

# A decadal outlook for global aquaculture

## 1 | INTRODUCTION

Feeding an expected global population of 9 billion by 2050 is a daunting challenge that is engaging millions of farmers, food processors, traders, researchers, technical experts, and leaders the world over. Fish and other aquatic products from aquaculture can and will play a major role in meeting the dietary demands of all people, while also meeting the food security needs of the poorest.

Recognizing the critical importance of aquaculture, and the need to exchange and discuss reliable information to further enhance its contribution to sustainable development, the Food and Agriculture Organization of the United Nations (FAO), at the request of its Members, collaborated with the Network of Aquaculture Centres in Asia-Pacific (NACA) and the Ministry of Agriculture and Rural Affairs of the People's Republic of China, to organize the Global Conference on Aquaculture Millennium +20 (GCA +20), on September 22–25, 2021 in Shanghai, the People's Republic of China. Under the theme “Aquaculture for food and sustainable development”, the hybrid conference brought together experts and stakeholders from the aquaculture sector to discuss the current state and future of aquaculture, as well as its role in achieving the Sustainable Development Goals (SDGs).

The GCA +20 was the fourth in a series of development-oriented conferences with the ambition of shaping the future of global aquaculture. The FAO Technical Conference on Aquaculture (Kyoto, Japan, 1976) reviewed the status, problems, opportunities, and potential for the culture of fish, crustaceans, mollusks, and seaweeds, and declared that the aquaculture sector had made encouraging progress in the past decades, producing significant quantities of nutritious food, income, and employment. The NACA/FAO GCA Millennium Conference (Bangkok, Thailand, 2000) adopted the *Bangkok Declaration and Strategy on Aquaculture Development Beyond 2000*, which articulated strategic elements addressing the role of aquaculture in alleviating poverty, enhancing food security, and maintaining the integrity and sustainability of natural resources and the environment (NACA/FAO, 2001). Importantly, the strong recommendations for enhanced international collaboration on global and regional aquaculture, which emerged from the conference, were brought to the attention of FAO's Committee on Fisheries (COFI) leading to the establishment of a new COFI Sub-Committee on Aquaculture in 2001, the only intergovernmental forum specifically dedicated to aquaculture (Halwart, 2022). The FAO/NACA GCA +10 (Phuket, Thailand, 2010) adopted the *Phuket Consensus: a re-affirmation of commitment to the Bangkok Declaration*, which recognized the continued value and relevance of the Strategy (FAO/NACA, 2012; Annex S1).

The GCA +20 in turn highlighted the crucial role of aquaculture in providing a sustainable source of aquatic food, rich in protein and micronutrients, for a growing global population. With harvesting of wild fish stocks at capacity or declining because of overfishing and climate and environmental changes, aquaculture has become an essential source of aquatic food, providing over half of the world's fish for human consumption. However, the conference also recognized that the growth of the industry has come with environmental and social challenges, such as habitat destruction, pollution, inequality, social injustice, and labor rights issues.

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Regional and thematic reviews represent core elements of the GCA +20. Nine technical themes were selected for GCA +20, by an International Programme Committee, for their current and future relevance in the transformation of aquaculture toward achieving the SDGs. The themes cover core technical subjects, the social and human dimensions of aquaculture, and the planning and governance of the sector. Nine thematic reviews based on the themes were prepared by a group of technical experts commissioned by FAO. The thematic reviews covered the key issues of the day regarding the development and future progress of the development of sustainable aquaculture. Each review detailed the current and future trends, challenges, and opportunities, and considered crosscutting issues including biodiversity, gender mainstreaming, climate change, and capacity building.

Following expert review, GCA +20 participants were invited to provide feedback on the reviews and their key messages, for a period before, during, and after the conference. At the conference, key findings from each thematic review were presented and then discussed by expert panels with input from the GCA +20 delegates. This written and oral feedback was provided for consideration by the authors in the preparation of the final draft and eight of these thematic reviews were selected for publication in this volume.

