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Advancing the climate-biodiversity-fisheries nexus in the UN Decade of Ocean Science for Sustainable Development

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Abstract

Climate-driven changes in marine ecosystem structure and function adversely impact the biodiversity and sustainability of living marine resources, food security, and the resilience of coastal communities. Understanding how climate change impacts marine ecosystem biodiversity and global fisheries, i.e. the "climate-biodiversity-fisheries nexus", is a fundamental element of the UN Decade of Ocean Science for Sustainable Development. Several Ocean Decade-endorsed Programmes within the climate-biodiversity-fisheries nexus are building global networks to transform our capacity to understand, forecast, manage, and adapt to climate-driven changes in ocean ecosystems, including sustaining blue food resources that provide essential food security and nutrition in a rapidly changing world. We compare the scope, objectives, global partnerships, and capacities of these Programmes, facilitating effective collaboration and identifying critical gaps in developing solutions to climate-driven changes in marine food webs, species assemblages, and global fisheries. This work complements the Ocean Decade Vision 2030 process by providing an assessment of actions that are underway and guidance to establish new actions needed to monitor and understand marine biodiversity and manage global fisheries within a changing climate. We provide recommendations for new and existing Ocean Decade Actions around the climate-biodiversity-fisheries nexus to help achieve the Ocean Decade outcomes of a "productive, predicted, healthy, and resilient ocean" by 2030.

Keywords: ocean decade; marine biodiversity; climate-ready fisheries; blue foods

Introduction

Global fisheries contribute to the diet of more than 3 billion people (FAO 2022), supplying more than 20% of their annual global protein intake. Commercial and subsistence fishing provides livelihoods for more than 600 million people and partial livelihood support to 8% of the world's population (Sumaila et al. 2011, FAO 2018) and contributes more than US$270 billion to the world economy (FAO 2022). Aquatic food consumption continues to grow (to ~160 million tonnes per year globally in 2020), through both capture fisheries and accelerating developments in aquaculture, and further growth is expected (FAO 2022). Global demand for aquatic foods is

expected to double by 2050 (Naylor et al. 2021). At the same time, there has been a corresponding increase in the percentage of overfished marine fishery stocks, from ∼10% in 1974 to >25% in 2019 (FAO 2022). In addition to inadequate regulation and overfishing, global capture fisheries are subject to many other human-induced challenges, including degradation of ecosystems through marine pollution, unsustainable human development, and transnational conflicts over fishing rights (Mendenhall et al. 2020).

Compounding these challenges is climate change, with warming oceans, changes in ocean circulation, deoxygenation and acidification, and changes in the productivity and composition of plankton and other biological foundations of marine food webs. The production, quality, and accessibility of fisheries are fluctuating greatly in response to climate variability and change, with significant socio-economic consequences (Barange et al.). Some climate models project increases in primary productivity with ocean warming at high latitudes and decreases at low/mid latitudes, with subsequent effects on fish production (Barange et al. 2014). Maximum fish catch potential is projected to increase by 30%–70% in some high latitude regions but to decrease by up to 40% in the tropics (Cheung et al. 2010, 2011, Barange et al. 2014, Lam et al. 2020). In addition to changes in fish biomass, there are projected distributional shifts (often, but not always, poleward) and regional shifts in species assemblages, leaving resource-limited fishing communities more vulnerable to climate change (Muhling et al. 2015, 2016, Pinsky et al. 2021, Cinner et al. 2022, Huntington et al. 2022, Mills et al. 2024). Extreme warming events in Exclusive Economic Zones can result in >75% declines in biomass and other disruptions for some exploited fishes, creating social and economic shocks in affected fishing communities (Mills et al. 2013, Cheung et al. 2021, Free et al. 2023). Least developed countries (LDCs) and Small lsland Developing States (SIDS) are often particularly reliant on fisheries resources and have less adaptive capacity, making these communities especially vulnerable to climate change and extremes (Lam et al. 2020, Tigchelaar et al. 2021). These climate-driven impacts on marine and coastal resources are widespread and acute and will require improved capacity in monitoring, research, management, governance, and strategic adaptation (Schmidt et al. 2019).

