifida*, *Sargassum fusiforme* and *Fucus vesiculosus*; Rhodophyta (red algae): *Porphyra haitanensis*, *Porphyra yezoensis*, *Palmaria palmata* and *Gelidium amansii* and Chlorophyta (green algae): *Ulva lactuca* (Chua et al., 2024). They have long been used by coastal societies for their nutritional, functional and technological applications. In recent years, advances in analytical chemistry and biochemistry have allowed the identification of even more compounds associated with these algae, from bioavailable proteins and trace nutrients to ω -3 fatty acids, dietary fibers, antioxidant phenolic compounds and polysaccharides with a wide range of useful biological activities (Reboleira et al., 2019).

THE CONSUMPTION OF PLANT-BASED FOODS FOR THE CONTROL OF OBESITY

(WHO) The World Health Organization indicates obesity as a body mass index of 30 kg/m² or higher (Najm and Desiree, 2010). Reducing the childhood obesity, eliminating health inequalities as well as preventing the further spread of this disease worldwide can be required not only policy interventions to achieve that plant-based foods economical and approachable

to children of all income levels, but also consciousness of sociocultural norms, which affects consumption (Newby, 2009).

Studies have been summarized that algae are very important in the diet for healthy living in terms of the nutrients they contain. Seaweeds contain high-value nutritional compounds, such as proteins, vitamins etc. (Salido et al., 2024). They are beneficial to health not only from a nutritional view point, but also because of the useful substances they contain. Seaweeds have bioactive polysaccharides that enhancing immune function through modulation of the gut microbiota (Wijesekara et al., 2024). In addition to the health benefits of seaweeds, a regular diet rich in seaweed can be a good alternative for increasing the nutritional content of food products (Pradhan et al., 2022). Besides, foods with a low glycemic index may have therapeutic potential in the management of obesity. For example, *Padina tetrastromatica* was stated an underused and potentially sustainable brown algae rich in the anti-obesity molecules polyphenols, total lipids, fucoxanthin and polysaccharides (Sharma et al., 2022). Furthermore, rhamnan sulfate, a rhamnose-rich sulfated polysaccharide, have been indicated in the cell walls of green seaweed belonging to the genus *Monostroma*. This macromolecule was indicated to be showed promising therapeutic properties, including anti-inflammatory, anticoagulant, anti-viral, thrombolytic and anti-obesity activities with potential in the food and medical applications as well as industries. However, rhamnan sulfate was reported by the authors that it could be much attention as other seaweed polysaccharides, including carrageenan, fucoidan and alginate (Chi et al., 2023). The aim of one study was to investigate the effect of the consumption of the Japanese diet during pregnancy as well as lactation on the risk of obesity and diabetes in offspring in later life. From these results, maternal consumption of the Japanese diet during lactation and pregnancy did not adversely affect the offspring, and continuous intake of this diet reduced the risk of developing diabetes and also obesity in the offspring later in life (Ishikawa et al., 2019). The use of seaweed in diets has been studied as an approach to control and avoid chronic diseases such as diabetes, obesity, heart disease, microbial infections, cancer, respiratory problems and hypertension. Algae-based nutraceuticals are also gaining importance in the field of dietary supplements, partly due to the idea of algal prebiotics and their capacity to influence the intestinal microbiota

(Ahmed et al., 2024). Besides, seaweed, which contained brown algae with rich bioactive components, could be effective for a glycemic management strategy and appetite control. For this approach in one study the authors investigated the effects of two brown edible seaweeds such as *Undaria pinnatifida* (UP) and *Laminaria digitata* (LD), on glucose metabolism and appetite after eating, following a starch load. Co-ingestion of brown algae could be helped for improving postprandial glycemic as well as appetite control in healthy and normal weight adults (Zaharudin et al., 2021). If the studies on the benefits of different algae species are continued. *Gracilaria changii*, containing high nutritional values, especially dietary fiber. Additionally, this seaweed specie was reported to be a low ω_6 / ω_3 ratio, as well as atherogenic and thrombogenic index. Additionally, the physicochemical properties of *G. changii*, namely its water retention and swelling capacity, were reported to be comparable to some commercial fiber-rich products. Hence, this work suggested that *G. changii* could potentially be used as an important ingredient to improve the nutritional value and textural quality of functional foods for human consumption (Chan and Matanjun, 2017). Furthermore, *Undaria pinnatifida* (Wakame) were indicated that it contained a number of biologically active lipophilic compounds, especially fucoxanthin, which had an anti-oxidant, anti-cancer, anti-inflammatory as well as anti-obesity properties (Billakanti et al., 2013).

PRODUCTION OF VARIOUS SALADS FROM SEAWEED



Picture 5. *U. rigida* salad with Buckwheat (Grechka) (Original)



Picture 6. *G. verrucosa* salad with Buckwheat(Grechka)(Original)



Picture 7. *E. intestinalis* salad with Buckwheat (Grechka) (Original)



Picture 8. *C. fragile* salad with Buckwheat (Grechka) (Original)



Picture 9. *U. rigida* salad with Quinoa (Original)



Picture 10. *G. verrucosa* salad with Quinoa (Original)



Picture 11. *E. intestinalis* salad with Quinoa (Original)



Picture 12. *C. fragile* salad with Quinoa (Original)



Picture 13. *U. rigida* salad with Green Tomato (Original)



Picture 14 *G. verrucosa* salad with Tomato (Original)



Picture 15. *E. intestinalis* salad with Green Tomato (Original)



Picture 16. *C. fragile* salad with Green Tomato (Original)

SEAWEEDS AND HEALTH EFFECTS ON HUMAN LIFE

Seaweeds are a large group of photosynthetic microalgae found in the world's oceans. They are important sources of bioactive compounds with various biological activities that could potentially contribute to the nutraceutical industries and functional food (Charoensiddhi et al., 2017). Currently considered as potential functional foods, seaweeds are widely consumed in parts of Europe and across Asia. About 2200 species of seaweed have been described throughout Africa. Only 1% of the harvested seaweed has been used locally in the African country that produces the most (Darko et al., 2025). Seaweed production globally has increased rapidly in nowadays. Most of the growth have been in Asia, but there have been production

increases in Africa and Latin America (Web et al., 2023). Let's summarize some of the studies done on the effects of seaweed on health as follows. Seaweed is a rich important source of iodine, essential for thyroid function, and also contains high values of other minerals such as iron and calcium (Hefft and Fornaciari, 2024). Usage of seaweed primarily as iodine source only begun around the 18th century (Darko et al., 2025). Seaweeds, which have various nutritional, therapeutic and ecological advantages, are a growing source of food and medicinal components globally. However, due to perception, they are underused in several parts of the world. So, there is very essential to inform the public about the potential health benefits of seaweed intake, as well as to create improved methods for collecting, cleaning and using them to make eating them safer and to formulate nutritious, healthy and acceptable products for a wider public (Fasogbon et al., 2024). Besides, Agriculture in the 21st century faces challenges in adopting efficient and sustainable production methods to feed the growing population. In this approach, seaweed not only offers greater advantages over terrestrial plants (Chin et al., 2023), but also increasing environmental concerns and the desire for health-conscious food choices are increasing consumers' demand for sustainable and ethical food sources. For example recent studies revealed that the seaweed species of *Ulva* (*Ulva* genus, Phylum Chlorophyta) is emerging as a promising candidate due to its rich nutrient profile, which includes proteins, carbohydrates, lipids and antioxidants. Additionally, *Ulva*'s unique compounds have impressive health benefits, including antioxidant, antimicrobial and antiviral properties, which offered exciting possibilities for human health (Khan et al., 2024). Actually, seaweeds can improve human health and contribute to the prevention and also the treatment of diseases. They are an important natural source of highly valuable bioactive compounds such as omega-3 fatty acids, carotenoids, proteins, carbonhydrates, enzymes, fats, dietary fibers, fucoxanthin, polyphenols, essential amino acids, and vitamins such as A, B, C, and E (Pradhan et al., 2022; Vishwas et al., 2025). Seaweeds have also minerals such as magnesium, sulfur, sodium, calcium, phosphorus, potassium, chlorine as well as micronutrients such as iron, iodine, selenium, zinc, copper, fluoride, boron, manganese, cobalt, molybdenum and nickel. They not only helps to reduce cardiovascular diseases, lipid absorption and obesity, but also helps to promote overall mortality, glycemic control, specific

mortality due to coronary heart disease and cancer, obesity, mental health, respiratory diseases and diabetes as well as quality of life and healthy aging, among others (Matos et al., 2024; Vishwas et al., 2025). In patients with diabetes mellitus, the toxic environment caused by abnormal glucose as well as free fatty acid use can lead to heart failure. This syndrome, called diabetic cardiomyopathy (DCM), usually occurs in the failure of traditional risk factors for HF, such as a history of myocardial infarction or hypertension. Low-carbohydrate diets have recently been approved as an effective therapeutic dietary approach to prevent and reverse cardiometabolic disease, including type 2 diabetes mellitus (Kleissl-Muir et al., 2023). Algae and their bioactive compounds, especially polysaccharides and phenolics, can be considered wonderful nutritional supplements with gut health benefits and prebiotics. These components are resistant to digestion by enzymes found in the human gastrointestinal tract, as well as stimulate the growth of beneficial intestinal bacteria and also the production of fermentation products such as short-chain fatty acids (Charoensiddhi et al., 2020).

Many types of seaweed are anticancer, anti-inflammatory, antibacterial, antiviral, antioxidant, antiestrogenic, anticoagulant, antihyperlipidemic, antimicrobial, antihypertensive, antifungal, antioxidant, prebiotic, neuroprotective, hypocholesterolemic, thyroid stimulating, immunomodulatory, and have tissue healing properties (Matos et al., 2024; Vishwas et al., 2025). Seaweed is a very important rich source of nutrients and minerals that are important for bone health. Various types of algae, including red, green and brown algae, have been found to be helpful for bone health and contain various amounts of minerals such as magnesium, calcium, phosphorus, which are necessary for the improvement and maintenance of healthy bones. In addition to these minerals, algae contain bioactive compounds such as polysaccharides, polyphenols and carotenoids, which have anti-inflammatory antioxidant properties that can support bone health. Researches showed that the consumption of algae or algae-derived supplements could increase bone density as well as they could reduce the risk of osteoporosis in humans (Siddiqui et al., 2024).

Bioactive seaweed substances (BASS), which have health benefits beyond basic nutrition, can help to design functional food products that can correct nutritional deficiencies, promote optimal health as well as reduce the

risk of diseases thanks to their diversified structure and properties. The application of modern science and technology in BASS research and development can be used to supply many additional functional foods as well as future scientific and technological developments promise an even wider range of health benefits for consumers (Qin et al., 2018). Besides, efforts should be needed to improve the seaweed growing process on a commercial scale and gain consumer acceptance in the world. Further research should also needed to improve seaweed protein extraction and improve their function for food and nutraceutical applications (Rawiwan et al., 2022).

CONCLUSION

The increasing population and the decreasing food resources are making it increasingly difficult for people to reach healthy food. For this reason, it is expected that the importance of algae will increase even more in the near future and it will be become an important source of food. Seaweeds are widespread in Asian countries, while they are partially consumed in European countries, their consumption is not widespread in our country. Nevertheless, it is also thought that the importance should be given to the dissemination of the production and consumption of seaweeds, which are valuable in terms of nutritional values, in our country. In the study, salads were produced in different formulations from seaweeds, which are important in terms of nutritional value. It is thought that increasing the consumption of salads in different formulations from edible algae is important for healthy living. It is estimated that the consumption of such seaweed salads will also be efficient in the prevention and control of many diseases, especially obesity control due to its low calorie content. It is also thought that it is necessary to disseminate scientific studies on this subject.

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CHAPTER 3

USE OF SOME MARINE CREATURES IN MEDICINE

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INTRODUCTION

Seafood is the basic source of nutrition for humans. It contains essential nutrients such as vitamins A, B1, B2 and D, fat, carbohydrates, fatty acids, protein, calcium and zinc. Seafood, which is among the most valuable nutrients in terms of nutritional components, has not only provided people with a healthy life through nutrition for centuries, but also directly or some products obtained from them have been used in the treatment of some diseases seen in humans. It is thought that these nutrients have a preventive role in many health problems from nervous system diseases to cardiovascular diseases. Such treatment methods, which were not previously based on scientific results and were applied only based on observations, have inevitably given way to modern medicine over time.

The seas have begun to be studied by scientists for medical purposes. More than 10,000 bioactive molecules have been obtained from marine organisms and new compounds are added every year. It is being investigated whether these compounds can provide positive results in the treatment of different diseases. Information on the use of marine organisms in the field of medicine and how to benefit from them is included.

It has been reported that there are currently many studies by pharmaceutical companies on seafood, which is said to have positive contributions to the development and treatment of many diseases. However, it is observed that people in many developed countries are turning to natural products as a complement to modern medical practices. The share of seafood in these products has an important place.

Therefore, this review aims to present practices and research on the prevention and treatment of diseases, both through nutrition and direct use, and thus to introduce seafood in this regard.

***Bugula neritina* (Brown Moss Animals)**

Scientific classification

Kingdom: Animalia

Phylum: Bryzoa

Classification: Gymnolaemata

Ordo: Cheilostomata

Familia: Bugulidae

Genus: *Bugula*

Species: *B. Neritina* (Oken, 1815)

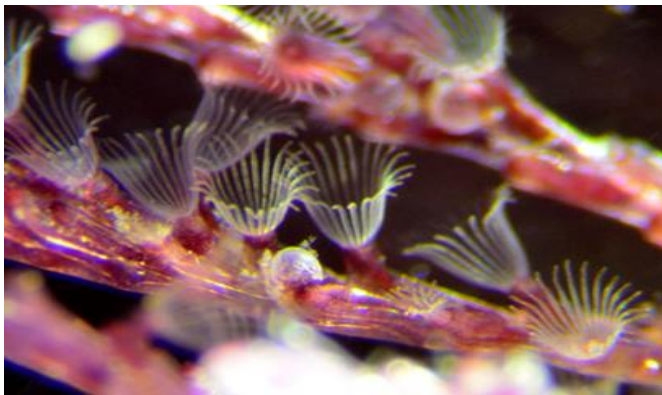


Figure 1. *Bugula neritina*

Features

It reaches up to 10 cm in length. It lives in colonies. It is purple-brown in color. It continues its life by attaching to bryzoan colonies and algae. It provides movement in water thanks to its tentacles.

Bugula neritina moves by attaching to oyster shells. It feeds on microscopic plankton. They have a cosmopolitan distribution. *Bugula neritina* provides the production of bioactive natural products bryostatins. 20 Types of bryostatins have been discovered since 2010. Approximately 1 ton of bryozoans is used to obtain 1 g of Bryostatin (Yamamura et al., 2000)

Area of Use in Medicine

The source of the bryostatin series is *B. neritina*. Bryostatin obtained from *Bugula neritina* has strong anti-tumor activities. Bryostatin-1 studies have been conducted for cancer chemotherapy. Studies using bryostatin have been initiated in blood tumors and solid tumors since 2014 (Pazourek, 2014).

Clinical studies have focused on anti-cancer and anti-AIDS/HIV disease (Halford, 2011). Bryostatin-1 is used for the treatment of neurological disorders such as Alzheimer's (Wallach et al., 2017). The synaptogenic compound bryostatin-1 has antidepressant effects when used intracerebroventricularly (Sun and Alkon, 2005).

Researchers from California have isolated a new cancer drug called bryostatin-1 from the marine polluting invertebrate *Bugula neritina*, which belongs to the Bryozoan family.

The drug is effective in leukemia and melanoma (mole cancers) and stimulates the immune system in breast cancer. Since the drug has a different effect than other cancer drugs, it is considered an important weapon against cancer. Interestingly, only *Bugulas* living deeper than 10 m can produce bryostatin-1, while *Bugulas* that are more superficial cannot.

"The bacterium *Endobugula sertula* which lives inside *Bugula*, is thought to play a key role in the production of bryostatin-1. There are two *E. sertula*, whose DNA differs by only four nucleotides. One of them lives inside *Bugula neritina*, which makes bryostatin-1, and the other one does not" (Scientist, 1998).

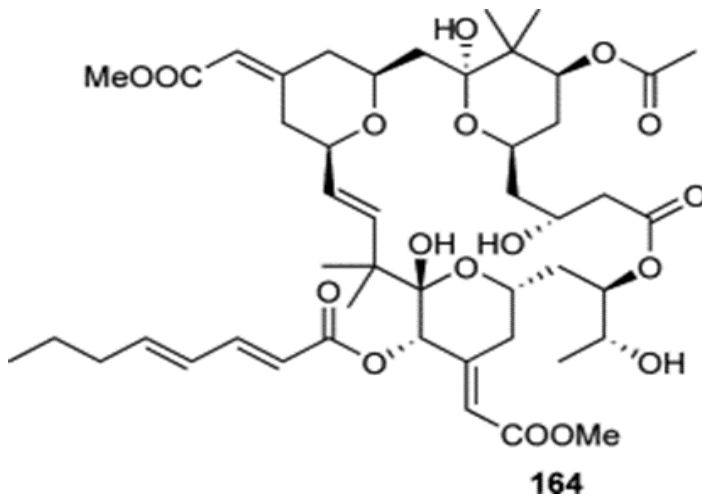


Figure 2. Bryostatin compound structure

***Conus magus* (Cone Snail)**

Bilimsel Sınıflandırma

Kingdom: Animalia

Phylum: Mollusca

Clasis: Gastropoda

Familia: Conidae

Genus: *Conus*

Species: *C. magus*
(Linnaeus, 1758)



Figure 3.*Conus magus*

Features

It is a cone-shaped sea snail. It is a poisonous species. They feed by catching small fish, mollusks and their venom. They constitute the largest marine invertebrate species. They hide in the sediments of the sea floor by removing their siphons (Ekici,2015). Cone snails have one eye at the end of two eye stalks. They detect their prey through a siphon. The siphon is a large tube that draws in sea water. It provides oxygen by absorbing it from the water. The spiral body is long and cylindrical. The shell is white. It may have orange, brown, and chestnut colors. Their distribution is the Pacific Ocean, the Red Sea, and the Indian.



Figure 4. Cone snail (George, 1879)



Figure 5. Internal structure of cone snail

Area of Use in Medicine

Ziconotide is obtained from *Conus magus* venom. Ziconotide works by blocking calcium channels in nerve cells that transmit pain and prevents pain

signals from being transmitted to the brain. It is applied to the spinal fluid by injection. Ziconotide is used if the success rate after analgesics are negative. It is prescribed only for people with certain types of cancer or neuropathic pain and patients who have suffered for a long time. Ziconotide blocks nervous system stimulation in synapses and starts working. When the excitatory nerve impulse reaches the end of a neuron, it stimulates the release of a chemical known as a neurotransmitter. Ziconotide prevents the release of neurotransmitters. Ziconotide also has side effects. They are depression, confusion, memory impairment and hallucinations. Problems increase when the dose increases (Crompton et al., 2020). It is stated that the snail's venom will be used in sclerosis, as it blocks sodium channels. It has given positive results in the treatment of diseases related to the nervous system such as schizophrenia and epilepsy (Ekici,2015). The venom gland of cone snails is called conotoxin

Conotoxins are increasingly being developed for the treatment of pain, Alzheimer's disease, Parkinson's disease, heart infarction, hypertension and different neurological diseases (Chen et al.,2005). In the United States, the drug has been approved by the FDA (Food and Drug Administration) under the trade name Prialt and is used as an analgesic. Insulin is present in the venom of the cone snail. Snail insulin is not the same as human insulin, but it is similar. Cone snail insulin works faster by avoiding the structural changes that human insulin undergoes to fulfill its function. While examining the three-dimensional structure of the snail's venom; It was found how to distribute the special structure found in human insulin and prolong its effect, and thus the speed of insulin's effect can be increased (Sukara et., 2020)

In 2002, researchers from the universities of Wollongong and Southern Cross announced that the molecule N-alkyl isatin, which contains cancer-preventing properties of snails, was isolated. By changing the composition of snail eggs to increase cancer-killing properties, researchers announced that the molecules found in snails killed all cancer cells resistant to chemotherapy drugs in the laboratory environment within 48 hours (Perrow and Davy, 2002).



Figure 6. Ziconotide obtained from *Conus magus*

***Dunaliella salina* (Water Algae)**

Scientific Classification

Phylum: Chlorophyta

Classification: Chlorophyceae

Ordo: Chlamydomonadales

Familia: Dunaliellaceae

Genus: *Dunaliella*

Species: *D. salina* (Guiry, 2012)

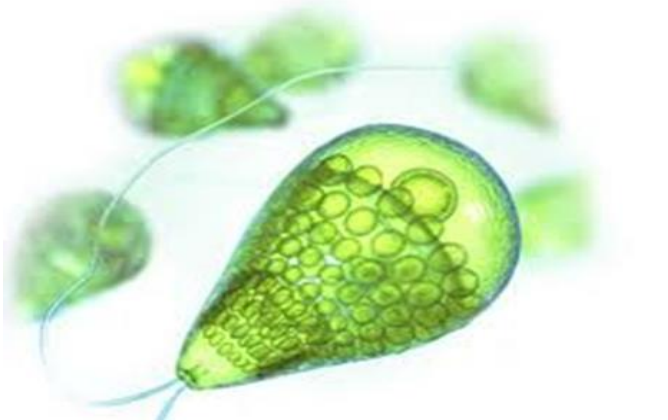


Figure 7. *Dunaliella salina*

Features

Dunaliella salina is frequently encountered in habitats such as salt lakes, salt pans and the sea. Its size is 10 microns. *D. Salina*'s structure includes a cell wall, contractile vacuole and chloroplast. *Dunaliella* can have different shapes

and symmetries due to environmental conditions. When *D. salina* is exposed to UV radiation, it has a protective feature against β -carotene. Its color appears red and orange due to the β -carotene in its structure. *Dunaliella salina* is an organism that has β -carotene against light and glycerol concentrations against osmotic pressure in order to continue its life. It is a halophilic green microalgae. It has two flagella of equal length (Paniagua, 2019).



Figure 8. Color produced by β -carotene in *Dunaliella salina*

Area of use in medicine

D. salina is an antioxidant and vitamin A precursor due to the abundance of β -carotene (Kumudha and Sarada, 2016). Carotenoids have inhibitory properties against tumors caused by UV light and chemicals. It has been determined that vitamin E and α -tokoferol protect the skin from UV rays due to the antioxidants it contains (Gökpınar et al., 2006). According to research, it is a source of vitamin B12 (Kumudha and Sarada, 2016). *Dunaliella salina* has a great effect in protecting free radicals, strengthening the immune system, protecting the cell against harmful rays and preventing cancer because it is a very good antioxidant (Çelekli and Dönmez, 2001). It is a species that prevents various cancer diseases. *D. salina* has an effect on antioxidant and cellular immune function in patients. It is used in the treatment of diseases such as vomiting, ulcers and wound healing. It protects against cell damage in cataracts, cardiovascular diseases and other chronic diseases. It was applied to patients in capsule form (15 mg) for 30 days.

It is an antioxidant and has effects on the cellular immune function. Vitamin A levels have increased. Accordingly, cell immune values such as tumor necrosis factor activity and lysis-phosphatidylinositol transformation rate have returned to normal. It has been observed that the antioxidant and immunological functions of pneumocaniosis patients have improved. As a result of the tests, it has been determined that the dose is safe for the patient.

***Ecteinasidia turbinata* (Sea grape)**

Scientific Classification

Kingdom: Animalia Phylum: Chordata

Subphylum: Tunicata

Clasis: Ascidiacea

Order: Enterogona

Familia: Perophoridae

Genus: *Esteinasidia*

Species: *E. turbinata*

(Herdman 1882)



Figure 9. *Ecteinasidia turbinata* (Sea grape)

Features

They are known as sea grapes. They grow up to 2.5 cm in height. They live in colonies. They form colonies up to 14 cm wide. They have siphons that

draw and push water. The edges of the siphons are orange due to the accumulation of carotenoids. They are distributed in the Caribbean Sea, Florida, North and South Carolina coasts and the Mediterranean Sea.

Area of Use in Medicine

Yondelis (trabectedin), a cancer drug, was obtained from *Ecteinascidia turbinata*. Yondelis is used in the treatment of breast cancer, prostate cancer, sarcomas and ovarian cancer (Spielmann et al., 2006). Yondelis has two types of cancer use in adults. It is a type of cancer that develops from advanced soft tissue sarcoma and supportive tissues. It means that advanced cancer has started to spread. They are patients with recurrent and platinum-containing drugs-sensitive ovarian cancer. For soft tissue sarcoma, the dose given as a single infusion lasting 24 hours every three weeks is 1.5 mg per square meter of surface area, calculating according to the patient's height and weight. For ovarian cancer, the three-hour infusion is 1.1 mg every three weeks (Ganjoo and Patel, 2009). Trabectedin is a substance that acts on marine-derived DNA and a transcription inhibitor. When the activity and feasibility of trabectedin were evaluated, it gave positive results (D'incalci and Jimeno, 2003). Depending on the severity of the adverse reaction to the drug, the dose can be cut, reduced or permanently discontinued. Yondelis is a drug used in cancer treatment containing the active substance trabectedin. It is a powder added to the solution for infusion (Martinez and Chaon, 2005).



Figure 10. Yondelis drug obtained from *Ecteinascidia turbinata*



Figure 11. *Holothuria tubulosa*



Figure 12. Drug production from sea cucumber

Features

Sea cucumber is an invertebrate animal and called echinoderm. It is known as the filter of the seas. The mouth and anus are located at two different ends of the body. There are tentacles around the mouth that are used for touching and feeding. *H. tubulosa* is 30 cm long (Demirsoy, 1998). They prefer to live among sea meadows called *Posidonia oceanica* (Taylor and Buttel, 1992). They live near the sea shores. They are distributed in our country on the Marmara, Aegean and Western Black Sea coasts (Emiroğlu and Günay, 2008). They have ambulacral tube feet and are used as a sensory organ. They breathe with an organ called the water lung in the body cavity. They feed on detritus, plankton and organic substances in mud. They can renew themselves and reproduce by laying eggs

Area of Use in Medicine

H. tubulosa is an important species in terms of health since it contains many trace elements and proteins in its structure. Since it contains saponin and polysaccharide, it has started to be used in the pharmaceutical industry as an anti-carcinogen. It is consumed to cure kidney system disorders and intestinal diseases. It is consumed as a source of capsules and tablets, vitamins and additional nutrients. Since *H. tubulosa* is rich in polysaccharide chondroitin sulfate, it is used for therapeutic purposes in reducing joint inflammation pain. Since it has a virus-reducing effect, it has been used in the treatment of HIV virus. It has started to be used in the treatment of cancer. Since it is a living creature with high nutritional value, it is used in AIDS disease (Huang et al.,2013).

Lagocephalus sceleratus (Puffer Fish)

Scientific Classification

Kingdom: Animalia

Phylum: Chordata

Clasis: Actinopterygii

Order: Tetradontiformes

Familia: Tetraodontidae

Genus: *Lagocephalus*

Species: *L. sceleratus* (Gmelin, 1789)



Figure 13. *Lagocephalus sceleratus* (Puffer Fish)

Features

It is a poisonous, bony marine fish. They feed on benthic invertebrates. It has tetrodotoxin in its ovaries and skin, which protects its skin from predators. It creates a toxic effect because it feeds on bacteria containing toxic substances (Noguchi & Arakawa, 2008). It has a long, thin body when it is not bloated. Its eggs and larvae are in the pelagic region. The poisonous fish has spines on the back of the head and the back of the body down to the tail (Özoğul et al., 2012). It is a species that migrates from the Suez Canal to the Mediterranean and the Aegean. It is most commonly found in Australia, Japan, the Indian Ocean, East Africa and the Red Sea.

Area of Use in Medicine

The venom of the puffer fish is used against cancer. The venom of the puffer fish has begun to be used in the fight against cancerous cells, in the treatment of heroin addiction, in migraine, rheumatism and fatal cancer pains in the world (Özoğul et al., 2012). Tetrodotoxin is a neurotoxin, in other words a poison, but this toxin is actually used in the pharmaceutical industry and the pharmaceutical industry. It was used as a raw material and commercialized under the name "Tektin" (Uzbay, 2019). Tüney; stated that the toxin contained in the puffer fish has been used in the production of medicines for several years, and said, "Studies have shown that the toxin obtained from the fish can be used as an effective painkiller in cancer patients. Since it quickly blocks sodium channels, its usability in the treatment of cardiac arrhythmia, migraine, rheumatism, neuralgia and heroin withdrawal has been proven" (Tüney, 2016).

***Saccharina japonica* (Brown Moss)**

Scientific Classification

Kingdom: Chromista

Phylum: Ochrophyta

Classification: Phaeophyceae

Ordo: Laminariales

Familia: Laminariaceae

Genus: *Saccharina*

Species: *S. Japonica*

(Areschoug, 1851)



Figure 14. *Saccharina japonica* (Brown moss)

Features

It is called brown seaweed. It is commonly found in China, Japan and Korea. Seaweed is cultivated in the ocean by a simple method by hanging it on ropes. It contains fucoidan in its structure and is a component of brown algae. Fucoidan is obtained from the leaves of the seaweed (Loughnane et al., 2008).



Figure 15. *Saccharina japonica*

Area of Use in Medicine

Fucoidan has anti-oxidation, anti-radiation, anti-thrombus and strengthens the immune system. It has anti-diabetes, anti-cancer effects. Tablets and capsules with anti-cancer, anti-coagulant, anti-thrombus and hypoglycemic functions are used. The sensitivity of cancer cells to chemotherapeutic drugs

increases. It destroys tumor cells by directly inhibiting their growth. It reduces blood pressure in patients with hypertension. It is used in treatment as an auxiliary antihypertensive drug for hypertension. The sensitivity of cancer cells to chemotherapeutic drugs increases. It destroys tumor cells by directly inhibiting their growth. It reduces blood pressure in patients with hypertension and is used in treatment as an auxiliary antihypertensive drug for hypertension. It lowers cholesterol. In renal failure, polysaccharide can reduce serum creatinine and improve protein content, and significant effects are seen on nephrotic syndrome. As a health supplement, the dosage should be between 300 mg – 1200 mg/day (Fitton, 2011)



Figure 16. Powder form of *Saccharina japonica*

***Stichopus chloronotus* (Spiny Sea Cucumber)**

Scientific Classification

Kingdom: Animalia

Phylum: Echinodermata

Classification: Holothuroidea

Ordo: Synallactida

Familia: Stichopodidae

Genus: *Stichopus*

Species: *S. chloronotus*

(Brandt, 1835)

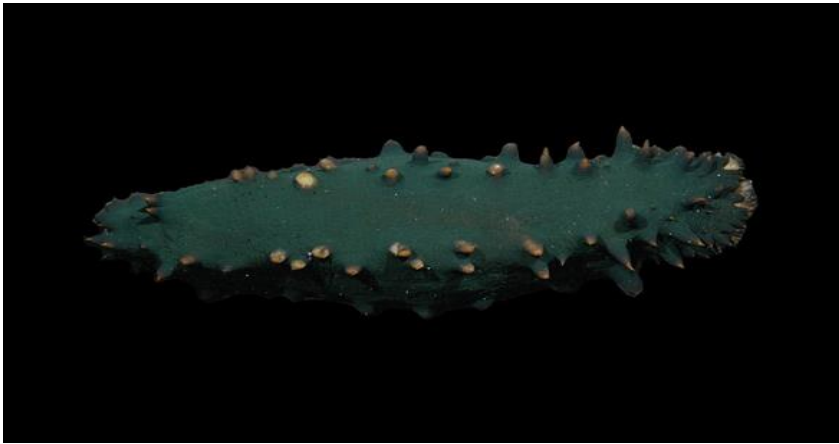


Figure 17. *Stichopus chloronotus*

Features

It is known as the spiny sea cucumber. They live in the Indo-Pacific region (Krumbholzet al., 2013). Its color is dark blackish green. Since they swallow large amounts of sand during their feeding, they ventilate the seabed, which is an important reason for this. They feed on plant and animal remains, bacteria, protozoa and diatoms. It grows up to 25 cm in length. The *S. chloronotus* species reproduces asexually as a reproductive feature. Its skin has a smooth structure. However, there are many fleshy papillae on the body (Hamel et al., 2013).

Area of Use in Medicine

S. chloronotus has been used pharmacologically. Since it contains oil and acid in its structure, it is effective in healing wounds. The therapeutic properties of sea cucumber include antioxidant, antimicrobial, anti-inflammatory, antiviral healing properties (Mazliadiyana, et al., 2017). This species is beneficial in the treatment of asthma, hypertension, rheumatism, sinus cuts and burns (Wen et al., 2010).

***Tectitethya crypta* (Water Sponge)**

Scientific Classification

Kingdom: Animalia

Phylum: Porifera

Clasis: Demospongiae

Order: Tethyida

Familia: Tethyidae

Genus: *Tectitethya*

Species: *T. crypta* (Laubenfels, 1949).

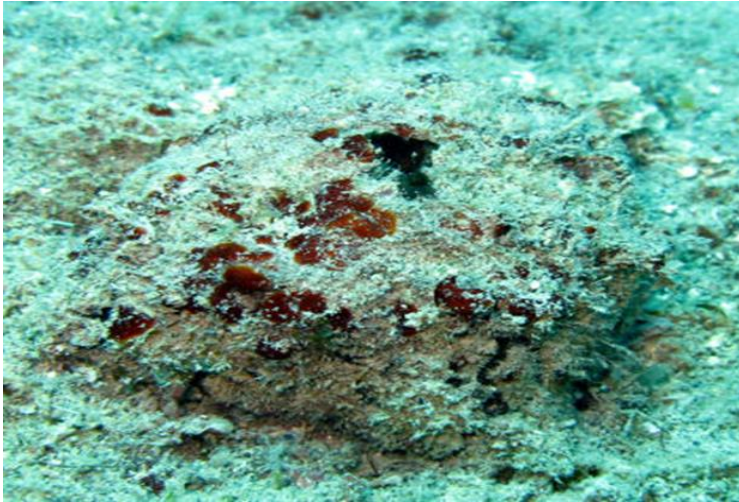


Figure 18. *Tectitethya crypta* (Laubenfels, 1949) (Water Sponge)

Features

It has a shapeless, irregular structure. Its colors are white or light gray due to the sediment cover. It is usually covered with sand and algae. They live in sediment in lagoon environments. They are distributed in the Caribbean Sea. They are generally 2 cm long



Figure 19. *Tectitethya crypta*

Area of Use in Medicine

Antiviral and anticancer drugs are obtained thanks to the nucleosides in its structure (Minotti et al., 2004). Nucleosides have been involved in the development of cytarabine for clinical use in the treatment of leukemia and lymphoma. A fluorinated derivative of cytarabine is gemcitabine. It is used for the treatment of pancreatic, breast, bladder and small cell lung cancer (Schwartzmann et al., 2001). Gemcitabine is a chemotherapy drug used in cancer treatment (Fischer and Ganellin 2006). American Health System Pharmacists use cytarabine as a chemotherapy drug in the treatment of acute myeloid leukemia, acute lymphocytic leukemia and lymphoma. Side effects; Liver and kidney problems, nausea, fever, rash, shortness of breath, mouth sores, diarrhea neuropathy, hair loss and bone marrow suppression. It is the safest and most effective drug on the list of the World Health Organization. Vidarabine is an antiviral drug. It is obtained from the compounds songothymidine and spangouride (Sagar et al., 2010).



Figure 20. Gemsitabin



Figure 21. Sitarabin

Thalassotherapy

It is a different area of use of algae and means sea therapy. It is the name given to the treatment method in which seaweed is used together with sea water for human health (Baytaşoğlu and Başusta, 2014). France is the first center of the thalassotherapy method. It has been implemented in all European countries. Thalassotherapy; Etymologically, thalassotherapy, which is formed by combining the Greek words thalasso (sea) and therapy (care), is a personal climatotherapy method performed on a seashore and under medical supervision for prevention or treatment purposes. It is applied in treatments such as weight loss, skin and body tightening, cellulite, stress, detoxification, elimination of circulatory disorders, depression, surmenage, etc. This method is a very effective treatment especially against rheumatism and joint pain.

It is defined as the combined use of some other substances obtained from the marine environment with different methods (Karagülle, 2008). It is a medically supervised treatment system applied for protective, therapeutic and curative purposes (Altındış, 2015). This treatment first started in France. Thalassotherapy and temalism are treatment methods that have been applied for thousands of years. Thalassotherapy covers a wide range from medical treatment of chronic diseases such as respiratory or skin diseases to methods of protecting healthy individuals from diseases (Uğurlu et al., 2016). *Laminaria digitata*, *Fucus vesiculosus* and *Lithothamnion corallioides* species are commonly used in the thalassotherapy method (Baytaşoğlu and Başusta, 2014).

Some of the ailments for which thalassotherapy treatment can be applied are; chronic skin and respiratory diseases, sleep disorders, general fatigue and stress, orthopedic pain and tension conditions, and thalassotherapy is also used to prevent infections by increasing body resistance.

***Laminaria digitata* (Brown Seaweed)**

Scientific Classification

Kingdom: Chromista

Phylum: Ochrophyta

Classification: Phaeophyceae

Ordo: Laminariales

Familia: Laminariaceae

Genus: *Laminaria*

Species: *L. Digitata* (Lamouroux , 1813).



Figure 22. *Laminaria digitata* (Brown Seaweed)

Features

It grows to about two or three meters. It is a hard, dark brown seaweed. It clings to rocks and stays. It is rich in iodine. It is found in the sublittoral region of the North and South Atlantic Ocea. Its stems are flexible and oval. *L. digitata* lives for 4-6 years. It provides weight loss and has antiseptic properties. It is used as a moisturizer to protect and repair the skin.

***Fucus vesiculosus* (Brown Seaweed)**

Scientific Classification

Kingdom: Chromista

Phylum: Ochrophyta

Classification: Phaeophyceae

Ordo: Fucales

Familia: Fucaceae

Genus: *Fucus*

Species: *F. Vesiculosus* (Guiry, 2017).



Figure 23. *Fucus vesiculosus*(Brown seaweed)

Features

The leaves of *F. vesiculosus* are 90 cm long and 2.5 cm wide. There are paired air sacs on each side of the leaf. It has many names such as rockweed, rock wrap. It is found in the North Sea and Western Baltic Sea regions (Lim et al., 2012).

This seaweed, which contains substances that prevent imbalances in the thyroid hormone, accelerates metabolism (Moro and Basile, 2000). It is the substance of iodine and various L-fucose compounds. L-fucose compounds have anti-obesity, anti-inflammatory, antioxidant and anti-carcinogenic properties. It is an edible seaweed used in herbal anti-obesity and goiter treatment. It is the first source of iodine discovered in the treatment of thyroid disorders (Moro and Basile, 2000). It has a chemical structure similar to heparin, an injectable anti-coagulant. The fucoidans in its structure contain 38.4% sulfur.

They have an effect on the immune system and cancer. They play a role in blood clotting (Ale et al., 2011). When kelp is consumed, it regulates and increases the duration of the menstrual cycle in premenopausal women with abnormal cycles (Skibola, 2004). Consumption of kelp can prevent the intake of fat-soluble, metabolic toxins and increase their excretion through the liver and intestines (Nakano, 2002).

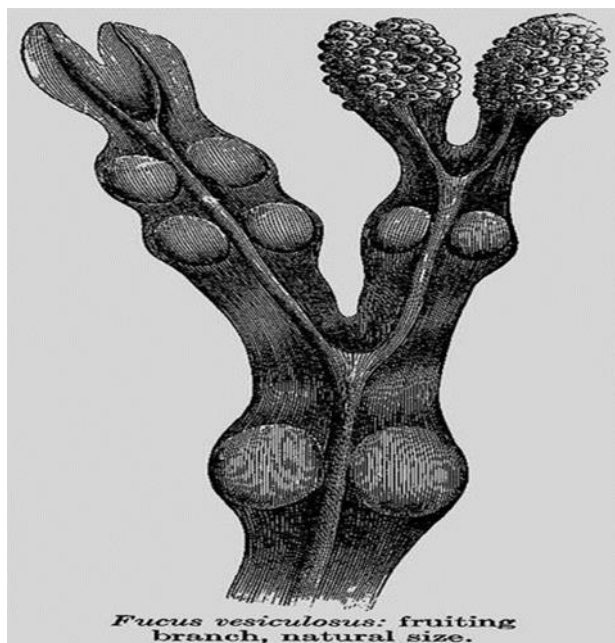


Figure 24. *Fucus vesiculosus*

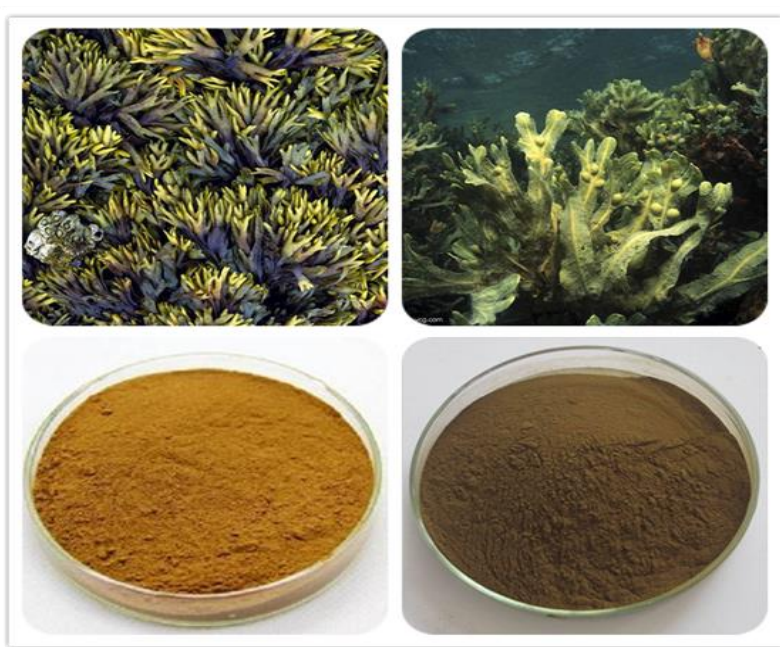


Figure 25. Transformation of *Fucus vesiculosus* into powder

***Lithothamnion corallioides* (Red Algae)**

Scientific Classification

Kingdom: Plantae

Phylum: Rhodophyta

Clasis: Floridephyceae

Order: Corallinales

Familia: Lithothamniaceae

Genus: *Lithothamnion*

Species: *L. corallioides*

(Crouan and Crouan, 1867).



Figure 26. *Lithothamnion corallioides* (Red Algae)

Features

It is a fragile algae species with a calcareous skeleton. Its shape is variable, it has a three-dimensional branched nodule structure. Its length is 4-5 cm. Its colors are bright pink when alive and white when dead. It is found in the Mediterranean region of Turkey. It is used in animal feed and water filtration systems. It is used in medicine, cosmetics and bone surgery.

OMEGA-3

Fish and other seafood, which are rich in polyunsaturated fatty acids, are at the top of the list of healthy foods. Poly Unsaturated Fatty Acids (PUFA) are fatty acids that contain more than two unsaturated bonds and their main source is marine oils. PUFAs are divided into two groups. Omega-3 and omega-6. Omega-6 fatty acids are generally produced by plants growing on land, while Omega-3 fatty acids are seen in fish oils. Especially fish such as herring, mackerel, sardine and salmon have been recorded as fish with rich fatty acid content (Karabulut and Yandi, 2006).

Today, it is thought that some diseases can be minimized with simple diet adjustments, nutritional supplements or fish oil tablets.

A study conducted on tumor mice found that types of cancer such as lung, colon, breast and prostate cancers could be slowed down in mice whose diets were supplemented with omega-3 containing oils or purified omega-3 fatty acids (Mol, 2008). Studies are also being conducted on the therapeutic properties of the two dominant omega-3 fatty acids found in fish, EPA and DHA.

The American Heart Association (AHA) reported that EPA and DHA, the basic ingredients of fish oils, have benefits such as regulating heart rhythm disorders, reducing the risk of sudden cardiac death, lowering plasma triglyceride levels and adjusting blood density (Kaya et al., 2004).

CHITOSAN

It is a polymer obtained by deacetylation of chitin (P-(1-4)-poly-N-acetyl-Dglucosamine), which is the most common polymer found in nature after cellulose and is found in the shells of arthropods such as crabs, shrimps, and lobsters (Demir and Seventekin, 2009). The fact that it does not have any toxicity and does not cause allergies or irritation makes chitosan an important and interesting biomaterial in the pharmaceutical and medical fields. Chitosan also has important biochemical properties such as hemostatic and bacteriostatic, fungistatic, spermicidal, anticarcinogenic, anticholesteremic, anti-acid, antiulcer, wound healing accelerator, bone healing accelerator and immune system stimulant (Duman and Şenel, 2004).

CONCLUSION

The marine environment contains many different type of living organisms of importance because of a diverse group of biochemical substances promising beneficial health effects. These substances make a wide field of research for finding cure hope in many medical conditions such as diabetes mellitus, Parkinson's disease, Alzheimer's disease, and most importantly cancer. Currently, it is well known that marine organisms contain so many chemical substances for treating such devastating diseases. This field of research has been gaining more importance and steadily continuing to grow.

Considering the fact that many different type of diseases such as cardiovascular diseases, atherosclerosis, cancer, and neurodegenerative conditions including Alzheimer's disease and Parkinson's disease have currently increased considerably, importance of consuming seafood with high nutritional value and obtaining beneficial substances from other marine organisms otherwise not routinely consumed will be understood easily. Hopefully, this field of research will continue to grow and yield many cure chance for the medical conditions aforementioned in the future.

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CHAPTER 4

FROM NATURE TO FUNCTION: AQUATIC-DERIVED BIOACTIVE COMPONENTS AND BIOMATERIALS

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INTRODUCTION

Humanity has tried different ways to combat various diseases from prehistoric times to the present day. The most widely used and known of these ways are natural products. Bioactive natural products can be defined as chemical compounds produced by living things and exhibiting biological activity against other organisms. These compounds may have therapeutic activity against human and animal diseases, toxic activity against disease-causing agents, and preventive effects against insects that cause losses in agricultural production (Özkaya et al., 2013).

Marine biomaterials, such as the shells of molluscs and corals, have been used for a variety of functions since ancient times. At this point in time, processing technology and mariculture methods have made industrial-scale implementation of applications possible. Marine biomaterials are used in medicine and cosmetics, for example, in collagen and gelatine. Despite the impact of overfishing, climate change and pollution from industrial waste, marine biomaterials remain abundant (Khrunyk et al., 2020).

TYPES OF AQUATIC BIOACTIVE COMPONENTS

Components showed bioactivity-guided, such as peptides, fatty acids especially polyunsaturated with long-chain, vitamins, polyphenols, and carotenoids, found in terrestrial sources as well as aquatic sources such as fish, shellfish, algae, etc., can directly influence living organisms, tissues, or cells, potentially enhancing health outcomes and preventing diseases.

Marine bio-resources produce a variety of specialized and potent bioactive chemicals, including natural organic substances such as peptides, proteins, polyethers, enzymes, polysaccharides, and fatty acids. Marine-sourced proteins demonstrate potential as functional food components owing to their various significant and distinctive qualities and characteristics, such as antibacterial activity, foaming capability, and gel-forming ability (Khora, 2013).

Because of their intriguing biological qualities, bioactive peptides derived from marine creatures have recently attracted more attention in the fields of cosmeceutical, pharmaceutical, and nutraceutical product development. The peptides are involved in defence, development, reproduction, and homeostasis, among other fundamental functions that allow life to exist.

Numerous marine animals and invertebrates have had their tissues examined to identify peptides with protective properties. Marine peptides exhibit a diverse range of biological activities, positioning them as a promising molecular foundation for the development of new antibiotics, analgesics, anticancer agents, and treatments for neurological problems. These activities include antibacterial, antidiabetic, antifungal, neurotoxic, antiviral, antifreeze, anticoagulant, cytotoxic, and immune-modulating properties (Ovchinnikova, 2019).

