Ocean Decade

Vision 2030

White Papers

Challenge 3:

Sustainably nourish the global population

The United Nations
Decade of Ocean Science
for Sustainable Development
(2021-2030)

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Published in 2024 by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization

7, place de Fontenoy, 75352 Paris 07 SP, France

For bibliographic purposes, this publication should be cited as follows:

Agostini, V. N., Olsen, E., Tiffay, C., Alison, E., Coetzee, J., Cojocaru, A.-L., Costello, C., Darias, M. J., Fabinyi, M., Fulton, B., Gelcich., S., Haraksingh Thilsted, S., Hassouni, F. Z., Mills, K. E., Msuya, F., Obura, D. & Tigchelaar., M. (2024). *Ocean Decade Vision 2030 White Papers – Challenge 3: Sustainably Nourish the Global Population.* Paris, UNESCO-IOC. (The Ocean Decade Series, 51.3.). https://doi.org/10.25607/r7qs-a228

Graphic design: UNESCO

(IOC/2024/ODS/51.3)

Ocean Decade Vision 2030 White Papers

Challenge 3: Sustainably nourish the global population

Generate knowledge, support innovation, and develop solutions to optimise the role of the ocean in sustainably nourishing the world's population under changing environmental, social, and climate conditions.

Writing Team

The Intergovernmental Oceanographic Commission (IOC) of UNESCO, extends its sincere appreciation to the co-chairs and members of the Working Group for their leadership and commitment in the process of drafting and authoring the present document.

Co-chairs

Vera Agostini	Food and Agriculture Organization (FAO)
Erik Olsen	Institute of Marine Research (IMR)

Working Group expert members

Edward Alison	Worldfish
Janet Coetzee	Department of Forestry, Fisheries and the Environment (DFFE), South Africa
Andreea-Laura Cojocaru	University of Stavanger
Christopher Costello	University of California Santa Barbara (UCSB)
Maria J. Darias	French National Research Institute for Sustainable Development (IRD)
Michael Fabinyi	Climate, Society and Environment Research Centre at the University of Technology Sydney
Beth Fulton	Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Stefan Gelcich	Instituto Milenio en Socio-Ecologia Costera, Pontificia Universidad Católica de Chile
Shakuntala Haraksingh Thilsted	Nutrition, Health and Food Security Impact Area Platform, CGIAR
Fatima Zohra Hassouni	Maritime Fisheries Department, Morocco
Katherine Mills	Gulf of Maine Research Institute
Flower Msuya	Zanzibar Seaweed Cluster Initiative
David Obura	CORDIO East Africa
Celine Tiffay	Food and Agriculture Organization (FAO)
Michelle Tigchelaar	Worldfish

Acknowledgments

This White Paper was the result of discussions between 15 members of the United Nations (UN) Decade of Ocean Science for Sustainable Development (hereafter, Ocean Decade) Vision 2030 process Working Group 3: Vera Agostini, Erik Olsen, Eddie Allison, Andreea L. Cojocaru, Christopher Costello, Maria J. Darias, Michael Fabinyi, Beth Fulton, Stefan Gelcich, Fatima Zohra Hassouni, Katherine E. Mills, Flower Msuya, Michelle Tigchelaar, Shakuntala Haraksingh Thilsted, and Céline Tiffay.

The work was further enabled by the engagement of the UN Food and Agriculture Organization (FAO) and the Norwegian Institute of Marine Research (IMR) who agreed to co-chair Working Group 3 (Vera Agostini, FAO; Erik Olsen, IMR), and with this dedicate substantial time, resources, expertise, and critical insights to the White Paper process. FAO also provided some funding to support the work.

The White Paper was reviewed by a diverse set of experts through the Vision 2030 review process and the Ocean Decade Conference (Barcelona, April 2024), bringing in constructive, valuable, and insightful feedback. This enabled a more robust final version of the White Paper.

Finally, the support of the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization (UNESCO/IOC) Decade Coordination Unit (DCU), charged with implementing the Vision 2030 process, was significant in coordinating and guiding the work of all Ocean Decade Working Groups, ensuring alignment, synergies, and collaboration.

Contents

Acronyms

AI	Artificial Intelligence
DCC	Decade Collaborative Centre (of the UN Ocean Decade)
DCO	Decade Coordination Office (of the UN Ocean Decade)
DCU	Decade Coordination Unit (of UNESCO/IOC)
FAO	Food and Agriculture Organization of the United Nations
FTT	FAO-Thiaroye Processing Technique
HLP	High Level Panel for a Sustainable Ocean Economy
HLPE	High Level Panel of Experts on Food Security and Nutrition
IFAD	International Fund for Agriculture Development
IMTA	Integrated multi-trophic aquaculture
IUU	Illegal, unreported, and unregulated fishing
SDGs	Sustainable Development Goals
SOFI	State of Food Security and Nutrition in the World (report of the FAO)
SOFIA	State of World Fisheries and Aquaculture (report of the FAO)
SSF	small-scale fisheries
SSF Guidelines	Voluntary Guidelines for Securing Sustainable Small-scale Fisheries in the Context of Food Security and Poverty Eradication of the FAO
SSFA	Small-scale fisheries and aquaculture
UN	United Nations
UNESCO/IOC	Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization
UNICEF	United Nations Children's Fund
WFP	World Food Programme (of the United Nations)
WHO	World Health Organization

1. EXECUTIVE SUMMARY

1.1 Introduction and scope of the White Paper

This White Paper has been prepared as part of the Vision 2030 process of the United Nations (UN) Decade of Ocean Science for Sustainable Development (hereafter, Ocean Decade). The Vision 2030 process aims to identify tangible measures of success for each of the ten Ocean Decade Challenges by 2030. From a starting point of existing initiatives underway in the Ocean Decade and beyond, and through a lens of priority user needs, the process determines critical gaps in science and knowledge, needs for capacity development, priority datasets, infrastructure, and technology for each Challenge. Focusing investments in science and knowledge to address these needs will help ensure progress towards meeting each critical Challenge by the end of the Ocean Decade in 2030.

The results of the process will contribute to the scoping of future Decade Actions, identification of resource mobilisation priorities, and ensure relevance of the Challenges over time. This White Paper is one of a series of ten White Papers, all of which have been authored by an expert Working Group and discussed at the 2024 Ocean Decade Conference. An Outcomes Report, authored by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization (UNESCO/IOC), will accompany the White Papers.

1.2 Strategic ambition of Ocean Decade Challenge 3

With a substantial portion of people depending on the ocean as a primary source of nutrition and livelihood, a significant challenge comes into focus: How can we ensure that the ocean's resources continue to effectively nourish an expanding global population? The Ocean Decade responds to this critical concern through its Challenge 3: "Sustainably nourish the global population".

Aquatic food systems are interlinked with multiple uses of the ocean and support a wide range of human activities; yet, ongoing provision of nutritious food from the ocean faces two "grand challenges": (1) How do we produce more nutritious aquatic foods sustainably? and (2) How do we ensure more equitable access to aquatic foods? It also faces cross-cutting barriers related to governance and emerging issues. Solutions require understanding these challenges as well as the needs of stakeholders and rights holders involved in aquatic food systems. The Ocean Decade is well poised to generate the science and knowledge to support solution pathways to address these barriers and needs.

The strategic ambition for Challenge 3 is to contribute to sustainably nourishing a global population with food from the ocean. The aim of Working Group 3 was to outline what is needed to generate the science and knowledge necessary to ensure the ocean is recognised and leveraged as a key contributor to nourishing the global population. The Group defined high-level science objectives and outlined targeted science priorities. The former provide a conceptual framework to guide policy- and decision-makers on the use of technical and financial resources for aquatic food systems in distinct contexts. The latter are intended to guide more specialised users to decide on priority scientific approaches for addressing specific challenges related to aquatic food systems. The list is not intended to be comprehensive, rather an initial set of areas identified by the Working Group.

By 2030, success for Challenge 3 will be a paradigm shift towards science that supports a "one food system" approach that leverages multiple disciplines to support a Blue Transformation of the aquatic food sector (FAO, 2022a). This will support work across fisheries, aquaculture, and value chains, a shift towards a nutrition-sensitive understanding of the production and consumption of aquatic foods, and a focus on equity in access and distribution to address hunger and malnutrition, whilst respecting ecological boundaries of aquatic food systems. To fully support and capitalise on

the potential of a Blue Transformation, the Ocean Decade must work to fill critical science and knowledge gaps related to effective governance, sustainable production, equitable access, and emerging issues. Success will also rely on co-design of science by engaging local agents of change, supporting two-way knowledge-, lesson-, and benefit-sharing, and increasing access to and leveraging of interdisciplinary science and knowledge. Capacity development will be critical to enhance local science capacity, enable knowledge and technology transfer (South-South, North-South, South-North, and North-North), and expand the use of different knowledge systems and new knowledge. Increased recognition of the role of local brokers and decentralised institutions for capacity sharing and development is essential.

Success will also depend on leveraging and enhancing existing and building new partnerships (e.g. public-private and multi-stakeholder collaboration, cooperation within and between small-scale and large-scale systems, and with relevant UN processes). Infrastructure will also be essential, including data infrastructure (e.g. storage, delivery, protocols for data sharing that are based on principles of equity, and inexpensive data collection, management, and visualisation methods and platforms), institutional infrastructure (especially in emerging nations), and technical infrastructure (e.g. supply chain infrastructure for small-scale fisheries and aquaculture (SSFA)). Finally, technical and social innovation for sustainable, feasible, and cost-effective production and distribution methods that are rooted in principles of equity, will be critical for success.

1.3 Key recommendations to achieve the strategic ambition

Below, a set of recommendations for the generation of science and knowledge within the Ocean Decade that will help ensure the ocean is recognised and leveraged as a key contributor to nourishing the global population (Challenge 3):

- Apply clear science objectives to guide overarching science governance and funding;
- Develop holistic and interdisciplinary science and knowledge, that spans across fisheries, aquaculture, and value chains, and is centred around an integrated food systems approach;
- Facilitate inclusive, proactive, and co-designed science and knowledge that leverages different knowledge systems;
- Facilitate science and knowledge to support an enabling environment for access to and distribution of aquatic foods, focusing on understanding and addressing trade-offs, and an improved understanding of the land-sea interface;
- Develop science and knowledge that helps enhance the focus on SSFA, women, and youth in aquatic food governance and management;
- Enhance partnerships with the private sector and actors from emerging nations;
- Facilitate science and knowledge to innovate existing and develop new technologies for distribution and production of nutritious aquatic foods while minimising environmental impacts and addressing socio-economic trade-offs.

1.4 Key milestones and indicators for the strategic ambition

The key milestones and indicators that will be used to measure the fulfilment of the strategic ambition include:

Milestone 1: Diverse Ocean Decade Actions

Increased diversity of aquatic food related Ocean Decade Actions that capture the multiple dimensions of science required to successfully optimise the role of the ocean in nourishing the global population and fill science gaps identified by the Vision 2030 process.