Through these regional and thematic reviews, the GCA +20 recognized a series of needs and challenges for the future development of sustainable aquaculture and the conference proposed a range of solutions, including improving aquaculture practices to reduce environmental impacts, strengthening governance and regulatory frameworks, and promoting social responsibility in the industry. The conference also emphasized the importance of integrating aquaculture into broader agri-food systems, including the use of innovative technologies that can increase productivity and reduce waste. The conference further recognized the need for greater investments in research and development to support the sustainable growth of the industry. This included improving breeding programs to enhance the health and resilience of farmed types and species, developing new feed formulations to reduce reliance on wild fish stocks, and advancing technologies that can improve efficiency and reduce environmental impacts. A key output from the GCA +20—the Shanghai Declaration on Aquaculture for Food and Sustainable Development—highlights the principles and strategic pathways to maximize sustainable aquaculture in achieving the SDGs, with a special focus on “Leaving no one behind” (FAO, 2022a, Annex S1).

## 2 | PRODUCTION TRENDS

FAO collects data on production from aquaculture and capture fisheries via annualized reporting from Member countries. These data are the most reliable and comprehensive basis for determining trends in production, although it should be noted that mechanisms for reporting aquatic food production are not always comparable with terrestrial livestock production in particular. For example, because of their emphasis on unprocessed wet weights, aquaculture and capture fisheries production values are not directly comparable in terms of edible animal sourced foods (Edwards et al., 2019). Total aquaculture production in 2021 comprised 90.9 million tonnes of aquatic animals and 35.2 million tonnes of algae, which when combined with 1900 tonnes of shells and pearls, accumulated to the highest ever total of aquaculture production at 126 million tonnes live weight with an estimated farm gate value of USD 296.5 billion (FAO, 2023a). Farmed finfish represents the greatest proportion of this production (47.1%) with a further 27.9%, 14.6% and 9.4% made up by seaweeds, mollusks, and crustaceans, respectively.

Global aquaculture is unevenly distributed, with Asia being the main producer representing, in 2020, 91.6% of global production (and 85% of value). China accounts for 56.7% of global aquatic animal production and 59.5% of algal production (FAO, 2022b). The Americas, Europe, and Africa account for respectively 3.6%, 2.7%, and 1.9% of global production. It is often cited that aquaculture represents the fastest growing food production sector over recent decades with an average annual growth rate of 6.7% over the past three decades (FAO, 2022b). As aquaculture matures and production figures rise, however, this rate of growth is slowing, with an annual average growth of 3.5% for the period 2016–2021. In absolute terms, aquaculture production is still growing very significantly at nearly

19 million tonnes per annum. When considering fed and unfed aquaculture (e.g., filter feeding mollusks and finfish, and seaweeds), the former is the principal driver of aquaculture growth. Fed aquaculture represented 60% of production in 2000 and now represents 72.2%. Absolute levels of production for non-fed species have remained relatively constant over recent decades (FAO, 2022b).

Marine and coastal aquaculture represents the largest percentage of aquaculture (55.5%), with the remainder being freshwater aquaculture. Nearly all algal production, the vast majority of mollusk production, and more than half of crustacean production come from marine environments. Freshwater aquaculture dominates in finfish production, representing 85.0% of global totals in 2021 (FAO, 2023a).

On a global scale, aquaculture accounts for 49.2% of total aquaculture and fisheries production, with proportions varying geographically and across different production sectors. In Asia, aquaculture makes up 61.9% of total production compared with less than 7% for Africa when Egypt, the region's major aquaculture producer, is excluded (FAO, 2022b). Aquaculture production exceeds capture fisheries production for all sectors except marine finfish, which remains dominated by capture fisheries. Aquaculture production also exceeds capture fisheries production in middle-income countries, whereas capture fisheries predominate in low-income and high-income countries.