Marine bioactive peptides found in food samples, are a popular and well-researched topic due to their non-ribosomal structure. Nevertheless, there are numerous challenges associated with the isolation and production of these peptides. These include the lack of standardisation in hydrolysis and extraction methods, the use of whole hydrolysates to determine activity, the limitations of purification and analysis technology, and the differing peptide compositions and structures of marine organisms (Pavlicevic et al., 2020). The extraction process typically employs the use of organic solvents, buffers, or water, which are subsequently purified through the application of diverse chromatographic techniques. The methods mentioned above may cause variability and confusion in the results obtained. Techniques such as microwave-assisted extraction and ultrasound-assisted extraction have the potential to produce high numbers of bioactive peptides, although yields vary. However, the actual yields may vary. Despite the fact that enzymatic hydrolysis is a highly reproducible and highly specific method, the intricate and complex interactions between the various components of marine animals' cells mean that it is unlikely to produce identical peptides in different species. The purification process typically uses a combination of chromatographic and filtration techniques, but is also faced with challenges. (Macedo et al., 2021).

Phenolic compounds are classified as secondary metabolites with recognized biological functions, making them attractive for biotechnological applications. Microalgae embody an exceptionally promising source for the environmentally sustainable creation of natural bioactive metabolites. Researchers have devised unique ways to the extraction of plant and marine bioactives, with a special focus on energy sources, surfactants, and extraction medium (Getachew et al., 2020). Researchers are exploring the potential of employing ionic liquids (ILs), deep eutectic solvents (DES), and natural deep

eutectic solvents (NDES) for the extraction of phenolic chemicals from marine resources. Ionic liquids (ILs) possess a number of advantageous characteristics, including the capacity to function as solvents over a broad range of temperatures and at low melting points. However, there is currently a paucity of evidence regarding the utilisation of ionic liquids in the extraction of marine phenolics. DESs are a family of solvents that can create hydrogen bonds between molecules, particularly between donors and acceptors of hydrogen bonds (HBDs). The aforementioned chemicals markedly reduce the melting point by diminishing the entropy associated with phase transitions. Their capacity to lower the melting point renders them particularly useful for the extraction of elements from terrestrial plants (Buarque et al., 2022). Further investigation is required to ascertain the long-term viability of these environmentally friendly solvents and their potential applications.

Marine nutraceuticals, despite their various medical benefits, have been improperly utilized for culinary purposes. Marine foods are considered a significant source of high-quality proteins and lipids abundant in unsaturated fatty acids. Marine-derived nutraceuticals originate from various sources, including marine plants, microorganisms and sponges each possessing distinct biomolecules that enable survival in their respective environments. Owing to their rich composition of polyphenols and carotenoids, seaweeds are presently under exploration as a remarkable source of antioxidants. The remarkable properties of the lipids present in shrimp, a highly esteemed seafood globally, have been explored concerning both muscle and exoskeleton (Gulzar et al., 2020). This exquisite blend comprises carotenoids, triglycerides, free fatty acids, and various lipids, with some components linked to the elegant art of cancer chemoprevention.

Components sourced from the ocean can be acquired through the use of products that emerge from the meticulous processing of fish and shellfish after harvest. Such products may therefore represent a potentially advantageous source of these components. Fish oil, rich in w-3 PUFAs, is complemented by vitamins E, D and A along with shark liver oil, enzymes, seaweed, peptides, chitin, chitosan and protein hydrolysates. Commercial processing of seafood waste produces significant amount of wastes, including shells, heads, intestines, scales, bones, and fins. By-catch fish are often discarded or converted into animal feed, posing environmental hazards. Nevertheless, innovations in

biotechnology present opportunities to transform waste into sources of exquisite nutraceuticals and premium ingredients like fish oil (Menon & Lele, 2015). It is of paramount importance to optimise the extraction process in order to produce omega-3 fatty acids with acceptable properties. Among the various methods utilized for obtaining omega-3 fish oil, wet pressing and solvent extraction stand out as two prominent techniques. Traditional extraction methods have satisfactory yields but also have long processes, high solvent consumption and toxic handling conditions. Marine byproducts serve as significant sources of compounds with remarkable technological, nutritional, and functional properties that, when expertly processed, can be seamlessly reintegrated into the food chain (Pateiro et al., 2021). Polyunsaturated fatty acids (PUFAs) and monounsaturated fatty acids (MUFAs) are abundantly found in fish and offer significant benefits when they remain unoxidized. Fish oil contains omega-3 fatty acids called polyunsaturated fatty acids (PUFAs), such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The fatty acids present in fish oils have been demonstrated to reduce serum triglyceride levels, lower blood pressure, enhance cardiac function, and mitigate inflammatory responses. These effects collectively confer protection against coronary heart disease (Awuchi et al., 2022). The presence of ω -3 fatty acids has been demonstrated to exert a profound influence on a multitude of physiological processes, including alterations in blood lipid profile, gene expression, cardiovascular system health, eicosanoid production, cell signalling cascades, and membrane lipid composition. One effective method for increasing omega-3 PUFA intake is to enhance food items with these fats. Among the numerous techniques employed for enrichment, fortification and microencapsulation are particularly noteworthy. Incorporation of fish oil into food such as baked goods, dairy products, and pasta, represents an expanding market, made possible by technological advancements. The primary technological challenges that must be addressed during the application phase include the limitation of lipid oxidation and the safeguarding of the sensory qualities of the food items in question (Senadheera et al., 2023).

Two marine bacterial species that are being looked into more and more as possible sources of new compounds are archaea and eubacteria. Actinobacteria produce thousands of naturally occurring compounds that are physiologically active and have a variety of uses (Ghosh et al., 2022).

The phrase "sea algae" refers to an exquisite array of unicellular and possibly multicellular benthic marine flora. The three classes of pigmentation found in marine algae include Rhodophyceae, known for its striking red hues, Chlorophyceae, celebrated for its vibrant green shades, and Phaeophyceae, which showcases captivating blue tones (Rengasamy et al., 2020). Microalgae, which may be a rich source of medicinal compounds, represent a compelling natural resource. These components include carotenoids, enzymes, minerals, polyunsaturated fatty acids (PUFAs), essential amino acids, vitamins and fibre. Microalgae represent an intriguing and novel source of functional nutrition, given their extensive potential. Seaweed represents a promising yet underexplored source of new chemicals for functional foods and nutraceuticals, offering a vast array of chemical potential that remains largely unexamined. Of particular interest are the bioactive peptides and sugars derived from seaweed. Seaweed contains a number of bioactive compounds that have been shown to exhibit a wide range of biological activity in both laboratory and in vivo settings. The aforementioned compounds are derived from seaweed. Bioactive peptides and polysaccharides have been demonstrated to exert a range of significant biological effects, including the reduction of blood pressure, the combating of cancer, the mitigation of inflammation, and the enhancement of the immunological response (Carpena et al., 2023). Carbohydrates, derived from marine organisms and integral to marine life, possess antioxidant and immunological enhancement capabilities, thereby establishing a basis for anti-aging. Aquatic organisms depend on carbohydrates as a source of nourishment. The predominant form of carbohydrates in marine habitats is polysaccharides, with monosaccharides and oligosaccharides being relatively scarce (Ghosh et al., 2022).

It has long been recognized that sponges contain a lot of bioactive substances as nucleosides, terpenes, sterols, cyclic peptides and alkaloids (Varijakzhan et al., 2021). Marine sponges are rich in unusual sterols, which have a variety of uses in biological membranes. Sulfated and alkaloid sterols have been shown to possess antibacterial properties. The richest natural sources of prostaglandins are cnidarians. Compounds from marine sponges, such as lectins from *A. donnani*, have shown antibacterial properties against Gram-negative bacteria. The compounds exhibit diminished effectiveness against *E. coli*, *K. pneumoniae*, and *Pseudomonas aeruginosa*, yet they show strong anti-

biofilm activity against biofilm-producing *P. aeruginosa* (Sadanandan & Rauf, 2018).

TYPES OF AQUATIC BIOMATERIALS

Edible marine invertebrates, including crabs, molluscs, and echinoderms, serve as sources of organic-based biopolymers for diverse applications. Humans have been using biopolymers, which are made of proteins and polysaccharides, as food and nutraceutical ingredients to treat a variety of illnesses for many years. Biopolymers, such as fucosylated chondroitin sulphate, glycosaminoglycans, chitin, and chitosan, have recently emerged as significant players in the biomedical industry for the treatment of various ailments. Annelida features exquisite marine worms, Porifera showcases elegant sponges, Cnidaria is adorned with stunning corals and jellyfish, molluscs present a collection of refined oysters, prawns, and crayfish, while echinoderms boast the beauty of starfish, sea cucumbers, and sea urchins. Collagen and gelatine are significant commercial products obtained from consumable marine organisms. Collagen constitutes approximately 30% of the total composition of the skin and bones in all animals. Collagen derived from marine organisms serves as a suitable alternative to mammalian collagen and is extensively utilized in biomedical applications (Ghosh et al., 2022). Collagen exhibits significant structural diversity and beneficial properties, including low immunogenicity, biocompatibility, bioactivity, and biodegradability, positioning it as an ideal biomaterial for various biomedical applications. Numerous studies indicate that FAB-derived aquatic collagen and its derivatives from species such as tilapia, carp, squid, jellyfish, and farmed frogs do not elicit notable inflammatory or immunogenic responses. Furthermore, type II collagen derived from squid cartilage has been shown to possess three anti-inflammatory properties (Cao et al., 2025).

Low and high magnesium calcites, along with aragonite, are significant mineral constituents in the shells of aquatic species owing to their early metamorphic characteristics. Initial metamorphic reactions can lead to the development of carbonate minerals abundant in Ca, Mg, Mn, and Fe. Natural sources exhibit significant bioactivity, biocompatibility, osteo induction, non-toxicity, thermal stability, and osteogenic capability, positioning them as promising starting biomaterials for hydroxyapatite (HA) ($\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$)

(Prihanto et al., 2022). Seashells serve as a by-product of the fishery industry and marine aquaculture. The disposal of waste seashells poses both environmental and economic challenges, as it necessitates methods such as incineration or burial (Fernandes-Penas et al., 2023). Green mussel shells (*P. viridis*) constitute biogenic waste abundant in carbonate minerals, originating from marine ecosystems. Low- and high-Mg calcites, along with aragonite, are significant mineral constituents because of their early diagenetic behaviour. Early diagenetic reactions can lead to the formation of carbonate minerals enriched in calcium, magnesium, manganese, and iron. The natural resources exhibit significant bioactivity, biocompatibility, osteoinduction, nontoxicity, thermal stability, and osteogenic capability, positioning them as promising starting biomaterials for hydroxyapatite (Prihanto et al., 2022).

Calcium phosphates (CPs) represent a group of compounds that serve as the principal inorganic constituents of biological hard tissues, typically located in bones, cuttlefish bones, cartilage, teeth, shells, carapace and the scales of aquatic organisms (Borciani et al., 2023; Cao et al., 2025). In the fishery and aquaculture sector, fish frames and mollusc shells are recognized as optimal sources of FAB-derived aquatic calcium phosphates due to their high availability. Bivalve aquaculture, which includes oysters, clams, scallops, and mussels, constitutes over 50% of mollusc aquaculture production, resulting in approximately 10 million tons of calcareous shell residues annually. Currently, these items are regarded as waste products in the fish and food industry, with discarded shells comprising 59% to over 75% of the total organism weight (Borciani et al., 2023). Calcareous shells consist of over 95% mineral content, primarily as highly ordered aggregates of calcium carbonate, including calcite and/or aragonite, which represent valuable potential resources for CPs. Calcium phosphates (CPs) can manifest as hydroxyapatite (HA), tricalcium phosphate (TCP), octa calcium phosphate (OCP), brushite, and monetite, contingent upon the calcium/phosphate (Ca/P) ratio (Cao et al., 2025). Additionally, the synthesized CaPs are enriched with substitutional ions such as Mg^{2+} , Sr^{2+} , Si^{4+} , Na^{+} , and K^{+} , which positively influence the biological performance of the material (Galotta et al., 2023).

Calcium carbonate sourced from mussel shells contains trace elements of Sr, Mg, and Na, which are essential for cellular activities and may improve the biological properties of the resulting bio ceramic material. The content of

substituent ions can vary based on the type of seashell source, its origin, geographical location, and potential environmental pollution (Galotta et al., 2023). Hydroxyapatite (HA) is the most extensively researched and utilized synthetic bone grafting material in clinical practice, attributed to its resemblance to the inorganic constituents of bones and teeth (Borciani et al., 2023). The utilization of synthetic hydroxyapatite in biomaterials has markedly increased, making substantial contributions to applications in both chemistry and biology. Despite its inadequate mechanical properties, the osteo inductivity of HA is considered a unique biological characteristic that may be enhanced by controlling particle size (Prihanto et al., 2022).

Advanced nanotechnology has significantly influenced the development of nanocrystalline hydroxyapatite (HA), garnering considerable interest for its applications in adsorption, catalysis, and optics, particularly within the field of biomaterials. HA-based nanocrystals exhibit superior bioactivity and absorbency compared to coarse crystalline bio ceramics. Nanosized HA is increasingly recognized as a biomaterial for prosthetic applications (Prihanto et al., 2022). The demand for bone substitutes is essential for the restoration of bone voids. Orthopaedic surgery, dentistry, and bone grafting represent some of the most executed tissue transplants, with over two million procedures conducted each year in the United States and an annual expenditure exceeding \$200 billion on their management. The current gold standard in bone grafting involves the utilization of autografts and allografts. Synthetic bone grafts are extensively studied to address the drawbacks of autografts, which necessitate supplementary surgery for tissue collection, leading to operative site morbidity, and allografts, which may pose risks of immunogenicity and potential pathogen transmission (Borciani et al., 2023).

Several techniques have been developed to convert mussel shells into hydroxyapatite (HA). Recently, a number of chemical processing methods have been proposed for the production of nanocrystalline hydroxyapatite, including solid-state, mechanochemical, aqueous crystallization, hydrolysis, sol–gel, and hydrothermal techniques (Prihanto et al., 2022). The two-step method consists of the calcination of CaCO_3 to CaO at temperatures ranging from 900 to 1200°C, followed by the reaction of Ca(OH)_2 , generated from the hydration of CaO , with a phosphate reagent, commonly H_3PO_4 . The hydrothermal method involves a three-step process: calcination of mussel shells, hydration, and

carbonation of the resulting CaO to yield precipitated CaCO₃ particles (Fernandez-Penas et al., 2023).

FUTURE PROSPECTS

The exploration of aquatic waste as a refined source of biomaterials presents an exquisite opportunity to elevate biomedical applications. This study offers an exquisite overview of the application of six distinguished classes of aquatic-derived biomaterials: aquatic collagen, chitin, calcium phosphates, hydroxyapatite, bioactive peptides, and lipids. The prospects for aquatic waste-derived biomaterials, particularly within the medical sector, are exceptionally bright. In this context, further extensive research is essential to uncover the sophisticated properties of aquatic-derived biomaterials.

ACKNOWLEDGEMENT

This study was presented as poster titled “From Nature to Function: Aquatic-Derived Bioactive Components and Biomaterials” at 52nd WEFTA Annual Meeting, 15-17 October 2024 in Çeşme, İzmir, Türkiye.

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CHAPTER 5

SPORTY FISHING

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INTRODUCTION

Fishing can be defined as the act of fishing, catching and collecting aquatic creatures for any purpose. Fishing can be classified into three categories:

Commercial Fishing, Amateur Fishing, and Sporty Fishing.

Commercial fishing, as the name suggests, is an activity carried out for financial gain. To perform this activity, legal permits and documents are required. Commercial fishing activities can be carried out by complying with the rules specified in the circular on the regulation of fishing for commercial purposes, numbered 6/1, published in the Official Gazette by the Ministry of Agriculture and Forestry (CMBS, 2024a).

Amateur fishing is done only for recreation and entertainment purposes, without any commercial purpose. In order to carry out this activity, a document must be obtained from the Ministry of Agriculture and Forestry. Amateur fishing can only be carried out by adhering to the rules specified in the regulation on fishing aquatic products for non-commercial purposes (CMBS, 2024b). In commercial fishing, fish are sold, whereas in amateur fishing, selling fish is prohibited. Fish can only be caught and consumed to the extent permitted by the laws.

Sporty fishing, on the other hand, is an individual fishing activity done for sport, entertainment, and leisure, free from any commercial or financial concerns, with the primary principle of releasing the fish back into the water unharmed and alive. In sporty fishing, like amateur fishing, selling or eating the fish is not permitted. The fish caught must be returned to the water alive.

In recent years, sport fishing tourism has gained significant importance in Turkey. Large-scale national and international fishing tournaments have started to be held. In Turkey, there are five international-level sport fishing tournaments, three of which are held in the Alaçatı and Seferihisar bays, and two in the Bodrum Peninsula (Beziran, 2019). Sporty fishing has also become a tourism industry in some countries. Special tours are organized to take groups of people to other countries for this purpose, and these tours are sold for high prices. For example, a 7-day package tour from Japan to Australia for sport fishing costs \$4,200 USD per person, while a similar tour to Thailand costs \$2,300 USD (Ateşşahin & Cılbız, 2023).

In this context, the following topics are covered in this section:

1. Fishing tools used in sporty fishing

2. Main materials used in sporty fishing
3. Auxiliary materials used in sporty fishing
4. Baits used in sporty fishing
5. Suggestions related to sporty fishing.

1. FISH GEAR USED IN SPORTY FISHING

The most important point to consider when doing sport fishing is to return the fish alive to the water without being damaged. Therefore, it is necessary to pay attention to this point when choosing the fishing gear. In addition, fishing gear is generally used in sport fishing activities all over the world. When choosing the material used in the fishing tackle, the material that will harm the fish the least should be used. For example, when choosing a fishing hook, a hook with no or few nails can be selected. Fishing tackle are fish gear used in all kinds of fishing. It basically consists of a line, hook, lead and floater. Fishing gear can contain various parts depending on the fishing method used and the type of fish to be caught.

2. FISHING TACKLE MATERIAL

We can generally divide fishing rod materials into two classes: main materials and auxiliary materials.

2.1. Main Materials

The main materials of the fishing tackle are the materials necessary for fishing.

Fishing Hooks, Fishing Lines, Swivels, Leads and Floaters

2.1.1. Fishing Hooks

Hooks are one of the key elements of fishing tackle. They are the part where the bait is tied and the fish is caught. As a working principle, it is stuck in the prey but does not come out of the place where it is stuck thanks to the palate section. The size of the hook varies according to the fish sizes.

The most important points to consider when choosing a hook;

- It should be sturdy, non-rusting, and have a very sharp tip.
- Water resistance, torsion, resistance to impacts, fishing efficiency
- Metals mixed with steel, bronze, nickel and chrome
- Behavior of the species to be fishing, mouth structure, size

2.1.1.1. Parts of the Hook

The part where the hook is attached to the fishing line is called the eye. After this part comes the shank. The shank is followed by the bend. The point part comes last. This part is the part that sinks into the fish, that is, the part that allows the fish to be caught. There is another sharp part that is curved inwards following the tip part. This part is called the barb (Figure 1).

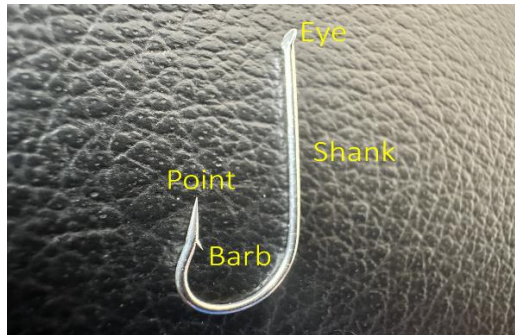


Figure 1. Parts of the Hook

2.1.1.2. Numbering of Hooks

Fish hooks are numbered starting from 1. As the number increases, the hook becomes smaller (Figure 2.).



Figure 2. Numbering of Hooks

The most important point in choosing a hook is the size of the hook. There are many fish species in both seas and freshwater. These species have a wide variety of sizes. During fishing, a hook that is directly proportional to the size of the fish and suitable for the mouth structure of the fish should be chosen.

For example, while a small hook is chosen to catch horse mackerel, we need to choose a larger hook to catch bluefish.

2.1.1.3. Types of Hooks

Hooks have many different types.. So, they can be single-ended hooks, double-ended hooks, triple-ended hooks (cross) or multi-ended hooks (umbrella). Or they can be short-handled or long-handled hooks. These hooks vary depending on the fish to be caught.

2.1.1.4. Jighead

Jigheads are fishing hooks that have a lead structure in various shapes that include the blade and part of the handle of the hook and have an eye suitable for tying on the upper part (Figure 3.).



Figure 3. Jighead

2.1.2. Lines

The main material to which fishing hooks, swivels, leads, and floaters are attached is called line. Lines are currently made of polyamide and polyester. Important criteria in lines are grouped into 6. (Hoşsucu 1998).

1. Elasticity
2. Breaking strength
3. Softness
4. Resistance to sunlight, mold, and chemicals
5. Colour
6. Resistance to bending (knotting strength)

One of the most important criteria in lines is the diameter of the line. In direct proportion to the diameter thickness, breaking strength and carrying capacity increase.. At the same time, we choose the diameter of the line according to the needle we will use (Figure 4.).



Figure 4. Fishing line

2.1.3. Swivels

It consists of two rings that can rotate on its own axis with the slightest force. The body is tied to one of the rings of the swivel, and the fishing line, that is, the fishing line, is tied to the other. The most important feature of swivels is to prevent the fishing line from getting tangled. It can be normal or clip-on (Figure 5.).



Figure 5. Swivels

2.1.4. Leads

It is the weight that allows the fishing gear to sink to the bottom or to throw the gear forward. Lead material is generally used. The types of leads vary according to different fishing rod structures and fishing types. For example, swivels, soundings, leaves, beads, torpedoes, pinch sinkers, etc. (Figure 6.)



Figure 6. Leads

2.1.5. Floaters

They undertake the tasks of adjusting the fishing tackle length of some fishing tackle used especially in freshwater fishing, keeping the bait at a certain distance, and setting the rod on reed and rock bottoms. Floaters are used to ensure that the bait remains at a certain height in the water and to see the fish strike at this time. However, their main purpose is to ensure that the bait remains at a certain height (Figure 7).



Figure 7. Floaters

2.2. Auxiliary Equipment

Fishing auxiliary equipment is not a necessity for fishing. It is the equipment that will make catching fish easier.

We can list many equipment such as scoop, bucket, knife, scissors, chair, bucket, raincoat, boots, hat and etc. (Figure 8.).



Figure 8. Auxiliary Equipment

3. BAITS

They are divided into 2 groups as natural baits and artificial baits.

3.1. Natural Baits

These are the baits that fish encounter and feed on in their natural environments. Worms, insects, young fish, etc. in fresh water; shrimps, crabs, mussels and sea worms, etc. in the seas can be given as examples of these.

3.2. Artificial Bait

3.2.1. Feathers Fishing Rods

It is the name given to fishing rods that carry a large number of hooks, usually made of poultry feathers, on the fishing line.

3.2.2. Spoon Fishing Rods

A fishing tackle with a long ellipse, flat or cylindrical piece made of nickel or chrome-plated sheet metal or other metals attached to its hook called a spoon (Çanakkale 1993). It is a fishing tackle looks like a bait fish made of materials such as steel nickel. There are needles in various parts of this material.

It is generally used in catching predatory fish. It is widely used in sport fishing (Figure 9.).



Figure 9. Spoon Fishing Rods

3.2.3. Rapala

Swimming fish models made of synthetic materials are called rapala (Figure 10.).



Figure 10. Rapala

3.2.4. Plastic Bait

A fishing tackle made of plastic material, usually containing a single-ended hook. These plastics are usually made to resemble the bait that the species to be hunted feeds on (Figure 11).



Figure 11. Plastic bait

3.2.5. Fly Fishing

This method, which is a type of fishing commonly used especially in freshwater fishing, is called fly fishing. This method is done with artificial baits that resemble real flies or insects. It is commonly used to catch trout in sport fishing (Figure 12).



Figure 12. Fly Fishing

CONCLUSION

Consequently, sporty fishing is an activity done for the purpose of having fun and relaxation. It is usually a sport done to relieve stress. The main purpose here is to have a good time in harmony with nature, to have fun and to find peace. Our main principle should be not to harm nature and living beings during this activity. In addition, our country is surrounded by seas on three sides and there are many potential water sources in the inland waters for sport fishing. These areas can be used for tourism purposes, making significant contributions to the country's economy.

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CHAPTER 6

DETERMINATION OF SUB-BASINS OF CATCHMENT BASIN USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS: A CASE STUDY OF LAKE VAN BASIN

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INTRODUCTION

Factors such as the rapidly increasing population, urbanization, agricultural production and industrialization around the world are increasing the pressure on water resources day by day. Sustainable management of water resources is of great importance not only for the continuity of human life but also for the protection of natural ecosystems (Gleick, 2003). In particular, global climate change has increased the pressure on water resources. It has led to irregularities in precipitation regimes, prolonged drought periods and a decrease in the amount of usable fresh water (Kundzewicz et al., 2007). This situation brings the management of water resources to a strategic position. Water management requires a holistic approach that requires consideration of many variables. In particular, the increasing pressure on water resources makes the management of these resources more complex. The basin-based approach in water management is one of the strategies that has come to the fore in recent years. The preservation of hydrological services provided by basins is the sustainable use of soil, water, biodiversity and other natural resources in the basin for the benefit of society. In other words, basin management is a natural resource management in which the presence of soil, water and vegetation within a basin border and human activities as a factor affecting them are considered together (Yazıcı et al. 2019; Wolf et al. 2003). In the early ages, mankind used water resources only in the form of drinking water, small-scale agricultural irrigation and limited fishing activities. However, with the development of technology and the increase in the human population, the areas of use of water resources have diversified and the need for water has increased exponentially. Especially with the developing technology, the revolution in irrigation systems has allowed the water in river beds to be transported hundreds of kilometers away and the size of the agricultural area irrigated in agriculture has increased compared to the past. Water resources are not only usable for people but also are among the sources that provide significant amounts of food together with fishing activities. Especially in recent years, increasing aquaculture activities are in competition with the total amount of product obtained by catching. The product obtained by fish catching and aquaculture is of vital importance in meeting the world's food needs and closing the employment gap. While a basin refers to the geographical area where a certain stream or lake collects water, a sub-basin is the division of this area into smaller, locally manageable units

(Hendriks, 2010). Water catchment basins are formed by different areas separated by precise geographical boundaries. Sub-water catchment basins, which are located within the same basin and form the main water catchment basin, are smaller areas. Although the climatic characteristics of these sub-basins are generally similar, each has different dynamics within itself. These dynamics are variables such as the total population living in the sub-basin, the total agricultural land irrigated and the total amount of water needed. Sub-basins with very different precipitation and temperature regimes can be found within the main water catchment basin, especially where altitude differences are high. In this respect, sub-basins within the same basin may have very different water management needs. Considering this situation, water collection basins should be divided into sub-basins and water management planning should be carried out by taking into account the characteristics of each basin. In terms of water resources, closed basins, which have no water connection to the outside, have a more fragile structure. The entire water budget of closed basins consists of snow and rain falling in the basin. Therefore, correct water management is important in regions with closed basin characteristics. Lake Van Basin is a closed basin and there is no water outlet from the outside to the basin or from the basin to the outside. The only water input to the basin is snowfall falling in the basin during the winter months and rainfall falling in different months throughout the year. Water outlet from the basin is only by evaporation. Therefore, the basin has an extremely fragile structure in terms of water scarcity during dry periods when precipitation decreases. Lake Van is a closed basin that does not receive water flow from outside and is fed only by the surrounding streams and underground water resources. Due to this feature, any intervention on the lake ecosystem and surrounding water resources directly affects the ecological and economic balance of the region (Aydın & Doğu, 2018). Accurate determination of the boundaries of basins and sub-basins is important in the sustainable management of water resources. At this point, Remote Sensing and Geographic Information Systems (GIS) technologies are effective tools used in basin and sub-basin analyses. Remote Sensing and GIS enable the determination of physical and morphological features of basins using digital elevation models (DEM) and satellite images (Moore, Grayson, & Ladson, 1991). These methods provide highly effective methods in performing basic analyses such as mapping water collection areas, determining flow directions

and modeling drainage networks (Jenson & Domingue, 1988). This study was carried out to determine the boundaries of the sub-basins of the Lake Van Basin. Within the scope of the study, the drainage areas of the streams flowing into Lake Van were determined using high-resolution digital elevation models and the sub-basins were defined. These analyses, which were conducted using ArcGIS software, provide basic data that will contribute to the development of basin-based water management policies. The findings obtained will enable the development of recommendations for the protection and sustainable management of water resources in the Lake Van Basin. The decrease in water resources and the increase in water demand make it necessary to use water in a protected manner and manage it effectively. This study, which was conducted specifically for the Lake Van Basin, aims to create awareness for the protection of closed basin ecosystems as well as to present recommendations based on scientific data. In this context, the use of remote sensing and GIS technologies is considered an important tool in terms of developing basin-based management strategies.

MATERIALS AND METHODS

In this study, hydrological analyses were conducted using ArcGIS software to delineate the sub-basins of the Lake Van Basin. The methods and application steps are detailed below. A high-resolution Digital Elevation Model (DEM) covering the Lake Van Basin was utilized in the study. The elevation data, including the heights of the basin, were obtained from the USGS Earth Explorer platform. Ensuring the correct coordinate system for the DEM data is crucial for the consistency of the analyses. Initially, the coordinate system of the DEM was checked and adjusted to WGS 1984 UTM projection. Accurate adjustment of the coordinate system is critical for reliable analyses.

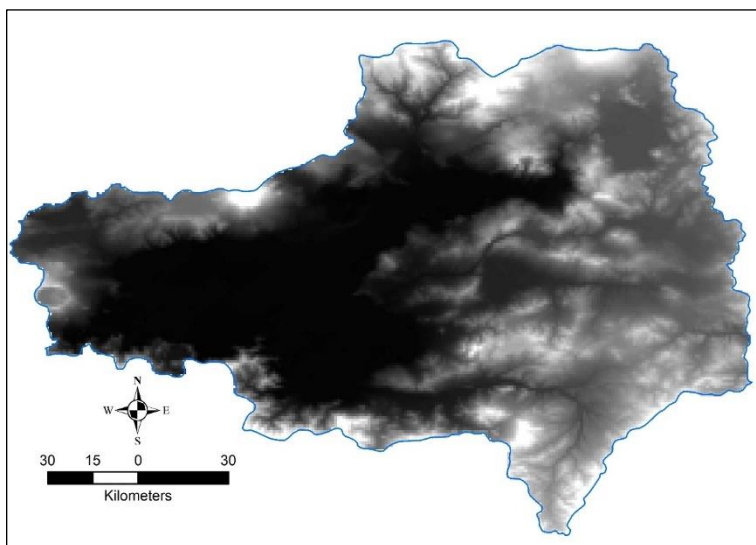


Figure 1. Lake Van Basin DEM Map

Anomalous low elevation values (sinks) in the DEM data were corrected to ensure accurate flow modeling. This process eliminated erroneous values affecting flow direction analyses by filling the depressions in areas with low elevation. One of the fundamental steps in hydrological analysis is flow direction, which was calculated using the Flow Direction Tool. This calculation determined the direction of water flow for each pixel in the DEM based on elevation differences and created a flow direction raster (Jenson & Domingue, 1988). To identify areas with high flow concentrations within the basin, the amount of water likely to accumulate in each pixel was calculated. This calculation enabled the identification of areas with significant flow intensity, a critical step in stream network delineation. Streams play a crucial role in delineating basins and sub-basins. The stream network in the basin was created using a specific flow accumulation threshold. The stream network was defined as areas where flow accumulation exceeded 1,000 cells. This threshold was adapted based on the morphological characteristics of the study area. After creating the main stream network, raster data were analyzed to assign a unique code number to each stream. This step prepared the data for delineating sub-basin boundaries. Basin boundaries were determined using flow direction data and pour points. The pour points of streams were aligned with the stream network to enhance precision. This analysis delineated the boundaries of the

sub-basins within the study area. The delineated sub-basin boundaries and stream network were converted to vector (discrete) data for better visualization. Each sub-basin polygon was styled with unique colors, providing a detailed map of basin and sub-basin boundaries.

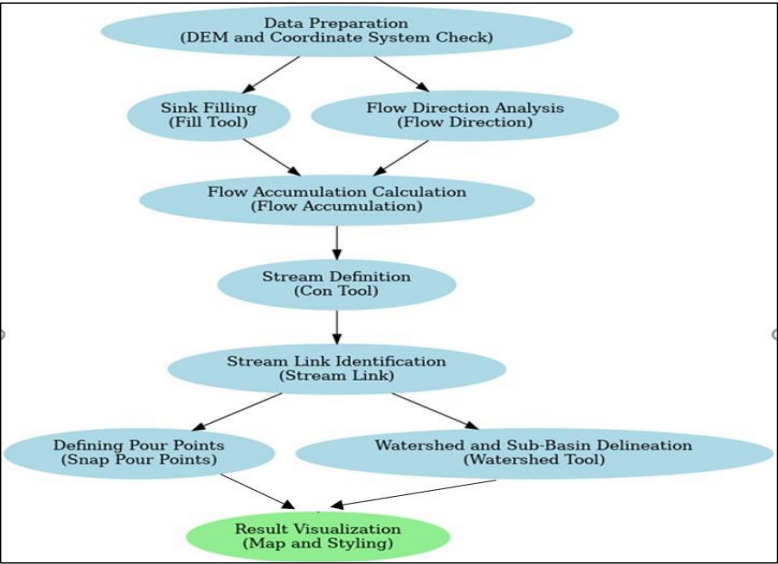


Figure 2. Analysis Flow Diagram

RESULTS

The study determined that there are 9 sub-basins in the Lake Van Basin, which has a surface area of approximately 18,000 km². The sizes of these basins, which were created by taking into account the rivers, vary between 599 km² and 3.853 km². It was determined that the basins located in the northern and eastern parts of the lake cover larger areas than those located in the southern part. In the western part of the lake, the presence of mountains such as Nemrut and Süphan has caused the slope to increase here. With the increasing slope, the land has a steeper structure. Therefore, it is seen that the sub-basins in this part of the lake are smaller. In the part of the lake located within the borders of Van province, it is seen that it consists of larger plains. In addition, the largest streams flowing into the lake, Bendimahi Stream, Engil Stream and Deliçay

Stream, flow from here. The sub-basins in the Lake Van Basin are listed below in order.

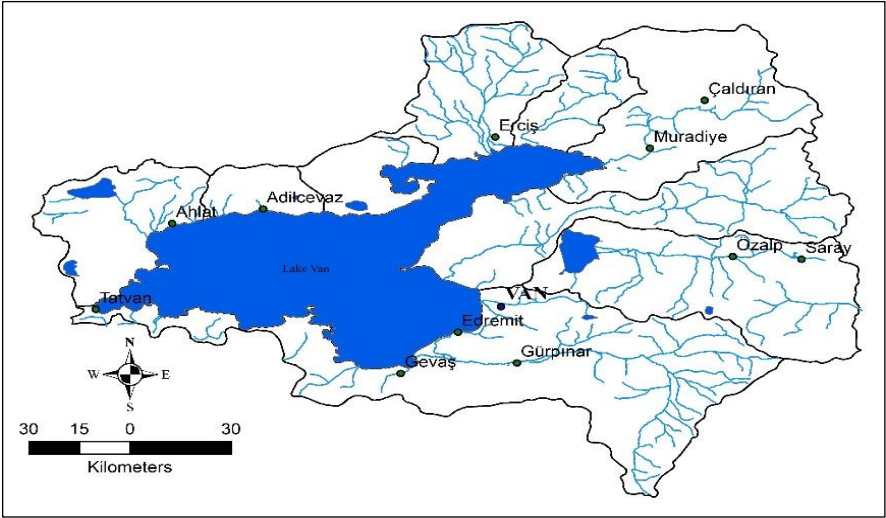


Figure 3. Sub-Basins in the Lake Van Basin

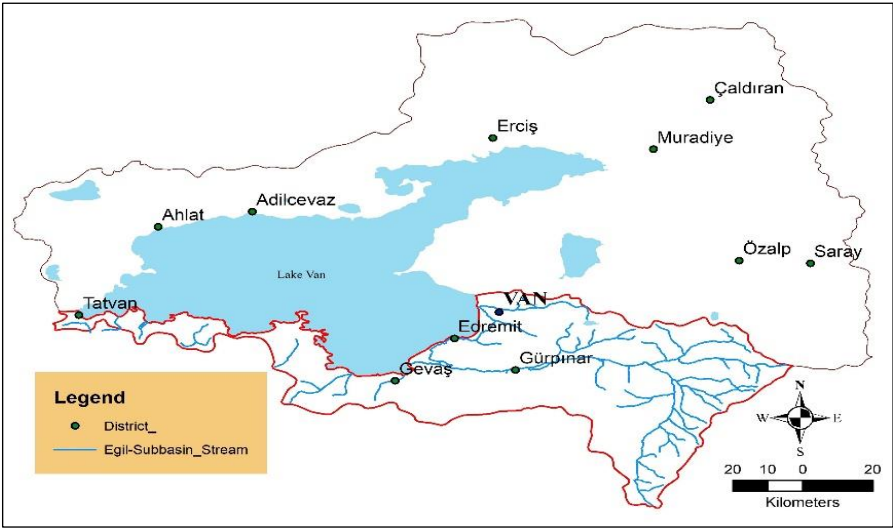


Figure 4. Engilsu Sub-Basin

The largest sub-basin in the basin is the Engilsu Stream basin. There is a stream network of approximately 658.69 km in length in the Engilsu sub-basin. Engilsu, Güzelsu and Gevaş Streams are the main ones. Engilsu sub-basin,

which covers the borders of Bitlis and Van provinces, has a land structure that narrows from east to west. The largest sub-basin in the Lake Van Basin, the Engilsu Sub-basin, has a surface area of 3.853 km².

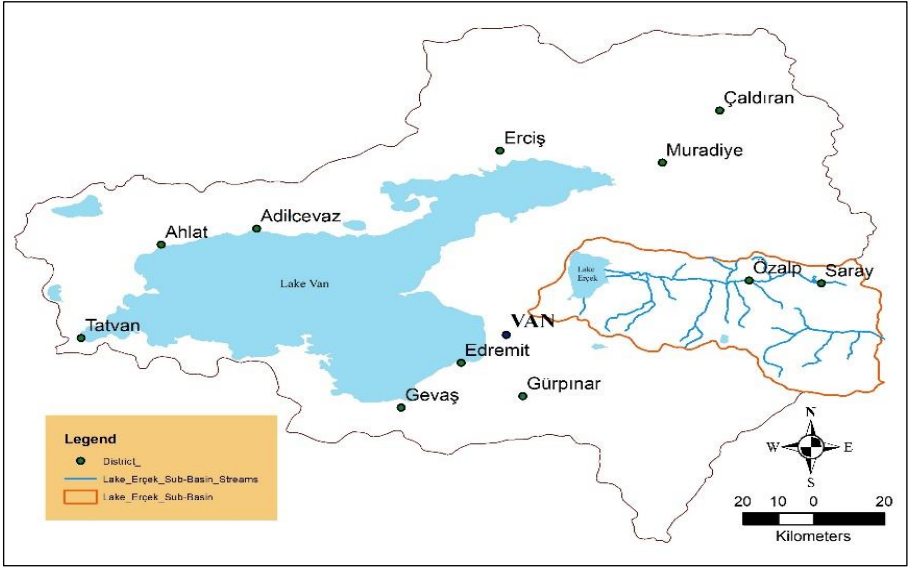


Figure 5. Lake Erçek Sub-Basin

The Lake Erçek sub-basin is a closed basin and the waters in this sub-basin flow into Lake Erçek. The Lake Erçek sub-basin in the Lake Van Basin, which does not flow into Lake Van, is a closed basin. The largest river in the basin is Memedik River. Lake Erçek is the second largest lake in the basin after Lake Van with an area of 114 km². The Memedik Stream is located in the sub-basin to the west of Lake Van. The Memedik Stream, which is fed by melted snow water especially in the spring months, reaches the point of drying up towards the middle of the summer months. The Memedik Stream is an important breeding ground for the pearl mullets that live in Lake Erçek and migrate to the rivers to breed in the summer months. The length of the river network in the basin is over 200 km. The surface area of the basin is 2.350 km².

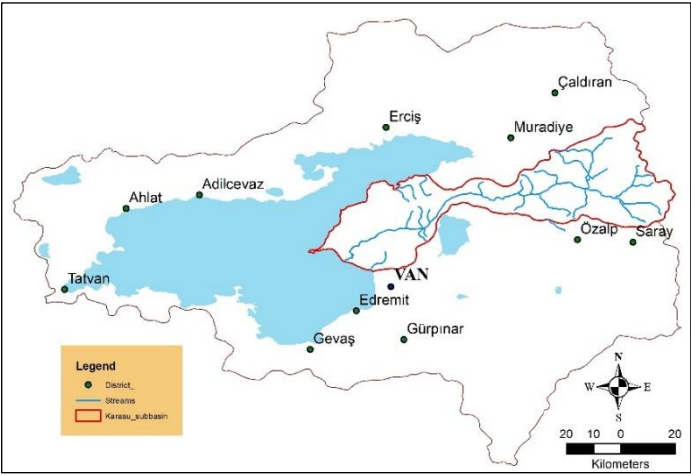


Figure 6. Karasu Sub-Basin

The Karasu sub-basin is located in the north of Van province. It is one of the basins where intensive agricultural irrigation is carried out among the sub-basins. The main streams in the basin are the Karasu Stream and the Akköprü Stream. The Karsu Stream is the longest stream in the basin, originating from the mountains on the Iranian border and flowing into Lake Van. The Sarımerhmet Dam built on the stream is used for fish farming and agricultural irrigation. The basin is 2.154 km² in size and the length of the river network in the basin is 355.5 km.

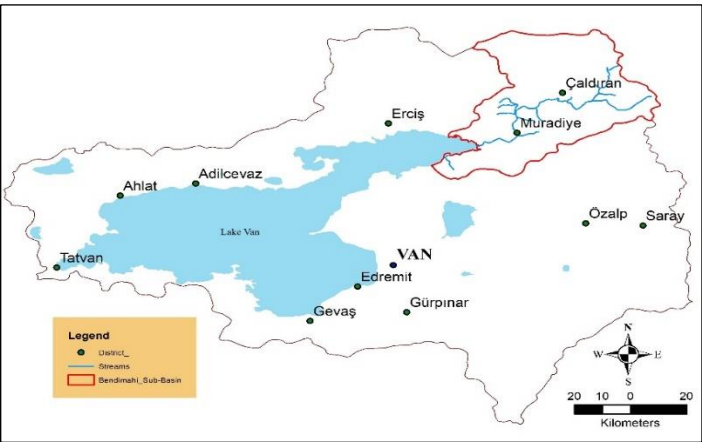


Figure 7. Bendimahi Sub-Basin

The Bedimahi sub-basin is located in the north of Lake Van. The basin, which takes its name from Bendimahi Stream, one of the largest streams flowing into Lake Van, basin is rich in terms of water resources. The Bendimahi Stream, which is fed from Kaz Lake within the borders of Çaldıran district, flows into Lake Van by passing through the borders of Muradiye district. The main water source in the basin, where intensive agricultural activities are carried out, is Bendimahi Stream. The basin has a stream network of 150.1 km in length and the size of the basin is 2.075 km².

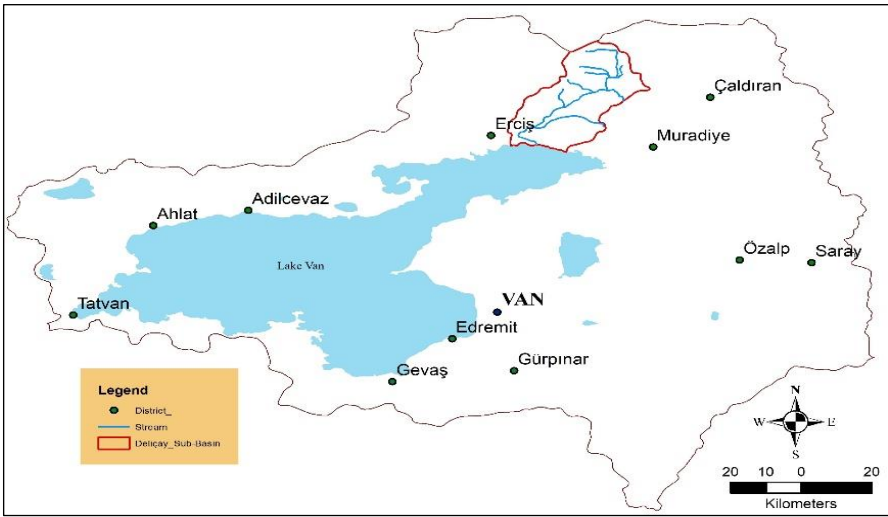


Figure 8. Deliçay Sub-Basin

Deliçay sub-basin is located within the borders of Erciş district. The main river branch in the basin is Deli Çay. Deliçay is one of the important rivers located in the northeast of Lake Van and flowing into the lake. Morgedik Dam, built on the river, is used for electricity generation and agricultural irrigation. The size of the basin is 599 km² and the length of the river network in the basin is 114.4 km.

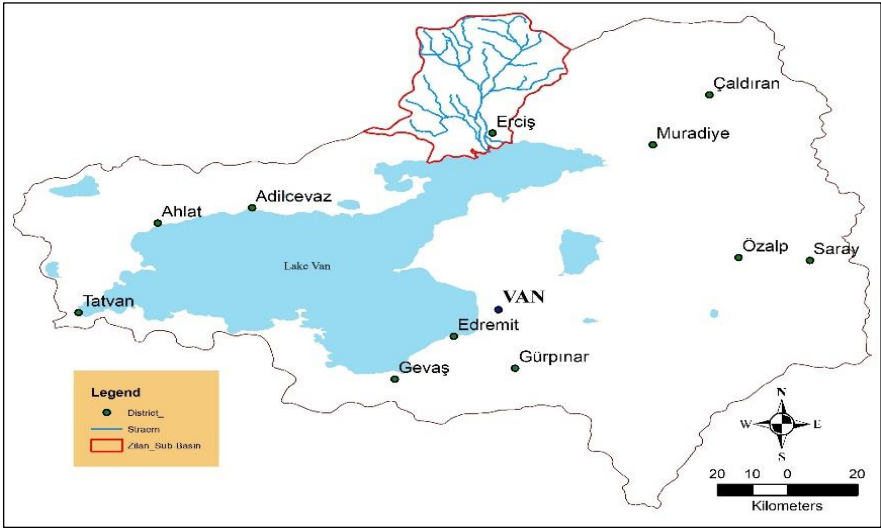


Figure 9. Zilan Sub-Basin

The Zilan sub-basin is located in the north of Lake Van. Zilan Stream is among the main streams feeding Lake Van. Rich in fish species, Zilan Stream is an important breeding ground for pearl mullets living in Lake Van. The size of the Zilan Sub-basin is 1213 km² and the length of the stream is 332.6 km.