Indicator 1.1: Number of new Ocean Decade Actions that address Challenge 3 science needs and current gaps identified by Working Group 3: Number of new programmes and projects initiated that focus on aquatic foods. These should be mapped to thematic and regional foci as well as science objectives outlined in this White Paper. This indicator will enable assessment of gaps or areas in need of growth and support the evaluation of proposals for new Actions.

Indicator 1.2: Number of targeted Calls for Actions under the Ocean Decade related to Challenge 3: Number of Calls for Actions that capture thematic areas outlined in this White Paper, and especially those identified as priorities and/or aligned with the Science Objectives outlined in this White Paper.

Indicator 1.3: Establishment of a Decade Collaborative Centre (DCC) / Decade Coordination Office (DCO) for Challenge 3 by 2026: Given that cooperation, collaboration, and a coordinated approach are key to addressing Challenge 3, the establishment of an Ocean Decade structure dedicated to developing science on aquatic food systems is critical.

Milestone 2: Increased funding for Ocean Decade Actions

Increased funding for aquatic food systems science.

Indicator 2.1: Amount of funding raised for Ocean Decade Actions related to Challenge 3: This indicator can be assessed by tracking the total financial and in-kind resources mobilised, including government funding, private sector investments, and philanthropic contributions related to aquatic food systems.

Indicator 2.2: Diversification of funding sources for all Ocean Decade Actions addressing Challenge 3: Proportion of funding, disaggregated by geography, received from different sectors, such as government, private sector, civil society organisations, and international funding mechanisms, to address Challenge 3.

Milestone 3: Diverse and inclusive stakeholder engagement

Increased diverse, inclusive, and meaningful stakeholder engagement and participation, in particular by SSFAs.

Indicator 3.1: Proportion of relevant stakeholders involved in Ocean Decade Actions and activities related to Challenge 3: Number and type of stakeholders and rights holder groups in the Ocean Decade ecosystem related to Challenge 3 (e.g. SSFAs, government agencies, private sector, etc.), disaggregated by region and gender. This will inform whether the Ocean Decade is effectively engaging relevant actors of aquatic food systems.

Indicator 3.2: Number of partnerships developed between key users of aquatic food systems within Ocean Decade initiatives: Given the need for holistic approaches to science, as well as the insufficient amount of partnerships linked to Challenge 3, under and beyond the Decade, tracking the number of partnerships (linking users, types of science, etc.), and the regions they connect to (especially emerging nations), will be a strong metric for moving away from silos as well as sharing knowledge and developing capacity. A focus should be placed on assessing institutional partnerships.

Indicator 3.3: Number of Ocean Decade Actions related to Challenge 3 led by emerging nations: Given that existing science under the Ocean Decade is dominated by leadership by Global North institutions, as well as a focus on Global North science (and knowledge systems), the Ocean Decade should prioritise subverting these tendencies; this indicator provides a means of assessing progress towards this goal. This can be assessed by tracking the origin of products developed under the Ocean Decade, comparing the number of overall products linked to Challenge 3 to those generated by actors from emerging nations. It should also be disaggregated by topic, to help assess whether identified science gaps are being addressed effectively.

Milestone 4: Developing capacity for Ocean Decade Challenges and sharing knowledge

Increased capacity of individuals, institutions, and communities to effectively address Challenge 3, and generation and sharing of scientific knowledge and information related to aquatic food systems, especially South-South-North knowledge sharing.

Indicator 4.1: Number of capacity development initiatives within the Ocean Decade ecosystem: Number and type of capacity development initiatives, workshops, training programmes, and educational activities implemented to develop capacity in addressing Challenge 3, disaggregated by country and region, and focus audience.

Indicator 4.2: Number of participants trained under Ocean Decade capacity development initiatives: Reach and impact of aquatic food system science capacity development initiatives organised under the Ocean Decade. It can be measured by tracking the number of participants enrolled, trained, or certified through these initiatives, disaggregated by country or region, gender, age, and membership to an indigenous population.

2. INTRODUCTION

Billions of people rely on the ocean for food and nutrients, livelihood, and culture; yet, this dependence is threatened by the triple planetary crises of climate change, pollution, and biodiversity loss. From this, a significant challenge comes into focus: How can we ensure that the ocean's resources continue to effectively nourish an expanding global population? The United Nations (UN) Decade of Ocean Science for Sustainable Development (hereafter, Ocean Decade) responds to this critical concern through its Challenge 3: "Sustainably nourish the global population".

The Ocean Decade Vision 2030 process Working Group 3 brought together critical interdisciplinary competencies and experience to identify science, knowledge, and innovation needs to support solutions for optimising the ocean's role in nourishing the world in the face of changing environmental, social and climate conditions. This White Paper outlines opportunities and barriers of aquatic food systems, identifies science and knowledge needs for achieving solutions, and determines metrics for evaluating progress and measuring success.

2.1 Background and purpose

The high and growing prevalence of hunger and malnutrition in the world (FAO et al., 2022), combined with climate and environmental challenges (IPCC, 2022), suggests that the global food system is failing to deliver safe, nutritious, sustainable, affordable, and equitable diets. Despite presenting an important opportunity for supporting the achievement of the Sustainable Development Goals (SDGs)[1], aquatic foods are widely undervalued. They remain absent from the UN SDG 2 (Zero Hunger) dialogue and are insufficiently represented in global nutrition reviews, such as the *EAT-Lancet Commission Report* (Willett et al., 2019). Despite recent rises, funding for developing the potential of aquatic food systems also remains scarce (Bennett et al., 2021). As a result, the international community is calling for a transformation of food systems, as highlighted in the 2030 Agenda for Sustainable Development and echoed during the 2021 UN Food Systems Summit. The UN Food and Agriculture Organization's (FAO) 2022-2030 roadmap for Blue Transformation outlines a path to maximise the contribution of aquatic food systems to achieve this transformation (FAO, 2022b). The UN Ocean Decade is well poised to support this Blue Transformation.

2.1.1 Opportunities presented by aquatic food systems

Aquatic foods represent all edible aquatic organisms, including fish, shellfish, algae, and

[1] Aquatic foods contribute to achieving the following SDGs: Zero poverty (SDG 1), Zero hunger (SDG 2), Health and wellbeing (SDG 3), Responsible consumption and production (SDG 12), Climate change (SDG 13), and Life below water (SDG 14).

aquatic plants, from marine and freshwater production systems (aquaculture and fisheries); Figure 1 provides an overview of the aquatic food system. The FAO (2018) defines a sustainable aquatic food system as one "that delivers food security and nutrition for all in such a way that the economic, social, and environmental bases to generate food security and nutrition for future generations are not compromised".

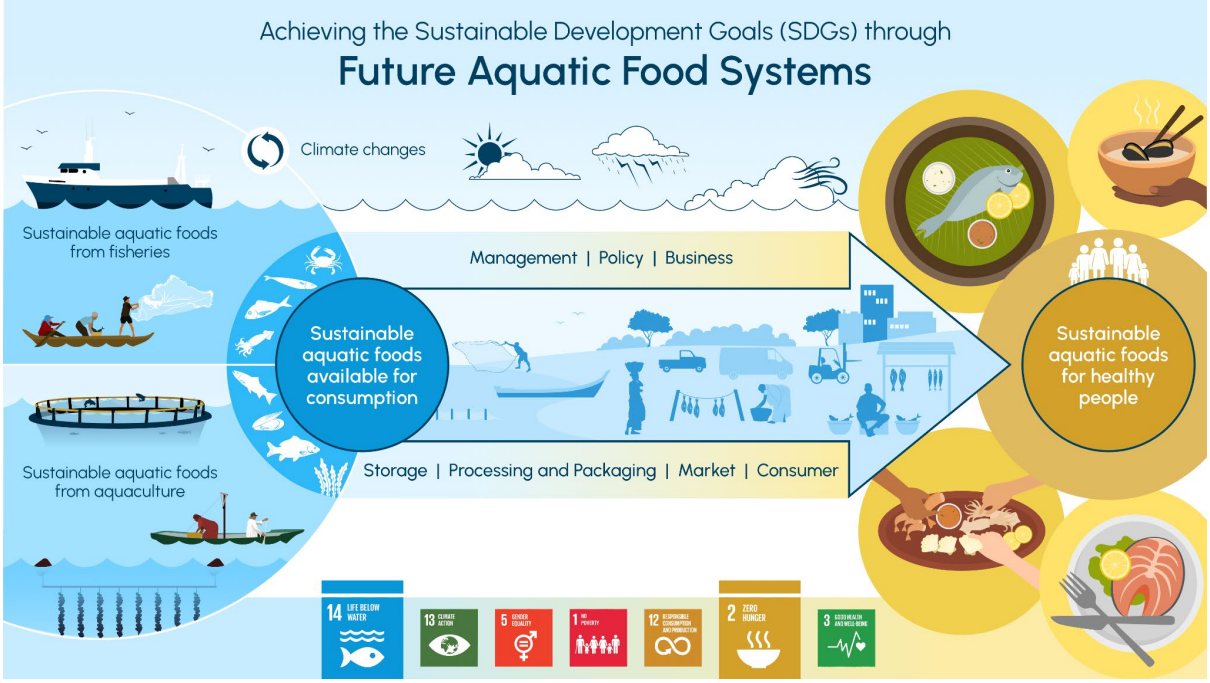

Figure 1. *Conceptual overview of future aquatic food systems and their contribution to key SDGs (prepared by the UN Ocean Decade Project "ClimeFOOD").*

Aquatic foods provide a critical source of micronutrients and omega-3 fatty acids. The high nutritional value of aquatic foods has been highlighted by several recent studies (Golden et al., 2021; UN Nutrition, 2021; FAO, 2022a). Nutritionally vulnerable populations are particularly dependent on aquatic foods for their diet, and aquatic foods have the potential to close critical nutrient gaps in areas vulnerable to hunger and malnutrition, such as West and sub-Saharan Africa (Hicks et al., 2019). Aquatic foods currently provide about 17 percent of animal protein worldwide, reaching more than 50 percent in several Asian and African countries (FAO, 2022a). The FAO, Duke University, and WorldFish (2023) estimate that marine small-scale fisheries (SSF) could provide 105.5 million women with 20 percent of the recommended nutrient intake for six nutrients (calcium, iron, selenium, zinc, vitamin A, and omega 3). Aquatic foods further benefit nutrition by offering an alternative to the consumption of red and processed meat, which can have adverse health impacts (Golden et al., 2021). They therefore are crucial to filling nutrient deficiencies globally, improving health, and lowering disease burden (Crona et al., 2023).

Aquatic food systems are also at the heart of livelihood opportunities for many coastal communities. The FAO (2022a) estimates that 600 million people depend, at least partially, on the aquatic food sector, including through direct consumption and nutrient intake, by creating employment, and through trade and export revenue. In the primary sector, an estimated 58.5 million people are employed in aquatic food systems, about 21 percent of whom are women. In the post-harvest sector, almost 50 percent of workers are women—the highest contribution by women in the fisheries and aquaculture value chain (FAO 2022a). Small-scale fisheries and aquaculture (SSFA) are particularly reliant on aquatic food systems for their livelihood; the SSF sub-sector employs an estimated 60.2 million people along the

value chain, with about 492 million people dependent, at least partially, on engagement in it (FAO, Duke University, and WorldFish, 2023). Aquatic foods, like most foods, also have important cultural value, linked to heritage, identity, norms, and practices which impact on food habits and nutritional needs of communities (Thilsted et al., 2016; Cojocaru et al., 2022; Tigchelaar et al., 2022).