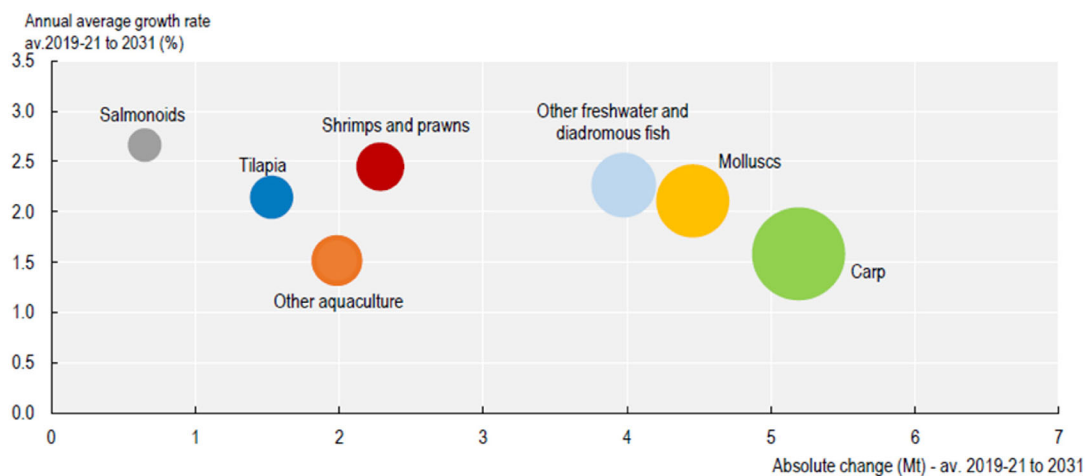
While FAO Member countries have reported farming 710 species or species items since recording began (FAO, 2023a), they report current production of nearly 450 species or species items (FAO, 2020). However, data from the *State of the World's Aquatic Genetic Resources for Food and Agriculture* (FAO, 2019) indicated close to 700 species are currently being cultured. A relatively small number of species predominate with 50% of aquaculture production by volume constituted by just 12 species or species items including three seaweeds, six finfish species, two mollusks, and one crustacean.

Aquaculture is estimated to directly employ 20.6 million producers, with 28% being women, compared with capture fisheries that employ 18% women. A relatively higher proportion of women are employed in the post-harvest sector in both capture fisheries and aquaculture.

Clearly, the high growth rates of aquaculture production over recent decades, compared with the relatively stagnant production levels from capture fisheries, mean that aquaculture has been the predominant contributor to meeting the demand created by the doubling of global per capita fish consumption since 1960. Aquatic food consumption is expected to continue to rise for the next decade at approximately 1.4% per annum which is, by comparison, higher than that anticipated for red meat consumption (1% per annum). Growth in aquaculture production is expected to slow slightly in the coming decade, mainly because of increasing feed costs and the impact of policy changes in China (OECD/FAO, 2022). It is expected that 90% of this production will be for consumption as aquatic food.

Apparent aquatic food (excluding seaweed) consumption globally is projected to reach 21.4 kg per capita in 2031, up from the baseline of 20.5 kg per capita (average 2019–2021). Per capita consumption will increase in all continents except Africa, the region with the fastest growing population (OECD/FAO, 2022). By 2030, aquaculture is projected to produce substantially more than capture fisheries (by around 6 million tonnes). In terms of total production, aquaculture will surpass capture fisheries in 2023 and by 2030 aquaculture will represent 52% of all aquatic animal production (i.e., excluding aquatic plants).

It is difficult to anticipate and project future production trends for individual species or species groups. Figure 1 illustrates average annual growth rates for key species groups contributing significantly to global production. The highest rates of growth are for higher value species such as salmonids and shrimps/prawns, but the greatest volumes of production and the highest rates of absolute growth in production come from the lower value species such as the carps. Evidence from terrestrial agriculture suggests that high volume production evolves for a relatively small number of species. Cai et al. (2022) point to an overall deceleration of species diversification in aquaculture although trends are regionally diverse. They predict this trend to continue with concentration of production on some of the key aquaculture species.