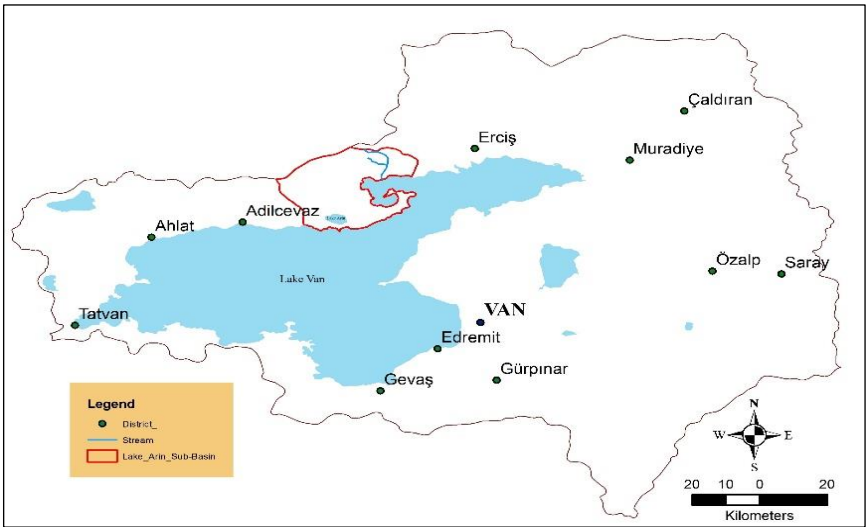


Figure 10. Lake Arin Sub-Basin

There is no major stream in the Lake Arin sub-basin within the borders of Bitlis province. In the basin, there is Lake Arin, which is salty and soda-based, like Lake Van. The total length of the stream network in the basin, which has a short stream network, is 20.3 km long. The total area of the basin is 574.2 km².

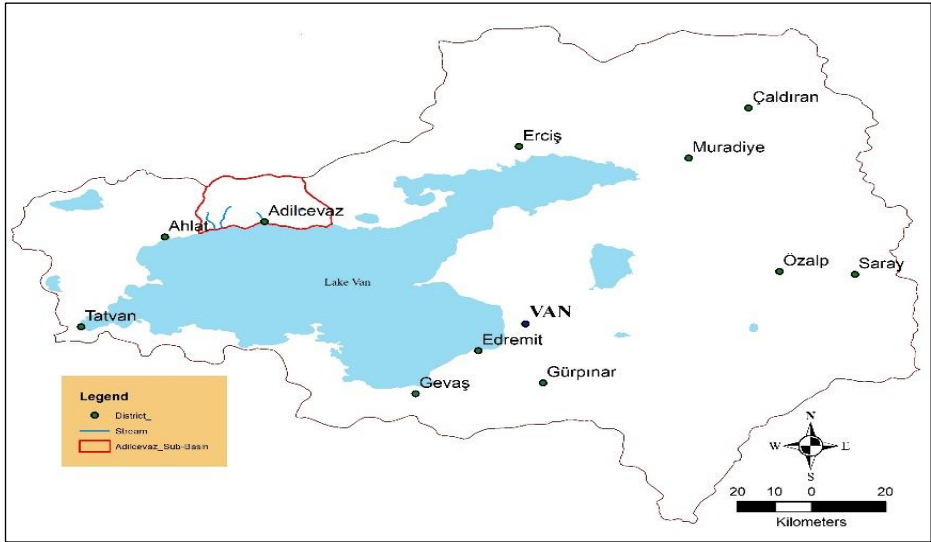


Figure 11. Adilcevaz Sub-Basin

The Adilcevaz sub-basin, located at the foothills of Mount Süphan, is one of the smallest sub-basins. Aygır Lake in the basin is freshwater and is used for agricultural irrigation and fish farming. The total size of the basin is 402.7 km². The total length of the streams in the basin is 18.8 km.

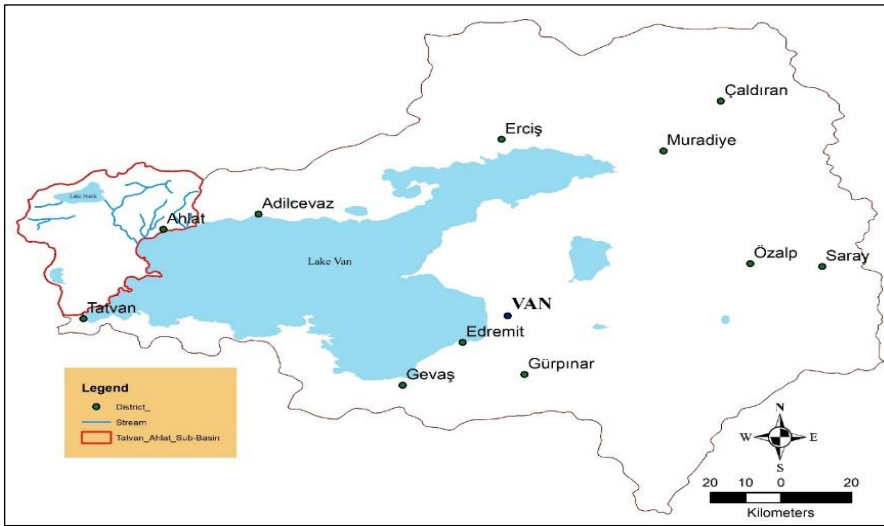


Figure 12. Tatvan Ahlat Sub-Basin

Tatvan-Ahlat Sub-basin is the largest sub-basin located west of Lake Van with its mountainous and rugged terrain structure. Güzelsu and Karmuç Streams are the largest streams in the basin, which includes large and small streams. The length of the stream network in the basin is 120.2 km. Lake Nazik, located in the sub-basin, is the largest fresh water source in the Lake Van Basin. Lake Nazik, which is located at coordinates of 38° 51' N 42° 14' E in Lake Van Basin, is a fresh water lake with an altitude of 1816 m. The lake was formed through volcanic damming. It has a surface area of 46.6 km², a maximum depth of 16 m and an average depth of 12.37 m, a volume of 576.376 hm³ and a coastal line length of 36.13 km (Akkuş and Sarı, 2019). The total size of the basin is 1181.5 km².

Table 1. Surface Area of Sub-Basins and Length of Stream System

No	Sub-Basin Name	Area (km ²)	Length of river network (km)
1	Engilsu	3.853	658.69
2	Lake Erçek	2.350	200
3	Karasu	2.154	355.5
4	Bendimahi	2.075	150.1
5	Deliçay	599	114.4
6	Zilan	1.213	332.6
7	Lake Arin	574.2	20.3
8	Adilcevaz	402.7	18.8
9	Tatvan-Ahlat	1.181	120.2

DISCUSSION

The Lake Van Basin is the largest closed basin in Turkey. The findings obtained within the scope of the study reveal how the accurate determination of basin boundaries and the analysis of sub-basins contribute to the development of water management policies. In particular, the depletion of water resources due to agricultural irrigation and other human activities is one of the most important problems threatening the ecosystems in the basin. This situation makes the protection of habitats of endemic species such as the pearl mullet even more important. Effective use of Remote Sensing and GIS technologies provides the opportunity to analyze the physical properties of the basins in detail. The digital elevation model (DEM) used in the study was effective in determining the sub-basins. Flow direction and flow accumulation analyses have revealed where water is concentrated in the basin and how important these areas are for water resources. In addition, drainage network analysis allows for more effective management of water resources at the local level by precisely determining the boundaries of sub-basins (Jenson & Domingue, 1988).

Accurate mapping of the sub-basins of Lake Van Basin will contribute to the regulation of agricultural activities in the region and more efficient use of water resources. In addition, the study findings will form a basis for better understanding the effects of global problems such as climate change on these sensitive ecosystems and developing appropriate strategies against them. However, the resolution and accuracy of the data sources used in the application of Remote Sensing and GIS technologies directly affect the reliability of the analysis results. The use of higher resolution satellite data can increase the accuracy level of similar studies.

CONCLUSION

This study has shown how Remote Sensing and GIS technologies can be used to effectively plan water management in closed basin ecosystems such as the Lake Van Basin. It is thought that the results of the study will make a significant contribution to the development of basin-based water management strategies. In particular, detailed analysis of the sub-sections of the basin will ensure more effective use of resources at the local level. The protection and sustainable use of water resources in the Lake Van Basin will not only contribute to the regional ecological balance but also to the quality of life of the local people. At this point, it will be useful to use Remote Sensing and GIS technologies more widely in the creation of sustainable management plans in closed basins such as the Lake Van Basin.

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CHAPTER 7

DATA ENVELOPMENT ANALYSIS OF THE WOS IN THE AQUACULTURE RESEARCH

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INTRODUCTION

Data Envelopment Analysis (DEA) is a tool that is in use in almost every industry. This paper aims to show how DEA is used in aquaculture, where it is being studied, what it is used for, what its inputs and outputs look like and what it is capable of doing.

DATA ENVELOPMENT ANALYSIS IN AQUACULTURE EXAMPLES

Fish polyculture generally aims to produce different species of fish or outputs using inputs such as seed or fry, feed, fertiliser and manure, labour and capital services of land, according to Saharma et al. in their 1999 study in China. The study focused on black, common, silver, bighead and noble carp. Data Envelopment Analyses (DEA) were used for both inputs (seeds, feed, labour, etc.) and outputs. In addition, provision of infrastructure, adequate inputs and modern fish farming technology were found to be critical to improving pond fish production performance in China. In addition, small and peri-urban enterprises have higher technical and economic efficiency than larger enterprises (Sharma et al., 2001).

Holland and Lee (2002) conducted a study on the overall development capacity of FAO. They examined the ability of DEA to provide accurate estimates of capacity and capacity operation for fisheries using Monte Carlo analysis. Therefore, they investigated whether the cost (random variation in propagation characteristics) was technically efficient. During the study, species from all drying environments were considered. For each of these datasets, dimensions of 50, 100, 200 and 400 were generated. Twenty-four details of the three aspects of data production examined were generated using this design. The scenario was simulated 1000 times and 400 observation shots were taken to repeat to reduce the wide variability in length four. For this iteration, the first 50, 100 and 200 observations from the original 400 observations were used to create the other dimensions. Cobb-Douglas Production Function (Capital, Labor) and Output were used as Inputs in the DEA analysis. The analysis showed that Monte Carlo analysis using the CCR model could introduce a significant upward bias in technically efficient estimates of random data noise. When the data were noise-free, the DEA estimates of the resulting efficiency were completely accurate. However, as the standard deviation of the random

noise increased, the mean deviations of the resulting estimate also increased. The result of the study was that, contrary to what would be expected from a stable model, the DEA estimates of the efficient output level were magnified by the mean deviation characteristics. As expected, when the data generation process was placed at 30 percent on the boundary, the mean deviation level was higher, and the same pattern of deviations was maintained with noise level and magnitude (Holland and Lee, 2002).

In a 2010 study in Taiwan, Chang and colleagues focused on how production efficiency and land subsidence, among others, might affect companies' exit decisions. The researchers analysed a nationally representative sample of aquacultural businesses in Taiwan. They recognised that, depending on the source of water used, production technology may differ between shellfish and non-shellfish. They recognized that the production technology for shellfish and non-shellfish may differ depending on the water source used. To carry out the efficiency analysis, they divided the aquaculture companies into four groups. They applied a separate DEA model to each group. The DEA application considered inputs (seed costs, total labor*day, hectares of land operated, feed costs), output, and fish production. They found that technical efficiency levels varied across firms. They also found that, on average, the most efficient shellfish producers are those that use groundwater, while the least efficient shellfish producers are those that don't use groundwater. Furthermore, the distribution of efficiency differs between the four groups of manufacturers analysed. However, for all groups of enterprises, the most technologically advanced enterprises were less likely to have ceased production than those with a lower level of efficiency. Aquaculture enterprises were more likely to stay in business if they had other sources of income or fish by-products. This is consistent with the notion that multiple income sources reduce overall income risk for highly volatile agricultural and aquacultural producers (Chang et al. 2010).

Nielsen (2012) conducted a study in Denmark to investigate potential production and profitability gains in freshwater aquaculture for nitrogen discharges from a feed-based input quota system. The species considered in the study was Rainbow Trout (*Oncorhynchus mykiss*). They used an overall output-oriented DEA model to determine technical efficiency for individual farms. They showed that, under different behavioural and technical

assumptions, interfarm quota trading poses a maximizing problem for the sector as a whole. Feed and fingerlings were inputs for the DEA analysis, while Trout Production Quantity was used as Output. The effect of extreme values was also tested and the results were that the effect on the profit and production estimates was very small. Estimating the technical efficiency of the sample of 142 enterprises using the output-based DEA model, the number of efficient enterprises in the sample is 46. This implies that one third of the farms were on the production frontier. The average technical efficiency was 1.23, which indicated that if all farms were producing on the border, Output could be increased by 23% without increasing input use (Nielsen, 2012).

Asche et al. (2013) estimated variation in Malmquist's total factor productivity (TFP) index for salmon farming in Norway between 1996-2008. The study considered salmon and trout species in Norwegian farming. In the DEA analysis, Feed, smolt, labour, area, and capital were used as inputs, while the production amount of the species was considered as Output. It found that while productivity growth had slowed over time, output growth had been matched by demand growth. Another way of achieving output growth was to slow down productivity growth and expand the area under production. It was emphasized that the scarcity of suitable production areas could be the most limiting factor for future production growth in the salmon aquaculture industry (Asche et al., 2013).

Schroback et al. (2014) conducted a study in Moreton Bay, Queensland, Australia. In this context, it was examined whether increasing production from specific lease clusters would require an increase in efficiency and capacity utilisation. The existence and causes of inefficiencies and inadequate capacity were identified to determine the extent of potential production increases. We do not know whether business preferences, personal characteristics, or Moreton Bay's environmental conditions limit the industry's capacity. This study uses output-oriented DEA to determine the DMU's maximum output given observed inputs. In the DEA analysis, hectare size and total labour were inputs, while production volume and price (small, medium, large, and others) were considered outputs. It found that most Moreton Bay oyster farms are inefficient. In contrast, most oyster operations were found to be operating at high or full capacity utilization. They found that they needed to make more efficient use of variable labour, although they had a reasonable amount of it. Most oyster

operations operated at or near the technical optimum scale, with a median scale efficiency score of 0.81. Given this, most operations in this sector cannot significantly increase their productivity by changing their activity level (labour) or the scale of their operations (Schrobbach et al., 2014).

Arita and Leung (2014) applied a more holistic analysis to TE analysis in their study in Hawaii. They aimed to classify the population of Hawaii's aquaculture farms according to several different classifications and dimensions. The study considered aquaculture species (Crustaceans, Fish, Ornamental fish, Mollusks and others). To do this, they used DEA for TE throughout the input-oriented farm. In the DEA analysis, land, labour, capital, feed, seed, fertiliser, chemicals and other variables were considered inputs, while aquaculture output was considered output. Their findings are that average excess input growth can be due to changes in wages and land prices. It found that in 2007, only 4 in 3 farms operated efficiently. They found a relationship between TE and farm size, with full-time farms having higher productivity than small farms. In summary, higher productivity levels do not necessarily correspond to higher profitability. (Arita and Leung, 2014).

In their study, Yin et al., 2014, China (Yancheng City) aimed to identify possible ways to increase productivity. This study evaluates technical, allocative and economic efficiencies of a sample of multiple cropping systems. The species considered in this study were crucian, bighead and silver carp. The choice of DEA for this study was for two reasons. As an example, DEA was used to identify efficient and inefficient units and to determine efficient inputs and outputs. Maximum likelihood estimation was used to estimate the Tobit model for polyculture farms. In the study, while the inputs were seeds, feed, fertilizers, pesticides, and labour, the sales prices of the produced species were taken as outputs. They found some evidence of positive relationships between farm size and productivity (Yin et. al., 2014).

A 2015 Malaysian study by Hamdan and colleagues aimed to assess aquaculture production performance under widespread environmental pressures resulting from climate change. In this study, they applied Malmquist Data Envelopment Analysis to identify global environmental issues known as climate change pressures and affect Malaysia's aquaculture production performance index. In the present study, different categories of brackish water aquaculture systems (pond and cage aquaculture) were considered to assess

their eco-efficiency. But the assumption is that all holdings had the same production technology at any given time. The inputs used in the study were mean annual maximum air temperature (0°C), mean annual minimum air temperature (0°C), mean annual rainfall (mm/day), mean annual relative humidity (%) and size of the aquaculture farm (ha for ponds and mm^2 for cages). The output was also the retail value (value added in RM). Finally, through the application of a novel dynamic environmental performance analysis. The study shows how climate change is affecting the environment and how it is affecting the production of aquacultural products in brackish waters. In terms of environmental performance aspects of aquaculture production. In addition, the study showed the importance of relative changes in eco-efficiency and environmental technical changes. In addition, the results of Malmquist RIAs indirectly indicated the level or index of vulnerability of countries' aquaculture activities to climate change stress. The results and components of Environmental Performance Indices highlighted key areas for improvement in improving production performance and managing climate change risks. In addition to formulating an adaptation strategy. There should be an emphasis upon reducing climate change risks from aquaculture production (Hamdan et al., 2015).

Iliyasu et al. (2015) carried out research in Malaysia, investigating technical and technological changes in cage fishfarming through the use of MPIs. For this purpose, they selected two representative regions for sampling: Pekan, where 155 of 384 holdings were sampled, and Temelor, where 45 of 112 holdings were sampled. The method used in the study, MPI, generally measures changes in the TFP index for a decision unit (DMU) or enterprise over two or more periods. However, the distance functions used to calculate the MPI can be estimated using DEA models. These functions measure the distance of the DMU/company to their optimal output relative to the rest of the DMU/companies in the sample. Inputs included stock densities, feed, labour, etc., while outputs included farm production. Technical, technological, pure technical, scale and total factor productivity growth are all positive and above 1. It was found that changes in technical efficiency made a positive contribution of about 62.1 per cent and a negative contribution of about 31 per cent to total factor productivity. Similarly, technological change's contributions to total factor productivity were 86.2% positive and only 13.1% negative. Moreover,

technological change did not experience any static growth rate, while technical efficiency change experienced about 7.0%. After analysing the growth paths, technical change was found to contribute more to total factor productivity growth (Iliyasu et. al., 2015).

Technical and technological change in cage aquaculture farms in Malaysia was investigated by Iliyasu et al. (2015) using MPI. The species used in the study were catfish and red tilapia production in cage aquaculture, which had the highest concentration of aquarium fish and technical efficiency. The study used two-stage DEA for the estimation of technical efficiencies, which were then regressed on socio-economic and farm variables. Furthermore, OLS proved to be more consistent than Tobit for the estimation of contextual factors. Inputs were stock densities, feeds, manpower and costs, and outputs were total fish production. The DEA results show that over 90% of the fish farmers in the sample have relatively good farm management skills. This means that the tank fish farmers have the stocks required for their farms and are knowledgeable about it. They pointed out that the small size of most tanks meant that fish farmers could more easily monitor them. They therefore stated: "The stocking rate is not an obstacle in aquaculture (Iliyasu and Mohamed, 2015).

Dos Santos' (2016) study aimed to analyse and examine aquaponics as an integrated smart city system. DEA is an econometric method which identifies DMUs which are efficient and those which are not. In the DEA analysis, inputs were taken to mean the inputs received by the enterprise and outputs were taken to mean the output produced by the enterprise. According to the findings of the analysis, the short supply chain and organic food without pesticides that the aquaponic system offers could represent a new integrated agricultural system, from producer to consumer, in an integrated manner (Dos Santos, 2016).

Iliyasu et al. (2016) used DEA and OLS to estimate technical efficiency and identify contextual factors that contribute to inefficiencies in fish farming in ponds in Malaysia. For this purpose, 100 sample respondents (pond fishermen only) were selected using simple random sampling from 539 farmers. Data was collected from these sample respondents using well-structured questionnaires and oral interviews. This is done by collecting data on inputs and outputs. This study used DEA and OLS regression. DEA used stocking densities, feeds, labor and other costs as inputs while total fish

production was used as output. It was found that fish farmers could reduce input use by around 14 per cent, achieving overall technical efficiency at current technology levels. Based on this result, they found that stocking rates should be reduced by 13.36% to achieve total productivity. They found that any increase in stocking rate beyond the recommended level will adversely affect fish growth. The importance of these factors for a high level of technical efficiency in the production of fish in ponds is evident. Contrary to what was expected, it is estimated that the coefficient of the age variable has a negative and statistically significant effect on the technical efficiency. This is due to the conservative nature of older fish farmers and their reluctance to adopt new or improved technology, resulting in low technical efficiency in production. The majority of fish farmers surveyed were small-scale. They relied on family labour, sometimes hiring one or two temporary workers for harvesting and preparation. The findings showed that the labor gaps for pond, cage, tank and pen farm were 0.78, 4.7, 3.5 and 1.0, respectively. This highlights the 0.78 per cent, 4.7 per cent, 3.5 per cent and 1 per cent reduction of labor input for the same level of output for ponds, cages, tanks and pens, respectively (Iliyasu et al., 2014).

Theodoridis et al. (2017) This study aimed to estimate levels of technical efficiency of shellfish farms in Greece, and to determine how different farm variables affect changes in estimated rates. With the help of DEA, which estimates the technical efficiency of Greek agricultural enterprises, they found 66 enterprises that were not efficient. Total hours worked (including family and non-deleted holdings), variable capital costs (expressed in euro) and fixed capital costs (mainly including annual expenditure on boats and accessories) are all expressed in euro. For output, however, gross output (gross euro income) has been selected. To allow the distribution of price variation to be taken into account, the output data used to estimate productivity were gross receipts, a function of both price and quantity. Mussel farms varied significantly in technical productivity, score between 0.492 and 1.000. Of the 66 sites, 17(24.2 %) had technical efficiency of less than 60 %, 20(30.3 %) had technical efficiency between 60 % and 79 %, and 13(19.7 %) were close to the limit of technical efficiency. Their technical efficiency ranged from 80 to 99 percent. The average technical efficiency of the farms surveyed is 0,761, which suggests that the farms are highly inefficient. We found that, controlling for input levels

and production techniques, farms that used these practices were able to improve their production gains by 23 %. The fact that the farmer does not make sufficient use of the entrepreneurial factor has been demonstrated by the existence of technical inefficiency. The economic performance of the plant is greatly influenced by this. Emphasise that in most cases, middle farmers with insufficient knowledge of agricultural programmes and accounting techniques, and lacking knowledge of modern planning, have to be equipped to modify the available resources, so they can deviate from the maximum number that can be obtained (Theodoridis, et al. 2017).

Hai et al. (2018) used two-stage DEA to measure the technological, allocative and economic efficiency of crayfish farming in three species of sea cages in Vietnam. In the DEA, the inputs were barnacles (spiny and green), feed and labour, while the production quantities of spiny and green were considered outputs. The results showed that the cost effectiveness ratios for crab, prawn and mixed culture were estimated to be .564, .591 and .801 respectively. This result highlighted that there was significant cost-effectiveness and room for improvement. They also found that allocation efficiency and cost-effectiveness were the most important reasons for spiny lobster and mixed farms. They also found that the green crawfish group used too much input. In the second stage bootstrapped truncated regression, farmer age had a statistically significant positive effect on productivity for both green lobster and mixed farm groups. For spiny lobster farms, total cage volume had a significant positive effect on profitability. Cage cleaning had a negative correlation with profitability in crawfish farms, but a positive correlation with profitability in green lobster farms. Mixed farms were less productive but spiny lobster farms were more productive the further the farms were from their neighbours. These findings suggest that improving allocation efficiency and reducing input overuse can significantly enhance the productivity of sea cage lobster aquaculture in Vietnam (Hai et al., 2018).

In 2018, Cang et al. aimed to develop an optimal approach including scale, technical and overall efficiency to ensure coordinated development of turbot aquaculture in Shandong, China in economic, resource and environmental terms. To do so, a random sample survey was carried out in 2015 in agricultural households involved in industrial turbot farming in Shandong. Altogether, 92 valid samples were taken. In total, 25 small, 22 small/medium,

16 medium, 18 medium/large and 11 large farming households were studied. The efficiency of turbot culture in industrial rivers has been investigated by means of the DEA method. The inputs in the DEA method were farm area in m², number of potatoes in 10000 t, fodder in 10000 Yuan, energy costs in 10000 Yuan, labour costs in 10000 Yuan, annual depreciation of fixed assets in 10000 Yuan and production in 5000 kg. The findings were the following. For the overall efficiency, the values were similar for small-scale and tiny/medium-scale, while there was room for improvement for low efficiency. The results for medium and medium/large were similar, highlighting a significant improvement in overall efficiency. This showed that the greatest overall efficiencies were achieved by large-scale growers. With increasing scale, the pure technical efficiency increased. Scale efficiencies were all high. The results showed that turbot resource use should be appropriately reduced in the Shandong Province industrial stream environment while maintaining production. In total, it is possible to reduce cropland by 480 m², or 11.66 % from present levels. The energy cost can be reduced by 0.53 Yuan/kg, a reduction of 11.50% compared to the current level. To reduce aquaculture costs and maximise efficiency, labour costs and fixed asset depreciation can be reduced by 0.32/kg and 0.36/kg respectively, a reduction of 12.50% and 12.90% from current levels. It is possible to use approximately 10 % less land, electricity, feed and labour than at present. There has been under-utilisation of capital assets. The actual stocking density is 26 per square metre, 41.30% higher than the survey result of 18.4 per square metre. Therefore, the current Shandong industrial river aquaculture's overall efficiency is low. Improving resource use efficiency and cost reduction requires enhanced management that reduces inputs but keeps output constant (Cang, et al., 2018).

Bayazid et al., in their study conducted in Bangladesh in 2019, aimed to measure the relative productivity of floodplain aquaculture, which currently shows significant internal differences. Data were collected on fish production for floodplain aquaculture. The official accounts for 2015-16 were recorded by carrying out two field visits to five selected sites in April - May and October - November 2016. A questionnaire specific to floodplain aquaculture was developed to collect data, and questions were supplemented with unstructured questions when needed during the field visits. For this purpose, they used the CCR model to measure technical efficiency. In RIA, Floodplain Area (ha),

Input was fingerlings (BDT million), feed and other (BDT million) and wages (BDT million) and output was sales of fishes (BDT million). The RIA analysis confirmed findings from previous studies. Without the use of RIA, their analysis revealed areas and sources of inefficiency that would have gone undetected. They found that six out of 15 selected NFPA's from five districts were efficient from a technological, size and mixture perspective. NFPA with four efficient units and better overall average efficiency 78.27 % and IFPA with two efficient units and better overall average efficiency 75.96 %. However, with the exception of Daudkandi district, the number of NFPA's in our sample is also higher due to the complete absence of IFPA's. Worth noting is that we found two efficient IFPA's (out of five) in this location, compared with only one efficient NFPA (out of six). In contrast, 3 out of 4 NFPA's in the other four sites were effective. The study highlighted the important role of NGOs in the effective operation of the relatively new NFPA's in the other locations, underlining their valuable contribution to the field. Tenanted FPA's were found to have better overall efficiency (79.56 %), but only two efficient units. Self-managed FPA's, on the other hand, had a lower average efficiency score of 75.19%. While these results are very informative, they also highlight the complexity of the field. The study failed to find a direct relationship between some of the differences (such as organisational structure and management) and farm efficiency. In addition, because sample sizes were small, DEA results made no valid statistical link between these internal variations and efficiency. The thoroughness and transparency of the study is underlined by this acknowledgement of its limitations (Bayazid et al., 2019).

In 2019, in the Brazilian state of Mato Grosso do Sul, Rodrigues and colleagues conducted a study aimed at analysing the sustainability of fish producers. For this purpose, larvae producers from AGRAER and Embrapa were identified and contacted by those businesses. Ten producers had this activity in 2015 and all of them were part of the study. To analyze sustainability, The environmental efficiency of the economic factors in the production process was assessed using DEA. Inputs were area, number of employees, salary per employee. The output was taken as the Aquaculture Sustainability Index (ASI). DEA results show that technical efficiency and sustainability levels of Mato Grosso's farms were present and optimal. Taking into account the level of education and experience of the operators, 70 % of the broodstock farms were

considered to be medium sustainable and 30 % were considered to be poorly sustainable. This is done by combining environmental efficiency analysis for each production unit with production efficiency analysis. As many as 80% of fish farms are inefficient at scale, with increasing yields reflecting inefficient resource allocation (Rodrigues, et. al., 2019).

The study of Forleo et al. (2019) aimed to make a contribution to the efficiency of Italian aquaculture companies, mainly through a focus on company structure. To that end, the research focused on two categories of companies with a special legal status, considering the type of company owned by the investment). The efficiency analysis was preceded by pre-processing of the raw data. This resulted in the final databases comprising 160 companies. This is defined as the difference between production values and production costs, including raw materials, labour, services, depreciation and supplies. The DEA takes the cost of raw materials, personnel, depreciation and other services as inputs, and the value of production as output. The results showed that 48 firms performed effectively under the VRS model and 17 firms under the CSR model. The results of these studies show that this study has a significant impact on the efficiency of aquaculture enterprises in Italy. General results show wide variation between companies in budget and efficiency indicators. The size of aquaculture firms is more important than their location regarding their efficiency performance, a key finding that can guide future strategies. While there is no significant difference between units located in northern and southern Italy, the worst situation is observed in the smallest units. There was no difference in corporate form among efficient companies (Forleo et al., 2019).

Mitra and colleagues (2019) conducted a significant study on total factor productivities (TFPs) and technical efficiencies (TE) of fishpond farmers in Bangladesh, across different environmental and farm characteristics. Seven central Bangladeshi districts were selected for their output: About 63% of Bangladesh's aquaculture area is located in these districts. In 2016, 600 aquaculture farms were selected through stratified random sampling and were interviewed through a survey and oral interview. Sampled from 580 fish farmers. Tilapia and pangasid are the main species produced in these farms. In the study area, about 60% of the farmers are producing pangasid and 40% tilapia. In this study, TFP and TE are estimated using the input-output DEA model and Fisher's unit value method. Furthermore, the differences between the farm

groups with different environmental characteristics were tested using a rank-sum test. DEA uses feed, manure, broodstock, manpower, drugs, chemicals and antibiotics as inputs, and farm output as outputs. Based on the DEA findings, the average TFP of Bangladeshi fish farmers was 38,310kg, with 70% of farmers producing from 15,001kg to 45,000kg. They found an average TE of 0.73, implying that if farmers were able to emulate best practice, they would use 27 per cent less input with no reduction in production. The analysis of the TFP/TE results showed that environmental features strongly influenced the maximization of TFP/TE. They found substantial differences in TFPs and TE for farmers with and without access to plentiful water sources. Furthermore, polycultures are better than monocultures for resource use under Bangladesh's extensive farming systems, while commercial forages apparently increase productivity compared with conventional and mixed forages. The productivity and efficiency of ponds used for other purposes is lower than that of ponds used for fish. Productivity was also found to be higher among farmers who were more environmentally conscious about their ponds. The productivity and efficiency of pond farming is lower than that of pond farming.

Aripin et al. conducted a study in Malaysia in 2020 to examine the efficiency of sea bass farming. They measured farm technical efficiency (TE), scale efficiency (SE), allocative efficiency (AE) and capacity utilisation (CU). To do so, we used multiple output DEA to estimate the productivity and capacity utilisation of sea bass farmers across the major producing areas of the Malaysian peninsula. The efficiency drivers were estimated in the second stage of Tobit analysis. At the individual production level, they estimated the effect of farmer characteristics and farm factors on the estimated efficiency and capacity utilisation values. In the DEA analysis, energy consumption, feed consumption, labour and farm area were taken as inputs, while sea bass and other species were taken as outputs. The DEA showed that much of Peninsular Malaysia's sea bass production in ponds and cages was relatively efficient, with most operating at or near optimal scale. On average, pond farms were significantly more efficient than cages in terms of technology and scale, although both had high average efficiencies. This reflects the relatively small proportion of cage farms requiring higher technical and scalable efficiency. This has important implications for the sea bass industry in Malaysia. The allocative and scale efficiency values were similar. Allocation efficiencies were

high for pond production but lower for cage production. Again, significant differences were found between the two groups. The result means that most farms produced at or near the optimum mix. However, as most pond farms were monoculture farms, this is an artefact of the data. Allocative efficiency was found to be lower in cage culture than in pond culture, but average allocative efficiency was found to be high. The distribution of neutral capacity utilisation (NCU) was wider for both groups, with a relatively high proportion of holdings showing a significant degree of under-utilisation. This result suggests that, even if the output level is efficient when considering the total input mix, many active farms have to make full use of fixed inputs. More production could have been achieved for a given level of input (e.g. cage or pond size). Mean UCU scores were lower in ponds than in cages, although they were only significantly different at 10% significance level (Aripin et al., 2020).

Long et al. (2020) firstly estimated cost effectiveness and technical efficiency using the proposed DEA model with two bootstraps. Second, to compare these estimated costs and technical efficiencies with those estimated using conventional DEA. Finally, the study was carried out to assess the technical performance of intensive shrimp farming in Vietnam. The impact of credit constraints on farm operating costs was also examined using a double bootstrap DEA model. From 442 registered intensive prawn farming households, 110 (25%) were randomly sampled. Data were collected using a project-developed questionnaire requesting relevant socio-economic characteristics, farm information, outputs and inputs in 2014. The questionnaire was tested in a pilot study and the necessary adjustments were introduced. One hundred and ten questionnaires were completed. Due to incomplete responses, only 102 were included in the analysis. The relationships between inputs and outputs have been studied using the input-output oriented VRS DEA framework.. Shrimp farms with limited access to finance were found to be less cost-effective and less technically efficient. There was no significant difference in the results of the two regression procedures comparing the Tobit estimator with unbiased points. The cost effectiveness corrected for bias and the technical efficiency corrected for bias were 0.533 and 0.723, respectively. The lower limit is .672 and the upper limit is .795. The biased technical efficiency and the biased cost efficiency are 0.490 and 0.595 respectively. Furthermore, the average cost and technical efficiency estimates are statistically significantly

lower using the two bootstrapping approaches than using The traditional DEA method. Therefore, the potential Cost and technology effectiveness improvements Suggestion by double bootstrap DEA were more significant DEA, which has been widely used for aquaculture. Other variables, such as credit constraints on operating costs, longer growing seasons and shrimp farmers working part time, were negatively associated with cost and technical efficiency (Long et al., 2020).

In the 2020 study, Gutiérrez et al aimed to estimate the productivity performance of aquaculture in EU countries in the fresh, marine and crustacean subsectors between 2014 and 2016. For this purpose, EU countries were examined in the freshwater, marine and shellfish sub-sectors between 2014 and 2016. This study analyses EU aquaculture producers' productivity performance for 2014-2016. A two-stage DEA approach was used in the study. In the first stage, country productivity was calculated using the DEA model of the SBM. In the second stage, these productivity scores were related to auxiliary variables by means of regression analysis in order to test which variables had an effect. The second stage regression models are linear (OLS), censored (ML) and fractional (QML). The DEA analysis revealed significant insights, which considered employment, assets, feed, livestock, other costs, production, energy, supply, and maintenance as inputs, and production quantity as Output. Following the DEA result, a non-guided SBM DEA model with non-discretionary inputs was used to assess the productivity of different EU Member States between 2014 and 2016. The output is the value of the fish produced, while the inputs taken into account include both operational and monetary variables. The DEA analysis shows that, with average efficiencies between 0.8 and 0.9, technical efficiency is higher for finfish than for mussels. This pattern may reflect fish producers having more control over their production cycle than mollusc producers, whose production is more dependent on environmental conditions. Furthermore, the analysis showed that for some variables, the potential input savings over the entire period were up to 25 %. The potential increase in production in the case of finfish is lower, reaching up to 2%. With regard to productivity changes over the period considered, freshwater finfish productivity fell, while marine finfish productivity rose. Due to the large number of productive countries, the results show that exogenous variables affect productive and less productive EU countries differently. In particular, the

productivity frontier is more likely to be found in countries with high GDP and low catch (Gutiérrez et al., 2020).

Hai and Speelman (2020) used a Data Envelopment Analysis (DEA) approach based on the Material Balance Principle (MBP) to examine the trade-offs between economic and environmental efficiency of caged lobster farming in Vietnam in Khanh Hoa and Phu Yen provinces. They sampled 353 farms and found that these included According to the type of lobster farmed, there were 150 farms that farmed fancy lobster, 166 farms that farmed spiny lobster and 37 farms that farmed mixed lobster. Mixing means that the two types of crawfish, fancy and spiny, are kept in different cages on the same farm. In the DEA analysis, Seed, feed, and labour were taken as Inputs, and the total amount of fancy (scaloped) lobster produced was taken as Output. In this study, the economic and environmental advantages of caged crayfish cultivation in Vietnam were evaluated using the DEA method. This shift towards an environmentally efficient status results in a substantial decrease in nutrient consumption, with changes of -55.3%, -49.0% and -30.7% and a fall in the cost of production of -19.5%, -21.8% and -1.4% respectively. With information on the price of inputs, farms can benefit the environment by using the right mix of inputs to be more cost effective. Similarly, production costs would be reduced if production were more environmentally efficient. The results suggest that the economic and environmental efficiency of lobster farming can be significantly improved through technical training programmes on the efficient use of inputs and the selection of better input combinations, given input price information. Overall, their results demonstrate that the DEA-MBP method has significant potential for use in the development of marine aquaculture (Hai and Speelman, 2020).

In 2020, Hai and his colleagues will look at ways of improving the environmental performance of crawfish farms in Vietnam. They combined material balance and meta-boundary data envelopment analysis approaches. They also used a bootstrapped truncated regression model to determine the efficiency ratios. In DEA, feed, Seed, and labour were taken as inputs, while lobster production was taken as Output. The DEA demonstrated a significant difference in the environmental efficiency of sea cage lobster farms in the study area. It also showed that the industry was ecologically inefficient. Differences in farm type, technology and input allocation between farm types were

responsible for this inefficiency. Farms producing luxury lobsters were found to be less environmentally efficient, while farms producing scalloped lobsters were found to be more efficient than the others. More caged farms were more environmentally efficient than less caged farms. Farms near other production facilities discharging into the marine environment appeared less efficient. Cage cleaning frequency did not influence environmental efficiency in the crawfish group, while it did in the scallop group. The findings of this study provide a roadmap for the aquaculture industry to improve its environmental performance, and it is the responsibility of all stakeholders to implement these findings (Hai et al.2020).

Long et al's 2020 survey of Vietnam aimed at estimating technical efficiency and metrics of intensive shrimp production. The provinces of Quang Ngai, Phu Yen, Khanh Hoa and Ninh Thuan were selected for the study. This involved surveying and interviewing in 2015. A random sample of 318 intensive fish farming households was interviewed. Specifically, 62 families were found at Quang Ngaidai Da, 59 families at Pho Yen, 95 families at Khanhhoa and 102 families at Ninh Thuan. The data, which focus on the social and economic characteristics of the business, the output produced and the inputs used, were collected through a business survey for 2014. A pilot study was carried out for the validation of the questionnaire. The study employed an input-output DEA model. The inputs were used in the DEA analysis, while the total production of shrimp per hectare per year was used as the output. An example of intensive Vietnam's shrimp farms on the south central coast is used to illustrate the results of the DEA analysis in this study. This implies that intensive shrimp aquaculture is not being operated with maximum efficiency (Long et al., 2020).

In Greece (Thermaikos gulf) in 2020, they wanted to find out whether improved production techniques and effective management methods had a positive impact on farm economic performance. Their findings have practical implications for the mussel aquaculture sector, as they suggest that productivity and competitiveness can be improved and strengthened by adopting "best farm practices" and innovations. In this study, a weight-constrained VRS-DEA model was used to estimate the TE of a sample of shellfish farms. VRS-DEA analysis included farm size in hectares of cultivation, total human work in hours, variable capital costs and fixed capital costs in euros. Conversely, the

analysis included output as gross revenue. Theodoridis et al., 2020). In order to avoid unrealistic weight schemes and to obtain realistic and comprehensive productivity values, weight restrictions were applied to the traditional DEA model.

Nielsen et al. (2021) The objective is the investigation of technical and dimensional efficiency of Mediterranean aquaculture farms. Relationship between technical efficiency and environmental variables associated with nutrient runoff. It contains information on quantities produced and input and output costs. The data selection is for 26 farms in 9 countries (Croatia, among others) from 2015 to 2017. It is based on data collected in 2018 as part of MedAID (Mediterranean Aquaculture Integrated Development). DEA with bootstrapping was used to estimate the correct technical efficiencies from the baseline model. Spearman correlation was also used to assess relationships between DEA efficiency values and farm reported environmental variables. In the DEA model, fingerling, feed, and labour were considered inputs, and production amounts were considered Outputs. They find baseline average technical efficiency of 0.83 - 0.84 and bias-corrected average technical efficiency of 0.73 - 0.66 for input-output based models. The findings showed that under input-biased regulations, farmers could reduce their input use by 17-27% on average without reducing output. The results showed that farmers who were able to produce more than the best were able to increase their output by 16 to 34% without increasing their inputs. By operating at the optimal scale, farmers can increase productivity by about 10%. In addition, the results show that there was a decline in technical efficiency in the countries analysed in 2016/2017. For the environmental variables reported, there has been no change in FCR over the past 20 years (Nielsen et al., 2021).

Beckensteiner and colleagues conducted a 2021 study Chesapeake Bay waters in Virginia to assess how tenants use the leased land and the available environment for oyster production. To this end, they analyzed active leases Chesapeake Bay waters in Virginia from 2007–2016. The data, which included leasing, oyster harvesting, environmental, management, and socioeconomic variables, was compiled by the Virginia Institute of Marine Sciences. Lease Capacity Utilization (LCU) for oyster production was estimated using Stochastic Frontier Analysis (SFA) and DEA models from 2007 to 2016. Consistencies and inconsistencies were identified by comparing utilisation rates

between the two methods. The results of the models were used to 1) estimate the degree of inefficiencies in the use of leasehold land under intensive oyster production, and 2) identify the drivers of lease use in relation to leaseholder characteristics and the spatial context of production. The study's findings suggest a significant potential for reducing inefficiencies in the industry. The development and application of models incorporating environmental and socio-economic data to evaluate aquaculture production potential is essential for improved spatial planning, which promotes efficient land use, reduces user conflicts and takes into account the trade-offs associated with aquaculture development. Accordingly, lease size (discretion) was taken as Input, while temperature, salinity, O₂, POC, and mean depth were taken as output Oyster Production. The DEA results suggest that oyster production in Virginia can be increased, or the amount of leased land can be reduced for efficient use of leased lands. Reducing inefficiency can be achieved by consolidating leases to increase rent per lessee, making better use of leases in densely settled areas to reduce idle space, or expanding production to areas of low conflict but high operating cost, such as along the Chesapeake Bay or the East Coast. (Beckensteiner et al., 2021).

Cort'es et al, 2021, combined LCA and DEA approaches to assess environmental and eco-efficiency of 38 semi-intensive shrimp farms in Sonora, Mexico. The environmental and economic efficiency was applied to profile the farm, identify critical activities, farm inefficiency, input reduction goals, and calculate the environmental impact of inefficiency in the shrimp farm. These operational targets aim to reduce the amount of input used while maintaining the output; Inputs such as seawater, feed, larvae, electricity, transport, nitrogen, and phosphorus were taken in the DEA. Output was taken as Shrimp production quantity. The DEAs showed energy consumption in the feed formulation and larval tank. By quantifying the environmental impacts associated with operational inefficiencies, the combined application of Life Cycle Assessment and Data Envelopment Analysis has provided an overall conclusion for the verification of eco-efficiency. Only 5 of the 38 farms are considered to be at full productivity. This led to an estimated reduction of 3.6 % to 69.9 % depending on DMU. Large farms maintained the highest productivity, while small and medium-sized farms experienced a decline (Cort'es et al, 2021).

Aung et al (2021) used radial, non-radial and two-stage dual bootstrap DEA to investigate the production efficiency of small-scale aquaculture in the Ayeyarwady Delta, Myanmar. Participants were selected using stratification, convenience and random sampling methods. A random sample of 440 farms with a total production of 1776 fish from the MYFC project was selected. In total, 423 households were included in the analysis, as 17 households did not catch any fish in the last farming cycle and were excluded from the analysis. From May to July 2019, the survey was conducted. Their found that increased technical efficiency is associated with women's participation in household decision-making. Their results show significant potential for increased productivity in the aquaculture sector. For example, male-headed households have been found to be more technologically efficient than female-headed households. This can be explained in large part by social and cultural norms which favour the participation of male heads of households in social networking. In order to assess technical efficiency, bias-corrected technical efficiency scores from the baseline model were bootstrapped into the Data Envelopment Analysis (DEA). Spearman correlation was also used to assess relationships between efficiency values obtained from DEA and farm reported environmental variables. By estimating CRS and VRS DEAs, it is possible to measure scale effectiveness (SE). Both pure technical efficiency and scale efficiency are included in the technical efficiency measures obtained by CRS DEA. The technical efficiency of the CRSs divided by the DEAs of the VRSs gives the scale efficiency. In the study, while Fry, Feed, and Labor were considered as Input, Production amount was considered as Output. According to the DEA results, the average technical efficiency for the input modules ranges from .83 to .84, while the average technical efficiency for the output modules ranges from .73 to .66. They found that, on average, input-based models allowed farmers to cut inputs by 17 to 27 per cent without reducing production, whereas output-based models allowed farmers to increase production by 16 to 34 per cent without raising inputs. Farmers could also increase productivity by around 10 per cent by working at optimum scales (Aung et al., 2021).

Dorji et al.'s (2022) study aimed to examine how productivity improvements might affect farmers' likelihood to exit small fish farming. Given that small-scale subsistence aquaculture is fundamentally different of large-

scale commercial aquaculture, the underlying productivity characteristics and reasons for exit behaviour are likely to be different. The objective was to examine how productivity gains affect the probability of exit from small aquaculture. A household survey was conducted in June 2018 on 202 Bhutanese small fish farmers. At the time of the survey, there were reportedly 467 fish farmers in 12 out of 20 dzongkhags. The survey was conducted to provide robust data for the study by NR&DCA, a leading research institution in Bhutan's aquaculture sector. In particular, there were 120, 78 and 90 fish farmers in Samdrupjongkhar, Samtse and Tsirang respectively, while there were less than 25 fish farmers in the other dzongkhags⁵ (excluding Sarpang). Farmers in these three selected dzongkhags were considered representative of Bhutan's fish farmers geographical, environmental, socio-economic and market characteristics. All fish farmers in the selected dzongkhags were identified and surveyed using the database. A structured questionnaire was developed and administered to dzongkhag-based extension workers to collect baseline data on relevant socio-economic indicators. Fish farm productivity was predicted using Slack-Based Productivity Estimator (SBME). The SME is calculated using the input surplus and the output gap. SBME is a more suitable method as it does not ignore input (Pond size, Culture period Months, Number of fingerlings, Daily household labour, Total household labour consumed, Fertilizers, Formulated feed, Other feeds, Lime, Management and harvesting labour costs, Other costs) surpluses and output (Production quantity) deficits in the calculation. To estimate SBME as a measure of productivity, cross-sectional data from small-scale fish producers in Bhutan were used. Regression analysis was then used to examine the impact of productivity improvements on the likelihood of exiting small-scale fish farming. Their findings indicate low productivity levels of Bhutanese fish farmers. They also found that there were significant differences in farmers' available production technologies. They also found that improving productivity had huge potential as a policy tool to prevent small-scale fish farmers from abandoning aquaculture (Dorji et al., 2022).

Long, (2022) conducted a study in Vietnam (Phu Yen) on cost-benefit analysis of shrimp farming, sampling bias correction and statistical inference. This was done using DEA. A two-stage bootstrap technique was applied. The second phase involved the development and implementation of the Farrell cost-benefit ratio. In the case of the intensive farming of white-legged prawn in Phu

Yen, Vietnam, socio-economic and farm characteristics are taken into account. The inputs considered in the DEA analysis were seed, feed, labor, chemistry, total cost of chemistry and drugs used, and energy. In contrast, the Output was considered Total shrimp production per hectare per year. The Phu Yen prawn farm, located on the central coast of Vietnam, has been analysed using the DEAs findings. The bias-corrected cost-effectiveness point estimate was 0.604, and the lower bound of the 95% confidence interval was 0.541 and the upper bound was 0.687. Underlining the importance of the findings from a policy point of view, the cost-benefit analysis showed considerable potential for improvement. Deconstruction of the cost-effectiveness showed that inappropriate allocation was the main cause of cost inadequacy, at prevailing prices, this implies an inappropriate input mix. The lower input levels of chemicals/pharmaceuticals and seeds are critical for this activity, given limited access to formal credit. (Long, 2022).