It is imperative to advance our understanding of how a changing climate will impact marine ecosystem health and biodiversity, and to develop strategies to maintain the resilience of sustainable fisheries, rebuild degraded ecosystems and fish stocks, and develop strategies to mitigate and adapt to climate change. The vision of the UN Decade of Ocean Science for Sustainable Development (2021–2030; The Ocean Decade) is "the science we need for the ocean we want" by 2030. To achieve this, the Ocean Decade provides a global platform and a unique opportunity to meet the challenges facing our oceans (Ryabinin et al. 2019, Claudet et al. 2020). Specifically, the Ocean Decade has identified 10 challenges to be addressed, including "protect and restore ecosystems and biodiversity" (Challenge 2), "sustainably feed the global population" (Challenge 3), and "unlock ocean-based solutions to climate change" (Challenge 5), to realize the Decade's desired outcomes, which include "a healthy and resilient ocean," "a productive ocean," "a predicted ocean," and "an inspiring and engaging ocean" (UNESCO-IOC 2021). Actions that aim to identify, understand, and predict the impacts of climate change on marine biodiversity and world fisheries, and to find

solutions to mitigate and adapt to these changes, are fundamental to tackling these challenges. As of July 2023, Challenges 2 and 5 have the largest number of Programmes and Projects, reflecting the global interest and urgency in tackling these Challenges (UNESCO-IOC 2023). Notably, Challenge 3 ("sustainably feed the global population") is represented by fewer Decade Actions. Ultimately, tackling these Challenges together will be critical in addressing the Decade's Challenge 10 ("change humanity's relationship with the ocean").

Here, we identify ongoing Ocean Decade-endorsed efforts and key gaps around the climate-biodiversity-fisheries nexus and provide recommendations to inform future Ocean Decade Actions. This review is not a comprehensive assessment of all Ocean Decade Actions related to climate, marine biodiversity, and fisheries issues; rather, we review a subset of endorsed Programmes for which the climate-biodiversity-fisheries nexus represents a core theme and which have formed a "community of practice" to exchange ideas and share resources. (Several Ocean Decade-endorsed Programmes have collaborated informally through virtual meetings, in-person workshops and webinar series.) We define the *climate-biodiversity-fisheries nexus* broadly as those activities centered on monitoring and understanding changes in marine biodiversity and managing global fisheries within a changing climate, which may encompass one or more categories:

(a) understanding climate impacts on the structure and function of marine ecosystems and their associated fisheries [SCIENTIFIC RESEARCH];

(b) building data sharing structures and the end-to-end (climate-ocean-ecological-social) modeling infrastructure to forecast, predict and project climate-driven impacts on marine ecosystems [OPERATIONS & INFRASTRUCTURE];

(c) developing and sharing capacity in fisheries management and adaptation strategies to increase the resilience of marine resources and the communities that depend on them [MANAGEMENT & APPLICATIONS]; and

(d) promoting gender equality, early career engagement and leadership opportunities for Indigenous peoples, underserved and underrepresented communities and developing nations in the co-design and implementation of actions [HUMAN DIMENSIONS].

This community of practice contributes knowledge, identifies gaps within the climate-biodiversity-fisheries nexus, and informs priorities for future Ocean Decade Actions.

Cumulative capacity of Ocean Decade programmes in the climate-biodiversity-fisheries nexus

There are several global Programmes endorsed by the UN Decade of Ocean Science for Sustainable Development that are addressing aspects of the climate-biodiversity-fisheries nexus (Fig. 1):

(A) Sustainable Blue Foods Futures for People and Planet (BFF): A Programme that builds on the past progress of the Blue Food Assessment and the Aquatic Blue Food Coalition to drive blue food science and policy actions through four primary activities: understanding the potential and limits of blue foods in global

Figure 1. Logos and thematic word clouds of seven Ocean Decade-endorsed Programmes that operate within the climate-biodiversity-fisheries nexus. Word clouds were derived from the Programme Ocean Decade fact sheets.

co-develop frameworks and tools to assess, evaluate, identify, and recommend actionable approaches to support climate resilience in marine fishery systems.