**FIGURE 1** Growth in world aquaculture production by major species groups (2019–2021). (Source: OECD/FAO, 2022).

### 3 | THE ROLE OF AQUACULTURE IN SUSTAINABLE DEVELOPMENT AND GLOBAL FOOD SYSTEMS

Recent, in-depth, global reviews of the rapid progress of aquaculture over the past decade toward increased environmental responsibilities and resource conservation (Boyd et al., 2020; Naylor et al., 2021) lay a new foundation for aquaculture's future contributions to the SDGs (Troell et al., 2023). The potential of aquaculture development throughout the world at all scales is now included in the assessments of the future of aquatic food or “blue foods”, or in a “blue transformation”, by international agencies, university centers, governments, nongovernmental and philanthropic organizations (CEA Consulting, 2020; Crona et al., 2023; Costello et al., 2019; FAO, 2022c; HLPE, 2014; Hoegh-Guldberg et al., 2019; O'Shea et al., 2019; SAPEA, 2017; Stuchtey et al., 2020). Transdisciplinary assessments of both fed and unfed aquaculture systems have shown that many types of aquaculture systems produce products of higher nutritional values and altogether aquaculture accounted for less than 1% of anthropogenic greenhouse gas (GHG) emissions in 2017, similar to emissions from sheep production (Gephart et al., 2016, 2021; Hallström et al., 2019; MacLeod et al., 2020). However, significant socio-cultural inequities lead to food justice inequality and consequently political opposition to aquaculture exists, which poses serious obstacles to its expansion and growth (Brugere et al., 2023; Carter, 2018; Krause et al., 2015).

As emphasized by Troell et al. (2023), a more in-depth understanding by policymakers and investors of the “extraordinary diversity of aquaculture, both species and systems, becomes crucial for development of the sector's present and future contributions to the different SDGs”. Aquaculture touches every one of the SDGs; and its scaling involves every socio-political dimension. As a result, the future expansion of aquaculture systems, and their abilities to play a greater role to achieve the SDGs, will require a greater integration with a wider diversity of economic and environmental professions engaged in planning and investments in the broader terrestrial/aquatic food-water-energy nexus, and the natural resource, rural development, and human health system communities. Outstanding examples of aquaculture's benefits to rural communities and health food system economies exist when such engagement and planned integrations have been developed (Hernandez et al., 2017). Troell et al. (2023) emphasizes this point, stating, “Having a broader value-chain perspective will be imperative for gaining deeper insights about aquaculture's overall contribution to the SDGs, for understanding outcomes from investments and transformation efforts especially in diversifying supply chains and livelihoods”.

The IPCC Sixth Synthesis Report (AR6) released in March 2023 (Lee et al., 2023) documents that during the last decade (2010–2019), GHG emissions continued to increase “from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, causing many weather and climate extremes...and led to widespread adverse impacts on food and water security, human health and on economies and society, related losses and damages to nature and people”. Over 90% of human food production comes from terrestrial agriculture, which accounts for an estimated one third of all GHG emissions (Gilbert, 2012). Expansion of terrestrial agriculture, to provide the projected need for foods to 2050, has serious resource and environmental constraints. If relied upon to the exclusion of aquaculture's options, further unacceptable destruction of the Earth's remaining natural ecosystems and reserves from deforestation, conversions of grasslands, expansion of water irrigation systems, etc. will occur (Costa-Pierce, 2016).

There are many proven options known for decades to integrate aquaculture efficiently and sustainably into terrestrial food systems. Expansion of these into Africa is a priority of the CGIAR systems and its WorldFish center ([worldfishcenter.org](http://worldfishcenter.org)). With the expansion of aquaculture technologies and global economies, land (e.g., recirculating aquaculture systems, RAS) and ocean-based aquaculture food systems developments will need to be integrated with emerging renewable energy systems at all scales (Buck & Langan, 2017; Scroggins et al., 2022; Vo et al., 2021). In addition, as tourism is estimated to account for upwards of 30% of the global economy, development of aquaculture tourism will not only assist in the economic viability of farming livelihoods but in the education of communities in areas of the world where aquaculture is new.

