AQUATIC FOODS : NUTRITIONAL ISSUES AND TOXICOLOGICAL RISKS IN TOGO

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Scientific Monograph

Mamatchi MELILA

Dedication

To all the fishers who risk their lives to feed the world with aquatic foods; though they may never read this book, it belongs to them**.**

PREFACE

It is with distinct honor and profound pride that I write this preface for the work of my former doctoral student, Dr. Mamatchi MELILA, who has established himself as an esteemed colleague and accomplished researcher. I still recall the passionate and rigorous young researcher who, under my supervision, already explored the intricacies of food biochemistry with remarkable acuity. To see him now offer such a masterful synthesis to the scientific community and the Togolese public is the greatest reward for one who had the privilege of supporting his first steps in research.

"**Aquatic Foods: Nutritional Issues and Toxicological Risks in Togo**" is not just another book on a familiar subject. It is a foundational work, a cornerstone that was critically missing from the edifice of knowledge on nutrition and food safety in our country. The author employs a highly insightful holistic approach, managing to articulate universal knowledge and local realities with exemplary clarity, from the shores of Lake Togo to the docks of Lomé port, and from the inland fish farms to the stalls of our markets.

In my capacity as Full Professor of Biochemistry and Nutrition, and President of the Nutrition Society of Togo (STN) and the Network of Nutrition Stakeholders in Togo (RésANuT), I can only applaud the scientific rigour and relevance of this publication. Dr. MELILA does not merely reiterate the universally acknowledged benefits of aquatic products – their exceptional richness in high-biological-value proteins, vitamins, minerals, and, critically, those precious omega-3 fatty acids so essential for neurological development and cardiovascular protection. He goes further by systematically contextualizing this contribution within the Togolese diet, emphasizing the vital role of sardinella, tilapia, or small dried fish in the fight against malnutrition and the micronutrient deficiencies that still affect too many of our compatriots, particularly women and young children.

But the great strength of this book lies in its courageous balance. With unwavering intellectual honesty, the author addresses the corollary of these benefits: the risks. The chapter on chemical, biological, and parasitic hazards is of pressing relevance for Togo. By linking heavy metal contamination risks to the realities of artisanal gold mining, questioning traditional smoking techniques, and highlighting cold chain challenges in our climate, Dr. MELILA provides a nuanced and indispensable analysis for informed food safety management.

This work is much more than a simple compilation of knowledge. It is a true decision-support tool. It is aimed equally at the student eager to understand the complexity of the aquatic food chain and the political decision-maker seeking empirical data to develop national strategies for food security, public health, or the development of sustainable aquaculture. Stakeholders in the fishing sector, processors, health professionals, and educators will find a wealth of practical and scientifically validated information to improve their practices and advice.

Upon closing the manuscript, I felt the satisfaction of seeing the promise I had discerned in the author materialize in the most brilliant manner. He has successfully transformed the rigour of his doctoral training into a mature, committed, and profoundly useful expertise for his nation. This book is not only an academic achievement; it is an act of citizenship, a tangible contribution to the well-being of the Togolese population.

I do not doubt for a moment that this work will be a landmark publication and an essential reference for anyone interested in nutrition and health in Togo and West Africa. May it inspire a new generation of researchers, enlighten public policies, and guide every consumer toward choices that maximize the bounty of our waters while protecting their health and the sustainability of these precious resources. It is with this profound conviction that I wish this book and its author all the success they deserve.

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I would like to express my profound gratitude to **Professor Ananivi DOH**, my very first mentor in scientific research. As a pioneer of Biochemistry and Nutrition in Togo, he laid the foundations upon which several generations of researchers, including myself, with great honor, have built their careers.

His scientific rigor, exemplary humility, and forward-looking vision for the development of this discipline in our country have profoundly shaped my professional journey. This book, dedicated to aquatic foods and their nutritional and toxicological implications, stands as a continuation of the scientific legacy he helped establish.

Through these lines, I pay tribute to him for the inspiration, guidance, and trust he has offered me since my earliest steps in research.

I extend my profound gratitude to **Dr. Mlatovi DEGBE** of the Department of Biochemistry at the University of Lomé. His meticulous review, valuable contribution, and enlightened suggestions significantly enriched the biochemical and nutritional accuracy of this manuscript.

My sincere thanks go to **Dr. P'ham BEIGUE ALFA**, Head of the Fisheries Division at the Ministry of Halieutic Resources, Animal Resources, and Transhumance Regulation (MRHART). Dr. BEIGUE ALFA's essential review, the provision of photographs of the various aquatic species, and his practical suggestions ensured that the book accurately reflects the realities and diversity of the Togolese fisheries sector.

I address my warm appreciation to **Dr. Boris Dodji KASSENEY**, Senior Lecturer in Animal Biology, Department of Zoology, Faculty of Sciences, University of Lomé. Dr. KASSENEY's expertise was vital for the exhaustive review, the precise zoological identification of the different species, and the constructive suggestions that provided a crucial biological context to the work.

I wish to express my deep gratitude to **Dr. Mouawiyatou BOURAIMA**, Head of the Nutrition Division at the Ministry of Health and Public Hygiene, as well as to his entire team, particularly **Mr. Midassirou BEBOU**, for their constant support, sound advice, and unwavering commitment to the promotion of nutrition in Togo. Their guidance and encouragement constituted valuable support in the realization of this work dedicated to aquatic foods and their nutritional and toxicological issues.

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I would like to express my sincere gratitude to **Mr. Dédényo ADOSSI**, an esteemed specialist in public nutrition whose commitment, multisectoral expertise, and leadership have greatly inspired my scientific approach. Through his strong analytical skills, coordination abilities, and diplomatic insight, he has helped strengthen the coherence of nutrition interventions across Africa while promoting a rigorous, evidence-based approach. His openness, guidance, and integrated vision, bridging research, public policy, and community action, have provided valuable insight that enriched the development of this book.

To my wife, **M. M. Solange BATAKA**, and to **my children (Béni, Christophe and Placide)**, I express my profound gratitude for their love, patience, and benevolent presence throughout the preparation of this work. Their understanding and constant encouragement were an invaluable source of motivation during the most demanding moments of this undertaking.

To **my extended family**, I pay tribute for their unwavering moral support, their prayers, and their encouragement which accompanied me throughout this scientific journey. This work is also dedicated to them, in testimony of my gratitude and affection.

Together, these collective efforts have made this synthesis a more robust, scientifically grounded, and comprehensive resource for the benefit of the scientific community and the public in Togo and beyond.

Preamble

Nutrition forms the fundamental substrate of human existence, orchestrating a complex interplay of biological processes vital for survival, growth, and homeostasis maintenance. Beyond the mere satisfaction of energetic needs, the ingestion of food supplies the macronutrients (carbohydrates, lipids, proteins) and micronutrients (vitamins, minerals) indispensable for cellular function, tissue repair, and the regulation of physiological systems. Adequate nutrition is intrinsically linked to the prevention of chronic diseases such as cardiovascular disorders, type 2 diabetes, and certain neoplasias, underscoring its pivotal role in public health. Conversely, nutritional deficiencies or excesses can lead to metabolic dysfunctions and compromise the organism's resilience against external stressors.

Human food sources exhibit a remarkable diversity, reflecting millennia of adaptation and innovation. Traditionally, terrestrial agriculture has dominated the supply, providing cereals (rice, wheat, maize), legumes, a multitude of fruits and vegetables, as well as livestock products (meats, poultry, dairy products). These terrestrial sources, although predominant, represent only a fraction of the global nutritional potential.

With 75% of its surface covered by water, the Earth offers an aquatic ecosystem of inestimable richness that contributes significantly to human nutrition. Aquatic food sources, often referred to as "seafood," encompass a vast category including fish (fatty fish such as salmon and mackerel, lean fish such as cod), crustaceans (shrimp, crabs, lobsters), mollusks (oysters, mussels, squid), and algae. These sources are particularly valued for their exceptional nutritional profile. Aquatic ecosystems (oceans, seas, lakes, and rivers) are teeming with exceptional biodiversity, which is essential to the terrestrial biosphere. Since the dawn of humanity, these aquatic ecosystems have constituted a primary source of nourishment, with aquatic foods being durably embedded at the core of diets and cultures across the globe. These products—fish, mollusks, crustaceans, algae, and other organisms—today represent a fundamental pillar of global food and nutritional security, providing high-quality proteins and a myriad of essential micronutrients to a considerable part of the planetary population. Their classification, which reflects a complexity influencing their composition, is based on biological, ecological, and sometimes commercial criteria. This work is dedicated to the exhaustive and rigorous exploration of the multiple facets of these foods, which are essential from historical, economic, and nutritional perspectives.

While adopting a resolutely international scope to integrate global knowledge and challenges, this work will pay particular and constant attention to the Togolese context. Indeed, Togo, endowed with a diverse network of watercourses such as the Mono, Zio, and Oti rivers, lagoons, the most significant of which is Lake Togo, and especially a coastline providing direct access to the Atlantic Ocean, sees the consumption of aquatic products representing a growing and significant share in the diet of its populations. This local focus will allow for the contextualization of the specific challenges and opportunities in this region, underscoring the crucial importance of adapting knowledge and solutions to local realities to ensure sustainable food and nutritional security.

Aquatic food sources are recognized for their specific nutritional benefits, notably their exemplary richness in bioactive compounds such as long-chain omega-3 polyunsaturated fatty acids (EPA and DHA), which are essential for health. The roles of these lipids in cardiovascular health, neurological development, and the modulation of inflammatory processes are widely established by science. These foods are thus intrinsically linked to major public health issues, offering promising perspectives for the prevention and management of various chronic pathologies.

However, this valuable source of nutritional benefits is not without its corollary of potential risks. Aquatic ecosystems, being receptacles for anthropogenic activities, can be subject to contamination by environmental pollutants such as heavy metals, pesticides, and persistent organic compounds. Furthermore, certain aquatic organisms can accumulate natural toxins produced by algae (phycotoxins) or harbor microbial and parasitic pathogens. This duality between major nutritional stakes and inherent intoxication risks constitutes a first-order scientific and societal challenge, the understanding of which is a *sine qua non* condition for ensuring food safety. In a global context marked by demographic growth, the imperatives of food security, the overexploitation of certain resources, and the impacts of climate change on aquatic ecosystems, a deep and nuanced understanding of this food category is more necessary than ever.

Addressing this theme with the required scientific rigor demands a convergence of knowledge from varied disciplines: marine and freshwater biology, ecology, analytical chemistry, toxicology, human nutrition, epidemiology, food science, biotechnology, and resource management. It is within this perspective that this work is situated. It aims to synthesize the current state of scientific knowledge to offer a critical and integrated analysis of the substantial nutritional benefits of aquatic food sources, while also examining in detail the associated health risks (chemical, toxic, microbial, parasitic) and the strategies aimed at controlling them, including good consumption practices from purchase to preparation, and the essential role of health authorities and regulatory frameworks. Sustainable production practices will also be explored, notably aquaculture with its advantages in terms of controlled production and its major challenges related to its environmental and societal sustainability, the integration of these foods into public health policies through nutritional recommendations and educational programs, as well as technological innovations and future perspectives for responsible and sustainable exploitation and consumption, including the potential of alternative sources like algae.

May the knowledge assembled within these pages contribute to a deeper and more nuanced understanding of aquatic food sources. The ultimate goal is to promote responsible exploitation and consumption that maximizes their benefits while protecting human health and the sustainability of the valuable ecosystems from which they originate, in order to guide informed choices and promote responsible practices for the benefit of human health and the preservation of aquatic ecosystems, both on a global scale and for the specific context of Togo.

Chapter 1

Introduction to Aquatic Foods

Aquatic ecosystems, in their vast diversity, have constituted a primordial source of food resources for humanity since time immemorial. The biodiversity they harbor translates into a wide array of edible organisms, collectively designated as **aquatic foods**. These foods, ranging from vertebrate fish to photosynthetic algae, play a crucial role not only in the subsistence and food security of many populations worldwide (FAO, 2024), but also in providing specific, essential, and often irreplaceable nutrients (Hicks et al., 2019).

This inaugural chapter aims to delineate the scope of these foods, establish a rigorous classification thereof, trace the history of their consumption by the human species, and finally, emphasize their paramount importance in contemporary global diets, illustrating certain aspects through the reality in Togo.

1.1. Definition and Classification of Aquatic Foods

Aquatic foods encompass all living organisms, animal or plant, originating from aquatic environments (oceans, seas, estuaries, lagoons, rivers, lakes, ponds, and aquaculture facilities) and intended for human consumption, either directly or after processing. The richness and complexity of aquatic biodiversity necessitate a structured, rigorous classification to adequately grasp this vast category.

1.1.1. Fish (Pisces)

Fish constitute the most emblematic and widely consumed group of aquatic foods. They comprise gill-bearing aquatic vertebrates, generally possessing fins and a body covered in scales. From a taxonomic and practical standpoint, they are subdivided into several taxa.

Cartilaginous Fish (Chondrichthyes) This class includes sharks, rays, and chimaeras. Their skeleton is composed of cartilage rather than bone. Although less consumed globally than bony fish, certain species hold notable local or commercial importance, such as dogfish and rays.

Bony Fish (Osteichthyes) Representing the vast majority of consumed fish species, their skeleton is ossified. This superclass is divided into two main groups:

> **Actinopterygii (Ray-finned fish):** These constitute virtually all commercial fish, such as salmon, tuna, cod, sardine, carp, and tilapia. In Togo, tilapias (*Oreochromis niloticus*), African catfish (*Clarias gariepinus*), sardinella (*Sardinella* spp.), and mackerels (*Scomber* spp.) feature among the most commonly caught and consumed species, both in freshwater (Lake Togo, rivers) and marine environments (Villanueva, 2004).
>
> **Sarcopterygii (Lobe-finned fish):** This group includes coelacanths and lungfish. Although their dietary importance is marginal, they hold major evolutionary significance.

Fish can also be classified according to their habitat (marine fish, freshwater fish, diadromous fish migrating between the two) or their lipid content (lean fish, medium-fat fish, and fatty fish).

1.1.2. Crustaceans (Crustacea)

Crustaceans are aquatic arthropods characterized by a chitinous exoskeleton impregnated with calcium carbonate and typically biramous appendages. Major groups of dietary importance include:

Decapods (Decapoda) This group is the most diverse and economically important. It includes shrimp, crabs, lobsters, spiny lobsters, and crayfish. The Togolese coasts and lagoons host various species of crabs and shrimp that are artisanally exploited and locally appreciated (Ahoedo et al., 2021; Ouro-Sama et al., 2021; Ministère de l'Environnement et des Ressources Forestières/ANGE/PASIET, 2022).

Euphausiids (Euphausiacea) Primarily represented by krill, small pelagic creatures that, while consumed directly in some regions, are mainly used for the production of animal feed and omega-3 rich oil (Nicol et al., 2012).

Other groups, such as certain stomatopods (mantis shrimp) or isopods, have a more localized dietary importance.

1.1.3. Mollusks (Mollusca)

Mollusks constitute a vast phylum of soft-bodied invertebrates, often protected by a calcareous shell. The main classes of dietary interest are:

Bivalves (Bivalvia) Characterized by a two-valved shell. This group includes highly prized filter-feeding species such as oysters, mussels, clams, cockles, and scallops. In Togo, the exploitation of bivalves like the mangrove oyster (*Crassostrea gasar*) in the lagoon system is a traditional activity, although efforts for sustainable management and the development of oyster farming are necessary to increase their potential (COMHAFAT/ATLAFCO, 2015).

Gastropods (Gastropoda) Generally equipped with a spiral, univalve shell, although some species lack one. Among the consumed marine species are whelks, periwinkles, and abalones. Certain terrestrial gastropods (snails) are also consumed but fall outside the strict aquatic scope, with the exception of a few freshwater species like apple snails (*Ampullariidae*).

Cephalopods (Cephalopoda) Highly evolved marine mollusks, characterized by a distinct head bearing prehensile tentacles. This group includes squid (calamari), cuttlefish, and octopuses.

1.1.4. Algae and other Aquatic Plants

Although less prominent in traditional Western diets, aquatic plants, particularly macroalgae (seaweed), constitute a significant food source, especially in Asia (Wells et al., 2017) and increasingly in Africa, where the consumption of spirulina, for example, is gaining importance (Habib et al., 2008). They are distinguished as:

Red Algae (Rhodophyceae): Such as nori (used for sushi) and dulse.
Brown Algae (Phaeophyceae): Such as kombu, wakame, and sea spaghetti.
Green Algae (Chlorophyceae): For instance, sea lettuce (*Ulva*).

Microalgae (e.g., spirulina, chlorella) and certain cyanobacteria, though often marketed as food supplements, also represent a growing potential as ingredients or whole foods (Becker, 2013). In Togo, spirulina cultivation is emerging and encouraged for its nutritional benefits, particularly in the fight against malnutrition. Local initiatives aim to develop this sector. Furthermore, some aquatic vascular plants (macrophytes), such as water chestnut and watercress, are also consumed.

1.1.5. Other Aquatic Organisms

Other less conventional taxonomic groups are also exploited for human consumption in various cultures. These include:

Echinoderms (Echinodermata) Primarily sea urchin gonads (called "roe" or "coral") and sea cucumbers (holothurians or bêches-de-mer), which are particularly prized in Asia (Purcell et al., 2013).

Tunicates (Tunicata) Such as sea squirts (ascidians), for example, sea violets or *biju* in the Mediterranean and Asia.

1.2. History of Aquatic Food Consumption

The relationship between the human species and aquatic food resources is deeply rooted in our evolutionary and cultural history.

1.2.1. Prehistoric Periods and Antiquity

Archaeological evidence attests to the consumption of aquatic foods by hominids as early as the Paleolithic era. Shell middens (*kjökkenmöddinger*), fish bone remains, and rudimentary fishing tools (bone harpoons, hooks) bear witness to the exploitation of coastal zones, estuaries, and riverbanks (Erlandson, 2001). For *Homo sapiens*, access to long-chain polyunsaturated fatty acids (LC-PUFA), particularly docosahexaenoic acid (DHA), which is abundant in aquatic products, is suspected to have played a decisive role in cerebral development (Crawford, 1999).

In Antiquity, the Egyptian (depictions of fishermen on the Nile), Greek, and Roman civilizations accorded a significant place to fish and seafood. More elaborate fishing techniques (nets, traps) and the beginnings of aquaculture (pond pisciculture and oyster farming) emerged. *Garum*, a fermented fish sauce, was an essential condiment in Roman cuisine.

1.2.2. From the Middle Ages to the Modern Era

In medieval Europe, fish consumption was heavily influenced by Christian religious prescriptions, which mandated "fast days" (abstinence from terrestrial meat). This stimulated the fish trade, particularly for herring and cod, which were preserved by salting, smoking, or drying to enable long-distance transport. Monasteries played a key role in the development of freshwater pisciculture.

The Renaissance and the Age of Discovery broadened access to new species and fishing grounds. Advances in navigation and shipbuilding technology allowed for more distant and productive fishing expeditions.

1.2.3. Contemporary Era and Industrialization

The 19th century marked a turning point with the advent of industrial fishing, driven by the steam engine and subsequently the diesel engine, the use of more efficient trawls, and the development of refrigeration and preservation techniques (canning). These innovations led to a massive increase in catches and a democratization of aquatic product consumption.

The 20th and early 21st centuries have seen this trend accelerate, but also the emergence of major concerns regarding the overexploitation of wild fish stocks. In response, aquaculture (the farming of fish, crustaceans, mollusks, and algae) has experienced spectacular growth, becoming an essential source of supply, even surpassing capture fisheries in volume for direct human consumption since the mid-2010s (FAO, 2022).

In Togo, although fishing remains predominantly artisanal, it is essential for local supply. Aquaculture, particularly of tilapia and clarias, is gradually developing to meet growing demand and reduce pressure on wild stocks, but requires technical and financial support for sustainable intensification (COMHAFAT/ATLAFCO, 2015).

1.3. Importance in Global Diets

Aquatic products are recognized for their high nutritional value and hold paramount importance for global nutrition and food security, although their contribution varies significantly by region, culture, and socioeconomic level.

1.3.1. Nutritional Profile and Health Benefits

Aquatic products constitute an excellent source of:

- **High-Biological-Value Proteins:** Rich in essential amino acids and easily digestible (Łuczyńska et al., 2016).
- **Long-Chain Omega-3 Polyunsaturated Fatty Acids:** Notably eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are crucial for neurological development and cognitive function, cardiovascular health (reducing the risk of coronary heart disease), inflammation modulation, and ocular health (Swanson et al., 2012). Fatty fish (salmon, mackerel, herring, sardine) are particularly rich in these.
- **Vitamins:** Including Vitamin D (essential for bone and immune health, and rare in other foods), Vitamin B12 (crucial for nerve function and red blood cell formation), and other B-group vitamins (niacin, riboflavin) (Borel, 2015).
- **Minerals and Trace Elements:** Such as iodine (essential for thyroid function, particularly abundant in marine products), selenium (a powerful antioxidant), zinc (involved in immunity and wound healing), iron (especially in certain mollusks and fish), phosphorus, and calcium (particularly in fish consumed with their bones, like small sardines) (Kawarazuka and Béné, 2011).

Algae, for their part, are notable sources of fiber, minerals (iodine, magnesium, calcium), vitamins, and specific bioactive compounds (phycocolloids, antioxidant pigments) (Rajapakse and Kim, 2011).

1.3.2. Contribution to Food and Nutritional Security

Globally, aquatic foods provide at least 20% of the average animal protein intake for approximately 3.3 billion people (FAO, 2022). For many coastal and island populations, particularly in developing countries, fish often represents the primary, if not the sole, source of animal protein and essential micronutrients, playing a vital role in preventing malnutrition and deficiencies (Béné et al., 2015).

In Togo, fish is an accessible and culturally accepted source of animal protein for a large part of the population, especially in rural and coastal areas (Ali et al., 2014; FAO, 2019; Che et al., 2022). Fishing and aquaculture are also major sources of employment and income for hundreds of thousands of Togolese, particularly in the informal sector, thereby contributing indirectly to household food security. Improving processing techniques (smoking, drying) to reduce post-harvest losses is a major challenge for optimizing this contribution.

1.3.3. Consumption Trends and Future Challenges

Global per capita consumption of aquatic products has more than doubled over the last fifty years, reaching record levels (20.2 kg in 2020). This trend is expected to continue, driven by population growth, urbanization, rising incomes, and an increasing awareness of the health benefits of these foods (FAO, 2024).

However, this rising demand exerts considerable pressure on resources. The sustainability of capture fisheries is a major issue, with a significant proportion of global stocks being fully exploited or overexploited (Pauly and Zeller, 2016). Aquaculture, while a solution to increase supply, must itself address sustainability challenges (feed for farmed species, environmental impacts, animal health) (Edwards et al., 2019). The effects of climate change (warming waters, ocean acidification, extreme events) pose an additional threat to aquatic ecosystems and the resources they provide (FAO, 2018).

For Togo, these challenges translate into increased pressure on coastal and continental fish resources, habitat degradation (marine pollution and pollution of Lake Togo, coastal erosion), and the necessity of developing a truly sustainable and resilient aquaculture sector. Key strategies for improvement include strengthening fisheries governance, promoting ecologically responsible aquaculture practices, investing in research for sustainable local aquafeeds, and diversifying farmed species.

Aquatic foods represent a food category of exceptional diversity and importance. Their historical role in human subsistence continues today through a major contribution to global nutrition and food security. Understanding their nature, history, and impact is fundamental to addressing the subsequent chapters, which will explore their composition, processing, and the challenges related to their sustainable production and consumption in greater detail, bearing in mind the necessity of adapting strategies to local contexts, such as that of Togo.

References

Ahoedo K., Chuku E. O., Adotey J., Kent K., Crawford B. (2021). Évaluation Participative de la Pêche des mollusques et crustacés dans les Écosystèmes d'Estuaires et de Mangroves du Togo. Centre for Coastal Management (Africa Centre of Excellence in Coastal Resilience) University of Cape Coast, Ghana and Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island. Narragansett, RI, USA. 44 pp.

Ali D., Ahoedo K. Folikoue E. E. A., Beigue Alfa P. (2014). Enquête cadre de la pêche artisanale maritime au Togo - année 2014 ; 99p.

Becker E. W. (2013). Microalgae for human and animal nutrition. *In*: Richmond A., Qiang Hu (Eds), 2013, Handbook of microalgal culture: applied phycology and biotechnology, 2nd edition, Wiley-Blackwell: 461-503.

Béné C., Barange M., Subasinghe R., Pinstrup-Andersen P., Merino G., Hemre G. I., Williams M. (2015). Feeding 9 billion by 2050–Putting fish back on the menu. Food security, 7 : 261-274.

Borel P., Caillaud D., Cano N. J. (2015). Vitamin D bioavailability: state of the art. Critical reviews in food science and nutrition, *55*(9) : 1193-1205.

Che B., N'Souvi K., Sun C., Leibrecht M., Nantob B. (2022). Between Tradition, Strategies and Taste: Understanding Fish Consumption Habits in Togo. Sustainability, 14 : 11475. https://doi.org/10.3390/su141811475

COMHAFAT/ATLAFCO (2015). Rapport de l'Atelier de restitution : Etudes des industries des pêches et de l'aquaculture dans les pays de la COMHAFAT ; du 28 au 29 décembre 2015 à Rabat (Maroc). https://www.comhafat.org/fr/files/actualites/doc_actualite_022.pdf

Crawford M. A., Bloom M., Broadhurst C. L., Schmidt W. F., Cunnane S. C., Galli C., Ghebremeskel K., Linseisen F., Lloyd-Smith J., Parkington J. (2000). Evidence for the unique function of docosahexaenoic acid during the evolution of the modern hominid brain. Lipids, 34 : S39-S47.

Edwards P., Zhang W., Belton B., Little D. C. (2019). Misunderstandings, myths and mantras in aquaculture: Its contribution to world food supplies has been systematically over reported. Marine Policy, 106 : 103547.

Erlandson J. M. (2001). The archaeology of aquatic adaptations: paradigms for a new millennium. Journal of Archaeological Research, 9(4) : 287-350.

FAO (2018). Impacts of climate change on fisheries and aquaculture ; Synthesis of current knowledge, adaptation and mitigation options. FAO fisheries and aquaculture technical paper. 654p. https://openknowledge.fao.org/server/api/core/bitstreams/9aeb8ade-a623-4954-8adf-204daae3b5de/content

FAO (2018). The state of world fisheries and aquaculture. Meeting the sustainable development goals. Rome. Licence: CC BY-NC-SA 3.0 IGO.

FAO (2019). Togo: GLOBEFISH Market Profile-2019 ; 4p. Rome. FAO (2024). The state of world fisheries and aquaculture 2024 – Blue transformation in action. Rome ; 264p. https://doi.org/10.4060/cd0683en

Habib M. A. B., Parvin M., Huntington T. C., Hasan M. R. (2008). A review on culture, production and use of Spirulina as food for humans and feeds for domestic animals. FAO Fisheries and Aquaculture Circular No. 1034. https://www.fao.org/4/i0424e/i0424e00.pdf

Hicks C. C., Cohen P. J., Graham N. A. J., Nash K. L., Allison E. H., D'Lima C., Mills D. J., Roscher M., Thilsted S. H., Thorne – Lyman A. L., MacNeil M. A. (2019). Harnessing global fisheries to tackle micronutrient deficiencies. Nature, 574(7776) : 95-98.

Kawarazuka N. & Béné C. (2011). The potential role of small fish species in improving micronutrient deficiencies in developing countries: building evidence. Public health nutrition, *14*(11) : 1927-1938.

Łuczyńska J., Tońska E., Krejszeff S., Żarski D. (2016). Comparison of fatty acids in the muscles and liver of pond-cultured and wild perch, Perca fluviatilis (L.), in Poland. Turkish Journal of Fisheries and Aquatic Sciences, 16(1) : 019-027.

Ministère de l'Environnement et des Ressources Forestières/ANGE/PASIET (2022). Premier Rapport sur l'Etat de l'Environnement Marin (REEM) du Togo. https://environnement.gouv.tg/wp-content/uploads/2022/12/PREMIER-RAPPORT-SUR-LETAT-DE-LENVIRONNEMENT-MARINREEM-DU-TOGO_FV.pdf

Nicol S., Foster J., Kawaguchi S. (2012). The fishery for Antarctic krill–recent developments. Fish and Fisheries, 13(1) : 30-40.

Ouro-Sama K., Afiademanyo K. M., Solitoke H. D., Tanouayi G., Badassan T. E.-E., Adje K., Agbere S., Gnandi K. (2021). Trace Elements in Mollusks, Crustaceans and Fish Commonly Consumed by the Catfish Chrysichthys nigrodigitatus Lacépède, 1803 from the Lake Togo-Lagoon of Aného Hydrosystem (Southern Togo). Journal of Environmental Protection, 12 : 1185-1203.

Pauly D. & Zeller D. (2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nature communications, *7*(1) : 10244.

Purcell, S. W., Mercier, A., Conand, C., Hamel, J. F., Toral-Granda, M. V., Lovatelli, A., & Uthicke, S. (2013). Sea cucumber fisheries: global analysis of stocks, management measures and drivers of overfishing. Fish and fisheries, 14(1) : 34-59.

Rajapakse N. & Kim S. K. (2011). Nutritional and digestive health benefits of seaweed. Advances in food and nutrition research, 64 : 17-28.

Swanson D., Block R., Mousa S. A. (2012). Omega-3 fatty acids EPA and DHA: health benefits throughout life. Advances in nutrition, *3*(1) : 1-7.

Villanueva M. C. S. (2004). Biodiversité et relations trophiques de quelques milieux estuariens et lagunaires dans l'Afrique de l'Ouest. Thèse de Doctorat d'Écologie et Environnement Aquatique, Institut National Polytechnique de Toulouse (France) ; 272p.

Wells M. L., Potin P., Craigie J. S., Raven J. A., Merchant S. S., Helliwell K. E., Smith A. G., Camire M. E., Brawley S. H. (2017). Algae as nutritional and functional food sources: revisiting our understanding. Journal of applied phycology, 29(2) : 949 – 982.

Chapter 2

Nutritional Benefits of Aquatic Foods

Beyond their diversity and socio-economic importance, aquatic-sourced foods are distinguished by an exceptional nutritional profile, which grants them a prominent position in a balanced and preventive diet.

This chapter is dedicated to the analysis of the main nutritional components of aquatic products and their physiological roles, highlighting their specific contribution to human health, especially in comparison with other nutrient sources.

2.1. Superior Protein Value and Essential Amino Acid Profile

Aquatic foods, particularly fish and seafood (crustaceans, mollusks), are universally recognized for their high protein content, generally ranging from 15 to 25% of their fresh weight.

These proteins are classified as having "High Biological Value" (HBV), meaning they provide all the Essential Amino Acids (EAAs) in optimal proportions for protein synthesis in humans.

The EAAs—histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine—cannot be synthesized by the organism and must imperatively be supplied through the diet.

The structure of fish protein, which is less rich in connective tissue (collagen and elastin) compared to terrestrial meats, gives it a particularly high digestibility, often exceeding 95%.

This increased bioavailability of amino acids promotes their efficient utilization by the body for growth, tissue repair, and the synthesis of biologically active molecules (enzymes, hormones, antibodies).

Furthermore, certain abundant amino acids, such as taurine (particularly in mollusks and some fish), although not essential, play important physiological roles in cardiovascular function, retinal development, and neurotransmission.

In Togo, where fish consumption is common, notably tilapia and catfish (*silure*), this source of high-quality protein can contribute significantly to the population's nutritional intake.

2.2. Long-Chain Omega-3 Polyunsaturated Fatty Acids

One of the most distinctive and beneficial nutritional characteristics of aquatic foods, especially fatty fish, lies in their richness in long-chain omega-3 (n-3) polyunsaturated fatty acids (PUFAs).

2.2.1. Nature and Sources of Omega-3 Fatty Acids

The two n-3 PUFAs of major interest are eicosapentaenoic acid (EPA, C20:5n-3) and docosahexaenoic acid (DHA, C22:6n-3).

These fatty acids are initially synthesized by marine phytoplankton and, to a lesser extent, by certain freshwater algae.

They then accumulate along the aquatic food chain, reaching high concentrations in fatty pelagic fish (e.g., salmon, mackerel, herring, sardine, anchovy, bluefin tuna) and, to a lesser degree, in lean fish and seafood.

The human body has a very limited capacity to convert α-linolenic acid (ALA, C18:3n-3, a plant-derived omega-3) into EPA and, especially, into DHA, making the direct dietary intake of the latter almost indispensable.

2.2.2. Role in Cardiovascular Health

An abundant and converging scientific literature supports the protective role of n-3 PUFAs, particularly EPA and DHA, against cardiovascular diseases.