(C) Global Ecosystem for Ocean Solutions (GEOS): A Programme that aims to develop, test, and deploy equitable, durable, and scalable ocean-based solutions to a wide range of issues facing the world's oceans, including food security through sustainable fisheries. Ocean solutions will be co-designed through a multi-sector community of researchers, engineers, innovators, investors, and decision-makers.

(D) Marine Life 2030: A Programme that aims to establish a globally coordinated system to deliver actionable, transdisciplinary knowledge of ocean life to those who need it, promoting human well-being, sustainable development, and ocean conservation. An anticipated outcome is an interoperable global network of researchers, local and indigenous communities, the private sector, and government that work together to advance ecosystem-based management using timely and accurate observations and forecasting of marine life.

(E) Ocean Biomolecular Observation Network (OBON): A Programme that will develop a global system to understand ocean life through emerging biomolecular technologies, allowing society to transform how to sense, harvest, protect, and manage ocean life within the context of multiple stressors. The network will be co-designed with ocean users to ensure societal relevance and will be a key component of next-generation ocean observing systems.

(F) Sustainability of Marine Ecosystems through Global Knowledge Networks (SmartNet): A Programme that leverages the infrastructure and longstanding partnership of two leading inter-governmental organizations, the International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Science Organization (PICES), to build global knowledge networks to advance understanding and share capacity around the themes of climate impacts and the resilience and sustainability of marine ecosystems.

(G) Sustainability, Predictability, and Resilience of Marine Ecosystems (SUPREME): A Programme sponsored by the US National Oceanic and Atmospheric Administration that aims to convene global partners through knowledge networks to share information and support robust climate- and ocean-related forecasts, predictions, and projections to guide effective marine ecosystem management and adaptation strategies in a changing climate.

Each Programme has a complementary focus on climate impacts on marine ecosystems, marine resources, and the coastal communities that depend on them. While the climate-biodiversity-fisheries nexus links these Programmes through shared thematic foci, each Programme emphasizes different aspects within the broad categories of scientific research, operations and infrastructure, management and applications, and human dimensions. This is illustrated in the keywords associated with each Programme (Fig. 1), developed from the Programmes' Ocean Decade Fact Sheets (see https://oceandecade.org/decade-actions/). BFF has a clear emphasis on "global food" security and "policy," while "fisheries resilience" and "ocean solutions" feature most prominently for

food systems; integrating blue foods into food, climate, and nature strategies and policies; co-developing blue foods solution initiatives with stakeholders; and strengthening partnerships, building capacity, and promoting access to blue food data and knowledge.