Hukom and colleagues used a unique approach to assess the effectiveness of Pokmaswas in addressing market failures such as polluting and transmitting disease. The study examines whether technical efficiency differs significantly in sub-regions where Pokmaswas is implemented versus other sub-regions where it is not. For this purpose, data was collected from the district of Sidoarjo. Interviews were conducted with a sample of 306 farmers in eight subdistricts of Sidoarjo between September 2017 and June 2018. They used the input-output DEA model to estimate technical efficiency. Mann-Whitney test and Tobit regression were used to test the significance of co-management. Finally, the relationship between environmental stressors and technical efficiency was tested by means of Spearman correlation test. DEA provides flexibility in the analysis of production units with more than one input and output. Inputs to the DEA analysis included yield, seed, feed, labour and other costs. The quantity produced was considered to be the output. The results of the DEA show that small-scale shrimp polyculture farmers can increase their technical efficiency through more efficient use of their inputs. The farmers are able to reduce the use of inputs by 56% and still produce the same output. These findings have practical implications for smallholder shrimp polyculturists by identifying the positive effects of co-managing on technical efficiency and stress resilience (Hukom et al., 20-22).

In a large trout farm in Mazandaran Province, Iran, Asadikia et al. (2022) aimed to assess the impact of import subsidies on the economic efficiency of trout supply. A two-step analysis of commercial viability of Mazandaran's trouts supply chain. In the first stage of the supply chain, local and imported trout fry and other basic production and hatchery inputs have been considered. Juvenile fish, domestic trout eggs and adult trout are considered as first level products. Given the controllable nature of inputs in fish culture, the study developed input-based models for maximizing production for a given input and thus maximize efficiency. Furthermore, the CCR model was used for measuring technical efficiency and the BCC model was used for calculating pure technical efficiency. Technical Efficiency and Pure Technical Efficiency were considered as equal. For returns to scale, the CCR model was therefore used. This study is an assessment of the technical efficiency of supply chains. The direct effect of the trout egg subsidy was then added to the economic efficiency. DEA considers feeds, manpower, diesel, electricity and imported eggs as inputs, and marketed trouts as outputs. According to the DEA result, the first obtained supply chains almost utilized the inputs best. They found that high entry costs and decreasing distribution rates across supply chains lead to significant performance differences, leading to deterioration of economic freedom. In the presence and absence of vertically integrated independent supply chains, the sale of imported trout eggs had a significantly higher economic efficiency. Second, the provision of more affordable inputs was critical given the low economic efficiency of most supply chains. Input price sensitivities were analysed in the presence and absence of import subsidies (Asadikia et al., 2023).

Dhande et al., in their study conducted in the West Godavari district of Andhra Pradesh, India, in 2023, aimed to uncover to improve the profitability and resource efficiency of polyculturing. Their findings shed light on the current state of polyculture and suggest measures for better resource utilization to boost production, productivity, and farm income. This study evaluated profitability and productivity of polyculture of common carp, which has emerged as a promising alternative to composite carp culture. A structured interview schedule was used to survey farmers (n=60) in Andhra Pradesh. The methodology used is Data Envelopment Analysis (DEA). The productivity of each DMU is measured in terms of a proportional change in inputs or outputs. An input-oriented model minimizes inputs (Seed, feed, medicine, energy,

labour, rental cost, other costs) but does not change Output (Cost of production), assuming constant returns to scale, which means that the Output remains the same even if the inputs are increased or decreased. Accordioning from Feed and labour day factors significantly affected farmers' income, and the polyculture system exhibited decreasing returns to scale. A higher percentage of large farmers are technically more efficient than small farmers. They found that farmers can produce the same level of output using a combination of inputs that corresponds to the minimum cost of production, with an 18% reduction in input use, a cost effectiveness score of 65% and an allocation score of 81% (Dhande et al., 2023).

Wang et al. (2024) Investigate the converging patterns of technical and environmental efficiency in aquaculture production and identify the gaps in developing aquaculture production. In short, we will examine how these factors affect aquaculture productivity in China. The environmental variables to be taken into account are: water catchment areas (pond, lake, etc.), climate conditions (temperature and precipitation) and natural catastrophes. The China Fishery Statistics Yearbook (2008-2019) and the China Environmental Statistics Yearbook (2008-2019) provide data for these variables. The results show that 3330 publications (in Google Scholar data) have been made in the world between 1999 and 2024, 42 of which have been searched in WOS and a total of 27 publications have been made in Turkey on DEA. The efficiency factors include GDP, GDP invested in R&D, GDP invested in environmental conservation, urbanization rate, percentage of farmers with higher education, years of farmers' education, and aquacultural area. These statistics were collected from the China Fishery Statistical Yearbook (2008 - 2019) and the China Science and Technology Statistical Yearbook (2008 - 2019). There are two reasons for choosing the DEA model instead of the Stochastic Frontier Analysis (SFA) method in this study. First, DEA makes no explicit assumptions about the functional form of production relations. In situations where the production relationship is unknown or difficult to model, this flexibility makes it more appropriate. Second, there are 228 DMUs in our study and each DMU consists of inputs, desired outputs and undesired outputs. In this study, we used DEA to evaluate the technical and environmental efficiency of aquaculture because Stochastic Frontier Analysis (SFA) is less suitable for analyses involving multiple inputs and outputs. This method combines the traditional

DEA model (DEA-CCR) with SFA to provide a more objective assessment by taking into account environmental factors, management inefficiencies and random errors. Machinery, labour and intermediate inputs are considered as inputs, while outputs are the production value of aquaculture (Wang et al., 2024).

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CHAPTER 8

EVALUATION OF SALINITY TOLERANCE IN KOI SWORDTAIL FISH (*Xiphophorus hellerii* Heckel, 1848)

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INTRODUCTION

The Poeciliidae family (Poeciliids) has 29 genera and 284 species (Fricke et al., 2024) with members distributed in fresh, brackish and salt waters. It has members that are laterally flatter and vary widely in size with a wide distribution from South America to Western India (Miller et al., 2005; Nelson, 2006). Poeciliids are also known to have populations in North and Central America, the Caribbean Sea, Northern Argentina, the Congo Basin and Madagascar (Parenti, 1981). Members of the family are benthopelagic, living in the pH range of 7.0 - 8.0, 9 - 19 dH; non-migratory, species that can tolerate the range of 22°C - 28°C (FishBase, 2024). Poeciliids are a very popular family that includes ornamental fish species such as Guppy, Mosquito, Swordtail, Pilati and Moli (Lucinda, 2003). These species, belonging to the Cyprinodontiformes order, are small fish that have live-bearing members is 3 years and these species are omnivorous and their food consists of various invertebrates, insect larvae and microalgae (Mills and Vevers, 1989).

The high salinity tolerance of this species belonging to the same family creates the idea of evaluating the viability of resistant family members with more visual color patterns in marine salinity values. The osmoregulation mechanism ensures ion balance and balances the amount of water, and as the salinity of the environment increases, blood serum osmolality increases significantly (Huang 2020). Exposure to high salinity levels can disrupt osmoregulation and ion balance, causing physiological stress and reduced growth rates (McKay and Gjerde, 1985). The organs and tissues where cellular and textural changes due to salinity stress are most observed are the kidney and especially the gills. Gills play a very important role in the osmoregulation mechanism as they interact directly with water, and they are also the first organs to be affected by environmental factors due to ion-gas exchange (Nascimento et al. 2012). Salinity tolerance of Koi Swordtail fish over 2 years old, exposed to different salinities (0‰, 10‰, 20‰ and > 20‰), was evaluated physiologically.

MATERIALS AND METHODS

Animals and Trial Pattern

A total of 60 Koi Swordtail (*Xiphophorus hellerii* Heckel, 1848) fish belonging to the Poeciliidae family, reached sexual maturity (2+ years old) were used in the study (Fig. 1). In this work, groups were created with 45 L glass aquariums at different salinity levels: 0 (control), 10 ‰, 20 ‰ and > ‰20. The trial was designed with 3 replicates in each group and 5 fish in each aquarium.

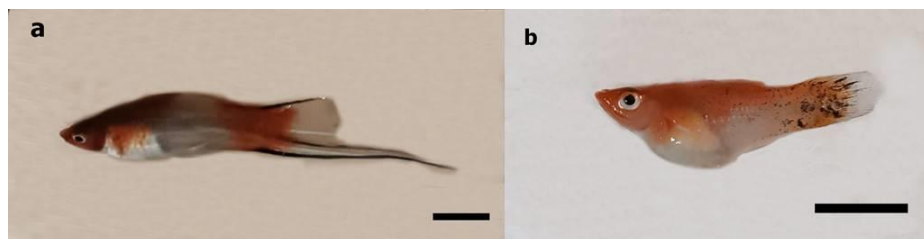


Figure 1. Fish used in the study (a: male, b: female, scale bar: 1 mm).

Salinity Acclimation Process

The experiment was started at the end of a 1 week acclimation period with a 2‰ salt increase (Capps et al., 2011; Olukolajo et al., 2013; Oğuz et al., 2023), except for the control group. In order to minimize salinity stress and ensure healthier adaptation, daily salt intake was considered to be kept low. Therefore, after the 10‰ salinity level was reached in all groups, the daily salt increase continued to 1‰. When the 20‰ salinity level was reached, the salt increase was stopped in the 20‰ groups.

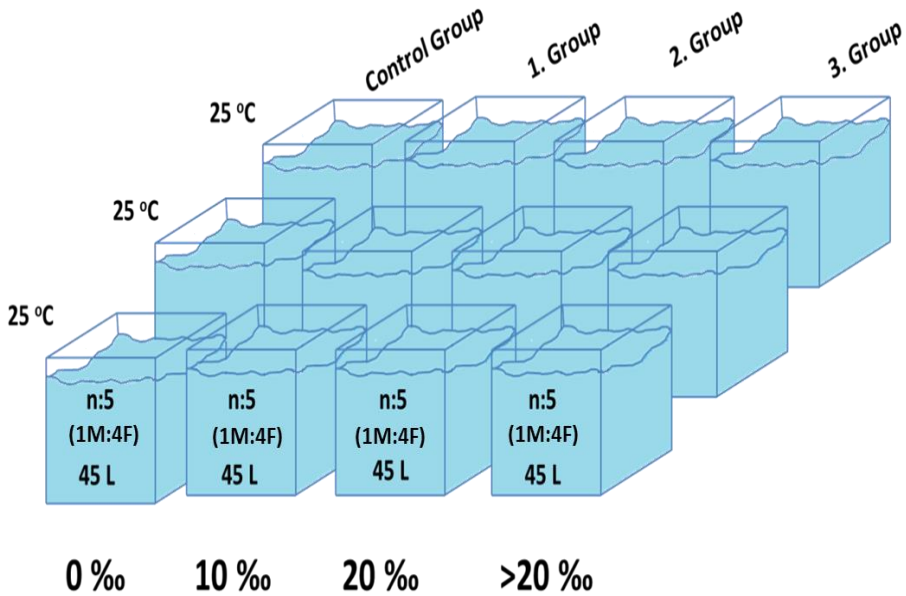


Figure 2. Design of trial groups and experimental setup (M: male, F: female).

Feeding was continued twice a day and at a rate of approximately 5% of the total body weight (0.1-0.2 g/fish per day) (Hekimoğlu and Albaz, 2003), using commercial flake feeds throughout the trial. In order to minimize the deterioration in water quality, a 15% water change was performed by performing a bottom flush every 4 days and water of the same temperature and salinity was added as much as the reduced volume, and also a sponge filter is placed in each aquarium. The death of approximately 40% of the number of individuals in the highest salinity aquariums (Nordlie et al., 1992) or complete cessation of feed intake were accepted as the upper limit of maximum salinity tolerance and the experiment was terminated. Ammonia (NH_3), ammonia nitrogen ($\text{NH}_3\text{-N}$), pH and Dissolved oxygen (DO) values were measured using HACH HQ 40d (Germany) multimeter and HACH LANGE DR 5000 (Germany) spectrophotometer devices during the experiment.

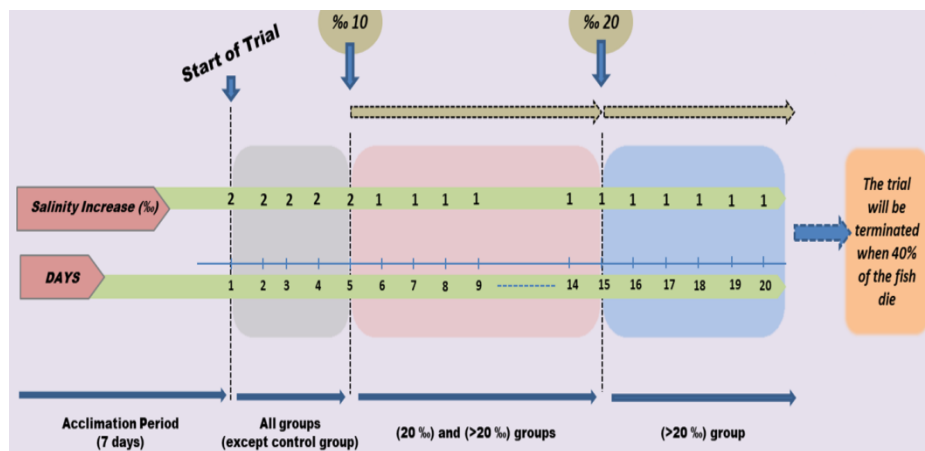


Figure 3. Salinity increase procedure by groups.

In the measurement of NH_3 and $\text{NH}_3\text{-N}$ parameters, mineral stabilizer, polyvinyl alcohol and Nessler reagents were used in the analyzes carried out with the 'Nessler' method (0-2.50 mg/L) numbered HACH 8038 (HACH, 2010).

RESULTS

The experiment started with 60 fish, but a total of 11 fish died during the experiment, especially in the maximum salinity groups. In the morphometric measurements made to select fish with similar lengths, the total length of fish was determined as 6.860 ± 0.234 cm (n:12) and 4.061 ± 0.113 cm (n:48). The trial was terminated on the 26th day by stopping feed intake in individuals exposed to planned salinity levels without salt addition. From the start of salt addition, no deaths were observed until the 5th day, when salinity reached 10‰ in all groups.

On the 7th day of the experiment, 1 individual in the control group and 2 individuals in the 10‰ group died. A total of 4 fish died in the 20‰ and 22‰ groups on the 17th day. The distribution of losses occurring in the ongoing process according to salinity groups is given in Table 1.

Table 1. Distribution of individuals who died during the experiment according to salinity rates and groups

Salinity groups	< ‰ 10	12 ‰ (7 th day)	15 ‰ (10 th day)	19 ‰ (14 th day)	22 ‰ (17 th day)
10	-	2	1	1	-
20	-	-	1	-	1
22	-	-	-	1	3
0 (Control)	-	1	-	-	-

NH₃, NH₃-N, pH and DO values at different salinity levels were measured in all groups and the changes in the obtained data are given in Figure 4.

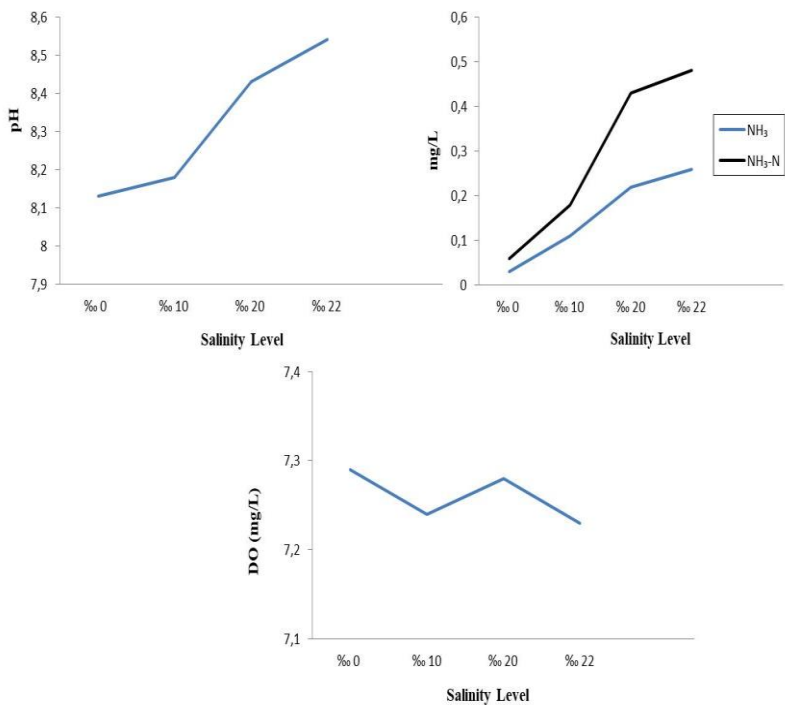


Figure 4. NH₃, NH₃-N, DO and pH changes due to increase in salinity.

CONCLUSIONS

It is directly related to various physiological changes such as salinity tolerance, ion exchange and osmolarity balance of fish. Studies that determine the salinity tolerance of fish (Naiman et al., 1976; Olukolajo et al., 2013) generally involve determining the lethal effect by exposing individuals to different salinity rates for certain periods of time. The important point in these studies is the exposure time. So in these studies, the period during which individuals are exposed to different salinity levels varies between 5 days (Haney, 1999) and 14 days (Nordlie, 1987). The experiment was terminated in 27 days and each trial group was exposed to different salinity levels for at least 7 days in this work. The salinity amount in the groups was not increased directly as in similar studies (Capps et al., 2011; Olukolajo et al., 2013), but was made in the form of daily increases at certain rates (1-2‰) throughout the trial. Just as there are experiments that are terminated when nearly 40% of all individuals die, complete cessation of feed intake is also sufficient to terminate the experiment. Because, considering that fish stop feeding will die soon, this reveals that it would not be appropriate to keep the fish species at that salinity level. In the study, it was observed that feed intake decreased or even stopped in all individuals at 22‰ salinity. This shows that the healthy upper limit is actually 22‰, considering the high salinity diet of the species.

There are studies in which blood serum osmolarity values were determined in fish species exposed to different salinities in order to observe the lethal and sublethal effects of salinity as well as to reveal its physiological effects (Haney, 1999; Capps et al., 2011; Perschbacher et al., 2011). In addition, the reactions and changes caused by salinity stress in tissues and organs are also evaluated immunohistochemically. The next stage of the study aims to reveal the histological and physiological changes that occur when the species is exposed to salinity.

FUNDING

This study was conducted using university facilities without any institutional financial support.

ETHICAL CONSIDERATIONS

The study was carried out following experimental animal ethical rules, grand number 2024/02-01(27/05/2024).

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CHAPTER 9

BIOSECURITY AND NON-NATIVE SPECIES IN THE ORNAMENTAL AQUATICS INDUSTRY

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INTRODUCTION

Maintaining aquatic animals and plants is a centuries-old hobby with an ever-increasing popularity and global reach. In recent years, there has been a sharp increase in interest and demand for ornamental fish, with more than one billion fish traded worldwide each year. There are more than 120 countries involved in ornamental fish trade. Altogether about 1.800 species of fish are traded, of which over 1.200 are of freshwater origin and the rest of marine origin. The global ornamental fish market was valued at USD 5.95 billion in 2023. For 2024, the market is estimated to be worth USD 6.41 billion, growing at 7.8% per annum between 2024 and 2032 to reach USD 11.69 billion in 2032 (Figure 1). Moreover, aquatic ornamental species and associated equipment trade has grown to a US\$15–30 billion per year industry (Silas et al., 2011; Raja et al., 2019; Atalah et al., 2022; Straits Research, 2024).

The European Union and the USA are the leading countries in the world aquarium fish market. 26 million marine aquarium specimens were imported into the European Union from more than 60 different countries, with an annual trade value of €24 million (Biondo et al., 2024). In Turkey, the aquarium hobby became popular in the 1980s and a large number and variety of aquarium fish began to be imported (Türkmen and Alpbaz, 2001). Expanding e-commerce globally in the future is estimated to create opportunities for the growth of the global ornamental fish market (Straits Research, 2024).

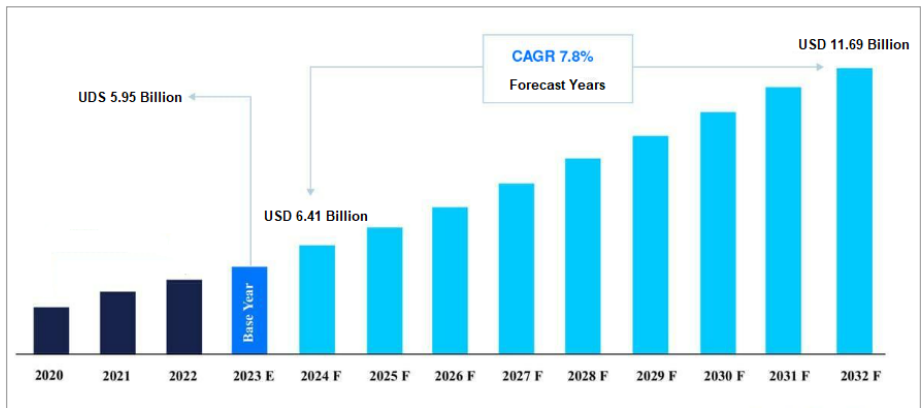


Figure 1. The Global Ornamental Fish Market (Straits Research, 2024)

The trade in aquatic ornamental species is an important pathway for the introduction and establishment of non-native species into aquatic environments. As worldwide interest in these species grows and warmer conditions occur under global warming, the probability of introduction of non-native species is expected to increase worldwide. One of the most important consequences of the global industry of aquatic ornamental species is global biotic exchange and the resulting impacts. The release of aquatic ornamental species results in the introduction and establishment of non-native species, especially in freshwater systems, and the associated negative impacts. This has resulted in large-scale distributions of goldfish and ornamental carp, lionfish along the western Atlantic coast, *Caulerpa taxifolia* in the Mediterranean, Australia and California, and the “invasion” of many important freshwater plants. In addition, the aquatic ornamental species that have become established because of these invasions have resulted in the exchange and differentiation of pathogens and parasites between water bodies (Atalah et al., 2022).

Biosecurity refers to measures taken to prevent diseases, invasive species and the spread of harmful organisms. It therefore covers both the spread of diseases and the introduction of non-native species. Biosecurity promotes animal welfare, prevents damage to natural ecosystems and reduces losses from your stocks when handling live fish, plants and invertebrates (OATA, 2023). The fish supply chain and biosecurity practices are extremely important in the sustainability of the aquatic ornamental fish industry. The fish trade supply chain generally includes; growers, distributors, intermediaries, wholesale exporters and importers, retailers in local shops and consumers. In each of these distribution processes, fish health and welfare is affected at each step (Saengsitthisak et al., 2021).

Different crops have different biosecurity risks. The risk of diseases moving from one place to another (translocation) is at different levels according to the products. The movement of live animals poses the greatest risk for the spread of diseases and invasion. (QSIA, 2018). Since the aquatic ornamental industry involves live fish and plants, it is in the highest risk group in terms of biosecurity. In this study, information on disease, quarantine and invasive alien species in the aquatic ornamental industry is presented (OATA, 2023).

2. RELATED ITEMS

2.1. Why Aquatic Ornamental Species Are Risky?

Most of the aquatic ornamental species are tropical species and are non-native for many countries. Non-native species that are transported and established in new habitats through the aquatic ornamental industry are considered invasive alien species (IAS) when they have biodiversity, ecosystem services, human health or economic impacts. The International Union for Conservation of Nature (IUCN) Invasive Species Specialist Group lists one-third of the aquatic species on the list of the 100 worst invasive species, the vast majority of which belong to freshwater aquarium or aquatic ornamental plants (Padilla and Williams, 2004; Edgerton and Ericson, 2016).

Aquatic Ornamental Species (AOS);

- AOS represent adult groups and are more likely to reproduce and survive.
- AOS are more resistant individuals selected from nature.
- AOS are individuals that have passed the difficult live transport process.
- Popular species are numerous and have a high probability of being released into the wild and becoming IAS.
- AOS that can reach large sizes are likely to be released into the wild.
- AOS that can reproduce and grow fast are likely to become IAS.

2.2. Risk Assessment

The most important element of biosafety is risk assessment. It includes biosafety threats from other businesses that can be caused by practices. These threats can be broadly divided into three main areas: entry, internal spread and transmission of biosecurity threats. It is very important to reduce the risk of any disease or invasive species entering the facility. Reducing the likelihood of biosecurity threats entering any operation can be achieved by:

- Purchasing through trusted suppliers
- Checking the shipments
- Effective quarantine and preparation for sale procedures

While it is very important to reduce the risk of entry of biosecurity threats, no system or method eliminates all risks. Therefore, appropriate

methods must be included to limit the spread of any biosecurity issue should it enter the facility. This can be achieved through:

- Effective system design
- Appropriate disinfection procedures (including personal hygiene)
- Meeting high standards of welfare

It is also important to reduce the likelihood of onward transmission of biosecurity threats. Biosecurity threats to other businesses, staff, consumers and the environment can be reduced by:

- Adhering to high biosafety standards
- Proper transportation of animals and plants
- Proper disposal of waste

Reducing the risk of biosafety threats usually comes at a cost. However, it is important to balance identifying potential threats to businesses with the cost of mitigating them. (OATA, 2023).

There are different practices in the risk management of invasive pathogens within the framework of biosecurity in aquarium fish trade and especially in imports. These species transferred from different countries can pose many biosecurity risks and problems for new destinations and locations. In order to minimize these biosecurity risks and manage the process properly, some measures need to be taken. These practices are pre-border measures, border measures and post-entry measures (Table 1) (Burgiel et al., 2006; OATA, 2006; IUCN, 2006).

Table 1. Biosecurity Measures at Different Stages in Aquarium Fish Imports (Burgiel et al., 2006)

Pre-Border Measures	At-Border Measures	Post-Entry Measures
Pre-shipment inspection	Visual inspection	Domestic inspection
Quarantine before shipment	Certification	Quarantine after entry
Certification	Defined ports of entry	Further tests if necessary
Preventive treatment	Quarantine in border facility	Treatment or disposal

Pre-Border Measures: It is carried out in the exporting country and by the exporting company. It includes pre-shipment quarantine, preventive treatment, especially against parasites, and the “Veterinary Health Certificate” issued by the competent person in the country.

At-Border Measures: In many countries, customs points where aquarium fish imports will be entered and where experienced personnel are available are determined separately. At customs, the fish are visually inspected by authorized persons and are allowed to enter the country if there is no health problem.

Post-Entry Measures: In many developed countries and island countries such as Australia and New Zealand, quarantine is used as a post-entry measure. Quarantine is usually implemented at authorized quarantine facilities or in-house quarantine units. After a certain period of surveillance, healthy consignments are allowed for sale. In case of illness, treatment is applied or the shipment is completely disposed of. The authorized person may request further examinations and the costs in this regard belong to the importer company (Burgiel et al., 2006; OATA, 2006; IUCN, 2006).

2.3. Conscious and Trustworthy Supplier(s)

One of the most effective and simplest measures in biosecurity is to buy from trusted suppliers who sell correctly identified, healthy stock. Ensuring healthy individuals of the correct, legal species reduces the likelihood of disease or invasive species entering the business. Wild-caught and captive-bred sources present different risks. Choosing suppliers with short supply chains is also beneficial. The less links in the supply chain, the lower likely it is that farm animals will be exposed to disease or that the wrong species will be included in a shipment. The reliability of the supplier is very important in this regard. Furthermore, businesses that do not have the capacity to quarantine and, if necessary, process as new stock should not accept livestock returns from customers. This is because it is not known what disease the returned specimens may have encountered in the home aquarium and therefore have a high potential for disease transmission (OATA, 2023). In addition, choosing specialized suppliers that only keep captive-bred species or wild-caught species in their facilities can reduce biosecurity risks.

2.4. Checking Shipments and Acclimatization

It is recommended to record the quality of all shipments (fish mortality and disease) and provide regular feedback to suppliers. This will allow suppliers to monitor their efficiency and solve the problem as soon as possible. Clean the outside of the live transfer boxes before entering the facility. Also, bags and similar packaging materials should be properly discarded or disposed of and not reused. Ensure that ordered species arrive correctly and that there are no unwanted hitchhikers. Ensuring that invasive species are not traded is important in this respect. Checking all shipments provides a chance to examine the health of the livestock and if there are any signs of disease, corrective measures can be taken earlier and the affected stock can be isolated from the main stock. Catching any problems early increases the likelihood of successful treatment and prevents contact with healthy individuals (OATA, 2023).

Aquarium fish are rested after transfer and kept in optimal conditions as stress-free as possible. This process is called acclimatization/adaptation. During this process, the fish can be observed to see if they are infected a disease. Water and equipment should not be transferred between different batches. In closed systems, the risk of cross-contamination should be avoided and waste water should be treated. Each batch of fish (shipment) must be isolated. This process has a cost. However, this cost is lower than the damage that a possible disease can cause to the business and/or the customer (OATA, 2006).

2.5. Quarantine

Quarantine is a key issue in the aquatic ornamental industry. The rapid spread of pathogens through water, as well as a less developed immune system compared to mammals, makes a correct “biosecurity plan” mandatory in aquatic species (Barrio, 2022). The definition of quarantine in the World Organization for Animal Health's Aquatic Animal Health Code (OIE, 2019) is:

Quarantine means maintaining a group of aquatic animals in isolation with no direct or indirect contact with other aquatic animals, in order to undergo observation for a specified length of time and, if appropriate, testing and treatment, including proper treatment of the effluent waters.

Even if the right, seemingly healthy animal has been purchased, the disease may not always be visible. Therefore, quarantine first is important to prevent undetected diseases from entering the system and to control shipments for invasive species or hitchhikers. This is particularly important when

importing cold-water species, as there is a high likelihood of disease spreading to local wildlife. The time required in quarantine depends on the species, their origin and the outcome being sought. Recommended quarantine periods by species are presented in Figure 2 (IGB, 2012; OATA, 2023).




	
Tropical Freshwater Fish (7 days)	Tropical Marine Fish (7 days)
	
Gourami Fish (4 days)	Cichlid Fish (4 days)
	
Gold Fish (21 days)	Koi Fish (21 days)

Figure 2. Recommended Quarantine Periods for Aquarium Fish (IGB, 2012).

A quarantine facility is important as the first barrier against infectious diseases. Quarantine systems should be completely isolated from other systems

(Figure 3). New fish is the greatest threat to the biosecurity of the aquarium and should come directly into the quarantine facility and be isolated from other species. Furthermore, specialized quarantine systems should have a specialized set of equipment (e.g. nets, buckets, siphons, sponges, shoes, etc.) and should only be accessible to trained personnel (Barrio, 2022; OATA, 2023).

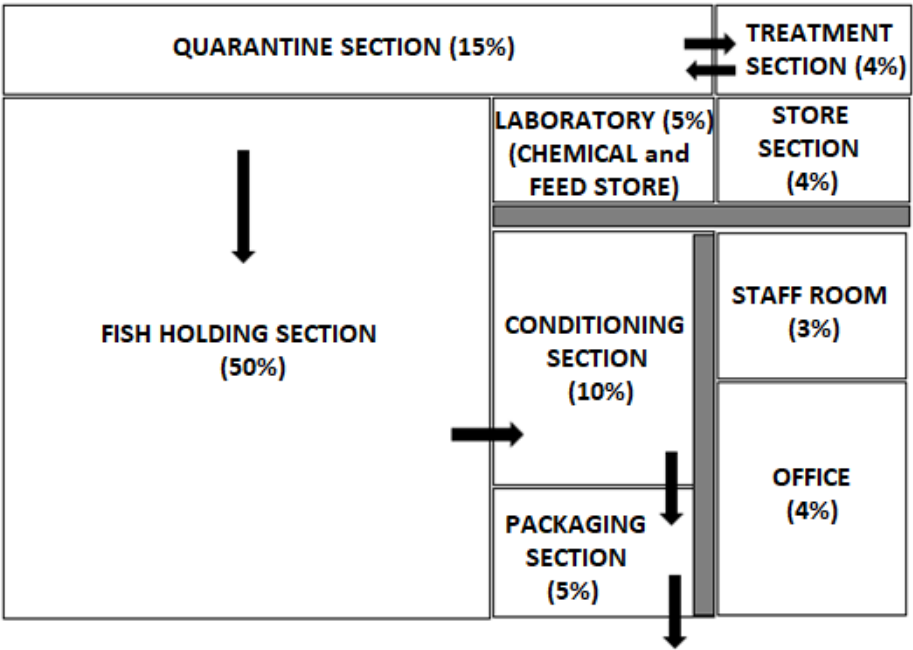


Figure 3. Model Design for Quarantined Ornamental Fish Facility (Silas et al., 2011).

Most diseases in fish are caused by poor management of water quality, lack of quarantine and preventive treatments, poor nutrition and incompatibility between tank mates. The great diversity of ornamental fish species makes it even more difficult. The key to a healthy aquarium includes adequate water quality, proper nutrition and preventive health care (Barrio, 2022). Mechanization and filter systems used in the aquarium, fish species and feeding techniques are among the factors that directly affect stock density (Table 2) and water quality standards (Table 3) (OATA, 2006; Silas et al., 2011).

Table 2. Fish Stock Densities by Fish Length, Weight and Species (OATA, 2006; Silas et al., 2011).

Fish Length	Cold-Water Species	Tropical Freshwater Species	Tropical Marine Species
≤ 5 cm	8 kg/1.000 l	1,5 kg/1.000 l	1 kg/1.000 l
≥ 5 cm		2,5 kg/1.000 l	2 kg/1.000 l

Table 3. Water Quality Parameters on Ornamental Fish Species (Silas et al., 2011)

Water Quality Parameters	Cold-Water Species	Tropical Freshwater Species	Tropical Marine Species
Dissolved Oxygen (mg/l)	min 6	min 6	min 5,5
Ammonia (mg/l)	max 0,02	max 0,02	max 0,01
Nitrite (mg/l)	max 0,2	max 0,2	max 0,125
Nitrate (mg/l)	max 50	max 50	max 40
pH			min 8,1

2.6. Pre-Sale Preparations

Species that may have notifiable diseases should be quarantined, as well as other species that are considered to cause a biosecurity problem for the establishment. For many fish species, there is no need for a full quarantine procedure before sale. However, it is recommended that all fish be rested before sale. This aging process varies depending on the source and the species concerned. Sensitive fish species or individuals with long supply chains may take longer to acclimatize to their new environment, recover from transportation and adjust to new aquarium feeds and light levels. It should be checked in communication with the supplier whether the supplier carries out pre-sale resting. In these cases, a degree of isolation between the resting aquarium/pond and the retail aquarium/pond should be implemented. It is also important to remember that stressed fish are more susceptible to disease. All

necessary precautions should be taken to reduce stress in new stock transfers (OATA, 2023). Aquatic ornamental species captured from natural sources should be handled with the highest biosecurity measures as they carry infectious pathogens. These species should be subjected to a longer quarantine period with stronger antiparasitic drugs and preventive treatments before being transferred to exhibition tanks (Barrio, 2022).

2.7. System/Facility Design

Effective system design should be used to prevent the spread of diseases and invasive species. Adequate quarantine and preparation sections and aquaria should be allocated for sales systems. Different aquariums/ponds should be used for different species from different sources. The requirements of retail systems should be determined by the species dealt with and the biosecurity measures taken. Facility management issues:

Basic Practice

- New stocks should be isolated and acclimatized.
- Work routines should be “clean to dirty.”
- Separate equipment for each aquarium/system and regular disinfection.

Water Management

- In single-use systems, the pathogen is removed by continuous dilution.
- Pathogen load accumulates in recirculated systems (mechanical cycling).
- 10-1000 mJ/cm² UV dose is used depending on organism size.
- Ozone disinfection dose of 0.4 g/m³/hour can be used.

Ventilation

- Especially in humid environments, aerosols can contain small pathogens.
- Change the air in the fish room by 50% and keep floors and surface dry.
- Mold and fungal spores can pose a risk to humans through inhalation.

Biofiltration and Disease Prevention

- Well-designed and installed biofilters reduce pathogen loads.
- Biofilters remove ammonia and nitrite and regulate oxygen content.

Good water quality reduces stress and is crucial in preventing disease outbreaks. The use of natural water resources increases the risk of disease, contaminants or unwanted species. All drainage should be discharged into the sewer after taking the necessary precautions (OATA, 2006; OATA, 2023).

2.8. Monitoring

Monitoring is often overlooked in biosafety management. Risks and preventive measures are not considered only when a facility is being built or when a problem arises. Biosecurity monitoring should be frequent and continuous. Biosecurity risks are volatile and can change during the natural operation of businesses:

- Your supplier may change suppliers
- Your supplier may change personnel and management practices
- It can be classified as a new type of invasive
- One-off events (e.g. delays) can cause disease problems
- Seasonal changes in stocked species (e.g. pool season)
- Increased stocking densities when shipments arrive

Therefore, regular record keeping and monitoring is essential in biosecurity management and allows you to identify and correct long-standing problems (OATA, 2023).

2.9. Responsible Selling

One of the most important roles that biosecurity can play in aquatic businesses is to sell responsibly to end consumers. Proper preparation of fish for sale, not selling incompatible species, educating hobbyists on water quality and stocking levels all help prevent disease outbreaks in home aquariums. This improves fish welfare, limits disease transfers within the hobby and keeps retail customers enthusiastic about keeping fish. Hobbyists should be informed about the following issues with aquatic ornamentals (Pet Code of Practice, 2017):

- How long will it live?
- How big will it grow?
- How much habitat will it need?
- What equipment will be needed?
- How much time will be needed for maintenance?
- How much will it cost?

An important factor to consider is the proper sale of species. Over time, hobbyists may release ornamental specimens that are too large for their aquariums into the wild, posing a risk to local biosecurity. End consumers should be informed about the adult size of large species and their compatibility with other species. It is also important to sell appropriate plant species; as invasive species can easily spread from garden ponds into natural habitats. Therefore, aquarium plants should only be sold for aquariums and should not be placed in ponds or outdoor habitats.

It is imperative that businesses only sell legal species. The best way to ensure this is to order stock using scientific names to prevent any illegal species being sold by accident (OATA, 2023).

3. DISEASE

3.1. Legalities on Fish Health and Biosecurity

At the international level, the World Organisation for Animal Health (OIE) is the main reference body for measures relating to international trade in animals and animal products. OIE members are committed to implementing the standards recommended by the OIE, usually through national legislation and policy. In some parts of the world supranational economic and political communities have developed, such as the European Union (EU), which implement common policies and legal frameworks. The legal instrument providing the biosecurity framework for aquatic animal health for the EU is Council Directive 2006/88/EC (on animal health requirements for aquaculture animals and products and on the prevention and control of certain diseases in aquatic animals). At national level, the role of the competent authority is to define means to prevent the introduction of exotic diseases and limit the impact of endemic diseases, to carry out import risk assessments, to follow international developments, and to play an important role in formulating and informing biosecurity strategies. It also supports the development of biosecurity plans at farm level (Oidtman et al., 2013).

There are very few international standards or guidelines for the establishment and operation of quarantine facilities for aquatic animals. The use of quarantine is one of the essential conditions for preventing the international spread of important pathogens listed in the OIE's Health Code for Aquatic Animals (OIE, 2023) and the Manual of Diagnostic Tests for Aquatic Animals (OIE, 2024). However, there is no detailed guidance on the minimum

standards that should be applied for the construction and/or operation of quarantine facilities. The International Council for the Exploration of the Sea (ICES), 'ICES Code of Practice on the Introduction and Transfer of Marine Organisms' (ICES, 2005) is a protocol for the introduction or transfer of living marine organisms, which recommends that consideration be given to the potential ecological, pathogen and genetic risks of the species being moved to the receiving country. The ICES Code provides a general protocol for long-term quarantine practices. Annex C of the ICES Code provides brief general guidelines on the management of quarantine facilities for aquatic animals intended for introduction or transfer (FAO, 2008).

The EU Invasive Alien Species Regulation is the core legislation for IAS (Invasive Alien Species) management in Europe, and its importance is highlighted in the EU Biodiversity Strategy for 2030. In this report, there have been identified and proposed several measures for improvement of the biosecurity and quarantine mechanisms related to EU and international practices on ornamental fish industry (Kleitou et al., 2021).

3.1.1. Animal Welfare Act 2006

The Animal Welfare Act 2006 states that all pet owners/aquarium hobbyists have a legal duty of care towards their pets and must fulfil the five animal welfare needs listed below:

- A suitable environment - an appropriately sized and equipped tank.
- A suitable diet that meets the needs of the fish.
- Behaviour - enough area for the fish to display their normal behaviour.
- Companionship - the harmonious co-existence of species.
- Health - protection from pain, injury, disease and regular maintenance.

3.1.2. Biosecurity Measures Plan

Most countries in the world, a biosecurity measures plan is a legal requirement of an authorised Importer and exporter, importing ornamental fish. In European Union, operators of aquaculture establishments are required to submit a documented biosecurity plan which will be considered during the approval process. The biosecurity plan must take certain elements into

consideration and apply measures accordingly depending on type of operations as per as per guidance in Article 5 of Regulation EU 2020/691 (Marine Institute Foras na Mara, 2024).

3.1.3. Disposal of Mortalities

European Union Regulation (EC) No 1069/2009 and Commission Regulation (EU) No 142/2011 allow dead fish in sealed plastic bags to be disposed of in the waste bin as an exception to Animal By-Product controls (OATA, 2023). However, in some applications it is recommended to keep dead fish in 10% Formol solution (dead fish volume: solution volume = 1:5) for at least 5 days before disposal (Silas et al., 2011).

3.2. General Information

3.2.1. Fish Immune System

The immune system is the most important factor for controlling diseases in aquatic species. In contrast, stress is one of the main factors that weaken the immune system. Low stress levels or a stress-free environment allows fish immune systems to function effectively and reduces the likelihood of disease, even if they are exposed to a pathogen. An important issue to consider is the acclimatization of the fish. Shipped fish are often under stress and may be exposed to pathogens they have not encountered before in their new environment. Therefore, it is very important to follow proper acclimatization procedures when transferring fish to new environments (OATA, 2023). Stress can come from many sources but the most common are:

- Incorrect or rapidly changing water chemistry
- Less than ideal temperature
- Aggression from tank mates
- Isolation (if a social species)
- High stock intensity
- Intense lighting
- Lack of shelter
- Malnutrition
- Poor handling

3.2.2. How Disease Spreads

Pathogens are disease-causing micro-organisms. They are very diverse and can spread between fish populations in different ways. Direct contact between fish in nature is rare, except during breeding and territorial disputes. In contrast, intensive stocking in aquarium conditions or live transport bags and the capture of fish in nets increases direct contact and can be an important route of disease transmission (OATA, 2006). The most common methods are skin-to-skin contact between fish, parasite infection, infection of open wounds, gill entry or ingestion. To reduce the likelihood of outbreaks in fish, it is important to reduce the ability of the disease to spread. For example, overstocking leads to increased fish contact, suspended solids clog gill filaments and poor quality live feeds may contain pathogens. Another factor affecting the likelihood of disease spread is the pathogen population. The more infected fish or the more advanced the infection, the greater the number of pathogens. The most obvious way to reduce pathogen levels is to remove and isolate fish showing signs of disease and eliminate mortalities. Early detection and removal of sick fish is important. Pathogen levels in a population can also be reduced directly (through water changes, use of ultraviolet or ozone, disinfection procedures and medications) and indirectly (good water quality, immediate removal of physical waste and diseased or dead individuals, as well as limiting the use of poor quality live feed) (OATA, 2023).

Keeping fish to the highest possible standards will allow their immune system to function effectively and will limit the spread and population of pathogens.

3.3. Good Practice

3.3.1. Health Checks

Daily health checks ensure that any signs of illness or disease are caught early, which reduces transmission and increases the effectiveness of any treatment required. A health checklist for assessing the health of aquatic animals is presented below (OATA, 2023):

- They swim normally
- They are alert and react to stimulus
- They occupy the right area of the aquarium/pond
- They are displayed in the correct colours
- Not more aggressive or submissive than usual

- They breathe at a steady, easy rate
- No changes in appearance (wheals, white spots, etc.)
- Have clear eyes
- No missing scales or injury
- In good condition (not too fat or thin)
- They have a good appetite for food

3.3.2. Water Quality

Good water quality helps prevent disease outbreaks, even when pathogens are present, and most disease outbreaks are due to the stress of poor water quality.

Contrary to what many people think, water quality is not just about ammonia or nitrite parameters. For example, temperatures that are too low or too high inhibit the functioning of the immune system. The wrong pH or hardness can cause long-term stress. Stability of water chemistry is also important, rapidly changing parameters (even in the right direction) can cause stress, which can trigger disease outbreaks. This should be especially taken into account when unpacking newly transferred fish. An increase in oxygen can rapidly raise the pH and increase the toxicity of ammonia. Using the wrong salinity or hardness will cause undue stress and can make individuals more susceptible to disease (OATA, 2023).

3.3.3. Ultraviolet Sterilisers and Ozone

Ultraviolet sterilizers and ozone units are used to disinfect water. An ultraviolet sterilizer uses ultraviolet light to kill pathogens, while ozone units create an unstable form of oxygen that will oxidize organisms. Excessive sterilization should not be used as it can reduce immune system functionality. Use and application should be balanced. Ultraviolet sterilizers are much more common than ozone because they are much safer, although they require more maintenance and higher operating costs (Table 4). UV water treatment units should operate in the 190-280 nm (254 nm recommended) spectral range and have a minimum dose rate of 130 mWs/cm². The operation time of the UV lamp should be monitored and replaced at the end of its useful life. It should be noted that the use of ozone can cause serious harm to aquatic life and to humans if it escapes from the water (FAO, 2008; OATA, 2023).

Table 4. Comparison of Ultraviolet Sterilizers and Ozone (OATA, 2023).

Ultraviolet sterilisers		Ozone	
Pros	Cons	Pros	Cons
Relatively low risk	High running cost	Very effective at killing pathogens	VERY dangerous if leaked
Will kill most pathogens	May limit water flow	Improves water clarity significantly	Careful monitoring required
Easy to install	Might need multiple units	Very low power	May kill all livestock if overdosed
Not harmful (unless light escapes)	Regular maintenance		Requires reaction chamber
	Produce heat		Excess needs to be removed
	Reduced efficacy in turbid water		

3.3.4. Disinfection

Disinfection of nets and surfaces (including the inside of aquariums and ponds) prevents the spread of pathogens between aquariums or ponds. This prevents newly transferred livestock from becoming infected. Disinfection should be carried out after physical cleaning and rinsed thoroughly afterwards. Disinfection of nets in direct contact with the skin of the fish is extremely important. The selected disinfectant should be chosen according to the contact time. For example, a disinfectant with a short contact time should be selected because nets are used frequently, while disinfectants used on aquarium or pool walls may have a longer contact time. Disinfectants that leave no residue behind after disinfection should be selected. Some aquatic pathogens have difficulty surviving when dried. Therefore, drying is an effective measure for both aquariums/ponds and nets and should be practiced periodically (OATA, 2023).

Some disinfectants and their respective concentrations for some fish diseases are presented in Table 5. (QSIA, 2018).

Table 5. Some Disinfectants and Their Respective Concentrations for Some Fish Diseases (QSIA, 2018).