Their mechanisms of action are multiple and pleiotropic:

- **Hypolipidemic effects:** Reduction of plasma triglyceride levels.
- **Antithrombotic effects:** Decrease in platelet aggregation and blood viscosity.
- **Anti-inflammatory effects:** Modulation of the production of pro-inflammatory lipid mediators (eicosanoids derived from arachidonic acid) in favor of less inflammatory or pro-resolving mediators (resolvins, protectins, maresins).
- **Antiarrhythmic effects:** Modulation of the electrophysiological activity of cardiomyocytes (blocking of ion channels (Na^+, K^+, Ca^{2+}) located on the cardiomyocyte membrane for the stabilization of the action potential; regulation of sinus rhythm by acting on the sinoatrial node and the atrioventricular node; reduction of the automaticity of abnormal cardiac cells).
- **Improvement of endothelial function** and slight reduction in blood pressure.

Thus, regular consumption of fish, particularly fatty fish, is associated with a significant decrease in the risk of coronary mortality, myocardial infarction, and ischemic stroke.

2.2.3. Crucial Importance for Brain Health and Neurological Development

Docosahexaenoic acid (DHA) is a major structural component of the phospholipids in the cell membranes of the brain and retina.

It is indispensable for the development and optimal functioning of these tissues:

- **Fetal and Infant Development:** An adequate DHA intake via maternal consumption of aquatic products during gestation and lactation is crucial for brain development, the maturation of visual function, and the child's cognitive development.
- **Cognitive Function in Adults:** DHA participates in neuronal membrane fluidity, neurotransmission, neuroprotection, and synaptic plasticity. Sufficient intake is associated with the maintenance of cognitive functions (memory, learning) during aging.
- **Prevention of Neurological and Psychiatric Disorders:** Although the mechanisms are not fully elucidated, studies suggest a potential role for n-3 PUFAs in the prevention or mitigation of certain neurodegenerative diseases (e.g., Alzheimer's disease) and mood disorders (e.g., depression).

2.3. Richness in Essential Minerals and Vitamins

In addition to specific proteins and lipids, aquatic foods constitute a privileged source of several essential vitamins and minerals, often less abundant in other food categories.

2.3.1. Vitamin D

Fatty fish (salmon, mackerel, herring, sardine) and fish liver oil figure among the richest natural dietary sources of Vitamin D (cholecalciferol, D3).

This fat-soluble vitamin is indispensable for maintaining calcium and phosphorus homeostasis, and thus for bone mineralization.

It also exerts pleiotropic effects, notably in the modulation of the immune system, cell differentiation, and the regulation of inflammatory processes.

2.3.2. Vitamin B12 (Cobalamin)

Vitamin B12, exclusively synthesized by microorganisms, is naturally found in animal-origin products.

Fish, mollusks (particularly bivalves such as clams and mussels), and crustaceans constitute excellent sources thereof.

This vitamin is indispensable for DNA synthesis, erythropoiesis (red blood cell formation), and the proper functioning of the nervous system, notably through the maintenance of the myelin sheath.

2.3.3. Iodine

Marine products (fish, seafood, and especially seaweed) constitute the most reliable and concentrated dietary source of iodine.

This trace element is an essential constituent of thyroid hormones (thyroxine T4 and triiodothyronine T3), which participate in the regulation of energy metabolism, growth, and development.

Its role is particularly critical during the fetal period and early childhood, notably for the optimal development of the central nervous system.

2.3.4. Selenium

Selenium is a trace element with major antioxidant properties, acting as a cofactor for several key enzymes (selenoproteins), such as glutathione peroxidases.

Fish and seafood figure among the best dietary sources of selenium.

This micronutrient plays a fundamental role in protection against oxidative stress, the proper functioning of the immune system, as well as in the metabolism of thyroid hormones.

It is interesting to note that selenium also plays a protective role against the toxicity of mercury, sometimes present in certain predatory fish.

In Togo, where soil selenium levels can vary, regular consumption of local fish constitutes an important nutritional lever to ensure an adequate intake of this essential trace element.

2.3.5. Other Minerals of Interest

Aquatic products also provide zinc (important for immunity, wound healing, and protein synthesis), phosphorus (bone health, energy metabolism), as well as potassium (hydro-electrolyte balance, nerve and muscle function).

Certain species, such as small fish consumed whole with their bones, or certain mollusks, are furthermore good sources of calcium and highly bioavailable heme iron.

In Togo, the consumption of small dried or fried fish, often eaten whole, constitutes a non-negligible source of calcium and iron, particularly for rural populations and children.

It is crucial to promote the consumption of these local species and ensure the sustainability of their fishing to maintain this precious nutritional contribution.

2.4. Contribution to Muscle Development and Prevention of Chronic Diseases

The synergy of nutrients present in aquatic foods confers significant assets for the maintenance of muscle mass and the prevention of various chronic conditions.

2.4.1. Support for Muscle Mass and Function

Thanks to their richness in high-biological-value proteins, aquatic products effectively promote muscle protein synthesis (anabolism).

This effect is particularly relevant for athletes, seeking to optimize recovery and muscle growth, as well as for the elderly, for whom the prevention of sarcopenia (age-related loss of muscle mass and function) is a major public health issue.

The presence of amino acids such as leucine, in notable concentration, is a stimulating factor for the **mTOR pathway** (*mammalian Target Of Rapamycin*, centered on a serine/threonine protein kinase), which acts as a sensor of the cellular nutritional and energetic state; it is an essential intracellular signaling pathway that regulates cell growth, proliferation, survival, and metabolism based on available nutrients, energy, and growth signals.

This pathway is essential in the regulation of protein synthesis.

For the Togolese population, especially growing children and adults with significant physical activity, local fish and seafood represent an ideal protein source for muscle development and maintenance.

2.4.2. Prevention of Non-Communicable Chronic Diseases (NCDs)

Beyond the cardiovascular diseases already mentioned, regular consumption of aquatic foods fits into prevention strategies for several NCDs:

- **Metabolic Syndrome and Type 2 Diabetes:** n-3 PUFAs can improve insulin sensitivity and lipid profile.

- **Chronic Inflammatory Diseases:** For example, rheumatoid arthritis, where the anti-inflammatory effects of EPA and DHA can contribute to reducing symptoms.

- **Certain Cancers:** Epidemiological studies suggest an inverse association between fish consumption and the risk of certain cancers (e.g., colorectal, prostate).

The mechanisms (involving n-3 PUFAs, selenium, vitamin D) are complex and multifactorial.

It should be emphasized that these benefits result from the entire "food matrix" of aquatic products, where nutrients act synergistically, rather than the isolated effect of a single component.

Face with the increase in NCDs in urban areas of Togo, promoting a traditional diet rich in aquatic products, rather than ultra-processed foods, could constitute a relevant public health strategy.

Awareness campaigns on these benefits are therefore necessary.

2.5. Nutritional Positioning Compared to Other Protein Sources

The evaluation of the nutritional benefits of aquatic foods takes on its full meaning when compared to other commonly consumed protein sources.

2.5.1. Comparison with Terrestrial Meats (Cattle, Pigs, Poultry)

- **Protein Quality:** Comparable, or even superior for some fish in terms of digestibility and EAA balance.
- **Lipid Profile:** Generally more favorable for aquatic products, with often lower content of saturated fatty acids (SFAs) and the unique presence of EPA and DHA. Red meats, in particular, tend to be richer in SFAs.
- **Micronutrients:** The profiles are distinct. Aquatic products excel in Vitamin D, iodine, and selenium. Red meats are major sources of heme iron and zinc, while poultry is a source of lean protein.

2.5.2. Comparison with Plant Proteins (Legumes, Cereals, Oilseeds)

- **Protein Completeness and Bioavailability:** Aquatic proteins are complete by definition. Most plant sources taken in isolation are deficient in one or more EAAs (e.g., lysine in cereals, methionine in legumes), requiring the complementarity of sources throughout the day to achieve a balanced profile. The digestibility of plant proteins can also be slightly lower. In Togo, where the staple diet relies on cereals (maize, sorghum, rice) and tubers (yam, cassava), supplemented by legumes (cowpea), the addition of fish can considerably improve the overall protein quality of the diet.
- **Omega-3 Fatty Acids:** Plant sources (nuts, flax, chia) provide ALA, whose conversion to EPA and DHA is, as mentioned, very inefficient. Algae and algal oils constitute an exception, providing EPA and/or DHA directly.
- **Micronutrients:** Plant sources are rich in fiber, certain polyphenols, vitamins (C, K, folates), and minerals (magnesium, potassium). However, the bioavailability of certain minerals (non-heme iron, zinc) can be reduced by the presence of anti-nutritional factors (phytates, oxalates), although preparation techniques (soaking, fermentation, germination) can mitigate their effect. Aquatic products are devoid of these factors and provide specific micronutrients (iodine, B12, D) often absent or scarcely present in the plant kingdom.

Nutrition programs in Togo could benefit from promoting the association of aquatic products with local staple foods to optimize nutrient intake and their bioavailability.

2.5.3. Synergy and Dietary Complementarity

It emerges that aquatic-sourced foods are distinguished by a unique nutritional profile, difficult to entirely replace with other food categories.

Far from opposing other protein sources, they advantageously complement them within a balanced diet.

A diversified diet, regularly integrating fish, crustaceans, or mollusks, alongside lean meats, poultry, eggs, and an abundance of plant sources, constitutes the cornerstone of optimal nutrition.

The specificity of long-chain n-3 PUFAs, Vitamin D, and iodine confers upon aquatic products a predominant role in public health recommendations worldwide.

At the conclusion of this chapter, it appears clearly that aquatic-sourced foods reveal themselves to be concentrates of essential nutrients, whose benefits for human health are multiple and scientifically substantiated.

From the superior quality of their proteins to the richness in omega-3 fatty acids, through a significant intake of key vitamins and minerals, they actively contribute to the harmonious development of the organism, the prevention of cardiovascular and neurological diseases, as well as the maintenance of muscle function and the fight against chronic diseases.

Their judicious integration into dietary regimes constitutes a leading nutritional strategy for the promotion of public health and individual well-being.

For a country like Togo, valorizing its local aquatic resources and ensuring their accessibility is an important lever for improving the nutritional status of its population and preventing diet-related diseases.

References

Allen, L. H. (2008). Causes of vitamin B12 and folate deficiency. *Food and nutrition bulletin*, *29*(2_suppl1), S20-S34.

Calder, P. C. (2013). Omega-3 polyunsaturated fatty acids and inflammatory processes: nutrition or pharmacology?. *British journal of clinical pharmacology*, *75*(3), 645-662.

Calder, P. C. (2015). Marine omega-3 fatty acids and inflammatory processes: Effects, mechanisms and clinical relevance. *Biochimica et Biophysica Acta (BBA)-Molecular and Cell Biology of Lipids*, *1851*(4), 469-484.

FAO. (2013). *Dietary protein quality evaluation in human nutrition. Report of an FAO Expert Consultation*. FAO Food and Nutrition Paper No. 92. Rome, FAO.

Consultation, F. E. (2011). Dietary protein quality evaluation in human nutrition. *FAO Food Nutr. Pap*, *92*(1-66), 26369006.

Agriculture Organization of the United Nations. Fisheries Department. (2018). *The state of world fisheries and aquaculture*. Food and Agriculture Organization of the United Nations.

FAO (2020) Action, S. I. (2020). World fisheries and aquaculture. *Food and Agriculture Organization*, *2020*, 1-244.

Gómez-Pinilla, F. (2008). Brain foods: the effects of nutrients on brain function. *Nature reviews neuroscience*, *9*(7), 568-578..

Helland, I. B., Smith, L., Saarem, K., Saugstad, O. D., & Drevon, C. A. (2003). Maternal supplementation with very-long-chain n-3 fatty acids during pregnancy and lactation augments children's IQ at 4 years of age. *Pediatrics*, *111*(1), e39-e44.

Holick, M. F. (2004). Sunlight and vitamin D for bone health and prevention of autoimmune diseases, cancers, and cardiovascular disease. *The American journal of clinical nutrition*, *80*(6), 1678S-1688S.

Huss, H. H. (1995). FAO Fisheries technical paper 348. *Food and Agriculture Organization of the United Nations, Rome*..

Kris-Etherton, P. M., Harris, W. S., & Appel, L. J. (2002). Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. *circulation*, *106*(21), 2747-2757.

Kris-Etherton, P. M., Harris, W. S., Appel, L. J., & Nutrition Committee. (2003). Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. *Arterioscler Thromb Vasc Biol*, *23*(2), e20-30.

Larsen, T., Thilsted, S. H., Kongsbak, K., & Hansen, M. (2000). Whole small fish as a rich calcium source. *British Journal of Nutrition*, *83*(2), 191-196.

Lauritzen, L. A., Hansen, H. S., Jørgensen, M. H., & Michaelsen, K. F. (2001). The essentiality of long chain n-3 fatty acids in relation to development and function of the brain and retina.

Vakil, D. (2023). Associations Between Red and Processed Meat Consumption and Risk of Developing Colorectal Cancer: A Comprehensive Meta-Analysis and Systematic Review. *UC Merced Undergraduate Research Journal*, *16*(1).

Mensink, R. P., & Katan, M. B. (1992). Effect of dietary fatty acids on serum lipids and lipoproteins. A meta-analysis of 27 trials. *Arteriosclero*.

Micha, R., Peñalvo, J. L., Cudhea, F., Imamura, F., Rehm, C. D., & Mozaffarian, D. (2017). Association between dietary factors and mortality from heart disease, stroke, and type 2 diabetes in the United States. *Jama*, *317*(9), 912-924..

Mozaffarian, D., & Rimm, E. B. (2006). Fish intake, contaminants, and human health: evaluating the risks and the benefits. *Jama*, *296*(15), 1885-1899.

Paddon-Jones, D., & Rasmussen, B. B. (2009). Dietary protein recommendations and the prevention of sarcopenia. *Current opinion in clinical nutrition & metabolic care*, *12*(1), 86-90..

Ralston, N. V., & Raymond, L. J. (2010). Dietary selenium's protective effects against methylmercury toxicity. *Toxicology*, *278*(1), 112-123.

Rayman, M. P. (2012). Selenium and human health. *The Lancet*, *379*(9822), 1256-1268.

Ripps, H., & Shen, W. (2012). taurine: a "very essential" amino acid. *Molecular vision*, *18*, 2673.

Buck, B. H., Troell, M. F., Krause, G., Angel, D. L., Grote, B., & Chopin, T. (2018). State of the art and challenges for offshore integrated multi-trophic aquaculture (IMTA). *Frontiers in Marine Science*, *5*, 165.

World Health Organization. (2020). *Ending childhood dental caries: WHO implementation manual*. World Health Organization..

Williams, C. M., & Burdge, G. (2006). Long-chain n- 3 PUFA: plant v. marine sources. *Proceedings of the Nutrition Society*, *65*(1), 42-50.

Wolfe, Robert R. "Branched-chain amino acids and muscle protein synthesis in humans: myth or reality?." *Journal of the International Society of Sports Nutrition* 14.1 (2017): 30.

Clinton, Steven K., Edward L. Giovannucci, and Stephen D. Hursting. "The world cancer research fund/American institute for cancer research third expert report on diet, nutrition, physical activity, and cancer: impact and future directions." *The Journal of nutrition* 150.4 (2020): 663-671.

Wu, Shengjun, et al. "Fish consumption and colorectal cancer risk in humans: a systematic review and meta-analysis." *The American journal of medicine* 125.6 (2012): 551-559.

Yurko-Mauro, Karin, et al. "Beneficial effects of docosahexaenoic acid on cognition in age-related cognitive decline." *Alzheimer's & Dementia* 6.6 (2010): 456-464.

Zimmermann, Michael B. "Iodine deficiency." *Endocrine reviews* 30.4 (2009): 376-408.

Table 1.1: Average Contents of Macronutrients, Essential Fatty Acids (EPA, DHA), Vitamins (D, B12), and Key Minerals (Iodine, Selenium, Zinc) in Major Categories of Aquatic Foods.

Aquatic Food Category	Protein (% fresh weight)	Lipids	EPA & DHA (Omega-3 Fatty Acids)	Vitamin D	Vitamin B12	Iodine	Selenium	Zinc
Fatty Fish (e.g., salmon, mackerel, herring, sardine)	15-25%	High	Particularly rich; Crucial for cardiovascular health, neurological development, and inflammation.	Very rich (among the best natural sources).	Excellent source.	Good source (especially marine species).	Excellent source.	Source.
Lean Fish (e.g., cod, hake)	15-25%	Low	Present, but in lower quantities than in fatty fish.	Source, but lower than fatty fish.	Excellent source.	Good source (especially marine species).	Excellent source.	Source.
Crustaceans (e.g., shrimp, crabs, lobsters)	15-25%	Generally low	Variable sources, less concentrated than fatty fish.	Variable sources.	Excellent source.	Source (especially marine species).	Good source.	Good source.
Mollusks (e.g., oysters, mussels, squid)	15-25%	Variable	Variable sources; certain bivalves may contain them.	Variable sources.	Particularly rich (especially bivalves).	Very good source (especially marine species).	Good source.	Very good source (especially oysters).
Seaweed/Algae (e.g., nori, kombu, spirulina)	Variable (spirulina is high)	Generally low	Certain microalgae are rich in EPA/DHA (an alternative to fish oils).	Variable sources.	Certain algae (e.g., nori) may contain B12 or its analogs.	Very rich, especially in iodine.	Variable sources.	Variable sources.
General Features of Aquatic Products	High biological value, high digestibility (>95%).	Often favorable lipid profile (less SFA	The human body has a limited capacity to convert plant-based ALA into EPA/DHA.	Essential for bone and immune health.	Crucial for nerve function, red blood cell formation.	Essential for thyroid function.	Powerful antioxidant, supports immune and	Important for immunity, wound healing.

		than red meats).					thyroid function.	

Table 1.2: Key Nutritional Contributions of Species Commonly Consumed in Togo.

Species (Common Name / Scientific Name)	Key Nutritional Contributions	Specific Notes for Togo
Tilapia (*Oreochromis niloticus*)	Source of high-quality protein. Generally low in lipids (lean to semi-fatty fish).	Widely consumed, including from aquaculture. Generally low in mercury. Locally recommended.
Sardinella (*Sardinella spp.*)	Rich in protein. Fatty fish, thus an important source of EPA and DHA. Source of Vitamin D. If consumed whole (small sizes): source of calcium and iron.	Widely consumed, often smoked or dried. Locally recommended.
Clarias (African Catfish) (*Clarias gariepinus*)	Source of high-quality protein. Variable lipid content.	Commonly fished and consumed, important in local aquaculture. Locally recommended.
Local Shrimp (Decapoda)	Source of protein. Low in lipids. May contain astaxanthin (antioxidant).	Traditionally fished/harvested and locally appreciated.
Local Crabs (Decapoda)	Source of protein. Low in lipids.	Various species traditionally harvested and locally appreciated.
Small Fish (consumed whole, dried/smoked)	Source of protein, calcium (bones), iron, zinc, and other minerals.	Important for complementary feeding of young children and for calcium/iron intake.

Table 1.3: Comparison of Essential Amino Acid (EAA) Profiles of Aquatic Proteins Versus Other Sources.

Protein Characteristic	Aquatic Proteins	Terrestrial Meat Proteins	Plant Proteins (Isolated)
Biological Value / EAA Completeness	High biological value: supply all EAAs in optimal proportions. Complete proteins by definition.	Comparable to aquatic, or even lower for some fish species in terms of EAA balance.	Most isolated plant sources are deficient in one or more EAAs (e.g., lysine in cereals, methionine in legumes). They require complementarity throughout the day.
Digestibility	Particularly high, often greater than 95% (less connective tissue).	Generally good, but may be slightly lower than that of certain fish.	May be slightly lower, sometimes affected by anti-nutritional factors (phytates, etc.).
Specific Amino Acids	Rich in lysine. Some (mollusks, fish) are rich in taurine (important physiological roles). Leucine is present in notable concentration.	Rich in leucine.	Variable by source. Legumes are good sources of lysine; cereals are less so.
Togolese Context	The addition of fish to the staple diet (cereals, tubers, legumes) significantly improves the overall protein quality of the diet.		The staple diet is often supplemented with fish.

Chapter 3: The Impact of Aquatic Foods on Human Health

Building upon the detailed nutritional profile presented in the previous chapter, this third chapter aims to thoroughly explore the direct and specific repercussions of consuming aquatic-origin foods on human physiology and health. It examines the mechanisms by which these foods exert their beneficial effects on key organ systems, their role in the management of certain metabolic conditions, as well as their influence on immune and inflammatory processes. This analysis is substantiated by a review of evidence-based scientific data derived from epidemiological studies and clinical interventions (Willett, 2013). In a context such as that of Togo, where non-communicable diseases are on the rise and nutritional security remains a challenge, understanding this impact is particularly relevant for guiding public health policies.

3.1. Protective and Structuring Effects on the Cardiovascular, Cerebral, and Skeletal Systems

Regular consumption of aquatic foods is associated with substantial benefits for cardiovascular health, brain function, and skeletal integrity, primarily mediated by their unique components such as long-chain omega-3 fatty acids, vitamin D, and specific minerals.

3.1.1. Primary Prevention and Adjuvant Benefits in Cardiovascular Health

The positive impact of aquatic foods, particularly fatty fish, on cardiovascular health is one of the most well-documented areas. The underlying mechanisms, primarily involving EPA and DHA, include:

- The reduction of serum triglyceride levels, an independent risk factor for coronary heart disease (Kris-Etherton et al., 2002, 2003).
- A slight decrease in blood pressure in hypertensive individuals (Miller et al., 2014).
- Antithrombotic effects through the modulation of platelet function and coagulation factors (Mozaffarian & Wu, 2011).
- A reduction in the risk of severe ventricular arrhythmias, notably through the stabilization of cardiomyocyte membranes (Leaf et al., 2003).
- The improvement of endothelial function and the reduction of vascular inflammation markers (e.g., C-reactive protein) (Thies et al., 2003).

Numerous prospective cohort studies and meta-analyses have demonstrated an inverse association between fish consumption (typically one to two servings per week, particularly of fatty fish) and the incidence of myocardial infarction, ischemic stroke, and overall cardiovascular mortality (Hu et al., 2002; He et al., 2004). Benefits have also been suggested in secondary prevention among patients who have already experienced a cardiovascular event, although the magnitude of this effect may be modulated by concomitant pharmacological treatments (GISSI-Prevenzione Investigators, 1999). In Togo, where arterial hypertension is a growing public health problem, promoting the consumption of local fish, rich in cardioprotective nutrients, could be an effective complementary strategy.

3.1.2. From Neurocognitive Development to Neuroprotection in Brain Health

The brain is an organ particularly rich in lipids, with DHA representing a predominant structural component of phospholipids in neuronal membranes and retinal photoreceptors.

Fetal and Infant Neurological Development An adequate intake of DHA via maternal consumption of aquatic products during gestation and lactation is fundamental for neurogenesis, synaptogenesis, myelination, and the development of cognitive and visual functions in the child (McCann & Ames, 2005; Koletzko et al., 2007). Several observational studies have correlated higher maternal fish consumption with better neurodevelopmental scores in offspring (Hibbeln et al., 2007). Awareness programs in Togo should target pregnant and lactating women regarding the importance of consuming fish for the optimal development of their child, prioritizing local species less likely to be contaminated.

Maintenance of Cognitive Functions in Adulthood and During Aging DHA contributes to membrane fluidity, neurotransmission efficiency, and synaptic plasticity processes. Regular fish consumption is associated with slower cognitive decline in the elderly and may reduce the risk of dementia, particularly Alzheimer's disease (Morris et al., 2003; Schaefer et al., 2006). Potential mechanisms include the reduction of cerebral inflammation, the modulation of amyloid-β peptide production, and protection against oxidative stress.

Influence on Mental Health Data suggest that omega-3 fatty acids may play a role in mood regulation. Lower levels of omega-3s have been observed in patients suffering from major depressive disorders, and some intervention studies indicate a potential beneficial effect of EPA/DHA supplementation, notably as an adjuvant to antidepressant treatments (Lin & Su, 2007; Sublette et al., 2011).

3.1.3. Bone Integrity and Density

Bone health depends on a complex balance between bone formation and resorption, influenced by numerous nutritional factors. Aquatic foods contribute to this in several ways:

Vitamin D Intake Fatty fish are one of the few natural dietary sources of vitamin D3, which is essential for the intestinal absorption of calcium and phosphorus, and thus for the mineralization of bone tissue (Holick, 2007).

Calcium Intake Small fish consumed whole with their bones (sardines, anchovies, or local equivalents such as "ablavi" or "adjon" in Togo) constitute a notable source of bioavailable calcium (Larsen et al., 2007). The valorization of these local species is an important avenue for improving calcium intake in the Togolese population.

Potential Role of Omega-3 Fatty Acids Research suggests that n-3 PUFAs could positively influence bone metabolism by modulating inflammation (which can exacerbate bone resorption), by favoring the activity of osteoblasts (bone-forming cells) and by inhibiting that of osteoclasts (bone-resorbing cells) (Watkins et al., 2000; Orchard et al., 2012). Adequate consumption of aquatic foods, integrated into a balanced diet, thus participates in the acquisition of maximal bone mass during growth and in the prevention of osteoporosis and fracture risk in adults and the elderly.

3.2. Contribution to Body Weight Management and Glycemic Regulation

Obesity and type 2 diabetes represent major public health challenges globally, including in Togo where their prevalence is rising, particularly in urban areas (Kpozehouen et al., 2015). Aquatic foods contain bioactive compounds whose effects can contribute to the prevention and management of these pathologies.

3.2.1. Satiety and Energy Intake Control

The high content of high-quality proteins in fish and seafood plays a key role in appetite regulation:

Superior Satiating Effect Proteins are recognized for inducing greater and more sustained satiety than carbohydrates or lipids, for an equivalent caloric intake (Westerterp-Plantenga et al., 2009). This is mediated by an increase in postprandial energy expenditure (thermic effect of food) and by the modulation of the secretion of gastrointestinal hormones regulating appetite (e.g., increase in glucagon-like peptide-1 (GLP-1) and peptide YY (PYY), reduction of ghrelin) (Weigle et al., 2005).

Influence of Specific Lipids Some studies suggest that n-3 PUFAs might also influence satiety and body composition, possibly by modulating leptin sensitivity and adipokine production (Parra et al., 2008). Integrating aquatic foods into a diet can thus facilitate the control of total energy intake, contributing to the prevention of weight gain or the success of weight loss strategies. Promoting fish as a healthy alternative in weight-loss diets in Togo could be beneficial.

3.2.2. Carbohydrate Metabolism and Insulin Sensitivity

Several epidemiological studies have reported an inverse association between fish consumption and the risk of developing type 2 diabetes (Patel et al., 2010; Villegas et al., 2008). The potential mechanisms are multifactorial:

Improvement of Insulin Sensitivity N-3 PUFAs could improve cell membrane fluidity and insulin signaling in peripheral tissues (muscle, adipose tissue) (Lalia & Lanza, 2016).

Reduction of Low-Grade Inflammation Chronic inflammation is a contributing factor to insulin resistance. The anti-inflammatory properties of aquatic nutrients can therefore indirectly favor better glycemic control (Calder, 2015).

Substitution Effect Replacing processed meats or meats rich in saturated fats with fish can lead to a macronutrient intake profile more favorable to diabetes prevention. These effects are particularly relevant in the context of metabolic syndrome. Dietary advice in Togo for the prevention and management of diabetes should emphasize the place of fish.

3.3. Modulation of the Immune and Inflammatory Systems

Nutrients abundant in aquatic foods, such as n-3 PUFAs, vitamin D, selenium, and zinc, exert a profound influence on the regulation of the immune system and the inflammatory response.

3.3.1. Strengthening and Balancing the Immune Response

Omega-3 Fatty Acids EPA and DHA are precursors to specialized lipid mediators called "Specialized Pro-resolving Mediators" (SPM), including resolvins, protectins, and maresins (Serhan, 2014). Unlike classical anti-inflammatories which block inflammation, SPMs actively participate in the resolution phase of inflammation, fostering the return to tissue homeostasis and limiting collateral damage. They also modulate the function of immune cells (lymphocytes, macrophages, neutrophils).

Vitamin D It possesses receptors on most immune cells and plays a crucial role in the regulation of innate immunity (e.g., production of antimicrobial peptides) and adaptive immunity (e.g., differentiation of T lymphocytes) (Aranow, 2011).

Selenium and Zinc Essential for the proper functioning of antioxidant enzymes and for the proliferation and maturation of immune cells (Shankar & Prasad, 1998). An optimal nutritional status in these nutrients, fostered by the consumption of aquatic foods, can therefore contribute to a more effective immune response against pathogens and better regulation of inflammatory processes, a crucial aspect in health contexts like that of Togo, where infectious diseases are still prevalent.

3.3.2. Attenuation of Chronic Inflammatory Processes

Chronic low-grade inflammation is a common denominator of many non-communicable chronic diseases (NCDs).

Reduction of Pro-inflammatory Mediators N-3 PUFAs can reduce the production of pro-inflammatory cytokines (e.g., TNF-α, IL-1, IL-6) and eicosanoids derived from arachidonic acid (Calder, 2013).

Clinical Relevance in Autoimmune Diseases In conditions such as rheumatoid arthritis or certain inflammatory bowel diseases (IBD), fish consumption or fish oil supplementation has shown benefits in terms of reducing symptomatology, morning stiffness, and the need for anti-inflammatory medications, acting as a valuable adjuvant treatment (Belluzzi et al., 1996; Goldberg & Katz, 2007). The overall impact is a modulation of the inflammatory milieu towards a less deleterious profile.

3.4. Illustrations via Significant Studies and Current Research Avenues

The benefits described above are supported by a growing body of scientific research.

3.4.1. Major Epidemiological Studies and Cohorts

Large-scale prospective studies, such as the "Nurses' Health Study" in the United States (Hu et al., 2002), the "GISSI-Prevenzione" study in Italy (GISSI-Prevenzione Investigators, 1999), or the "JELIS" study (Japan EPA Lipid Intervention Study) (Yokoyama et al., 2007), have provided robust evidence of the association between regular fish consumption and/or higher omega-3 levels and a reduction in the risk of major cardiovascular events. Similarly, birth cohorts have often highlighted links between maternal fish consumption during pregnancy and better neurocognitive development indicators in the child (Oken et al., 2008). These observational studies identify strong correlations and guide research hypotheses.

3.4.2. Clinical Intervention Trials

Numerous randomized controlled trials (RCTs) have evaluated the effects of fish oil supplementation (rich in EPA/DHA) or dietary advice aimed at increasing fish consumption. Results have confirmed beneficial effects on cardiovascular risk factors (notably triglycerides) and certain inflammatory parameters (Abdelhamid et al., 2020). The variability of results for other outcomes may be explained by differences in study design.

3.4.3. Research on Specific Bioactive Compounds (Beyond Omega-3)

Current research is increasingly interested in other bioactive compounds present in aquatic foods:

- Marine Peptides: Resulting from the hydrolysis of fish proteins, some peptides have shown antihypertensive, antioxidant, or antimicrobial activities (Kim & Wijesekara, 2010).
- Taurine: Particularly abundant in mollusks and certain fish, its roles are being explored (Ripps & Shennan, 2012).
- Specific Carotenoids: Such as astaxanthin (salmonids, shrimp), a powerful antioxidant (Guerin et al., 2003).
- Sulfated Polysaccharides from Algae: Such as fucoidans or carrageenans, studied for their immunomodulatory, antiviral, and anticoagulant properties (Fitton et al., 2015). The potential of Togolese aquatic species for such compounds remains a research field to be explored.

3.4.4. Challenges and Future Research Directions

Despite accumulated knowledge, several questions remain:

- The fine characterization of the specific effects of different local aquatic species, including those from Togo, based on their complete nutritional profile and culinary preparation method.
- Understanding the interindividual variability of responses, linked to genetic factors (nutrigenomics) or the composition of the gut microbiota (Merra et al., 2020; 2022).
- Optimization of consumption recommendations for specific subgroups of the Togolese population.
- Integrating the imperatives of sustainability of Togo's aquatic resources (Lake Togo, Atlantic coast) into public health recommendations. It is crucial to invest in local research to adapt global recommendations to the Togolese context, taking into account available species, cultural habits, and sustainability challenges.

This chapter has allowed us to understand that aquatic-origin foods exert a positive and multifactorial impact on human health, attested by a convergence of scientific data. Their role in the prevention of cardiovascular diseases, support for the development and maintenance of brain functions, preservation of bone health, weight and glycemic management, as well as the modulation of immune and inflammatory systems, makes them pillars of a preventive and therapeutic diet. Continued

References

Abdelhamid A. S., Martin N., Bridges C., Brainard J. S., Wang X., Brown T. J., Hanson S, Jimoh OF, Ajabnoor S. M., Deane K. H. O., Song F., Hooper L. (2018). Polyunsaturated fatty acids for the primary and secondary prevention of cardiovascular disease (Review). Cochrane Database of Systematic Reviews, 7(7) : CD012345 ; 555p. DOI: 10.1002/14651858.CD012345.pub2.

Aranow C. (2011). Vitamin D and the immune system. Journal of investigative medicine 59(6) : 881-886.

Belluzzi A., Brignola C., Campieri M., Pera A., Boschi S., Miglioli M. (1996). Effect of an enteric-coated fish-oil preparation on relapses in Crohn's disease. New England Journal of Medicine, 334(24) : 1557-1560.