(B) Fisheries Strategies for Changing Oceans and Resilient Ecosystems by 2030 (FishSCORE2030): A Programme that seeks to globally advance climate-resilient marine fisheries by increasing information exchange and collaborative efforts through a network of scientists, fishers, resource managers, community practitioners, and policymakers. This network will
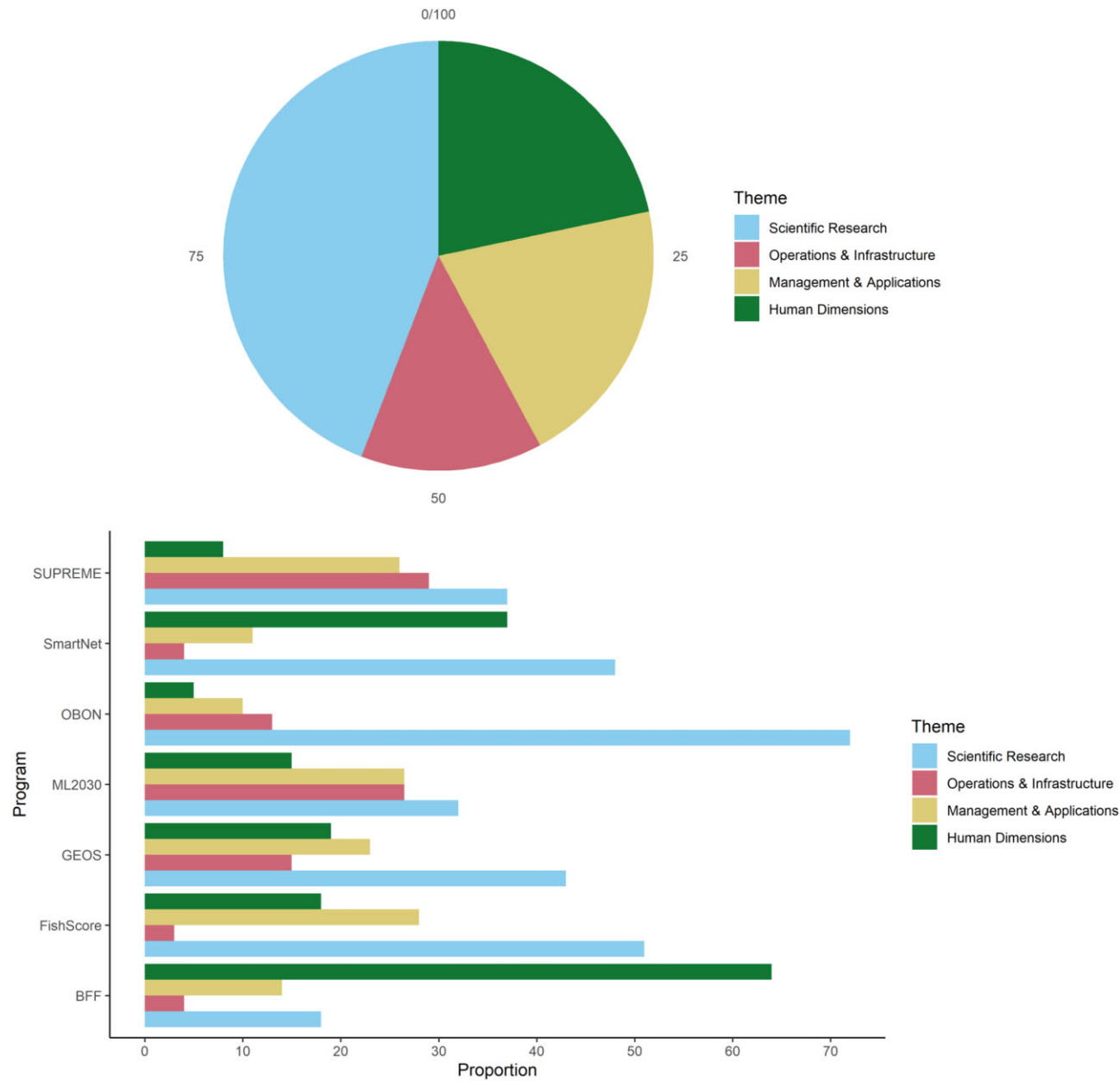
Figure 2. Themes covered by the Ocean Decade-endorsed Programmes as determined by frequency (% usage) of categorical word use for (top) all Programmes and (bottom) each Programme derived from content analysis of the Programme fact sheets.

FishSCORE2030 and GEOS, respectively. Both Programmes also emphasize "climate." A focus on "ocean life" is apparent for Marine Life 2030 and OBON, with the former emphasizing "managing" for "healthy" ecosystems and the latter emphasizing "biomolecular" techniques. SUPREME is characterized by an emphasis on "ocean modeling", while SmartNet's keywords reflect its emphasis on networking activities, especially "communication," "engagement", and "partnership" (Fig. 1). All Programmes refer to keywords associated with human dimensions and societal impact (e.g. "equitable," "collaborative," "co-design," and "communities").

Conducting content analysis on each of the fact sheets, we measured the frequency of word use within the four categories to determine and compare the areas of the climate-biodiversity-fisheries nexus emphasized by each Programme individually and the combined capacity across the Programmes (Fig. 2). This analysis quantifies the strengths and gaps these Programmes bring to the climate-biodiversity-fisheries nexus and informs recommendations for future Ocean Decade Actions. Keywords related to Scientific Research comprise the most significant component for each Programme except BFF, which has its strongest emphasis on Human Dimensions (Fig. 2). OBON has the highest proportional emphasis on research, though research comprises a significant component for FishSCORE2030, GEOS, and SmartNet as well. Collectively, Programme keywords emphasize Scientific Research (Fig. 2), reflecting the background of the individuals and institutions leading these Programmes. However, given the Programmes' objectives to address the Ocean Decade Challenges, Management and Applications, and

Human Dimensions are also well represented. The most prominent gap across the Programmes is in Operations and Infrastructure, although both Marine Life 2030 and SUPREME emphasize this component (Fig. 2). We note that each Programme's objectives and activities will be iteratively assessed through the Ocean Decade to ensure they are achieving their goals and vision.