Aquatic food systems have a lower environmental footprint compared with land-based production systems, according to criteria including greenhouse gas, nitrogen emissions, and land and water use. Although most aquatic foods perform well according to their environmental impact, some have particularly low impact (e.g. farmed bivalves and algae) and several also have higher nutrition density (Gephart et al., 2021; Hallstrom et al., 2019).

Overall, aquatic foods have the potential to help transition the global food system towards diets that are socially, economically, and environmentally sustainable. For this, a Blue Transformation is needed to expand aquatic food systems and increase their contribution to nutritious and affordable healthy diets for the most vulnerable, while fostering equitable growth, especially for communities that depend on fisheries and aquaculture (FAO, 2022a).

As outlined above, aquatic food systems present many opportunities, however their availability and safety are heavily dependent on wider ecosystem health and climate change. Changes generated by climate impacts and ecosystem degradation can disrupt food webs and the ability of aquatic organisms to grow, multiply, and thrive (Barange et al., 2018; Lam at al., 2020). Access to and utilisation of aquatic foods are also linked to the wider Blue Economy and other ocean industries (e.g. tourism, shipping, and energy). Whilst sustainable production of aquatic foods has a relatively low detrimental effect on ocean systems, unsustainable production can contribute to negative impacts including overfishing, pollution, antimicrobial resistance, habitat destruction, biodiversity loss, and the introduction of invasive species.

2.1.2 Barriers to achieving Ocean Decade Challenge 3

Aquatic food systems face a wide range of barriers, reflective of their complexity. They include many subsystems (e.g. input supply systems, waste management, etc.) and interact with and are embedded in other key systems (e.g. trade and health systems) (FAO, 2018). The diverse and cross-cutting nature of aquatic food systems translates into obstacles that extend beyond those traditionally faced by ocean sciences, management, and governance to include broader food system challenges, amongst others. Understanding and framing these complex barriers is critical to effectively identifying science needs and developing solutions.

The challenges to optimising the ocean's role in sustainably nourishing the world's population have already been extensively documented.[2] Working Group 3 found that most of these barriers can be summarised into two "grand challenges", with associated cross-cutting challenges (see Table 1 below):

1. How do we *produce* more nutritious aquatic foods sustainably?
2. How do we ensure more equitable *access* to aquatic foods?[3]

The production of aquatic foods is predicted to significantly increase in the coming decades, with fisheries and aquaculture production (excluding algae) expected to reach 202 million tonnes by 2032 from the current 182 million

[2] These include the Blue Food Assessment, the High Level Panel for a Sustainable Ocean Economy (HLP) initiative (see Costello et al., 2019), the periodic FAO State of World Fisheries and Aquaculture (SOFIA) reports, the UN Nutrition (2021) review of aquatic foods, and the *Illuminating Hidden Harvests* study (FAO, Duke University, and WorldFish, 2023).

[3] In this context, "access" refers to the process of accessing food physically and economically, thereby also encompassing dimensions of distribution and allocation.

tonnes, of which about 90 percent will be for human consumption (OECD/FAO, 2023; Wang et al., 2023). In parallel, consumption of aquatic foods is expected to increase by 25 percent by 2050, although with considerable regional variation (Naylor et al., 2021; FAO, 2022a). A Blue Transformation is needed to meet this global demand, requiring a comprehensive approach that integrates sustainable aquaculture development—currently, the fastest-growing food sector worldwide—with ambitious and effective management of capture fisheries, and the establishment of innovative and efficient value chains (FAO, 2022a). Yet, the current "business-as-usual" approach to production fails to sufficiently address key barriers to sustainability (Table 1). This could result in a drop in annual per capita consumption of aquatic foods to 18.5 kg by 2050, returning to pre-2012 levels, thus inhibiting food and nutrition security (FAO, 2022a).

Equitable access to aquatic foods is also critical to effectively and sustainably nourish the global population. Whilst malnutrition reduction policies have previously focused on production, global priorities are shifting to "move beyond a focus on food production and to consider the whole food system", recognising that increased production does not necessarily equate to nutritious food being provided to populations in need (Béné et al., 2019; HLPE, 2019). Indeed, despite as many as 783 million people lacking sufficient food and nutrition (FAO et al., 2023), about one-third of the food produced globally is lost or wasted annually, presenting a critical challenge both in terms of food security and environmental sustainability (FAO, 2011; FAO, 2020). The barriers to equitable access to aquatic foods are many and varied (Table 1), with causal mechanisms linked to ecosystems (e.g. shifting distribution of fish stocks), access rights, and market and health system dynamics (e.g. price, unequal trade, etc.). Addressing the challenge of equitable aquatic food access will be one of the most important elements in sustainably nourishing the global population; this will involve an optimised use of resources as opposed to increased pressure on them, and the promotion of consumption, processing and preparation of nutrient-dense sustainably produced aquatic foods that considers cultural norms and values.

Sustainable production of and equitable access to aquatic foods are impacted by cross-cutting barriers linked to governance and new frontiers (e.g. alternative food sources, technology, and innovation). The complexity of the aquatic food system requires a holistic, integrated, and coordinated approach to governance; yet, currently, this is impeded by fragmented and siloed approaches, resulting in power imbalances, mal-adaptations (e.g. solutions to a sectoral challenge leading to increased carbon dioxide emissions), and vulnerability to climate change and geopolitical shocks. Since aquatic foods are dynamic systems, anticipating and proactively addressing emerging challenges linked to new frontiers is essential.

When it comes to governance challenges, recent international efforts have acknowledged the specific challenges experienced and the opportunities presented by SSFA in aquatic food systems, including SDG Target 14.b to "provide access of small-scale artisanal fishers to marine resources and markets" and the FAO (2015) *Voluntary Guidelines for Securing Sustainable Small-scale Fisheries in the Context of Food Security and Poverty Eradication (SSF Guidelines)*. Yet, SSFAs remain undervalued and underrepresented in aquatic food system analyses, governance, and investments, and are thus particularly impacted by systemic barriers. Given their often-limited production area and economic and technical means, SSFA are sensitive to environmental changes and the impacts of climate change. Inadequate access and property rights also tend to disadvantage SSFA, resulting in insufficient aquatic foods being kept and consumed locally, both in quantity and quality. Addressing the specific and diverse needs of SSFA is essential to effectively nourishing vulnerable populations through direct aquatic food consumption by local populations and aquatic food-derived income (Short et al., 2021; Viana et al., 2023).

Table 1. *Key barriers to addressing Ocean Decade Challenge 3: "Sustainably nourish the global population".*

GRAND CHALLENGES	
SUSTAINABLY PRODUCING AQUATIC FOODS	**EQUITABLY ACCESSING AQUATIC FOODS**

• Unsustainable fisheries and aquaculture (management and practices):
  ○ Habitat degradation, biodiversity loss, water quality,
  ○ Overfishing and bycatch,
  ○ Pollution, invasive species, animal welfare, and biosecurity,
  ○ Illegal, Unreported and Unregulated Fisheries (IUU),
  ○ Harmful subsidies,
  ○ Social inequality
• Climate change (e.g. extreme events, ocean warming, acidification, and deoxygenation).
• Lack of access to finance and credit for SSFAs (including aquaculture).
• Crowded ocean space under an expanding Blue Economy and population growth.
• Unsustainable consumption and limited consumer preferences, exacerbated by underinvestment in consumer awareness and in development of culturally accepted aquatic food products.
	• Lack of secure property and tenure rights, and access to resources and services.
	• Inaccurate and untransparent valuation of nutrition, economic, and social benefits by markets and trade.
	• Lack of access to nutritious, safe, and affordable aquatic foods (often exacerbated by climate change and other anthropogenic impacts).
	• Excessive loss and waste linked to inadequate post-harvest capacities, infrastructure, and logistics for distribution.
	• Insufficient monitoring and transparency of supply chains (to trace environmental impacts and human rights abuses).
	• Inadequate social protection schemes for vulnerable value chain actors and consumers.

CROSS-CUTTING CHALLENGES	
GOVERNANCE • Lack of integrated food policies and management frameworks (balancing multiple dimensions of sustainability, addressing incoherence across food systems). • Lack of climate-adaptive management and access systems (e.g. to respond to changing distribution and productivity of species and habitats). • Insufficient engagement and support to SSFAs, women, indigenous groups, youth, and emerging nations (to improve equity and power balances). • Geopolitical tensions and resulting market shocks, crisis, conflict, and uncertainty. • Need for transboundary and international cooperation to manage shared resources, limit power imbalances amongst actors and address global challenges (e.g. IUU fishing). NEW FRONTIERS • Ensuring synergies and circularity between aquatic and terrestrial food systems ("one food system"). • Developing participatory platforms and methodologies for co-creating knowledge and collaboratively designing innovative solutions. • Ensuring sustainability, equity and food safety of innovative (or currently lightly exploited) alternative aquatic food sources (e.g. lower-trophic species, seaweeds, microalgae, genetically modified species, and plant-based foods). • Developing and employing new technologies and digital tools (e.g. artificial intelligence (AI)). • Expanding innovation in alternative production systems (e.g. offshore aquaculture, integrated multi-trophic aquaculture (IMTA) systems).	

2.2 Methodology for setting the strategic ambition

To outline the elements needed to meet the strategic ambition for Ocean Decade Challenge 3, a variety of sources were consulted, and expertise leveraged to identify aquatic food system users and their needs, determine the science and knowledge to support these, and develop milestones and indicators to measure success. Annex 1 provides a more detailed overview of the methodology.

3. SETTING THE STRATEGIC AMBITION: SCIENCE NEEDS TO SUPPORT SOLUTIONS

The strategic ambition for Challenge 3 is to contribute to sustainably nourishing a global population with food from the ocean. The aim of Working Group 3 was to outline what is needed to generate the science and knowledge necessary to ensure the ocean is recognised and leveraged as a key contributor to nourishing the global population. By 2030, success for Challenge 3 will be a paradigm shift towards science that supports a "one food system" approach that leverages multiple disciplines to support a Blue Transformation of the aquatic food sector (FAO, 2022a). This will support work across fisheries, aquaculture, and value chains, a shift towards a nutrition-sensitive understanding of the production and consumption of aquatic foods, and a focus on equity in access and distribution to address hunger and malnutrition, whilst respecting ecological boundaries of aquatic food systems.

3.1 Users of Ocean Decade Challenge 3

Challenge 3 is characterised by a wide array of users. The most obvious users are aquatic food producers, ranging from large-scale industrial fishing companies to small-scale subsistence fishers and aquaculture producers. These include suppliers (e.g. hatcheries, aquafeed producers, health and disease management specialists, equipment, and technology providers, etc.), processors, distributors, and retailers of aquatic foods. Land-sourced food producers are also relevant, given the connectedness of aquatic foods to the broader food system (e.g. use in animal feed). The private sector is critical as it carries out most of the activities within the aquatic food system. Consumers of aquatic foods and derived products (e.g. fishmeal and fish oil) are also key actors. As a result of the interconnected nature of aquatic food systems, actors within the wider ocean space (e.g. tourism, energy, and shipping) and health, nutrition, and environmental experts and stakeholders are also important.