Fisheries and aquaculture interact in many ways, for example with fishers shifting from fishing to aquaculture, and also operate in the same markets with similar products. Thus, the effective integration of planning and management of the two sectors is vital to their future development and sustainability. Klinger et al. (2013) recognized that ocean food systems (OFS) of fisheries and aquaculture cannot be separated but are increasingly “hybrid seafood systems” whose products enter a common marketplace. Capture fisheries and aquaculture are researched, planned, and managed throughout the world as if they are independent entities ignoring their complex and evolving interdependencies. Such divisions and binary management approaches do not fit the current realities, opportunities, and innovations in hybrid OFS, and do not integrate knowledge across professions. Integration of knowledge across professions is needed to make better decisions on ocean food interventions that would incorporate data on rural economic development, producers and their mixed ocean/land-based livelihoods, seasonal employment patterns, tourism, marketing, trade, and consumer behaviors. In the coming decade a greater diversity of hybrid OFS will likely evolve with accelerated climate and social changes, and their system complexities, intimate interactions in global-to-local marketplaces, and contributions to advancing mixed, rural livelihoods will need more attention. Integration of knowledge across professions will be needed to make better decisions on the appropriate development of aquaculture as an aquatic food intervention. Assessments will need to incorporate data on rural economic development, producers and their mixed aquatic/ocean/land-based livelihoods, seasonal employment patterns, tourism, marketing, trade, and consumer behaviors (Costa-Pierce, 2023).

Lastly, the expansion of aquaculture requires technologies, investments, and policies that will not only benefit industries and communities but also mitigate impacts or even restore adjacent natural ecosystems. The Ecosystem Approach to Aquaculture (EAA) laid an important foundation for this work in the last decade (FAO, 2010), but progress has been slow (Brugere et al., 2019). New guidelines, policies, and applied science being led by global non-governmental organizations such as the Nature Conservancy, World Wildlife Fund, and their partners in “restoration, regenerative, conservation, and ecological” aquaculture offers new sustainable expansion pathways to aquaculture in the coming decades (Alleway et al., 2018, 2023; Jones et al., 2022; TNC, 2021; World Economic Forum, 2023). At the same time, governments now increasingly recognize and support new examples of international cooperation and partnerships for new models of sustainable aquaculture development. An example is the new Center for Ecological Aquaculture at Shanghai Ocean University in P.R. China, which was established as a result of, and commitment to, the GCA +20 process, pays particular attention to the ecological dimension of aquaculture development, and will facilitate implementation and upscaling of agro-ecological and nutrition-sensitive approaches through integrated agriculture–aquaculture (Dabbadie et al., 2019). FAO Members “encouraged FAO to work in partnership with such

initiatives to promote sustainable aquaculture, emphasizing the importance of the Ecosystem Approach to Aquaculture, and requesting technical assistance for its implementation” (FAO, 2022d). FAO is incorporating the concept specifically into their global Guidelines on Sustainable Aquaculture currently under review.

## 4 | KEY OUTPUTS AND OUTCOMES FROM THE GCA +20

The thematic reviews provided an evidence base for the GCA +20 and supported the drafting of the *Shanghai Declaration on Aquaculture for Food and Sustainable Development* (Annex S1). The conference culminated in the adoption of the Shanghai Declaration by the participants and this was followed by the tabling of statements of support by government agencies, national and international organizations, the private sector, and civil society.<sup>1</sup>

The Shanghai Declaration provides a road map to optimize the role that aquaculture can play in achieving the 2030 Agenda for Sustainable Development. It provides the shared vision of conference participants of sustainable aquaculture, five overarching commitments, 10 strategic priorities, and a call for action.

In summary, the Shanghai Declaration recommends stakeholders make a series of overarching commitments toward achieving the vision for sustainable aquaculture including: promoting responsible aquaculture development and good governance; strengthening partnerships to generate and share knowledge, information and technology; investing in aquaculture innovation, research, and development; and creating open and transparent communication.