Each Programme incorporates basic and applied scientific research, including different types of knowledge, based upon the collection and equitable access of data and integration of ecosystem observations into ocean observing systems. Research foci include marine biodiversity (Marine Life 2030), biomolecular observations such as eDNA (OBON), fishery systems (FishSCORE2030), and the role of blue foods in global food systems (BFF). SmartNet advances scientific research through expansion of thematic ICES-PICES joint Working Groups, such as those focused on the ecology of small pelagic fish and the impacts of ocean warming on growth rates and fisheries yields. SUPREME is focused on the development and implementation of modeling systems to understand the mechanisms of climate impacts on marine ecosystems. GEOS is developing "task forces" to co-design solutions "roadmaps" that identify critical research and innovation needs. FishSCORE2030 is based on the approach of knowledge co-production as an iterative, collaboration building process that brings together multiple sources and types of knowledge to develop a holistic understanding of the impacts of climate change on diverse marine fisheries and identify potential solutions. Marine Life 2030 links the research community around measurement and data formatting standards through close collaboration with the Global Ocean Observing System, the Marine Biodiversity Observation Network, and data management efforts including the Ocean Biodiversity Information System, the Global Biodiversity Information Facility, and FishBase.

Each Programme also aims to develop a lasting and complementary operational infrastructure to gather, synthesize, and disseminate scientific and other forms of knowledge, as well as tools and resources to address the Ocean Decade Challenges. This includes supporting existing observing systems and advising on the establishment of new ones to fill gaps. Key focus areas are interoperable, accessible data portals (Marine Life 2030, OBON), end-to-end modeling frameworks to manage fisheries and ecosystems in a changing climate (SUPREME), assessments of ecosystem health and resilience (FishSCORE2030, Marine Life 2030, OBON, SmartNet), forecasts and projections of ecosystem structure and function (Marine Life 2030, SUPREME), and knowledge and capacity exchange within fishery (FishSCORE2030) and science-to-policy avenues for blue foods (BFF). With its emphasis on nutrition, livelihoods, equity, and food-system policies, BFF has a strong human dimensions component, as does GEOS through its co-designed ocean solutions roadmaps (Figs 1 and 2). Likewise, FishSCORE2030 is seeking to co-design strategies for building resilience across the ecological, socioeconomic and governance realms, and a core framing for this Programme is the need to think holistically about fisheries as complex social-ecological systems. Critically, all of these Programmes contribute to larger, collaborative transdisciplinary networks to facilitate information exchange, capacity sharing, and implementation of ocean-based solutions to key Challenges. These collaborations are based on partnerships across science, education, management, policy, industry, ocean users,

and the public. All Programmes have goals to promote equity and inclusivity in their activities through a commitment to gender, geographical, and generational diversity and active participation of Early Career Ocean Professionals.

While the individual Programmes reviewed here have highest capacity in different components of the climate-biodiversity-fisheries nexus, the collective breadth of activities and expertise represented by these Programmes speaks to the necessity of collaboration across Ocean Decade Actions. These collaborations can be facilitated in many ways, for example, through the Ocean Decade Network and thematic Communities of Practice. In the present example, our cross-Programme collaboration evolved organically through co-convened workshops at international fora (e.g. the *PICES Annual Meetings* in Korea in October 2022 and the USA in October 2023 and the *Effects of Climate Change on the World's Oceans Symposium* in Norway in April 2023) and periodic communications. Several of these Programmes host monthly webinar series together on "*Topics at the Nexus of Climate Change, Fisheries and Blue Foods*" and "*Biodiversity Networking Fridays*." In addition, each of these Programmes hosts several Ocean Decade-endorsed Projects, illustrating the regional and disciplinary breadth of the climate-biodiversity-fisheries nexus within the Ocean Decade (Supplemental Table 1). Through collaborative efforts such as these, the impact of each Programme will be amplified by reaching wider audiences and facilitating transfer of ideas across diverse groups as efforts increase worldwide to incorporate planning for climate change into fisheries assessment and management. These programmatic collaborations are particularly valuable to the Ocean Decade goals to realize synergies in researching and supporting sustainable fisheries, healthy communities, and ocean ecosystems.