Higher-level users, such as governments, policymakers, managers, scientists, non-governmental and intergovernmental organisations, and educational institutions can play a critical role in creating an enabling environment for sustainable and equitable aquatic food systems. Other high-level actors include investors, financial and trading organisations, as well as certification and standards organisations related to production (e.g. supply chain transparency) and influencing consumption. It is important to note that many of these types of high-level users from emerging nations are often not able to engage sufficiently due to limited access and resources.

Small-scale actors are particularly critical users, given their central role within the aquatic food system. Recent estimates indicate that globally, marine SSF contribute 25.1 million tonnes to the global ocean catch, representing almost 30 percent of the global marine catch (FAO, Duke University, WorldFish, 2023). The importance of SSFA is especially significant in emerging nations, where challenges of malnutrition and hunger are prevalent (Short et al., 2021). A key priority for the Ocean Decade moving forward must be to ensure that the challenges, perspectives, and needs of SSFAs, including indigenous communities, women, youth, and early career ocean professionals, are fully acknowledged, and addressed.

3.2 The science we have

Substantial science already exists pertaining to aquatic food systems. This body of work has primarily focused on the physical sciences and key species, actors, and regions. Although it has contributed to some sustainable outcomes (e.g. the recovery of overfished stocks in North America, Oceania, and Europe), it is limited by a siloed approach that neglects the multiple dimensions of aquatic food systems and the importance of alternative types of knowledge. There is also a gap between existing science and decision- and policy-making, pointing to the need for improved processes for the uptake of science.

3.2.1 Science under the Ocean Decade

Of the 431 Ocean Decade Actions, 5 Programmes, 23 Projects, and 5 Contributions focus solely on Challenge 3 (as of November 2023), making Challenge 3 slightly less represented across Actions compared to other Ocean Decade Challenges. A diverse set of aquatic food topics are nonetheless covered, with a focus on the climate resilience of aquatic food systems, food security and nutrition, ecosystem approaches for fisheries management, and technological and social innovations for sustainable and nutrition-sensitive aquaculture. Yet, critical thematic and geographic gaps remain. For instance, supply chain components of aquatic foods, linkages with the wider ocean economy, technological innovations for new frontiers, and, significantly, most dimensions of equity in aquatic food systems as well as the visibility and inclusion of SSFA and local and indigenous communities remain underrepresented. Most of the knowledge and data being generated for Challenge 3 is focused on environmental and biological aspects, with more limited knowledge production on the socio-economic dimensions of the system.

The global distribution of Actions reflects diverse geographical coverage, with several focused-on Africa—a particularly important area for aquatic foods and hunger and malnutrition—and the Indian Ocean. Yet, institutions leading the Actions are nearly all based in Europe and North America, reflecting a broader lack of representation of emerging nations at the institutional level; a key exception is the AfriMAQUA programme. In addition, the South Pacific is underrepresented; a critical gap given the importance of aquatic food systems in the region.

In addition, capacity development is not sufficiently integrated across Decade Actions for Challenge 3, with only a few Actions touching on this but limited to specific issues and regions. Ocean Decade Actions focused on developing partnerships, which are essential for connecting the various Challenge 3 users (e.g. the private sector, SSFA, women, indigenous peoples, and youth) also remain limited. Finally, it is also noteworthy that several Ocean Decade Actions address similar themes, potentially leading to repetition in data and knowledge generated under the Ocean Decade.

3.2.2 Science external to the Ocean Decade

A significant part of the science and knowledge on aquatic foods extends beyond the ocean and the current scope of the Ocean Decade. To understand aquatic foods and their role in sustainably and equitably nourishing the global population, it is critical to examine what happens to these products once they are out of the water. This includes the processing, transformation, and distribution of aquatic food products, science and data related to land-sourced food (and its relation to aquatic foods), and monitoring food safety. Socio-economic data on household consumption and consumer preferences and behaviours, along with nutrition and health data on the impacts and benefits of various aquatic foods, are critical for understanding how best to nourish an expanding global population. In addition, a large share of aquatic food production occurs in brackish and freshwater environments (especially aquaculture); hence, fully addressing barriers in aquatic food systems requires a science agenda that spans all

aquatic environments. Harnessing this extensive relevant science, a portion of which exists but does not currently reside under the Ocean Decade, will be critical in moving forward to address Ocean Decade Challenge 3.

3.3 The science we need

Solutions to address barriers within aquatic food systems have been proposed by a number of international initiatives.[4] Despite the breadth of initiatives, the proposed solutions converge on key pathways for change and align with the Blue Transformation vision (FAO, 2022a; FAO, 2022b). They highlight the three components of aquatic food systems around which interventions should be structured: capture fisheries (their value and management), aquaculture (emphasising mariculture, technological innovation, and sustainable intensification), and supply chains. At the governance level, they highlight the need for integrated approaches to aquatic food systems, consideration of the Blue Economy, and a focus on food safety, nutrition, and health. The initiatives also underscore the central role of equity and pay specific attention to SSFA.

The solutions proposed by these international initiatives have focused on policy and practice, with less emphasis on identifying specific science needs to support these solutions. A two-tiered approach to identifying the science and knowledge needs for aquatic food systems was developed to address the needs of different types of actors in the Ocean Decade: (1) A definition of high-level science objectives, intended to provide a conceptual framework to guide policy- and decision-makers on technical and financial resources needed for a robust scientific enterprise that supports aquatic food systems, and (2) An outline of science priorities related to specialised topics of critical importance for addressing aquatic food system challenges.

3.3.1 High-level science objectives

To inform sound decision-making on science investments and guide science programmes, Working Group 3 identified five high-level science objectives (Figure 2). These were developed with the understanding that high-level decision-makers (including in the Ocean Decade) typically have to operate with a limited in-depth understanding of specific science approaches, and act with the aim to identify where in the science value chain a need or gap exists, and how resources should be deployed to address these. The proposed framework is centred on five key roles (or "objectives") that scientific information plays in aquatic food systems. These are not linear—one is not a prerequisite for another—but rather form a framework for systematically evaluating any proposed scientific investment.

[4] These include the High-Level Panel on a Sustainable Ocean Economy (Costello et al, 2020), Farmery et al. (2021), the Future Seas Project (Farmery et al., 2022), Tigchelaar et al. (2022), Crona et al. (2023) based on the outcomes of the Blue Food Assessments, the Blue Transformation roadmap (FAO, 2022b), and the *Illuminating Hidden Harvests* study (FAO, Duke University, and WorldFish, 2023).

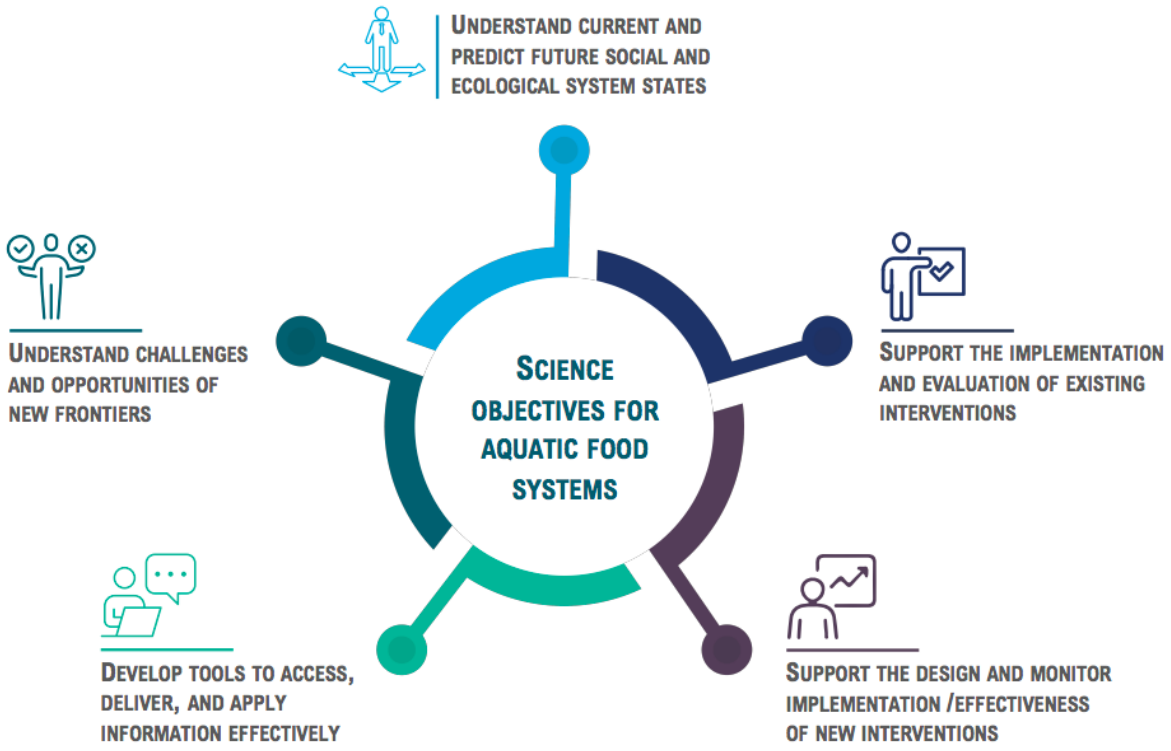

Figure 2. *Science objectives for sustainable and equitable aquatic food systems.*

The first objective focuses on the most obvious role of science: to understand the current state of the system and predict future changes. This understanding is fundamental to all actions in the ocean, and predicting future states helps to effectively anticipate problems and capitalise on opportunities. The second objective focuses on the role of scientific information in implementing and evaluating existing interventions. For example, effective catch quotas may require stock assessments and catch monitoring, while implementing IMTA systems requires data on ecological interactions between different trophic levels. The third objective relates to the design, implementation, and evaluation of new interventions (e.g. international agreements to prevent overfishing of transboundary stocks) which may require new scientific monitoring (e.g. vessel tracking information); for instance, evaluating the success of a new sustainability standard for aquaculture may require modern causal inference techniques. On a broader scale, the fourth objective concerns the development of tools to make scientific information and knowledge available (e.g. new platforms for public access to real-time data on oceanography, trade, fishing activity, and aquaculture expansion monitoring), which can encourage more efficient and equitable decision-making. The fifth objective captures the role of science in identifying new challenges and opportunities, recognising the role of science in uncovering previously unanticipated challenges. For instance, researching induced sterility through gene editing to support more sustainable aquaculture practices in the future.

This framework can serve as an initial filter for any proposed investment in scientific information, including guiding targeted efforts in the Ocean Decade (e.g. Calls for Actions). Investments should be assessed against this framework to help determine how, where, and by whom the information produced could be used and identify gaps or imbalances in the Ocean Decade. If the information does not have direct implications for interventions or a home in this framework, it should receive lower priority for investment.

3.3.2 Targeted science priorities

Recognising that there are a multitude of science needs and that any list is necessarily partial, we did not intend for our list of science priorities to be exhaustive. Here, we highlight

examples of priority science needs to address the key barriers identified in section 2.2.