Calder P. C. (2013). Omega-3 polyunsaturated fatty acids and inflammatory processes: nutrition or pharmacology? British journal of clinical pharmacology, 75(3) : 645-662.

Calder P. C. (2015). Marine omega-3 fatty acids and inflammatory processes: Effects, mechanisms and clinical relevance. Biochimica et Biophysica Acta (BBA)-Molecular and Cell Biology of Lipids, 1851(4) : 469-484.

Fitton J. H., Stringer D. N., Karpiniec S. S. (2015). Therapies from fucoidan: An update. Marine drugs, 13 (9) : 5920-5946.,

GISSI-Prevenzione Investigators. (1999). Dietary supplementation with n-3 polyunsaturated fatty acids and vitamin E after myocardial infarction: results of the GISSI-Prevenzione trial. The Lancet 354(9177): 447-455.

Goldberg R. J. & Katz J. (2007). A meta-analysis of the analgesic effects of omega-3 polyunsaturated fatty acid supplementation for inflammatory joint pain. Pain, 129(1-2): 210-223.

Guerin M., Huntley M. E., Olaizola M. (2003). Haematococcus astaxanthin: applications for human health and nutrition. TRENDS in Biotechnology, 21: 210-216.

He K., Song Y., Daviglus M. L., Liu K., Van Horn L., Dyer A. R., Greenland P. (2004). Accumulated evidence on fish consumption and coronary heart disease mortality: a meta-analysis of cohort studies. Circulation, 109(22) : 2705-2711.

Hibbeln J. R., Davis J. M., Steer C., Emmett P., Rogers I., Williams C., Golding J. (2007). Maternal seafood consumption in pregnancy and neurodevelopmental outcomes in childhood (ALSPAC study): an observational cohort study. The Lancet, 369(9561) : 578-585.

Holick M. F. (2007). Vitamin D Deficiency New England Journal of Medicine 357 (3) : 266 – 281. doi: 10.1056. NEJMra070553.

Hu F. B., Bronner L., Willett W. C., Stampfer M. J., Rexrode K. M., Albert C. M., Hunter D., Manson J. E. (2002). Fish and omega-3 fatty acid intake and risk of coronary heart disease in women. JAMA, 287(14) : 1815-1821.

Kim S. K. & Wijesekara I. (2010). Development and biological activities of marine-derived bioactive peptides: A review. Journal of Functional foods, 2(1) : 1-9.

Koletzko B., Cetin I., Brenna J. T., Perinatal Lipid Intake Working Group. (2007). Dietary fat intakes for pregnant and lactating women. British Journal of Nutrition, 98(5) : 873-877.

Kpozehouen A., Djrolo F., Sossa C., Gbary A., Chouehanou Y., Fambo D., Tchabi Y., Salamon R., Houinato D. (2015). Prevalence and Associated Factors of Diabetes Mellitus in Benin. Open Journal of Epidemiology, 5 : 163-171. doi: 10.4236/ojepi.2015.53021.

Kris-Etherton P. M., Harris W. S., Appel L. J. (2002). Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Circulation, 106(21) : 2747-2757.

Kris-Etherton P. M., Harris W. S., Appel L. J., Nutrition Committee. (2003). Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Arterioscler Thromb Vasc Biol, 23(2) : e20-30.

Lalia A. Z. & Lanza I. R. (2016). Insulin-sensitizing effects of omega-3 fatty acids: lost in translation? Nutrients 8(6): 329. doi:10.3390/nu8060329

Larsen T., Thilsted S. H., Kongsbak K., Hansen M. (2000). Whole small fish as a rich calcium source. British Journal of Nutrition, 83(2) : 191-196.

Leaf A., Kang J. X., Xiao Y. F., Billman G. E. (2003). Clinical prevention of sudden cardiac death by n-3 polyunsaturated fatty acids and mechanism of prevention of arrhythmias by n-3 fish oils. Circulation, 107(21) : 2646-2652.

Lin P. Y. & Su K. P. (2007). A meta-analytic review of double-blind, placebo-controlled trials of antidepressant efficacy of omega-3 fatty acids. Journal of Clinical Psychiatry, 68(7) : 1056-1061.

McCann J. C. & Ames B. N. (2005). Is docosahexaenoic acid, an n- 3 long-chain polyunsaturated fatty acid, required for development of normal brain function? An overview of evidence from cognitive and behavioral tests in humans and animals. The American journal of clinical nutrition, 82(2) : 281-295.

Merra G., Noce A., Marrone G., Cintoni M., Tarsitano M. G., Capacci A., De Lorenzo A. (2020). Influence of mediterranean diet on human gut microbiota. Nutrients, 13(1) : 7.

Merra G., Noce A., Marrone G., Cintoni M., Tarsitano M. G., Capacci A., De Lorenzo A. (2022). Influence of mediterranean diet on human gut microbiota. Kompass Nutrition & Dietetics, 2(1) : 19-25.

Miller P. E., Van Elswyk M., Alexander D. D. (2014). Long-chain omega-3 fatty acids eicosapentaenoic acid and docosahexaenoic acid and blood pressure: a meta-analysis of randomized controlled trials. American journal of hypertension, 27(7) : 885-896.

Morris M. C., Evans D. A., Bienias J. L., Tangney C. C., Bennett D. A., Wilson R. S., Aggarwal N., Schneider J. (2003). Consumption of fish and n-3 fatty acids and risk of incident Alzheimer disease. Archives of neurology, 60(7) : 940-946.

Mozaffarian D. & Wu J. H. (2011). Omega-3 fatty acids and cardiovascular disease: effects on risk factors, molecular pathways, and clinical events. Journal of the American College of Cardiology, 58(20) : 2047-2067.

Oken E., Wright R. O., Kleinman K. P., Bellinger D., Amarasiriwardena C. J., Hu H., Rich - edwards J. W., Gillman M. W. (2005). Maternal fish consumption, hair mercury, and infant cognition in a US cohort. Environmental health perspectives, 113(10) : 1376-1380.

Orchard T. S., Pan X., Cheek F., Ing S. W., Jackson R. D. (2012). A systematic review of omega-3 fatty acids and osteoporosis. British Journal of Nutrition, 107(S2) : S253-S260.

Parra D., Ramel A., Bandarra N., Kiely M., Martínez J. A., Thorsdottir I. (2008). A diet rich in long chain omega-3 fatty acids modulates satiety in overweight and obese volunteers during weight loss. Appetite, 51(3) : 676-680.

Patel P. S., Sharp S. J., Jansen E., Luben R. N., Khaw K. T., Wareham N. J., Forouhi N. G. (2010). Fatty acids measured in plasma and erythrocyte-membrane phospholipids and derived by food-frequency questionnaire and the risk of new-onset type 2 diabetes: a pilot study in the European Prospective Investigation into Cancer and Nutrition (EPIC)–Norfolk cohort. The American journal of clinical nutrition, 92(5) : 1214-1222.

Ripps H. & Shen W. (2012). Review : taurine: a "very essential" amino acid. Molecular vision, 18 : 2673 - 2686.

Schaefer E. J., Bongard V., Beiser A. S., Lamon-Fava S., Robins S. J., Au R., Tucker K. L., Kyle D. J., Wilson P. W. F., Wolf P. A. (2006). Plasma phosphatidylcholine docosahexaenoic acid content and risk of dementia and Alzheimer disease: the Framingham Heart Study. Archives of neurology, 63(11) : 1545-1550.

Serhan C. N. (2014). Pro-resolving lipid mediators are leads for resolution physiology. Nature, 510(7503) : 92-101.

Shankar A. H. & Prasad A. S. (1998). Zinc and immune function: the biological basis of altered resistance to infection. The American journal of clinical nutrition, 68(2) : 447S-463S.

Sublette M. E., Ellis S. P., Geant A. L., Mann J. J. (2011). Meta-analysis of the effects of eicosapentaenoic acid (EPA) in clinical trials in depression. The Journal of clinical psychiatry, 72(12) : 1577 – 1584.

Thies F., Garry J. M., Yaqoob P., Rerkasem K., Williams J., Shearman C. P., Gallagher P. J., Calder P. C., Grimble R. F. (2003). Association of n-3 polyunsaturated fatty acids with stability of atherosclerotic plaques: a randomised controlled trial. The Lancet, 361(9356) : 477-485.

Villegas R., Xiang Y. B., Elasy T., Li H. L., Yang G., Cai H., Ye F., Gao Y. - T., Shyr Y., Zheng W., Shu X. - O. (2011). Fish, shellfish, and long-chain n- 3 fatty acid consumption and risk of incident type 2 diabetes in middle-aged Chinese men and women. The American journal of clinical nutrition, 94(2) : 543-551.

Watkins B. A., Li Y., Allen K. G., Hoffmann W. E., Seifert M. F. (2000). Dietary ratio of (n-6)/(n-3) polyunsaturated fatty acids alters the fatty acid composition of bone compartments and biomarkers of bone formation in rats. The Journal of nutrition, 130(9) : 2274-2284.

Weigle D. S., Breen P. A., Matthys C. C., Callahan H. S., Meeuws K. E., Burden V. R., Purnell J. Q. (2005). A high-protein diet induces sustained reductions in appetite, ad libitum caloric intake, and body weight despite compensatory changes in diurnal plasma leptin and ghrelin concentrations. The American journal of clinical nutrition, 82(1) : 41-48.

Westerterp-Plantenga M. S., Nieuwenhuizen A., Tome D., Soenen S., Westerterp K. R. (2009). Dietary protein, weight loss, and weight maintenance. Annual review of nutrition, 29(1) : 21-41.

Willett W. (2013). Nutritional epidemiology. 3rd edn Oxford University Press.

Yokoyama M., Origasa H., Matsuzaki M., Matsuzawa Y., Saito Y., Ishikawa Y., Oikawa S., Sasaki J., Hishida H., Itakura H., Kita T., Kitabatake A ., Nakaya N., Sakata T., Shimada K., Shirato K. (2007). Effects of eicosapentaenoic acid on major coronary events in hypercholesterolaemic patients (JELIS): a randomised open-label, blinded endpoint analysis. The lancet, 369(9567), 1090-1098.

Chapter 4: Health Risks Associated with the Consumption of Aquatic-Origin Foods

While the preceding chapters have amply demonstrated the substantial nutritional benefits and positive health impacts linked to the consumption of aquatic-origin foods, it is imperative to also address the potential health risks. Aquatic ecosystems, acting as final receptacles for numerous pollutants and natural habitats for various microorganisms, can indeed lead to the contamination of fish, crustaceans, mollusks, and algae. This chapter aims to examine the principal dangers of chemical and biological origin, as well as those related to post-harvest handling, in order to provide an essential framework for informed and safe consumption, both on a global scale and with a particular focus on the realities in Togo.

4.1. Chemical Contaminants of Anthropogenic and Environmental Origin

Chemical contamination of aquatic environments is a major concern, as aquatic organisms are susceptible to accumulating persistent toxic substances derived from industrial, agricultural, or domestic activities.

4.1.1. Toxic Metallic Trace Elements (TMTE) / Heavy Metals

Toxic metallic trace elements are ubiquitous and persistent contaminants.

Mercury (Hg) Mercury is released into the environment by natural sources (volcanism, degassing) and anthropogenic sources (coal combustion, artisanal gold mining, industrial discharges) (Driscoll et al., 2013). In aquatic environments, inorganic mercury is transformed by microorganisms into methylmercury (MeHg), a highly toxic and bioaccumulative organic form. MeHg concentrates along the trophic chain (biomagnification), reaching high levels in large predatory fish (e.g., tuna, swordfish, shark, marlin, billfish). MeHg is a potent neurotoxin, particularly deleterious to the developing central nervous system of the fetus and young child (Karagas et al., 2012). It also possesses nephrotoxic and cardiovascular effects. Specific consumption recommendations are issued for vulnerable populations (pregnant and lactating women, young children) regarding the most contaminated species. In Togo, artisanal and small-scale gold mining (ASGM) contributes to the mercury contamination of adjacent watercourses (Mulenga et al., 2024). Increased surveillance of mercury levels in fish caught in these zones and sensitization of local populations, particularly pregnant women, regarding risks and species to prioritize or avoid would be important measures. Specific studies on mercury bioaccumulation in local consumed fish species would also be relevant.

Lead (Pb) Lead contamination primarily stems from industrial discharges, corrosion of old pipelines, and atmospheric deposition resulting from the historical use of leaded gasoline (WHO, 2023). Lead accumulates in sediments and can be ingested by benthic organisms, notably mollusks. It exerts neurotoxic effects (particularly in children), as well as hematotoxic and nephrotoxic effects, and can affect reproduction. Urban areas, such as Greater Lomé, and industrial zones, like the port area and the phosphate mining and treatment zone of Togo, can be sources of lead contamination in coastal and lagoon aquatic ecosystems due to effluent discharges and waste management (Gnandi, 2002; Gnandi et al., 2006; Kantati et al., 2013; Solitoke et al., 2018; Ouro-Sama et al., 2020; Badassan et al., 2020; Mélila et al., 2019 and 2022). A mapping of potential sources and an evaluation of contamination in fishery products in the Lomé lagoon system and Lake Togo would be useful.

Cadmium (Cd) Sources of cadmium include industrial discharges (metallurgy, batteries, effluents), sewage sludge spreading, and the use of phosphate fertilizers (Panel et al., 2011a and b). Cadmium accumulates preferentially in mollusks, crustaceans, and fish offal (liver, kidneys). It is primarily nephrotoxic, and chronic exposure can lead to bone demineralization (*Itai-Itai* disease). The use of phosphate fertilizers in intensive agriculture within watersheds can lead to cadmium enrichment in surface waters. Surveillance of cadmium levels in freshwater fish and aquaculture products, in conjunction with agricultural practices, is recommended (Adouayi et al., 2020).

4.1.2. Persistent Organic Pollutants (POPs)

POPs are synthetic organic compounds that resist degradation, accumulate in living organisms (lipophilicity), and can be transported over long distances (Jones and de Voogt, 1999).

Organochlorine Pesticides Compounds such as DDT (dichlorodiphenyltrichloroethane), dieldrin, or chlordane, although their use is now largely banned or restricted by the Stockholm Convention, persist in the environment and contaminate aquatic food chains (Desai, 2020). They are suspected endocrine disruptors, neurotoxins, and potentially carcinogenic. Despite prohibitions, past or illicit use of certain organochlorine pesticides in agriculture could have contaminated soils and waters. Studies on the persistence of these compounds in sediments and aquatic organisms, particularly in agricultural zones and estuaries, would be necessary to assess the exposure of Togolese consumers. The promotion of sustainable agricultural practices and the secure management of obsolete pesticide stocks are crucial.

Polychlorinated Biphenyls (PCBs) Used in the past as dielectric and heat-transfer fluids, PCBs are highly persistent. They accumulate in the adipose tissues of fatty fish. Exposure to PCBs is associated with carcinogenic, immunotoxic, and neurodevelopmental effects, as well as endocrine disruption (Faroon et al., 2003). Old industrial installations and electrical transformers can be sources of PCBs. An inventory of equipment containing PCBs and an evaluation of contamination in port and industrial zones are important steps to prevent the contamination of aquatic products. To this end, the Autonomous Port of Lomé, with its deep-water facility and industrial installations, remains a potential source of contamination.

Dioxins (PCDD) and Furans (PCDF) These compounds are unintentional by-products of industrial processes (metallurgy, waste incineration). 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) is the most toxic. They are classified as known human carcinogens (IARC) and exert immunotoxic and endocrine-disrupting effects (Van den Berg et al., 2006). Open-air waste burning practices, still common in certain zones, can release dioxins and furans. Better waste management, including controlled incineration systems with flue gas filtration, is necessary to limit these emissions and their impact on aquatic ecosystems. African coastal capitals like Lomé contain numerous open-air dumpsites where tires and other wastes containing various chemical products are burned. These ashes are generally washed away by runoff waters towards the continental slope. These are potential sources of contamination by metallic trace elements.

4.1.3. Other Chemical

Contaminants of Interest Other substances are arousing increasing concern, such as veterinary drug residues (antibiotics, antiparasitics) in aquaculture, polycyclic aromatic hydrocarbons (PAHs) resulting from oil spills or the incomplete combustion of organic matter (e.g., traditional fish smoking), brominated flame retardants (PBDEs), or perfluoroalkyl substances (PFAS) (Leung et al., 2015). The issue of microplastics and nanoplastics, as potential vectors for these contaminants, is also the subject of intense research (Gallo et al., 2018). The development of aquaculture in Togo must be accompanied by good practices regarding the use of veterinary medicines. Regarding PAHs, traditional fish smoking methods, which are widespread, can lead to high levels of these compounds (Eklu-Gadegbeku et al., 2020; Beigue Alfa et al., 2022). Research on optimizing smoking techniques to reduce PAH formation while preserving organoleptic qualities and shelf life would be beneficial (Beigue Alfa et al., 2022). Visible plastic pollution on coasts and in lagoons suggests probable contamination by microplastics, necessitating local studies.

4.2. Natural Marine Biotoxins

Certain aquatic organisms can accumulate toxins produced by planktonic or benthic microalgae, particularly during Harmful Algal Blooms (HABs). These phycotoxins are generally thermostable and are not destroyed by cooking (Visciano et al., 2016).

4.2.1. Phycotoxins from Harmful Algal Blooms (HABs)

Ciguatoxins (CTX), Ciguatera Fish Poisoning (CFP) Ciguatoxins are produced by benthic dinoflagellates of the genus *Gambierdiscus*, proliferating in tropical and subtropical coral ecosystems (Friedman et al., 2017). They accumulate and transform within the reef food chain, affecting numerous herbivorous and carnivorous fish. Intoxication (ciguatera) manifests as gastrointestinal, neurological (paresthesia, dysesthesia with characteristic temperature reversal, ataxia), and cardiovascular disorders. Although the Togolese coast is not typically characterized by vast coral reefs, the presence of *Gambierdiscus* spp. and the risk of ciguatera cannot be excluded, especially with climate change modifying species distribution. Health monitoring and regional collaboration for information sharing on ciguatera episodes in the Gulf of Guinea would be relevant if suspected cases were reported.

Saxitoxins (STX) and Analogs, Paralytic Shellfish Poisoning (PSP) These potent neurotoxins are produced by dinoflagellates of the genera *Alexandrium*, *Gymnodinium*, and *Pyrodinium* (Wiese et al., 2010). They are accumulated by filter-feeding bivalve mollusks (oysters, mussels, cockles, scallops). Symptoms include perioral paresthesia progressing to muscle paralysis, potentially leading to fatal respiratory distress.

Domoic Acid (DA), Amnesic Shellfish Poisoning (ASP) Domoic acid is a neurotoxin produced by certain diatoms of the genus *Pseudo-nitzschia* (Trainer et al., 2012). It accumulates in filter-feeding mollusks, but also in certain crustaceans and planktivorous fish. Aquatic mollusks are consumed moderately in Togo according to reports on fishery product consumption (Rapport-Togo 2015). Intoxication causes gastrointestinal disorders followed by severe neurological symptoms (headaches, confusion, short-term memory loss, or even permanent brain damage).

Okadaic Acid (OA) and Dinophysistoxins (DTXs) – Diarrheic Shellfish Poisoning (DSP) These lipophilic toxins are produced by dinoflagellates of the genera *Dinophysis* and *Prorocentrum* and accumulated by bivalve mollusks (Reguera et al., 2014). They cause intense gastrointestinal disorders (diarrhea, nausea, vomiting, abdominal pain).

Brevetoxins (PbTx)

Neurotoxic Shellfish Poisoning (NSP) Produced by the dinoflagellate *Karenia brevis*, brevetoxins accumulate in mollusks (Watkins et al., 2008). Intoxication combines gastrointestinal and neurological symptoms. Exposure via inhalation of marine aerosols containing these toxins can also cause respiratory irritation. Mollusk consumption (mangrove oysters, shellfish) exists in Togo, although perhaps less structured than in other regions. Establishing a surveillance program for harmful algal blooms and phycotoxins in mollusk collection zones, even if modest initially, would be an important preventive measure, especially if a commercial production sector develops.

4.2.2. Tetrodotoxin (TTX)

Tetrodotoxin is an extremely potent neurotoxin, not linked to HABs, but produced by symbiotic bacteria associated with certain marine animals, notably pufferfish (*Fugu*), as well as certain gastropods, crabs, and starfish (Noguchi and Arakawa, 2008). Ingestion of TTX blocks voltage-gated sodium channels, leading to progressive paralysis and respiratory failure. *Fugu* consumption is highly ritualized and requires preparation by specially trained chefs in Japan to remove organs containing the toxin (mainly liver and ovaries). Pufferfish species are present in Togolese waters. Although their consumption is not traditionally widespread, it is crucial to inform fishermen and consumers of the deadly dangers associated with these fish if they are not correctly identified and if their consumption is considered.

4.3. Microbiological Hazards

Raw, undercooked, or post-cooking contaminated aquatic foods can be vectors for pathogens.

4.3.1. Bacterial Infections

Vibrio spp.

Bacteria of the genus *Vibrio* (*V. parahaemolyticus*, *V. vulnificus*, *V. cholerae*) are naturally present in warm marine and estuarine environments (Baker-Austin et al., 2018). *V. parahaemolyticus* is a frequent cause of gastroenteritis associated with the consumption of raw or undercooked seafood. *V. vulnificus* can cause gastroenteritis but also severe septicemia and wound infections in immunocompromised individuals or those suffering from chronic liver disease. *V. cholerae* (serogroups O1 and O139) is the agent of cholera, transmitted by contaminated water or food. The warm coastal and lagoon waters of Togo are conducive to the proliferation of *Vibrio*. Cholera epidemics, although controlled, have been reported in the past. The sanitation infrastructure in the Togolese capital remains limited. Wastewater drainage systems often discharge directly into the ocean, creating a significant risk of microbial contamination—including Vibrio spp.—for aquatic resources harvested near these outfalls. These sewers generally drain towards the ocean where they discharge their contents. This situation presents a potential risk of contamination of aquatic-origin foods with microorganisms including vibrios derived from both animal and human organisms. Coastal urban centers like Lomé face significant waste management challenges, where the open burning of waste—including tires and chemical products—is common. The resulting ash, often laden with toxic compounds, is carried by runoff into the coastal marine environment, acting as a potential source of trace metal contamination

Salmonella spp. and Pathogenic *Escherichia coli*

These enterobacteria are not naturally present in clean aquatic environments, but their presence indicates fecal contamination (e.g., wastewater discharges) or post-harvest cross-contamination (FAO/WHO, 2009). They cause gastroenteritis. Insufficient management of domestic wastewater in certain zones, particularly around Lake Togo and the Lomé lagoon system, can lead to fecal contamination of fishing waters. Improving sanitation infrastructure is a major issue for the safety of aquatic products and public health.

Listeria monocytogenes

This ubiquitous bacterium is psychrotrophic (capable of multiplying at refrigeration temperatures). It represents a significant risk for ready-to-eat products with a long shelf life, such as cold-smoked fish (Rocourt et al., 2003). It is the agent of listeriosis, a severe, potentially fatal infection in at-risk populations (pregnant women, newborns, elderly individuals, immunocompromised persons).

Clostridium botulinum (Type E)

This type of *C. botulinum* is primarily associated with aquatic environments. It is an anaerobic spore-forming bacterium capable of producing botulinum neurotoxin in poorly preserved or insufficiently heat-treated fishery products (artisanal canned goods, vacuum-packed smoked or fermented fish) (Soni et al., 2022). Processed products such as smoked or dried fish are widely consumed in Togo. Studies on production parameters (salting, drying, smoking) and storage conditions would be useful to assess and control risks associated with *Listeria* and *Clostridium* (for vacuum-packed or poorly fermented products). Training processors in good manufacturing practices is essential.

4.3.2. Viral Infections

Norovirus and Hepatitis A Virus (HAV)

These enteric viruses are a major cause of foodborne illnesses linked to seafood. Filter-feeding bivalve mollusks (oysters, mussels, clams), harvested in waters contaminated by wastewater discharges, concentrate these viruses (Lees, 2000). They are resistant in the environment and to certain treatments. Norovirus causes acute gastroenteritis, while HAV is the agent of hepatitis A. Thorough cooking is necessary for their inactivation. As with fecal bacteria, the risk of viral contamination of mollusks is linked to the quality of collection waters. Improving sanitation and monitoring the microbiological quality of shellfish harvesting zones are key preventive measures.

4.3.3. Parasitic Infestations

The consumption of fish or seafood that is raw or insufficiently treated can expose individuals to various parasites.

Nematodes (Anisakids)

Larvae of nematodes of the genera *Anisakis*, *Pseudoterranova*, and *Contracaecum* are frequently present in the abdominal cavity and musculature of many marine fish and cephalopods. Ingestion of live larvae causes anisaki(do)sis, characterized by acute abdominal pain, nausea, vomiting, and sometimes severe allergic reactions (Recht et al., 2020). Freezing to the core (-20°C for at least 24 hours or -35°C for at least 15 hours) or thorough cooking (>60°C core temperature) kills the larvae. Fish is rarely consumed raw in Togo, which limits the risk of anisakiasis. However, rapid evisceration after capture and proper cooking remain important recommendations. Sensitizing fishermen to visual inspection of fish can also play a role. In Togo, fish is commonly consumed fried. However, small species such as anchovies and juvenile fish are typically fried whole without prior evisceration. This practice represents a potential transmission route for parasites if the thermal treatment is insufficient to reach the internal organs

Cestodes (Tapeworms) The best known is *Diphyllobothrium latum* (fish tapeworm), whose plerocercoid larvae develop in the flesh of freshwater fish (pike, perch, salmonids in certain regions). Human infestation (diphyllobothriasis) is often asymptomatic or manifests as minor digestive disorders, but can lead to anemia due to vitamin B12 deficiency (Scholz et al., 2009). Freezing or cooking are preventive measures.

Trematodes (Flukes) Several species of flukes (e.g., *Clonorchis sinensis*, *Opisthorchis viverrini*, *Opisthorchis felineus*, *Paragonimus* spp.) can infest humans following the consumption of raw or poorly cooked freshwater fish or crustaceans, particularly in certain regions of Asia, Eastern Europe, and Latin America (Keiser and Utzinger, 2009). These parasites can cause severe hepatobiliary damage (cholangiocarcinoma for *Clonorchis* and *Opisthorchis*) or pulmonary damage (*Paragonimus*). These parasitic diseases are primarily linked to the consumption of raw or insufficiently cooked freshwater fish. In Togo, although cooking is generally practiced, it is important to maintain this habit, particularly for fish from lakes and rivers. Targeted epidemiological surveys could assess the prevalence of these parasitic diseases if risk factors (consumption of specific raw products) were identified.

4.4. Risks Related to Inadequate Handling, Preservation, and Preparation

Incorrect practices throughout the food chain, from capture to the plate, can introduce or exacerbate hazards.

4.4.1. Break in the Cold Chain and Microbial Proliferation

Fishery products are highly perishable. Rapid and continuous refrigeration (0-4°C) is crucial to slow the growth of spoilage bacteria and pathogens (Ghaly et al., 2010). Any temperature abuse (break in the cold chain) favors their multiplication. The cold chain is a major challenge in Togo, due to the hot climate and the frequent lack of adequate refrigeration infrastructure, from landing sites to markets and consumers. The use of ice (produced with potable water) must be encouraged and made more accessible. Maintaining the cold chain is further complicated by power grid instability. Despite efforts to diversify energy supplies, frequent load shedding ('délestage') poses a critical challenge for the preservation of frozen stocks. Indeed, although laudable efforts have been realized in Togo's electrification projects by diversifying supply sources from Ghana (Akosombo) and Nigeria (the gas pipeline leaving Nigeria to serve Benin, Togo, and Ghana), it is still sad to note that these cases of load shedding are increasingly recurrent. Investments in cold infrastructure (cold rooms, refrigerated vehicles, quality coolers) and training of sector actors are essential to improve product quality and safety.

4.4.2. Cross-Contamination

The transfer of pathogenic microorganisms from a contaminated food (often raw) to a healthy food (cooked or ready-to-eat) can occur through direct or indirect contact (via hands, utensils, work surfaces) (Redmond and Griffith, 2003). In markets and households, good hygiene practices (hand washing, separation of raw and cooked foods, cleaning of surfaces and utensils) must be constantly promoted through awareness campaigns. Access to potable water in markets is also a key factor.

4.4.3. Insufficient Cooking

Cooking that does not reach a sufficient internal temperature (generally >63°C core temperature) does not guarantee the destruction of pathogenic bacteria, viruses, or parasites (Blakistone et al., 2019). Although Togolese culinary traditions often imply thorough cooking, it is important to reiterate this, notably for large fish or preparations where heat might not penetrate uniformly.

4.4.4. Histamine Formation (Scombroid Poisoning or Scombrotoxism)

Histamine can form in large quantities in the flesh of certain fish (mainly from the Scombridae family: tuna, mackerel, bonito, but also mahi-mahi, sardines) that are poorly refrigerated after capture. Bacteria naturally present on the fish (e.g., *Morganella morganii*) decarboxylate histidine (an amino acid abundant in these fish) into histamine (Hungerford, 2010). Ingestion of histamine causes pseudo-allergic symptoms (flushing, headaches, palpitations, digestive disorders). Histamine is thermostable, so cooking does not destroy the toxin once formed; prevention relies exclusively on the strict maintenance of the cold chain from the moment of capture. The fish species concerned (tuna, mackerel, etc.) are caught and consumed in Togo. The risk of histamine formation is high if the fish is not quickly iced after capture. Improving the cold chain is therefore paramount here as well. Sensitizing fishermen to the importance of immediate refrigeration is crucial. Rapid histamine detection tests could be envisaged for batches intended for export or large canneries.

Conclusion

Although the list of potential hazards may seem exhaustive, it is crucial to emphasize that aquatic-origin foods remain a valuable component of a healthy diet. Health risks are, to a large extent, controllable through an integrated approach to food safety:

Surveillance and Regulation Implementation by competent authorities of monitoring programs for chemical contaminants and biotoxins in production zones and markets, and establishment of regulatory maximum levels, adapted to the national and international context. This notably implies strengthening the capacities of national laboratories (e.g., National Institute of Hygiene, Togolese Institute of Agricultural Research - ITRA) for the analysis of contaminants and pathogens in aquatic products. Developing and updating national standards based on international recommendations (Codex Alimentarius) and local data.

Good Practices It is necessary to ensure the application of Good Hygiene Practices (GHP), good fishing practices, and Good Aquaculture Practices (GAP) to minimize contamination at the source. These objectives can be achieved by developing and disseminating guides to good practices adapted to actors in artisanal fishing, aquaculture, and processing (particularly women processors). Organizing regular training sessions.

Food Safety Management Systems It would be necessary to ensure the deployment of systems such as HACCP (Hazard Analysis Critical Control Point) in processing enterprises, particularly those targeting exports or structured urban markets. Accompanying small and medium-sized enterprises in the sector in the progressive implementation of quality and safety management systems.

Traceability Provisions allowing products to be traced back to their origin in case of problems must be taken. This will contribute to exploring simple traceability systems adapted to the context of artisanal fishing and local marketing circuits.

Consumer Information and Education Acquired knowledge will serve to raise awareness of domestic hygiene rules, appropriate conservation and cooking methods, and specific recommendations for vulnerable populations. Mass education projects will be conducted through public information campaigns (radio, television, posters in markets) on health risks and means of prevention, using local languages. Emphasizing the importance of the cold chain, thorough cooking, and hand and utensil hygiene.

A profound knowledge of hazards, supported by local research, and the rigorous application of prevention and control measures, involving all actors in the sector, from the fisherman to the consumer, including processors and authorities, will allow for

References

Beigue Alfa P., Dossou B. R., Souho T., Mensah L. K., Banakinao T. B., Awili T., Amouzou K. (2022) : Assessment of the health safety of fish smoked in improved ovens in Togo by determination of Polycyclic Aromatic Hydrocarbons (PAHs). *Journal of Chemical, Biological and Physical Sciences*, 13(1) : 011-021.

Gnandi K. (2002). L'impact de l'exploitation des phosphates sédimentaires de Hahotoé-Kpogamé sur la pollution chimique des sédiments de la rivière Haho et du Lac-Togo (Sud Togo), J. Rech. Sci. Univ. Lomé (Togo), Tome 6, 2 : 95–105.

Gnandi K., Tchangbedji G. Killi K., Baba G. Abbé K. D. (2006). The Impact of Phosphate Mine Tailings on the Bioaccumulation of Heavy Metals in Marine Fish and Crustaceans from the Coastal Zone of Togo, International Journal of Mine Water and Environment, 7, 25(1) : 56-62.

Kantati Y. T., Kodjo M. K., Gnandi K., Ketoh G. K., Gbeassor M. (2013). Effects of pollution on oxidative stress in aquatic species: case of the fish Sarotherodon melanotheron in Bè Lagoon (Lomé). Int. J. Biol. Chem. Sci. 7(2): 717-725.