Fish Diseases	Draying out	Heat	UV mj/cm ²	Ozone mg/L/min	Chlorine mg/L	Iodine (mg/L)	Formalin	Bezalkonium Chloride mg/L	Virkon S
Channel Catfish Virus	>2 d	>60°C 1 hr	>0.2		540/30min	250/30min			
Grouper Iridoviral Disease	>200 d				200/2 hr		200mg/L 2h		1%/1min
IPN	✓	>80°C 10min	>250	0.5	50/30min	10/2.5min	2%/5min		1%/10min
ISKNV-like viruses	✓	>50°C 30min	5		200/30min				
Red Sea Bream Iridovirus	✓	>56°C 30min	5		200/30min				
VER	>7 d	>60°C 30min	>200	0.5	100/5min	100/30min	0.2%/6hr	50/10min	
VHS	>10 d	>50°C 10min	>10		50/1min	100/10min		125/5min	0.1%/15min
<i>Aeromonas salmonicida</i>	✓	>50°C 2min	>6	0.5	2/1min	2.675min		300/2min	0.5%/10min
Bacterial Kidney Disease	✓	>65°C 15min	>20		10/1min	25/5min			1%/10min
Enteric Septicaemia of Catfish	✓	>60°C 1 hr	>5		50/1min	50/1min			
ERM – Hagerman Strain	✓	>75°C 1min	>5	0.7	250/2 hr	25/15sec			1%/10min
EUS	✓		>210		100/5min	100/5min			
Furunculosis	✓	>60°C 1 hr	>6	0.5	2/1min	2/1min		300/2min	0.5%/10min

3.3.5. Personal Hygiene

Personal hygiene is important to reduce the risk of disease transfer in the aquatic ornamental industry. Hands and arms should be clean, disinfected and allowed to dry before contact with another aquarium or pond. Alcohol is the best method for this as it dries quickly, kills most pathogens and is easily available. For contact with animals showing signs of illness, it is best to use disposable gloves and then disinfect hands and arms. In some facilities foot baths are a useful addition to prevent pathogens being picked up on footwear, but these are not practical for a retail environment. Good personal hygiene (especially hands) (Table 6) also helps prevent the potential spread of zoonotic diseases (OATA, 2023).

Table 6. Hand Hygiene Methods and Their Bacterial Effects (OATA, 2006).

Method	Bacterial Effects	Result
Washing hands with soap and hot water (~60 °C)	Reduces bacteria on the skin by 30-50%	Soap breaks down bacterial cell walls, hot water kills some bacteria
Use of bactericidal soap (containing triclosan or tricloban)	Can reduce the number of bacteria by 60-90%	
Washing hands with 40-60% alcohol after washing with soap	Can reduce the number of bacteria by 99.5%	
Addition of iodine or chlorhexadine gluconate	99,99%	

3.3.6. Isolating Stock

Cold-water fish are risky fish for KHV or SVC diseases. It is therefore important not to mix cold-water fish from different suppliers. Planning which species are in contact with each other according to their origin reduces the possibility of outbreaks and makes it easier to trace the source of a disease. New deliveries of fish should be kept separate from existing stocks. Fish showing signs of disease should be isolated in a closed system. Separate equipment should be used in isolation aquariums (OATA, 2023).

3.3.7. Antibiotics Use

Antibiotic resistance is when a pathogen develops resistance to drugs. This is usually caused by overuse or misuse of antibiotics. If antibiotics are used too often or treatment is not completed, some pathogens survive. These multiply and form a strain that is resistant to the drugs and the disease becomes much more difficult to treat. Bacteria can transmit this resistance through contact with new populations, and resistance can spread even if a population has not been directly exposed to the drugs. Furthermore, overuse or prophylactic use of antibiotics can cause fish to mount weak immune responses when exposed to pathogens. The cure should be completed even if symptoms

begin to improve. Antibiotics should not be used prophylactically, especially during transportation (FAO, 2008; OATA, 2023).

3.3.8. Mortalities

Despite aquarists' efforts to keep fish alive, in some cases they may have to euthanize them to prevent suffering. A good way to do this is to administer an overdose of anaesthesia and to induce brain death after the anaesthesia has taken effect. A few drugs that can be used in this procedure are presented in Table 7. (OATA, 2023).

Table 7. Some Drugs Used in Euthanasia in Fish (OATA, 2023).

Drugs	Euthanasia Dose	Implementation
Tricaine methane sulphonate, MS222	1 gram/litre	pH buffering agent should be added
Benzocaine	10 ml stock solution/litre	100 g beznzocaine/aceteno or ethanol (stock solution)
2-Phenoxyethanol	2.5 ml/litre	must be whisked vigorously to improve its solubility
Clove oil	10 drops/litre	must be whisked vigorously to improve its solubility

3.4. Specific Diseases

3.4.1. Identifying Diseases

For all diseases, early and accurate diagnosis is crucial for both good biosecurity and successful treatment. Daily health checks should be carried out and staff should have a good knowledge of the species in stock. There are many different diseases in aquatic animals and it is very difficult to know all of them. However, it is useful to know some basic indicators that should be used to identify potential disease (FAO, 2008; OATA, 2023).

3.4.2. Changes in Behaviour

Abnormal and non-species-specific swimming behaviour in fish can be potential signs of infection. Hitting/rubbing against objects in the aquarium is a characteristic sign of irritation and may indicate infection or problems caused by poor water criteria. Furthermore, fish subjected to aggression are stressed and more likely to contract diseases. The stocking rate should be considered according to the species, age, size and sex ratio of the fish (OATA, 2023).

3.4.3. Changes in Appearance

Changes in appearance may indicate stress or disease in the fish. Some fish become dull recluse when stressed, but this should not be confused with differences between sexes or fry colouration. White spots, raised growths, open sores or protruding eyes ('pop eyes') are the most obvious signs of disease and can be used to diagnose a specific problem. It can also be a sign of disease if the fish look particularly weak or suddenly become very large (OATA, 2023).

3.4.4. Respiratory Changes

In fish, the volume of water passing through the gills is an important determinant of O₂ consumption and thus aerobic metabolic rate. Aeration adjustments are made according to metabolic needs and the associated O₂ consumption. Therefore, changes in gill movement are an important indicator of fish health. Stress, gill parasites and water quality problems can cause rapid respiration in fish. Respiration rate slows down in weak and developmentally impaired fish. Fish suspended near the water surface are a sign of a lack of oxygen in the water or a reduced ability of the fish to take oxygen from the water (usually associated with disease). Under normal conditions fish breathe regularly and 'deeply', there may be small increases in respiratory rate after activity (OATA, 2023; Perry et al., 2023).

3.4.5. Changes in Appetite

Feed is one of the most important external signals that stimulate feeding behaviour and growth in fish. Under normal conditions, a healthy fish will eat when offered food. A reduced appetite is often associated with stress or illness. However, it is normal for appetite to decrease gradually with feed intake. Fish with normal feed intake but weight loss may be suffering from an internal parasite or other pathogen. However, feeding habits are species-specific. When

fish are given the wrong size or type of feed, they may not eat. Fish get used to a new type/brand of feed over time. Before considering a problem with feed intake as a sign of disease, it is necessary to make sure that the correct diet is being followed (Assan et al., 2021; OATA, 2023).

3.4.6. Changes in the Stock Population

It is important to monitor the behaviour of all livestock in the system. Effective monitoring of individual fish can prevent the transmission of disease to all fish and prevent the pathogen load from increasing. However, it is more likely to be a population-wide sign of disease or stress if more than one individual shows the same symptoms. If fish of different species exhibit the same behaviour or appearance changes in different aquariums/ponds, this is a clear sign of a problem and requires immediate action. There are two very important diseases in the aquaculture trade. These are Koi Herpes Virus (KHV) and Spring Viremia of Carp (SVC) (OATA, 2023).

3.4.7. Koi Herpes Virus and Spring Viraemia of Carp

Koi Herpes Virus (KHV) and Spring Viremia of Carp (SVC) can cause massive mortality in carp (*Cyprinus carpio*). There is currently no cure for KHV and SVC and they are notifiable diseases as they can affect native species (Table 8). According to Council Directive 2006/88/EC, there is an obligation to declare a Veterinary Health Certificate for Ornamental Aquatic Animals declaring that aquarium fish imports come from the country, region, area or section of the relevant OIE standard free from KHV (Koi herpes virus) and SVC (Spring Viremia of Carp) diseases. Reporting of an outbreak or suspected outbreak is mandatory and there are penalties for non-reporting. If diseases are detected, a number of action plans are implemented, including temporary closure. Recovery from KHV disease can be misleading and fish that survive the initial outbreak may carry the latent virus. These fish should be considered carriers. There is currently no test to diagnose KHV latency and all surviving carp should be suspected of carrying KHV. SVC disease usually occurs with the change of season from winter to spring, but can also occur from summer to autumn. The change in temperature combined with winter stress can cause outbreaks, especially in young fish. The best way to protect facilities from KHV from SVC is to use high quality suppliers, have an effective quarantine procedure (at least two weeks), maintain good water quality and continuously

disinfect equipment, containers and surfaces after handling or transporting fish (OATA, 2023; Council Directive 2006/88/EC, 2024).

Table 8. Symptoms of KHV and SVC Diseases (OATA, 2023)

Koi Herpes Virus (KHV)	Spring Viraemia of Carp (SVC)
Can diagnosed with PCR or ELIZA	Cell culture with confirmatory tests, PCR
Mortalities only in carp and varieties	Mortalities only in carp and varieties
Damaged (pale/dead) or bleeding gills	Pale gills
Mortalities occur: 18-27 °C	Mortalities occur: 7-17 °C
Mortalities can be rapid (24-28 hours)	Abdominal swelling
Hanging in the water	Loss of balance
Sunken eyes	Swollen eyes
Nervous system (erratic behaviour)	Lethargy/ Hyperactivity
Pale patches on skin from reduced mucus	Darkening of skin
Fish feel rough if handled	Trailing faecal casts, protrusion of the vent
Secondary infections from other pathogens	Bleeding into skin, gills or internal organs
Effect large proportion of the population	Effect large proportion of the population
Quarantine at 23-28 °C / 14 days	Quarantine for at least 2 weeks

3.4.8. Zoonosis

Zoonosis is the spread of disease between animals and humans. Aquatic species are biologically very different from us and their diseases have not evolved to infect humans. Good hygiene practices help prevent the spread of such diseases to humans. Some zoonotic diseases and non-zoonotic diseases and toxins can effect humans (Table 9). People become infected by handling diseased fish or contaminated equipment, or through aquarium/pool water (especially mouth siphoning) with diseased fish (Figure 4). (Harper and Erickson, 2016; Ziarati et al., 2022; OATA, 2023).

Table 9. Zoonotic and Non-Zoonotic Diseases and Toxins (OATA, 2023)

	Fish Tuberculosis/ <i>Mycobacterium</i>	<i>Vibrio</i>	<i>Aeromonas</i>	Non-zoonotic diseases
Fish symptoms	weight loss, discolouration, lethargy, ulcers, abdominal swelling,	ulcers, lethargy, skin inflammation	ulcers, lethargy, skin inflammation	Salmonella, Weil’s disease (Leptospirosis), Cryptosporidium,
Human symptoms	non-healing ulcers on the hands or arms	vomiting, diarrhoea, inflammation, open wounds	vomiting, diarrhoea, inflammation, open wounds	Legionella, Palytoxin, Blue green algae
Treatment	antibiotic	antibiotic	antibiotic	

	
<i>Mycobacterium marinum</i>	<i>Mycobacterium marinum</i>
	
<i>Vibrio vulnificus</i>	<i>Vibrio vulnificus</i>

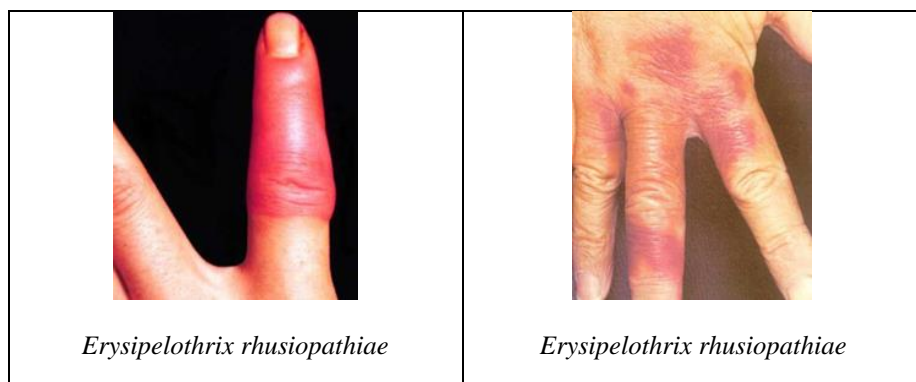


Figure 4. Some Zoonotic Fish Diseases (Harper and Erickson, 2016).

If a zoonotic or associated disease is detected in a system, the aquariums/pools concerned should be marked and staff should be informed and warned. Personal hygiene must be observed at all times to protect against zoonosis and other diseases related to the aquatic environment. Staff should:

- Avoid contact with water in areas with open wounds
- Do not flush using your mouth
- Wear gloves when preparing bait or handling carcasses
- Wash your hands before eating, drinking or smoking
- Wash hands between systems
- Dispose of waste properly
- Sterilise surfaces and equipment regularly
- Have a separate washbasin for human use
- Use specialised equipment for individual systems

4. INVASIVE NON-NATIVE SPECIES

4.1. Introduction to Invasive Non-Native Species

If a species is endemic, it is classified as native. If a species overcomes a barrier by human activities or enters a new habitat, then it is an alien or non-native species, not all alien species are perceived negatively or pose a threat to natural biodiversity (Carlton, 1996). When these alien/non-native species have a negative impact on biodiversity, ecosystem services, human health or economic impact, they are referred to as Invasive Non-native Species (INNS) (Figure 5). However, the definition of INNS adopted here recognizes that the species is introduced through human intervention, whether intentional or

unintentional (Regulation (EU) No 1143/2014). Therefore, species that are introduced and established in new habitats through the aquatic ornamental industry are considered invasive non-native species when they have biodiversity, ecosystem services, human health or economic impacts.

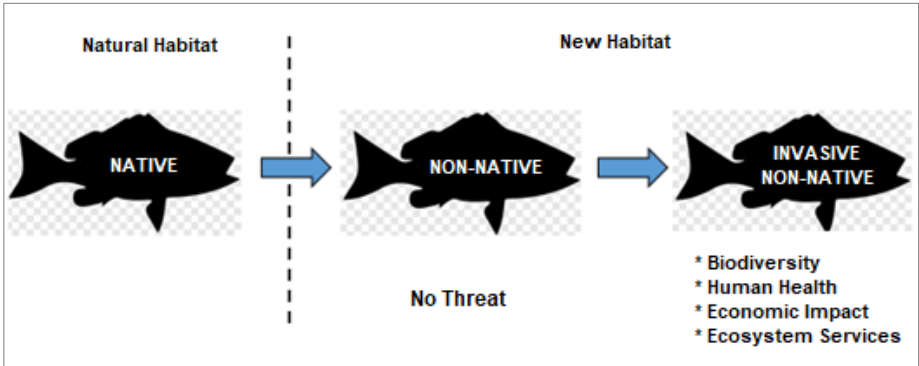


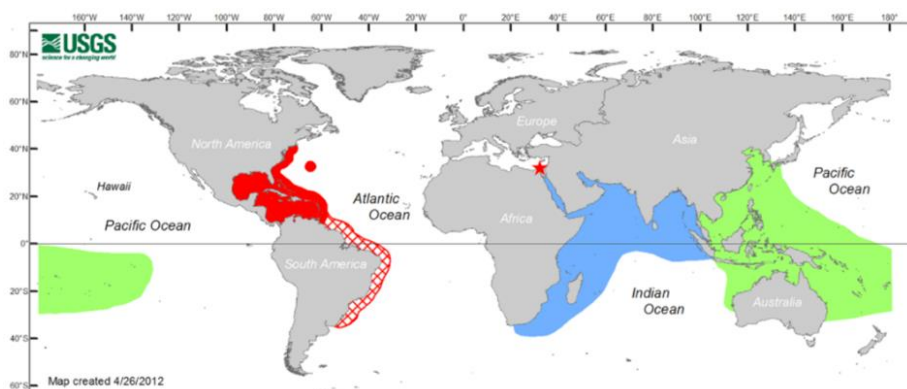
Figure 5. Native, Non-Native and Invasive Non-Native Species (Türkmen, 2023)

Invasive non-native species can cause many changes in the ecosystem and the effects can be dramatic (Table 10).

Table 10. What INNS Can Do and What the Effects Can Be? (OATA, 2023)

What INNS can do?	These effects can lead to
Alter habitats/make them unsuitable for native species	Damage to infrastructure
Predate on native species	Changing of food webs
Spread disease to native species	Physical damage to habitats
Outcompete native species for resources	Extinction of native species

The lionfish is native to the Indo-Pacific. However, it has become increasingly widespread along the Atlantic coast of the Americas (due to deliberate releases from aquariums) and in the Mediterranean (through movement along the Suez Canal) (Figure 6). Lionfish pose a threat to human health due to their poisonous spines, which can cause serious injury and potential anaphylactic shock in humans (Fleming et al. 2023; Bray et al., 2024).



Green colour: *Pterois volitans*, Blue colour: *Pterois miles* natural habitat, Red colour: Invaded areas

Figure 6. Lionfish (*Pterois volitans* / *Pterois miles*) Invasion (Masna, 2017).

For countries with relatively colder climates, tropical species are difficult to escape and survive if released into the wild. However, pond plants and fish species pose a higher risk as they can live year-round. Either way, plants and animals for aquariums and ponds should be prevented from escaping into the wild and should never be deliberately released. Increasing awareness on this issue is extremely important (OATA, 2023).

4.2. Legislation

Trade in aquatic ornamental species is a difficult biosecurity risk pathway to manage due to large-scale international trade, wide species diversity, large and dispersed end-user populations and motivation for environmental release. Policy mechanisms to reduce the number of entries through this pathway have long been advocated and implemented to varying degrees in different countries around the world. Regulatory frameworks include banned species lists ('black lists'), controls on the import of species using permitted species lists ('white lists'), and release bans on imported species (Atalah et al., 2022).

The EU Invasive Alien Species Directive on Invasive Alien Species (IAS) is the key legislation for IAS management (Regulation (EU) No 1143/2014). The European Invasive Alien Species Strategy aims to “Prevent fish escapes in public aquariums and raise awareness among dealers, retailers and the public, and develop standards and procedures on good practices” in order to minimize the introduction of IAS into countries. For this purpose, it

has been adopted to cooperate and collaborate with OFI (Ornamental Fish International) and OATA (Ornamental Aquatic Trade Association) organizations (European Strategy on Invasive Alien Species, 2004).

4.3. Guidelines and Good Practise

Guidelines on international legislation and codes of conduct for biosecurity and quarantine mechanisms in the aquarium fish sector are available (Table 11). Guidelines are incentive, voluntary, and not a legally obligatory instrument. The most important guideline or rule for everyone involved in the ornamental waters industry:

“Do not release, or allow escaping, any live animals or plants from the ornamental trade into the wild.”

This is a message that should be spread by business owners to educate consumers and raise awareness (OATA, 2023).

Table 11. Guidelines for the Aquatic Ornamental Industry (Türkmen, 2023).

International	Aquatic Animal Health Code (OIE)
International	CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora)
International	Pets, Aquarium, and Terrarium Species: Best Practices for Addressing Risks to Biodiversity (CBD)
European Union	European Code Of Conduct on Pets and Invasive Alien Species
European Union	European Code of Conduct on Zoological Gardens and Aquaria and Invasive Alien Species
European Union	Guidance Document nn E-Commerce and IAS
European Union	Code of Conduct on Horticulture and Invasive Alien Plants
Australia	Controls to manage biosecurity risks in the importation of freshwater and marine ornamental fish
Australia	Aquarium and Pond Keeper’s Code of Conduct
Canada	National Code on Introductions and Transfers of Aquatic Organisms
England	Guidance Importing or moving fish to the UK

England	Biosecurity and The Ornamental Aquatics Industry (OATA)
England	Pet Code of Practice (OATA)
England	Code of Conduct (OATA)
Ireland	Code of Practice for Sellers and Suppliers of Pet Animals
Israel	Risk Management in Import of New Species
New Zealand	Import Health Standard Ornamental Fish and Marine Invertebrates

4.3.1. Responsible Selling

In the aquarium hobby, aquarists often tend to release species that they cannot keep in the long term, especially fast-growing animals or fast-spreading plants. This increases the likelihood of invasive species spreading. Retailers should therefore consider this when selecting the species, they stock and choose species that can be kept in the long term (Pet Code of Practice, 2017; OATA, 2023; Türkmen, 2023).

4.3.2. Controlling Shipments

Some invasive species resemble species that are legal to import. Invasive species can therefore be mistaken for legal species and included in shipments. Careful checking of shipments can significantly prevent the potential introduction of invasive species (OATA, 2023). It is also useful to have identification guides for legal species that resemble invasive species.

4.3.3. Conscious and Trustworthy Supplier(s)

It is important that the suppliers conscious and trustworthy and provide healthy and correctly identified stock. Incorrectly identified species may contain invasive species. Suppliers should be warned if invasive species are detected in orders. If similar situations continue, the supplier should be warned or changed (OATA, 2023).

4.3.4. System/Facility Design

A properly designed system significantly prevents the possibility of an invasive species spreading in the system/facility. All system water outlets

should be discharged into the sewerage system. Ponds should be located away from any natural masses and outside flood plains (FAO, 2008; OATA, 2023).

4.3.5. Monitoring

The accuracy, reliability and quality of supplier shipments should be continuously monitored. It is also important to monitor invasive species legislation as new species may be added to the invasive species category. Orders should be placed according to legal species lists, if available. It should be known who to contact in case of notifiable disease issues or any problems with invasive aquatic animal species OATA (The Ornamental Aquatic Trade Association) aims to keep its members up to date. Information on invasive species can be found here from the UK example: (OATA, 2023)

Animals:

- Invasive non-native (alien) animal species: rules in England and Wales – GOV.UK (www.gov.uk)
- ID sheets » NNSS (nonnativespecies.org)

Plants:

- Invasive non-native (alien) plant species: rules in England and Wales – GOV.UK (www.gov.uk)
- Invasive non-native plants | NatureScot

5. CONCLUSION

In recent years, international shipping volumes, demand for aquaculture products, growth in the global aquarium trade and the spread of invasive alien species around the world have continued to steadily increase. As a result, it is becoming increasingly difficult and important to understand the scale and magnitude of biosecurity risks in aquatic environments. These threats are particularly important and urgent in an ecosystem facing climate and biodiversity crises. Also in a dynamic sector where online trade is thriving, it is important to periodically assess import trends and keep abreast of risks related to changing environmental conditions, infestation histories and potentials, and animal health and disease issues. Aquarium releases are a problem in waterways globally and the after-effects are extremely costly. Raising awareness of the responsibilities of the public and industry is essential to prevent unintended impacts in waterways and to support the biosecurity implications of regulations for the import of aquatic ornamental species.

Therefore, awareness should be raised and educational materials on the proper care and disposal of aquatic ornamental species should be provided at points of sale, including websites (Trujillo-González et al., 2018; Atalah et al., 2022; (Bray et al., 2024).

Inadequate or poorly regulated international trade rules for ornamental fish pose risks to both biodiversity and economic activities through invasive alien species and exotic pathogens. Border security authorities have difficulties in correctly identifying species. They need robust tools for species verification, which requires hard-to-obtain taxonomic literature and expertise. (Collins, 2012). Today, global and national biosecurity systems are poorly prepared to tackle the challenges due to miscommunicated research and policy environments that often ignore risks across sectors or stakeholder needs and fail to recognise the processes involved in biological invasions. (Bray et al., 2024)

Biosecurity is an interdisciplinary issue. In aquatic environments, alien species have various negative impacts on human, animal, plant, marine and ecosystem health (Figure 7) (Bray et al., 2024). In its recent Thematic Assessment Report on Invasive Alien Species and Control, the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services adopted the Single Biosafety single biosafety approach. In this approach, collaborative linkages between the human, animal, plant and ecosystem health sectors are envisioned to provide frameworks for the prevention and control of invasive alien species, strengthened through multi-sectoral approaches. The Single Biosecurity approach is essential to manage sectoral risks arising from the rapidly growing and often poorly regulated aquatic ornamental industry (Roy et al. 2023; Bray et al. 2024).

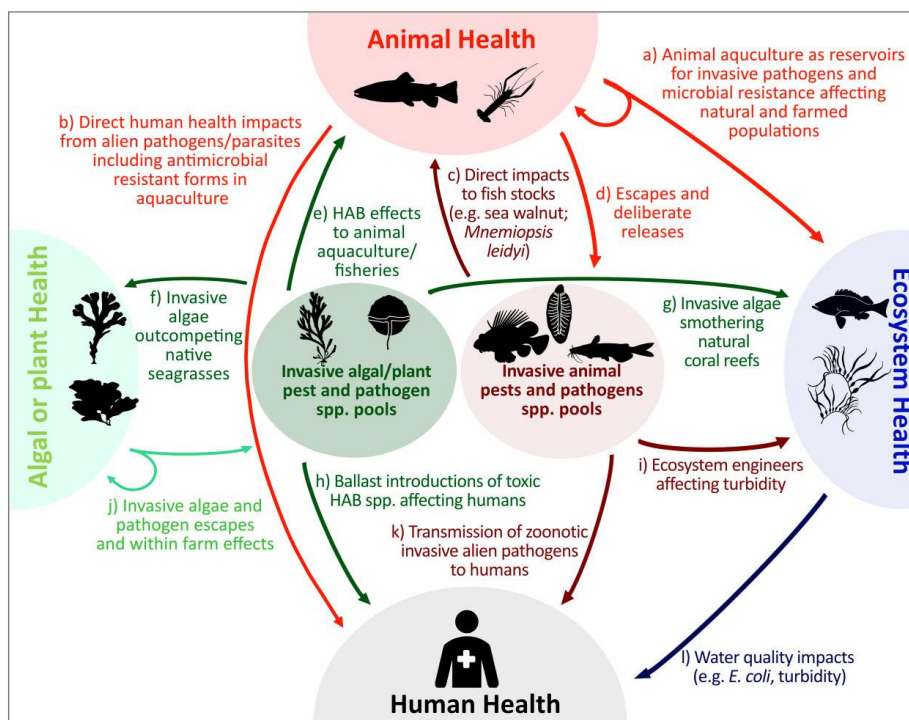


Figure 7. One Biosecurity Approach for the Management of Human, Animal, Plant and Ecosystem Health Against Biological Invasions (Bray et al., 2024).

There are numerous links between the human, animal, plant and ecosystem health sectors in aquatic environments. Ensuring appropriate biosecurity risk management requires a holistic approach that encompasses all four sectors. Currently, the risks posed by aquatic invasions to human, animal, plant and ecosystem health are addressed in a fragmented and sectionalized manner. This leads to a search for solutions through different international and national legal instruments specific to individual problems. Current legal and regulatory approaches are therefore inadequate to manage invasions (Lee et al. 2008; Bray et al., 2024).

The borders of countries are defined according to international rules. The borders of countries show different characteristics according to their geographical location and characteristics. Some countries are completely surrounded by land borders, while others are bordered by rivers, lakes and seas. These borders, which exist and are accepted geopolitically, interact with rivers, lakes and marine ecosystems by providing transition to each other. For

example, a fish deliberately released from an aquarium into a river in one country may pose a threat not only to that country but also to many other countries in the same river ecosystem. Therefore, one biosecurity approach and legal regulations need to be addressed worldwide.

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CHAPTER 10

THE POWER OF TECHNOLOGY IN SMART AQUACULTURE

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INTRODUCTION

The aquaculture industry, long regarded as the cornerstone of global food security, is undergoing a profound transformation. As the demand for sustainable and efficient food production intensifies, the integration of cutting-edge technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), machine learning, and computer vision into aquaculture practices is not just a trend—it's a revolution. This technological convergence has birthed the concept of "smart aquaculture," where traditional farming methods are augmented by real-time data analysis, predictive algorithms, and automated systems. These advances enable farmers to monitor water quality, optimize feeding regimes, and even predict disease outbreaks with unprecedented precision. The result is a more resilient, efficient, and sustainable aquaculture system that can meet the growing global demand for seafood. This chapter examines the transformative power of these technologies and explores how they are reshaping the aquaculture landscape. From the deployment of AI-driven decision support systems to the implementation of IoT-enabled sensors, the shift toward smart aquaculture represents a significant leap forward in the pursuit of sustainable food production. As we stand on the cusp of a new aquaculture era, understanding the potential and implications of these innovations. This chapter aims to provide a comprehensive overview of the current state of smart aquaculture, identify the technologies driving this transformation, and identify future possibilities.

Artificial intelligence (AI) is transforming the aquaculture industry by enabling the development of smart aquaculture systems that use technologies such as the Internet of Things (IoT), machine learning, and computer vision (Vo et al., 2021). These technologies are being applied across various aspects of aquaculture, from predicting water quality in biofloc aquaculture (Rashid et al. (2021) to monitoring fish, detecting diseases, and managing environmental conditions (Dhinakaran, 2023; Islam, 2024). Automation technologies, like the SMART ARTIFICIAL FISH FARMING AND MAINTENANCE SAFF-M, are optimizing tasks such as feeding and waste management, reducing labor requirements, and ensuring ideal conditions for fish welfare (Preethap, and Rathinavel, 2024). The integration of AI and IoT in aquaculture is driving the development of intelligent fish farms that leverage edge computing, 5G, and AI algorithms to enhance operations and tackle the challenges present in traditional

aquaculture practices (Wang et al., 2021). For example, precision aquaculture utilizes multi-mode sensors to gather data on fish and environmental conditions, enabling the training of data-driven prediction models to improve understanding of aquaculture environments and fish farm conditions (Lan et al., 2022). In addition, deep learning methods aid in fish species identification, behavior trajectory analysis, and anomaly detection in underwater fish farming (Vásquez-Quispesivana et al., 2022; Xu et al., 2020; Wang et al., 2020). AI is also employed for fish classification based on DNA barcoding, with deep learning models proving effective in classifying fish species (Lu et al., 2021). Furthermore, AI techniques for fish disease detection and control are considered cutting-edge technologies that offer promise for early pathogen detection and disease outbreak management at the farm level (Islam, 2024). These advancements in AI applications in aquaculture are paving the way for enhanced productivity, sustainability, and profitability.

1. INTRODUCTION TO SMART AQUACULTURE

- Overview of Traditional Aquaculture Practices
- Need for Technological Advancements

1.1. Overview of Traditional Aquaculture Practices

Aquaculture, the cultivation of aquatic organisms such as fish, shellfish, and plants in controlled environments, has a rich history spanning thousands of years. Traditional aquaculture practices, deeply rooted in the agricultural traditions of various cultures, have been vital to supplementing wild fisheries and ensuring a steady supply of aquatic products. These practices range from simple pond-based systems to more complex forms like rice-fish farming, each adapted to the local environmental conditions and species being cultivated.

One of the most common traditional aquaculture methods is pond culture, in which fish are reared in artificial or natural ponds. This method is particularly popular in Asia, where small-scale farmers have long relied on it for both subsistence and commercial purposes. Pond culture typically involves the stocking of fingerlings, regular feeding, and periodic harvesting. Ponds are often fertilized with organic or inorganic materials to stimulate the growth of plankton, which serve as a natural food source for fish. The simplicity and low cost of pond culture make it an accessible option for smallholder farmers.

Another traditional practice is the use of cages or enclosures in natural water bodies, such as rivers, lakes, and coastal areas. This method allows for the rearing of fish in natural habitats while providing some level of control over the environment. Cage culture is widely used in Southeast Asia and Africa, where it supports the livelihoods of many fishing communities. The cages are typically made of bamboo, wood, or netting and are anchored to the bottom or floating on the water's surface. While this method is more exposed to environmental variables such as water quality and predators, it can be more sustainable by reducing the need for artificial inputs like feed and fertilizers.

Integrated farming systems, such as rice and fish farming, represent another traditional approach. In this system, fish are cultured in flooded rice paddies, providing mutual benefit to both crops. The fish help control pests and weeds, reduce the need for chemical inputs, and use waste products to fertilize the rice. This symbiotic relationship exemplifies the resource-efficient nature of traditional aquaculture practices, which often seek to maximize productivity while minimizing environmental impact.

Despite the diversity of traditional aquaculture practices, they share common challenges, including susceptibility to diseases, dependence on natural environmental conditions, and limited scalability. These limitations have spurred the development of modern technology-driven methods aimed at enhancing productivity, sustainability and resilience in aquaculture. However, traditional practices continue to play a crucial role in global food security, particularly in rural areas where they provide a vital source of nutrition and income.

Traditional aquaculture practices, while historically significant and still widely used, face several problems and bottlenecks in today's rapidly changing world. These challenges stem from various factors, including environmental sustainability, economic efficiency, and the growing demand for seafood. Understanding these issues sheds light on why there is a strong trend toward modern breeding techniques that incorporate advanced technologies.

1.2. Problems and Bottlenecks of Traditional Aquaculture Methods

Environmental Impact: Traditional methods such as pond culture and cage farming often heavily rely on local ecosystems. The overuse of fertilizers, feed, and other inputs can lead to water pollution, eutrophication, and

degradation of the surrounding environment. In addition, the escape of farmed species into the wild can disrupt local biodiversity, leading to problems with invasive species.

Resource Intensity: Traditional aquaculture practices typically require significant amounts of water, land, and feed, making them resource-intensive. In areas where these resources are scarce or are becoming increasingly limited because of climate change, traditional methods may not be sustainable in the long term.

Disease Management: Disease outbreaks are a major concern in traditional aquaculture systems, where the density of farmed species and limited control over water quality can promote the spread of pathogens. This issue is exacerbated by the lack of advanced monitoring and early detection systems, which often lead to substantial losses for farmers.

Labor and sustainability: Traditional aquaculture is labor-intensive and requires continuous manual intervention for feeding, monitoring, and harvesting. This labor requirement can limit operations scalability, particularly in regions facing labor shortages or high labor costs.

Economic Viability: Economic returns from traditional methods can be unpredictable, influenced by factors such as fluctuating market prices, seasonal variations, and susceptibility to environmental changes. This unpredictability can make traditional aquaculture less attractive to investors and farmers who seek stable and profitable ventures.

1.3. Reasons for the Shift toward Modern Aquaculture

Technological Advancements: Modern breeding techniques leverage technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), machine learning, and computer vision technologies to enhance efficiency and productivity. These technologies enable real-time monitoring, automated feeding, and precise control over environmental conditions, leading to higher yields and reduced resource use.

Sustainability: There is growing emphasis on sustainable aquaculture practices that minimize environmental impact. Modern systems are designed to optimize resource use, reduce waste, and mitigate the environmental footprint

of aquaculture. Recirculating aquaculture systems (RAS), for example, allow efficient use of water and recycling of waste products.

Disease Control: The use of advanced monitoring systems and biosecurity measures in modern aquaculture helps to detect and prevent disease outbreaks more effectively. This proactive approach reduces the need for antibiotics and other chemical treatments and promotes healthier stock and safer products for consumers.

Economic Efficiency: Modern methods offer greater economic efficiency through improved productivity, lower operational costs, and enhanced scalability. Automated systems reduce labor costs and human error, whereas data-driven decision-making improves overall farm management.

Meeting Global Demand: The global demand for seafood is increasing because of population growth and changing dietary preferences. Modern aquaculture systems are better equipped to meet this demand by producing more food with fewer resources and by ensuring a steady and reliable supply.

In conclusion, the shift toward modern aquaculture breeding methods is driven by the need to address the limitations of traditional practices. These include environmental concerns, resource inefficiencies, disease management challenges, and economic pressures. By embracing technological innovations, aquaculture can achieve greater sustainability, productivity, and resilience in the face of growing global challenges.

2. THE ROLE OF ARTIFICIAL INTELLIGENCE IN AQUACULTURE

- AI-Driven Predictive Analytics
- Decision Support Systems
- Case Studies: AI Applications in Aquaculture

2.1. AI-Driven Predictive Analytics

AI-driven predictive analytics are increasingly transforming various industries, including aquaculture. By utilizing artificial intelligence (AI) algorithms, predictive analytics can assist aquaculture professionals in anticipating and addressing challenges, optimizing operations, and improving decision-making processes. In the realm of aquaculture, AI-driven predictive

analytics employs advanced algorithms to analyze extensive datasets, recognize patterns, trends, and correlations, and predict outcomes related to fish health, environmental conditions, production efficiency, and resource management (Choudhary 2024; Addy, 2024). The integration of AI-driven predictive analytics into aquaculture offers numerous advantages. For example, through the analysis of historical data and real-time information, AI algorithms can forecast potential issues such as disease outbreaks, water quality variations, and feed requirements, empowering farmers to take proactive measures to prevent negative events (Arinze, 2024; Khan, 2024). Additionally, predictive analytics can enhance feeding schedules, monitor fish behavior, and predict growth rates, thereby improving production efficiency and resource utilization (Akintuyi, 2024; Eboigbe, 2023). Moreover, AI-driven predictive analytics contributes to aquaculture sustainability by enabling the prediction of environmental impacts, optimizing resource allocation, and reducing waste generation (Nzeako, 2024; Guerra, 2024). By forecasting demand, managing inventory levels, and anticipating market changes, aquaculture businesses can streamline supply chain operations and enhance overall responsiveness to market dynamics (RPA and AI-Driven Predictive Analytics in Banking for Fraud Detection, 2022). Furthermore, predictive analytics supports decision-making processes by offering actionable insights and recommendations based on data-driven predictions (Majeed & Hwang, 2021; Nyathani, 2023). In conclusion, AI-driven predictive analytics holds significant promise in revolutionizing aquaculture practices by facilitating data-driven decision-making, improving operational efficiency, and fostering sustainability. By harnessing AI algorithms to analyze complex datasets and forecast outcomes, aquaculture stakeholders can optimize production processes, enhance resource management, and ultimately drive innovation and growth.

2.2. Decision Support Systems

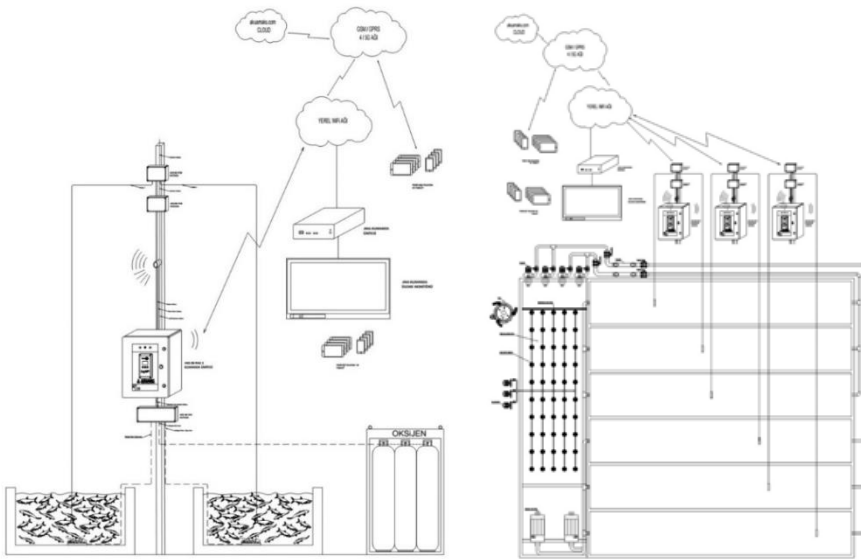
Decision Support Systems (DSS) are essential tools in the aquaculture industry that use artificial intelligence (AI) technologies to enhance decision-making processes. These systems analyze complex data, identify patterns, and provide valuable insights to assist aquaculture stakeholders in making informed decisions (Stavarakidis-Zachou et al. (2018). In the context of aquaculture, DSSs are increasingly incorporating multi-criteria approaches to effectively support

decision-making by considering various factors that impact farm operations, production, and profitability (Hossain et al., 2021). The development of DSSs for aquaculture involves integrating climate information, expert opinions, and stakeholder perceptions to create decision frameworks that aid in managing risks and optimizing operations (Hossain et al., 2021). By utilizing AI algorithms and predictive analytics, DSSs can help aquaculture professionals anticipate and mitigate challenges related to environmental changes, disease outbreaks, and resource management (Wong, 2024). Additionally, DSSs can assist in species selection based on traits that interact effectively with different production systems, thereby enhancing environmental performance and sustainability (Wong, 2024). Moreover, decision support tools are utilized to evaluate trade-offs associated with aquaculture practices, such as the co-location of offshore windfarms and aquaculture, to inform policy choices and sustainable management practices (Schmitt & Brugere, 2013). By incorporating Bayesian Belief Networks and GIS modeling frameworks, DSSs can capture ecosystem services, stakeholders' preferences, and potential trade-offs, facilitating the development of diversified management practices (Schmitt & Brugere, 2013). Furthermore, DSSs based on fuzzy models and neural networks can predict aquaculture outcomes and optimize facility design and management planning (Wang et al., 2009). In conclusion, Decision Support Systems powered by AI revolutionize aquaculture practices by providing stakeholders with data-driven insights, facilitating risk management, optimizing resource allocation, and supporting sustainable decision-making processes. Through the integration of advanced technologies and multi-criteria approaches, DSSs can significantly enhance the efficiency, productivity, and environmental sustainability of the aquaculture industry.

2.3. Case Studies: AI Applications in Aquaculture

Artificial Intelligence (AI) applications in aquaculture have shown significant potential for transforming the industry through innovative technologies and decision-making support systems. Case studies illustrating AI applications in aquaculture demonstrate the various ways in which AI can improve the productivity, sustainability, and efficiency of fish farming practices. A notable case study involves the creation of a chatbot called AquaGent for smart aquafarm practices. Jasmin et al. (2022). This AI-based

chatbot offers real-time assistance and information to different stakeholders in the aquaculture industry, enhancing communication and providing access to crucial insights. Additionally, AI technologies have been employed to control aquaculture solar thermal water heating systems with the goal of enhancing process efficiency, reducing energy and water losses, and improving the understanding of overall processes (Atia et al., 2011). AI-driven predictive analytics and decision support systems have also been integrated into aquaculture to optimize operations and improve decision-making processes. For example, AI technologies have been used to forecast water quality in aquaculture fishponds, allowing for proactive management of environmental conditions and optimal fish health (Yang et al., 2023). An example of this is the activities developed by private organizations in the aquaculture production sector in Turkey, which have been successfully implemented in many parts of the world (Yıldırım, 2023). These predictive analytics tools enable aquaculture professionals to anticipate challenges, mitigate risks, and optimize resource allocation to enhance farm performance. Furthermore, AI applications in aquaculture extend to precision fish farming, where technologies such as the Internet of Things (IoT), big data analytics, and AI algorithms are combined to enable autonomous fish production (Kaur et al., 2023). Through the utilization of AI and cloud services, aquaculture operations can achieve improved monitoring, data-driven decision-making, and enhanced efficiency in fish farming practices (fig. 1). In conclusion, the case studies of AI applications in aquaculture highlight the transformative impact of AI technologies on various aspects of fish farming, from environmental monitoring (fig.2) to decision support systems. These innovative applications not only enhance operational efficiency and productivity but also contribute to the sustainability and growth of the aquaculture industry.



Figures 1 and 2. Measurement tracking and recording systems in terrestrial aquaculture production facilities via artificial intelligence-supported cloud (Yıldırım, 2023).

3. HARNESSING THE INTERNET OF THINGS (IoT)

- IoT-Enabled Sensors for Real-Time Monitoring
- Data Collection and Management in Aquaculture
- Implementing IoT in Aquaculture Operations

3.1. IoT-Enabled Sensors for Real-Time Monitoring

Utilizing the Internet of Things (IoT) in aquaculture has enhanced the industry by real-time monitoring through IoT-enabled sensors. These sensors collect data on parameters like water quality, temperature, dissolved oxygen levels, and feeding patterns within aquaculture systems (Yang et al., 2023). By utilizing IoT technology, aquaculture operators gain real-time insights into their fishponds or aquafarms, allowing for proactive decision-making and timely interventions to maintain optimal conditions for fish health and growth (Yang et al., 2023). The integration of IoT-enabled sensors not only boosts operational efficiency but also promotes sustainability by optimizing resources and reducing environmental impacts (Ismail et al., 2020). Additionally, data from these sensors can be analyzed using artificial intelligence algorithms to predict water quality changes, identify anomalies, and optimize feeding schedules,

ultimately enhancing farm productivity and profitability (Yang et al., 2023). Overall, IoT-enabled sensors for real-time monitoring represent a significant advancement in aquaculture practices, providing a data-driven approach to decision making and ensuring the well-being of aquatic organisms while supporting sustainable aquaculture operations.



Figure 3. Monitoring and control systems used in cage systems (Dikel and Öz., 2022)

3.2. Data Collection and Management in Aquaculture

Data collection and management in aquaculture have been significantly enhanced through the utilization of Internet of Things (IoT) technology, particularly with the implementation of IoT-enabled sensors. These sensors play a crucial role in collecting real-time data on various parameters essential to aquaculture operations, such as water quality, temperature, dissolved oxygen levels, and feeding patterns (Lin & Tseng, 2019). By leveraging IoT-enabled sensors, aquaculture practitioners can access a continuous stream of data that provides insights into the environmental conditions within fishponds or aquafarms, enabling them to make informed decisions promptly (Lin & Tseng, 2019). The data collected by these sensors not only facilitate monitoring but also support predictive analytics and decision-making in aquaculture. Through efficient data management systems, aquaculture professionals can analyze collected data to identify trends, anomalies, and correlations, allowing for proactive interventions to maintain optimal conditions for fish health and

overall farm productivity (Lin & Tseng, 2019). Furthermore, the integration of IoT-enabled sensors for data collection and management in aquaculture contributes to sustainability efforts by optimizing resource utilization, reducing environmental impacts, and enhancing operational efficiency (Krishna & Leema, 2022). Overall, the adoption of IoT technology for data collection and management in aquaculture represents a significant advancement in modern fish farming practices, enabling data-driven decision-making and fostering sustainable aquaculture operations.

3.3. Implementing IoT in Aquaculture Operations

The integration of Internet of Things (IoT) technology into aquaculture operations has significantly improved the industry by enabling advanced monitoring and control systems. By incorporating IoT sensors into aquaculture systems, crucial parameters such as water quality, temperature, dissolved oxygen levels, and feeding patterns can be collected Gleiser and Moro (2023). These data are then utilized for predictive analytics, early warning systems, and intelligent remote control to enhance decision-making processes and operational efficiency in aquaculture (Sen et al., 2023). Additionally, IoT-based water quality monitoring systems have been implemented to maintain optimal conditions for aquatic organisms, identify anomalies, and prevent disease outbreaks in fish farms. The utilization of IoT in aquaculture not only boosts productivity and quality and fosters sustainability by optimizing resource utilization and reducing environmental impacts. Overall, the application of IoT in aquaculture operations represents a significant advancement in modern fish farming practices, providing a data-driven approach to monitoring, managing, and decision-making for sustainable aquaculture practices.

4. MACHINE LEARNING IN AQUACULTURE

- Machine Learning Models for Predicting Aquaculture Outcomes
- Automated Feeding Systems
- Machine Learning for Disease Detection and Prevention

4.1. Machine Learning Models for Predicting Aquaculture Outcomes

Machine learning is a combination of algorithms that analyze data and use what they learn to make informed decisions. This technology uses data to

create algorithms that learn the relationship between data inputs and outputs, requiring little human intervention during the deployment phase. Computers can develop their own predictive capabilities based on the amount of data they receive and continually improve their algorithms based on the information they receive. Machine learning forms the basis of many AI systems, allowing such systems to work independently on large datasets without the need for human intervention. Machine learning uses two main methods to produce results. The first is supervised learning, where the model is trained based on input and output data and can therefore predict future needs. The third method is unsupervised learning, which allows bots to discover hidden patterns and trends in the data on their own.