Science priorities for governance

A primary science need for governance is understanding trade-offs and trends across and within aquatic food systems to enable policy coherence.[5] The ambition to use aquatic foods to nourish the world must be balanced against the global targets to reduce carbon dioxide emissions and minimise impacts on habitats and biodiversity. Within the various dimensions of aquatic food systems (e.g. food security, nutrition, equity, and environmental sustainability) and use of ocean spaces (e.g. in exclusive economic zones, including for marine spatial planning) further trade-offs exist. These form a multi-faceted "wicked problem", necessitating strong multi- and interdisciplinary science to identify pathways that balance these trade-offs and address the interests of different sectors and governance interventions to regulate them (e.g. subsidies that distort production and consumption).

Aquatic food science and management must also become more climate-adaptive, starting with assessing and monitoring climate change impacts (e.g. range shifts, species establishment in novel locations and adaptation, and social impacts on vulnerable communities), including cumulative impacts. Whilst this science already exists, there are major gaps and regional disparities that must be addressed.

Science to better understand and support the sustainability of aquatic food systems in the face of geopolitical tensions is another priority. This involves fostering intergovernmental cooperation and understanding potential ramifications of macro-level tensions and shocks on aquatic food production and access, and on the governance of science itself. Proactive science-driven approaches are crucial for building preparedness and resilience, thereby mitigating adverse effects of geopolitical uncertainties.

Barriers to participation in governance operate at multiple scales; therefore, science that is more localised and inclusive, and knowledge sharing processes at local, national, and international levels, is necessary (Kawarazuka et al., 2023). In addition, scientists need to engage with decision-makers to both understand policy needs and share knowledge. Critical science is also required to facilitate the involvement of SSFA, with a particular focus on women, indigenous groups, and youth, encompassing the need to engage diverse knowledge systems (e.g. indigenous and traditional knowledge) across dimensions of aquatic food science, and include heritage values. This must amplify the voices of rights holders in governance, building on efforts to promote and develop SSFA capacity to engage in decision-making (CFFA, 2022). The Ocean Decade can serve as a platform to integrate different forms of knowledge and transform how science is understood and used to support the sustainable development of aquatic food systems.

Science priorities for sustainable production

Science priorities for sustainable aquatic food production must provide knowledge and data to address challenges such as unsustainable fisheries and aquaculture (including lack of effective monitoring and enforcement of regulations in place), climate change impacts, underinvestment, and credit constraints for SSFA, crowded ocean spaces, and unsustainable consumption and consumer preferences, among others. In parallel, science should also support strengthening of existing sustainable practices, providing capacity and resources for continuation and replication.

Science priorities include providing holistic and transdisciplinary knowledge, specifically collecting nutritional, pollutant, and health data on aquatic foods at the species level and considering the impact of processing methods

[5] FAO (2016) provides a detailed overview of challenges, solutions and needs related to policy coherence and improved governance for aquatic food systems.

to make production and access more nutrition-sensitive (e.g. species-specific nutrition and pollution data linked to aquatic food diversity). Assessing the multiple sustainability outcomes of aquatic food production is also key. In parallel, science to understand consumer preferences and support consumer awareness should include tools for science communication, consumer education, and understanding leverage points to align consumer behaviour with sustainable and equitable production. Science that investigates trade-offs to support managing conflicts in ocean spaces (e.g. science for spatial analysis and siting of aquaculture farms and exploring synergies between fisheries and aquaculture) is also a priority for sustainably increasing production.

Science for production innovation, technology, and infrastructure is critical, including the development and implementation of adaptive management tools and methods, more sustainable and energy-efficient aquaculture methods (e.g. improved selective breeding, feeding, and disease and waste management practices, IMTA systems) and capture fisheries processes (e.g. ethical gears), and enhancing animal welfare and biosecurity. Moreover, a focus on developing efficient and cost-effective methods for resilient aquatic food production, habitat restoration, integrated environmental and contaminant monitoring, and preparedness for extreme events is also important. Beyond production environments, cost-effective tools and interventions to assess and reduce food loss and waste and promote circularity—in supply chains, from subsistence to high-value export markets—is a high priority from both a nutrition and environmental sustainability perspective. It is also critical to use existing sustainable resources where they already exist. Science is also needed to evaluate how advancements in innovation, technology, and infrastructure to sustainably increase aquatic food production interact with efforts to promote equitable access to aquatic foods and to identify governance tools to manage trade-offs.

Given the variety of actors in aquatic food production, sustainable production requires science to be accessible across different scales and stakeholders. There is a need to develop inexpensive methods for longitudinal data collection, management, analysis, and interpretation, especially in data-deficient regions to capture the needs of local communities (FAO, Duke University, and WorldFish, 2023). The development of tools for forecasting and intuitive visualisation of data is also critical. In particular, accessible near real-time data (e.g. on exploitation, stocks, and physical conditions) are vital given the dynamic nature of aquatic food systems. Alongside the development of new methodologies and approaches, it is critical to implement capacity-development initiatives to minimise the digital divide.

Science priorities for equitable access

Science priorities related to equitable access to aquatic foods are perhaps the most neglected under the Ocean Decade, and in ocean science more generally, given their connection to disciplines not commonly associated with ocean sciences. Enabling just and equitable aquatic food systems requires science that harnesses the diversity of actors, values, and interests, ensuring that they are legitimised, respected, and considered. A fundamental aspect of this research should inform how costs and benefits from aquatic foods are accessed and what determines inequality, in particular for SSFA, through a lens of Blue Justice.

Science should explore how power imbalances and institutionalised structures can create barriers to participation in aquatic food systems, resulting in burdens or benefits falling on particular social groups (Hicks et al., 2022). Specific science areas to prioritise should focus on better understanding trade-offs between different values and objectives of the aquatic food system (e.g. production, affordability, nutrition, etc.) and equity (Gelcich et al., 2006; Viana et al., 2019). Research to support SSFA and their viability in the face of dysfunctional institutions, inequitable access to

resources and opportunities, and environmental change is critical. Understanding the role of small-scale actors in post-harvest, trade, and marketing, including the level of organisation, can provide a means to assess the resilience of supply chains and address power imbalances along the aquatic food value chain. Diverse and regular data collection and analysis is required, including social, economic, and ecological data, providing insights into all dimensions of sustainability (during and post- production) and information spanning income levels, geographical locations, and cultural contexts. In addition, science and data on the nutritional value of aquatic foods and related use patterns (e.g. local/domestic human consumption, trade, non-human consumptions) is key to understanding their contribution to equitable access to nutrients.

A focus on science to better understand the relationship between trade and markets is useful to shed light on dynamics of market forces and their impacts on vulnerable populations, co-benefits for businesses, and mechanisms for incentivising compliance, and support transparency and accountability. Addressing teleconnections, where distal consumer preferences and market dynamics can threaten or improve aquatic food systems, is also key (Castilla et al., 2016). It is particularly relevant for science on equitable access to be regionally sensitive and place-based. Also important is research to address the design and scalability of social welfare safety nets to aid vulnerable value chain actors and consumers when faced with crisis or shocks (e.g. role of social and income protection in sustainable resource management).

Equitable access in aquatic food systems also needs science for monitoring and transparency of supply chains (e.g. methods to securely provide supply chain and provenance tracking). In addition, science should support improved post-harvest governance more broadly by reducing losses and enhancing the utilisation of byproducts from processing of fish, which can be as high as 70 percent (FAO, 2020). Indeed, improving use of and access to what is already produced has the lowest carbon footprint, contributes to increased available nutrition, and can likely have a positive impact on habitats and biodiversity. Given the practical challenges to distribution, the development of innovation, technology, and infrastructure is a key science need for equitable access. This includes developing methods for full use/circularity and decarbonisation, and for prolonged safe food storage (e.g. cold chain, temperature-controlled supply chain) and logistics. Simple technologies exist to improve shelf life of aquatic foods and make more food available and reduce loss and waste. Sustainable technology for SSFA (e.g. solar-powered ice boxes, FAO-Thiaroye Processing Technique (FTT) ovens, etc.) is especially needed.

In essence, research that supports the implementation of the UN Human rights-based approach framework[6], in the context of aquatic food access, is a priority.

Science priorities for new frontiers

New frontiers in aquatic food systems require proactive science, effectively anticipating and addressing emerging issues. Examples of areas in need of knowledge generation include alternative aquatic food sources, the development of technological innovation for production, the systematic integration of terrestrial and aquatic systems, and the development of participatory platforms and methodologies for co-creating knowledge and collaboratively designing innovative solutions.

Science should specifically prioritise understanding opportunities for and risks associated with macro- and microalgal biotechnology, genetically engineered aquatic food organisms, such as induced-sterility, and plant-based alternatives to aquatic foods. In addition, with the influx of invasive species from climate change, it will become increasingly

[6] Information about the UN Human Rights-Based Approach is available at: https://unsdg.un.org/2030-agenda/universal-values/human-rights-based-approach.

important to manage and, where possible, commercialise these species to reduce their impact on the environment and capture nutritional benefits. Technological innovation is critical to a sustainable aquatic food system. Enhancing understanding of the impacts of advancing technological frontiers, for example, by adopting AI-based technologies, is essential. Furthermore, science should focus on technological innovations for the diversification and sustainable intensification of aquatic food production. This includes advancements in IMTA systems in open waters, land-based, and urban setups, feed, welfare, and biosecurity; aquaculture in offshore and less explored areas; stock regeneration and translocation for capture fisheries and restorative aquaculture.

The paradigm shifts to a "one food system" hinges on the improved understanding of connections between terrestrial and aquatic food systems, encouraging increased cooperation and integration at multiple scales (from local to global). Adopting a circular approach opens avenues for creating resilient solutions for a sustainable food system. Understanding the trade-offs and synergies at a system level—across economic, environmental, and social dimensions—is necessary to support the applications of new solutions for circularity.

Ultimately, addressing emerging issues requires an emphasis on the development and use of effective participatory tools for the co-creation of knowledge and innovative solutions, integrating different knowledge systems. For instance, local and traditional knowledge serves as an important tool to monitoring habitat and stock changes, as well as climate impacts, thereby aiding in the understanding of novel ecosystems in the context of changing local conditions.

3.4 Co-creating and making science accessible to users

Connecting all aquatic food systems users with existing and new science, knowledge, and innovation involves many dimensions—from general steps typical of co-creation and knowledge-sharing to needs specific to aquatic foods (e.g. specific infrastructure needs). These aspects are summarised in Figure 3.

CO-CREATION

- **Co-design** science with local agents of change (e.g. rights holders, SSFA actors, local and indigenous communities, policy- and decision-makers, and industry members).
- **Collect and share** data, incorporating traditional and local knowledge, and citizen science.
- **Support** respectful, ongoing two-way knowledge and lesson sharing, in particular relating to SSFA, local and indigenous communities, gender, and youth.
- **Ensure** inclusive, free, prior, and informed consent, respecting the principle of "not about us without us" and protecting intellectual property.
- **Share** the benefits stemming from the co-creation of science across aquatic food systems.