Melila M., Rajaram R., Ganeshkumar A., Kpemissi M., Pakoussi T., Agbere S., Lazar I. M., Lazar G., Amouzou K., Paray B. A., Gulnaz A. (2022). Assessment of renal and hepatic dysfunction by co-exposure to toxic metals (Cd, Pb) and fluoride in people living nearby an industrial zone. Journal of Trace Elements in Medicine and Biology 69 (2022) 126890.

Melila M., Rajendran R., Awaga K. L., Arumugam G., Kpemissi M., Agbere S., Lazar G., Amouzou K. (2019). Cardiovascular dysfunction and oxidative stress following human contamination by fluoride along with environmental xenobiotics (Cd &Pb) in the phosphate treatment area of Togo, West Africa, J. Trace Elem. Med. Biol. 56 (2019) : 13–20.

Eklu-Gadegbeku, K. (2020). Human health risk assessment of polycyclic aromatic hydrocarbons (PAH) in smoked fishes in Togo. *Journal of Agriculture and Environmental Sciences*, *9*(2), 6-13.

Aduayi-Akue, A. A., Gnandi, K., Tete-Benissan, A., Degbe, M., Tanouayi, G., & Gbeassor, M. (2015). Evaluation des teneurs des métaux lourds dans le sang des sujets de la zone de traitement des phosphates au Sud du Togo. *International Journal of Biological and Chemical Sciences*, *9*(4), 1972-1982.

Mulenga, M., Ouma, K. O., Monde, C., & Syampungani, S. (2024). Aquatic mercury pollution from artisanal and small-scale gold mining in sub-Saharan Africa: Status, Impacts, and Interventions. *Water*, *16*(5), 756.

Recht, J., Schuenemann, V. J., & Sánchez-Villagra, M. R. (2020). Host diversity and origin of zoonoses: The ancient and the new. *Animals*, *10*(9), 1672.

Baker-Austin, C., Oliver, J. D., Alam, M., Ali, A., Waldor, M. K., Qadri, F., & Martinez-Urtaza, J. (2018). Vibrio spp. infections. *Nature Reviews Disease Primers*, *4*(1), 1-19.

Driscoll, C. T., Mason, R. P., Chan, H. M., Jacob, D. J., & Pirrone, N. (2013). Mercury as a global pollutant: sources, pathways, and effects. *Environmental science & technology*, *47*(10), 4967-4983.

Panel, E. C., & Chain, F. (2011). Statement on tolerable weekly intake for cadmium. *EFSA Journal*, *9*(2), 1975.

Panel, E. C. (2011). *Scientific Opinion on tolerable weekly intake for cadmium. EFSA Journal 2011; 9 (2): 1975, 19 pp*.

WHO, G. S. (2011). Risk assessment of Vibrio parahaemolyticus in seafood. Interpretative summary and technical report.

Faroon, O., Jones, D., & De Rosa, C. (2000). Effects of polychlorinated biphenyls on the nervous system. *Toxicology and industrial health*, *16*(7-8), 305-333.

FDA (U.S. Food and Drug Administration). (2022). *Seafood Guidance Documents & Regulatory Information*. [Consulté sur le site de la FDA]

Blakistone, B., & Mavity, S. (2019). Seafood. In *Food Traceability: From Binders to Blockchain* (pp. 97-111). Cham: Springer International Publishing.

Friedman, M. A., Fernandez, M., Backer, L. C., Dickey, R. W., Bernstein, J., Schrank, K., ... & Fleming, L. E. (2017). An updated review of ciguatera fish poisoning: clinical, epidemiological, environmental, and public health management. *Marine drugs*, *15*(3), 72.

Gallo, F., Fossi, C., Weber, R., Santillo, D., Sousa, J., Ingram, I., ... & Romano, D. (2018). Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. *Environmental Sciences Europe*, *30*, 1-14..

Ghaly, A. E., Dave, D., Budge, S., & Brooks, M. S. (2010). Fish spoilage mechanisms and preservation techniques. *American journal of applied sciences*, *7*(7), 859.

Hungerford, J. M. (2010). Scombroid poisoning: a review. *Toxicon*, *56*(2), 231-243.

Jones, K. C., & De Voogt, P. (1999). Persistent organic pollutants (POPs): state of the science. *Environmental pollution*, *100*(1-3), 209-221.

Karagas, M. R., Choi, A. L., Oken, E., Horvat, M., Schoeny, R., Kamai, E., ... & Korrick, S. (2012). Evidence on the human health effects of low-level methylmercury exposure. *Environmental health perspectives*, *120*(6), 799-806.

Keiser, J., & Utzinger, J. (2009). Food-borne trematodiases. *Clinical microbiology reviews*, *22*(3), 466-483.

Ouro-Sama, K., Solitoke, H. D., Tanouayi, G., Lazar, I. M., Bran, P., Nadejde, M., ... & Lazar, G. O. (2020). Spatial and seasonal variation of trace elements contamination level of the waters from the hydrosystem Lake Togo-Lagoon of Aného (South of Togo). *SN Applied Sciences*, *2*, 1-18.

Badassan, T. E. E., Avumadi, A. M. D., Ouro-Sama, K., Gnandi, K., Jean-Dupuy, S., & Probst, J. L. (2020). Geochemical composition of the Lomé lagoon sediments, Togo: Seasonal and spatial variations of major, trace and rare earth element concentrations. *Water*, *12*(11), 3026.

SOLITOKE, H. D., Kamilou, O. U. R. O., TANOUAYI, G., BADASSAN, T. E. E., AHOUDI, H., NYAMETSO, A. Y., ... & GNANDI, K. (2018). Study of the metallic contamination of the sediments in a tropical hydro system: Case of the system Lac Zowla-Aneho Lagoon (South-Togo). *Environmental and Water Sciences, public Health and Territorial Intelligence Journal*, *2*(4), 41-51.

Lees, D. (2000). Viruses and bivalve shellfish. *International journal of food microbiology*, *59*(1-2), 81-116.

Leung, A. O., Duzgoren-Aydin, N. S., Cheung, K. C., & Wong, M. H. (2008). Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in southeast China. *Environmental science & technology*, *42*(7), 2674-2680.

Soni, A., Bremer, P., & Brightwell, G. (2022). A comprehensive review of variability in the thermal resistance (D-values) of food-borne pathogens—A challenge for thermal validation trials. *Foods*, *11*(24), 4117.

Noguchi, T., & Arakawa, O. (2008). Tetrodotoxin–distribution and accumulation in aquatic organisms, and cases of human intoxication. *Marine drugs*, *6*(2), 220-242.

Redmond, E. C., & Griffith, C. J. (2003). Consumer food handling in the home: a review of food safety studies. *Journal of food protection*, *66*(1), 130-161.

Reguera, B., Riobó, P., Rodríguez, F., Díaz, P. A., Pizarro, G., Paz, B., ... & Blanco, J. (2014). Dinophysis toxins: Causative organisms, distribution and fate in shellfish. *Marine drugs*, *12*(1), 394-461..

Rocourt, J., Jacquet, C., & Reilly, A. (2000). Epidemiology of human listeriosis and seafoods. *International journal of food microbiology*, *62*(3), 197-209.

Scholz, T., Garcia, H. H., Kuchta, R., & Wicht, B. (2009). Update on the human broad tapeworm (genus Diphyllobothrium), including clinical relevance. *Clinical microbiology reviews*, *22*(1), 146-160.

Trainer, V. L., Pitcher, G. C., Reguera, B., & Smayda, T. J. (2010). The distribution and impacts of harmful algal bloom species in eastern boundary upwelling systems. *Progress in oceanography*, *85*(1-2), 33-52.

Desai, B. H. (2020). 14. United nations environment programme (UNEP). *Yearbook of International Environmental Law*, *31*(1), 319-325..

Van den Berg, M., Birnbaum, L. S., Denison, M., De Vito, M., Farland, W., Feeley, M., ... & Peterson, R. E. (2006). The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicological sciences*, *93*(2), 223-241.

Visciano, P., Schirone, M., Berti, M., Milandri, A., Tofalo, R., & Suzzi, G. (2016). Marine biotoxins: occurrence, toxicity, regulatory limits and reference methods. *Frontiers in microbiology*, *7*, 1051.

Watkins, S. M., Reich, A., Fleming, L. E., & Hammond, R. (2008). Neurotoxic shellfish poisoning. *Marine drugs*, *6*(3), 431-455.

World Health Organization. (2023). *Report on activities during the ninth International lead poisoning prevention week, 24-30 October 2021*. World Health Organization.

Wiese, M., D'Agostino, P. M., Mihali, T. K., Moffitt, M. C., & Neilan, B. A. (2010). Neurotoxic alkaloids: saxitoxin and its analogs. *Marine drugs*, *8*(7), 2185-2211.

Table 2.1: Main Chemical Contaminants with Sources, Affected Aquatic Foods, and Health Effects.

Chemical Contaminant	Main Sources	Most Affected Aquatic Foods	Main Health Effects	Specific Notes for Togo
Mercury (Hg) (especially Methylmercury - MeHg)	Coal combustion, artisanal gold mining, industrial discharges, natural sources.	Large predatory fish (tuna, swordfish, shark) via bioaccumulation and biomagnification.	Potent neurotoxin (especially affecting CNS development in fetuses/young children), nephrotoxic, cardiovascular effects.	Artisanal gold mining is a source of watercourse contamination. Increased surveillance is necessary in these areas, especially for pregnant women.
Lead (Pb)	Industrial discharges, corrosion of old pipes, atmospheric deposition (legacy leaded gasoline).	Benthic organisms, particularly mollusks.	Neurotoxic (especially in children), hematotoxic, nephrotoxic, may affect reproduction.	Urban/industrial areas (Greater Lomé) are potential sources for coastal/lagoon ecosystems via effluents/waste.
Cadmium (Cd)	Industrial discharges (metallurgy, batteries), sewage sludge spreading, phosphate fertilizers.	Mollusks, crustaceans, fish offal (liver, kidneys).	Primarily nephrotoxic; chronic exposure can cause bone demineralization.	The use of phosphate fertilizers in agriculture can enrich surface waters. Surveillance recommended for freshwater fish and aquaculture.
Persistent Organic Pollutants (POPs)	Synthetic organic compounds resistant to degradation, bioaccumulative, long-range transport.	Accumulate in aquatic food chains, especially in fatty fish.	Variable: endocrine disruptors, neurotoxic, immunotoxic, potentially carcinogenic.	
Organochlorine Pesticides (DDT, etc.)	Past or illicit use in agriculture.	Fish (bioaccumulation).	Suspected endocrine disruptors, neurotoxic, potentially carcinogenic.	Studies on persistence are necessary in agricultural/estuarine areas. Management of obsolete pesticide stocks is crucial.
Polychlorinated Biphenyls (PCBs)	Legacy dielectric/heat transfer fluids; old industrial facilities, transformers.	Fatty fish (accumulation in adipose tissue).	Carcinogenic, immunotoxic, neurodevelopmental, endocrine disruption.	Autonomous Port of Lomé is a potential source. Contamination assessment of port/industrial areas is necessary.
Dioxins (PCDD) and Furans (PCDF)	Unintentional by-products of industrial processes (steelmaking, waste incineration).	Accumulate in the food chain.	TCDD (the most toxic) classified as a known carcinogen (IARC); immunotoxic, endocrine disruptors.	Open-air waste burning (common) can release dioxins/furans. Open dumps in Lomé are potential sources via ash runoff.

Polycyclic Aromatic Hydrocarbons (PAHs)	Oil spills, incomplete combustion of organic matter (e.g., traditional fish smoking).	Smoked fish, products exposed to combustion smoke.	Carcinogenic, mutagenic.	Traditional fish smoking is widespread and may lead to high levels. Optimization of smoking techniques is necessary.
Veterinary Drug Residues	Use in aquaculture (antibiotics, antiparasitic agents).	Farmed fish and crustaceans.	Risk of developing antibiotic resistance, potential toxic effects.	Aquaculture development must be accompanied by good drug use practices.
Microplastics / Nanoplastics	Widespread plastic pollution in aquatic environments.	Ingested by many aquatic organisms; potential vectors for other contaminants.	Direct effects are still under study; concerns regarding contaminant transfer and inflammation.	Visible plastic pollution on coasts/lagoons suggests probable contamination; local studies are needed.

Table 2.2: Phycotoxins with Producer Organisms, Affected Seafood, and Symptoms.

Phycotoxin (Associated Syndrome)	Producer Organisms	Affected Seafood	Intoxication Symptoms	Specific Notes for Togo
Ciguatoxins (CTX) (Ciguatera Fish Poisoning - CFP)	Benthic dinoflagellates (*Gambierdiscus spp.*) in tropical/subtropical coral reef ecosystems.	Numerous herbivorous and carnivorous reef fish (bioaccumulation).	Gastrointestinal, neurological (paresthesia, reversal of hot/cold sensation, ataxia), and cardiovascular disorders.	The Togolese coast is not typically reef-based, but the risk is not excluded (climate change). Health monitoring/regional collaboration is relevant for suspected cases.
Saxitoxins (STX) and Analogs (Paralytic Shellfish Poisoning - PSP)	Dinoflagellates (*Alexandrium*, *Gymnodinium*, *Pyrodinium spp.*).	Filter-feeding bivalve mollusks (oysters, mussels, cockles, scallops).	Perioral paresthesia progressing to muscle paralysis, potentially fatal respiratory distress.	Consumption of mollusks (mangrove oysters) exists. Monitoring of HABs (Harmful Algal Blooms) and phycotoxins is important if the sector develops.
Domoic Acid (DA) (Amnesic Shellfish Poisoning - ASP)	Certain diatoms (*Pseudo-nitzschia spp.*).	Filter-feeding mollusks, certain crustaceans, and planktivorous fish.	Gastrointestinal disorders, followed by severe neurological symptoms (headaches, confusion, short-term memory loss, permanent brain damage).	Mollusks are consumed in Togo. Relevant surveillance.
Okadaic Acid (OA) and Dinophysistoxins (DTXs) (Diarrheic Shellfish Poisoning - DSP)	Dinoflagellates (*Dinophysis*, *Prorocentrum spp.*).	Bivalve mollusks.	Intense gastrointestinal disorders (diarrhea, nausea, vomiting, abdominal pain).	Consumption of mollusks (mangrove oysters) exists. Relevant surveillance.
Brevetoxins (PbTx) (Neurotoxic Shellfish Poisoning - NSP)	Dinoflagellate (*Karenia brevis*).	Mollusks.	Gastrointestinal and neurological symptoms; respiratory irritation via inhalation of marine aerosols.	Consumption of mollusks (mangrove oysters) exists. Relevant surveillance.
Tetrodotoxin (TTX) (Pufferfish Poisoning)	Symbiotic bacteria associated with certain marine animals (pufferfish/Fugu, gastropods, crabs, starfish).	Pufferfish (especially liver, ovaries), certain other marine organisms.	Sodium channel blocker: progressive paralysis, respiratory failure, often fatal.	Pufferfish species are present in Togolese waters. Consumption is non-traditional but it is crucial to inform about the lethal dangers.

Table 2.3: Microbiological Hazards with At-Risk Foods and Associated Pathologies.

Microbiological Agent	Sources of Contamination / At-Risk Foods	Associated Pathologies	Specific Notes for Togo
Bacteria			
Vibrio spp. (*V. parahaemolyticus*, *V. vulnificus*, *V. cholerae*)	Naturally present in warm marine/estuarine environments. Raw or undercooked seafood.	*V. parahaemolyticus*: Gastroenteritis. *V. vulnificus*: Gastroenteritis, severe septicemia (in immunocompromised individuals). *V. cholerae* (O1/O139): Cholera.	Warm coastal/lagoon waters are conducive. Sewage discharge into the sea in Lomé = risk. Awareness and hygiene are essential. Local studies on prevalence are useful.
Salmonella spp. and Pathogenic *Escherichia coli*	Fecal contamination (e.g., wastewater discharge) or post-capture cross-contamination.	Gastroenteritis.	Insufficient wastewater management (Lake Togo, Lomé Lagoon) can lead to contamination. Improved sanitation is a major challenge.
Listeria monocytogenes	Ubiquitous, psychrotrophic bacterium (multiplication in cold conditions). Ready-to-eat products with a long shelf life (cold-smoked fish).	Listeriosis (serious/fatal infection in at-risk populations: pregnant women, newborns, elderly, immunocompromised individuals).	Smoked/dried fish is widely consumed. Studies on production/preservation parameters and processor training are essential.
***Clostridium botulinum* (Type E)**	Associated with aquatic environments; spore-forming anaerobe. Poorly preserved/heat-treated fishery products (artisanal preserves, vacuum-packed smoked/fermented fish).	Botulism (neurotoxin).	Smoked/dried fish is widely consumed. Risk if products are vacuum-packed or poorly fermented. Processor training is essential.
Viruses			
Norovirus and Hepatitis A Virus (HAV)	Enteric viruses. Filter-feeding bivalve mollusks (oysters, mussels, clams) harvested from waters contaminated by wastewater discharge. Resistant, complete cooking is necessary.	Norovirus: Acute gastroenteritis. HAV: Hepatitis A.	Risk related to the quality of mollusk harvesting waters. Improved sanitation and monitoring of harvesting water quality are key measures.
Parasites			
Nematodes (Anisakids: *Anisakis*, *Pseudoterranova*, *Contracaecum*)	Larvae in the abdominal cavity/musculature of marine fish and cephalopods. Ingestion of live larvae (raw/undercooked fish). Freezing (-	Anisakiasis: acute abdominal pain, nausea, vomiting, allergic reactions.	Raw fish is rare, which limits the risk. Rapid evisceration and proper cooking are important. Tilapia, anchovies, and small fry fried whole without evisceration = potential source.

	20°C/24h) or cooking (>60°C) kills the larvae.		
Cestodes (Tapeworms, e.g., *Diphyllobothrium latum*)	Plerocercoid larvae in the flesh of freshwater fish (pike, perch, etc.). Raw/undercooked fish. Preventive freezing/cooking.	Diphyllobothriasis: often asymptomatic or minor digestive issues; may cause anemia (B12 deficiency).	Cooking is generally practiced for freshwater fish, which should be maintained.
Trematodes (Flukes, e.g., *Clonorchis*, *Opisthorchis*, *Paragonimus*)	Consumption of raw/undercooked freshwater fish or crustaceans in certain regions (Asia, Eastern Europe, Latin America).	Severe hepato-biliary diseases (cholangiocarcinoma for *Clonorchis*/*Opisthorchis*) or pulmonary diseases (*Paragonimus*).	Cooking is generally practiced, which should be maintained. Targeted epidemiological surveys if risk factors are identified.
Others			
Histamine (Scombroid Poisoning)	Formation by bacteria (e.g., *Morganella morganii*) decarboxylating histidine in the flesh of poorly refrigerated fish (tuna, mackerel, sardine, etc.) after catch. Thermostable (cooking is not preventative).	Pseudo-allergic symptoms (flushing, headaches, palpitations, digestive disorders).	Relevant species (tuna, mackerel) are fished/consumed. High risk if fish is not rapidly iced. The cold chain is paramount, and fisherman awareness is needed.

Chapter 5. Food Safety Pertaining to the Consumption of Aquatic Products

The integration of aquatic products into the human diet is recognized for its substantial nutritional contributions, particularly high biological value protein, omega-3 polyunsaturated fatty acids, vitamins, and trace elements. However, the perishable nature of these commodities and their environmental origin expose them to diverse potential contaminants, whether microbiological, chemical, or parasitological. Therefore, rigorous risk management, from selection through to consumption, is imperative to ensure consumer safety. This chapter proposes to examine best practices for consuming aquatic foods, addressing the judicious selection of products, essential precautions during purchase, preparation, and cooking, optimal preservation methods, as well as the crucial role of national and international sanitary bodies, while integrating perspectives and challenges specific to the Togolese context.

5.1. Selection of Wholesome Aquatic Foods

The first step toward safe consumption lies in the informed choice of products. Several factors must guide this selection.

5.1.1. Importance of Origin and Traceability

The geographical origin of aquatic products is a primary indicator of their potential quality. Capture or farming waters may be subject to industrial pollution (heavy metals such as mercury, cadmium, lead), agricultural pollution (pesticides, nitrates), or urban pollution (effluents) (FAO, 2020). Similarly, certain areas are more prone to the development of toxic algal blooms, which are responsible for the contamination of bivalve molluscs by phycotoxins (e.g., Paralytic Shellfish Poisoning (PSP), Diarrhetic Shellfish Poisoning (DSP), Amnesic Shellfish Poisoning (ASP) toxins). Traceability is an essential tool for tracking the product from the plate back to the fishing or farming location. Robust traceability systems, often mandated by regulations (e.g., Regulation (EC) No 178/2002 in Europe), allow for the rapid identification of a contamination source and the withdrawal of affected batches from the market. For the consumer, seeking information on the origin (FAO fishing area, country of rearing) constitutes a preliminary preventive measure. Products derived from aquaculture must, in turn, come from operations that adhere to strict specifications regarding water quality, animal feed, and the use of veterinary medicines (Caceres et al., 2023).

In Togo, the majority of aquatic products come from artisanal fishing (marine, lagoon, and continental) and a developing aquaculture sector. Formal traceability is often limited in these supply chains. In the absence of formal certification, establishing a direct relationship with fishers or vendors and inquiring about capture zones constitutes a prudent consumer practice.

It is therefore important to encourage the establishment of simplified traceability systems within fishers' cooperatives or groups of fish vendors, for example, through batch identification by day and by recognized canoe/fishing zone. Support should be provided for studies characterizing fishing and aquaculture zones to identify lower-risk areas and, conversely, those requiring increased surveillance or corrective measures (e.g., concerning the water quality of Lake Togo and the lagoon system).

5.1.2. Role of Labels and Certifications

Given the complexity of individually assessing wholesomeness, labels and certifications offer additional guarantees. They attest to compliance with specific standards throughout the production chain. Among the most relevant are:

Sustainable Fishing Labels These include labels such as the Marine Stewardship Council (MSC) for wild-caught fish or the Aquaculture Stewardship Council (ASC) for aquaculture. While primarily focused on environmental sustainability, they often incorporate good practice and traceability requirements that indirectly contribute to safety (MSC, 2023; ASC, 2023).

Organic Labels (Bio) These guarantee the absence of GMOs, a strict limitation on synthetic chemical inputs in farmed fish feed, and farming conditions that respect animal welfare and the environment (e.g., Regulation (EU) 2018/848).

Protected Geographical Indications (PGI) or Controlled/Protected Designations of Origin (AOC/PDO) These labels promote specific expertise and geographical origin, often associated with traditional and controlled production methods.

Specific National or Regional Sanitary Quality Labels Some countries or regions develop their own certification marks attesting to enhanced sanitary controls.

Consumers are advised to familiarize themselves with the meaning of these labels to guide their choices toward products offering better guarantees.

International labels are not very common on the local Togolese market, being more of a requirement for export products.

It would be relevant to explore the possibility of developing local or regional initiatives for quality enhancement, including sanitary criteria, for Togolese fishery and aquaculture products. This could begin with "good practice charters" promoted by interprofessional organizations with the support of authorities, potentially evolving into nationally recognized distinctive quality marks. Raising consumer awareness of the importance of provenance and the efforts of certain producers could also orient the market.

5.1.3. Initial Visual and Olfactory Inspection

Before any purchase, a **sensory inspection** of the product is crucial (Huss, 1995).

Whole Fish It should have a bright appearance, taut and pigmented skin, and adherent scales. The eyes must be vivid, clear, bulging, and not concave or opaque. The gills should be red or pink, moist, and without excessive mucus. The abdomen should not be swollen. Finger pressure on the flesh should leave an imprint that fades quickly. The odor must be fresh, marine, evocative of iodine or algae, and free from any ammoniacal, putrid, or rancid notes.

Fillets and Steaks The flesh must be firm, elastic, with a homogeneous, pearly color. It should not show brownish blood stains or discolored areas. The odor should be neutral or pleasantly marine.

Crustaceans (Shrimps, Crabs, Lobsters) If alive, they must be **vigorous and reactive**. When cooked, their shell must have a bright, uniform color. The odor should be delicate. The flesh, once shelled, must be firm.

Bivalve Molluscs (Oysters, Mussels, Cockles) They must be purchased alive and closed, or close when tapped. The shells must be intact. Once cooked, those that remain closed must be discarded. The odor must be iodized and fresh. They should be accompanied by a sanitary tag mentioning the date of packaging and the production area.

Any deviation from these freshness criteria must prompt caution and potential rejection of the product.

In Togolese markets, where preservation conditions can be precarious (frequent lack of ice or refrigerated displays), visual and olfactory inspection by the consumer is an essential and often well-mastered skill.

Strengthen the awareness of consumers and especially vendors (fish vendors, fishmongers) regarding these freshness criteria. Encourage vendors to adopt practices that improve presentation and preservation (systematic use of **clean ice**, protection against flies and dust). Simple demonstrations and illustrated guides could be disseminated in the markets.

5.2. Precautions During Purchase, Preparation, and Cooking

Once the product is selected, vigilance must continue through the subsequent steps.

5.2.1. Purchase Phase and Maintenance of the Cold Chain

The purchase of aquatic products should ideally be made at the end of shopping to minimize the time spent outside a refrigerated environment. The use of an insulated bag, or even a cooler with ice packs, is strongly recommended for transport, especially in hot weather or for long journeys (WHO, 2006). It is crucial to verify that refrigerated products are kept at an adequate temperature (close to 0°C, on a bed of melting ice) at the distributor, and that frozen products are maintained at a temperature of -18°C or lower, without signs of partial thawing (presence of excessive frost, deformed packaging).

The maintenance of the cold chain is a major challenge in Togo, given the hot climate and often limited infrastructure. Fish is frequently sold at ambient temperature in the markets.

Promote the purchase of fish as early as possible after its arrival at the market or directly from the fishers if possible. Encourage the use of individual coolers by consumers. For vendors, emphasize the importance of ice (made with potable water; "pure water" sachets would be suitable) and the necessity of protecting the fish from the sun. Support initiatives aimed at equipping markets and landing sites with ice production units and small community cold rooms.

5.2.2. Preliminary Storage at Home

Upon arrival at home, fresh aquatic products must be immediately placed in the coldest part of the refrigerator (generally between 0°C and +4°C) and consumed within 24 to 48 hours (Blakistone et al., 2019). It is preferable to leave them in their original packaging or place them in an airtight container to avoid cross-contamination and the diffusion of odors. Frozen products must be transferred without delay to the freezer (≤ -18°C). Thawing must be done slowly, in the refrigerator, and never at ambient temperature to limit microbial proliferation. Rapid thawing in the microwave is possible if the product is cooked immediately afterwards. A thawed product must never be refrozen in its raw state.

Refrigerator ownership is not universal, and power cuts can compromise refrigeration. For households without a refrigerator, advise consumption on the day of purchase. If a refrigerator is available, reiterate these good practices, emphasizing the speed of consumption after purchase. In the event of a prolonged power outage, check the product's condition before consumption.

5.2.3. Hygienic Preparation

The preparation phase is critical for preventing foodborne illnesses.

Hand and Surface Hygiene Thorough hand washing with hot, soapy water before and after handling raw aquatic products is fundamental. Work surfaces, cutting boards, and utensils (knives, etc.) must be meticulously cleaned and disinfected after each use, especially if they have been in contact with raw fish. The ideal is to use a cutting board dedicated to seafood (WHO, 2006 – The Five Keys to Safer Food).

Prevention of Cross-Contamination It is imperative to avoid all contact between raw aquatic products and ready-to-eat foods (salads, cooked foods). Raw fish juices, rich in microorganisms, must not drip onto other food items. Utensils used to handle raw food must not be reused for cooked food without thorough cleaning.

Evisceration and Rinsing For whole fish, evisceration must be carried out quickly if it has not been done by the fishmonger. Viscera can be a significant source of bacteria and parasites (e.g., *Anisakis*). Abundant rinsing with cold running water is then necessary.

Access to running potable water and soap may be limited in some households or artisanal processing sites (markets).

Promote adapted solutions: use of clean containers for washing, water storage, use of local soap. Insist on the importance of these simple actions to prevent diseases. Encourage the rapid evisceration of fish, which is often already practiced.

5.2.4. Appropriate Cooking

Cooking is one of the most effective ways to eliminate microbiological hazards (bacteria such as *Vibrio spp., Salmonella spp., Listeria monocytogenes*) and parasitic hazards (such as *Anisakis* or flukes) (Blakistone et al., 2019).

Core Temperature The general recommendation is to reach a core temperature of at least 63°C for several minutes. For fish, flesh that becomes opaque and flakes easily with a fork generally indicates sufficient cooking. Bivalve molluscs must open under the effect of heat; those that remain closed after cooking must be strictly discarded.

Raw or Undercooked Consumption The consumption of raw fish (sashimi, sushi, tartare), marinated fish (ceviche), or cold-smoked fish presents increased risks. For these preparations, it is essential to use fish of irreproachable freshness that has undergone prophylactic freezing at -20°C for at least 24 hours (or -35°C for 15 hours), to kill parasitic larvae such as *Anisakis* (EFSA, 2010). Pregnant women, young children, the elderly, and immunocompromised individuals should refrain from consuming raw or insufficiently cooked aquatic products.

Histamine Risk Certain fish (tuna, mackerel, sardines, etc.) are rich in histidine, an amino acid that can be converted into histamine by bacteria if the cold chain is broken. Histamine is thermostable and is not destroyed by cooking. Prevention, therefore, relies exclusively on maintaining rigorous freshness of the product from the moment of capture (Hungerford, 2010).

Togolese culinary traditions generally involve complete cooking (frying, braising, or long-simmered sauces), which is an important protective factor.

It would be beneficial to value and maintain these practices of complete cooking. If new trends in raw or undercooked fish consumption emerge (restaurants, external influence), provide information on the specific risks and preventive measures (prior freezing). Recall the importance of the cold chain for scombroid fish, which are widely consumed, to prevent the histamine risk.

5.3. Preservation Methods and Risk Management

Mastering preservation is a cornerstone of food risk management related to aquatic products.

5.3.1. Refrigeration

Refrigeration (between 0°C and +4°C) significantly slows the growth of most spoilage and psychrotrophic pathogenic microorganisms (capable of developing in the cold), but does not stop it. The shelf life in the refrigerator is limited: 1 to 2 days for fresh fish and seafood, hermetically sealed. Cooked products can be stored slightly longer, generally 2 to 3 days.

5.3.2. Freezing

Freezing ($\leq -18°C$) allows for long-term preservation (several months, depending on the species and fat content) by halting microbial proliferation and inactivating parasites (under specific time/temperature conditions, as previously seen for *Anisakis*). However, it does not eliminate potentially pre-formed toxins or all bacteria (some can survive in a spore or quiescent state). Rapid freezing and slow, controlled thawing in the refrigerator are essential to preserve textural quality and limit sanitary risks.

5.3.3. Other Preservation Methods

Other traditional or industrial techniques contribute to preservation (Huss et al., 2003):

- **Salting**: Reduces water activity (aw), inhibiting microbial growth.
- **Smoking**: Combines partial dehydration, the action of antimicrobial compounds in the smoke, and, for hot smoking, a thermal effect. Cold smoking does not guarantee the destruction of pathogens like *Listeria monocytogenes*.
- **Marinating**: The acidity of the medium (vinegar, lemon) inhibits certain microorganisms.
- **Canning (Appertization)**: A high-temperature thermal treatment (sterilization) destroys microorganisms and their spores, allowing for long-term storage at ambient temperature as long as the can remains intact.

Smoking, drying, and salting are very widespread traditional preservation methods in Togo, making fish available far from fishing areas and for longer periods.

Promote the improvement of traditional techniques. For example, the use of improved smoking kilns (FTT-Thiaroye or Chorkor type) can reduce exposure to harmful polycyclic aromatic hydrocarbons (PAHs), improve energy efficiency, and enhance the quality of the finished product. Ensure sufficient salting and drying to guarantee preservation and limit microbial risks. Study local practices to identify critical points and propose accessible improvements.

5.3.4. Management of Leftovers and Consumption Times

Leftovers from aquatic product dishes must be rapidly refrigerated (within 2 hours of cooking completion) in clean, airtight containers. They should be consumed within 24 to 48 hours and thoroughly reheated (reaching 70°C core temperature) before consumption. If in doubt about the freshness or storage conditions of a leftover, it is preferable to discard it. Adherence to 'use-by' dates (DLC) for pre-packaged products is imperative.

5.4. The Role of Health Authorities and International Organizations

The safety of aquatic foods does not rest solely on consumer vigilance but is regulated by a framework of regulatory and surveillance mechanisms.

5.4.1. National Surveillance and Regulation

Each country has competent health authorities (e.g., ANSES and DGCCRF in France, FDA in the United States) responsible for:

- Establishing and enforcing regulations related to the production, processing, distribution, and marketing of aquatic products. This includes microbiological standards, maximum levels for chemical contaminants (heavy metals, dioxins, PCBs, veterinary drug residues), and hygiene requirements for establishments (often based on HACCP principles - Hazard Analysis Critical Control Point) (Codex Alimentarius, 2020).
- Implementing surveillance and control plans for production areas (shellfish water quality), products placed on the market (sampling and analysis), and establishments.
- Managing health alerts, ordering the withdrawal and recall of non-compliant or dangerous products, and communicating with professionals and the public.
- Providing consumption recommendations, particularly for sensitive populations (e.g., consumption limitations of certain mercury-rich predatory fish for pregnant women).