Supervised machine learning uses humans to help machine learning predictions based on existing information. These algorithms use known datasets to answer queries and perform predictive analysis. Unsupervised learning, on the other hand, requires bots to discover hidden themes and patterns in the data on their own. This method makes it possible to make inferences from incomplete data sources. Clustering is one of the most widely used unsupervised machine learning techniques, and it enables exploratory data analysis in areas such as object recognition and market research.

Machine learning (ML), a subset of artificial intelligence (AI), has become a powerful tool in the aquaculture industry, offering the ability to predict a wide range of outcomes with remarkable accuracy. By analyzing large datasets and identifying patterns, machine learning models can forecast crucial factors that influence the success of aquaculture operations. This predictive capability is transforming how farmers manage their operations, leading to increased efficiency, reduced risks and enhanced sustainability.

One of the primary applications of machine learning in aquaculture is predicting growth rates and harvest times. By analyzing data such as water temperature, pH levels, oxygen concentration, and feeding rates, machine learning models can predict how quickly fish grow under varying conditions. These predictions enable farmers to optimize feeding schedules, manage stocking densities, and plan harvests with greater precision. This strategy not only maximizes productivity but also reduces feed waste, which is a significant cost factor for aquaculture.

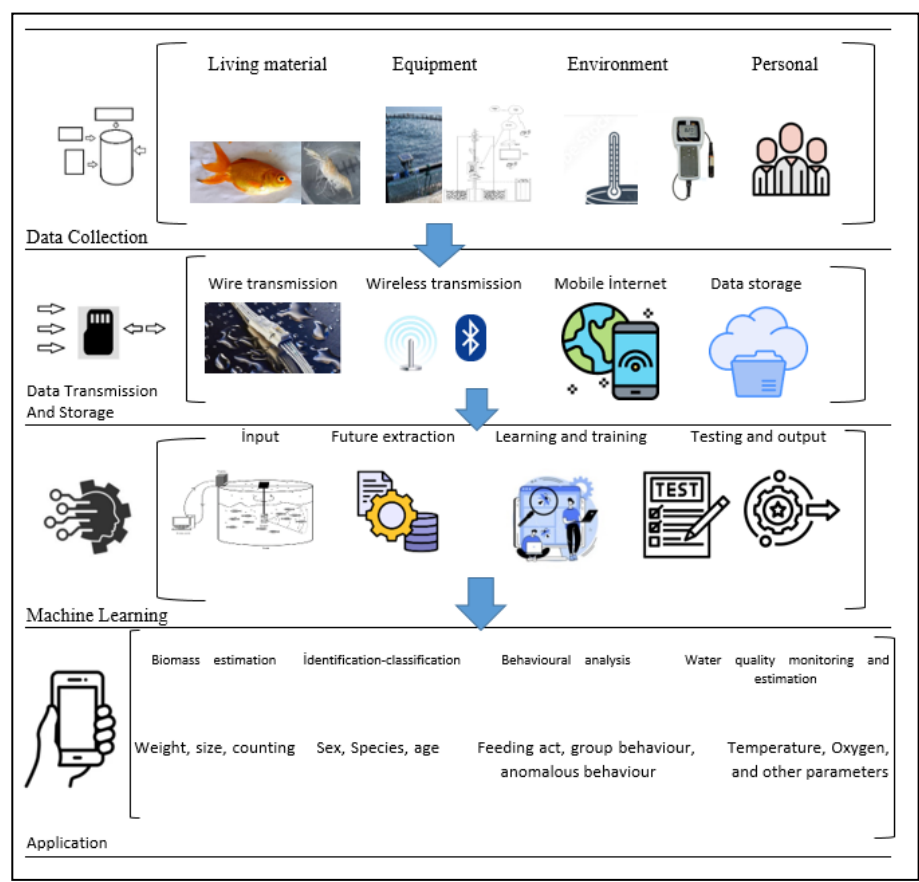


Figure 4. Structural diagram for applying machine learning in aquaculture.

Machine learning is also instrumental in predicting disease outbreaks, which are major challenges in aquaculture. By continuously monitoring water quality, fish behavior, and environmental conditions, machine learning algorithms can detect early signs of disease or stress in the stock. For instance, changes in swimming patterns or feeding behaviors coupled with environmental data can indicate the onset of a health issue. By predicting these outbreaks before they fully develop, farmers can take preventive measures, such as adjusting water conditions or applying treatments, to mitigate the impact on their stock.

Another important application of the proposed method is predicting water quality parameters. Machine learning models can analyze historical and real-time data from sensors deployed in aquaculture systems to forecast

changes in key water quality metrics like ammonia levels, dissolved oxygen, and temperature. These predictions are critical for maintaining optimal fish growth and health conditions. For example, if a model predicts a drop in oxygen levels, automated systems can trigger aeration devices to maintain adequate oxygenation, preventing stress or mortality among the fish (Figure 4).

In addition, machine learning models are used to predict market trends and optimize economic outcomes. By analyzing data on market prices, consumer demand, and production costs, these models can help farmers decide when to sell their products or adjust production strategies to maximize profitability.

The integration of machine learning into aquaculture is not without challenges. The prediction accuracy depends heavily on the quality and quantity of the available data. Therefore, successful machine learning applications require robust data collection systems and data analysis expertise. However, as these technologies continue to evolve, their predictive capabilities will likely become even more sophisticated, providing farmers with powerful tools to manage their operations more effectively and sustainably.

In summary, machine learning models are revolutionizing aquaculture by providing predictive insights that help farmers optimize growth rates, prevent disease, maintain water quality, and maximize economic returns. These advances are paving the way for a more efficient, sustainable, and resilient aquaculture industry.

4.2. Automated Feeding Systems

The integration of machine learning (ML) technologies into aquaculture, particularly automated feeding systems, represents a significant advancement in the efficiency and sustainability of fish farming practices. Automated feeding systems (AFS) leverage artificial intelligence (AI) technologies, including machine learning algorithms, to optimize feeding processes, thereby enhancing fish growth while minimizing waste and environmental impact. Recent studies have highlighted the role of AI in developing sophisticated AFS that utilize Convolutional Neural Networks (CNNs) and Gated Recurrent Units (GRUs) to predict feeding requirements based on real-time data. This approach not only automates the feeding process but also adjusts the quantity of feed according to the specific needs of the fish, which can vary with age and environmental

conditions (Son, and Jeong, 2024). Such systems are designed to ensure that fish receive the optimal amount of feed, which is crucial for growth and health. Moreover, the application of Internet of Things (IoT) technology in AFS has been transformative. IoT-enabled systems can monitor various parameters, such as water quality and fish behavior, allowing for precise control over feeding schedules and amounts. For instance, a multi-factor intelligent precision feeding system integrates sensors for water quality monitoring and fish activity, facilitating a comprehensive management approach that enhances feeding efficiency (Liu et al., 2023). This integration of IoT with machine learning not only streamlines operations but also reduces labor costs and improves overall fish welfare (Preethap and Rathinavel, 2024). The benefits of automated feeding systems extend beyond operational efficiency; they also contribute to aquaculture sustainability. By minimizing feed waste and optimizing feeding strategies, these systems can help reduce the environmental footprint of fish farming. Research indicates that intelligent feeding control methods, which include mathematical models and computer vision, have been effective in improving feeding accuracy and reducing excess feed that can lead to water pollution (Zhou et al., 2017). Furthermore, advancements in robotics and artificial intelligence have paved the way for the development of smart aquaculture systems that can autonomously manage feeding and other critical operations. These systems are designed to replace manual labor, thereby addressing labor shortages in the aquaculture industry while ensuring that fish are fed in a timely and efficient manner (Wang et al., 2021). The shift toward automation in aquaculture is not merely a trend but a necessary evolution to meet the growing global demand for seafood while ensuring sustainable practices (Dikel 2023). In summary, the implementation of machine learning in automated feeding systems is revolutionizing aquaculture. By utilizing AI and IoT technologies, these systems enhance feeding efficiency, improve fish welfare, and contribute to the sustainability of aquaculture practices. As the aquaculture industry continues to evolve, the integration of advanced technologies will be crucial to addressing the challenges faced by aquaculture, ensuring that it remains a viable source of food for future generations.

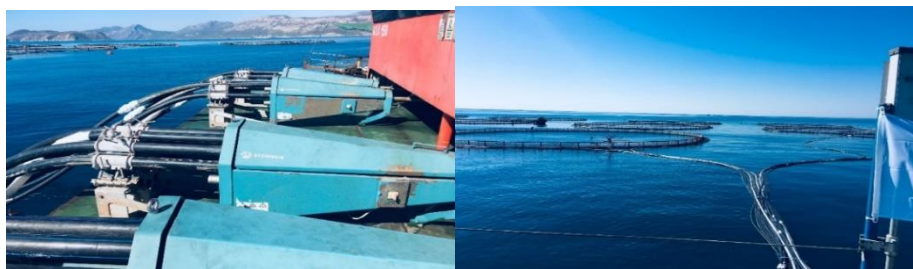


Figure. 5 Automatic feed distribution system from the feed storage unit (Barge) to the cages via pneumatic pipes used for feeding in offshore cage systems (Dikel 2023).

4.3. Machine Learning for Disease Detection and Prevention

The application of machine learning (ML) in aquaculture has emerged as a transformative approach for disease detection and prevention, significantly enhancing the health management of aquatic species. By leveraging advanced algorithms, aquaculture practitioners can identify potential disease outbreaks early, thereby mitigating risks and improving overall fish health. One of the primary advantages of ML in disease management is its ability to analyze vast datasets derived from genomic and environmental factors. For instance, studies have demonstrated the effectiveness of machine learning algorithms, such as random forests and support vector machines, in predicting disease resistance in aquaculture species like striped catfish to pathogens such as *Edwardsiella ictaluri* (Vu et al., 2021). These predictive models utilize genomic data to assess the likelihood of disease outbreaks, enabling farmers to implement proactively preventive measures. Furthermore, machine learning techniques have been employed to monitor water quality parameters, which are critical for preventing disease outbreaks. Poor water quality is often linked to increased susceptibility of fish to infection. By integrating ML algorithms with IoT devices, aquaculture systems can continuously monitor water conditions and alert farmers to deviations that may indicate a potential health risk (Islam, 2024). This real-time monitoring facilitates timely interventions, such as adjusting water quality and administering treatments, thereby reducing mortality rates. In addition to environmental monitoring, machine learning has been used to identify pathogens in aquaculture settings. For example, the application of high-throughput community analysis has been shown to enhance the detection of bacterial pathogens, such as *Flavobacterium* species, which pose significant threats to fish health (Testerman et al., 2021). By employing ML-based

methods, aquaculture operations can achieve faster and more accurate pathogen identification, allowing for swift responses to emerging health threats. Moreover, the integration of machine learning techniques with genomic tools has enabled the development of targeted screening methods for at-risk populations, such as North American Atlantic salmon. These methods help identify genetic introgression from aquaculture into wild populations, which can have significant implications for conservation and disease management strategies (Nugent et al., 2022). By understanding the genetic factors associated with disease susceptibility, aquaculture producers can better manage breeding programs to enhance disease resistance. Overall, the incorporation of machine learning into disease detection and prevention strategies in aquaculture not only improves the health and welfare of aquatic species and contributes to the sustainability of aquaculture. As ML technologies continue to evolve, their potential to revolutionize disease management in aquaculture will likely expand, offering new avenues for research and practical applications.

Ahmed et al.,(2022) in the alliance of flawless image processing and machine learning mechanism, detected infected fish caused by various pathogens, and there were two parts in their study. In the first part, image preprocessing and segmentation were applied to reduce noise and exaggerate the image, respectively. In the second part, they extracted relevant features to classify diseases using the support vector machine (SVM) algorithm of kernel function machine learning. Processed images of the first part passed through this (SVM) model. In this study, they revealed remarkable judgment of the applied SVM performances with 91.42% and 94.12% accuracy with and without augmentation, respectively (fig x y z).

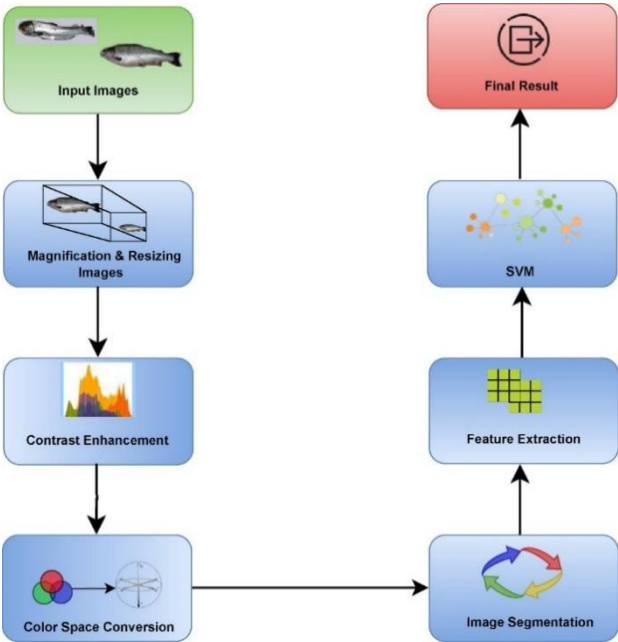


Figure 6. Diagram showing relevant technologies and a solution framework for the classification of an example (salmon) fish disease is provided (Ahmed et al.,2022).

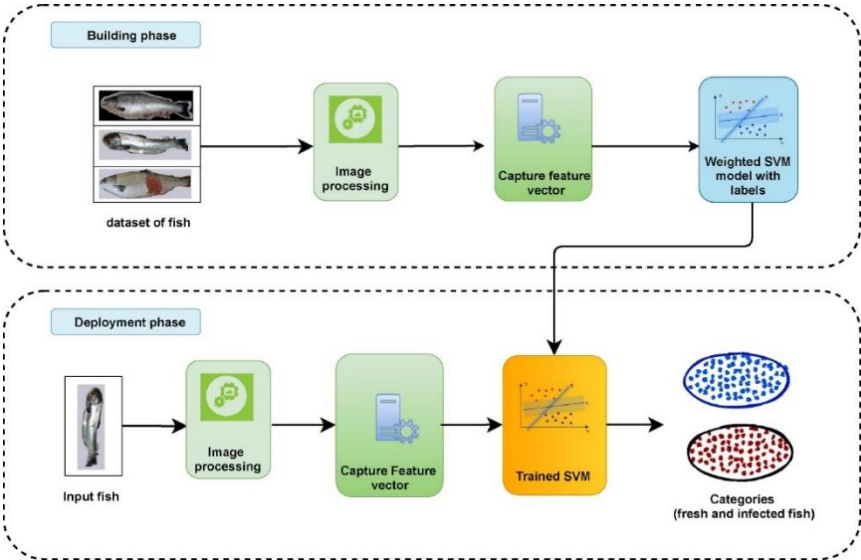


Figure 7. System architecture, which includes Data collection, model training, and class prediction (Ahmed et al.,2022).

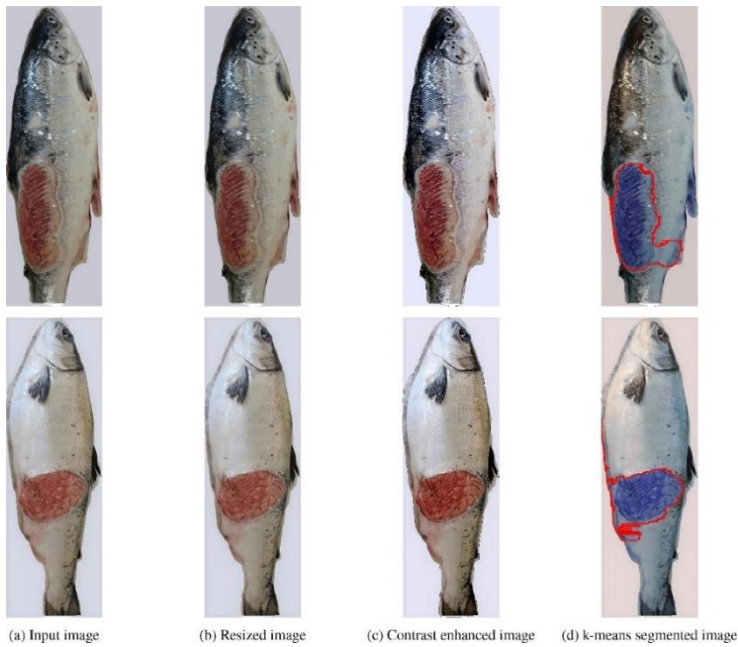


Figure. 8. Diagram showing the four stages of image processing (Ahmed et al.,2022).

Deep learning, a subset of artificial intelligence, has emerged as a powerful tool for aquaculture. By leveraging machine learning algorithms and computer vision techniques, researchers have developed innovative solutions that help aquaculture operators quickly identify and address disease outbreaks (Dikel and Demirkale 2024). The use of deep learning in aquaculture supports sustainable practices by minimizing the need for chemical treatments and antibiotics, which can have negative environmental impacts. Automated monitoring systems powered by deep learning can continuously assess water quality, fish behavior, and health metrics, providing real-time information that enables more precise and targeted management strategies. This leads to more efficient use of resources and waste reduction, contributing to the overall sustainability of aquaculture operations.

5. THE POWER OF COMPUTER VISION

- Using Computer Vision to Monitor Fish Behavior and Growth
- Image and Video Analysis in Aquaculture
- Innovations and Future Trends in Computer Vision Applications

5.1. Using Computer Vision to Monitor Fish Behavior and Growth

Computer vision technologies are revolutionizing the aquaculture industry by offering advanced tools for monitoring and analyzing fish behavior and growth. Under the subheading Fish Behavior and Growth Monitoring Using Computer Vision, this technology enables continuous observation of fish populations, allowing for the detection of subtle behavioral changes that can indicate health issues or stress. This real-time monitoring facilitates timely intervention, leading to improved fish welfare and optimized growth rates.

The integration of computer vision into fish behavior and growth monitoring represents a significant advancement in aquaculture management. Traditional methods of assessing fish growth and behavior often rely on manual observation, which can be subjective and labor-intensive (fig. 9). Recent studies have demonstrated that computer vision techniques, particularly those based on deep learning algorithms, can enhance the accuracy and efficiency of these assessments. For instance, the authors explored the use of Mask R-CNN for fish segmentation in sonar images, highlighting the potential of convolutional neural networks (CNNs) in extracting relevant features from aquatic environments, which is crucial for monitoring fish behavior and growth (Chang et al., 2021). Moreover, the role of computer vision in intelligent feeding systems was emphasized, noting that these systems can provide real-time data on fish behavior, allowing for adaptive feeding strategies that align with the fish's growth status (An et al., 2020). This capability is particularly beneficial because it surpasses traditional methods that fail to monitor fish behavior dynamically. The ability to analyze feeding activity through motion detection, as demonstrated by , further illustrates how computer vision can quantify fish shoal behavior, thereby providing insights into feeding patterns and overall health (Han et al., 2020). Understanding fish behavior is not only essential for optimizing feeding practices but also for improving welfare in aquaculture settings. pointed out that intelligent monitoring systems utilizing computer vision can significantly enhance the precision of husbandry practices, thereby promoting better fish welfare and farm performance (Georgopoulou et al., 2021). Additionally, the work on automatic recognition of fish behavior through a fusion of RGB and optical flow data underscores the advancements in deep learning that facilitate long-term monitoring of fish health and welfare (Wang et al., 2021). Furthermore, the application of computer vision extends to

environmental monitoring, where fish behavior serves as an indicator of water quality and ecological health. For instance, studies have shown that variations in dissolved oxygen levels can affect fish behavioral trajectories, which can be quantitatively analyzed using low-cost computer vision systems (Huang et al., 2019). This dual capability of monitoring fish behavior and environmental conditions is crucial for sustainable aquaculture practices, as highlighted by (Huang et al., 2019). In conclusion, the incorporation of computer vision technologies into fish behavior and growth monitoring not only enhances the precision of aquaculture management but also contributes to the welfare of fish populations. As these technologies continue to evolve, they promise to revolutionize the way aquaculture operations are conducted, ensuring more sustainable and efficient practices.

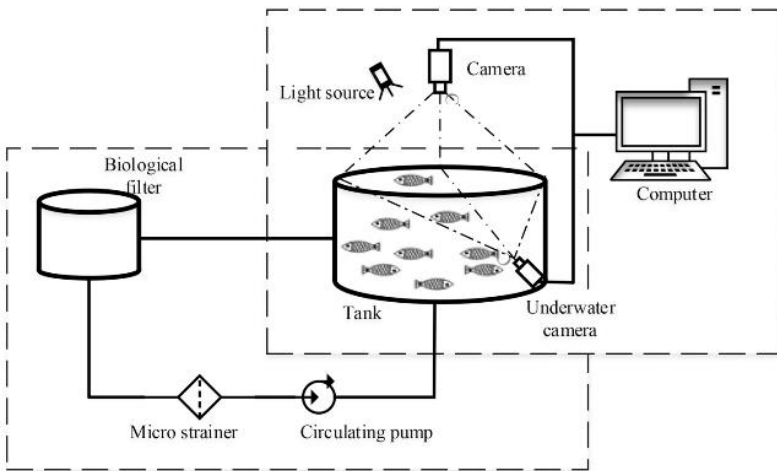


Figure 9. Sample diagram showing the structure of a computer vision-based fish feeding behavior recognition system (Li et al., 2020).

5.2. Image and Video Analysis in Aquaculture

In the area of Image and Video Analysis in Aquaculture, computer vision algorithms process vast amounts of visual data, providing insights into fish density, size distribution, and even individual fish identification. These capabilities enhance the precision of stock management and feeding strategies, reduce waste, and promote sustainable practices.

The application of image and video analysis in aquaculture has emerged as a transformative approach for enhancing aquaculture monitoring and

management practices. Utilizing advanced imaging technologies, researchers have developed methodologies that enable efficient tracking of fish populations, assessment of aquaculture environments, and optimization of production processes. For instance, the integration of remote sensing techniques, particularly through the use of Synthetic Aperture Radar (SAR) and optical imagery, has proven effective for mapping aquaculture ponds and monitoring their expansion over time. noted that SAR sensors offer significant advantages over optical remote sensing by providing continuous mapping capabilities, which are crucial for assessing coastal aquaculture (Ottinger et al., 2017). This capability is particularly important given the challenges posed by the small size of aquaculture ponds, which can be difficult to identify in lower-resolution images (Sun et al., 2020). Moreover, the development of algorithms for tracking multiple aquatic animals in video footage has further enhanced the precision of fish behavior analysis. ToxId, an efficient algorithm designed to resolve occlusions when tracking fish, has demonstrated potential for real-time monitoring of fish movements (Rodríguez et al., 2017). This capability is vital for understanding fish dynamics and optimizing feeding strategies, which can improve growth rates and overall fish stocks. Similarly, the use of deep learning techniques, such as convolutional neural networks (CNNs), has been instrumental in extracting relevant features from underwater images, thereby facilitating the identification and classification of fish species in aquaculture settings (Fu et al., 2021). In addition to monitoring fish behavior, image analysis plays a crucial role in assessing the environmental conditions of aquaculture systems. For example, the study highlighted the importance of high-resolution imagery in detecting changes in marine aquaculture areas, emphasizing the need for effective monitoring to inform marine spatial planning (Wang et al., 2022). Furthermore, the advancement of real-time video analysis systems, such as those utilizing ImageJ software, allows for immediate assessment of fish health and behavior, which is essential for timely interventions (Pasqualin et al., 2018). The potential of drone technology in aquaculture monitoring has also gained attention, with a cloud-based autonomous drone system that employs AI and computer vision to survey aquaculture sites (Ubina et al., 2021). This innovative approach not only enhances the scalability of monitoring efforts and provides valuable data for decision-making in aquaculture management. In conclusion, the integration of

image and video analysis into aquaculture represents a significant leap forward in the effective monitoring and management of aquatic environments. By leveraging advanced imaging technologies and analytical algorithms, stakeholders in aquaculture can enhance productivity, ensure sustainability, and improve the welfare of aquatic species.

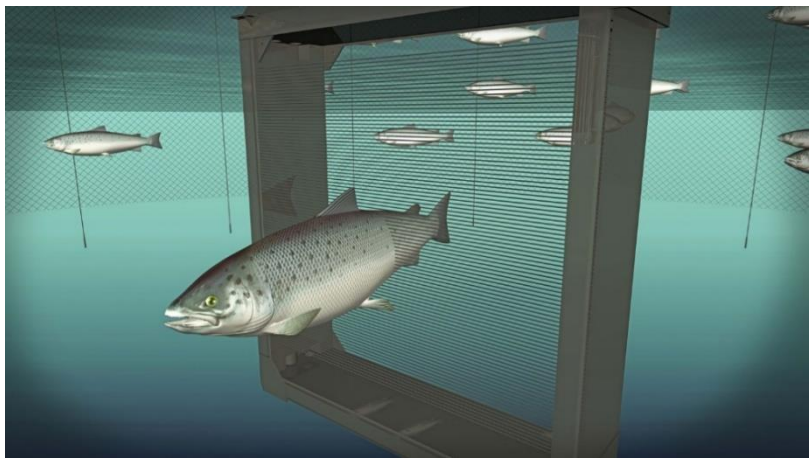


Figure.10. Consisting of a frame, this system provides a 24/7 overview of the average weight, size distribution, condition factors, and growth of fish within the cage (Anonymous, 2024a).

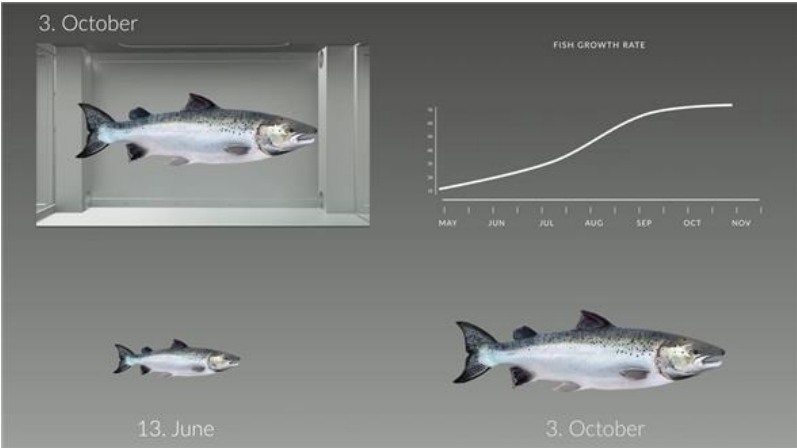


Figure. 11. With this equipment, fish growth can be automatically detected and recorded digitally over different time periods. (Anonymous 2024b)

5.3. Innovations and Future Trends in Computer Vision Applications

Looking forward, innovation and future trends in computer vision applications are set to further transform aquaculture. Emerging technologies like deep learning and 3D imaging, are pushing the boundaries of what is possible, enabling more accurate and automated systems. Future developments are likely to include even more sophisticated monitoring tools, predictive analytics, and integration with other technologies like IoT and machine learning, to make aquaculture more efficient and resilient.

Innovations in computer vision applications are rapidly transforming various sectors, driven by advancements in artificial intelligence (AI) and machine learning (ML). One of the most significant trends is the adoption of Vision Transformers (ViT) for image recognition tasks, which has shown promise in enhancing performance across various computer vision challenges, including detection and segmentation Dosovitskiy (2020). This shift toward transformer-based models indicates a move away from traditional convolutional neural networks (CNNs), that future applications may increasingly leverage these architectures to improve accuracy and efficiency when processing visual data. Furthermore, the integration of computer vision technologies with the Internet of Things (IoT) is paving the way for smarter agricultural practices. As highlighted, the application of AI and computer vision technologies in agriculture has gained momentum, particularly during the COVID-19 pandemic, as farmers seek innovative solutions to optimize yield and resource management (Cornejo-Olivares, 2023). This trend reflects a broader movement toward Industry 4.0, where intelligent automation and real-time monitoring are becoming standard practices in various industries. In addition to agriculture, the healthcare sector is witnessing transformative changes through computer vision. The application of AI in medical imaging has enabled more accurate diagnosis and personalized treatment plans. For instance, innovations in image analysis are enhancing the detection of cancerous lesions, with AI systems achieving performance levels comparable to those of experienced clinicians (Yu, 2022). This intersection of computer vision and healthcare not only improves patient outcomes and streamlines workflows, allowing for more efficient use of resources. Moreover, the rise of mixed reality and augmented reality (AR) technologies is expanding the

horizons of computer vision applications. discuss the development of digital companions that learn user habits and preferences, utilizing advanced computer vision techniques to perceive and interact with the environment (Spirig et al., 2021). This innovation is indicative of a future where human-computer interaction will become more intuitive and context-aware, thereby enhancing user experiences across various applications. The exploration of crowdsourcing methods to detect biases in image datasets also represents a critical innovation in the field. The importance of addressing fairness and trustworthiness in computer vision systems is particularly important because these technologies are applied to sensitive areas, such as surveillance and autonomous navigation (Hu et al., 2020). Focusing on ethical considerations is essential as the field continues to evolve, ensuring that innovations contribute positively to society. In conclusion, the future of computer vision applications will be characterized by a convergence of advanced technologies, including AI, IoT, and mixed reality. As these innovations continue to unfold, they promise to enhance efficiency, accuracy, and user engagement across diverse sectors, from agriculture to healthcare and beyond.

6. INTEGRATION OF TECHNOLOGIES: BUILDING SMART AQUACULTURE SYSTEMS

- Synergizing AI, Internet of Things, and Computer Vision
- Challenges and Considerations in System Integration
- Case Studies: Successful Smart Aquaculture Implementations

The integration of advanced technologies is pivotal to developing smart aquaculture systems that enhance productivity, sustainability, and efficiency. By combining cutting-edge technologies such as the Internet of Things (IoT), artificial intelligence (AI), machine learning, and computer vision, smart aquaculture systems can automate and optimize key aspects of fish farming. IoT devices play a crucial role in this transformation by enabling the real-time monitoring of environmental parameters such as water temperature, pH, and dissolved oxygen. For instance, IoT-based systems can continuously monitor these critical factors, allowing farmers to maintain optimal conditions for fish health and growth (Hantoro, 2023). This capability not only improves fish welfare and reduces the risk of disease outbreaks, thereby enhancing overall productivity. Artificial intelligence and machine learning further augment the

capabilities of smart aquaculture systems by facilitating data-driven decision making. Algorithms can analyze vast amounts of data collected from IoT sensors to predict optimal feeding schedules, detect anomalies in water quality, and identify potential health issues in fish populations. They highlight the use of machine learning algorithms to optimize water quality management and automate feeding processes, which can lead to significant resource savings and improved fish yields (Dhinakaran, 2023). This integration of AI allows for a more responsive and adaptive approach to aquaculture management, where farmers can make informed decisions based on real-time data. Computer vision technologies have also contributed significantly to the advancement of smart aquaculture. By using image and video analysis, farmers can monitor fish behavior, assess growth rates, and detect signs of stress or disease. For example, the implementation of computer vision systems in smart fish farms can automate the monitoring process and provide insights into fish health and environmental conditions (Angani et al., 2019). This automation reduces the labor burden on farmers and enhances the accuracy of monitoring efforts. Moreover, the combination of these technologies promotes sustainability in aquaculture practices. By optimizing resource use and minimizing waste, smart aquaculture systems can help improve sustainable fish farming practices. The study emphasizes that IoT-enabled monitoring systems can lead to more efficient hatchery management and better environmental stewardship (Zamzari et al., 2022). In conclusion, the integration of IoT, AI, machine learning, and computer vision into smart aquaculture systems represents a significant leap forward in the industry. These technologies not only enhance productivity and efficiency but also promote sustainability, ensuring that aquaculture can meet the growing global demand for fish while minimizing environmental impact.

6.1. Synergizing AI, Internet of Things, and Computer Vision

The synergistic integration of Artificial Intelligence (AI), the Internet of Things (IoT), and computer vision technologies is revolutionizing various sectors, particularly smart aquaculture systems. This convergence of technologies enhances the productivity, sustainability, and operational efficiency of fish farming. IoT devices serve as the backbone of these systems, enabling real-time monitoring of environmental parameters such as water quality, temperature, and oxygen content. For instance, highlighted the use of

cloud-based autonomous drones equipped with computer vision capabilities to monitor aquaculture sites, providing a non-invasive and cost-effective method for data collection (Ubina et al., 2021). Real-time monitoring is crucial for maintaining optimal fish health and growth conditions, thereby reducing the risk of disease outbreaks and improving overall yield. AI and machine learning algorithms further enhance the capabilities of smart aquaculture systems by analyzing vast amounts of data collected from IoT sensors. These algorithms can predict optimal feeding schedules, detect anomalies in water quality, and even identify potential health issues in fish populations. It was emphasized that the integration of AI and IoT in aquaponic systems allows for real-time decision-making, which is essential for maximizing resource efficiency and enhancing yield (Gayam, 2023). This data-driven approach not only optimizes fish farming practices and contributes to sustainable aquaculture by minimizing waste and resource consumption. Computer vision plays a pivotal role in this integration by automatically monitoring fish behavior and growth. Advanced image processing techniques allow for the detection of stress indicators in fish, which can prompt timely interventions. discussed how machine learning and computer vision applications can be deployed in various aquaculture systems to enhance the monitoring of fish health and environmental conditions (Vo et al., 2021). This capability is particularly valuable in large-scale operations where manual monitoring is impractical. Moreover, the combination of these technologies promotes a more sustainable approach to aquaculture. By optimizing resource use and minimizing environmental impacts, smart aquaculture systems can help improve the long-term viability of fish farming. The work on water quality prediction using hybrid deep learning models exemplifies how AI can enhance the management of aquaculture environments, ensuring that they remain conducive to fish growth while protecting marine ecosystems (Haq & Harigovindan, 2022). In conclusion, the synergistic integration of AI, IoT, and computer vision is transforming aquaculture into a more efficient, productive, and sustainable industry. As these technologies continue to evolve, they promise to address the challenges facing traditional aquaculture practices, paving the way for a more resilient and environmentally friendly future in fish farming.

6.2. Challenges and Considerations in System Integration

The integration of technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and computer vision technologies into smart aquaculture systems presents numerous challenges and considerations that must be addressed for successful implementation. One of the primary challenges is the interoperability of different technologies and systems. As noted by , the seamless integration of various devices and platforms is crucial for effective data sharing and communication in smart farming environments (Gupta et al., 2020). This requires standardized protocols and frameworks that can accommodate the diverse range of sensors and devices used in aquaculture. Another significant challenge is data management and analysis. The vast amounts of data generated by Internet of Things (IoT) devices and computer vision systems can overwhelm traditional data processing methods. Effective data analytics tools are essential to extract actionable insights from such data. As highlighted by , the development of ontology models can facilitate better knowledge representation and information sharing in aquaponic systems, thereby improving decision-making processes (Abbasi et al., 2022). However, the complexity of data integration and the need for advanced analytical capabilities hinder effective system implementation. Security and privacy concerns also play critical roles in the integration of such technologies. As smart aquaculture systems rely heavily on interconnected devices, they become vulnerable to cyberattacks and data breaches. emphasized the importance of implementing robust security measures to protect sensitive data and ensure the integrity of the systems (Gupta et al., 2020). This includes encryption, secure communication protocols, and regular security audits to mitigate potential risks. Moreover, the cost of implementing advanced technologies can be a barrier for many aquaculture operators, particularly small-scale farmers. The initial investment required for IoT devices, AI algorithms, and computer vision systems can be substantial. As noted by , the economic feasibility of adopting these technologies must be carefully evaluated, considering both the potential benefits and the financial constraints faced by aquaculture businesses (Islam et al., 2021). Lastly, there is a need for training and education to ensure that personnel are equipped with the necessary skills to operate and maintain these advanced systems. Although the reference discusses the importance of digital technologies in achieving sustainable development goals, it does not

specifically address the training needs of smart aquaculture systems (Nayal et al., 2021). Therefore, this claim should be presented without citation or rephrased to reflect the general need for training in technology adoption. In conclusion, while the integration of AI, IoT, and computer vision technologies into smart aquaculture systems holds great promise for enhancing productivity and sustainability, addressing the challenges of interoperability, data management, security, cost, and training is essential for realizing the full potential of these technologies.

6.3. Case Studies: Successful Smart Aquaculture Implementations

The implementation of smart aquaculture systems has been successfully demonstrated in various case studies, demonstrating the potential of integrating advanced technologies to enhance fish farming productivity and sustainability. One notable example is the use of biofloc technology (BFT) in shrimp aquaculture, which was explored by investigating the dynamics of bacterioplankton communities in biofloc-based systems for rearing *Litopenaeus vannamei*. The study highlighted how specific microbial communities can improve water quality and shrimp health, ultimately leading to increased productivity and biosecurity (Song et al., 2022). This case illustrates how smart aquaculture can leverage biological processes to create more sustainable farming environments. Another significant case study involves the application of machine learning and IoT to optimize aquaculture operations. In Indonesia, research on ant colony optimization algorithms demonstrated that smart devices can monitor environmental parameters in real time, allowing for data-driven decision-making in aquaculture management (Munif, 2024). By automating processes such as feeding and water quality monitoring, farmers can enhance their operational efficiency and reduce labor costs, leading to improved fish growth rates and overall farm productivity. Additionally, the integration of computer vision and deep learning technologies has shown promising results in fish size estimation and monitoring. An image-based, unsupervised method was developed to estimate fish size from commercial landings using deep learning techniques. This approach not only streamlines the monitoring process but also provides valuable data for sustainable management of fish stocks sustainably (Álvarez-Ellacuría et al., 2020). These innovations demonstrate the potential of smart aquaculture

systems to enhance data accuracy and operational efficiency. Moreover, the implementation of recirculating aquaculture systems (RAS) has been a game-changer in the industry. The study on RAS in Ukrainian aquaculture highlighted how these systems can optimize water use and improve fish growth conditions by maintaining controlled environments (Tiutiunnyk, 2023). RAS technology exemplifies how smart aquaculture can contribute to environmental conservation while maximizing production efficiency. Lastly, the development of smart aeration control systems was another successful implementation. The benefits of smart aeration were analyzed in aquaculture, emphasizing its role in maintaining optimal oxygen levels and improving fish health (Lin et al., 2022). This case study underscores the importance of integrating smart technologies to address specific aquaculture challenges, such as water quality management. In conclusion, this case studies illustrate the successful implementation of smart aquaculture systems through the integration of advanced technologies. By leveraging IoT, AI, machine learning, and computer vision technologies, aquaculture operations can enhance productivity, sustainability, and efficiency, paving the way for a more resilient industry.

7. SUSTAINABILITY AND ENVIRONMENTAL IMPACTS

- Reducing the Environmental footprint through Smart Technologies
- Sustainable Practices Enabled by Smart Aquaculture
- Assessing Long-Term Impact on Ecosystems

7.1. Reducing the Environmental footprint through Smart Technologies

Aquaculture's rapid growth has highlighted the need for sustainable practices that minimize environmental footprints. Smart technologies have emerged as pivotal tools for achieving this goal by optimizing resource use, monitoring, and reducing waste.

Precision Feeding Systems: One of the most impactful ways to reduce the environmental footprint is through precision feeding systems. These systems use sensors and artificial intelligence to monitor fish behavior and appetite, ensuring that feed is administered at the right amounts at the right times. This minimizes overfeeding, reduces waste, and lowers the risk of water contamination from uneaten feed, leading to more efficient use of resources.

Water Quality Management: Maintaining optimal water quality is crucial for the health of aquatic species and the surrounding environment. Smart technologies such as IoT-enabled sensors continuously monitor water parameters like oxygen levels, pH, and temperature. Real-time data allow immediate adjustments to maintain ideal conditions, thereby reducing the need for chemical treatments and minimizing the impact on local ecosystems.

Energy Efficiency: Smart technologies contribute to aquaculture energy efficiency by automating processes such as water circulation, aeration, and lighting. Automated systems can adjust operations based on real-time data, thereby reducing energy consumption and lowering the carbon footprint of aquaculture facilities.

Waste Management and Recycling: Advanced waste management systems, enabled by smart technologies, ensure that by-products like fish waste are efficiently collected and processed. Technologies like biofiltration and recirculating aquaculture systems (RAS) help to recycle water and nutrients, reduce environmental impact, and enhance the sustainability of aquaculture operations.

Traceability and Supply Chain Management: Smart technologies improve traceability throughout aquaculture supply chains, ensuring that products are sourced sustainably. Blockchain and RFID technologies enable detailed tracking of the journey from farm to table, promoting responsible practices, and reducing the environmental impact of transportation and processing.

By integrating these smart technologies, aquaculture can significantly reduce its environmental footprint and contribute to the long-term sustainability of the industry.

7.2. Sustainability and Environmental Impact of Aquaculture

Sustainable Practices Enabled by Smart Aquaculture

Smart aquaculture integrates advanced technologies to promote sustainable practices that balance productivity with environmental stewardship. These technologies enable more efficient resource use, minimize ecological disruption, and support long-term sustainability in aquaculture operations.

Resource Optimization: Smart aquaculture systems use AI, IoT, and machine learning to optimize the use of water, feed, and energy. By collecting and analyzing real-time data, these systems ensure efficient use of resources, waste reduction, and minimize environmental impact. This approach not only conserves resources but also lowers operational costs, making sustainability economically viable.

Ecosystem Preservation: One of the key goals of sustainable aquaculture is to preserve local ecosystems. Smart technologies, like automated monitoring systems, help maintain water quality and prevent the overuse of antibiotics and chemicals. These technologies also enable precise control of farming conditions, thus reducing the risk of disease outbreaks and the subsequent need for treatments that harm the environment.

Biodiversity Protection: Sustainable aquaculture practices supported by smart technologies help protect biodiversity by minimizing habitat disruption. For example, smart sensors and monitoring systems can detect and prevent the escape of farmed species into the wild, where they can become invasive. In addition, technologies that enhance breeding practices can help maintain genetic diversity within farmed populations, reducing the risk of negative impacts on wild species.

Circular Economy Models: Smart aquaculture facilitates the adoption of circular economy principles, in which waste from one process becomes a resource for another. Technologies such as recirculating aquaculture systems (RAS) allow for the reuse of water and nutrients, thus reducing the need for fresh inputs and minimizing waste output. This closed-loop approach enhances sustainability by reducing the overall environmental footprint of aquaculture operations.

Climate Resilience: Smart technologies can improve aquaculture operations' resilience to climate change. By using predictive analytics and automated systems, farmers can anticipate and respond to changes in the environment, such as temperature fluctuations and extreme weather events. This adaptability helps to maintain stable production while mitigating the environmental impacts of climate change.

By embracing these sustainable practices enabled by smart technologies, aquaculture can continue to grow while minimizing its impact on the environment, ensuring that the industry remains viable and responsible in the long term.

7.3. Assessing Long-Term Impact on Ecosystems

Understanding and mitigating the long-term impacts of aquaculture on ecosystems are crucial for ensuring that aquaculture continues to be sustainable. This requires continuous assessment of how aquaculture activities influence the surrounding environment and the implementation of practices that protect and preserve the ecological balance.

Monitoring Environmental Changes: Continuous environmental monitoring is key to assessing the long-term impacts of aquaculture on ecosystems. By deploying sensors and remote sensing technologies, data on water quality, sediment composition, and biodiversity can be collected over extended periods. These data help identify trends and potential issues, such as eutrophication, that could harm local ecosystems.

Biodiversity Impact Assessment: Aquaculture can affect local biodiversity, particularly when non-native species are introduced or when farmed species escape into the wild. Long-term impact assessments involve studying these interactions and their effects on native species and habitats. Research and monitoring programs help ensure that aquaculture practices do not lead to the decline of native species or disruption of local ecosystems.

Cumulative Impact Analysis: The cumulative effects of multiple aquaculture operations in a region can significantly impact ecosystems. Assessing these cumulative impacts involves evaluating the combined effects of various activities, such as nutrient loading, chemical use, and habitat alteration. This comprehensive approach helps us understand the broader ecological implications and design strategies to minimize negative outcomes.

Habitat Restoration and Conservation: Long-term impact assessments also focus on the potential for habitat degradation due to aquaculture activities. Efforts to restore and conserve habitats, such as mangrove and seagrass beds, are essential for maintaining ecological balance. These initiatives often involve

collaboration between aquaculture operators, environmental organizations, and local communities to ensure that conservation goals are met.

Adapting Practices for Sustainability: Based on long-term impact assessment findings, aquaculture practices can be adapted to minimize environmental harm. This might include adjusting stocking density, modifying feeding practices, or implementing better waste management systems. The goal is to develop practices that support sustainable aquaculture while preserving ecosystem integrity.

Assessing the long-term impacts of aquaculture on ecosystems requires ongoing collaboration between scientists, industry stakeholders, and policymakers. By continuously monitoring and adapting practices, the aquaculture industry can ensure that its growth does not come at the expense of environmental health.

8. CHALLENGES AND BARRIERS TO ADOPTION

- Technological Challenges
- Economic and Regulatory Barriers
- Resistance to Change in the Industry

8.1. Technological Challenges

Adapting to smart aquaculture presents several technological challenges that hinder the widespread adoption and effective implementation of advanced systems. One of the primary challenges is the integration of various technologies into a cohesive system. Smart aquaculture relies on a combination of sensors, Internet of Things devices, data analytics, and automation tools, each with different requirements and specifications. Ensuring that these components work seamlessly together requires significant expertise and often involves complex customization, which can be a barrier to smaller or less technically proficient operations.

Another challenge lies in the reliability and accuracy of the corresponding technologies. The sensors used to monitor water quality, fish behavior, and environmental conditions must be highly accurate and durable, especially in harsh aquatic environments. Malfunctioning or inaccurate sensors can lead to incorrect data, potentially resulting in poor decision-making and negative impacts on fish health and productivity. The development of robust,

reliable technology that can withstand the rigorous demands of aquaculture environments is an ongoing challenge that requires continuous innovation and improvement.

Data management and analysis also pose significant challenges in smart aquaculture. The vast amount of data generated by smart systems can be overwhelming, especially for operations that lack the infrastructure or expertise to manage and interpret such data effectively. Converting raw data to actionable insights requires sophisticated algorithms and machine learning models, which may not be readily accessible or affordable for all aquaculture producers. Ensuring data security and privacy is also crucial because cyber threats can compromise sensitive information or disrupt operations.

The high cost of adopting smart technologies is another barrier, particularly for small farmers. Initial investments in smart aquaculture systems, including hardware, software, and training, can be prohibitively expensive. This financial burden is often compounded by ongoing maintenance, upgrades, and technical support costs. Without sufficient funding or financial incentives, many producers may be reluctant or unable to adopt these technologies.

Finally, there is the challenge of technological obsolescence. As technology evolves rapidly, the cutting-edge systems that are currently in use may become outdated within a few years. This necessitates continuous investments in upgrades and new technologies, which can be difficult for aquaculture operations to sustain over the long term. Addressing these technological challenges is essential for the successful and widespread adoption of smart aquaculture systems.

8.2. Economic and Regulatory Barriers

Economic and regulatory barriers are significant obstacles to the widespread adoption of smart aquaculture, impacting both the feasibility and the pace at which these technologies are implemented. Economically, the high upfront costs associated with smart technologies can be prohibitive, particularly for small and medium-sized aquaculture operations. Investing in advanced systems like automated feeding, water quality monitoring and data analytics platforms requires substantial capital, which many producers may not have access to. In addition, the ongoing costs related to maintenance, software

updates, and technical support add to the financial burden, making it difficult for smaller operators to justify or sustain these investments.

Access to financing is another economic barrier. Traditional lending institutions may be hesitant to fund aquaculture ventures because of the perceived risks associated with the industry, especially when adopting unproven or rapidly evolving technologies. The lack of tailored financial products for aquaculture further exacerbates this issue, limiting producers' ability to secure the necessary funds to transition to smart systems. Moreover, economic uncertainties, such as fluctuations in fish and other aquaculture product markets, can make it challenging for producers to plan and commit to long-term investments in smart technologies.