CAPACITY DEVELOPMENT

- **Enhance** local science infrastructure (e.g. access to energy, the Internet) and capacity, strengthen individual and institutional capacity (e.g. through activities like the EAF-Nansen Programme), enable knowledge and technology transfer (e.g. in post-harvest sector), and expand/use different knowledge systems.
- **Recognise** the role of local brokers and decentralised institutions for capacity-sharing and development and involve private sector actors.
- **Streamline** data and knowledge-sharing platforms adaptable to local capacities and circumstances.

TECHNOLOGY, INNOVATION, AND GAMIFICATION

- **Develop** technical innovation for sustainable, feasible, and cost-effective production methods, especially for SSFA (focus on enhancing existing resources, not duplicate efforts).
- **Transfer** existing and new marine technology to the emerging nations, including the infrastructure and capacity to support this.
- **Develop** partnerships with specialists in human communication, behaviour change, and decision-making, including knowledge brokers, behavioural economists, advertisers, educators, behavioural scientists, human geographers, psychologists, and neurologists.

INFRASTRUCTURE REQUIREMENT

- **Develop** data infrastructure (storage and delivery).
- **Establish** protocols for data sharing (respecting confidentiality, intellectual property).
- **Support** inexpensive data collection and recording platforms, including qualitative data collection approaches (e.g. ethnographic methods for localised data collection).
- **Enhance** transdisciplinary and accessible data visualisation platforms, including collaboration with Ocean Decade Challenge 8.
- **Strengthen** institutional infrastructure in emerging nations for engaging in aquatic food science.
- **Improve** technical infrastructure, in particular across the supply chain and for SSFA.

PARTNERSHIPS AND FUNDING / RESOURCES

- **Cooperate** across multiple international initiatives (e.g. UN programmes). The involvement of FAO in the Ocean Decade, UN-Oceans, and Regular Process for aquatic food systems provides a good example of lessons learned and successful outcomes. In addition, developing linkages (currently un/under-developed) between the UN Ocean Decade (Challenge 3) and the UN Decade of Action on Nutrition could reinforce the nutrition agenda of aquatic foods.
- **Improve** public-private partnerships, including SSFA in science, management, and decision-making.
- **Strengthen** multi-stakeholder collaboration, involving businesses, industry members, governments, communities, networks of private individuals, researchers, educators, NGOs, media influencers, and traditional knowledge holders.
- **Develop** targeted support from philanthropic organisations for critical research, community projects, and infrastructure in aquatic food systems.

***Figure 3**. Dimensions of co-creation of knowledge for Ocean Decade Challenge 3.*

3 SUSTAINABLY FEED THE GLOBAL POPULATION

4. INTEGRATION, SYNERGIES, AND INTERDEPENDENCIES WITH OTHER CHALLENGES

Aquatic food systems are complex and integrated, influenced by and impacting on wider ocean dynamics. Thus, Challenge 3 is strongly interconnected with all other Ocean Decade Challenges (Annex 3 provides a breakdown of specific linkages).

Challenge 3 and Challenge 4 (Develop a sustainable and equitable ocean economy) are clearly interconnected, given that aquatic food systems are part of the Blue Economy. Yet, synergies between the two require further development as the ocean economy often falls short of including aquatic food systems as a whole, considering all dimensions and actors of these systems. Likewise, solutions to Challenge 3 need to be further grounded in the context of a shared ocean space, in which multiple industries operate. It is therefore critical to establish a stronger coordinated approach under the Ocean Decade to addressing Challenges 3 and 4.

Challenge 7 (Expand the global ocean observing system), Challenge 8 (Create a digital representation of the ocean), and Challenge 9 (Skills, knowledge, and technology for all) are cross-cutting Challenges. As such, there already exist strong synergies with Challenge 3; yet important gaps remain (e.g. non-physical data in the ocean observing system and digital representations of the ocean). Given the gaps identified in capacity development related to aquatic foods under the Ocean Decade (see section 3.4), developing linkages between Challenge 3 and Challenge 9 is especially important.

The synergies between aquatic food systems and Challenge 1 (Understand and beat marine pollution), Challenge 2 (Protect and restore ecosystems and biodiversity), and Challenge 5 (Unlock ocean-based solutions to climate change) are already well recognised. Several initiatives under and beyond the Ocean Decade focus on these links and related opportunities to contribute to a healthier and more sustainable ocean. Challenge 3 should support the objectives of Challenge 1 and 2, and collaborate with Challenge 5 to build climate resilience, enhancing existing linkages.

Challenge 6 (Increase community resilience to ocean hazards) and Challenge 10 (Change humanity's relationship with the ocean) represent the least explored synergies with Challenge 3. Yet, strong ocean hazard early warning systems support improved aquatic foods management and contribute to safety at sea; as such, strengthened understanding of ocean hazards constitutes a science priority for sustainable production. In addition, Challenge 10 focuses on holistic and integrated approaches to ocean science which align with objectives for Challenge 3. Moreover, the focus on behavioural change of Challenge 10 reflects science priorities for aquatic food systems related to understanding consumption and production behaviour to achieve sustainable and equitable aquatic foods.

Overall, Challenge 3 closely connects to all other Ocean Decade Challenges, underlining the need for an approach to ocean science that transcends silos and engages across challenges, disciplines, and stakeholders.

5. MILESTONES AND INDICATORS

The Ocean Decade provides a useful framework for addressing science-gaps related to aquatic food systems and thereby optimising the role of the ocean in sustainably feeding the global population. To this end, the below milestones and indicators provide a mechanism for evaluating progress and measuring success of the Ocean Decade Challenge 3. These milestones and indicators are intended to be specific, measurable, achievable, relevant, and, importantly, trackable by the Decade Coordination Unit (DCU) and its partners under the Ocean Decade.

Milestone 1: Diverse Ocean Decade Actions

Increased diversity of aquatic food Ocean Decade Actions that capture the multiple dimensions of science required to successfully optimise the role of the ocean in nourishing the global population

and fill the science gaps identified by the Vision 2030 process.

Indicator 1.1: Number of new Ocean Decade Actions that address Challenge 3 science needs and current gaps identified by Working Group 3: Number of new programmes and projects initiated that focus on aquatic foods. These should be mapped to thematic and regional foci as well as science objectives outlined in this White Paper. This indicator will enable assessment of gaps or areas in need of growth and support the evaluation of proposals for new Actions.

Indicator 1.2: Number of targeted Calls for Actions under the Ocean Decade related to Challenge 3: Number of Calls for Actions that capture thematic areas outlined in this White Paper, and especially those identified as priorities and/or aligned with the Science Objectives outlined in this White Paper.

Indicator 1.3: Establishment of a Decade Collaborative Centre (DCC)/Decade Coordination Office (DCO) for Challenge 3 by 2026: Given that cooperation, collaboration, and a coordinated approach are key to addressing Challenge 3, the establishment of an Ocean Decade structure dedicated to developing science on aquatic food systems is critical.

Milestone 2: Increased funding for Ocean Decade Actions

Increased funding for aquatic food systems science.

Indicator 2.1: Amount of funding raised for Ocean Decade Actions related to Challenge 3: This indicator can be assessed by tracking the total financial and in-kind resources mobilised, including government funding, private sector investments, and philanthropic contributions related to aquatic food systems.

Indicator 2.2: Diversification of funding sources for all Ocean Decade Actions addressing Challenge 3: Proportion of funding, disaggregated by geography, received from different sectors, such as government, private sector, civil society organisations, and international funding mechanisms to address Challenge 3.

Milestone 3: Diverse and inclusive stakeholder engagement

Increased diverse, inclusive, and meaningful stakeholder engagement and participation, in particular by SSFAs.

Indicator 3.1: Proportion of relevant stakeholders involved in Ocean Decade Actions and activities related to Challenge 3: Number and type of stakeholders and rights holder groups in the Ocean Decade ecosystem related to Challenge 3 (e.g. SSFAs, government agencies, private sector, etc.), disaggregated by region and gender. This will inform whether the Ocean Decade is effectively engaging relevant actors of aquatic food systems.

Indicator 3.2: Number of partnerships developed between key users of aquatic food systems within Ocean Decade initiatives: Given the need for holistic approaches to science, as well as the insufficient amount of partnerships linked to Challenge 3, under and beyond the Decade, tracking the number of partnerships (linking users, types of science, etc.), and the regions they connect to (especially emerging nations), will be a strong metric for moving away from silos as well as sharing knowledge and developing capacity. A focus should be placed on assessing institutional partnerships.

Indicator 3.3: Number of Ocean Decade Actions related to Challenge 3 led by emerging nations: Given that existing science under the Ocean Decade is dominated by leadership by Global North institutions, as well as a focus on Global North science (and knowledge systems), the Ocean Decade should prioritise subverting these tendencies; this indicator provides a means of assessing progress towards this goal. This can be assessed by tracking the origin of products developed under the Ocean Decade, comparing the number of overall products linked to Challenge 3 to those generated by actors from emerging nations. It should also be disaggregated by topic, to help assess whether identified science gaps are being addressed effectively.

Milestone 4: Developing capacity for Ocean Decade Challenges and sharing knowledge

Increased capacity of individuals, institutions, and communities to effectively address Challenge 3, and generation and sharing of scientific knowledge and information related to aquatic food systems, especially South-South-North knowledge sharing.

Indicator 4.1: Number of capacity development initiatives within the Ocean Decade ecosystem: Number and type of capacity development initiatives, workshops, training programmes, and educational activities implemented to develop capacity in addressing Challenge 3, disaggregated by country and region, and focus audience.

Indicator 4.2: Number of participants trained under Ocean Decade capacity development initiatives: Reach and impact of aquatic food system science capacity development initiatives organised under the Ocean Decade. It can be measured by tracking the number of participants enrolled, trained, or certified through these initiatives, disaggregated by country or region, gender, age, and membership to an indigenous population.

Milestone 5: Sustainable policy and governance implementation

Increased science that supports development and implementation of policy and governance frameworks.

Indicator 5.1: Percentage of Ocean Decade Actions and activities that include a component focused on the science-policy interface: This can be calculated by tracking the number of approved Ocean Decade Actions and activities more generally that include a component aimed at facilitating the science-policy interface.

Indicator 5.2: Number of policy fora and tools supported by the Ocean Decade: The extent to which information generated by the aquatic food Ocean Decade ecosystem (e.g. Actions, DCCs, DCOs, etc.) has informed adoption and/or implementation of relevant policies, legislation, and regulations. It can be measured by tracking the number of policy fora and tools that the Ocean Decade has supported.

Milestone 6: Enhanced ocean data availability and accessibility

Increased availability and accessibility of data and knowledge on aquatic food systems, including of non-ecological data (e.g. social, behavioural, and economic) and streamlining of data- and knowledge-sharing platforms, adaptable to local capacities and circumstances.

Indicator 6.1: Percentage of non-ecological datasets generated and/or used by the Ocean Decade: Given the importance of an integrated approach to science on aquatic food systems, a critical measure of success is the generation and/or use of data from diverse disciplines (e.g. social, behavioural, and economic). This can be measured by tracking the datasets generated and/or used by Ocean Decade Actions or other activities, disaggregated by discipline.