In Togo, several entities are involved in food safety, notably the Directorate of Livestock (*Direction de l'Élevage*) (for fishing and aquaculture aspects), the National Institute of Hygiene (*Institut National d'Hygiène - INH-Togo*) for analyses, the High Authority for Quality and the Environment (*Haute Autorité de la Qualité et de l'Environnement - HAUQE*) for standardization, and the ministries in charge of Health, Agriculture, and Commerce.

Strengthen the capacity of these institutions in terms of qualified human resources, analytical equipment, and inspection and control means in the field. Develop and implement a national plan for monitoring contaminants in aquatic products. Promote the adoption of HACCP principles by processing units, even small-scale ones. Establish a reactive and transparent health alert system. Improve inter-ministerial coordination and coordination with private stakeholders.

5.4.2. International Standards and Recommendations

At the international level, several organizations play a key role:

- **The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO)**: They collaborate closely on food safety issues. They provide scientific risk assessments, develop guidelines and recommendations, and strengthen the capacity of member countries in food control (Ndondo et al., 2023).
- **The Codex Alimentarius Commission**: A joint FAO/WHO body, it develops international food standards, codes of practice, and guidelines aimed at protecting consumer health and ensuring fair practices in the food trade. Codex standards (e.g., for fish, crustaceans, molluscs, contaminants) often serve as a reference for national legislation and for international trade agreements (WTO SPS Agreement) (Codex Alimentarius, 2023).
- **The World Organisation for Animal Health (OMSA, formerly OIE)**: It establishes standards for the prevention and control of diseases in aquatic animals, which has a direct impact on the safety of aquaculture products.

These bodies promote the harmonization of regulatory approaches and facilitate the international trade of safe aquatic products.

Togo is a member of these organizations and benefits from their recommendations. It is therefore necessary to ensure that national legislation and practices are, as far as possible, **aligned with the Codex Alimentarius standards and recommendations**. Actively participate in the work of these bodies to assert regional and national specificities and benefit from shared experience. Utilize the tools and guides produced by the FAO and WHO to strengthen national capacities.

5.4.3. Role in Health Crisis Management

In the event of large-scale contamination (e.g., a *Vibrio* outbreak linked to oyster consumption, an accidental marine pollution), close coordination between national authorities and international organizations is essential. This enables rapid information sharing, joint risk assessment, the issuance of global alerts if necessary, and the implementation of harmonized management measures to protect public health and maintain confidence in the trade of aquatic products.

It is urgent to develop and regularly test a national food health crisis management plan, specifically including aquatic products. This plan should clearly define the roles and responsibilities of the different institutions, communication procedures, and mechanisms for coordination with international partners.

Conclusion

The consumption of aquatic products, while nutritionally beneficial, requires a proactive and informed approach from the consumer to minimize inherent health risks. The judicious choice of products based on their origin, labels (when they exist and are reliable), and rigorous organoleptic inspection, coupled with strict precautions during purchasing, transport, hygienic preparation, and adequate cooking, constitutes the first line of defense. Preservation methods, notably the scrupulous adherence to the cold chain and appropriate freezing/thawing practices, as well as the improvement of traditional preservation techniques in Togo, are also fundamental. Finally, the action of national health authorities, with the support of international organizations, through the establishment of adapted standards, surveillance, control, and alert management, provides an essential framework that complements individual vigilance. It is through the combination of these individual and collective efforts, taking into account the realities and specific challenges of the Togolese context, that the safety and benefits of aquatic foods can be fully assured for the consumer.

REFERENCES

COUNCIL, M. S. Thon durable: le guide du MSC.

Codex Alimentarius Commission. (2020). *Code of Practice for Fish and Fishery Products (CXC 52-2003, Amended 2020)*. FAO/WHO.

Codex Alimentarius Commission. (2023). *About Codex Alimentarius*. [Consulté sur le site FAO/WHO]

EFSA Panel on Biological Hazards (BIOHAZ). (2010). Scientific opinion on risk assessment of parasites in fishery products. *EFSA journal*, *8*(4), 1543.

European Union. (2002). Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. *Official Journal of the European Communities*, L 31/1.

Dreyer, M., & Renn, O. (2009). *Food safety governance* (pp. 111-120). Berlin: Springer.

European Union. (2018). Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007. *Official Journal of the European Union*, L 150/1.

Agriculture Organization of the United Nations. Fisheries Department. (2018). *The state of world fisheries and aquaculture*. Food and Agriculture Organization of the United Nations.

Ndondo, J. T. K. (2023). Review of the Food and Agriculture Organisation (FAO) Strategic Priorities on Food Safety 2023. In *Food Safety-New Insights*. IntechOpen.

FDA (U.S. Food and Drug Administration). (2022). *Selecting and Serving Fresh and Frozen Seafood Safely*. [Consulté sur le site de la FDA]

Blakistone, B., & Mavity, S. (2019). Seafood. In *Food Traceability: From Binders to Blockchain* (pp. 97-111). Cham: Springer International Publishing.

Hungerford, J. M. (2010). Scombroid poisoning: a review. *Toxicon*, *56*(2), 231-243.

Huss, H. H. (1995). FAO Fisheries technical paper 348. *Food and Agriculture Organization of the United Nations, Rome*..

Huss, H. H., Ababouch, L., & Gram, L. (2004). Assessment and management of seafood safety and quality.

Council, M. S. (2022). MSC fisheries standard. *Version*, *3*, 26.

Caceres, P., Awada, L., Weber-Vintzel, L., Morales, R., Meske, M., & Tizzani, P. (2023). The World Animal Health Information System as a tool to support decision-making and research in animal health. *Revue Scientifique et Technique-Office International Des Epizooties*, *42*, 242-251.

World Health Organization. Regional Office for the Western Pacific. (2006). *Field manual for capacity assessment of health facilities in responding to emergencies*. World Health Organization.

Table 3.1: Recommendations for Aquatic Food Consumption

Population Group	General Recommendations (WHO/FAO, National Agencies)	Possible Adaptation / Key Points for Togo
General Adult Population	WHO/FAO: 1–2 times per week, particularly oily fish (approx. 250 mg EPA+DHA/day on average). ANSES (France): Fish 2 times/week (1 oily + 1 lean). USA Guidelines: At least 8 ounces (approx. 227g) of seafood/week, emphasizing variety.	Emphasize the consumption of small marine pelagic fish (sardinella, anchovies—often smoked/dried, affordable) and freshwater fish (tilapia, *Clarias* spp./catfish). Insist on species diversity and healthy preparation methods. Provide reassurance regarding the low mercury content of common local species, but advise caution in polluted areas.
Pregnant and Lactating Women	WHO/FAO: At least 200 mg of DHA/day. Crucial importance of DHA for fetal/infant development. ANSES: Limit exposure to methylmercury (via species choice). Avoid raw/undercooked products.	Priority target group. Promote fish consumption during prenatal/postnatal consultations. Advise on selecting local species with a low risk of contamination. Tactfully address local beliefs (fish discouraged) if they are unfounded. Insist on the importance of fish for both the mother and the baby.
Infants and Young Children (0–3 years/ 5 years)	WHO/FAO: DHA is important for development. ANSES: Recommendations on complementary feeding. Limit methylmercury exposure (species choice). Avoid raw/undercooked products.	Priority target for combating chronic malnutrition/growth stunting. Integrate fish (even in small quantities, e.g., dried fish powder) into complementary feeding from 6 months of age. Promote fish (local, affordable) in school canteens. Highlight the importance of fish for children's brain development.
Elderly Individuals	Avoid raw/undercooked products if immunocompromised. Benefits for maintaining cognitive function.	Highlight the role in maintaining muscle mass (high-quality proteins).
General (Benefit/Risk Balance)	Diversify consumed species. Prioritize smaller or less predatory fish. Limit consumption frequency of the most contaminated species (especially for vulnerable groups). Majority of assessments: benefits > risks for the general population if recommendations are followed.	Most fish consumed in Togo (small pelagics, tilapia) generally have low levels of methylmercury. The risk may be more related to local chemical pollution. Promote good preparation practices (evisceration, washing) to reduce certain risks. Value traditional thorough cooking as a protective factor.

Table 3.2: Freshness Criteria for Selecting Aquatic Products

Product Type	Visual, Olfactory, and Tactile Freshness Criteria
Whole Fish	**General Appearance:** Shiny, taut and pigmented skin, adhering scales. **Eyes:** Bright, clear, bulging (not concave or opaque). **Gills:** Red or pink, moist, without excessive mucus. **Abdomen:** Not swollen. **Flesh:** Firm, elastic (finger pressure mark disappears quickly). **Odor:** Fresh, marine (iodine, seaweed), free from ammoniacal, putrid, or rancid notes.
Fish Fillets and Steaks	**Flesh:** Firm, elastic, uniform and pearly color. No brownish blood spots or discolored areas. **Odor:** Neutral or pleasantly marine.
Crustaceans (Shrimp, Crabs, etc.)	**Live:** Vigorous and reactive. **Cooked:** Shell of a bright and uniform color. Flesh firm once peeled. **Odor:** Delicate.
Bivalve Mollusks (Oysters, Mussels, Cockles, etc.)	**Purchase:** Must be alive and closed, or close when tapped. Intact shells. Health label with packaging date and production zone. **Odor:** Iodized and fresh. **After Cooking:** Those that remain closed must be discarded.
Note for Togo	Visual and olfactory inspection is an essential skill, often well-mastered by consumers and **vendors** in local markets. Reinforce awareness of these criteria to ensure food safety.

Table 3.3: Recommended Storage Temperatures and Durations

Storage Method	Recommended Temperature	Estimated Shelf Life	Key Precautions	Specific Notes for Togo
Refrigeration (Fresh Products)	Coldest part of the refrigerator, ideally between 0°C and +4°C.	Fresh fish and seafood: 1 to 2 days. Cooked products: 2 to 3 days. Leftovers: Consume within 24–48h after rapid refrigeration (within 2h after cooking).	Place immediately in the refrigerator after purchase. Store in original packaging or an airtight container. Avoid cross-contamination. Reheat leftovers thoroughly (70°C at the core). Discard if there is any doubt about freshness/storage. Respect the use-by date.	Refrigerator ownership is not universal; frequent power outages. If no refrigerator is available, consume the same day. Importance of the cold chain from purchase and during transport (insulated bag/cooler). Maintaining the cold chain is a major challenge. Promote early morning purchase or directly from fishermen.
Freezing	≤ −18°C.	Several months (depending on species and fat content).	Transfer without delay to the freezer. Slow thawing in the refrigerator (never at room temperature). Rapid thawing in the microwave is possible if immediate cooking follows. Never refreeze a product that has been thawed as is. Prophylactic freezing to kill parasites (e.g., *Anisakis*): -20°C for at least 24h or -35°C for 15h.	Power outages can compromise freezing. Check the state of the product after a prolonged outage.
Smoking, Drying, Salting (Traditional Methods)	Variable (hot vs. cold smoking). Sun drying or improved ovens. Salting to reduce water activity (aw).	Variable, can allow for long-term preservation.	Cold smoking does not guarantee pathogen destruction (e.g., *Listeria*). Histamine: Thermostable, prevention by maintaining freshness before processing. PAHs (Polycyclic Aromatic Hydrocarbons): Can form during smoking.	Very widespread methods, allowing fish availability over long periods/in remote areas. Promote technique improvement: improved ovens (PAH reduction, better quality). Ensure sufficient salting/drying.

Chapter 6. Aquaculture and its Impacts on Aquatic-Sourced Foods

Aquaculture, defined as the farming of aquatic organisms (fish, molluscs, crustaceans, algae) in controlled or semi-controlled environments, has experienced spectacular expansion over the last few decades. In the face of the stagnation, and even decline, of many global capture fisheries and a growing demand for seafood, aquaculture has become a key sector for food security and the economy in many regions. Nevertheless, this rapid growth raises legitimate concerns regarding its environmental, health, and socio-economic implications. This chapter aims to analyze the development of aquaculture, its advantages and challenges, explore sustainability paradigms, identify the risks inherent in its practices, and assess its overall impact, with a particular focus on the situation and potential in Togo.

6.1. Development of Aquaculture

The rise of modern aquaculture is a multifactorial response to increasing global needs and ecological constraints.

6.1.1. Sectoral Expansion and Dynamics

Since the second half of the 20th century, and particularly since the 1980s, global aquaculture production has increased exponentially. In 2022, aquaculture supplied 51% of the total production of aquatic animals and 57% of aquatic products destined for human consumption (FAO, 2024). This growth is particularly pronounced in Asia, which dominates global production, but other regions, such as Latin America and Africa, show significant development rates. The diversification of farmed species (more than 720 species recorded in 2022, although production is dominated by a few) and production systems (ranging from traditional extensive systems to intensive Recirculating Aquaculture Systems) demonstrates the sector's plasticity and adaptability (FAO, 2024).

In Togo, aquaculture is a developing sector, yet still modest compared to its potential. It is primarily focused on continental fish farming (pisciculture), with species such as Nile Tilapia (*Oreochromis niloticus*) and African Catfish (*Clarias gariepinus*), predominantly raised in extensive or semi-intensive ponds (Kossi et al., 1994). The Togolese government, through national agricultural development and food security plans, has identified aquaculture as a strategic sector for increasing national fish production, creating employment, and improving rural incomes.

Accelerating aquaculture development in Togo therefore requires targeted investments in research (selection of high-performing local strains, feed optimization), farmer training, value chain structuring (access to quality inputs – fingerlings, feed – and markets), and the establishment of support infrastructure (hatcheries, feed mills).

6.1.2. Advantages of Aquaculture

The positive contributions of aquaculture are manifold:

- **Food and Nutritional Security** It provides an accessible source of high-quality animal protein, essential fatty acids (omega-3), vitamins (D, B12), and minerals (iodine, selenium, zinc), contributing to the fight against malnutrition, particularly in developing countries (Fisheries, 2014).
- **Alleviation of Pressure on Wild Stocks** In theory, increased aquaculture production can reduce reliance on overexploited or fully exploited capture fisheries. However, this

assertion must be qualified by the dependence of certain forms of aquaculture on fishmeal and fish oil derived from reduction fisheries (see section 6.1.3).

- **Economic Development and Employment** Aquaculture generates direct income and employment (farming, processing) and indirect income and employment (feed supply, equipment, services) in rural and coastal areas, diversifying livelihood sources (FAO, 2024).
- **Control over the Production Cycle** Compared to fishing, aquaculture allows for better control over production parameters (density, feeding, health), volume predictability, and a certain regularity of supply to markets.

For Togo, these advantages are particularly relevant. Aquaculture can contribute significantly to the national fish supply, which is currently in deficit, improve rural household incomes, and create jobs for youth and women. It can also enhance the value of marginal lands or inland water bodies. Integrating aquaculture into rural development and poverty reduction policies, with an emphasis on supporting small family farms and producer groups.

6.1.3. Major Challenges of Aquaculture

Despite its strengths, the aquaculture sector faces considerable challenges:

- **Dependence on Exogenous Feeds** The feeding of farmed carnivorous species (salmon, trout, sea bass, sea bream, shrimp) still largely relies on fishmeal and fish oil (FMFO) derived from the fishing of small pelagic species (Tacon and Metian, 2015). This dependence creates indirect pressure on marine ecosystems and raises sustainability issues (FIFO ratio - Fish In / Fish Out).
- **Health Management and Diseases** High stocking densities promote the emergence and rapid spread of bacterial, viral, or parasitic diseases, leading to significant economic losses and sometimes excessive use of treatments (antiparasitics, antibiotics) (Stentiford et al., 2012).
- **Environmental Impacts Effluents** (rich in organic matter and nutrients), the use of chemicals, the escapes of non-native species, and the conversion of sensitive habitats (mangroves for shrimp farming) are major concerns (Diana et al., 2013).
- **Social Acceptability and Use Conflicts** The establishment of aquaculture farms can generate conflicts with other users of coastal or inland water spaces (artisanal fishermen, tourism, conservation) and raise issues of equity in the distribution of benefits.
- **Governance and Regulation** Adequate regulation and control are necessary to frame the sector's development, but their effective implementation remains a challenge, particularly in countries with low institutional capacity.

In Togo, the main challenge for feeding farmed fish (tilapia, clarias) is the availability and cost of formulated feeds. The importation of feed or their major components burdens the profitability of farms. Health management often relies on empirical practices, and access to specialized veterinary services is limited. Environmental impacts, although localized due to the current small scale, could increase with intensification if preventive measures are not taken (pond effluent management, site selection).

It is necessary to promote research and development of local feeds based on agricultural and agro-industrial by-products available in Togo (cottonseed cake, soybean meal, brewery spent grain, etc.). Strengthen extension and technical advisory services for health management and good farming practices. Develop a simple and adapted regulatory framework for aquaculture, including guidelines for site selection and effluent management.

6.2. The Sustainability of Aquaculture Practices

Faced with these challenges, the orientation towards sustainable aquaculture has become an imperative. Sustainability in aquaculture is based on the balance between economic viability, environmental responsibility, and social equity (FAO, 2010).

6.2.1. Principles and Pillars of Sustainable Aquaculture

Sustainable aquaculture aims to:

- **Minimize the ecological footprint**: Reduction of pollutant discharges, efficient use of resources (water, feed), preservation of biodiversity and habitats.
- **Ensure long-term economic viability**: Optimization of technical performance, resilience to hazards, market access, and profitability for producers.
- **Guarantee social equity and well-being**: Respect for workers' rights, positive contribution to local communities, production of healthy and safe food, respect for animal welfare.

6.2.2. Innovative Approaches and Technologies

Several avenues are being explored to enhance sustainability:

- **Recirculating Aquaculture Systems (RAS)** These closed systems allow for strict control of water parameters, drastic reduction in water consumption and discharges, but require high initial investment and significant technical expertise (Martins et al., 2010).
- **Integrated Multi-Trophic Aquaculture (IMTA)** It involves combining the culture of a main species (fish, shrimp) with that of extractive species (filter-feeding molluscs, algae) that utilize dissolved or particulate nutrients and organic matter derived from the main species, thereby reducing discharges and diversifying production (Chopin et al., 2012).
- **Genetic Improvement and Selection** The selection of strains more resistant to diseases, with faster growth, or capable of better utilizing alternative feeds contributes to **efficiency and the reduction of inputs**.
- **Sustainable Aquaculture Feeds** Intensive research on the partial or total substitution of FMFO with alternative protein sources (plant proteins, insects, microalgae, agro-industrial by-products) and lipid sources (vegetable oils, algal oils) (Fernandes et al., 2024).
- **Judicious Use of Veterinary Products** Development of vaccines, probiotics, prebiotics, and improvement of farming practices to prevent diseases and limit While the current cost and accessibility of veterinary antibiotics limit their widespread use among small-scale Togolese producers, the sector's intensification carries an inherent risk of increased antimicrobial usage
- For Togo, implementing IMTA in simplified forms (e.g., fish-rice association, using pond effluents for irrigating market gardens) offers interesting prospects for small producers. Research on feeds based on local ingredients is a priority. RAS are currently less suited to the smallholder context but could be considered for larger projects or high-value-added production.

In this context, it is essential to support action-research on integrated aquaculture systems adapted to local conditions. Promote the use of probiotics or local plant extracts for disease prevention, as an alternative to the uncontrolled use of pharmaceuticals.

6.2.3. Certifications and Good Management Practices (GMP)

Good practice frameworks (such as those promoted by the FAO) and certification labels (ASC - Aquaculture Stewardship Council, BAP - Best Aquaculture Practices, GlobalG.A.P., Label Rouge, Organic) are developing to guide producers and inform consumers. These certifications attest to compliance with strict environmental and social criteria, promoting a qualitative and sustainable upscaling of the sector.

International certifications are still rare in Togo and mainly concern export markets. It is therefore urgent to develop and disseminate a national guide to Good Aquaculture Practices (GAP) adapted to Togolese realities, drawing inspiration from FAO principles. This guide could serve as a basis for a future voluntary national certification for producers wishing to enhance the value of their products.

6.3. Risks Associated with Aquaculture

If not managed responsibly, aquaculture can generate significant risks.

6.3.1. Use of Antibiotics and Development of Antimicrobial Resistance (AMR)

The use of antibiotics, sometimes prophylactic or in sub-therapeutic doses in certain intensive farming systems, constitutes a major concern. It contributes to the selection and dissemination of antibiotic-resistant bacteria in the aquatic environment, with potential risks of resistance gene transfer to human pathogens (zoonoses) and a reduction in the effectiveness of antibiotic treatments in human and veterinary medicine (Cabello et al., 2013; Region et al., 2015).

The use of antibiotics in Togolese aquaculture is likely limited by their cost and accessibility for small-scale producers. However, with intensification and the entry of new actors, this risk could increase. It is therefore important to establish surveillance of veterinary medicine use in aquaculture. Promote alternatives to antibiotherapy (good farming practices, biosecurity, vaccination where available and relevant, phytotherapy). Raise awareness among stakeholders about the risks of antimicrobial resistance.

6.3.2. Chemical and Organic Pollution

Untreated aquaculture effluents can be loaded with organic matter (faeces, uneaten feed) and nutrients (nitrogen, phosphorus). Their discharge into the receiving environment can lead to water deoxygenation, eutrophication (excessive algal proliferation), and degradation of benthic habitats (Cao et al., 2007). The use of chemicals (disinfectants, antifouling agents, pesticides to treat ectoparasites such as sea lice) can also contaminate water and sediments, affecting non-target organisms.

The pollution risk is currently linked to the management of fish pond effluents, which can affect small streams or lagoons if farms are poorly sited or managed. It is therefore necessary to integrate clear recommendations into the GAP guide regarding site selection, water and effluent management (e.g., sedimentation ponds, use of sludge as fertilizer, respecting distances from sensitive watercourses).

6.3.3. Escape of Farmed Species and Genetic Impacts

The escapes of farmed individuals (often selected for specific traits) into the natural environment are frequent. These escaped species can:

- Compete with wild populations for food and habitat.

- Interbreed with wild conspecifics, leading to genetic introgression likely to dilute the local adaptation of natural populations and reduce their genetic diversity (Glover et al., 2017).
- Introduce allochthonous (non-native) species that may become invasive and disrupt local ecosystems.

In Togo, the main farmed species (Nile Tilapia, *Clarias gariepinus*) are already present in or acclimatized to natural ecosystems. The major risk would be the introduction of genetically modified or highly selected strains that could weaken the resilience of local wild populations. It is nevertheless necessary to promote the use of local strains selected for their performance under Togolese conditions. Frame the introduction of new species or exotic strains with rigorous risk assessments.

6.3.4. Spread of Diseases and Parasites

The high concentration of animals in aquaculture can act as an amplifier for pathogens and parasites, which can then be transmitted to surrounding wild populations. Conversely, pathogens present in the natural environment can infect farmed stocks (Brooks et al., 2007). The transfer of pathogens during the movement of live aquatic animals (fingerlings, broodstock) locally or internationally is also a significant risk vector.

Disease management is a weakness. Mortalities can occur without precise diagnosis. It is therefore necessary to establish a basic epidemiological surveillance network for farmed fish diseases. Train technicians and veterinarians in the diagnosis and control of aquaculture pathologies. Promote biosecurity measures on farms and in hatcheries.

6.4. Environmental and Societal Impact

The footprint of aquaculture extends beyond direct risks and encompasses broader impacts on ecosystems and societies.

6.4.1. Impacts on Aquatic Ecosystems

- **Habitat Conversion and Degradation** The most documented example is the destruction of mangroves for the establishment of shrimp farms in Asia and Latin America, with consequences for biodiversity, coastal protection, and ecosystem services. The construction of ponds in inland wetlands can also have impacts.
- **Pressure on Water Resources** Certain types of aquaculture, particularly freshwater, can exert significant pressure on local water resources, both in terms of quantity and quality.
- **Modification of Trophic Networks** Dependence on reduction fisheries for animal feed creates a direct link between aquaculture and removals from wild fish stocks located at the base of marine food chains. Escapes and disease transmission can also disrupt ecological balances.

Current impacts are limited by the scale of production, but spatial planning is necessary to prevent the conversion of ecologically sensitive areas (lagoon edges, small humid valleys) as the sector develops. Water management for pond filling must be considered, especially during the dry season. It is therefore necessary to carry out a mapping of areas suitable for aquaculture, taking into account environmental aspects and other uses. Promote water-efficient systems.

6.4.2. Socio-Economic Impacts

While aquaculture can generate substantial economic and social benefits (employment, income, food security), it can also be a source of problems:

- **Conflicts over Use and Access to Resources** Competition for space (terrestrial and aquatic) and water with other activities (artisanal fishing, agriculture, tourism, conservation).
- **Equity and Inclusion** The concentration of production in large companies can **marginalize small producers**. Benefits are not always equitably distributed within local communities.
- **Working Conditions** In certain regions and for certain sectors, working conditions can be precarious, with issues of safety, wages, and social rights.
- **Economic Dependence** Communities heavily dependent on aquaculture can be vulnerable to market fluctuations or health crises affecting the farms.

Aquaculture development in Togo must aim for the inclusion of small producers and women (often active in processing and marketing). It is necessary to anticipate and manage potential conflicts over the use of water and land. Promote family or community-based aquaculture models. Ensure consultation with local communities when establishing aquaculture projects. Support the structuring of producer organizations to improve their access to services and negotiation power.

6.4.3. Towards Improved Governance for Responsible Aquaculture

The minimization of negative impacts and the maximization of aquaculture's benefits require **strengthened governance**. This includes:

- **Spatial planning** integrating environmental and social considerations for farm establishment (**aquaculture zoning**).
- **Clear and enforced regulatory frameworks** for effluent management, the use of chemicals, the prevention of escapes, and health management.
- **Capacity building** for producers, particularly smallholders, in good practices and sustainable technologies.
- The **participation of stakeholders** (local communities, scientists, NGOs, private sector) in decision-making processes.
- **Investment in research and development** for more sustainable systems and practices.

Togo is in the process of structuring its aquaculture value chain. This presents a unique opportunity to lay the foundations for good governance from the outset. It is therefore possible to develop and implement a national strategy for sustainable aquaculture development, with a clear action plan, monitoring indicators, and an allocated budget. Strengthen the state services responsible for aquaculture oversight (Directorate of Livestock, decentralized services). Establish a multi-stakeholder consultation platform for the development of the sector.

Conclusion

Aquaculture is at a critical juncture. Its potential to contribute to global food security and economic development is undeniable. However, the long-term viability of this potential is intrinsically linked to the sector's capacity to address the associated environmental, health, and social challenges. A transition towards truly sustainable aquaculture practices, supported by technological innovation, effective governance, incentive policies, and a commitment from all sector stakeholders, including consumers through their informed choices, is essential. For countries like Togo, where aquaculture is still at an early but promising stage of development, there is a unique opportunity to build a responsible sector from the very beginning, by learning from global experiences and adapting best practices to the local context. The challenge is to reconcile productivity with responsibility, so that aquaculture can continue to feed the planet – and contribute significantly to Togo's food security – without compromising the health of aquatic ecosystems and the well-being of the societies that depend on them.

REFERENCES

Kossi, G. (1994). Solidarité sociale traditionnelle et promotion des structures coopératives en milieu rural africain. *Cah. Sci. hum*, *30*(4), 749-764.

Cabello, F. C., Godfrey, H. P., Tomova, A., Ivanova, L., Dölz, H., Millanao, A., & Buschmann, A. H. (2013). Antimicrobial use in aquaculture re-examined: its relevance to antimicrobial resistance and to animal and human health. *Environmental microbiology*, *15*(7), 1917-1942.

Cao, L., Wang, W., Yang, Y., Yang, C., Yuan, Z., Xiong, S., & Diana, J. (2007). Environmental impact of aquaculture and countermeasures to aquaculture pollution in China. *Environmental Science and Pollution Research-International*, *14*, 452-462.

Chopin, T., Cooper, J. A., Reid, G., Cross, S., & Moore, C. (2012). Open-water integrated multi-trophic aquaculture: environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture. *Reviews in Aquaculture*, *4*(4), 209-220.

Diana, J. S., Egna, H. S., Chopin, T., Peterson, M. S., Cao, L., Pomeroy, R., ... & Cabello, F. (2013). Responsible aquaculture in 2050: valuing local conditions and human innovations will be key to success. *BioScience*, *63*(4), 255-262..

FAO. (2010). *Aquaculture development. 4. Ecosystem approach to aquaculture*. FAO Technical Guidelines for Responsible Fisheries. No. 5, Suppl. 4. Rome, FAO.

FAO. (2024). *The State of World Fisheries and Aquaculture 2024: Blue Transformation in action*. Rome

Fernandes, A. M., Calduch-Giner, J. À., Pereira, G. V., Gonçalves, A. T., Dias, J., Johansen, J., ... & Pérez-Sánchez, J. (2024). Sustainable fish meal-free diets for gilthead sea bream (Sparus aurata): integrated biomarker response to assess the effects on growth performance, lipid metabolism, antioxidant defense and immunological status. *Animals*, *14*(15), 2166.

Glover, K. A., Solberg, M. F., McGinnity, P., Hindar, K., Verspoor, E., Coulson, M. W., ... & Svåsand, T. (2017). Half a century of genetic interaction between farmed and wild Atlantic salmon: Status of knowledge and unanswered questions. *Fish and Fisheries*, *18*(5), 890-927.

Fisheries, H. S. (2014). Aquaculture for Food Security and Nutrition. *A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome*.

Martins, C. I. M., Eding, E. H., Verdegem, M. C., Heinsbroek, L. T., Schneider, O., Blancheton, J. P., ... & Verreth, J. A. J. (2010). New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. *Aquacultural engineering*, *43*(3), 83-93.

Brooks, B. W., Brain, R. A., Huggett, D. B., & Ankley, G. T. (2009). Risk assessment considerations for veterinary medicines in aquatic ecosystems.

Stentiford, G. D., Neil, D. M., Peeler, E. J., Shields, J. D., Small, H. J., Flegel, T. W., ... & Lightner, D. V. (2012). Disease will limit future food supply from the global crustacean fishery and aquaculture sectors. *Journal of invertebrate pathology*, *110*(2), 141-157.

Tacon, A. G., & Metian, M. (2015). Feed matters: satisfying the feed demand of aquaculture. *Reviews in Fisheries Science & Aquaculture*, *23*(1), 1-10.

Region, A., Region, S. E. A., Region, E. M., & Region, W. P. (2015). Global action plan on antimicrobial resistance. *Microbe Mag*, *10*(9), 354-355..

Table 4.1: Comparison of Different Aquaculture Systems

Aquaculture System	General Description	Key Advantages	Drawbacks / Key Challenges	Estimated Costs (Investment / Operational)	Potential Environmental Impacts	Relevance / Notes for Togo
Extensive Systems	Low stocking density, use of natural food sources or fertilization to stimulate primary productivity. Typically in ponds or lagoons.	Low input costs, simple technology, reduced animal stress.	Low yields per unit area, reliance on environmental conditions, long production cycle.	Low (investment and operational).	Habitat conversion (if poorly sited), potential eutrophication if over-fertilized, water consumption/usage.	Primarily used for tilapia and clarias in ponds (alongside semi-intensive). Suitable for small-scale producers.
Semi-Intensive Systems	Moderate stocking density, feed supplementation (formulated feeds), more active water management. Typically in ponds.	Improved yields compared to extensive systems, better production control.	Higher feed costs, necessary effluent management, increased disease risk.	Moderate.	Eutrophication from untreated effluents (rich in organic matter and nutrients), water consumption.	Primarily used for tilapia and clarias in ponds (alongside extensive). Reliance on formulated feeds (cost, availability) is a challenge.
Intensive Systems	High stocking density, complete reliance on formulated feeds, strict control of water quality parameters (aeration, filtration). In ponds, raceways, or cages.	High yields per unit area/volume, shorter production cycles, enhanced predictability.	High investment and feed costs, significant energy consumption, high risk of disease transmission/spread, complex waste management, potential antibiotic use.	High.	Pollution from concentrated effluents (organic matter, N, P), use of chemicals (disinfectants, etc.), pressure on water resources.	Potential for development with new stakeholders; sanitation management and environmental impacts must be anticipated.
Recirculating Aquaculture Systems (RAS)	Closed or nearly closed systems with water treatment and reuse. Very strict	Drastic reduction in water consumption and discharge, optimal production control, high	Very high initial investment, high level of technical expertise required, significant energy costs (though	Very High.	Low footprint in terms of water and nutrient discharge. Waste can be valorized (biogas, fertilizers). Energy	Currently less suited for small-scale operators, but feasible for larger projects or

	parameter control. Often land-based.	biosecurity, geographical independence (can be land-based, away from coasts).	improvements are ongoing).		footprint can be a drawback.	high-value added production.
Integrated Multi-Trophic Aquaculture (IMTA)	Association of species from different trophic levels: a fed species (fish, shrimp) and extractive species (filter-feeding mollusks, algae) that utilize the former's waste.	Reduction of nutrient discharge (bioremediation), diversification of production and income, promotion of a circular economy.	Complexity in design and management (balance between species), further research and development still needed for certain combinations.	Variable, potentially higher initially.	Reduction of effluent impact, improvement of surrounding water quality.	Simplified forms (fish-rice, pond effluent for irrigation) offer interesting prospects for small-scale producers. IMTA pilot projects (fish-mollusks-algae) could be considered in the lagoons.
Offshore Aquaculture (in open sea)	Farming in the open sea, using submersible or large-scale structures.	Minimizes conflicts over coastal space use and impact on sensitive areas. Good effluent dispersion.	Significant technical and logistical challenges (maintenance, weather conditions), high investment and operational costs.	Very High.	Possible localized impact of waste under the cages, but better dilution. Risks of escapes and disease transmission to wild stocks.	Less relevant in the short/medium term for Togo, which prioritizes the management of its coastal resources and the development of continental/lagoon aquaculture.