Key gaps and recommendations to advance progress in the climate-biodiversity-fisheries nexus within the Ocean Decade

While the Programmes and their affiliated Projects span a breadth of disciplines and expertise, as presented in Figs 1 and 2, it is important to identify elements within the climate-biodiversity-fisheries nexus that, to date, are not sufficiently supported through formal or informal collaborations amongst these Programmes. Identifying these gaps now can contribute to strategic prioritization of future Ocean Decade Calls for Action. While we do not have the scope to compile a comprehensive list of key knowledge and operational gaps within the climate-biodiversity-fisheries nexus, our aim here is to highlight key issues that could be potential impediments to our Programmes' success in addressing Challenges over the life of the Ocean Decade. The success of Ocean Decade Challenge 2, for instance, is dependent on timely and widespread availability of scientific information about biodiversity and ecosystem changes, identification of the human and natural drivers of those changes, and the capacity to use this information to advance sustainable management of marine resources (Müller-Karger et al. 2024).

We have identified key issues spanning all components of the climate-biodiversity-fisheries nexus where progress is needed. From a **research perspective**, there remains a knowledge gap in our understanding of the mechanisms by which climate variability and change impact the structure and function of marine ecosystems and the resources they supply,

knowledge that is needed to effectively forecast and manage for climate-driven changes. Recommendations to close this knowledge gap include Actions to:

- Understand mechanisms by which climate variability, climate extremes, and climate change impact marine ecosystems, resources, and associated human communities.
- Determine drivers and limitations of forecast skill, improve skill in climate and ecological models.
- Define, understand, and monitor attributes of resilience in climate-impacted fishery systems (e.g. Mason et al. 2022).
- Assess and evaluate the potential for response strategies and interventions to achieve management or societal goals.

Progress on this knowledge gap is hampered, in turn, by limitations in our collective **operational capacity** and resources to model the key processes and create skillful forecasts. These limitations are especially acute in LDCs and SIDS, pointing to a critical need to develop long-lasting structures to effectively and equitably share knowledge, data, and capacity, including free, prior and informed consent. Similarly, the observing systems that are needed to inform models and to monitor ecosystem status and health are grossly and asymmetrically deficient, with many regions and ecosystem components lacking the observational baseline needed to quantify climate change. Reducing limitations in operational capacity will require actions to:

- Enhance resources to build stable communication, data and knowledge exchange networks.
- Fill gaps in observational capacity driven by region, economic status, and ecosystem components.
- Mobilize resources for ocean and biological observations, tool building, training, and capacity sharing.
- Enhance multi-directional, evidence-based science communication to researchers, end users, decision makers, policymakers, governments, and the general public.
- Mobilize private sector to co-design and support climate adaptation and mitigation strategies.
- Mobilize trans-governmental funding opportunities to support collaborative research and operations.
- Maintain stability in Ocean Decade-established networks, i.e. beyond the life of the Ocean Decade.

Finally, the methods and capacity to utilize ecosystem information for **management and policy** decisions, and the regional, national, and international governance structures needed to facilitate the uptake of that advice, are not well established. To address these gaps, and ensure Ocean Decade science contributes to societal well-being, future actions should:

- Establish protocols and mechanisms to identify indices to monitor ecosystem state and deliver climate information to management.
- Determine thresholds for decision-making and improve nimbleness of management bodies.
- Improve international governance structures to manage ecosystems, conserve or enhance marine biodiversity, and mitigate transboundary disputes.
- Develop strategies for marine spatial planning and coastal community adaptation in the context of climate change.

- Facilitate recognition of fisheries and aquatic food systems in international food system planning and policy.
- Enhance resources and mechanisms to share capacity (observing platforms, models, tools, and training) between nations, particularly between developed nations and LDCs/SIDS.
- Enhance resources and expertise to advance climate change adaptation in global fishery systems (e.g. Bryndum-Buchholz et al. 2021, Galappaththi et al. 2022).
- Enhance support for close partnerships between scientists, practitioners, rightsholders, and other stakeholders to co-develop priorities and actions to support resilience to climate-related and broader changes.