Indicator 6.2: Percentage of relevant privately-held data on aquatic food systems made accessible by the Ocean Decade: The proportion of proprietary aquatic food systems data, currently held by private entities, made available by the Ocean Decade can be measured by calculating the percentage of relevant datasets that are publicly accessible and/or findable, considering factors such as data completeness, timeliness, and quality.

Indicator 6.3: Percentage of data and knowledge products under the Ocean Decade, related to Challenge 3, focused on emerging nations: This indicator provides a means of assessing progress towards addressing regional gaps related to Challenge 3 in the Ocean Decade. It can be assessed by tracking whether Ocean Decade Actions and activities address geographical science needs identified, disaggregating information by region and theme.

Indicator 6.4: Percentage of aquatic food systems data generated by the Ocean Decade made available in real time: It can be calculated as the percentage of all datasets made publicly available. It should be disaggregated by region/nation so digital divide related issues can be monitored as well.

Indicator 6.5: Level of interoperability of data generated by the Ocean Decade: The extent to which different data sources and formats are harmonised and interoperable, including across disciplines and disaggregated by region/nation. This can be measured by evaluating the adoption of standardised data formats, metadata standards, and data integration protocols across different data providers within the Ocean Decade, mindful of digital divide related issues.

Milestone 7: Advancement in ocean technology and innovation

Increased advancement in ocean technology, innovation, and infrastructure to support sustainable and equitable optimisation of the ocean to nourish the global population.

Indicator 7.1: Number of technological innovations for aquatic food systems implemented under the Ocean Decade: This indicator can be measured by counting the number of new technological innovations resulting from Ocean Decade Actions and activities that support and innovate aquatic food systems. It should be disaggregated by topic and region/country in order to assess whether these innovations fill critical science, capacity, and infrastructure gaps, including those identified by this White Paper.

Indicator 7.2: Percentage of research infrastructure enhancement: The percentage increase in research infrastructure investments put in place by Ocean Decade ecosystems dedicated to aquatic food system science, disaggregated by region/nation, demonstrating the commitment across the globe to improving the tools and facilities essential for ocean exploration and research.

6. CONCLUSION

Aquatic food systems hold great potential to help sustainably nourish the global population and achieve the UN 2030 Agenda. To realise this potential, a Blue Transformation (FAO, 2022a) is needed with actions across fisheries, aquaculture, and value chains, to overcome two "grand challenges": (1) Sustainably *producing* more nutritious aquatic foods, and (2) Ensuring equitable *access* to aquatic foods. The UN Ocean Decade is well poised to generate the science and knowledge needed to support solution pathways that will address these barriers and help achieve a Blue Transformation.

Substantial science already exists, within and beyond the Ocean Decade, on aquatic food systems. That science has supported effective management of several aquatic foods, for instance enabling the drastic recovery of several overfished stocks in North America, Oceania, and Europe. However, critical thematic and regional gaps in the science still remain, and science is often fragmented and siloed. Aquatic food systems are interlinked through multiple uses of the oceans and support many human activities. This leads to an extensive set of science needs generated by a diverse set of users and spanning across multiple disciplines and sectors. As a result, aquatic food systems can contribute positively to achieving multiple SDGs.

The Ocean Decade aims to take us from the "ocean we have" to the "ocean we want"; a critical component of this process is understanding the "we" that qualifies who are the actors, stakeholders, and rights holders of the ocean and this transformation. This paper draws attention to the broad diversity of users of Challenge 3 and the critical importance of inclusive stakeholder engagement to address science needs related to aquatic food. To capture this complexity and diversity, we propose a two-tiered approach to developing science towards achieving Challenge 3: (1) definition of high-level science objectives, and (2) outline of targeted science priorities.

Given that aquatic foods are linked to the wider food system including nutrition and health dimensions, science that may not be traditionally considered ocean science, and thus not have an apparent home in the Ocean Decade (e.g. distribution and use of aquatic food products on land), will need to be harnessed. Science that can foster cooperation across sectors and disciplines to support

circular value chains, identification and balancing trade-offs, and social and political components (e.g. gender, equity, culture, and indigenous rights) is paramount. Our analysis reveals the critical need to strengthen science that supports holistic approaches for sustainable and equitable management of integrated socio-economic marine systems. To get there, high-quality sectoral data and methods to assess environmental, economic, and social effects of future management options are needed. Effective communication of the results will also be critical to foster necessary changes in management, businesses, finance, and society at large. A focus on building synergies between Ocean Decade Challenge 3 and 4 will also support this targeted holistic approach. A clear focus on protecting, enhancing, and uplifting SSFA contributions to aquatic foods through science, practice, and governance is also required given these are some of the most important, yet most under-represented and under-valued, users of Challenge 3.

Addressing Ocean Decade Challenge 3 also needs science that supports the uptake of sustainability and equity dimensions into management. Current Ocean Decade efforts need to strengthen their focus on these dimensions, and future initiatives need to be selected to support this ambition. In addition, cross-pollination and collaboration between Ocean Decade Actions should be prioritised to avoid repetition in data generated and knowledge developed. A clear need also exists to focus more activities in emerging nations, the area where the majority of the ocean is located, where the challenges are the greatest, but also, and more importantly, to ensure global ownership of good governance of aquatic food systems. The current centre of gravity for leading the Ocean Decade in advancing more sustainable and equitable aquatic food systems is worrying as it is first and foremost anchored in Europe and North America. Getting broader, and more global, engagement in Challenge 3 should be a high priority for the Ocean Decade.

In addition, since aquatic food systems are so closely linked to business and industry, increasing the global reach of this Challenge should also capture the private sector, as it is this sector that carries out the activities of the food systems. In parallel, the Ocean Decade should prioritise facilitating the diversification and increase of financing for Ocean Decade Actions and activities to meet the science needs identified by Working Group 3, with a focus on connecting the many actors and stakeholders under the Ocean Decade with appropriate funding opportunities (e.g. philanthropic organisations through the OceanMatcher application).

Many solutions to addressing the "grand challenges" outlined in this document are already common knowledge, often already implemented in legislature and through strategies in a diverse set of countries. The Ocean Decade can support the development of new ones based on strong interdisciplinary science and knowledge. A holistic multi-sector approach will be critical, where equity, rights, and responsibilities are duly evaluated, taking into account related agreed global commitments and instruments (e.g. SDGs, *SSF Guidelines*, etc.). Large-scale global coordination, especially focusing on engaging emerging countries, small island developing states, SSFAs, women, indigenous people, and youth is paramount to success, and the Ocean Decade provides an excellent vehicle to achieve this.

Large-scale transformative change of terrestrial food systems has happened in the past through concerted, coordinated, long-term strategic efforts and partnerships between governments, research, and the private sector (Moberg et al., 2021). The Blue Transformation (FAO, 2022a; FAO, 2022b) is well poised to catalyse a similar change in aquatic systems, and the Ocean Decade provides a unique opportunity to support this.

References

Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. and Poulain, F., (eds.) (2018) 'Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options', *FAO Fisheries and Aquaculture Technical Paper*, 627. Rome, FAO. https://www.fao.org/3/i9705en/i9705en.pdf.

Béné, C., Oosterveer, P. Lamotte, L., et al. (2019) 'When food systems meet sustainability – Current narratives and implications for actions, World Development, 113, pp.116-130. Available at: https://doi.org/10.1016/j.worlddev.2018.08.011.

Bennett, A., Basurto, X., Virdin, J. et al. (2021) 'Recognize fish as food in policy discourse and development funding', *Ambio,* 50, pp. 981–989. Available at: https://doi.org/10.1007/s13280-020-01451-4.

Castilla, J.C., Espinosa, J.E., Yamashiro, C., Melo, O., and Gelcich, S. (2016) 'Telecoupling Between Catch, Farming, and International Trade for the Gastropods Concholepas concholepas (Loco) and Haliotis spp. (Abalone), Journal of Shellfish Research, 35(2), pp.499-506. Available at: https://doi.org/10.2983/035.035.0223.

CCFA. (2022) *A call to action from small-scale fishers*. Coalition for Fair Fisheries Arrangements. Available at: https://www.cffacape.org/ssf-call-to-action. Cojocaru, A.L., Liu, Y., Smith, M.D., et al. (2022) 'The "Seafood" System: Aquatic Foods, Food Security, and the Global South', Review of environmental economics and policy, 16(2). Available at: https://www.journals.uchicago.edu/doi/full/10.1086/721032.

Costello, C., L. Cao, S. Gelcich et al. (2019) *The Future of Food from the Sea*. Washington, DC: World Resources Institute. Available at www.oceanpanel.org/future-food-sea.

Costello, C., Cao, L., Gelcich, S. et al. (2020) 'The future of food from the sea', *Nature,* 588, pp.95–100. Available at: https://doi.org/10.1038/s41586-020-2616-y.

Crona, B.I., Wassénius, E., Jonell, M. et al. (2023) 'Four ways blue foods can help achieve food system ambitions across nations', *Nature*, 616, pp.104–112.

FAO. (2011) *Global food losses and food waste – Extent, causes and prevention*. Rome, FAO. Available at: https://www.fao.org/3/mb060e/mb060e.pdf .

FAO. (2015) *Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication*. Rome, FAO. Available at: https://www.fao.org/3/i4356en/i4356en.pdf.

FAO. (2016) Strengthening sector policies for better food security and nutrition results: Fisheries and aquaculture. Rome. Available at: http://www.fao.org/3/a-i6227e.pdf.

FAO. (2018) 'Sustainable food systems Concept and framework', FAO Brief. Available at: https://www.fao.org/3/ca2079en/CA2079EN.pdf.

FAO. (2020) *The State of World Fisheries and Aquaculture 2022. Sustainability in Action*. Rome, FAO. Available at: https://doi.org/10.4060/ca9229en.

FAO. (2022a) *The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation*. Rome, FAO. Available at: https://doi.org/10.4060/cc0461en.

FAO. (2022b) *Blue Transformation - Roadmap 2022–2030: A vision for FAO's work on aquatic food systems*. Rome, FAO. Available at: https://doi.org/10.4060/cc0459en.

FAO, IFAD, UNICEF, WFP and WHO. (2022) The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable. Rome, FAO. Available at: https://doi.org/10.4060/cc0639en.

FAO, Duke University & WorldFish. (2023) *Illuminating Hidden Harvests – The contributions of small-scale fisheries to sustainable development*. Rome. Available at: https://doi.org/10.4060/cc4576en.

FAO, IFAD, UNICEF, WFP and WHO. (2023) The State of Food Security and Nutrition in the World 2023. Urbanization, agrifood systems transformation and healthy diets across the rural–urban continuum. Rome, FAO. Available at: https://doi.org/10.4060/cc3017en.

FAO and WorldFish. (2021) 'Aquatic food systems under Covid 19'. Brief. Available at: https://www.fao.org/3/cb5398en/cb5398en.pdf.

Farmery, A.K. et al. (2021) 'Blind spots in visions of a "Blue economy" could undermine the ocean's contribution to eliminating hunger and malnutrition', *One Earth*, 4(1), pp.28–38. Available at: doi:10.1016/j.oneear.2020.12.002.