Regulatory barriers also hinder the adoption of smart aquaculture. The regulatory landscape for aquaculture is often complex and varies significantly between regions, creating challenges for producers that wish to implement new technologies. Regulations may not always keep pace with technological advancements, leading to outdated or ambiguous guidelines that can hinder innovation. For example, strict environmental regulations, while necessary for sustainability, may impose limitations on the deployment of certain technologies or require lengthy and costly approval processes. This can deter producers from experimenting with or adopting new smart technologies.

Additionally, there is often a lack of clear regulatory frameworks for the use of data generated by smart aquaculture systems. Issues related to data ownership, privacy, and sharing can create legal uncertainties, discouraging producers from fully utilizing these technologies. Furthermore, the absence of standardized regulations across regions can lead to inconsistencies in the implementation and monitoring of smart aquaculture practices, creating additional hurdles for producers operating in multiple jurisdictions.

Overcoming these economic and regulatory barriers requires coordinated efforts between industry stakeholders, policymakers, and financial institutions to create supportive environments that facilitate the adoption of smart aquaculture technologies.

8.3. Resistance to Change in the Industry

Resistance to change is a significant challenge in adapting to smart aquaculture, particularly in an industry that has long relied on traditional

practices. Many aquaculture operators, especially those who have successfully used conventional methods, may be skeptical about adopting new technologies. This skepticism often stems from fear of the unknown, concerns about the reliability and effectiveness of smart technologies, and potential disruption to established workflows. Overcoming this resistance requires not only demonstrating the tangible benefits of smart aquaculture but also addressing the underlying concerns that fuel this resistance.

One of the primary factors contributing to resistance is the perceived complexity and learning curve associated with new technologies. Many aquaculture producers lack the technical expertise to operate advanced systems such as IoT devices, data analytics platforms and automated feeding systems. This apprehension can be particularly pronounced among older operators who are less familiar with digital technologies. To address these issues, comprehensive training and education programs are essential. These programs should be designed to simplify the adoption process by providing hands-on training, easy-to-understand guides, and ongoing support to help operators build confidence in using smart technologies.

Another factor is the concern about the financial risks associated with adopting new technologies. Many operators fear that investments in smart aquaculture will not yield the expected returns, particularly in the short term. This financial anxiety can lead to a preference for maintaining the status quo rather than taking on the perceived risks of innovation. Addressing this resistance requires demonstrating the long-term economic benefits of smart aquaculture, such as increased efficiency, reduced waste, and improved product quality. Additionally, providing financial incentives, such as subsidies, grants, or low-interest loans, can help alleviate the financial burden and encourage adoption.

Cultural and generational factors also contribute to resistance to change. In some cases, a deep-rooted attachment may exist to traditional methods, with operators viewing smart technologies as a threat to their way of life. Engaging with these communities and involving them in the development and implementation of smart aquaculture solutions can help build trust and acceptance. Showcasing successful case studies from similar operations can also serve as powerful motivators, illustrating that smart technologies can complement rather than replace traditional practices.

Ultimately, addressing resistance to change in the aquaculture industry requires a multifaceted approach that combines education, financial support, and community engagement to facilitate a smooth transition toward smart aquaculture practices.

9. FUTURE DIRECTIONS AND INNOVATIONS IN SMART AQUACULTURE

- Emerging Technologies in Aquaculture
- Future of AI and IoT in Aquaculture
- Vision for a Sustainable and Smart Aquaculture Industry

9.1. Emerging Technologies in Aquaculture

Emerging technologies are set to revolutionize aquaculture, driving the industry toward greater efficiency, sustainability, and productivity. These innovations expand the capabilities of smart aquaculture, offering new tools and methods for managing aquatic environments, optimizing resource use, and enhancing the quality and yield of farmed species.

Artificial Intelligence (AI) and Machine Learning: AI and machine learning technologies are becoming increasingly integral to smart aquaculture, enabling more precise control and decision-making. These technologies can analyze vast amounts of data collected from sensors and other monitoring devices, identifying patterns and predicting outcomes that would be difficult for humans to discern. For instance, AI-driven systems can optimize feeding schedules based on real-time data on fish behavior and environmental conditions, thereby reducing waste and improving growth rates.

Blockchain Technology: Blockchain is emerging as a key technology for enhancing aquaculture transparency and traceability. By providing a secure and immutable record of every stage of the production process, from hatchery to harvest, blockchain ensures that consumers and regulators can verify the sustainability and origin of aquaculture products. This technology can also help to combat fraud and ensure compliance with environmental and food safety standards.

Advanced Bioengineering: Innovations in bioengineering, including the development of genetically modified organisms (GMOs) and selective

breeding techniques, are poised to play a significant role in the future of aquaculture. These technologies can create strains of fish and shellfish that grow faster, are more resistant to disease, and require fewer resources. Although regulatory and ethical considerations are involved, the potential benefits for productivity and sustainability are substantial.

Nanotechnology: Another emerging field with promising applications in aquaculture. Nanomaterials can improve water quality, enhance the delivery of nutrients and medications, and create more efficient filtration systems. For example, nanoparticles can be engineered to target specific pathogens or pollutants, thereby reducing the need for broad-spectrum antibiotics and minimizing environmental impact.

Aquaponics and Vertical Farming: Aquaponics, which combines aquaculture with hydroponics, and vertical farming are innovative approaches that are gaining traction in urban and resource-limited environments. These systems allow for efficient use of space and resources, with fish and plants growing in a symbiotic relationship. The integration of smart technologies into these systems can further enhance their efficiency and scalability, providing viable solutions for sustainable food production.

These emerging technologies are poised to drive the next wave of innovation in aquaculture, helping the industry meet the growing global demand for seafood while addressing environmental and sustainability challenges.

9.2. Future of Artificial Intelligence and the Internet of Things in Aquaculture

Artificial Intelligence (AI) and the Internet of Things (IoT) are set to play increasingly pivotal roles in the future of aquaculture, driving significant advancements in efficiency, sustainability, and precision. The convergence of these technologies will enable aquaculture operations to become more intelligent, adaptive, and responsive, fundamentally transforming the way in which aquaculture is conducted.

Advanced Predictive Analytics: As AI algorithms become more sophisticated, they will be able to predict and optimize various aspects of aquaculture with greater accuracy. This includes forecasting growth rates,

disease outbreaks, and environmental changes, allowing farmers to make proactive decisions that minimize risks and enhance productivity. Machine learning models will continue to evolve, learn from historical data, and improve their predictions over time, leading to more efficient resource use and better management practices.

Automated and Autonomous Systems: Integrating AI with IoT will lead to the development of fully automated and autonomous aquaculture systems. These systems will be capable of managing daily operations with minimal human intervention, from feeding and water quality monitoring to waste management. Autonomous drones and underwater robots equipped with AI perform tasks such as inspecting nets, monitoring fish health, and collecting data in real time, significantly reducing labor costs and improving operational efficiency.

Enhanced Precision Farming: IoT devices, such as smart sensors and connected platforms, will continue to improve the precision of aquaculture operations. These devices collect detailed data on water parameters, fish behavior, and environmental conditions, which AI systems analyze to optimize farming practices. For example, precision feeding systems use real-time data to deliver the exact amount of feed needed, thereby reducing waste and improving growth rates. This level of precision will enable farmers to fine-tune their operations to maximize efficiency and minimize environmental impact.

Data-Driven Decision Making: The future of aquaculture will increasingly rely on data-driven decision-making processes that use AI and IoT. Cloud-based platforms will aggregate data from multiple sources, providing farmers with comprehensive insights into their operations. These platforms will offer actionable recommendations based on AI analysis, enabling farmers to optimize their strategies and achieve better outcomes. This shift toward data-driven practices will not only improve efficiency but also enhance the sustainability of aquaculture operations by reducing resource use and minimizing environmental impact.

Scalability and Global Integration: As AI and IoT technologies become more accessible and affordable, their adoption will scale across the global aquaculture industry. This will lead to more connected and integrated

systems in which data from farms worldwide can be shared and analyzed collaboratively. Such global integration will facilitate the dissemination of best practices, enable the development of global standards, and support the growth of a more sustainable and resilient aquaculture industry.

The future of AI and IoT in aquaculture promises to unlock new levels of efficiency, sustainability, and innovation, driving the industry toward a smarter, more interconnected future.

9.3. Vision for a Sustainable and Smart Aquaculture Industry

The future of aquaculture represents an industry that is not only highly productive but also deeply committed to sustainability, driven by the integration of advanced technologies and smart practices. This vision encompasses the creation of aquaculture systems that are efficient, environmentally responsible, and capable of meeting the growing global demand for seafood while preserving natural ecosystems.

Holistic Ecosystem Management: The future of smart aquaculture involves managing aquaculture operations as part of a broader ecosystem. This approach ensures that farming practices are aligned with environmental conservation goals and minimizes the ecological footprint of aquaculture activities. Technologies like AI and IoT will play a crucial role in monitoring and managing such ecosystems, enabling real-time adjustments that will protect biodiversity, water quality, and habitat integrity.

Closed-Loop Systems and Resource Efficiency: A key element of this vision is the widespread adoption of closed-loop systems that maximize resource efficiency. In such systems, waste from one process is reused as input for another, creating a circular economy within aquaculture operations. For example, nutrient-rich effluent from fish tanks can be used to fertilize plants in aquaporin systems, thus reducing the need for external inputs and minimizing waste. Advanced filtration and recirculation technologies will further enhance water conservation and quality, making aquaculture more sustainable.

Sustainable Feed and Breeding Practices: The industry will increasingly focus on sustainable feed sources and responsible breeding practices. This includes developing alternative feed ingredients, such as insect protein or algae, that reduce reliance on wild-caught fishmeal and fish oil.

Additionally, selective breeding and genetic innovations will produce strains of fish and shellfish that are more resilient, require fewer resources, and are better suited to farmed environments, all while maintaining or improving product quality.

Global Collaboration and Knowledge Sharing: A sustainable and smart aquaculture industry will be characterized by global collaboration and knowledge sharing. The integration of digital platforms and cloud-based technologies will allow producers around the world to share data, insights, and best practices, fostering a culture of continuous improvement. This collaborative approach will help standardize sustainable practices across regions, ensuring that smart aquaculture benefits are realized globally.

Consumer Engagement and Transparency: This vision also includes greater transparency and consumer engagement, with technology enabling traceability from farm to fork. Blockchain and other traceability technologies will allow consumers to access detailed information about the origins and sustainability of their seafood, building trust and driving demand for responsibly produced products. This transparency will encourage producers to adhere to higher standards of sustainability and ethical practices.

In summary, the vision for a sustainable and smart aquaculture industry is one in which technological innovation and environmental stewardship go hand in hand, creating a resilient, efficient, and globally interconnected industry that supports both human needs and the health of the planet.

10. CONCLUSION

In conclusion, the transition to smart aquaculture represents a transformative shift in the industry, offering unprecedented opportunities to enhance efficiency, sustainability, and productivity. Key insights from this exploration highlight the critical role of emerging technologies, such as AI, IoT, and blockchain, in optimizing aquaculture practices. These innovations enable precise monitoring and control, allowing for more efficient resource use, improved animal welfare, and reduced environmental impact. Moreover, the integration of these technologies facilitates better decision-making through data-driven approaches, ensuring that aquaculture operations can adapt to changing conditions and challenges. The way forward for smart aquaculture

development involves addressing the challenges and barriers that currently hinder widespread adoption. This includes overcoming technological hurdles, such as the need for reliable and interoperable systems, as well as economic and regulatory barriers that can hinder smaller operators from investing in and implementing smart technologies.

Additionally, fostering an innovation and collaborative culture within the industry is essential. By engaging stakeholders such as producers, policymakers, and technology developers, the industry can accelerate the adoption of smart practices and ensure that these innovations are accessible and beneficial to all. Education and training programs are vital to equipping the next generation of aquaculture professionals with the skills needed to leverage these technologies effectively. The implications for global food security are profound. As the global population continues to grow, the demand for sustainable and reliable food sources will also become increasingly critical. Smart aquaculture offers a viable solution to meet this demand by enhancing the productivity and sustainability of aquaculture farming. By producing more seafood with fewer resources and fewer environmental impacts, smart aquaculture can significantly contribute to global food security. Furthermore, the ability to trace and verify the sustainability of aquaculture products through technologies like blockchain will help build consumer trust and support the shift toward more responsible and sustainable consumption patterns. In essence, the future of aquaculture lies in its ability to innovate and adapt, integrating advanced technologies to create systems that are not only more productive but also aligned with sustainability principles. This vision of a smart, sustainable aquaculture industry is not just an opportunity for growth but a necessity for ensuring that we can meet future generations' nutritional needs while preserving the health of our planet.

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CHAPTER 11

USE OF FERMENTED SOYBEAN IN AQUACULTURE FEED

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INTRODUCTION

Fish production plays a critical role in feeding the world's population, supporting livelihoods and sustaining marine ecosystems. As one of the most widely consumed animal proteins in the world, fish provides essential nutrients, including omega-3 fatty acids, vitamins and minerals, which are essential for human health. In many coastal and developing countries, fish farming and wild capture fisheries are important sources of employment and income, directly benefiting millions of people. In addition, sustainable fish production helps conserve biodiversity and supports marine conservation efforts. As demand for seafood continues to grow, responsible fish production practices such as aquaculture and sustainable fishing are key to ensuring food security, environmental health and economic stability for future generations (Finegold, 2009); (Hua et al. 2019).

Aquaculture production has surpassed fishing for the first time, marking a new high in global fisheries and aquaculture production in 2022. Global production of fisheries and aquaculture increased to 223.2 million tonnes in 2022, and 4.4 % rise from 2020. According to the FAO report 37.8 million tonnes of algae and 185.4 million tons of aquatic animals were produced. Aquaculture production reached 130.9 million tonnes, of which 94.4 million tonnes were aquatic animals, representing half of the world fisheries production (FAO, 2024).

Turkey's aquaculture production has shown a significant development especially in the last decade in parallel with the development in the world. The amount of Turkey aquaculture production has exceeded the amount of fisheries production since 2020 due to the increase in capacity and the cultivation of new alternative species. According to BSGM data, Turkey's aquaculture production in 2023 was around 850,000 tonnes, of which 514,805 tonnes came from aquaculture and 335,000 tonnes from fisheries (BSGM, 2023).

The most important resource for the development of aquaculture is fish feed. Fish feed is critically important in global aquaculture, as it directly influences the growth, health, sustainability, and profitability of aquaculture systems. In commercial aquaculture, feed accounts for around 40-60% of the entire production costs, making it a crucial input. Fish feed has a significant impact on the growth, health, and productivity of farmed fish and is essential to the sustainable growth of aquaculture. High quality, nutritionally balanced

feeds ensure that fish receive the essential nutrients required for optimal growth, reproduction and disease resistance, thereby increasing the overall yield and profitability of aquaculture operations (Kumaraguru et al., 2015); (Boyd ve McNevin, 2022); (Sathishkumar et al. 2021); (Zlaugotne et al. 2022).

The main protein and lipid sources in aquaculture feeds are fishmeal and fish oil (Hodar et al. 2020). Fishmeal is an excellent source of fish feed with high protein, amino acid composition, long chain omega-3 fatty acids, EPA and DHA, calcium, phosphorus, magnesium, potassium and selenium and Fish oil is an excellent source of energy for fish, with a rich composition of fatty acids to meet their requirements (Einarsson et al. 2019). As aquaculture production increased, the amount of fishmeal and fish oil used in feed also increased, causing the prices of these raw materials and the cost of fish production to rise rapidly. Due to the problems caused by fishmeal and fish oil, most recent studies have focused on finding potential alternatives to fishmeal and fish oil for use in aquaculture diets (Glencross et al. 2007).

Plant protein sources ((soybeans, wheat, grains or oilseeds, peas, etc.) are the best alternative to fishmeal because they provide the right amount of protein, are inexpensive, stable and are available from a wide variety of sources. Beside this the main reasons for using plant ingredients in aquafeeds are their amino acid profile, energy density, fiber, and nutrient absorption. But there are some disadvantages of plant proteins compared to fish meal, such as high cellulose content, unbalanced amino acid profile and lack of some EAAs, i.e. lysine, tryptophan and methionine, and low palatability. Plant ingredient also have anti-nutritional factors (ANFs), as a phytic acid and inhibitors (Hussain et al. 2024); (Jannathulla et al. 2019).

In aquafeed, soybean meal (SBM) has been identified as one of the best substitute protein sources for fishmeal due to its extensive availability, sustainable supply, low price, high level of protein (45–50%), and suitable amino acid profile (Lin and Lou, 2011); (Hussain et al. 2024) (Meng et al.2020). Despite its many benefits, soybean meal has a number of nutritional disadvantages compared to fishmeal, including low protein, mineral and vitamin content, poor palatability, a high concentration of anti-nutritional factors (ANFs) and a lack of several key amino acids (Lim et al. 2011); (Zhu et al. 2020).

Considering the importance of soybean meal in fish feed, it has become very important to reduce or eliminate the adverse effects associated with its nutritional content. During feed extrusion and infrared micronisation, anti-nutritional factors can be reduced. In addition, processed (solvent and heat treated) soy protein concentrates have low concentrations of many anti-nutritional factors. The suitability of soybean meal as an alternative protein source in fish diets can also be improved by fermentation (Francis et al. 2001); (Barrows et al. 2007); (Barnes et al. 2012)

Fermentation technology has played an important role in feed production in recent years. After fermentation with microorganisms, crude protein, free amino acids, active components such as small peptides and soy isoflavones have been increased, nutrient availability and palatability are improved while a large number of anti-nutritional factors have been degraded (Song et al. 2008); (Shi et al. 2017); (Qin et al. 2023).

FERMENTATION PROCESS OF SOYBEAN

Fermentation is a traditional, inexpensive and effective method of processing food. It converts plant raw materials into more functional and palatable foods through microbial growth and enzymatic activity (Xie and Gänzle, 2023). Fermentation is a biological process in which carbohydrates in the raw material are converted to lactic acid or ethanol and carbon dioxide in an anaerobic environment.

The fermentation of soybeans is generally carried out in either a solid-state or a submerged mode, or a combination of the two processes (Elhalis et al. 2023). The main difference between these two fermentation processes is the amount of free water in the substrate (Ghorbel ve Koşum, 2023).

Submerged fermentation, also known as liquid fermentation, uses free-flowing liquid substrates such as broth, whey, molasses, etc. Bioactive compounds are secreted into the fermentation broth. During the fermentation the substrates are used up very rapidly, so they require constant replacement/supply of nutrients. This fermentation technique is best suited for microorganisms such as bacteria that require a high moisture content (Singhania, 2011); (Subramaniam and Vimala, 2012).

Solid culture fermentation is the growth and metabolic activity of microorganisms on moist or humidified solid substrates without free water. In

this method, water for microbial growth is provided by moisture in the substrate. In solid culture fermentation, the substrates are used at a very slow and steady rate, so that the same substrate can be used for long periods of fermentation. Thus, the technology is conducive to controlled nutrient release. This fermentation technique is best suited to fermentations with fungi and microorganisms requiring lower humidity (Subramaniam and Vimala, 2012); (Ghorbel ve Koşum, 2023).

A simple representation of the differences in the fermentation process is shown in Figure 1.

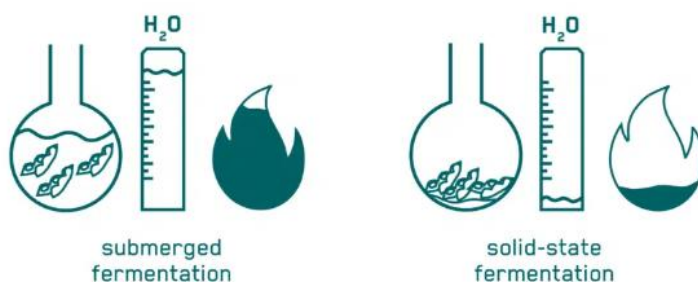


Figure 1. Main differences between submerged and solid-state fermentation

Source: European Protein (<https://www.europeanprotein.com/what-is-fermented-soybean-meal/>)

Compared to submerged fermentation systems, solid-state fermentation has several advantages, such as reduced energy and water requirements, increased production, and a decreased need for sterility (Wang et al. 2023).

The fermentation process involves the use of specific microbial cultures that break down complex compounds in soybean meal, improving its nutritional profile and reducing anti-nutritional factors. Fermentation initiates enzymatic activity that breaks down large, complex proteins into smaller peptides and amino acids that are more easily absorbed by fish. Key anti-nutritional compounds such as trypsin inhibitors and lectins are also significantly reduced. Fermentation also increases the levels of beneficial metabolites such as organic acids and certain vitamins, which can improve gut health and immunity in fish. The fermentation process can use solid state fermentation or submerged

fermentation or both, but the common point is the microorganisms used during fermentation. For microbial fermentation, a fungus or a bacterial species are used. However, these microorganisms must be selected according to the moisture content of the product used. Lactic acid bacteria, *Bacillus* spp, yeast strains and fungi species (*Aspergillus* genus) are commonly used in the fermentation of SBM. These microorganisms produce enzymes that break down proteins, fibres and ANFs, resulting in a nutrient-dense and highly digestible product suitable for aquafeeds (Kiers et al. 2000); (Song et al. 2008); (Noaman et al. 2015); (Mukherjee et al. 2016); (Qin et al.2023).

A simple schematic diagram of soybean meal solid-state fermentation is shown in Figure 2.

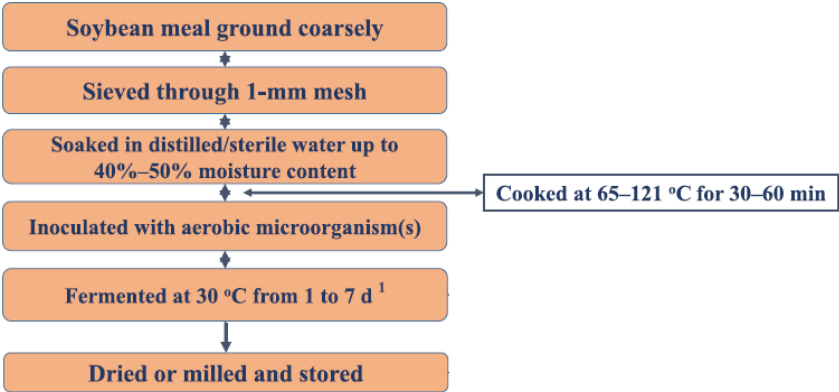


Figure 2. Schematic diagram of the solid state fermentation of soybean meal

Source: (Lambo et al. 2023)

The effects of fermentation and microorganisms used in fermentation on soybean nutrient content are given in Table 1 (Mukherjee et al. 2016).

Table 1. Nutrient quality comparison of unfermented, fungus-fermented, and bacterially-fermented soybean meal

Nutritional components affected by fermentation	Unfermented soybean meal	Fermented soybean meal	
		Types of organism used for fermentation	
		Fungi	Bacteria
Crude protein content (0/0)	34.5	37.4	37.5
Soluble protein content 0%)	20	24	33
In-vitro digestibility (pepsin)	60.5	67.4	76
Anti-oxidant activity 0%)	8	27	38
Small-sized peptides (<15 kD) %	5	35	63

(Mukherjee et al. 2016)

ADVANTAGES AND DISADVANTAGES OF THE USE FERMENTED SOYBEAN IN ANIMAL FEED

Fermentation process causes many positive changes on soybean meal which is very important for fish feed. These can be listed as follows (Mukherjee et al. 2016); (Shi et al. 2017); (Qin et al. 2023); (Lambo et al. 2023); (Siddik et al. 2024).

- 1. Improved digestibility: Fermentation breaks down complex proteins and carbohydrates, making nutrients more accessible to the fish, leading to better growth rates and feed conversion.
- 2. Improved nutritional profile: Fermented soybeans can have higher levels of certain vitamins, amino acids and beneficial compounds such as probiotics that can support fish health.
- 3. Reduced anti-nutritional factors: Fermentation helps to reduce compounds such as oligosaccharides and trypsin inhibitors that can negatively affect fish digestion and nutrient absorption.

4. Improved palatability: The fermentation process can enhance the flavour and aroma of the feed, making it more appealing to fish, which can improve feed intake.

5. Improved gut health: Fermented products can introduce beneficial microorganisms that support a healthy gut microbiome, potentially improving disease resistance.

6. Environmental benefits: Fermentation can be more sustainable by reducing waste and enhancing the nutritional value of feed, resulting in lower overall feed requirements.

7. Increased bioactive compounds: Fermented soy can produce bioactive peptides that may have health-promoting properties, contributing to overall fish health and immunity.

These benefits make fermented soybean a valuable ingredient in aquaculture, supporting both fish growth and overall health.

In addition to the benefits above, there are also some potential disadvantages of using fermented soybean in feed (Dai et al. 2020); (Siddik et al. 2024):

1. Nutrient variability: The fermentation process can lead to variability in nutrient content depending on the strains of micro-organisms used and the fermentation conditions, making it more difficult to ensure consistent feed quality.

2. Digestibility problems: Fermentation can improve the digestibility of certain nutrients. However, it can also reduce the bioavailability of others.

3. Shelf life: Fermented products may have a shorter shelf life due to microbial activity, requiring careful drying, storage and management to prevent spoilage.

4. Processing requirements: The fermentation process requires additional steps, equipment and time, which can complicate feed production and supply chains.

5. Flavour issues: While fermentation can improve palatability, some fish species may be sensitive to the flavour changes, which could reduce feed acceptance in certain cases.

6. Risk of contamination: There is a potential risk of pathogenic micro-organisms if fermentation conditions are not strictly controlled, which could be detrimental to fish health.

These factors must be carefully considered when deciding whether to use fermented soybeans in aquaculture feeds.

In recent years, fermented soybean meal has been used in aquaculture to substitute fishmeal due to its nutritional benefits.

APPLICATION OF FERMENTED SOYBEAN MEAL IN AQUAFEED

In recent years, fermented soybean meal has been used in aquaculture to substitute fishmeal due to its nutritional benefits. The inclusion rate of fermented soybean in feeds and its effects on fish meal substitution rates vary according to species. However, most of the studies show that fermented soybean is an important resource for the sustainability of aquaculture.

An overview of studies examining the use of fermented soy meal (FSBM) as a substitute for fish meal (FM) in aquatic organisms has given in Table 2. Studies on the use of fermented soybean meal (FSBM) in the nutrition of aquatic organisms are given in Table 2.

As indicated in Table 2, fermented soybean has been applied as a substitute for fish meal in the diets of numerous aquatic species. Nevertheless, no studies have been identified that examine the use of fermented soybean meal in the diets of sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*), which are intensively cultivated in the Mediterranean region. However, studies on some carnivorous marine fish that utilise fermented soybean meal indicate that this raw material can also be employed in the diets of sea bass and sea bream species (Pang et al. 2023); (Dan et al. 2022).

Table 2. The utilisation of fermented soybean (FSBM) as a substitute for fishmeal (FM) in the diet of aquatic organisms

Species	Duration	Effects	References
Pacific white shrimp, <i>Litopenaeus vannamei</i>	8 weeks	Without affecting shrimp's immunological and antioxidant capacities, FSBM can substitute 25% of the fish meal.	Chen et al. 2024
Coho Salmon, <i>Oncorhynchus kisutch</i>	12 weeks	Diets containing 18% FM protein and 10% FSBM protein had a positive effect on growth performance, protein deposition, antioxidant enzyme activity, digestive	Zang et al. 2023

		enzyme activity, and protein synthesis of juvenile coho salmon compared to diets containing 28% FM protein.	
Pearl gentian grouper (hybrid)	10 weeks	Pearl grouper suffering from intestinal inflammation due to high substitution of FSBM for fish meal (%20 ve %40)	Pang et al. 2023
Largemouth Bass, <i>Micropterus salmoides</i>	8 weeks	FSBM could replace 100g/kg fishmeal in a 350g/kg fish meal diet without negative effects on the growth, feed utilization and intestinal health of largemouth bass.	Yang et al. 2022
African Catfish, <i>Clarias gariepinus</i>	8 weeks	The growth performance and health of <i>C. gariepinus</i> could be improved by replacing 40% FSBM with fish meal in aquafeed.	Zakaria et al. 2022
Turbot, <i>Scophthalmus maximus</i>	10 weeks	Fish fed diets containing 45% FSBM increased growth and feed intake compared with equal levels of SBM, but no difference was found with the 55% FM control.	Dan et al. 2022
Largemouth bass, <i>Micropterus salmoides</i>	8 weeks	FSM could substitute 30% FM in the diet without having a negative effect on growing performance	He et al. 2020
Rainbow trout, <i>Oncorhynchus mykiss</i>	8 weekss	Fish meal could be replaced by 40% FSBM without any negative effect on growth and feed conversion.	Choi et al. 2020
Barramundi, <i>Lates calcarifer</i>	75 days	Apparent protein digestibility coefficient improved by replacing 75% of fish meal with fermented soybean meal	Ilham and Fotedar, 2017
Orange-spotted grouper, <i>Epinephelus coioides</i>	84 days	FM was substituted by 29.32% using FSBM.	Chiu and Liu, 2015
Nile tilapia, <i>Oreochromis niloticus</i>	84 days	The optimal growth rate was observed at an inclusion level of 37.4% fermented soybean meal, which replaced 50% of the fish meal. This resulted in a notable improvement in the physiological indices.	Hassaan et al. 2015

Black sea bream, <i>Acanthopagrus schlegeli</i>	8 weeks	Increased survival and specific growth rate compared to the control group when the 40% fish meal was replaced by FSBM in diets supplemented with methionine, taurine and lysine.	Azarm and Lee, 2014
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The utilisation of fermented soy as a substitute for fish meal in aquatic feeds represents one of the most extensively researched topics in recent years. The majority of studies indicate that fermented soybean meal can be employed as a substitute for fish meal at varying ratios. Nevertheless, there are some constraints associated with this approach. The microorganisms selected for the fermentation process must be capable of producing the target metabolites, including enzymes, acids, alcohols, vitamins, and other compounds, in sufficient quantity and quality to support optimal fish health. Furthermore, the microorganisms employed in the fermentation process must not pose a contamination risk that could negatively impact fish health. The quality and composition of the final product are dependent on the microbial population, fermentation time, and temperature. Consequently, alterations in these factors can lead to variations in the product's quality. For instance, an extended fermentation period may result in a decline in protein quality and amino acid structure, potentially impairing fish growth and feed efficacy (Siddik et al: 2023); (Dai et al. 2020).

CONCLUSION

Despite the advantages offered by the use of fermented soybean in aquaculture, a number of challenges remain. These include the variability inherent in fermentation processes, the need for quality control, and the economic constraints that must be taken into account. It is imperative that the fermentation process is consistent and that FSM products are standardised in order to guarantee reliable results across a range of aquaculture operations. Further research is required to optimise fermentation conditions, identify suitable microbial strains, and evaluate the long-term impacts on fish health and performance across species. The development of more efficient, scalable fermentation technologies could significantly enhance the accessibility of FSM for aquaculture, thereby making it a more viable alternative to traditional fish

meal. The ongoing shift towards sustainable aquaculture practices further underscores the need for research and development in alternative protein sources such as FSM.

The use of fermented soybean as an ingredient in fish feed formulations is becoming increasingly prevalent, particularly as a sustainable alternative to fish meal. Fish meal has historically constituted a principal protein source in aquaculture feeds. However, its elevated cost and environmental impact resulting from overfishing have prompted the pursuit of alternative ingredients. The fermentation of soybean represents a viable solution, as the process enhances the nutritional profile of the resulting product by increasing protein digestibility, reducing anti-nutritional factors, and improving the availability of essential amino acids and micronutrients. Furthermore, the fermentation process can yield beneficial bioactive compounds, which can further promote fish health and growth. By substituting fish meal with fermented soybean, aquaculture operations can reduce their reliance on wild-caught fish, improve sustainability, and provide a more cost-effective, nutritionally balanced feed for farmed fish.

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CHAPTER 12

MICROPLASTICS IN AQUAFEEDS

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INTRODUCTION

MICROPLASTICS IN AQUAFEEDS

The prevalence of microplastics (MPs) in commercial aquafeeds is a growing concern, as these contaminants can significantly impact aquatic organisms and food safety. Research indicates that microplastics are commonly found in aquafeeds, originating from various sources, including the breakdown of larger plastic debris and wastewater treatment processes (Su et al. 2024; Bhusare et al. 2024). The ingestion of these particles by aquatic species can lead to detrimental health effects, including impaired growth, immune response issues, and even neurotoxicity (Nabi et al. 2024; Ghanem, 2024).

SOURCES OF MICROPLASTICS IN AQUAFEEDS

Microplastics (MPs) enter commercial aquafeeds through various pathways, primarily stemming from environmental contamination and inadequate management practices. The presence of MPs in aquafeeds poses significant risks to both aquatic organisms and human health, necessitating a thorough understanding of their sources and entry mechanisms. While the focus on microplastics in aquafeeds is critical, it is also essential to consider the broader implications of plastic pollution in aquatic environments, which can affect entire ecosystems and food chains, highlighting the need for comprehensive environmental management strategies.

Major contributors to microplastic pollution in aquatic environments (Bhusare et al. 2024). Feed Production: Contamination during the manufacturing process of aquafeeds (Su et al. 2024). MPs are prevalent in aquatic ecosystems due to direct emissions and fragmentation of larger plastic debris, which can be absorbed by feed ingredients (Ali et al. 2023; Ghanem, 2024).

The use of plastic materials in packaging and storage of feed ingredients contributes to contamination. Studies indicate that all fish feed samples analyzed contained MPs, with a mean abundance ranging from 500 to 2200 MPs/kg (Siddique et al. 2023). The manufacturing and packaging processes of aquafeeds can introduce MPs, especially if plastic materials are used in equipment or storage (Siddique et al. 2023).

Recirculating aquaculture systems (RAS) can accumulate MPs from source water and operational materials, with significant concentrations found in both feed and fish (Zhou et al. 2024).

Fish meal and other marine-derived components are often contaminated with MPs, as they are sourced from environments heavily polluted with plastics (Jeyasanta et al. 2024). Ingredients derived from agricultural sources can also contain MPs, particularly when these materials are processed or stored in plastic containers (Muhib & Rahman, 2023). Fish meal derived from dried fish is particularly susceptible to MP contamination, with reported levels ranging from 210 to 1154 items/kg (Jeyasanta et al. 2024).

Feed made from agricultural sources also contains MPs, with concentrations reaching up to 11,600 particles/kg (Muhib & Rahman, 2023).

Water used in aquaculture can introduce MPs, especially if sourced from polluted environments (Wicaksono, 2022).

CHARACTERISTICS OF MICROPLASTICS IN AQUAFEEDS

Types and Sizes: Common polymers found in aquafeeds include polyethylene (PE), polypropylene (PP), and polyvinyl chloride (PVC), with sizes ranging from 14 μm to 4480 μm (Muhib & Rahman, 2023; Jeyasanta et al. 2024). Common polymers found in aquafeeds include polypropylene (PP), polyethylene terephthalate (PET), and nylon-6 (NY-6) (Muhib & Rahman, 2023).

Microplastics in feeds typically range from 14 μm to 4480 μm , with fiber-shaped particles being predominant (Zhou et al. 2024). Studies report that fish feeds can contain between 500 to 11,600 MPs per kg, with no significant differences across various feed types (Siddique et al. 2023; Muhib & Rahman, 2023).

While the focus has been on the contamination pathways, it is essential to consider the potential for mitigation strategies. Addressing the sources of MPs in aquafeeds could significantly enhance food safety and sustainability in aquaculture. However, the challenge remains in the lack of standardized methods for monitoring and assessing MP contamination (Su et al. 2024).

Polyethylene (PE) is the most prevalent type, constituting approximately 37.71% of identified microplastics. Polyvinyl Chloride (PVC) accounts for

about 27.14% of the microplastics found. Polypropylene (PP) represents around 22.08% of the contamination. Polyethylene Terephthalate (PET) comprises about 13.07% of the microplastics detected (Siddique et al. 2023).

Additional plastics such as polystyrene (PS) and polyamide (PA) have also been reported in aquaculture systems (Egea-Corbacho et al. 2023; Miserli et al. 2023).

IMPACT ON AQUATIC ORGANISMS

Microplastics can accumulate in the tissues of fish, leading to health issues such as intestinal damage (Bhusare et al. 2024). Microplastics can move through food webs, affecting higher-order predators and altering ecosystem Dynamics (McHale & Sheehan, 2024).

MPs can carry heavy metals and other contaminants, posing additional health risks to farmed fish and, subsequently, to humans consuming these fish (Muhib & Rahman, 2023; Jeyasanta et al. 2024).

The ingestion of microplastics by aquatic organisms can lead to adverse health effects, including growth impairment and potential transfer to human consumers (Su et al. 2024; Miserli et al. 2023). Microplastic ingestion has significant physiological effects on fish health and development, impacting various biological systems. Research indicates that the size and concentration of microplastics play crucial roles in determining the extent of these effects, leading to compromised growth, altered behavior, and reproductive issues.

Environmental Concerns: The accumulation of microplastics in aquaculture systems raises significant concerns regarding sustainability and food safety (Yao et al. 2021).

The impact of microplastics on juvenile fish varies significantly with particle size, influencing growth rates and survivability. Research indicates that smaller microplastics tend to have more detrimental effects compared to larger ones, affecting physiological parameters and overall health. Smaller microplastics (25-50 μm) led to reduced weight gain and specific growth rates in juvenile striped catfish, with the lowest survivability recorded at 65% (Shahriar et al. 2024).

Smaller microplastics (25-50 μm) significantly reduce weight gain and specific growth rates in juvenile striped catfish, with a notable decrease in survivability (65% in smaller microplastics) (Shahriar et al. 2024).

In tilapia, a significant decline in growth metrics was observed at higher microplastic concentrations, particularly at 1 mg per 0.75 g of feed (Putrajab et al. 2024). Exposure to microplastics inhibited hatching and decreased growth rates in European perch larvae, altering their feeding behaviors and increasing predator vulnerability (Lönnstedt & Eklöv, 2016). In zebrafish, smaller polystyrene nanoplastics (80 nm) caused neurodevelopmental issues, while larger sizes induced oxidative stress (Chen et al. 2024).

Histological analyses revealed that smaller microplastics caused severe intestinal abnormalities across various fish species, indicating a direct link between microplastic size and physiological stress (Zhang et al. 2023). Conversely, while smaller microplastics generally pose greater risks, larger microplastics can still induce significant physiological stress, albeit to a lesser extent. This suggests a complex interaction between microplastic size and the health of juvenile fish. Intestinal Damage: Histopathological examinations reveal severe intestinal deformities, such as epithelium degeneration and mucosal atrophy, particularly with smaller microplastics (Shahriar et al. 2024).

While the evidence predominantly highlights detrimental effects, some studies suggest that microplastics may have neutral impacts on certain physiological processes, indicating a complex interaction that warrants further investigation (Hossain & Olden, 2022).

Ingestion of microplastics leads to decreased hemoglobin and blood glucose levels, indicating stress and potential anemia (Shahriar et al. 2024).

Microplastics induce neurobehavioral abnormalities, affecting social interactions and cognitive functions due to altered neurotransmitter levels (Arman et al. 2024).

Microplastics can disrupt endocrine signaling, leading to delayed egg production and reduced offspring viability in fathead minnows (Bucci et al. 2024). This disruption can impair reproductive success, affecting population dynamics.

MITIGATION AND PREVENTION STRATEGIES

To mitigate the impact of microplastics in aquaculture systems, several strategies can be implemented that focus on prevention, removal, and regulation. These strategies aim to address the sources of microplastics and their effects on aquatic organisms and food safety.

Implementing better practices to reduce plastic waste entering aquatic systems. Establishing policies to oversee microplastic pollution in aquaculture. Implementing stringent monitoring protocols and regulations can help manage MP pollution in aquaculture (Ghanem, 2024). Transitioning to non-plastic packaging for feed ingredients can significantly reduce contamination risks (Siddique et al. 2023).

While the focus on microplastics in aquafeeds highlights significant risks, it is essential to consider the broader implications of plastic pollution on entire aquatic ecosystems, which may also suffer from reduced biodiversity and altered food web dynamics due to microplastic contamination (McHale & Sheehan, 2024; Nabi et al. 2024).

Ensuring that aquafeeds are free from microplastics by enhancing production processes can minimize contamination (Su et al. 2024). Implementing improved wastewater treatment processes can capture microplastics before they enter aquatic environments (Samuel et al. 2024). Strengthening management practices to intercept microplastics in aquaculture systems can help reduce their prevalence (Ghanem, 2024).

Developing plastic products that are reusable or made from biodegradable materials can significantly reduce microplastic generation at the source (Samuel et al. 2024). Biodegradable ingredients, particularly polyhydroxyalkanoates (PHA), play a significant role in developing aquafeeds aimed at minimizing microplastic contamination. These biopolymers, produced by microbes, serve as sustainable alternatives to conventional plastics and can be integrated into aquaculture feeds. Their application not only reduces reliance on traditional plastic but also addresses the issue of microplastic pollution in aquatic environments.

PHA can enhance the nutritional profile of aquafeeds, acting as single-cell proteins and improving growth and gut health in aquatic species (Asiri, 2024). The use of biodegradable plastics in aquaculture can potentially lower the amount of microplastics entering marine ecosystems, as they are designed to break down more readily than conventional plastics (Widjajanti & Rohendi, 2023).

CHALLENGES AND CONSIDERATIONS

The high cost of producing PHA and other biodegradable materials remains a barrier to widespread adoption in aquafeeds (Asiri, 2024). While biodegradable plastics can reduce microplastic pollution, they may still produce biodegradable microplastics (BMPs) that can be harmful to aquatic life. In contrast, while biodegradable ingredients offer promising solutions, their effectiveness in completely mitigating microplastic contamination is still under scrutiny, as some biodegradable materials may not fully degrade in natural conditions, potentially leading to new environmental challenges (Mut et al. 2024)

REGULATORY MEASURES

Establishing and enforcing regulations regarding plastic waste management is crucial for controlling microplastic pollution (Ghanem, 2024). Educating stakeholders about the risks of microplastics and promoting sustainable practices can foster community involvement in mitigation efforts (Singh et al. 2024).

The effectiveness of regulatory frameworks within the aquafeed industry is profoundly shaped by enforcement challenges, which often result in compliance gaps and elevated operational costs. These challenges typically arise from insufficient monitoring mechanisms and the industry's dynamic and evolving nature, which complicates effective regulatory oversight. The sections that follow provide a detailed examination of the key factors through which enforcement difficulties influence the overall efficacy of regulatory measures.

Regulatory costs can account for a substantial portion of production expenses, with U.S. tilapia farms facing on-farm regulatory costs averaging 15% of total production costs (Engle et al. 2023). Catfish farms reported total regulatory costs of \$45 million annually, with significant lost revenues due to compliance burdens (Hegde et al. 2022).

Smaller farms experience disproportionately higher regulatory costs per kilogram produced, indicating a need for more efficient regulatory frameworks (Hegde et al. 2022). Enforcement gaps arise when regulatory agencies lack comprehensive knowledge of all entities subject to regulation, leading to delayed compliance among firms (Andarge & Lichtenberg, 2020).

In Maryland, a significant portion of farms was not included in the enforcement registry, which negatively impacted compliance with nutrient management regulations (Andarge & Lichtenberg, 2020).

The regulatory framework must balance environmental sustainability with economic viability, as excessive regulatory burdens can stifle growth in the aquaculture sector (Gutsulyak et al. 2023) (Innes et al. 2017). Streamlining licensing and reducing administrative burdens can enhance compliance without compromising regulatory quality, potentially fostering industry growth (Innes et al. 2017).

Conversely, although enforcement challenges can impede the effectiveness of regulations, they underscore the critical need for adaptive regulatory frameworks capable of evolving alongside industry dynamics. Such adaptability has the potential to enhance compliance rates and promote more sustainable practices within the aquafeed sector. While these strategies represent a forward-thinking approach to addressing microplastic pollution, significant obstacles persist, particularly in the development of standardized methodologies for monitoring and evaluating microplastic contamination in aquaculture. Addressing these challenges will require further research and collaborative efforts among industry stakeholders, policymakers, and researchers to achieve comprehensive and effective solutions.

CONCLUSION

Microplastics represent a significant issue in aquaculture, particularly in aquafeeds. They are observed to have both direct and indirect effects on fish health, production efficiency, feeding rates, and sustainability. Various methods for the removal of microplastics have been developed and are summarized in this study. The use of materials with high bioavailability and effective microplastic control are critical aspects of this issue. Microplastic management is an essential topic for ensuring sustainable aquaculture and minimizing environmental impact. Future research is expected to focus on microplastic management and improving bioavailability to enhance sustainability and mitigate ecological harm.

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CHAPTER 13

ENVIRONMENTAL EFFECTS OF BIVALVES AND BIVALVE FARMING ON THE ECOSYSTEM

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INTRODUCTION

The world population is estimated to be 9.7 billion in 2050 and the demand for animal protein is projected to increase by 70% (FAO, 2009; 2016). Due to important factors such as population growth, climate change and deterioration of environmental conditions due to various reasons, nutrition, which is the basic need of humanity, will face difficulties in the coming years. With the modernization of terrestrial agriculture to provide more protein, the diversification of production has caused great damage to the environment. Around 30% of carbon dioxide from human activities (anthropogenic) has been absorbed by the oceans, resulting in ocean acidification (IPCC, 2014). Agricultural sources are the largest source of nitrogen pollution for most of the planet's coastal marine ecosystems. This nitrogen pollution causes global ocean eutrophication and oxygen scarcity, habitat degradation, altered food chain structure, biodiversity loss and harmful algal blooms (Howarth, 2008). While humanity carries out food production, it also develops environmentally compatible-friendly production models. Some production models enable the cultivation of needed food in harmony with the environment, while others serve to improve deteriorating environmental conditions.

Fisheries and aquaculture activities of fish and other organisms in marine and fresh waters make a significant contribution to the animal protein needs of humanity. While capture fisheries are slowing down due to excessive exploitation of wild stocks, interest in aquaculture is increasing. According to the latest data (FAO, 2024), the total world production increased by 4.4% in 2022 compared to 2020 data, reaching 223.2 million tons. While 185.4 million tons of this amount is aquatic animals, 37.8 million tons are provided by algae production. Although the production provided by capture of aquatic animals is 92.3 million tons, aquaculture increased to 94.4 million tons, accounting for 50% of the total production. The main reason for aquaculture activities is on human food and animal feed production, but also some species are also used or cultured to improve the deteriorating conditions in the aquatic environment.

More than 40% of aquaculture production depends on the conversion of products collected or fished from the wild environment into industrial feed (Deutsch et al., 2007). Generally, fish production has a negative impact on the ecosystem with both nutritional needs and metabolic wastes. However, bivalves

have lower farming needs due to their feeding behavior by filtering the water and can have positive rather than negative effects on the ecosystem.

Bivalves are one of the important aquatic invertebrates cheap and high-quality protein sources used as human food mainly in the marine environment (Lök et al., 2010). They are also known as sea fruits because they are rich in minerals and vitamins. Their shells are used in many areas such as ornaments, cosmetics and medical products (Sami, 2024).

Various species of bivalves are found in both freshwater and marine areas, generally fed by filtering water. In addition to being produced as a food source, effective activities are carried out to reduce the negative environmental impacts in many marine and freshwater areas by using their filtration characteristic. Bivalves improve water quality by removing particles (silt, organic matter, bacteria, viruses, etc.) from the water column through filtration (Shumway et al., 2003). Due to this filtration characteristic, they are defined as biological filters of water.