And more broadly:

- Pursue opportunities to bring together science and end-user communities, including through workshops, hands-on training, and personnel exchanges.
- Improve methods to incorporate different knowledge systems into activities.
- Improve methods to break down disciplinary, language, and cultural barriers across sectors.

While the Ocean Decade Programmes reviewed here have been designed to address these limitations, the organizational structure and available resources within the Ocean Decade are currently not sufficient to fully achieve our Programme and broader Ocean Decade objectives. Thus, we further recommend that the Ocean Decade governance:

- Mobilize "matchmaking" funding opportunities to overcome capacity limitations.
- Provide more support for convening/collaboration activities, including connecting Decade Actions with relevant government-led initiatives.

Conclusions

The UN Decade of Ocean Science for Sustainable Development provides a unique opportunity to strengthen and build new networks of partners to address the challenges facing the world's oceans (Nash et al. 2021). Ocean Decade Programmes are building global networks to transform our capacity to understand, forecast, manage, and adapt to climate-driven changes in our ocean ecosystems, including sustaining biodiversity and the provisioning of blue food resources that provide essential food security to a rapidly changing world (Golden et al. 2021). These networks are engaging industry, governments, academia, and the public to address key issues within the climate-biodiversity-fisheries nexus through the Ocean Decade. A clear path to the "ocean we want" requires that these networks continue to grow and strengthen, that they develop new pathways to share knowledge and capacity, and that they provide the knowledge and infrastructure to operate beyond 2030. Such a climate-biodiversity-fisheries nexus would truly be transformative.

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Author contributions

Supplementary data

Supplementary data is available at *ICES Journal of Marine Science* online.

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Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

References

Barange M, Bahri T, Beveridge MCM *et al*. Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options: FAO Fisheries and Aquaculture Technical Paper No. 2018. **627**. Rome: FAO, 628.

Barange M, Merino G, Blanchard JL *et al*. Impacts of climate change on marine ecosystem production in societies dependent on fisheries. *Nat Clim Change* 2014;**4**:211–6. https://doi.org/10.1038/nclimate2119

Bryndum-Buchholz A, Tittensor DP, Lotze HK. The status of climate change adaptation in fisheries management: policy, legislation and implementation. *Fish Fish* 2021;**22**:1248–73. https://doi.org/10.1111/faf.12586

Cheung WW, Dunne J, Sarmiento JL *et al*. Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential under climate change in the Northeast Atlantic. *ICES J Mar Sci* 2011;**68**:1008–18. https://doi.org/10.1093/icesjms/fsr012

Cheung WW, Frölicher TL, Lam VW *et al*. Marine high temperature extremes amplify the impacts of climate change on fish and fisheries. *Sci Adv* 2021;**7**:eabh0895. https://doi.org/10.1126/sciadv.abh0895

Cheung WW, Lam VW, Sarmiento JL *et al*. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biol* 2010;**16**:24–35. https://doi.org/10.1111/j.1365-2486.2009.01995.x

Cinner JE, Zamborain-Mason J, Maire E *et al*. Linking key human-environment theories to inform the sustainability of coral reefs. *Curr Biol* 2022;**32**:2610–2620.e4. https://doi.org/10.1016/j.cub.2022.04.055

Claudet J, Bopp L, Cheung WW *et al*. A roadmap for using the UN decade of ocean science for sustainable development in support of science, policy, and action. *One Earth* 2020;**2**:34–42. https://doi.org/10.1016/j.oneear.2019.10.012

F.A.O. *The State of World Fisheries and Aquaculture 2018–Meeting the Sustainable Development Goals*. F.A.O. Rome, 2018.

F.A.O. *The State of World Fisheries and Aquaculture. Towards Blue Transformation*. F.A.O. Rome, 2022.