Farmery, A.K., Alexander, K., Anderson, K. et al. (2022) 'Food for all: designing sustainable and secure future seafood systems', Reviews in Fish Biology and Fisheries, 32, pp.101–121. Available at: https://doi.org/10.1007/s11160-021-09663-x.

Gelcich, S., Edwards-Jones, G., Kaiser, M.J. et al. (2006) 'Co-management Policy Can Reduce Resilience in Traditionally Managed Marine Ecosystems', Ecosystems, 9, pp.951-966. Available at: https://doi.org/10.1007/s10021-005-0007-8.

Gephart, J.A., Henriksson, P.J.G., Parker, R.W.R., et al. (2021) 'Environmental performance of blue foods', Nature. Available at: https://pubmed.ncbi.nlm.nih.gov/34526707/.

Golden, C.D., Koehn, J.Z., Shepon, A. et al. (2021) 'Aquatic foods to nourish nations', *Nature,* 598, pp.315–320. Available at: https://www.nature.com/articles/s41586-021-03917-1.

Hallström, E., Bergman, K., Mifflin, K., Parker, R., Tyedmers, P., Troell, M., and Ziegler, F. (2019) 'Combined climate and nutritional performance of seafoods', *Journal of Cleaner Production*, 230, pp. 402-411. Available at: https://doi.org/10.1016/j.jclepro.2019.04.229.

Hicks, C.C., Cohen, P.J., Graham, N.A.J. et al. (2019) 'Harnessing global fisheries to tackle micronutrient deficiencies', *Nature*, 574, pp.95–98. Available at: https://doi.org/10.1038/s41586-019-1592-6.

Hicks, C.C., Gephart, J.A., Koehn, J.Z. et al. (2022) 'Rights and representation support justice across aquatic food systems', Nature Food, 3, pp.851-861 (2022). Available at: https://www.nature.com/articles/s43016-022-00618-4#citeas.

HLPE. (2019) Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance 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.

IPCC. (2022) *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner, H.-O., Roberts, D.C., Tignor, M., et al. (eds.)]. Cambridge University Press: Cambridge, UK and New York, NY, USA. Available at: https://report.ipcc.ch/ar6/wg2/IPCC_AR6_WGII_FullReport.pdf.

Kawarazuka, N., Mabhaudhi, T., Green, R., et al. (2023) 'Inclusive diets within planetary boundaries', *One Earth*, 6(5), pp.443-448. Available at: https://doi.org/10.1016/j.oneear.2023.05.003.

Lam, V.W.Y., Allison, E.H., Bell, J.D. et al. (2020) 'Climate change, tropical fisheries and prospects for sustainable development', *Nat Rev Earth Environ*, 1, pp.440–454.

Mansfield, E.J., Micheli, F., Fujita, R. et al. (pending publication) 'Anticipating trade-

offs and promoting synergies between small-scale fisheries and aquaculture to improve social, economic , and ecological outcomes'.

Moberg, E., Allison, E.H., Harl, H.K., Arbow, T., Almaraz, M., Dixon, J., Scarborough, C., Skinner, T., Rasmussen, L.V., Salter, A. and Lei, X.G. (2021) 'Combined innovations in public policy, the private sector and culture can drive sustainability transitions in food systems', *Nature Food*, 2(4), pp.282-290. Available at: https://doi.org/10.1038/s43016-021-00261-5.

Naylor, R.L., Kishore, A., Sumaila, U.R. *et al.* (2021) Blue food demand across geographic and temporal scales. *Nat Commun,* 12, 5413. https://doi.org/10.1038/s41467-021-25516-4.

OECD/FAO. (2023) OECD-FAO Agricultural Outlook 2023-2032. OECD Publishing, Paris. Available at: https://doi.org/10.1787/08801ab7-en.

Short, R.E., Gelcich, S., Little, D.C. et al. (2021) 'Harnessing the diversity of small-scale actors is key to the future of aquatic food systems', *Nature Food*, 2, pp.733–741. Available at: https://doi.org/10.1038/s43016-021-00363-0.

Thilsted, S.H., Thorne-Lyman, A., Webb, P., et al. (2016) 'Sustaining healthy diets: The role of capture fisheries and aquaculture for improving nutrition in the post-2015 era, Food Policy, 61, pp.126-131. Available at: https://doi.org/10.1016/j.foodpol.2016.02.005.

Tigchelaar, M., Leape, J., Micheli, F., et al. (2022) 'The vital roles of blue foods in the global food system', *Global Food Security*, 33. Available at: https://doi.org/10.1016/j.gfs.2022.100637.

Viana, D.F., Gelcich,S., Acenes-Bueno, E., Twohey, B., and Gaines, S.D. (2019) 'Design trade-offs in rights-based management of small-scale fisheries', *Conservation Biology*, 33(2), pp.361-368. Available at: https://doi.org/10.1111/cobi.13208.

Viana, D.F., Zamborain-Mason, J., Gaines, S.D. et al. (2023) 'Nutrient supply from marine small-scale fisheries', Scientific Reports, 13, 11357. Available at: https://doi.org/10.1038/s41598-023-37338-z.

UN Nutrition. (2021) The role of aquatic foods in sustainable healthy diets. Available at: https://www.unnutrition.org/wp-content/uploads/FINAL-UN-Nutrition-Aquatic-foods-Paper_EN_.pdf.

Wang F., Cage A., Mosnier F., (2023) 'Avoiding Aquafailure', *Planet Tracker*. Available at: https://planet-tracker.org/wp-content/uploads/2023/05/Aquafailure-VF.pdf.

Willett, W., Rockström, J., Loken, B., et al. (2019) 'Food in the Anthropocene: the EAT-*Lancet* Commission on healthy diets from sustainable food systems', *The Lancet Commissions*, 393(10170), pp.447-492. Available at: https://doi.org/10.1016/S0140-6736(18)31788-4.

Annex 1

Methodology

An initial review of the literature was undertaken to provide a foundational understanding of the status of aquatic foods and barriers to their ability to support sustainably nourishing the global population. The literature was identified through specific recommendations by Working Group 3 members as well as by searching for key terms and phrases in various academic and policy databases to address gaps. Diverse sources were obtained and analysed, including academic articles and reports from regional and international organisations. This process was key to orienting discussions and provided a means of triangulation with knowledge and input provided by Working Group 3 experts.

Working Group 3 members were convened for a series of online meetings (monthly to bi-monthly) between August 2023 and March 2024. These virtual discussions supported a continuous iterative process for developing the strategic ambition, ensuring inclusion of and dialogue about nuanced perspectives and diverse viewpoints. In parallel, Working Group members contributed text to and undertook reviews of preparatory working documents and the White Paper. A three-day virtual Working Group 3 workshop took place in January 2024 to provide an in-depth review and discussion of Version 0 of the White Paper and begin integrating feedback from the first DCU-led White Paper review process (January to February 2024). Throughout the process, the Working Group Co-Chairs and consultant guided discussions and the writing process, adjusting and adapting objectives, content, and writing teams as needed.

Regular consultations with wider Ocean Decade structures, including other Working Groups, the Decade Advisory Board, and the DCU, coupled with open public review sessions of initial drafts of this paper, provided important external perspectives to further refine the strategic ambition and avoid duplication or conflicting approaches. The Ocean Decade Conference (Barcelona, April 2024) provided a final opportunity for experts and the broader public to provide constructive, valuable, and insightful feedback, leading to a more robust final version of the White Paper.

Annex 2

Linkages between Challenge 3 and other Ocean Decade Challenges

OCEAN DECADE CHALLENGES	LINKAGES TO CHALLENGE 3
Challenge 1: Understand and beat marine pollution	Capture fisheries and aquaculture management and practices can potentially contribute to marine pollution (e.g. eutrophication, fishing gear, etc.). In addition, pollution impacts on the health of aquatic food systems and thereby their ability to produce nutritious food.
Challenge 2: Protect and restore ecosystems and biodiversity	Capture fisheries and aquaculture management and practices can potentially damage marine ecosystems (e.g. overfishing, trawling, etc.). Equally, unhealthy marine ecosystems impact on the ability of aquatic foods to thrive and provide nutritious foods.
Challenge 4: Develop a sustainable and equitable ocean economy	Aquatic food systems are a key component of the Blue Economy; governance and management of these systems must therefore be integrated in a wider framework, with consideration of other ocean industries.
Challenge 5: Unlock ocean-based solutions to climate change	Climate change is a key barrier to sustainable and equitable aquatic food systems, and aquatic food systems can also provide critical climate solutions by supplying low-carbon, high-quality nutrition. An enhanced understanding of the ocean-climate nexus, climate-resilience and mitigating climate change impacts on fisheries and aquaculture is central to optimising the ocean's contribution to nourishing the global population. This synergy is currently the most developed under the Ocean Decade, with several Challenge 3 related Ocean Decade Actions focused on climate resilience.
Challenge 6: Increase community resilience to ocean hazards	Ocean hazards directly impact on production of and access to aquatic foods (e.g. through damage to ecosystems, infrastructure, etc.). Ocean hazard early warning systems thereby support improved aquatic foods management and contribute to safety at sea.
Challenge 7: Expand the Global Ocean Observing System	Addressing Challenge 3 relies on extensive ecological, but also social, economic, and behavioural, data. Although extensive data already exists, Challenge 7 can continue to support Challenge 3 through more targeted data collection on aquatic food and related systems, with a particular focus on data currently often left out of ocean systems.
Challenge 8: Create a digital representation of the ocean	Availability of detailed digital representations of knowledge and data is critical to effective governance and management of aquatic food systems; this is especially important to address the needs of SSFA. There are currently extensive representations of aquatic food systems, but these are usually limited to ecological dimensions of the system and location-specific (with important regional gaps).
Challenge 9: Skills, knowledge, and technology for all	Capacity development is critical to the required knowledge, skills, and technology transfer to achieve sustainable production, equitable access, and effectively tackle new frontiers in aquatic food systems. Given the breadth of users of Challenge 3, capacity sharing and development is particularly important to ensure effective practices across levels, scales, and geographies.
Challenge 10: Change humanity's relationship with the ocean	Societal change is central to aquatic food systems, in particular behavioural changes related to consumption and production to be more sustainable and equitable in aquatic foods systems. In addition, a cultural change is needed to consider aquatic foods as a key source of food in a food system currently dominated by land-based agriculture.

United Nations Decade of Ocean Science for Sustainable Development (2021-2030)

Proclaimed in 2017 by the United Nations General Assembly, the UN Decade of Ocean Science for Sustainable Development(2021-2030), provides a convening framework to develop the scientific knowledge and partnerships needed to catalyse transformative ocean science solutions for sustainable development, connecting people and our ocean. The Ocean Decade is coordinated by UNESCO's Intergovernmental Oceanographic Commission (IOC).

Established during the Preparatory Phase and to continue throughout implementation until 2030, the IOC's Ocean Decade Series will provide key documentation about this global initiative and aims to serve as a primary resource for stakeholders seeking to consult,monitor and assess progress towards thevision and mission of the Ocean Decade.

oceandecade.org

@UNOceanDecade

@unoceandecade

@UN Ocean Decade

@UN Ocean Decade

unesco

Intergovernmental Oceanographic Commission