Chapter 7. Aquatic Foods and Public Health

Aquatic products, owing to their unique nutritional richness, hold a prominent position in public health strategies aimed at improving populations' nutritional status and preventing certain chronic diseases. Their contribution of long-chain polyunsaturated omega-3 fatty acids (LC-PUFA), notably eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), as well as high-biological-value proteins, vitamins (D, B12), and trace elements (iodine, selenium, zinc), is extensively documented. This chapter examines how these attributes translate into nutritional recommendations globally and nationally, explores the resulting public health programs, and emphasizes the crucial importance of consumer awareness and education for optimizing health benefits, with a particular focus on opportunities and challenges in Togo.

7.1. Nutritional Recommendations

The development of nutritional recommendations concerning aquatic product consumption is based on a rigorous scientific evaluation of health benefits, balanced by the consideration of potential risks associated with contaminants.

7.1.1. Scientific Basis of Recommendations

Scientific evidence accumulated over decades converges to highlight the beneficial effects of regular aquatic product consumption. Omega-3 LC-PUFAs (EPA and DHA) are particularly studied for their role in:

- **Cardiovascular Health:** This includes the reduction of blood triglycerides, blood pressure, the risk of thrombosis and arrhythmia, and the improvement of endothelial function (Mozaffarian and Rimm, 2006; Siscovick et al., 2017).
- **Neurological and Cognitive Development:** DHA is a major structural component of brain and retinal cell membranes, crucial during gestation, early childhood, and for maintaining cognitive functions throughout life (Swanson et al., 2012; Koletzko et al., 2014).
- **Modulation of Inflammation:** EPA and DHA metabolites possess anti-inflammatory properties (Calder, 2015).

In addition to omega-3s, aquatic products are a significant source of Vitamin D (essential for bone and immune health), Vitamin B12 (a cofactor in numerous metabolic reactions), iodine (crucial for thyroid function), and selenium (an antioxidant and immune modulator) (Borel et al., 2015; FAO, 2020).

In Togo, where cardiovascular diseases are on the rise and maternal and child health remains a priority, the nutrients found in fish are of paramount importance. The prevalence of anemia and micronutrient deficiencies (such as iodine, despite salt fortification efforts) could be mitigated by increased consumption of local aquatic products, particularly small fish consumed whole, which are rich in calcium and other minerals. Local studies are therefore needed to more accurately assess the impact of local fish consumption on the nutritional status of Togolese populations, especially women and children.

7.1.2. Recommendations from International Bodies

The World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) recognize the importance of aquatic products in a balanced diet. They generally recommend consuming fish, especially fatty fish, one to two times per week, corresponding to an average intake of approximately 250 mg of EPA+DHA per day for the adult population (WHO/FAO, 2003; FAO/WHO, 2011). These recommendations aim for the prevention of cardiovascular diseases and the promotion of optimal health. Specific recommendations exist for pregnant and lactating women (at least 200 mg of DHA per day), as well as for young children, emphasizing the importance of DHA for fetal and infant development.

These international recommendations serve as a reference. Togo could draw upon them to develop its own clear and adapted national nutritional guidelines, integrating locally available and affordable fish species, and disseminated by the Ministry of Health and Public Hygiene.

7.1.3. National Adaptations and Specificities

Many countries translate these international recommendations into national guidelines, taking into account their cultural contexts, local product availability, dietary habits, and specific public health issues. For instance:

- **The French Agency for Food, Environmental and Occupational Health & Safety (ANSES)** recommends consuming fish twice a week, combining a fatty fish (salmon, mackerel, sardine, herring, etc.) and a lean fish. It also issues specific advice to limit methylmercury exposure for sensitive populations (pregnant women, breastfeeding women, young children) (ANSES, 2019).
- **The "Dietary Guidelines for Americans" in the United States** advise consuming at least 8 ounces (approximately 227 g) of seafood per week for adults, emphasizing variety in choices (Snetselaar et al., 2021).

These national adaptations aim to maximize benefits while minimizing risks, providing practical advice on the types of fish to favor or limit. For Togo, national recommendations could emphasize the consumption of small marine pelagic fish (sardinella, anchovies), often smoked or dried and thus accessible, as well as freshwater fish from local fishing and aquaculture (tilapia, *clarias*). The focus would be on species diversity and healthy preparation methods (avoiding excessive frying in reused oils).

7.1.4. Benefit/Risk Balance in Recommendations

One of the major challenges in developing recommendations is finding a balance between proven nutritional benefits and the risks associated with the potential presence of environmental contaminants (methylmercury, dioxins, PCBs). Predatory fish at the top of the food chain (swordfish, shark, certain tunas) tend to bioaccumulate more methylmercury. Recommendations, therefore, often include advice to diversify the species consumed, favor smaller or less predatory fish, and limit the frequency of consumption of the most contaminated species, particularly for vulnerable groups (EFSA, 2014; FAO/WHO, 2011). The majority of scientific assessments conclude that, for the general population, the benefits of moderate fish consumption far outweigh the potential risks, provided that specific recommendations are followed.

The types of fish most commonly consumed in Togo (small pelagic fish, tilapia) generally exhibit low levels of methylmercury. The risk may be more related to local chemical pollution in certain fishing areas (see Chapter 4). Togolese recommendations should offer reassurance regarding the consumption of common local species while advising caution for fish caught in areas known for pollution. Promoting good preparation practices (evisceration, washing) can also help reduce some risks.

7.2. Public Health Programs and Aquatic Product Consumption

Beyond simple recommendations, public health programs are implemented to **actively encourage** aquatic product consumption and improve the health status of populations.

7.2.1. Program Objectives and Targets

These programs generally aim to:

- Increase the intake of essential nutrients (omega-3s, Vitamin D, iodine) in the population.
- Reduce the incidence of cardiovascular and other non-communicable diseases.
- Improve cognitive development and perinatal health.
- Combat micronutrient deficiencies in specific populations (e.g., iodine deficiency, iron-deficiency anemia).

Target groups can be the general population or specific groups considered more vulnerable or likely to benefit more from increased consumption (pregnant/lactating women, children, the elderly, low-income populations). In Togo, priority targets would be pregnant and lactating women, children under five (to combat chronic malnutrition and growth stunting), and low-income households. Specific programs targeting these groups should be developed, for example by integrating the promotion of fish consumption into prenatal and postnatal consultations and child growth monitoring.

7.2.2. Intervention Strategies

The strategies employed are varied and may include:

- **Health Promotion Campaigns:** Use of media, educational materials, and events to inform about the benefits of aquatic products and encourage their integration into the daily diet.
- **Integration into National Food Guides:** This involves the clear positioning of aquatic products within official dietary recommendations.
- **School Feeding Programs:** Introduction of fish-based meals in school canteens to familiarize children and improve their nutritional status.
- **Support for Access and Affordability:** Measures aimed at making aquatic products more accessible, particularly for disadvantaged populations (targeted subsidies, development of low-cost local sustainable aquaculture value chains, improvement of value chains to reduce post-capture losses).
- **Food Fortification:** Although less common for whole fish, some processed products can be enriched (e.g., fish oils in margarine or dairy products), or fish oil supplementation may be recommended in certain clinical contexts.
- **Training of Health Professionals:** Awareness-raising and training of doctors, dietitians, midwives, and community health workers so they can effectively relay recommendations to their patients and communities.

Specific actions in Togo should include:

- Implementing awareness campaigns via radio (local languages), community television, and community relays.
- Supporting the integration of fish (local and affordable) into school canteen programs, linked to the development of local aquaculture (see Chapter 6).
- Training health workers to advise on fish consumption, particularly small dried or smoked fish, which are easy to store and rich in nutrients, for complementary feeding of young children.
- Exploring partnerships with fish processors (women) to improve processing techniques (enhanced smoking) to preserve nutrients and reduce contaminants, while ensuring an affordable product.

7.2.3. Examples of National or Regional Programs

Throughout the world, various programs illustrate these strategies. In Japan, traditionally high fish consumption is supported by a strong food culture and public health policies that value these products. In Nordic countries like Norway or Iceland, active campaigns promote the benefits of local fatty fish. In some developing countries, small-scale aquaculture programs aim to improve local availability of fresh fish and combat protein-energy malnutrition and micronutrient deficiencies. For example, FAO initiatives support the integration of fish into school feeding programs in Africa or Asia (Agbozo et al., 2018, "Fish in School Meals"). Togo could be inspired by successful programs in other West African countries. It is necessary to document and evaluate existing local initiatives (even small-scale ones) for promoting fish consumption and consider their scaling-up. Collaboration with NGOs and international partners should be sought to develop ambitious and adapted programs.

7.2.4. Evaluation of Program Effectiveness and Limitations

Evaluating the impact of these programs is complex. It requires indicators to monitor consumption, nutritional status, and, in the long term, disease incidence. Challenges include funding sustainability, reaching the most isolated or disadvantaged populations, competition with cheaper and more easily accessible processed food products, and cultural barriers or taste preferences. Effectiveness is often enhanced when programs are multi-faceted, integrated, and adapted to the local context. Any program initiative in Togo should, from its conception, include a monitoring and evaluation component with simple and measurable indicators (for example, frequency of fish consumption in targeted households, diversity of species consumed, mothers' knowledge of the benefits of fish for children).

7.3. Consumer Awareness and Education

Clear, accessible, and scientifically grounded information is **indispensable** to enable consumers to make informed dietary choices that benefit their health.

7.3.1. Importance of Information for Informed Choices

Faced with a complex food supply and sometimes contradictory messages, consumers need tools to navigate and make decisions aligned with public health recommendations. Nutritional education aims to bridge the gap between scientific knowledge and daily dietary behaviors. It must enable understanding not only of what to consume but also why and how.

7.3.2. Communication Channels and Tools

Information dissemination can use various channels:

- National or regional media campaigns (television, radio, press, internet, social networks).
- Educational materials: brochures, leaflets, institutional websites (Ministries of Health, food safety agencies), mobile applications.
- Nutritional labeling: Information on key nutrient content on packaging.
- Interventions in school and professional settings.
- Personalized advice from health professionals (doctors, dietitians, pharmacists, community health workers).
- Cooking workshops and demonstrations to show how to prepare healthy and tasty dishes based on aquatic products.

In Togo, high-reach and accessible channels should be prioritized: radio in local languages, community forum theaters, educational talks in health centers and markets. Use simple visual aids (picture boxes, posters) for less literate populations. Involve community and religious leaders as information relays.

7.3.3. Key Educational Content

Educational messages must be clear, concise, and actionable. They should cover:

- **Specific nutritional benefits:** Role of omega-3s, vitamins, and minerals for different health aspects and at different life stages.
- **Consumption recommendations:** Quantity, frequency, importance of species variety.
- **Informed species selection:** How to choose to maximize beneficial nutrient intake while minimizing contaminant exposure (e.g., favoring small, fatty fish, diversifying).
- **Good purchasing, storage, and preparation practices** (freshness, cold chain, adequate cooking – linked to Chapter 5).
- **Understanding labels:** Meaning of quality, sustainability (MSC, ASC, Organic) labels and origin indications for more responsible choices (more relevant for urban consumers or export products).
- **Adaptation to specific needs:** Advice for pregnant women, children, the elderly, or those with particular medical conditions.

Regarding the specific case of Togo, messages should emphasize:

- The benefits of local fish (e.g., "doèvi (sardinella) is good for children's hearts and brains").

- The importance of fish for the pregnant woman and the baby.
- How to integrate fish (even in small quantities, such as dried fish powder) into the complementary feeding of young children from 6 months of age.
- Local preparation methods that preserve nutrients (steaming, local *papillote*, soups) compared to prolonged frying.
- The nutritional value of often-neglected parts that are consumed locally (heads, bones of small fish).

7.3.4. Awareness Challenges

Several obstacles can hinder the effectiveness of awareness campaigns:

- **Information overload and misinformation:** Difficulty for the consumer to distinguish reliable information from unfounded claims or "fake news."
- **Health literacy:** A low level of understanding of health-related information can limit the adoption of recommendations.
- **Socio-economic and cultural barriers:** The cost of aquatic products, entrenched dietary habits, taste preferences, or cultural beliefs can slow down behavioral change.
- **Accessibility and availability:** Recommendations can be difficult to follow if products are not easily accessible or affordable locally.
- **Risk perception:** An excessive focus on contaminant risks, sometimes misinterpreted, can discourage consumption despite proven benefits.

In Togo, specific challenges include:

- The **cost of fresh fish** compared to other protein sources, although smoked/dried fish is often more affordable.
- **Seasonal variations** in availability.
- **Local beliefs** (for example, certain fish discouraged for pregnant women – to be verified and addressed tactfully if not scientifically founded).
- The need to produce messages in **several national languages**.
- The importance of the **source's credibility**: health workers, traditional chiefs, and women's groups are often trusted vectors of information.

Conclusion

The judicious integration of aquatic foods into the diet constitutes a major public health lever. Nutritional recommendations, based on solid scientific data and adapted by global and national bodies, provide an essential framework for guiding consumer choices. Public health programs, through their various intervention strategies, strive to translate these recommendations into concrete improvements in populations' nutritional status and health. However, the effectiveness of these mechanisms largely relies on continuous consumer awareness and education. Providing clear, accessible, and credible information that considers the benefit/risk balance and local contexts is fundamental to enable everyone to make the most of the valuable nutritional assets of marine and freshwater products. For Togo, this represents an opportunity to significantly improve the nutritional health of its population by valuing its local aquatic resources through targeted, culturally adapted, and participatory public health policies and programs, thereby contributing to sustainable individual and collective well-being.

REFERENCES

ANSES (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail). (2019). *Actualisation des repères du PNNS : élaboration des recommandations sur l'alimentation complémentaire et les pratiques à conseils individualisés pour les enfants de 0 à 3 ans et pour les femmes pendant la grossesse*. Avis de l'Anses.

SHS, H. L'Anses (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail).

Calder, P. C. (2015). Marine omega-3 fatty acids and inflammatory processes: Effects, mechanisms and clinical relevance. *Biochimica et Biophysica Acta (BBA)-Molecular and Cell Biology of Lipids*, *1851*(4), 469-484..

EFSA Scientific Committee. (2015). Statement on the benefits of fish/seafood consumption compared to the risks of methylmercury in fish/seafood. *EFSA journal*, *13*(1), 3982..

Agriculture Organization of the United Nations. Fisheries Department. (2018). *The state of world fisheries and aquaculture*. Food and Agriculture Organization of the United Nations.

Agbozo, F., Atitto, P., Jahn, A., & Abubakari, A. (2018). Nutrient composition and dietary diversity of on-site lunch meals, and anthropometry of beneficiary children in private and public primary schools in Ghana. *Nutrition and health*, *24*(4), 241-249.

FAO/WHO. (2011). *Report of the Joint FAO/WHO Expert Consultation on the Risks and Benefits of Fish Consumption*. Rome, Food and Agriculture Organization of the United Nations; Geneva, World Health Organization.

Koletzko, B., Bauer, C. P., Bung, P., Cremer, M., Flothkötter, M., Hellmers, C., ... & Wöckel, A. (2014). German national consensus recommendations on nutrition and lifestyle in pregnancy by the 'Healthy Start-Young Family Network'. *Annals of Nutrition and Metabolism*, *63*(4), 311-322.

Borel, P., Caillaud, D., & Cano, N. J. (2015). Vitamin D bioavailability: state of the art. *Critical reviews in food science and nutrition*, *55*(9), 1193-1205.

Mozaffarian, D., & Rimm, E. B. (2006). Fish intake, contaminants, and human health: evaluating the risks and the benefits. *Jama*, *296*(15), 1885-1899.

Siscovick, D. S., Barringer, T. A., Fretts, A. M., Wu, J. H., Lichtenstein, A. H., Costello, R. B., ... & Mozaffarian, D. (2017). Omega-3 polyunsaturated fatty acid (fish oil) supplementation and the prevention of clinical cardiovascular disease: a science advisory from the American Heart Association. *Circulation*, *135*(15), e867-e884.

Swanson, D., Block, R., & Mousa, S. A. (2012). Omega-3 fatty acids EPA and DHA: health benefits throughout life. *Advances in nutrition*, *3*(1), 1-7.

USDA and U.S. Department of Health and Human Services (HHS). (2020). *Dietary Guidelines for Americans, 2020-2025*. 9th Edition

Snetselaar, L. G., de Jesus, J. M., DeSilva, D. M., & Stoody, E. E. (2021). Dietary guidelines for Americans, 2020–2025: understanding the scientific process, guidelines, and key recommendations. *Nutrition today*, *56*(6), 287-295.

WHO/FAO. (2003). *Diet, nutrition and the prevention of chronic diseases*. Report of a Joint WHO/FAO Expert Consultation. WHO Technical Report Series, No. 916. Geneva: World Health Organization.

Chapter 8. Innovations and Future Perspectives in the Field of Aquatic Foods

The aquatic food sector, which is fundamental to global food security and nutritional balance, is undergoing continuous transformation. This dynamic is fueled by sustained scientific research and constant technological progress. Faced with the challenges posed by climate change, increasing pressure on fishery resources, and the food demand of a growing world population, innovation proves more crucial than ever. This chapter aims to explore the new advancements in understanding the properties of aquatic foods, the emerging technologies dedicated to their safety and valorization, the growing role of previously underutilized marine organisms, as well as the future prospects for sustainable aquaculture and new marine food sources. For a country like Togo, which has a maritime facade and inland water bodies, and where fishing contributes significantly to employment and food security (Belhabib et al., 2015), these innovations represent significant opportunities to strengthen food security and develop a sustainable blue economy.

8.1. New Research on Nutritional and Bioactive Properties

Knowledge of the multiple benefits of foods derived from aquatic environments is continuously being refined, moving beyond the simple consideration of macronutrients and **omega-3 fatty acids**, elements already widely recognized for their importance (Simopoulos, 2002).

8.1.1. In-Depth Exploration of Bioactive Compounds

Current scientific research is focused on the precise identification, detailed characterization, and rigorous evaluation of the health effects of a vast array of **bioactive compounds** present in fish, crustaceans, mollusks, and algae. Beyond the well-known **EPA (eicosapentaenoic acid)** and **DHA (docosahexaenoic acid)**, scientific interest is now directed towards:

- **Bioactive Peptides:** Obtained through enzymatic hydrolysis of aquatic proteins, these peptides (e.g., hydrolyzed marine collagen, antimicrobial, antihypertensive, or antioxidant peptides) demonstrate considerable potential for **nutraceutical** and pharmaceutical uses (Kim & Wijesekara, 2010). Ongoing research (estimated to be relevant in May 2025) is dedicated to optimizing their production processes, improving their bioavailability, and clinically validating their beneficial effects. In Togo, the exploitation of artisanal fisheries by-products could serve as a local source for these peptides, contributing to better resource valorization.
- **Marine Enzymes:** Certain enzymes derived from marine organisms, which are adapted to extreme environmental conditions (such as high temperatures or pressures), possess unique properties promising for the food industry (e.g., fish pepsin for milk coagulation) and for the biotechnology sector (Haard, 1992).
- **Complex Polysaccharides:** Primarily extracted from algae (such as fucoidans, carrageenans, and alginates) and certain marine invertebrates (such as chitosan derived from crustacean shells), these compounds are studied for their multiple properties, notably immunomodulatory, antiviral, anticoagulant, and **prebiotic** effects (Jiao et al., 2011).
- Compounds such as **astaxanthin**, present particularly in crustaceans and salmon, are recognized for their powerful antioxidant capacity (Hussein et al., 2006).

8.1.2. Impact of Processing and Valorization Methods

Innovation in this field is also manifested through the development of so-called "gentle" processing techniques (such as high-hydrostatic pressure, pulsed electric fields, or encapsulation). These methods aim to maximize the preservation of nutrients and bioactive compounds, while ensuring the sanitary safety of the products (Chemat et al., 2017). The valorization of co-products from fishing and aquaculture (such as heads, bones, skins, and viscera), which constitute a significant fraction of the harvested biomass, represents a major and strategic trend (Rustad et al., 2011). The extraction of collagen, gelatin, omega-3 rich oils, or the production of protein hydrolysates from these co-products is fully aligned with a circular economy approach and the fight against food waste. In Togo, where artisanal fish processing (smoking, drying) is widespread, the integration of co-product valorization techniques could reduce post-harvest losses and generate additional income for fishing communities. Research projects active in 2025 are focusing on the fermentation of these co-products to produce high-value functional ingredients.

8.1.3. Nutrigenomics and Personalized Approaches

The application of nutrigenomics and nutrigenetics to aquatic foods opens up promising prospects for personalized nutrition. A better understanding of how individual genetic variations modulate the metabolic response to marine nutrients (particularly omega-3 fatty acids) could ultimately allow for the formulation of more targeted and effective dietary recommendations (de Roos, 2013). Although this field of research is still in its early stages, "omics" tools (genomics, transcriptomics, proteomics, metabolomics) are increasingly being used to elucidate these complex interactions between genes and nutrients.

8.2. Technological Progress for Sanitary Safety

Ensuring the wholesomeness of aquatic products remains an absolute priority, an objective supported by notable technological advancements in danger detection and decontamination.

8.2.1. Rapid, Sensitive, and Multiplex Detection Methods

Techniques used for contaminant detection are evolving towards greater execution speed, increased sensitivity, and the ability to simultaneously analyze multiple compounds (a multiplex approach):

- **Biosensors and Nanosensors:** The development of biosensors, based on antibodies, aptamers, or enzymes, coupled with optical, electrochemical, or piezoelectric transduction systems, enables the rapid, on-site detection of pathogens (such as *Vibrio spp.*, *Listeria monocytogenes*), marine biotoxins (such as saxitoxin, okadaic acid), antibiotic residues, or allergens (Turner, 2013). Portable prototypes are in the validation phase in 2025, which could be particularly useful for controls along the value chain in Togo, from landing to local markets.
- **Advanced Mass Spectrometry:** Coupled techniques (e.g., LC-MS/MS, GC-MS/MS) and High-Resolution Mass Spectrometry (HRMS) allow for the precise identification and quantification of traces of persistent organic pollutants, veterinary drug residues, and new emerging toxins (Chaudhary et al., 2024). Mass spectrometry imaging is also being explored to localize contaminants within the tissues of aquatic organisms themselves.
- **Molecular Tests (Quantitative PCR, Next-Generation Sequencing - NGS):** These tools are increasingly being used for the rapid detection and characterization of pathogenic microorganisms, as well as for species identification, thereby contributing to the fight against fraud (Rasmussen et al., 2008).

8.2.2. Decontamination and Purification Technologies

Innovative technologies, often non-thermal to best preserve the organoleptic and nutritional quality of the products, are currently under study or beginning to be applied to reduce microbial load or degrade certain toxins:

- **High Hydrostatic Pressure (HPP):** This proves effective in inactivating pathogens and extending shelf life, particularly for mollusks and ready-to-eat products (Ohshima et al., 1993).
- **Atmospheric Cold Plasma:** This is an emerging and promising technology for the surface disinfection of aquatic products and their packaging (Misra et al., 2011).
- **Pulsed Light and UV-C:** These techniques are used for water decontamination in aquaculture and, increasingly, for the surface treatment of foods (Oms-Oliu et al., 2010).
- **Advanced Membrane Filtration and Adsorption Processes:** These methods are employed for the removal of specific toxins present in farming waters or in seafood extracts.

8.2.3. Digital Traceability and Artificial Intelligence

Blockchain technology is being explored to strengthen the traceability of aquatic products, from the fishing or farming location to the consumer's plate ("from sea/farm to fork"). It aims to improve transparency, more effectively combat Illegal, Unreported, and Unregulated (IUU) fishing and fraud, and facilitate product recall management (Thompson et al., 2023). In Togo, where IUU fishing is a concern, such technologies could, in the long term, strengthen sustainable fisheries management. Artificial Intelligence (AI) and machine learning are being utilized to analyze vast datasets (Big Data) to predict toxic algal blooms, optimize aquaculture practices, and enhance sanitary surveillance.

8.3. The Emerging Role of Algae and Other Marine Organisms

The exploration of marine biodiversity continues to reveal considerable potential for diversifying food and nutritional sources.

8.3.1. Macroalgae

Macroalgae, including brown algae (such as Kombu), red algae (such as Nori), and green algae (such as sea lettuce), are traditionally consumed in Asia and are gaining global popularity. Their cultivation, algaculture or seaweed farming, is rapidly expanding (FAO, 2022). They are distinguished by their richness in:

- Specific dietary fibers (e.g., alginates, carrageenans, fucoidans) with prebiotic and texturizing properties (Brownlee et al., 2005).
- Minerals and trace elements (iodine, calcium, magnesium, iron).
- Vitamins (A, C, some B-group vitamins).
- Proteins (content varies by species, but some, like *Porphyra spp.*, can reach 40% of their dry weight).
- Bioactive compounds (polyphenols, phlorotannins, sulfated polysaccharides) with antioxidant, anti-inflammatory, and potentially antiviral effects (Holdt & Kraan, 2011). Research ongoing in 2025 focuses on optimizing cultivation and processing techniques to improve the digestibility and bioavailability of their nutrients. The integration of these algae as functional ingredients in processed foods is also an active avenue. Although algae consumption is not traditional in Togo, their potential as a source of income and nutrients could be explored, particularly through small coastal algaculture initiatives.

8.3.2. Microalgae

Microalgae (e.g., *Spirulina platensis*, *Chlorella vulgaris*, *Haematococcus pluvialis*, *Schizochytrium sp.*) are cultivated for their high content of:

- Complete proteins (*Spirulina* can contain up to 70% of its dry weight) (Becker, 2007).
- Antioxidant pigments (phycocyanin, chlorophyll, astaxanthin).
- Long-chain polyunsaturated fatty acids, notably EPA and DHA (produced by certain species like *Schizochytrium* or *Nannochloropsis*), thus offering a non-animal source alternative to fish oils (Adarme-Vega et al., 2012). They are already used as dietary supplements and ingredients. Future challenges lie in reducing large-scale production costs and improving their organoleptic acceptability for broader incorporation into everyday diets. Precision fermentation, using microalgae to produce specific compounds, is a rapidly growing field. For Togo, *Spirulina* cultivation is already a small-scale reality and could be further developed to combat malnutrition.

8.3.3. Underutilized Marine Invertebrates

Beyond algae, other marine organisms such as holothurians (sea cucumbers), sea urchins, tunicates (ascidians), or certain jellyfish are traditionally consumed in various cultures and are attracting increasing interest due to their nutritional profiles (richness in proteins, minerals, bioactive compounds) and their potential for aquaculture (Bordbar et al., 2011). Research is focused on developing sustainable farming methods for these species and evaluating their potential contribution to food security and pharmacology. The study of Togolese marine biodiversity could reveal local invertebrate species with such potential.

8.4. The Future of Sustainable Aquaculture and New Marine Food Sources

Aquaculture must imperatively continue its transition towards increased sustainability, while also being capable of meeting growing global demand. Simultaneously, new approaches to marine food production are emerging.

8.4.1. Sustainable Intensification of Aquaculture

- **Recirculating Aquaculture Systems (RAS):** Their development continues, with notable improvements in energy efficiency, better waste management (which can be valorized into biogas or fertilizers), and adaptation to new species (Martins et al., 2010). Land-based RAS help reduce impacts on fragile coastal ecosystems, a relevant aspect for the Togolese coast.
- **Offshore Aquaculture:** Open-sea farming, using submersible or large-scale structures, minimizes conflicts over space use and the impact on sensitive coastal areas. However, this approach raises significant technical and logistical challenges.
- **Integrated Multi-Trophic Aquaculture (IMTA):** The optimization and generalization of IMTA systems, where waste produced by one species becomes a nutritional resource for another (e.g., a combination of fish, mollusks, and algae), are essential for promoting a circular economy at the farm level (Chopin et al., 2001). IMTA pilot projects could be considered in the Togolese lagoons.
- **Genetic and Genomic Improvement:** The use of Marker-Assisted Selection (MAS) and, more prospectively and subject to strict supervision, genomic editing (e.g., CRISPR-Cas9 technology) aims to develop farmed strains that are more disease-resilient, better adapted to climate change (increased tolerance to heat, hypoxia), and capable of better utilizing alternative feeds (Houston et al., 2020). Ethical and public acceptability issues surrounding these technologies remain crucial discussion points in 2025.

8.4.2. Development of Innovative and Sustainable Aquafeeds

Reducing aquaculture's dependence on fish meal and fish oil (FMFO) derived from reduction fisheries remains a priority objective (Tacon & Metian, 2008). Avenues for innovation include:

- **Insect Proteins:** Insect meal presents itself as a promising alternative, with an interesting nutritional profile and potentially more sustainable production (Nogales-Mérida et al., 2019). In Togo, where **entomophagy** is practiced and insect farming for animal feed is developing, this avenue is particularly relevant.
- **Proteins from Yeasts, Bacteria, or Fungi (Single Cell Proteins - SCP):** These microorganisms can be cultivated on a variety of substrates, including agricultural or industrial by-products.
- **Microalgae and Macroalgae-based Ingredients:** These are valued for their contribution of protein, lipids (notably EPA/DHA), and other essential micronutrients.
- **By-products from Agriculture and the Food Industry:** Better valorization and processing of these materials for aquafeeds are being sought. The overall goal is to achieve FIFO (Fish In / Fish Out) ratios close to zero for carnivorous species and to develop optimized feeds for omnivorous or herbivorous species.

8.4.3. Cellular Aquaculture

The production of fish or seafood "meat" from *in vitro* animal cell culture constitutes a potentially disruptive innovation (Rubio et al., 2019). Although it is still in an intensive research and development stage in 2025, facing major challenges in terms of production costs, industrial scale-up, texture, taste, and regulatory framework, it offers long-term potential to:

- Reduce pressure on wild stocks and traditional aquaculture.
- Produce foods free from environmental contaminants and antibiotics.
- Offer products with customizable nutritional profiles. The first demonstration products are beginning to appear, but large-scale commercialization is not expected for several years and will heavily depend on consumer acceptance and the implementation of a clear regulatory framework.

8.4.4. Sustainable Exploitation of Mesopelagic Resources

The mesopelagic zone, located between 200 and 1,000 meters deep, harbors a considerable biomass of small fish and crustaceans. The possibility of exploiting them for direct or indirect human consumption (in the form of fish meal) is the subject of intense debate (Hidalgo & Browman, 2019). However, current knowledge about these ecosystems and their crucial role in the biological carbon pump is still limited. An extremely cautious approach, based on in-depth scientific research aimed at assessing sustainability and potential ecological impacts, is essential before considering any form of large-scale exploitation of these resources. For Togo, the priority remains the sustainable management of its coastal resources and the accessible EEZ (Exclusive Economic Zone).

REFERENCES (réelles)

Adarme-Vega, T. C., Lim, D. K., Timmins, M., Vernen, F., Li, Y., & Schenk, P. M. (2012). Microalgal biofactories: a promising approach towards sustainable omega-3 fatty acid production. *Microbial cell factories*, *11*, 1-10..

Becker, E. W. (2007). Micro-algae as a source of protein. *Biotechnology advances*, *25*(2), 207-210.

Belhabib, D., Sumaila, U. R., & Pauly, D. (2015). Feeding the poor: Contribution of West African fisheries to employment and food security. *Ocean & Coastal Management*, *111*, 72-81.

Bordbar, S., Anwar, F., & Saari, N. (2011). High-value components and bioactives from sea cucumbers for functional foods—a review. *Marine drugs*, *9*(10), 1761-1805..

Brownlee, I. A., Allen, A., Pearson, J. P., Dettmar, P. W., Havler, M. E., Atherton, M. R., & Onsøyen, E. (2005). Alginate as a source of dietary fiber. *Critical reviews in food science and nutrition*, *45*(6), 497-510.

Ohshima, T., Ushio, H., & Koizumi, C. (1993). High-pressure processing of fish and fish products. *Trends in Food Science & Technology*, *4*(11), 370-375.