EFFECTS OF BIVALVE FARMING TO MITIGATE GLOBAL WARMING

Although carbon absorption and storage have an important place in terrestrial ecosystems (Piao et al. 2009), the effect of forest and vegetation on the carbon cycle is short-term since carbon is released into the atmosphere through decomposition. It is known that the atmospheric CO₂ concentration has increased from 280 ppm to 394 ppm in the last 200 years and that human-caused CO₂ has been absorbed by the oceans (Sabine et al., 2009).

However, the marine carbon cycle is much longer term. Cultivated shelled organisms play an important role in capturing and removing carbon in the long term. Most shellfish are cultivated in many countries, especially in China, for use in the production of food, animal feed, chemicals, cosmetics and pharmaceutical products. With this production, not only are people provided with quality and safe products, but they also have the ability to improve the ecosystem in which they exist by absorbing atmospheric CO₂ (Hu, 1996; Tang et al., 2011).

The CO₂ emission from mussel farming is 0.22 kg CO₂-e/kg mussels, while many other animal productions are very high (19-36.7 kg CO₂-e/kg beef,

23-36 kg CO₂-e/kg mutton, 3-6.5 kg CO₂-e/kg chicken, and 4.2-5.4 kg CO₂-e/kg salmon) (Suplicy, 2018).

The main role of mussel farming is as food. However, it can make positive contributions to the environment through carbon fixation. Therefore, it improves the quality of coastal ecosystems by absorbing atmospheric carbon dioxide from anthropogenic sources through carbon fixation (Tang et al., 2011). Mussel soft tissue is 46% carbon and absorbs significant amounts of carbon into their shells, which are 12.7% carbon, through calcification to thicken or enlarge their shells, which is CaCO₃.

Carbon is used by *Mytilus galloprovincialis* in 2 ways: (1) to build CaCO₃ shells using dissolved HCO₃ from seawater; (2) to consume organic carbon to sustain their growth and metabolism (Munari et al., 2013). Seaweed is effective in converting dissolved inorganic carbon in the environment into particulate organic carbon through photosynthesis (Paine et al., 2021). When this transformed carbon is filtered by the bivalves, a significant portion of it is used in the formation of a shell.

During the calcification process, one mole of CO₂ is released for every mole of CaCO₃ (Lerman and Mackenzie, 2005). CO₂ is also produced because of the consumption of organic matter. Considering the fast growth and intensive culture of *M. galloprovincialis*, it can be said that mussel farming is an important CO₂ source for seawater (Ceccherelli and Rossi, 1984). In a study on the Adriatic coast of Italy, *M. galloprovincialis* absorbed 136.6 mol CO₂/m² for shell formation over 1 year but released 187.8 and 86.8 mol CO₂/m² from respiration and calcification, respectively. Therefore, mussels appear to be CO₂ producers and release more than any other calcifying organism (Munari et al., 2013). However, Tang et al (2011) suggest that with large capacity shellfish aquaculture, most of the carbon in the water is taken up directly or indirectly and some of it is removed. In addition, as a result of their research in China, they reported that 0.86 tons of carbon is removed from the ecosystem annually by shellfish harvesting and 0.67 tons of carbon is stored in their shells.

Clam and mussel farming release 22 and 55 g of CO₂ eq. to the environment for shell formation during their growth, while they can take 254 and 146 g of CO₂ from the water. Net carbon capture capacities are 233 and 91 g CO₂/kg fresh product for clam and mussel, respectively (Tamburini et al.,

2022). It is clear that the capacity of bivalve farming to capture carbon in water is significant.

The carbon dioxide released through remineralization (rearrangement of minerals) of the feces excreted by mussels with or without digestion changes the benthic and pelagic situation. The arrival and impact of mussel biodeposits in the benthos depends on the nutrients in the environment and the size of the mussel, but can also vary depending on regions, seasons and the structure of the mussel population (Giles and Pilditch, 2004). From an ecosystem perspective, mussel farms will ensure that a greater proportion of primary production is degraded under oxygenated conditions, rather than decomposing in sediment without oxygen (Fenchel et al. 2017). In a strongly autotrophic ecosystem, CO₂ production through carbonate precipitation or reduction, organic productivity can be neutralized through absorption of the CO₂ formed. Thus, there may be a reduction in CO₂ transfer from water to the atmosphere or from the atmosphere to water (Tang et al. 2011).

EFFECTS OF BIVALVE FARMING TO THE REDUCTION OF EUTROPHICATION IN WATERS

Eutrophication in coastal waters is a serious environmental problem with high costs (Petersen et al. 2016). Eutrophication is caused by nitrate and phosphorus in various forms. As a result of eutrophication, dissolved oxygen in water decreases and biological oxygen demand increases. Bivalves play an effective role in reducing eutrophication. Bivalve species such as *Dreissena rostriformis bugensis*, *Dreissena polymorpha* and *Mytilus edulis* give successful results in such eutrophicated waters. Bivalves can remove up to 80% of chemical oxygen demand (COD) within 3 days and reduce Nitrate and Phosphorus levels by 80-90% and pathogens by 90-95% within 7 days of treatment (Deepthi et al., 2020).

Mussel farms have significant and positive environmental impacts on water clarification, primarily through the water filtration activities of mussels. During filtration, they utilize the phytoplankton as food in the water and their tissues contain about 1.4% nitrogen and 0.14% phosphate (Shumway et al. 2003; Rose et al. 2015). Phytoplankton take up dissolved nutrients, primarily nitrogen, from water. By filtering the phytoplankton of the bivalves, dissolved nutrients are indirectly reduced from the water (Figure 1).

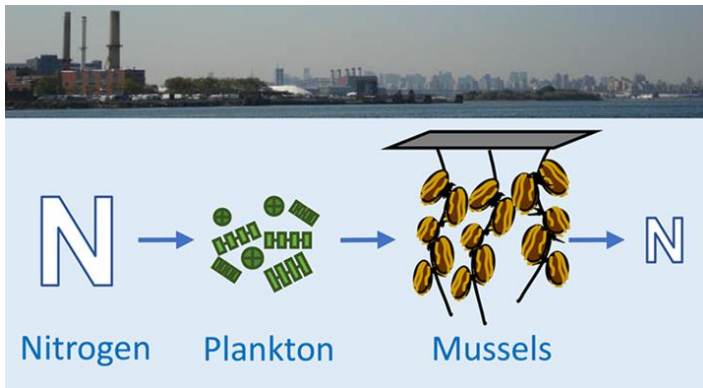


Figure1. Nitrogen bioextraction from water by mussel filtration

Source: Galimany et al., 2017.

These nutrients are stored in mussels and removed from the marine environment when harvested (Petersen et al. 2016). Each mussel filters 5-10 liters of water per hour, removing 15-150 mg of particulate organic and inorganic matter. Thus, it reduces turbidity by removing nutrients from the water both directly and indirectly (Tang and Riisgard 2017). Mussel farms act as a large filter or biological filter. Their capacity to convert and remove nitrogen is very high (Kaspar et al. (1985).

Nitrogen removal rate may vary depending on mussel filtration, growth rate, nutrient availability and density, water temperature, salinity and mussel density. According to the results of the studies, more than 100 kg of nitrogen is used (taken) from 1 hectare in 1 year by mussel farms. In simple terms, this uptake is equivalent to the nitrogenous waste of 40-50 coastal residents (Shumway et al. 2003). In mussel farms, nitrogen reduction (through harvest and increased denitrification) is 68% higher than the reference point (Kaspar et al., 1985).

Bivalve farming in the EU coasts contributes to reducing eutrophication by reducing nitrate in water, with an annual value of US\$20–30 billion (Smaal et al., 2018).

Another way in which mussels can contribute to reducing eutrophication in water is by being cultured together with marine fish farms in Integrated Multi-Trophic Aquaculture (IMTA) systems (Reid et al. 2013). In the IMTA concept, cultured organisms are selected and planned to balance each other. The uneaten feeds, wastes and nutrients generated in the system are taken up by

other species and converted into energy, resulting in by-products from the system (Soto, 2009). One species' waste becomes another species' feed. In these systems, externally fed species, such as fish, are complemented by water filterers, such as mussels, those that eat what accumulates in the sediment, such as sea urchins or sea cucumbers, and marine plants that take up nutrients dissolved in the water. The choice and combination of species is very variable.

From an environmental perspective, mussels effectively remove waste from IMTA systems by directly assimilating it (Sanz-Lazaro and SanchezJerez, 2017). It is known that the growth and meat yield rates of mussels in IMTA systems are much higher than mussels grown in monoculture systems (Gvozdenovic et al. 2017).

Although fish-mussel co-culture systems are beneficial but not mandatory when establishing farms, some countries, such as the Netherlands, are trying to establish new rules when establishing new farms for fish farming in net cages. One of the main options being considered is to establish mussel farms together with fish farms (Fenchel et al. 2017). Thus, the impact on the ecosystem caused by fish farms can be reduced by mussels.

Suspended particulate matter and chlorophyll-a values may be higher in areas under the influence of fish farms. Many studies have shown that bivalve species such as mussels grow faster when cultivated in these areas. The excess nutrients in the environment are used for their growth and are reduced by being converted into meat and at the same time ensure that the condition of the products is high (Kurtay and Lök, 2023). With such co-cultures, while the nutrient in the environment is reduced, it becomes a beneficial production that is environmentally friendly for both the environment and the producer.

The first pilot application of mussels (*Mytilus galloprovincialis*) in a gulf region in Turkey for the reduction of suspended particulate matter (organic and inorganic) and chlorophyll-a was carried out in Izmir Bay (İZKA Project, 2023). A total of 470 kg of netted mussels with an average length of 67 mm were hung on a 5*5 m pilot system (Figure 2). Our results showed that the amount of chlorophyll and suspended particulate matter was successfully reduced by 50% compared to the control point without mussels, thanks to the ability of mussels placed in the pilot system to filter water. The other important result is the decrease in turbidity due to mussel filtration in the pilot system area compared to control point and the visibility distance increased 2-3 times.



Figure 2. Pilot mussel culture system, netted mussels and mussel ropes

Bivalve species such as blue mussels and mediterranean mussels, which are used for human consumption, and have commercial value, play a major role in improving water quality. However, it is not possible to harvest bivalves from polluted waters under urban and suburban influence. In such areas, cultivation for consumption cannot be done and harvesting is also prohibited. Due to their filter-feeding characteristics, they also absorb many harmful particles in their environment and may put public health at risk when consumed.

The lack of a commercial market, wide natural geographical distribution and ability to effectively filter a variety of particles of different sizes including bacteria, make *Geukensia demissa* an important species as a bioextractor (Langdon and Newell, 1990). The ribbed mussel (*Geukensia demissa*), which lives in the intertidal marshes of the sea, can filter suspended particles in the water and reduce particulate organic matter in the areas where it is found. It filters out about a third of the particulate phosphorus suspended in the water daily and converts most of it into feces and pseudofeces (Vaiella et al., 1978). With this filtration activity, the transport of particulate matter from the water to the sediment as feces and pseudofeces matter becomes a food source for deposit feeders (Jordan and Valiela, 1982).

The East River/Bronx River estuary in New York Harbor, USA, has a densely populated watershed and an industrial coastline (. It is also under the influence of the Hunt's Point wastewater treatment plant. To increase habitat and improve water quality around the treatment plant, ribbed mussel aquaculture was implemented using mussel raft farming techniques (Figure 3, 4). Ribbed mussels collected from the natural environment were netted and suspended from the raft system.

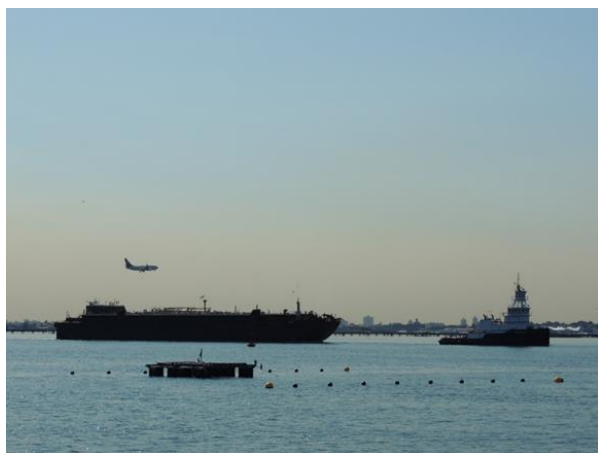


Figure 3. Raft near Hunt's Point in the East River/Bronx

In the study, 2.25 kg and approximately 197 mussels were stocked on 1 m of mussel rope. It was determined that 1 m of mussel rope filters 41 liters of water per hour and removes 351 mg of particles from the environment. As a result, by using 2.25 kg of ribbed mussels, an average of 1 ton of water can be filtered daily, and 8.6 tons of particulate matter can be bioextracted from the environment (Dixon et al., 2012; Wikfors et al., 2013).



Figure 4. Ribbed mussel and filtration activity measurements

Clearance rates ($\text{L g}^{-1} \text{h}^{-1}$) and filtering rates ($\text{mg g}^{-1} \text{h}^{-1}$) are commonly calculated based on individual dry mass to describe filtration capacity (Vaughn and Hoellein, 2018). The clearance rate varies according to the species. Marine mussels, scallops, cockles, and oysters have clearance rates of 2.3-4.2, 3.6-7.9, 1.1-4.8 and 2.8-6.0 $\text{L g}^{-1} \text{h}^{-1}$, respectively (Cranford et al., 2011).

BIOREMEDIATION

Bioremediation is a method used to prevent and reduce the uncontrolled spread of environmental pollutants in contaminated areas from human-induced or natural pollution sources such as industrial activities (detergent, dye, etc. from manufacturing industries; fertilizers, pesticides, herbicides, etc., from agricultural activities; cyanide, sulfuric acid from mining; cement, metals etc. from construction companies) (Kour et al., 2022) and oil spills. Thereby, depending on the type of biological organism used, pollutants are reduced to less toxic or non-toxic forms, transformed or eliminated in the polluted environment. Bacteria, algae, fungi, and yeast (Enerijiofi et al., 2021) are among the commonly used biological organisms.

Bivalves can tolerate and accumulate contaminants in water. Interest in their use as biological filters for chemicals, metals and pathogens has increased in recent years. They can be used to remove contaminants from the environment as well as nutrients (bioextraction) (Gifford et al. 2007).

Bivalves that accumulate contaminants are harvested but not consumed. Yesso scallop (*Patinopecten yessoensis*) cultivated in Japan has been found to accumulate cadmium in the hepatopancreas. The hepatopancreas is separated during the meat processing process and studies are being conducted on its reuse as fertilizer (Gifford et al. 2007).

Since bivalves used in polluted water bodies can be harvested to treat pollution, they can be used in biological treatment in industrial treatment plants. However, the water in which they can live should have minimum water conditions and their growth or reproduction should be kept under control. Otherwise, they become a threat to the life of other organisms in the environment (Deepthi et al., 2020).

BIOMONITORING

The vast majority of bivalves are sessile organisms and remain in the same habitat throughout their lives. While filtering the water they live in, they accumulate many substances in the water column (microorganisms, chemicals, petroleum products, pharmaceuticals, heavy metals, etc.) in their bodies. Recent studies show that bivalves can be good biomonitors for monitoring microplastics and determining their ecological impacts (Rochman et al. 2017). By monitoring bivalves at regular intervals, changes or accumulations in the aquatic ecosystem are followed (O'Connor 2002). They are ideal organisms for pollution monitoring programs.

EFFECTS OF BIVALVE FARMING TO REDUCING WATER AND LAND USE FOR FOOD PRODUCTION

We can say that 2.5% of all water in the world is freshwater and only 0.3% of this is available for use when groundwater, ice and snow are taken into account (Alexandratos 2005). Terrestrial animal production requires large amounts of freshwater and consumes 8% of the global water supply (Schlink et al., 2010). Seafood aquaculture is the sector that produces food that is least dependent on freshwater availability. In mussel farming, it is very advantageous compared to other animal production sources due to the fact that freshwater is not used.

Considering that the terrestrial area is limited in terms of animal protein production and will be insufficient in the future, more effective and efficient use of marine areas will be inevitable. One of the most important cultivation advantages of mussels is that they are not mobile like fish and can be produced in the whole water volume by using different culture systems at different depths.

Today, the vast majority of food is provided by grass-fed animal farming, covering one-third of the world's surface (5 billion hectares) (Ramankutty et al., 2018).

Today, the vast majority of food is provided by grass-fed animal farming, covering one-third of the world's surface (5 billion hectares). It is becoming increasingly difficult to meet the food needs of the human population. Considering the increasing use of land for other purposes along with the need for housing, the effects of climate change on agriculture, the decrease in the

health and productivity of land, etc., land use demand and competition will increase. The need for agricultural land for food production is likely to exceed the current land area by 2050 (Röös et al., 2017). The aquaculture sector, including bivalve farming, especially mussels, is growing rapidly and has significant potential to meet future food needs (Herrero, et al., 2015; Ottinger, et al., 2016).

The biggest advantage of aquatic production is that volumetric production is done. The fact that the entire water volume can be used with appropriate methods compared to the yield to be obtained from animal production on land increases efficiency. Therefore, it reduces the use of space compared to terrestrial production. In bivalve farming, there is no need to provide external nutrients for feeding. Rather than nutrient input into the environment, there is an output or reduction of existing nutrients. On the other hand, in terrestrial animal husbandry, the necessity of producing the feed (plant, grass, etc.) to be given to the animals in separate lands is among the most important compelling factors, along with additional land use, water, labor, time, and other factors.

USABILITY AS FEED IN FISH AND ANIMAL NUTRITION

Feed is one of the most important resources in fish farming. Fish farming depends on the preparation or availability of quality and sustainable feed. In this respect, mussels with a balanced amino acid profile have the potential to be used as a protein source in the preparation of fish feeds. Mussels that are small for human consumption and mussels grown in areas close to urban settlements or around fish farms to reduce nitrogen and phosphorus overload can be used as mussel meal instead of fish meal in fish feeds (Lindahl 2013). Since mussels are at the second step of the marine food chain, using mussels instead of fish in fish meal production provides a great ecological advantage (Muminovic, 2010).

VERSATILITY OF MUSSEL WASTE AND BY-PRODUCTS

The main waste material from mussel farms is empty mussel shells. Efforts are being made to develop economic and ecological practices to utilize shells. Mussel shells are used in handicrafts, the jewelry industry and button making, as well as in the construction industry as building material, in water purification, in agriculture and in human health (FAO, 2016).

The use of mussel shells in soil remediation increases the retention or removal of fluoride, reducing the risk of environmental pollution due to excessive fluoride concentration in soil or liquid media. It is effective in removing phosphorus in wastewater treatment (Paradelo et al., 2016). With powdered mussel shells, dyes such as methylene blue, methyl red and metals such as chromium and cadmium in water are highly removed.

OTHER POSITIVE IMPACTS OF BIVALVES

Bivalve farming is defined as “Green Industry” which has less greenhouse gas emissions, freshwater use, land use, and a lower potential for eutrophication compared to fish and other meat production and various agricultural products (Tamburini et al., 2020).

By filtering organic matter, nutrients, and any material large enough to filter, mussels improve water clarity, light transmission and critical habitat conditions by ensuring the survival of critical habitat species, including submerged vegetation (Shumway et al. 2003). In bivalve cultivation, it is important to pay attention to the selection of culture methods and carrying capacity, as well as site selection (nutrient availability and variety, suitability of water parameters, depth, habitat, etc.) (Lök et al., 2007; Lök, 2018).

Mussel farms act as floating artificial reefs, creating habitat for both benthic and pelagic fish species (Wang et al. 2015). Rafts, lines and nets used in aquaculture provide a substrate for other invertebrate and algal species to attach on. Six months after the mussel culture system was placed in Izmir Bay (IZKA, 2023), it was observed that the system and mussel ropes were used as habitats by many living creatures such as macroalgae, balanus, polychaete and newly attached mussel spat (Figure 5). Bivalves also serve the ecosystem in terms of habitat provision, fisheries enhancement and coastal protection (Weitzman, 2019).



Figure 5. Macroalgae and newly attached mussel spat on pilot system in İzmir

It creates a complex habitat structure for the larvae and juveniles of many species to hide and protect them from other organisms (Dumbauld, et al. 2009). In this way, mussel farms support and increase biodiversity. The use of mussels as bait by fish hiding and staying in mussel farms can cause significant losses for mussel farms. Mussel farms are food sources for fish, crabs, sea stars, gastropod species and even birds and ducks.

Shell Aggregations

Shell aggregations throughout marine, lake, and river habitats represent unique habitats for a variety of organisms. Shells are persistent in the environment due to their hard durable structure and provide a stable surface for attachment of other organisms in habitats dominated by soft sediments or where space constraints exist (Gutierrez et al. 2003).

Water flow rates are low in areas with shell accumulations. It is an advantageous habitat for many organisms. Thus, it contributes to the increase of diversity and richness in shell-based shallow marine areas. It creates a natural area for the attachment of spat individuals of an epifaunal bivalve such as oysters to hard surfaces (Grabowski et al. 2012).

Shells or live mussels falling to the seabed from mussel farms attract other organisms such as starfish, which consume mussels as food, to gather in these areas ((Inglis and Gust 2003).)

Connections to Other Habitats

Bivalves have an impact on habitats in shallow coastal areas. They buffer waves, protect shorelines, and reduce coastal erosion (La Peyre et al. 2015).

NEGATIVE IMPACTS OF BIVALVES

While mussel farming has many benefits and advantages, it can also have some negative impacts. Farms established in coastal and shallow waters may have some undesirable effects on the local ecosystem. There may be concerns that the biological sediments formed because of the metabolic activities of mussels will accumulate on the seabed.

If the mussel density is too high in shallow coastal areas with low water circulation, waste accumulates on the ground. This stresses the organisms living on the ground, causing a decrease in oxygen and an increase in ammonium levels.

In order to eliminate these concerns, the selection of the location where bivalves such as mussels will be cultivated is very important. Production planning should be made in accordance with the carrying capacity of the area together with the water conditions, flow regime, depth, habitat structure and similar factors of the selected area. When these issues are not taken into consideration, it is reported that although accumulation is observed at the bottom, there is no increase in hypoxic and anoxic conditions (Interreg Baltic Sea, 2019).

In bivalve culture areas, in addition to the reduction of suspended particles by filtration, 1/4 of them are transferred from the water column to the seabed as feces and pseudofeces. In areas with bivalves, particulate matter sedimentation is 1.75 times higher than in areas without bivalve culture (Cai et al. 2003). Although sedimentation seems to be a disadvantage, it mixes back into the water column in areas where there is water movement due to waves, wind, etc. And the particulate organic carbon used by bivalves is transported to the seabed again.

Zebra mussels (*Dreissena polymorpha*) can selectively reject the cyanobacterium *Microcystis aeruginosa* by excreting it as pseudofeces, which can exacerbate algal blooms (Vanderploeg et al., 2013).

Negativities can be prevented by taking “Good Management Practices” into consideration and selecting farm areas with suitable depth and water flow with the right culture method. After the farm is established, the farm area and production are kept under control by regular monitoring.

Certification bodies such as the World Wildlife Foundation (WWF) and the Aquaculture Stewardship Council (ASC) certify mussel farming as an

environmentally friendly production. Since bivalve culture is not need to give feed, when attention is paid to the choice of cultivation site, there is a problem-free environmentally friendly production (McKindsey et al., 2006).

CONCLUSION

Mussels are a valuable source of animal protein in human nutrition with their richness in macro-micro elements and vitamins. In Far Eastern cultures, mothers are asked to consume plenty of bivalve seafood, especially mussels, in order for the child to be strong, durable, healthy and intelligent.

Mussel farming is one of the most ideal productions within the scope of environmentally friendly and compatible aquaculture. High marketing value and quality products are obtained without additional feeding. The production of the enterprises can be defined as a production model that is sustainable and compatible with the ecosystem. The most important effect on the ecosystem is to reduce the particulate matter load in the water by filtering, thus eliminating the turbidity of the water, reducing or preventing eutrophication and increasing its clarity, balancing the oxygen content in the water, stabilizing the water environment and contributing to the other living things in the ecosystem to live in harmony and balance. Due to its positive effects on the environment, mussel production is described as “green or blue production”, “environmentally friendly production”, “ecosystem compatible production”.

Demand for mussel farming has increased in recent years. Reducing the negative impacts on the ecosystem as a result of intensive aquaculture activities not only satisfies other users who share the coastal area, but also satisfies both producers and consumers, as sustainable, profitable and reliable products are produced.

In many European countries, mussel farms are considered as eco-tourism areas. Tourists are introduced to mussel production by touring the farms and making a significant contribution to the economy by consuming mussel dishes in restaurants in coastal areas. Considering all the above-mentioned features, mussel farming will provide significant contributions to Turkey's Aquaculture Production (animal protein, new business areas, foreign currency inflow through exports) and will bring a new and different perspective to the Tourism sector when evaluated in terms of Eco-Tourism.

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CHAPTER 14

THE RELATIONSHIP BETWEEN CLIMATE CHANGE AND AQUATIC ANIMALS NUTRITION AND FEED UTILIZATION

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INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) is an international body established in 1988 by the World Meteorological Organization and the United Nations Environment Programme to assess the science related to climate change. Since 1988, it has been studying climate change and its political and economic impacts and presenting assessment reports with up-to-date information on its results (IPCC, 2024).

According to the Intergovernmental Panel on Climate Change (IPCC), climate change is defined as “*a change in the mean and/or variability of climate characteristics that occurs over a significant period of time, at least a decade or longer*”. These changes can be caused by natural causes such as oscillations in the solar cycle. However, according to IPCC reports, since the 1800s, human activity has been the primary cause of climate change. As a result of human activities, through greenhouse gas emissions, the global surface temperature increased by 1.1°C in 2011-2020 compared to the 1850-1900s (IPCC,2023).

According to the IPCC AR6 Climate Change 2021: The Physical Science Basis 2021 report;

“Human activities have resulted in rapid and large-scale changes in the planet's climate. The climate has warmed at an unprecedented rate over the last 2000 years. Some of these impacts are irreversible. In all scenarios, the planet is projected to warm by at least 1.5°C. Even in the scenario where the most ambitious steps are taken in terms of emission reductions, the planet warms by 1.5°C by the 2030s, exceeding 1.6°C in these years, but temperatures fall back to 1.4°C by the end of the century.” (IPCC 2021).

In addition to rising temperatures, there are other impacts such as rising sea levels, inclement weather, and changing wildlife populations due to habitat change. Earth's climate is an integrated system of weather phenomena such as sun, wind, rain and snow, terrestrial areas such as forests, deserts and savannas, and aquatic areas such as oceans, rivers and seas, as well as human activities. Considering that aquatic systems cover more than two-thirds of the Earth's surface, it is predicted by various scientists that the negative effects of climate change will be mostly on water resources, the water cycle will be disrupted and water quality will change as the Earth's temperature continues to increase (Yazdi &Shakouri 2010; IPCC 2019; Çapar, 2019; IPCC 2022; Mehrim, & Refaey 2023; WaterCalculator, 2024).

Regarding this issue, some of the points in the IPCC 2023 (SYR) climate change report state the following;

- *Widespread and rapid changes have occurred in the atmosphere, ocean, cryosphere and biosphere. Human-induced climate change is already affecting many weather and climate extremes in every region of the world. This has led to widespread negative impacts and related losses and damage to nature and people.*
- *It is certain that human influence is warming the atmosphere, ocean and land. Global average sea level rose by 0.20 m between 1901 and 2018.*
- *Climate change has caused significant damage and increasingly irreversible losses to terrestrial, freshwater, cryospheric and coastal and open ocean ecosystems. Hundreds of local species losses have resulted from increases in the magnitude of temperature extremes and mass mortality events recorded on land and in the ocean.*
- *Climate change is unevenly distributed across systems, regions and sectors, causing widespread negative impacts on nature and people and associated losses and damages. Economic damages from climate change have been identified in climate-exposed sectors such as agriculture, forestry, fisheries, energy and tourism.”*

The impact of climate change on the quality of water resources can be monitored by physico-chemical parameters such as temperature, pH, dissolved oxygen, micropollutants such as metals, pesticides and pathogenic microorganisms, and biological parameters such as fish and green algae (Delpla et al., 2009; Çapar 2019). For example, while changing air temperature causes sudden severe weather events such as tornadoes, it also causes physico-chemical changes in water resources. For every 3°C increase in temperature, the oxygen concentration in water decreases by 10%.

In its report “Climate change and food security: risks and responses” published in 2015, FAO expresses this situation as follows;

“changes will be seen in physical and chemical parameters in the aquatic environment. Since most aquatic organisms are cold-blooded, their metabolic rates will be affected by external environmental conditions, especially temperature and oxygen. Changes in temperature have significant effects on fish reproductive cycles, including growth rates, sexual maturity and timing of reproduction (Parry et al., 2005; Pörtner, 2008). Reductions in current oxygen levels (due to warming of surface water) will cause a reduction in the maximum body weight of fish species worldwide, leading to lower catch potential in the

near future. In addition, species that do not tolerate hypoxia (e.g. tuna) will see their habitat shrink and thus may be less productive in the future (Stramma et al., 2010; 2012). Various fish species are migrating poleward, resulting in the rapid “tropicalization” of mid- and high-latitude systems. A large-scale redistribution of global marine fish catch potential is projected, with a reduction of up to 40 percent in the tropics and an increase of 30 to 70 percent in high-latitude regions. In the Mediterranean, invasive species from low-latitude regions have been observed to make a new introduction every four weeks in recent years. The abundance and species diversity of river fishes are particularly sensitive to disturbances in the amount and timing of water flows and to falling water levels, particularly during dry seasons. Pressures on river flows may be exacerbated by human actions to retain water in reservoirs and irrigation canals. Increased pressure on water resources due to climatic factors and anthropogenic stressors such as pollution and overfishing could lead to a serious shortage in capture fisheries production. In addition to the gradual development of climate change-related drivers, variability events (e.g. El Niño) and extreme events (e.g. floods, droughts, storms) are likely to affect the stability of marine and freshwater resources that adapt to or are affected by them. For example, rising sea levels and floods displace brackish and freshwater in river deltas, eliminating some aquaculture practices and destroying wetlands.”

Approximately 25 percent of the CO₂ released as a result of anthropogenic activities is sequestered by the oceans, playing a crucial role in regulating the Earth's climate (FAO, 2018). Freshwater systems are also significantly affected by climate change. The IPCC counts freshwater systems among the most threatened on the planet due to anthropogenic impacts. In addition, it is inevitable that human demand for water resources will increase with the expansion of urbanization and agriculture in parallel with the increase in human population (Settele et al., 2014). These pressures on water resources will have impacts on the fisheries and aquaculture sector. FAO (2018) explains these impacts in its report as follows;

“Species productivity and fish growth are already changing, with consequences for fisheries and aquaculture yields as a result of shifts in fish distribution, larval transport or changes in the thermal tolerance of farmed fish. Fishing and farming activities are also expected to be affected by short-term events, such as extreme weather events, or medium and long-term changes, such as lake levels or river flow, which could affect the safety and working conditions of fishermen and fish farmers. Food control procedures will be drastically reshaped to

protect consumers from the potential increase in contaminant and toxin levels resulting from changes in water conditions”.

Food is a basic daily need. It is the right of every human being to meet this need on a daily basis. But even today, most of the human population is unable to meet this need. 800 million of them are malnourished, while three billion people do not have a healthy diet. Hunger and malnutrition affect the poorest communities, while obesity and micronutrient deficiencies are common in developed countries (FAO, 2015; UN, 2022.).

It is clear that seafood is one of the most sustainable solutions for a healthy diet. This is because aquatic foods have incredible potential to improve nutritional quality due to their high content of nutrients such as protein, Omega-3 fatty acids and rich micronutrients. There is a wide diversity of species found in different water sources. As such, they provide sustenance and livelihoods for communities that depend on oceans, rivers, lakes and their resources. In addition, compared to animal production systems on land, aquatic production systems are more efficient, have lower environmental footprints and lower greenhouse gas emissions. Due to these features, they have more sustainable production. For example, it requires about 1000 L of water to produce one kilogram of farmed fish, while the same weight of rice or wheat may require two to four times more water volume (Shaalán et al., 2018). Moreover, while water is used only once in agriculture, fish farmers can use water several times.

Aquaculture is of greater importance in terms of more significant consequences, keeping the changes under control and planning for the future. In line with these views, aquaculture will also be significantly affected by climate change. The impacts of climate change on aquaculture production are expected to be both direct and indirect (Handisyde et al., 2006; De Silva and Turchini, 2009; FAO, 2018; Elsheikh, 2021). Direct impacts include affecting the physical condition and physiology of fin and shellfish stocks in production systems. These include the negative effects of changing environmental conditions on production conditions, increased temperature and consequently increased oxygen demand, stress in fish due to the decreasing pH of the environment, increased mortality rates due to reasons such as lack of resistance to diseases, reproductive disorders or changes in reproductive periods. Indirect impacts include changes in ecosystem productivity and structure, input supply and product prices, extreme weather events, severe waves and currents, sea

level rise and shoreline change, negative impacts on feed intake due to uncertainty about the future of fishmeal and fish oil from capture fisheries, negative impacts of fishmeal and fish oil costs on feed costs, and changes in other goods and services needed by fishers and aquaculturists. Due to such problems, the aquaculture sector is expected to face great challenges (Handisyde et al., 2006; Brander 2007; De Silva and Turchini, 2009; Freeman, 2017; Adhikari et al., 2018; Elsheikh, 2021).

This requires appropriate technical solutions, adequate policies and innovative partnerships to support and advance long-term sustainable development (FAO, 2015). This is why in 2022, FAO published the Blue Transformation Roadmap (FAO, 2022), which underpins the Sustainable Development Goals (SDGs), recognizing the importance of aquatic food systems as drivers of food security and nutrition, employment, economic growth, social development and environmental recovery.

The Blue Transformation Roadmap sets three objectives:

- 1 Increasing and expanding sustainable aquaculture,
- 2 Effective management of all fisheries
- 3 Improved value chains, ensuring social, economic and environmental viability of aquaculture food systems.

There are many innovative ways in which aquaculture can develop to promote sustainable aquaculture. These include topics such as;

- Expansion of aquaculture in non-agricultural areas,
- Diversified aquaculture production at different trophic levels from algae to animals, in addition to the integration of rice and fish systems,
- Application of aquaculture for environmental restoration purposes, such as restocking economically valuable species, rehabilitation of seaweed and seagrass beds, or restoration of shellfish reefs as functional aquatic ecosystems,
- Integrating eco-tourism with aquaculture, using improved formulation and precision feeding practices in aquatic feed production. Reducing fish meal and fish oil in favor of alternative ingredients, providing more fish production with the same amount of feed ingredients as a result of innovative approaches to feeding,

- Expanding the use of modern technologies such as Artificial Intelligence in aquaculture,
- Increasing production efficiency through the supply of quality seeds (progeny) and genetic resource management and the breeding of farm species that are better adapted to culture systems,
- Implementation of farm management systems such as farm design and business protocols, insurance plans, business planning and risk management plans,
- Effective management of farm wastewater, combining fish farming with other production systems such as integrated agricultural aquaculture or aquaponics, recycling and efficient reuse of waste,
- Since modern aquaculture generally has high energy consumption, solar energy integration includes topics such as the use of solar-powered equipment, energy-efficient pumps and storage facilities (FAO,2022).

CLIMATE CHANGE AND TURKIYE

Turkiye is a country with a coastline of 8,333 km and surrounded by seas on three sides. Its average elevation is approximately 1100 m. The Black Sea is in the north of the country, the Aegean Sea in the west and the Mediterranean in the south. There are 160 rivers in the country, more than 320 natural lakes including small lakes in the mountains, and 861 dam lakes (State Hydraulic Works,2024). The total surface area of sea and inland water resources in Turkiye is approximately 25 million hectares. Turkiye has a Mediterranean climate, with hot and dry summers and cool and rainy winters (Türkeş, 2008).

Turkiye's aquaculture production in 2023 was 1 million 7 thousand 921 tons. Total production through hunting was 454 thousand 59 tons, while aquaculture production was 553 thousand 862 tons (TurkStat, 2024). The amount of sea fish caught was 387 thousand 115 tons. When the distribution of the sea fish caught by species was examined, it was seen that anchovy fish was the fish caught in the highest amount with 273 thousand 915 tons. Anchovy was followed by sprat with 45 thousand 764 tons and sardine with 17 thousand 311 tons. In 2023, 399 thousand 529 tons (72.1%) of aquaculture production was realized in the seas and 154 thousand 333 tons (27.9%) in inland waters. The most important fish species cultivated were trout with 154 thousand 6 tons in

inland waters, sea bass with 160 thousand 802 tons and sea bream with 154 thousand 11 tons (TurkStat, 2024).

There are approximately 2000 aquaculture enterprises in Türkiye (Republic of Türkiye Ministry of Agriculture and Forestry, 2023). In the coastal provinces, sea fish (sea bream *Sparus aurata*, sea bass *Dicentrarchus labrax*,) and mussel (*Mytilus galloprovincialis*) production is common, while trout (*Onchorhynchus mykiss*) and carp (*Cyprinus carpio*) production is predominant in other regions.



Figure 1. Numerical Distribution of Aquaculture Farms by Region (Nationsonline,2024).(<https://www.nationsonline.org/oneworld/map/turkey-map.htm>)

In its report on how Türkiye's aquatic ecosystem will be affected by climate change, Turkish Marine Research Foundation (TUDAV) states that

“ the impact of global climate change should be evaluated as a whole in the form of land - sea - atmosphere interaction. Turkey is a country surrounded on three sides by seas with different characteristics. It is important to know how both land and seas will be affected by global warming. It is obvious that global warming will affect our seas in many ways. We cannot reduce the impact of global warming on our seas only to the change in biodiversity. With the disrupted atmospheric rhythm, a different wind and current system will emerge in our seas, transportation will be disrupted in some of our ports, navigation of our fishing fleets and all kinds of marine vessels will become difficult, fish farms will be exposed to severe waves, transportation to islands will be disrupted, and the marine environment will become more risky than the land area. Since 27 of our provinces are on the sea coast, coastal structures, commercial activities such as fishing and tourism in these provinces will be seriously damaged. While

our seas are still a protein storehouse in our country where the population growth rate is 2.1%, the problems that will arise with global warming will deal a serious blow to traditional fisheries, fishing species and methods.” (TÜDAV,2024).

How the Mediterranean and Black Sea, which constitute the seas of our country, may be affected by climate change is discussed in Chapter 7 of FAO's 2018 report “Impacts of climate change on fisheries and aquaculture. Synthesis of current knowledge, adaptation and mitigation options” (Chapter 7: Climate change impacts, vulnerabilities and adaptations: Mediterranean Sea and the Black Sea marine fisheries) some of the statements are as follows;

- *Surface warming, increasing heatwaves and a decrease in precipitation are very likely over the Mediterranean, with changes in circulation, sea level rise and winter weather regionally likely. In the Black Sea, surface warming, changes in thermohaline structure, sea level rise and extreme weather events are likely.*
- *Meridionalization (occurrence of warm water species in northern regions) and tropicalization (expansion of non-native tropical species) in the Mediterranean, and Mediterraneanization (spreading of Mediterranean species) in the Black Sea, are strengthened by warming and will have positive and negative impacts on fisheries.*
- *Longitudinal gradients in the rate of warming and changes in primary production are likely and result in an expected increase in fish diversity in the Eastern Mediterranean and decrease in the Western Mediterranean. In the Black Sea, projections show an increase in primary production in the north and a decrease in the south.*
- *Changes in primary production and runoff will likely have a negative impact on the optimum habitats for small pelagic fish in the Mediterranean. In the Black Sea, changes in anchovy migration, overwintering and schooling behaviour as a result of warming will negatively affect fisheries in several countries (Hidalgo et al.,2018).*

CLIMATE CHANGE AND ITS EFFECTS ON NUTRITION OF AQUATIC ANIMALS

Changes in climate will affect the country's aquatic species diversity, the quantity and quality of aquatic species caught and produced, the status of production farms, and the subsidiary sectors that contribute to aquaculture. Among these, the feed sector will need to adapt to this change the most.

All living things, regardless of their species, must be fed. Therefore, the effects of climate change on feed and feed raw materials should be addressed as a priority. In aquatic feeds, raw materials obtained from lipid and protein sources of marine origin are generally used. Fish meal and fish oil, which are the main feed raw materials in aquatic feeds, are largely based on capture fisheries. Aquaculture uses most of the world's fish meal (68 percent) and fish oil (88 percent), while the rest is used in livestock and pet food (Tacon, 2005; Tacon, et al., 2006; Tacon and Metian, 2008). In this respect, the aquaculture sector will be significantly affected by climate change, which will limit the availability of fishmeal and fish oil. Therefore, there is a need to reformulate aquatic feeds with environmentally friendly and sustainable ingredients that are less dependent on natural fish stocks. Several scientific studies have been conducted to identify alternative protein and fat sources to replace traditional ingredients in aquaculture feeds. Various insect meals, fish processing residues, and various agricultural by-products as alternative animal-based protein sources are included in aquatic feeds. It is also recommended that more than 50% of the fish oil added to feeds should be replaced with vegetable oils (Costa-Pierce et al., 2012).

However, climate change also threatens agricultural production. This situation has both direct and indirect effects on agricultural production. In particular, temperature changes and rainfall directly affect agricultural production systems and cause changes in the physical properties of the product. In addition, the presence or absence of pollinators, pests, disease vectors and invasive species in the environment are other indirect effects that affect production. Globally, negative impacts are more common than positive impacts. For example, climate change has had a negative impact on wheat and maize yields in many regions and globally. IPCC (2014) stated that climate change may have positive or negative impacts in northern latitudes, while crop production in low latitude countries will be continuously and negatively affected by climate change in the future. While some high-latitude regions may become climatically more favorable for crops, soil quality and water availability may limit the sustainability of agricultural production growth in these locations (FAO, 2015). Studies point to potential changes in the nutritional quality of some foods (e.g. reduced concentration of proteins and some vitamins and minerals) due to elevated CO₂, especially for flours derived

from major cereals and cassava. Brazil is one of the world's largest soybean producers. About one-seventh of Brazil's rainforest has been cleared for agriculture, of which about 15 percent is dedicated to soybean production. Soybeans that are lighter in color reflect more solar radiation, heating the surface of the soil less and reducing the amount of hot air transported from the ground, resulting in less cloud formation and reduced rainfall (Costa et al. 2007).

Restricted access to sources of feed raw materials linked to terrestrial production will also restrict aquaculture production (Khatri-Chhetri et al., 2019; Maulu et al. 2021). Increasing aquaculture consumption of the world's cereals and oils is reported to raise concerns about the spread of unsustainable agricultural practices (Costa-Pierce et al., 2012). This is also questioned in terms of food availability. Instead of using these resources as a source of nutrients in animal production, their direct use as human food is being adopted. Climate change may also have impacts on the quality of drinking water, which is crucial for the absorption of nutrients. Therefore, future aquafeeds will largely depend on lower quality raw materials or by-products from waste product. However, these raw materials will need to be further improved in quality through processing and biotechnological transformation by feed technology to become adequate and balanced sources of nutrition for aquaculture species. These various available raw materials with different quality and costs will further require innovative models in feed formulation and feeding strategies based on availability and cost-benefit relationship (Costa-Pierce et al., 2012).

Increases in air temperature as a result of climate change can cause problems in the storage of both feed raw materials and feed. An important consequence of changing weather conditions on crops used in the aquafeed industry is the increase in harmful fungi and molds. Feed raw materials of plant origin are particularly vulnerable to mycotoxin contamination. Mycotoxins are highly stable to physiochemical processes and their direct consumption by livestock affects health and production (Rosen & Standen, 2024). In order to prevent this situation, the use of anti-fungal and anti-mold additives in feeds of aquatic species will become widespread.

In addition, several studies have been conducted on the effect of various feed supplements on the growth performance and immune response of various aquaculture species under high temperature conditions (Schrama et al., 2017; Hassaan et al., 2019; Herrera et al., 2019; Islam et al., 2021). These include various nutrients such as vitamin C, vitamin E, selenium, amino acids and polyunsaturated fatty acids (Chen et al. 2004; Ilham et al. 2016; Norambuena et al. 2016; Elkatatny et al. 2020) pigments (Liu et al. 2019; Cheng et al. 2018), essential oils (Magouz et al. (2022), prebiotics, probiotics, (Mohapatra, et al, 2014; Jha, et al., 2015); Feed additives such as nanoparticles (Kumar et al., 2020; Sarkar et al., 2022) and single cell proteins such as microalgae, macroalgae, yeast (Flores-Vergara et al. 2004; Hégaret et al. 2004; Abass et al. 2018) and raw materials derived from them (Mugwanya et al., 2022). The use of these and similar substances will be measures that can prevent the adverse effects of climate change on the growing conditions of aquatic species. Because the exposure of fish to high temperatures has a direct effect on their metabolic rate. Therefore, fish need to be well fed in order to meet their energy needs and to tolerate stress due to harsh environmental conditions. Feed quantity and quality are some of the commonly used strategies for aquatic animals to adapt to changing water temperatures (Dawood et al., 2021; Mugwanya et al., 2022).

Climate change is closely related not only to environmental conditions but also to diseases. Changing weather conditions can alter the expected season of disease, the geographical range of pathogens and associated pathologies. For example, several endemic diseases of salmonids are likely to become more widespread and difficult to control as water temperatures increase. Similarly, outbreaks of koi herpesvirus in carp are likely to occur over a longer period each summer (Marcos-López et al., 2010). Several studies have clearly demonstrated that organic acids can better combat gram-negative pathogens, while phytogetic feed additives may be more effective against gram-positive bacterial threats (Islam et al., 2021).

CONCLUSION

While it is not clear how climate change will affect the future of commercially important aquatic species, it will certainly have an impact on aquaculture. The most obvious impact is certain to be on the production of fishmeal and oil, which relies on the capture of natural pelagic species.

However, increased use of fish processing waste and commercialization of alternative feed sources such as black soldier fly larvae, microalgae and seaweeds could reduce the dependence on FM and FO. In the Mediterranean, meridionalization (the introduction of warm-water species in northern regions) and tropicalization (the spread of non-native tropical species) can create alternative sources for fishmeal and oil. Water consumption by aquaculture will increase competition for the resource in places where freshwater availability and quality are declining due to climate change. This problem can be addressed through technological and management improvements.

FAO (2018) lists specific measures to reduce the vulnerability of aquaculture in line with the ecosystem approach to aquaculture as follows;

- *Improving the management of farms and the choice of species farmed,*
- *Improving the spatial planning of farms taking into account climate-related risks,*
- *improved environmental monitoring involving users,*
- *improved local, national and international coordination of prevention and mitigation actions* (Soto et al., 2018).

It is also recommended to reduce the impacts of climate change;

- Feed raw materials with lower emissions, such as locally sourced oilseeds, can be selected for aquatic feeds.
- The nutrient content and availability of feed can be optimized through the development of formulations and technology.
- Feed management can be improved. Appropriate fertilization can be applied in production in ponds. Reduce the amount of available nitrogen in the environment by reducing uneaten feed.
- Water quality management can be improved. For example, dissolved oxygen levels can be increased to efficiently increase feeding. Although ponds are exposed to the open environment, protective cover and aeration equipment can be used to control dissolved oxygen levels.
- Fish welfare and health can be improved. For example, paying attention to appropriate fish stocking densities, ensuring the correct use of medicines (Robb et al., 2017; FAO 2018.)
- Polyculture of different aquaculture species can be practiced. In this way, one species can provide nutrients to another species and thus

increase its tolerance and immunity to environmental stress factors (Mugwanya et al.,2022).

- For stronger animals, it will be important to consider other factors such as genetic programs, production systems (indoor vs. outdoor for shrimp), area (coastal vs. offshore for marine species) and species selection (Rosen & Standen, 2021).

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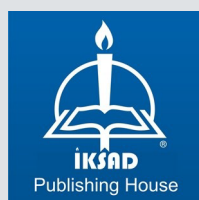
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ISBN: 978-625-367-959-0