Free CM, Anderson SC, Hellmers EA *et al*. Impact of the 2014–2016 marine heatwave on U.S. and Canada West Coast fisheries: Surprises and lessons from key case studies. *Fish Fish* 2023;**24**:652–74. https://doi.org/10.1111/faf.12753

Galappaththi EK, Susarla VB, Loutet SJ *et al*. Climate change adaptation in fisheries. *Fish Fish* 2022;**23**:4–21. https://doi.org/10.1111/faf.12595

Golden CD, Koehn JZ, Shepon A *et al*. Aquatic foods to nourish nations. *Nature* 2021;**598**:315–20. https://doi.org/10.1038/s41586-021-03917-1

Huntington HP, Zagorsky A, Kaltenborn BP *et al*. Societal implications of a changing Arctic Ocean. *Ambio* 2022;**51**:298–306. https://doi.org/10.1007/s13280-021-01601-2

Lam VW, Allison EH, Bell JD *et al*. Climate change, tropical fisheries and prospects for sustainable development. *Nat Rev Earth Environ* 2020;**1**:440–54.

Mason JG, Eurich JG, Lau JD *et al*. Attributes of climate resilience in fisheries: from theory to practice. *Fish Fish* 2022;**23**:522–44. https://doi.org/10.1111/faf.12630

Mendenhall E, Hendrix C, Nyman E *et al*. Climate change increases the risk of fisheries conflict. *Mar Policy* 2020;**117**:103954. https://doi.org/10.1016/j.marpol.2020.103954

Mills KE, Kemberling A, Kerr LA *et al*. Multispecies population-scale emergence of climate change signals in an ocean warming hotspot. *ICES J Mar Sci* 2024;**81**:375–389.

Mills KE, Pershing AJ, Brown CJ *et al*. Fisheries management in a changing climate: lessons from the 2012 ocean heat wave in the Northwest Atlantic. *Oceanography* 2013;**26**:191–5, https://doi.org/10.5670/oceanog.2013.27

Muhling BA, Brill R, Lamkin JT *et al*. Projections of future habitat use by Atlantic bluefin tuna: mechanistic vs. correlative distribution models. *ICES J Mar Sci* 2017;**74**:698–716. https://doi.org/10.1093/icesjms/fsw215

Muhling BA, Liu Y, Lee S-K *et al*. Potential impact of climate change on the Intra-Americas Seas: Part-2. Implications for Atlantic bluefin tuna and skipjack tuna adult and larval habitats. *J Mar Syst* 2015;**148**:1–13. https://doi.org/10.1016/j.jmarsys.2015.01.010

Müller-Karger FE, Hwai ATS, Allcock L *et al*. *Ocean Decade Vision 2030 White Papers—Challenge 2: Protect and Restore Ecosystems and Biodiversity*. Paris: UNESCO-IOC, 2024.

Nash KL, Alexander K, Melbourne-Thomas J *et al*. Developing achievable alternate futures for key challenges during the UN decade of ocean science for sustainable development. *Rev Fish Biol Fish* 2021;**32**:19–36.

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

Pinsky ML, Fenichel E, Fogarty M *et al*. Fish and fisheries in hot water: what is happening and how do we adapt? *Popul Ecol* 2021;**63**:17–26. https://doi.org/10.1002/1438-390X.12050

Ryabinin V, Barbière J, Haugan P *et al*. The UN decade of ocean science for sustainable development. *Front Mar Sci* 2019;**6**:470. https://doi.org/10.3389/fmars.2019.00470

Schmidt JO, Bograd SJ, Arrizabalaga H *et al*. Future ocean observations to connect climate, fisheries and marine ecosystems. *Front Mar Sci* 2019;**6**:550. https://doi.org/10.3389/fmars.2019.00550

Sumaila RU, Cheung WWL, Lam VWY *et al*. Climate change impacts on the biophysics and economics of world fisheries. *Nat Clim Change* 2011;**1**:449–56. https://doi.org/10.1038/nclimate1301

Tigchelaar M, Cheung WW, Mohammed EY *et al*. Compound climate risks threaten aquatic food system benefits. *Nat Food* 2021;**2**:673–82. https://doi.org/10.1038/s43016-021-00368-9

UNESCO-IOC. Ocean Decade Progress Report 2022–2023. The Ocean Decade Series, 46, UNESCO, Paris, 2023.

UNESCO-IOC. The United Nations Decade of Ocean Science for Sustainable Development (2021-2030) Implementation Plan. IOC Ocean Decade Series, 20. UNESCO, Paris, 2021.

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