Chemat, F., Rombaut, N., Sicaire, A. G., Meullemiestre, A., Fabiano-Tixier, A. S., & Abert-Vian, M. (2017). Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review. *Ultrasonics sonochemistry*, *34*, 540-560.

Chopin, T., Buschmann, A. H., Halling, C., Troell, M., Kautsky, N., Neori, A., ... & Neefus, C. (2001). Integrating seaweeds into marine aquaculture systems: a key toward sustainability. *Journal of phycology*, *37*(6), 975-986.

De Roos, B., & Brennan, L. (2017). Personalised interventions—a precision approach for the next generation of dietary intervention studies. *Nutrients*, *9*(8), 847.

FAO. (2022). *The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation*. Rome, FAO.

Haard, N. F. (1992). A review of proteotlytic enzymes from marine organisms and their application in the food industry. *Journal of Aquatic Food Product Technology*, *1*(1), 17-35.

Hidalgo, M., & Browman, H. I. (2019). Developing the knowledge base needed to sustainably manage mesopelagic resources. *ICES Journal of Marine Science*, *76*(3), 609-615.

Holdt, S. L., & Kraan, S. (2011). Bioactive compounds in seaweed: functional food applications and legislation. *Journal of applied phycology*, *23*, 543-597.

Houston, R. D., Bean, T. P., Macqueen, D. J., Gundappa, M. K., Jin, Y. H., Jenkins, T. L., ... & Robledo, D. (2020). Harnessing genomics to fast-track genetic improvement in aquaculture. *Nature Reviews Genetics*, *21*(7), 389-409.

Hussein, G., Sankawa, U., Goto, H., Matsumoto, K., & Watanabe, H. (2006). Astaxanthin, a carotenoid with potential in human health and nutrition. *Journal of natural products*, *69*(3), 443-449.

Jiao, G., Yu, G., Zhang, J., & Ewart, H. S. (2011). Chemical structures and bioactivities of sulfated polysaccharides from marine algae. *Marine drugs*, *9*(2), 196-223.

Thompson, B. S., & Rust, S. (2023). Blocking blockchain: Examining the social, cultural, and institutional factors causing innovation resistance to digital technology in seafood supply chains. *Technology in Society*, *73*, 102235.

Kim, S. K., & Wijesekara, I. (2010). Development and biological activities of marine-derived bioactive peptides: A review. *Journal of Functional foods*, *2*(1), 1-9.

Martins, C. I. M., Eding, E. H., Verdegem, M. C., Heinsbroek, L. T., Schneider, O., Blancheton, J. P., ... & Verreth, J. A. J. (2010). New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. *Aquacultural engineering*, *43*(3), 83-93.

Misra, N. N., Tiwari, B. K., Raghavarao, K. S. M. S., & Cullen, P. J. (2011). Nonthermal plasma inactivation of food-borne pathogens. *Food Engineering Reviews*, *3*, 159-170..

Nogales-Mérida, S., Gobbi, P., Józefiak, D., Mazurkiewicz, J., Dudek, K., Rawski, M., ... & Józefiak, A. (2019). Insect meals in fish nutrition. *Reviews in Aquaculture*, *11*(4), 1080-1103.

Oms-Oliu, G., Martín-Belloso, O., & Soliva-Fortuny, R. (2010). Pulsed light treatments for food preservation. A review. *Food and Bioprocess Technology*, *3*, 13-23.

Rubio, N., Datar, I., Stachura, D., Kaplan, D., & Krueger, K. (2019). Cell-based fish: a novel approach to seafood production and an opportunity for cellular agriculture. *Frontiers in Sustainable Food Systems*, *3*, 435832.

Rasmussen, R. S., & Morrissey, M. T. (2008). DNA-based methods for the identification of commercial fish and seafood species. *Comprehensive reviews in food science and food safety*, *7*(3), 280-295.

Chaudhary, P., Choudhary, K., & Rajput, R. (2024). A Review of Omics Technologies in Seafood Safety and Quality Control: Integrating Modern Approaches with Traditional Practices. *European Journal of Nutrition & Food Safety*, *16*(11), 221-239.

Rustad, T., Storrø, I., & Slizyte, R. (2011). Possibilities for the utilisation of marine by-products. *International Journal of Food Science and Technology*, *46*(10), 2001-2014.

Simopoulos, A. P. (2002). Omega-3 fatty acids in inflammation and autoimmune diseases. *Journal of the American College of nutrition*, *21*(6), 495-505.

Tacon, A. G., & Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture*, *285*(1-4), 146-158.

Turner, A. P. (2013). Biosensors: sense and sensibility. *Chemical Society Reviews*, *42*(8), 3184-3196.

Chapter 9: Addressing the Challenges of Aquatic Foods in Togo: Strategies and Solution Approaches

Previous chapters have underscored the crucial importance of aquatic foods for global food and nutritional security, while also identifying the multiple challenges related to their sustainable exploitation and safe consumption. For Togo, a country endowed with significant aquatic potential yet facing specific issues, a targeted and integrated approach is essential to maximize the benefits of these resources while minimizing the risks. This chapter aims to analyze the main challenges raised concerning the Togolese context and to outline strategies and solution approaches, based on current knowledge and available data.

9.1 Sustainable Management of Fishery Resources and Protection of Aquatic Ecosystems

Togo is facing increasing pressure on its fishery resources, both coastal and continental, exacerbated by the degradation of aquatic habitats, notably the pollution of Lake Togo and coastal erosion (as mentioned in Chapter 1). Fisheries, which are predominantly artisanal, constitute a socio-economic pillar for many communities (Belhabib et al., 2015), but their sustainability is threatened.

Solution Approaches:

1. **Strengthening Governance and Surveillance**
    - Implement a participatory fisheries management plan, involving fishing communities, local authorities, scientists, and civil society, to define access rules, quotas (if applicable and scientifically grounded for local stocks), minimum catch sizes, and protected or biological rest areas. In Togo, where IUU (Illegal, Unreported, and Unregulated) fishing is a concern (Chapter 8), strengthening surveillance capacities for both coastal and inland water bodies is crucial. Technologies such as simplified digital traceability, adapted to the artisanal context, could be explored (Chapter 5, 8).
    - Support fishery stock characterization studies to provide updated scientific data enabling informed decision-making. The lack of Togo-specific data is a recurrent hindrance, necessitating investment in local fisheries research.
2. **Combating Habitat Degradation**
    - Develop and implement integrated action plans for the restoration and protection of key ecosystems such as the Lomé lagoon system, Lake Togo, and mangroves. This includes combating pollution from industrial, agricultural (use of phosphated fertilizers which can enrich waters with cadmium – Chapter 4), and domestic sources (discharge of untreated wastewater – Chapter 4), particularly through the improvement of sanitation infrastructure in Lomé and around major water bodies. Studies such as those by Ouro-Sama et al. (2020) and Badassan et al. (2020) on the contamination of the Lomé lagoons provide an important foundation.
    - Promote sustainable agricultural practices in watersheds to reduce pesticide and nutrient runoff. The management of obsolete pesticide stocks is also a key issue (Chapter 4).
    - Raise awareness among riparian populations about the importance of preserving these ecosystems for fishery resources and their own well-being.
3. **Support for Fishing Communities**
    - Facilitate artisanal fishers' access to more selective and sustainable fishing gear and to training on good fishing practices.
    - Promote income diversification for fishing-dependent communities, for instance through responsible ecotourism or the value chain development of fishery products.

9.2 Improving the Health Safety and Quality of Aquatic Products

Health risks associated with the consumption of aquatic products in Togo are multifaceted: chemical contaminants (mercury from artisanal gold mining – Mulenga et al. (2024), lead, PAHs from traditional smoking – Eklu-Gadegbeku (2020)), natural toxins, and microbiological hazards favored by a warm climate and frequent cold chain disruptions (Chapter 4, 5).

Solution Approaches:

1. **Strengthening Health Surveillance and Control**
    - Increase the capacity of national laboratories (such as the INH and the ITRA) for the regular analysis of chemical and microbiological contaminants in aquatic products from different fishing areas and markets (Chapter 4, 5). Data from Aduayi-Akue et al. (2015) on heavy metals in phosphate processing areas highlight the importance of such monitoring.
    - Establish a national phycotoxin surveillance program in mollusk harvesting areas, particularly mangrove oysters (Chapter 4).
    - Develop and enforce national health safety standards, aligned with Codex Alimentarius recommendations, while taking local specificities into account (Chapter 5).
    - Map contamination risk zones (proximity to artisanal gold mining activities, significant industrial or urban discharges such as those from the Port Autonome de Lomé or sewers discharging into the sea – Chapter 4) and communicate this information to fishers and consumers.
2. **Improving Post-Capture and Processing Practices:**
    - Promote the systematic use of ice (made with potable water) immediately after capture and throughout the marketing chain. Investment in ice production units and community cold storage equipment is necessary (Chapter 5), taking into account challenges related to electricity outages (Chapter 4).
    - Disseminate and support the adoption of improved processing techniques, especially for fish smoking (use of improved ovens such as FTT-Thiaroye or Chorkor) to reduce PAH formation and enhance the quality of the finished product (Chapter 5). A socio-economic study on the profitability and cultural acceptability of these ovens by women processors would be relevant.
    - Strengthen training for sector stakeholders (fishers, fishmongers/middlemen, processors) on Good Hygiene Practices (GHP) and handling, based on adapted guides and regular training sessions (Chapter 4, 5). Access to potable water and soap at processing and sales sites is a prerequisite (Chapter 5).
3. **Consumer Information and Awareness**
    - Conduct public information campaigns on health risks and prevention methods (fish selection, storage, hygienic preparation, complete cooking), using local languages and appropriate channels (radio, markets – Chapter 4, 7).
    - Raise awareness about specific dangers such as the consumption of improperly prepared pufferfish (Chapter 4) or the consumption of raw or whole fried fish without prior evisceration (potential source of parasites – Chapter 4).

9.3 Developing Sustainable and Responsible Aquaculture

Togolese aquaculture, although still modest and primarily focused on tilapia and clarias in ponds (Chapter 6), is identified as strategic for increasing national fish supply and improving rural incomes (Chapter 6). Its development must be supervised to avoid pitfalls encountered elsewhere.

Solution Approaches:

1. **Strategic Planning and Regulatory Framework:**
    - Develop a national sustainable aquaculture development strategy, including spatial planning (mapping of suitable areas while avoiding ecologically sensitive zones – Chapter 6) and a simple, enforced regulatory framework for site selection, water and effluent management, use of veterinary drugs, and prevention of escapes (Chapter 6).
    - Promote the use of high-performing local strains and rigorously regulate the introduction of new species or exotic strains after risk assessment (Chapter 6).
2. **Research, Development, and Extension**
    - Invest in research to develop local and affordable aquafeeds based on agricultural and agro-industrial by-products available in Togo (oilseed cakes, spent grains – Chapter 6, 8), to reduce dependence on costly imports (Chapter 6). The use of insect proteins is a promising avenue (Chapter 8).
    - Support action research on Integrated Aquaculture Systems (e.g., rice-fish, adapted IMTA such as fish-mollusk-algae association in lagoons – Chapter 6, 8) and water-efficient practices.
    - Strengthen agricultural extension and technical advisory services for the dissemination of Good Aquaculture Practices (GAPs), health management (prevention, biosecurity, alternatives to antibiotics such as probiotics or phytotherapy – Chapter 6), and financial management of farms.
3. **Support for the Sector and Socio-economic Inclusion:**
    - Facilitate small producers' access to quality inputs (fingerlings, feed), appropriate credit, and markets, particularly by supporting the structuring of producer organizations (Chapter 6).
    - Encourage family or community aquaculture models, ensuring the inclusion of women (often active in processing and marketing) and youth (Chapter 6).
    - Develop and disseminate a national Guide to Good Aquaculture Practices (GAPs), which could serve as a basis for voluntary national certification to enhance the quality of Togolese products (Chapter 6).

9.4 Promoting Informed Consumption for Public Health

Despite the risks, local aquatic products are a valuable source of essential nutrients for the Togolese population, contributing to the fight against malnutrition and the prevention of chronic and infectious diseases (Chapter 2, 3, 7). Micronutrient deficiencies and the rise in non-communicable diseases in urban areas are major concerns (Chapter 3, 7).

Solution Approaches:

1. **Development and Dissemination of Adapted Nutritional Recommendations**
    - Develop **clear national nutritional guidelines** for aquatic food consumption, based on international recommendations (WHO/FAO) but adapted to the Togolese context: locally available and affordable species (sardinella, anchovies, tilapia, clarias, small dried/smoked fish), healthy preparation methods (promote traditional complete cooking – Chapter 5, avoid excessive frying), and taking into account specific identified risks (Chapter 7).
    - Specifically target vulnerable groups: pregnant and lactating women (importance of DHA, choosing species with low contamination), young children (integration of fish, including fish powder, into complementary feeding from 6 months to combat chronic malnutrition) (Chapter 3, 7). Tactfully address cultural beliefs that might limit consumption by these groups (Chapter 7).
2. **Nutritional Education and Behavior Change**

- Implement long-term nutritional education programs, using varied and credible communication channels (local language radio, health workers, community leaders, schools – Chapter 7).
- Messages should be simple, visual, and emphasize the benefits of local fish, the nutritional value of often-consumed parts (heads, bones of small fish), and the importance of dietary diversity (Chapter 7).
- Support the integration of local fish into school feeding programs, in conjunction with the development of local aquaculture (Chapter 7).

3. **Research to Inform Policies**
    - Conduct **local studies** to more accurately assess the impact of consuming different local fish species (and their preparation methods) on the nutritional status of the Togolese population (Chapter 3, 7).
    - Assess contaminant levels in the most consumed species and in different fishing areas to refine the benefit/risk balance (Chapter 4, 7). The lack of precise quantitative data for Togo on these aspects is a frequent limitation that justifies targeted research.

9.5 Socio-economic, Cultural Aspects, and Cross-Sectoral Governance

The aquatic food sector in Togo is deeply rooted in a socio-economic and cultural fabric. Its sustainable enhancement requires a holistic approach.

Solution Approaches:

1. **Analysis and Consideration of Socio-economic and Cultural Factors**
    - Conduct in-depth socio-economic analyses of the fishing and aquaculture sectors, including the distribution of income, the role of women (often the majority in processing and marketing), access to credit, and the profitability of various activities. This data is essential for designing equitable and effective interventions.
    - Understand and integrate cultural aspects related to fish consumption (preferences, taboos, traditional uses) in the development of public health policies and sector development programs. For example, the strong tradition of consuming smoked or dried fish (Chapter 4, 7) is an asset for preservation but requires attention to smoking techniques.
    - Anticipate and manage potential conflicts over the use of water and land between fishing, aquaculture, agriculture, and other sectors (Chapter 6).
2. **Strengthening Institutional Coordination and Capacities**
    - Improve inter-ministerial coordination (Ministries in charge of Fisheries, Environment, Health, Commerce, Research) and with private actors, civil society, and technical and financial partners (Chapter 5). The creation of a multi-stakeholder platform for the sustainable development of the aquatic sector could be considered (Chapter 6).
    - Strengthen the technical and human capacities of national institutions responsible for fisheries management, aquaculture supervision, health control, research, and extension (Chapter 5, 6).
    - Develop and implement a national food safety crisis management plan specific to aquatic products (Chapter 5).

The challenges are numerous; however, the opportunities for sustainably valuing aquatic foods in Togo are real. This requires strong political commitment, targeted investments in research and infrastructure, capacity building at all levels, and active participation from all stakeholders. The absence of specific local data on certain aspects highlights the urgent need to intensify national research efforts to inform decisions and measure the impact of interventions. It is through such a concerted and adapted approach that Togo can ensure its aquatic resources fully and sustainably contribute to the food security, health, and well-being of its population.

REFERENCES

Aduayi-Akue, A. A., Gnandi, K., Tete-Benissan, A., Degbe, M., Tanouayi, G., & Gbeassor, M. (2015). Evaluation des teneurs des métaux lourds dans le sang des sujets de la zone de traitement des phosphates au Sud du Togo. *International Journal of Biological and Chemical Sciences, 9*(4), 1972-1982.

Badassan, T. E. E., Avumadi, A. M. D., Ouro-Sama, K., Gnandi, K., Jean-Dupuy, S., & Probst, J. L. (2020). Geochemical composition of the Lomé lagoon sediments, Togo: Seasonal and spatial variations of major, trace and rare earth element concentrations. *Water, 12*(11), 3026.

Belhabib, D., Sumaila, U. R., & Pauly, D. (2015). Feeding the poor: Contribution of West African fisheries to employment and food security. *Ocean & Coastal Management, 111*, 72-81.

Eklu-Gadegbeku, K. (2020). Human health risk assessment of polycyclic aromatic hydrocarbons (PAH) in smoked fishes in Togo. *Journal of Agriculture and Environmental Sciences, 9*(2), 6-13.

Mulenga, M., Ouma, K. O., Monde, C., & Syampungani, S. (2024). Aquatic mercury pollution from artisanal and small-scale gold mining in sub-Saharan Africa: Status, Impacts, and Interventions. *Water, 16*(5), 756.

Ouro-Sama, K., Solitoke, H. D., Tanouayi, G., Lazar, I. M., Bran, P., Nadejde, M., ... & Lazar, G. O. (2020). Spatial and seasonal variation of trace elements contamination level of the waters from the hydrosystem Lake Togo-Lagoon of Aného (South of Togo). *SN Applied Sciences, 2*, 1-18.

Conclusion

This work has explored the complexity and richness of aquatic food sources, revealing their central role in human diets across history and cultures. From the intrinsic diversity of species—fish, crustaceans, mollusks, and algae—to their socio-economic and environmental significance, a nuanced picture emerges where considerable nutritional benefits coexist with potential risks and sustainability challenges.

As detailed in the preceding chapters, the nutritional value of aquatic foods is undeniable. They constitute a high-quality protein source with a complete profile of essential amino acids. They are also notably rich in long-chain polyunsaturated fatty acids (LCPUFAs)—particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)—whose physiological roles in cardiovascular health, neuronal development, and the modulation of inflammatory processes are extensively documented and recognized by the scientific community (Chapters 2 and 3). Their contribution of essential micronutrients, such as Vitamins D and B12, iodine, selenium, zinc, and iron, is crucial for the prevention of nutritional deficiencies on a global scale.

However, the exploitation of aquatic resources and their integration into the human food chain are not without challenges. Risks of exposure to environmental contaminants such as heavy metals (notably mercury), persistent organic pollutants (POPs), as well as the presence of natural toxins produced by microalgae (phycotoxins) or microbial and parasitic pathogens, represent legitimate food safety concerns (Chapter 4). These risks, though variable depending on species, geographical areas, and production methods, demand constant vigilance and the application of rigorous management measures.

The mitigation of these risks rests upon the strict adherence to Good Practices regarding the selection, handling, preservation, and cooking of aquatic products, as highlighted in Chapter 5. The role of both national and international health authorities is fundamental for establishing and enforcing safety standards, monitoring contaminants, and informing the public. The rise of aquaculture, presented in Chapter 6, offers considerable potential to meet the growing demand for aquatic products in the face of wild fishery limitations. Nevertheless, for aquaculture to fully realize its potential without compromising ecosystem health or the sanitary safety of its products, it must be resolutely committed to sustainability, minimizing its environmental impact, guaranteeing animal welfare, and strictly controlling the use of antibiotics and other inputs.

In this perspective, the Public Health Recommendations (Chapter 7) aim to guide consumers toward beneficial and safe consumption. The most relevant approach is not avoidance, but rather informed and moderate consumption, integrated into a diverse and balanced diet, prioritizing species with a potentially low contaminant content and sourced from sustainably managed populations. The innovations described in Chapter 8, such as new technologies for purification, risk detection, or the exploration of alternative sources like algae, open promising prospects for further enhancing the safety and sustainability of the aquatic food supply chain. Continued research into the nutritional and functional properties, alongside the development of more resilient aquaculture practices, remains essential for the future.

Concluding this exhaustive journey through the world of aquatic food sources, it is clear that these resources largely transcend the scope of a mere food category. They constitute a cultural heritage, a biological wealth, and a tangible promise for the future of human nutrition. Moreover, they crystallize major health, environmental, and socio-economic challenges that require coordinated and sustainable responses.

This work has striven to unravel this complexity by providing a rigorous overview of current knowledge. It has consistently and clearly sought to anchor this global reflection in the specific realities of Togo, in order to illuminate the possible pathways toward a sustainable and secured valorization of aquatic resources for the benefit of health and development.

We have underscored the exceptional nutritional value of fish, crustaceans, mollusks, and algae, which prove to be true concentrates of high-biological-value proteins. Their essential amino acid composition makes them prime allies for a balanced diet. Crucially, they are rich in long-chain polyunsaturated fatty acids, notably EPA and DHA, whose beneficial effects on cardiovascular health, cognitive development, and the regulation of inflammatory processes are now well established.

Their contribution of essential micronutrients—Vitamins D and B12, iodine, selenium, zinc, iron—is of paramount importance, particularly in preventing the nutritional deficiencies that persist in many regions worldwide, including Togo. Chapters 2 and 3 of this book provided in-depth insight into these aspects, demonstrating the fundamental role of aquatic foods in the fight against malnutrition and the promotion of durable and optimal health.

However, this coin has its reverse side. Aquatic ecosystems, acting as true receptacles for human activities, can concentrate chemical contaminants such as heavy metals and persistent organic pollutants (POPs), while aquatic organisms are susceptible to accumulating natural biotoxins or harboring microbial and parasitic pathogens. Chapter 4 highlighted these risks, emphasizing that sanitary safety is a *sine qua non* condition for fully realizing the nutritional advantages of aquatic foods. In the Togolese context, this implies heightened vigilance in fishing zones exposed to urban, industrial, and agricultural pollution, particularly those affecting Lake Togo and the Greater Lomé coastline. Reinforced surveillance, combined with rigorous management strategies, is essential to guarantee product wholesomeness and protect public health.

Faced with this duality, risk management is paramount. Chapter 5 insisted on the importance of Good Practices at all levels: rigorous product selection, adherence to the cold chain—a major challenge in Togo—hygienic preparation, and adequate cooking. These measures are indispensable for guaranteeing food wholesomeness and preserving the nutritional benefits of aquatic products. The role of health authorities, both national and international, is fundamental here for establishing standards, ensuring surveillance, and informing the public. Aquaculture, examined in Chapter 6, is presented as an essential solution for increasing the supply of aquatic products in the face of pressure on wild stocks. Nevertheless, its development in Togo, while promising, must be firmly rooted in a sustainability framework: control of ecological impact, prevention of health risks associated with farming, and inclusive socio-economic integration for the benefit of local communities.

The Public Health Recommendations presented in Chapter 7 aim to translate scientific knowledge into practical advice for informed and responsible consumption of aquatic products. They seek to establish an optimal balance between nutritional benefits and potential health risks. For Togo, this approach involves several priority areas of action: the valorization of local species that are easily accessible and present a low contamination risk; the promotion of improved traditional processing methods, such as smoking, which ensure both food security and the preservation of nutritional qualities; and finally, the active integration of fish into policies combating infant and maternal malnutrition, where its role as a key food is fundamental.

Finally, the technological and scientific innovations addressed in Chapter 8 open encouraging perspectives: faster detection methods, gentler decontamination techniques, valorization of co-products, development of sustainable aquaculture feeds from local resources, and exploration of the potential of algae or other marine organisms. For Togo, these innovations could translate into support for applied research to adapt these new approaches to the local context, for example, by developing aquaculture feeds based on national agricultural by-products or exploring the potential of spirulina cultivation.

Ultimately, aquatic food sources are a treasure of the biosphere, particularly valuable for nations like Togo. Their potential to nourish the world and promote health is immense but can only be fully realized through a holistic and responsible approach. This requires a convergence of knowledge and actions, involving fishers—to whom this work is dedicated—aquaculturists, processors, scientists, policymakers, health professionals, and consumers. It is by understanding and respecting the complexity of aquatic ecosystems, investing in research adapted to local realities, strengthening national management and control capacities, and educating every citizen, that we can collectively ensure that these gifts of nature continue to sustainably support food security, health, and well-being for present and future generations, in Togo as well as globally.

At the conclusion of this book, it emerges that aquatic food sources constitute a fundamental pillar for human nutrition and health. However, the full realization of their potential requires their production and consumption to be guided by constant scientific rigor and a keen sense of responsibility. It is imperative to adopt a holistic vision that integrates the health of aquatic ecosystems, the sanitary safety of food, the sustainable management of resources, and consumer education. Only a synergy between actors in fishing, aquaculture, the agri-food industry, regulatory bodies, researchers, and the general public will make it possible to maximize the benefits of aquatic foods while controlling the associated risks, thereby ensuring their sustainable contribution to the health and well-being of global populations for future generations.

APPENDICES

Appendix 1: Main Freshwater and Brackish Fish in Togo

Family	Scientific Name	Common Name
Characidae	*Alestes spp*	Sardine
Characidae	*Brycinus spp*	Sardine
Characidae	*Hydrocynus spp*	Tigerfish
Hepsetidae	*Hepsetus odoe*	Hepsetus
Cyprinidae	*Labeo spp*	Labeo
Cyprinidae	*Barbus spp*	Barbel
Osteoglossidae	*Heterotis niloticus*	Heterotis
Gymnarchidae	*Gymnarchus niloticus*	African knife-fish
Mormyridae	*Mormyrus ssp, Hyperopisus bebe, Mormyros spp, Brienomyrus niger, Marcusenius spp, Petrocephalus spp*	Mormyrids
Notopteridae	*Papyrocranus afer*	Notopterid
Protoperidae	*Protopterus annectens*	African Lungfish
Channidae	*Parachanna spp*	Parachanna
Polypteridae	*Polypterus spp*	Bichir
Schilbeidae	*Schilbe spp*	Schilbe
Bagridae	*Clarotes laticeps*	Clarotes
Bagridae	*Bagrus spp*	Bagrus
Bagridae	*Chrysichthys spp*	Catfish
Bagridae	*Auchenoglanis biscutatus*	Auchenoglanis
Clariidae	*Clarias spp*	Catfish
Clariidae	*Heterobranchus africanus*	Heterobranchus
Malapteruridae	*Malapterurus electricus*	Electric Catfish
Mochokidae	*Synodontis spp*	Synodontis
Clupeidae	*Pellonula leonensis*	Sprat
Clupeidae	*Ethmalosa fimbriata*	Bonga Shad
Centropomidae	*Lates niloticus*	Nile Perch
Cichlidae	*Oreochromis niloticus*	Tilapia
Cichlidae	*Sarotherodon spp*	Tilapia
Cichlidae	*Hemichromis spp*	Tilapia
Cichlidae	*Tilapia spp*	Tilapia
Sciaenidae	*Pseudotolithus spp*	Croaker
Elopidae	*Elops lacerta*	Ladyfish
Mugilidae	*Mugil cephalus*	Mullet
Mugilidae	*Liza falcipinnis*	Mullet
Sparidae	*Dentex spp, Pagellus spp, Pagrus spp*	Sea Bream
Lutjanidae	*Lutjanus spp*	Snapper
Gobiidae	*Porogobius schlegelii, Gobionellus occidentalis*	Goby
Bothidae	*Citharichthys stampflii*	Flounder
Soleidae	*Dicologoglossa spp, Microchirus spp, Pegusa spp, Synaptura spp*	Sole
Polynemidae	*Polydactylus quadrifilis*	Threadfin
Polynemidae	*Galeoides decadactylus, Pentanemus quinquarius*	Small Threadfin
Cynoglossidae	*Cynoglossus spp, Symphurus spp*	Tongue Sole
Carangidae	*Trachinotus spp*	Pompano
Carangidae	*Caranx spp*	Jack
Portunidae	*Portunus validus, Callinectes aminicola*	Crab
Eleotridae	*Eleotris spp*	Sleepers
Eleotridae	*Kribia kribensis*	Kribia

Peneidae	*Penaeus monodon*	Giant Tiger Prawn
Peneidae	*Penaeus spp*	Shrimp/Prawn
Palaemonidae	*Macrobrachium spp*	Crayfish/Prawn
Distichodontidae	*Distichodus spp*	Distichodus
Haemulidae	*Pomadasys spp*	Grunt
Gerreidae	*Gerres spp*	Mojarra
Sphyraenidae	*Sphyraena spp*	Barracuda
Psettodidae	*Psettodes belcheri*	Spiny Turbot

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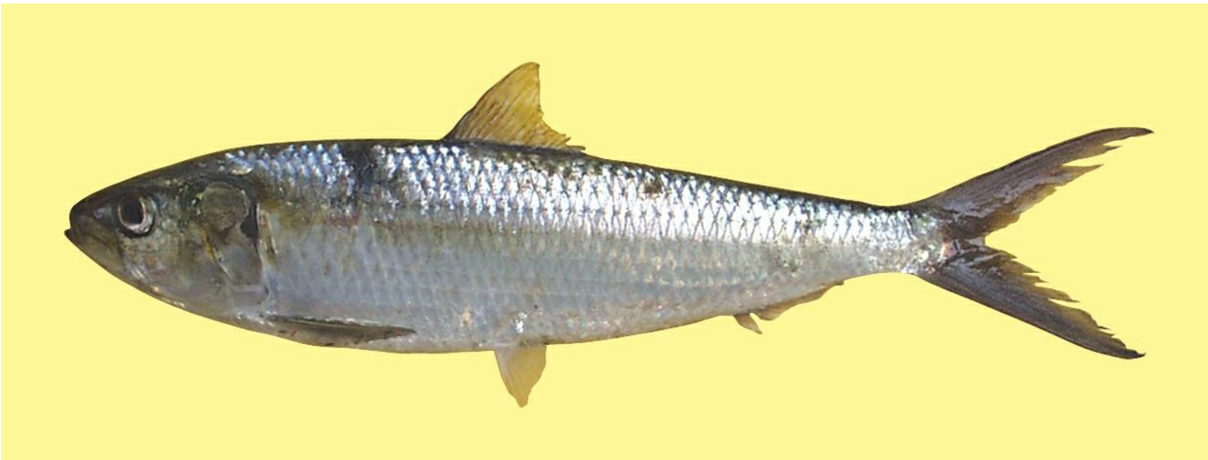
Appendix 2: LIST OF MAIN MARINE SPECIES LANDED IN TOGO

Species	English Common Name	Ewe Name
Engraulis encrasicolus	European Anchovy	Abobi
Ethmalosa fimbriata	Bonga Shad	Folévi
Pseudotolithus senegalensis	Cassava Croaker	Ekan
Pseudotolithus typus	Longneck Croaker	Ekan
Scomber japonicus	Chub Mackerel	Zadou
Scomberomorus tritor	Wahoo / Spanish Mackerel	Zadou
Auxis thazard	Frigate Tuna	Kpokou
Sarda sarda	Atlantic Bonito	Kpokou
Euthynnus alletteratus	Little Tunny	Kpokou
Katsuwonus pelamis	Skipjack Tuna	Guégou
Thunnus albacares	Yellowfin Tuna	Guégou
Thunnus obesus	Bigeye Tuna	Guégou
Sphyraena guachancho	Guinean Barracuda	Lizi
Sphyraena sphyraena	European Barracuda	Lizi
Chloroscombrus chrysurus	Atlantic Bumper	Gbèdjèvi
Caranx hippos	Crevalle Jack	Panpan
Caranx crysos	Blue Runner	Panpan /Tsii
Selene dorsalis	African Moonfish	Ngogba
Trachurus trachurus	Atlantic Horse Mackerel	Tsii
Decapturus punctatus	Spotted Scad	Tsii
Penaeus notialis	Southern Pink Shrimp	Bolou
Penaeus monodon	Giant Tiger Prawn	Bolou
Drepane africana	Sickle Fish	Kpenukpa
Lethrinus atlanticus	Atlantic Emperor	Sipklin
Xiphias gladius	Swordfish	Hatalikofi
Isthiophorus albicans	Atlantic Sailfish	Hatalikofi
Maikaira nigricans	Blue Marlin	Hatalikofi
Makaira indica	Black Marlin	Hatalikofi
Tetrapturus albidus	White Marlin	Hatalikofi
Tetrapturus pfluegeri	Longbill Spearfish	Hatalikofi
Dentex canariensis	Canary Dentex	Sica -sica
Pagrus caeruleosticus	Blue-spotted Sea Bream	Sica -sica
Pagellus bogaraveo	Red Sea Bream	Sica -sica
Pagellus belzonetii	Axillary Bream	Sica -sica
Trichiurus lepturus	Largehead Hairtail	Anipa
Coryphaena equiselis	Pompano Dolphinfish	Agbako
Panulirus regius	Royal Spiny Lobster	Fia bolou
Lutjanus dentatus	African Snapper	Ehan/Agnato

Lutjanus goreensis	African Red Snapper	Ehan/Agnato
Lutjanus fulgens	Golden African Snapper	Ehan/Agnato
Aspilus fuscus	Fuscus Snapper	Afino
Epinephelus aeneus	White Grouper	Toboko
Hemiramphus brasiliensis	Ballyhoo	Dayi
Strongylura senegalensis	Senegal Needlefish	Dayi
Exocoetus volitans	Tropical Two-wing Flyingfish	Zozrovi
Cynoglossus cadenati	Ghanean Tongue Sole	Afohomé
Cynoglossus monodi	Monodi Tongue Sole	Afohomé
Pomadasys jubelini	Sompat Grunt	Kokovi
Pomadasys peroteti	Grunt	Kokovi
Brachydeuterus auritus	Bigeye Scad (or small fried fish)	Dégbénou madui/Hawui
Sardinella aurita	Round Sardinella	Vétim
Sardinella maderensis	Madeiran Sardinella (Herring)	Manvi
Ilisha africana	West African Ilisha	kafla
Balistes punctatus	Spotted Balistes	Akpagba/Egbo
Balistes capriscus	Grey Triggerfish	Akpagba
Elops lacerta	West African Ladyfish	Gbanvi
Rhizoprionodon acutus	Milk Shark	Gbowlé
Alopias pelagicus	Pelagic Thresher Shark	Gbowlé
Sphyrna lewini	Scalloped Hammerhead Shark	Gbowlé
Mugil cephalus	Flathead Mullet	Guéssou
Sepia officinalis	Common Cuttlefish	Bosran/Adito

ENGEN01	*Engraulis encrasicolus*	TL 14 cm	Morocco	W3
Tr. st. 818	N 31° 08' W 09° 53'	Fishing/bottom depth: 72/72 m 11.12.1998		OA



CLUSL01	*Sardinella aurita*	TL 36 cm	Angola	A4
Tr. st. 1682	S 11° 29' E 13° 33'	Fishing/bottom depth: 70/70 m 15.05.1998		OA

CLUSL02	*Sardinella maderensis*	TL 32 cm	Angola	A4
Tr. st. 1688	S 11° 47’ E 13° 43’	Fishing/bottom depth: 45/45 m 16.05.1998	OA	

CLUIL01	*Ilisha africana*	TL 25 cm	Angola	A4
Tr. st. 1660	S 10° 27’ E 13° 32’	Fishing/bottom depth: 26/26 m 12.05.1998	OA	

CLUIL012	*Ilisha africana*	TL 29 cm	Angola	A4
Tr. st. 1810	S 06° 05’ E 12° 06’	Fishing/bottom depth: 5/39 m	19.08.1998	OA

PLNPD01	*Polydactylus quadrifilis*	TL 110 cm	Benin	IG
Tr. st. 25	N 06° 18’ E 02° 37’	Fishing/bottom depth: 20/20 m	20.04.1999	OA

PLNGA01	*Galeoides decadactylus*	TL 20 cm		Angola	A4
Tr. st. 1660	S 10° 27' E 13° 32'	Fishing/bottom depth: 26/26 m	12.05.1998		OA

PLNPE01	*Pentanemus quinquarius*	TL 19 cm		Benin	IG
Tr. st. 25	N 06° 18' E 02° 37'	Fishing/bottom depth: 20/20 m	20.04.1999		OA

ALBAL01	*Albula vulpes*	TL 41 cm	Togo	IG
Tr. st. 34	N 06° 07’ E 01° 25’	Fishing/bottom depth: 20/20 m	21.04.1999	OA

Sparus Aurata

LUTAS01	*Apsilus fuscus*	TL 37 cm	Ghana	IG
Tr. st. 54	N 05° 17’ W 00° 35’	Fishing/bottom depth: 21/21 m	24.04.1999	OA

LUTLU01	*Lutjanus goreensis*	TL 31 cm	Ghana	IG
Tr. st. 25	N 06° 18’ E 02° 37’	Fishing/bottom depth: 20/20 m	20.04.1999	OA

a

LUTLU03 *Lutjanus fulgens* TL 36 cm Ghana IG

Tr. st. 66 N 04° 42' W 01° 47' Fishing/bottom depth: 47/47 m 25.04.1999 OA

LUTLU031 *Lutjanus fulgens (?)* TL 11 cm Côte d'Ivoire IG

Tr. st. 95 N 05° 03' W 05° 22' Fishing/bottom depth: 26/26 m 02.05.1999 OA

LUTLU031	*Lutjanus fulgens (?)*	TL 11 cm	Côte d'Ivoire	IG
Tr. st. 95	N 05° 03' W 05° 22'	Fishing/bottom depth: 26/26 m 02.05.1999		OA

LUTLU24	*Lutjanus dentatus*	TL 90 cm	Ghana	IG
Tr. st. 146	N 05° 42’ E 00° 29’	Fishing/bottom depth: 26/26 m 03.09.2000		OA

LETLE01	*Lethrinus atlanticus*	TL 23 cm	Benin	IG
Tr. st. 25	N 06° 18’ E 02° 37’	Fishing/bottom depth: 20/20 m 20.04.1999		OA

BOTBO01	*Bothus podas africanus*	TL 14 cm	Togo		IG
Tr. st. 34	N 06° 07’ E 01° 25’	Fishing/bottom depth: 20/20 m		21.04.1999	OA

BOTSC01 *Syacium micrurum* TL 17 cm Côte d'Ivoire IG

Tr. st. 348 N 05° 05' E 003° 25' Fishing/bottom depth: 41/41 m 01.08.2002 OA

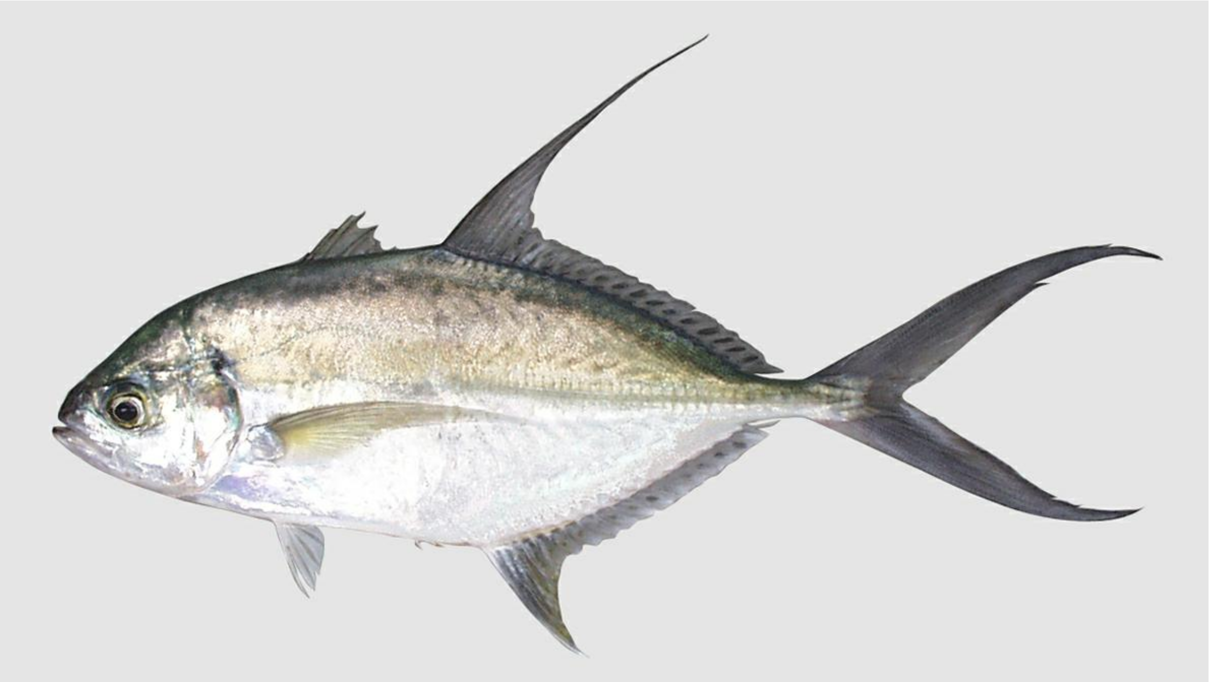
PSEPS01 *Psettodes belcheri* TL 32 cm Togo IG

Tr. st. 35 N 06° 03' E 01° 25' Fishing/bottom depth: 44/44 m 21.04.1999 OA a

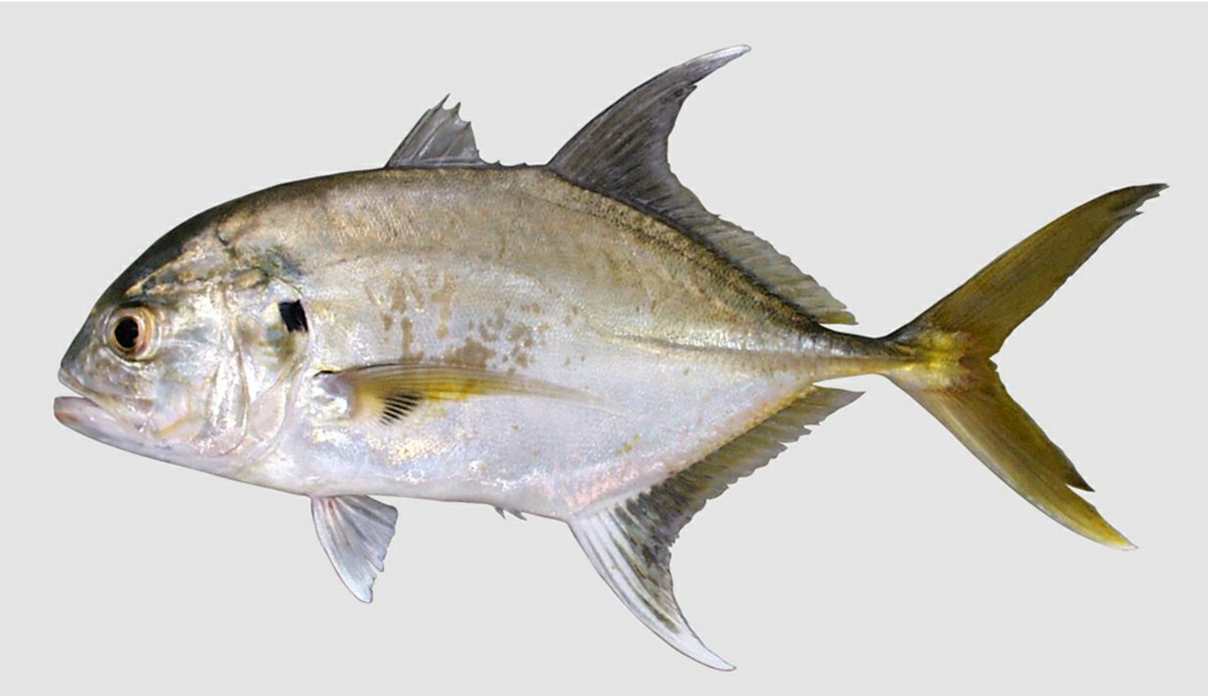
CARAL01	*Alectis alexandrinus*	TL 56 cm	Benin	IG
Tr. st. 33	N 06° 12’ E 01° 52’	Fishing/bottom depth: 24/24 m	20.04.1999	OA

CARCA02	*Caranx crysos*	TL 51 cm	Angola	A4
Tr. st. 1786	S 08° 01’ E 13° 06’	Fishing/bottom depth: 10/42 m	14.08.1998	OA

CARCA03	*Caranx senegallus*	TL 43 cm	Angola	A4
Tr. st. 1805	S 06° 27’ E 12° 07’	Fishing/bottom depth: 5/50 m	18.08.1998	OA



CARCA031	*Caranx senegallus*	TL 34 cm	Benin	IG
Tr. st. 252	N 06^o 14' E 02^o 15'	Fishing/bottom depth: 27/27 m 18.07.2002		OA



CARCA14	*Caranx hippos*	TL 37 cm	Benin	IG
Tr. st. 251	N 06^o 12' E 02^o 15'	Fishing/bottom depth: 38/38 m 18.07.2002		OA

CARCH01 *Chloroscombrus chrysurus* TL 25 cm Angola A4

Tr. st. 1660 S 10° 27’ E 13° 32’ Fishing/bottom depth: 26/26 m 12.05.1998 OA

CARCH012 *Chloroscombrus chrysurus* TL 23 cm Angola A4

Tr. st. 1774 S 09° 13’ E 12° 55’ Fishing/bottom depth: 10/32 m 12.08.1998 OA

CARDE01 *Decapterus punctatus* TL20 cm Ghana IG

Tr. st. 60 N 04° 49’ W 01° 13’ Fishing/bottom depth: 10/40 m 25.04.1999 OA

SCMSA01	*Sarda sarda*	TL 51 cm	Angola	A4
Tr. st. 1786	S 08° 01’ E 13° 06’	Fishing/bottom depth: 10/42 m 14.08.1998	OA	

SCMEU01 *Euthynnus alletteratus* TL 31 cm Angola A4

Tr. st. 1768 S 09° 44' E 13° 08' Fishing/bottom depth: 10/44 m 11.08.1998 OA

SCMAU01 *Auxis thazard* TL 28 cm Angola A4

Tr. st. 1800 S 07° 15' E 12° 03' Fishing/bottom depth: 5/362 m 16.08.1998 OA

SCMSC01 *Scomber japonicus* TL 44 cm Angola A4

Tr. st. 1682 S 11° 29' E 13° 33' Fishing/bottom depth: 70/70 m 15.05.1998 OA

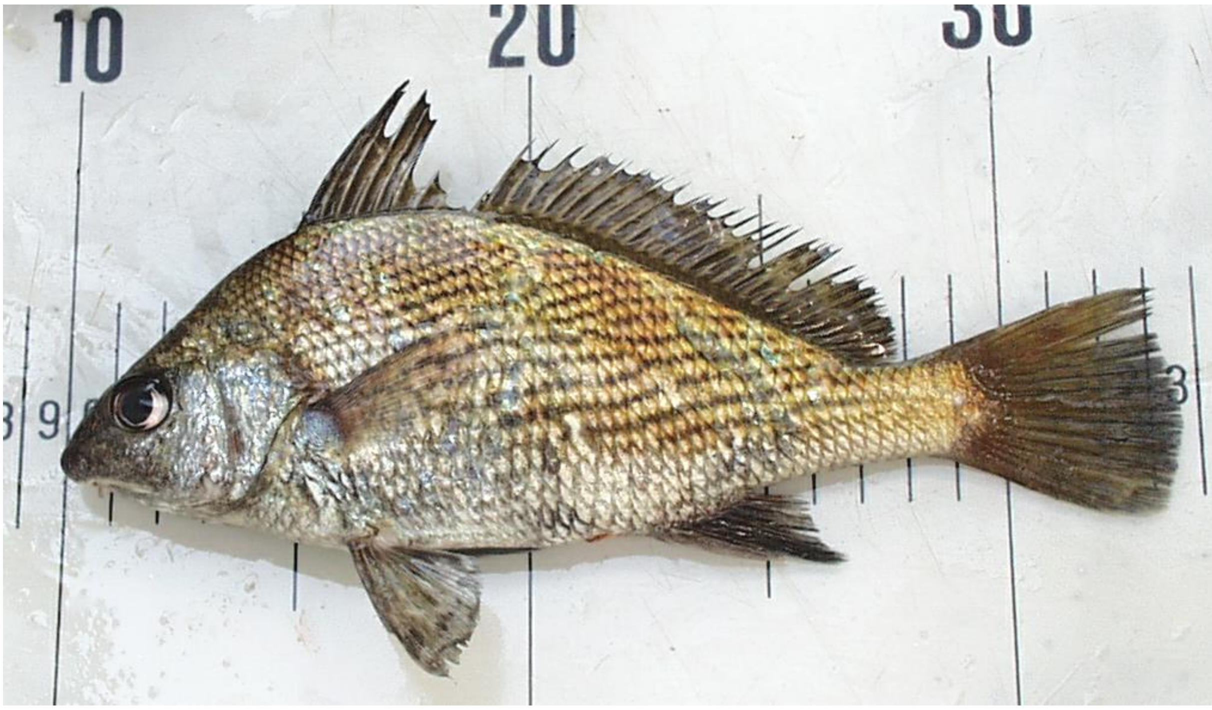
SCMSC012 *Scomber japonicus* TL 32 cm Angola A4

Tr. st. 1801, S 07° 02' E 12° 15' Fishing/bottom depth: 10/87 m 17.08.1998 OA

SCMSC013 *Scomber japonicus* TL 20 cm Morocco W3

Tr. st. 936, N 23° 14' W 16° 55' Fishing/bottom depth: 10/65 m 25.11.1999 OA

SCMSM01	*Scomberomorus tritor*	TL 52 cm	Angola	A4
Tr. st. 1798	S 07° 11' E 12° 46'	Fishing/bottom depth: 10/21 m 16.08.1998	OA	



SCIUM01	*Umbrina canariensis*	TL 23 cm	Angola	A4
Tr. st. 1640	S 09° 29' E 12° 55'	Fishing/bottom depth: 88/88 m 09.05.1998	OA	

SCIUM02	*Umbrina steindachneri*	TL 30 cm	Ghana	IG
Tr. st. 146	N 05^o 42’ E 00^o 29’	Fishing/bottom depth: 26/26 m	03.09.2000	OA

CARDE02 *Decapterus rhonchus* TL 17 cm Angola A4

Tr. st. 1660 S 10° 27’ E 13° 32’ Fishing/bottom depth: 26/26 m 12.05.1998 OA

CARDE022 *Decapterus rhonchus* TL 29 cm Angola A4

Tr. st. 1744 S 11° 40' E 13° 45' Fishing/bottom depth: 15/33 m 06.08.1998 OA

CARDE02 *Decapterus rhonchus* TL 17 cm Angola A4

Tr. st. 1660 S 10° 27' E 13° 32' Fishing/bottom depth: 26/26 m 12.05.1998 OA

CARDE022 *Decapterus rhonchus* TL 29 cm Angola A4

Tr. st. 1744 S 11° 40’ E 13° 45’ Fishing/bottom depth: 15/33 m 06.08.1998 OA

SCIPS02 *Pseudotolithus senegalensis* TL 28 cm Angola A4

Tr. st. 1778 S 08° 22’ E 13° 19’ Fishing/bottom depth: 24/24 m 13.08.1998 OA

SCIPS03	*Pseudotolithus typus*	TL 46 cm	Ghana	IG
Tr. st. 73	N 04° 47' W 02° 12'	Fishing/bottom depth: 29/29 m	26.04.1999	OA

PODPO02 *Pomadasys incisus* TL 22 cm Angola A4

Tr. st. 1682 S 11° 29' E 13° 33' Fishing/bottom depth: 70/70 m 15.05.1998 OA

PODPO021 *Pomadasys incisus* TL 20 cm Ghana IG

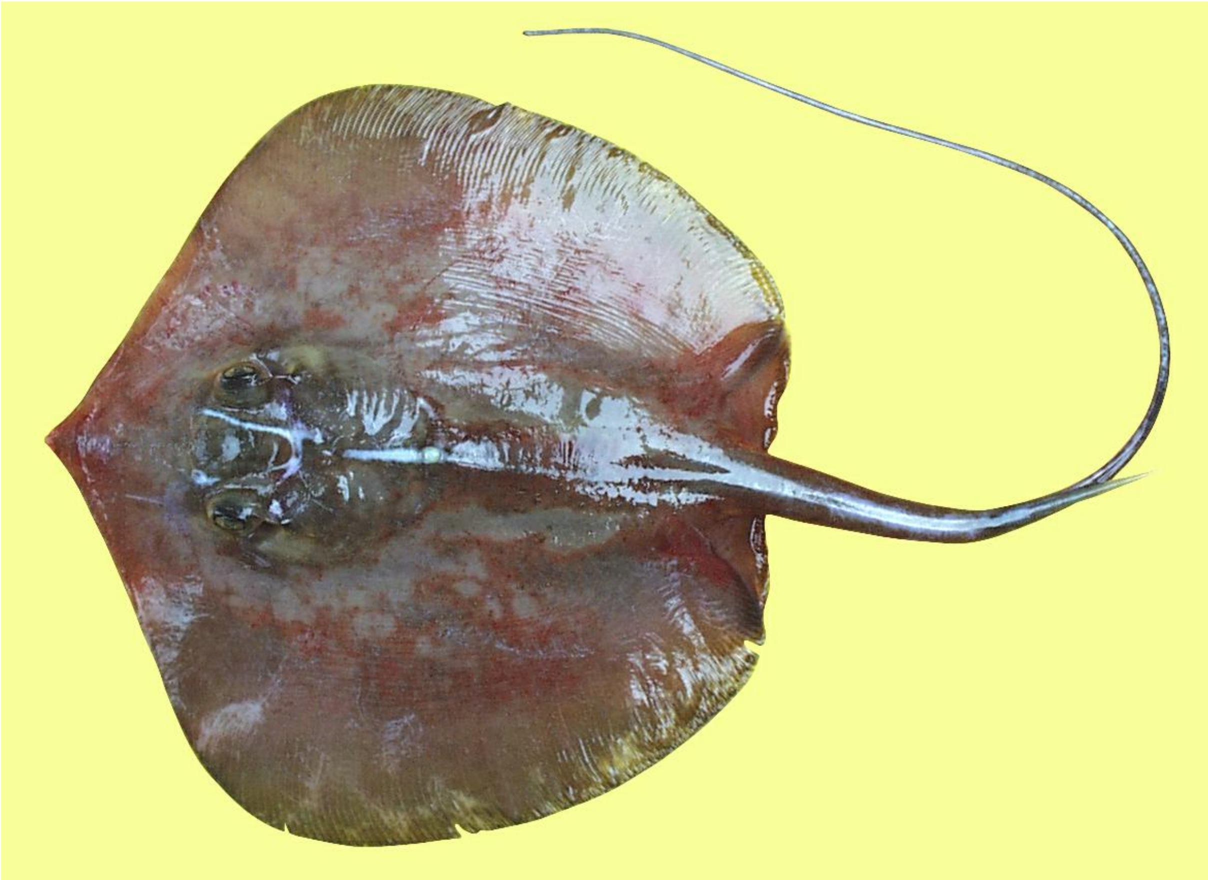
Tr. st. 303 N 05° 05' W 00° 33' Fishing/bottom depth: 45/45 m 25.07.2002 OA

DREDR01	*Drepane africana*	TL 16 cm	Benin	IG
Tr. st. 25	N 06° 18’ E 02° 37’	Fishing/bottom depth: 20/20 m	20.04.1999	OA

ACAAC01	*Acanthurus monroviae*	TL 38 cm	Côte d'Ivoire	IG
Tr. st. 114	N 05° 06' W 03° 22'	Fishing/bottom depth: 27/27 m	05.05.1999	OA

BALBA021	*Balistes punctatus*	FL 20 cm	Ghana	IG
Tr. st. 305	N 05° 16' W 00° 36'	Fishing/bottom depth: 21/21 m	25.07.2002	OA

ARDAR01	*Arius heudeloti*	TL 50 cm	Côte d'Ivoire	IG
Tr. st. 398	N 04° 17' W 007° 29'	Fishing/bottom depth: 40/40 m	07.08.2002	OA



RAYDA11	*Dasyatis margarita*	DL 17 cm	Angola	A4
Tr. st. 1741	S 11° 59' E 13° 43'	Fishing/bottom depth: 10/29 m	05.08.1998	OA

RAYRA16	*Dasyatis pastinaca*	DW 43 cm	Côte d'Ivoire	IG
Tr. st. 397	N 04° 19' W 007° 29'	Fishing/bottom depth: 28/28 m	07.08.2002	OA

RAYDA18	*Dasyatis marmorata*	DW 31 cm	Ghana	IG
Tr. st. 317	N 04° 55’ E 001° 13’	Fishing/bottom depth: 35/35 m	27.07.2002	OA

RAYRB16 *Rhinobatos albomaculatus* TL 87 cm Angola A4

Tr. st. 1746 S 11° 33’ E 13° 41’ Fishing/bottom depth: 36/36 m 06.08.1998 OA

RAYRB163 *Rhinobatos albomaculatus* TL 29 cm Côte d'Ivoire IG

Tr. st. 381 N 04° 53' E 006° 05' Fishing/bottom depth: 23/23 m 05.08.2002 OA

CYGCY01 *Cynoglossus canariensis* TL 40 cm Angola A4

Tr. st. 1660 S 10° 27' E 13° 32' Fishing/bottom depth: 26/26 m 12.05.1998 OA

CYGCY012 *Cynoglossus canariensis* TL 43 cm Angola A4

Tr. st. 1778 S 08° 22' E 13° 19' Fishing/bottom depth: 24/24 m 13.08.1998 OA

CITCI01 *Citharus linguatula* TL 19 cm Angola A4

Tr. st. 1648 S 09° 49’ E 12° 56’ Fishing/bottom depth: 113/113 m 10.05.1998 OA

CITCI011 *Citharus linguatula* TL 17 cm Morocco W3

Tr. st. 1268 N 22° 35’ W 17° 06’ Fishing/bottom depth: 72/72 m 23.11.2000 OA

CORCO02 *Coryphaena equiselis* TL 44 cm Côte d’Ivoire IG

Tr. st. 85 N 04° 30’ W 06° 44’ Fishing/bottom depth: 2/102 m 01.05.1999 OA

CRACA11 *Calappa rubroguttata* CW 12 cm Benin IG

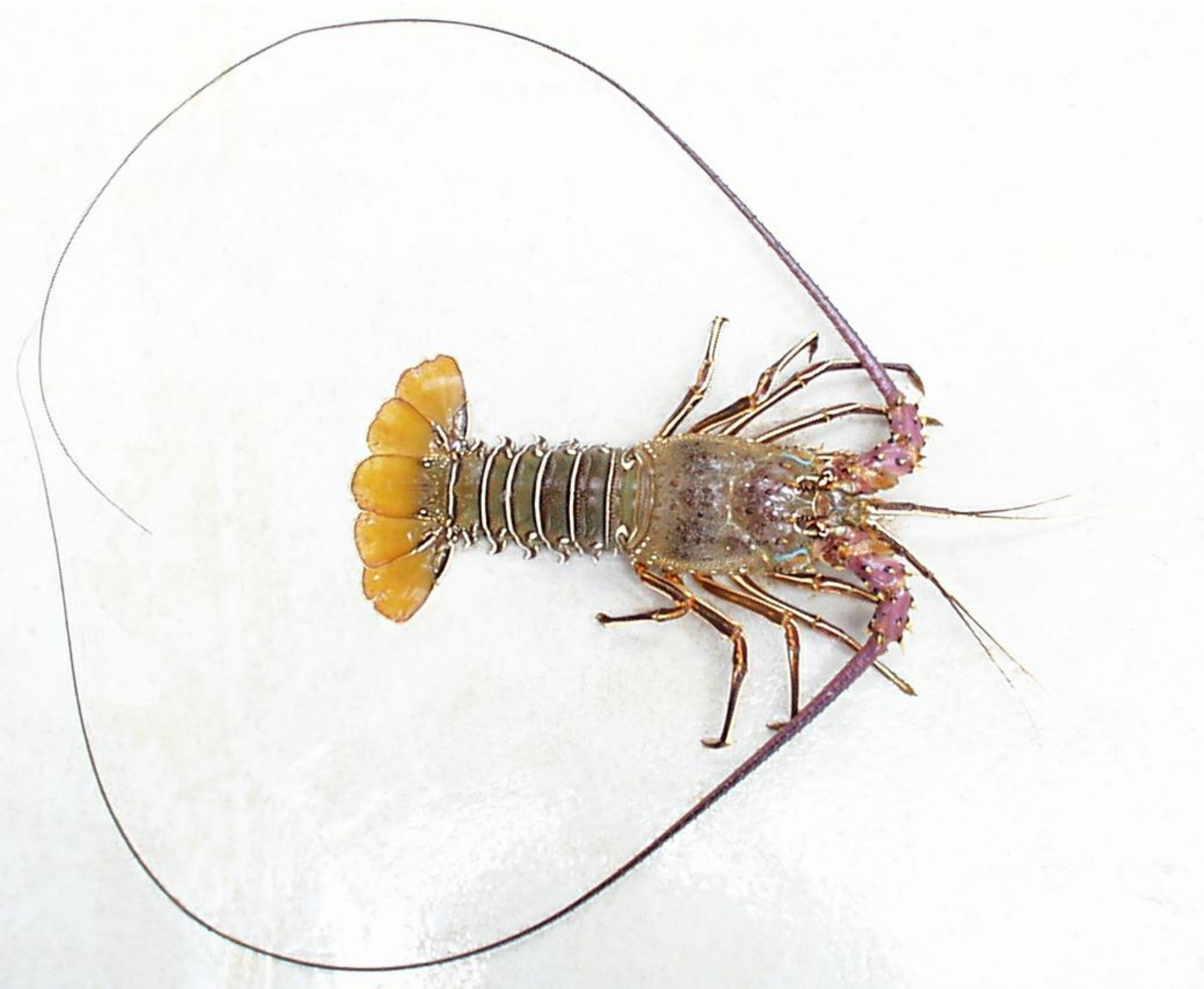
Tr. st. 26 N 06° 12’ E 02° 37’ Fishing/bottom depth: 42/42 m 20.04.1999 OA

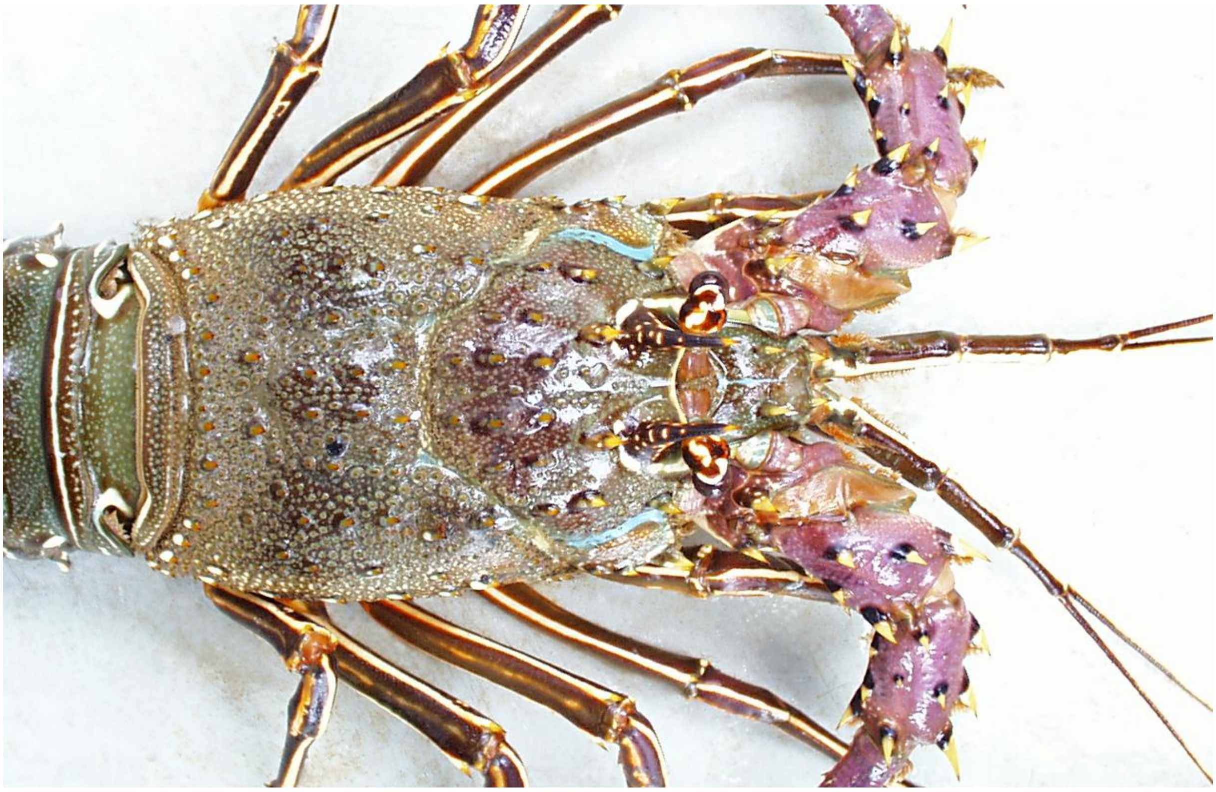
CRACA15 *Calappa pelli* Angola A4

Tr. st. 1688 S 11° 47’ E 13° 43’ Fishing/bottom depth: 45/45 m 16.05.1998 OA

CRAPO311 *Portunus validus* CW 18 cm Côte d'Ivoire IG

Tr. st. 218 N 05° 03' W 05° 35' Fishing/bottom depth: 20/20 m 12.09.2000 OA





LOBPA23	*Panulirus regius*	CL 109 mm	Côte d'Ivoire	IG
Tr. st. 388	N 04° 41' E 006° 37'	Fishing/bottom depth: 35/35 m	06.08.2002	OA

LABXY01	*Xyrichthys novacula*	TL 18 cm	Togo	IG
Tr. st. 34	N 06° 07’ E 01° 25’	Fishing/bottom depth: 20/20 m 21.04.1999	OA	

LABBO011	*Bodianus speciosus*	FL 36 cm	Ghana	IG
Tr. st. 290	N 05° 41’ E 00° 16’	Fishing/bottom depth: 24/24 m	23.07.2002	OA