The Declaration identified calls to action on 10 strategic priorities to accelerate sustainable aquaculture development and its contribution to the SDGs:

- A. Expand the contribution of aquaculture to sustainable agri-food systems for nourishing nations, reducing poverty, and providing healthy, nutrient-rich, and climate-friendly food to people.
- B. Integrate aquaculture with the natural environment, agriculture, capture fisheries, forestry, tourism, renewable energy, and other sectors, and within agri-food systems for increased resilience.
- C. Continually improve the performance of aquaculture, and its capacity to minimize impact on, make better use of natural resources, and enhance ecosystem services.
- D. Promote aquaculture development approaches that conserve and improve ecosystems and biodiversity and reduce the carbon intensity of food production systems.
- E. Protect and develop aquaculture-based livelihoods and promote decent work and socially responsible enterprises.
- F. Ensure women's empowerment by enhancing women's full access to equal opportunities through gender-transformative policies.
- G. Promote opportunities for young women and men.
- H. Promote Indigenous Peoples' participation in aquaculture.
- I. Prepare for and potentially mitigate impacts from global crises, such as climate change, biodiversity loss, pollution, and pandemics.
- J. Strengthen data and information collection and analysis for monitoring the progress and contributions of aquaculture.

The unanimous adoption of the Declaration by the conference participants is an important milestone for global aquaculture, and all stakeholders are encouraged to consider it when working toward sustainable aquaculture.

<sup>1</sup>It is worthwhile noting that the Shanghai Declaration is a stakeholders' document not intended to be officially endorsed by FAO Members, as was the case previously with GCA and GCA +10 declarations. The great value of technical guidance emerging from these processes is widely recognized. Consequently, some of the thematic discussions and the technical recommendations of the Declaration, as considered important and relevant for FAO Members, are currently being considered in the intergovernmental process leading to the adoption of global Guidelines for Sustainable Aquaculture - for more information please see [www.fao.org/in-action/gsa](http://www.fao.org/in-action/gsa).

## 5 | FAO'S BLUE TRANSFORMATION

The COFI Declaration for Sustainable Fisheries and Aquaculture (FAO, 2021) recognizes “the potential of aquaculture for further growth, particularly through innovative practices that support environmental stewardship, as well as the benefits of new and ongoing inclusive sustainable aquaculture development programs, and the need for investments to support capacity building, research, and extension services, with a particular attention to regions where population growth will challenge food systems most”.

The goal of FAO's Blue Transformation Roadmap 2022-2031 (FAO, 2022c), which aligns with the COFI Declaration, is to provide a basis for the provision of enough aquatic food for a growing population. This should be achieved in a way that is environmentally, socially, and economically sustainable and equitable, and ensures the availability and accessibility of safe and nutritious aquatic food for all, in particular for vulnerable populations, and reduces food loss and waste. It should also ensure that aquatic food systems contribute to improving rights and income of vulnerable communities to achieve equitable livelihoods and support resilience in aquatic food systems that are highly influenced by dynamic anthropogenic and nonanthropogenic processes, including from a changing climate.

In relation to aquaculture, the objective is to achieve the sustainable intensification and expansion of aquaculture in a way that satisfies global demand for aquatic food and distributes benefits equitably. This would be achieved through global and regional cooperation, effective planning and governance, application of technology and management, promotion of aquaculture operations that minimize environmental impact and use resources efficiently, and is supported by regular monitoring and reporting of the growth and impacts of aquaculture.

Among the key tools proposed to support and promote sustainable growth of the sector are the Guidelines for Sustainable Aquaculture currently under preparation by FAO, which will provide a voluntary and non-binding framework for countries to drive forward the development of sustainable aquaculture.<sup>2</sup>

At present there is no universally agreed upon definition of sustainable aquaculture, but we recommend it be defined as “the practice of producing nutritious aquatic food and associated products in a manner that is environmentally and socially responsible, economically viable, and able to meet the needs of present and future generations. It involves using production systems and technologies that minimize negative impacts on the environment, and promote the long-term health and productivity of aquatic ecosystems, and support economically viable livelihoods that build vibrant communities, human health, and wellness.”

Sustainable aquaculture practices may include using low-impact farming methods, such as non-fed aquaculture, recirculating aquaculture systems, or integrated agriculture-aquaculture, to reduce the use of water and land resources and minimize waste. They may also involve sourcing feeds and other inputs from sustainable sources, conservation and effective management of aquatic biodiversity, minimizing the use of antibiotics and other chemicals, and ensuring high animal welfare standards.

Sustainable aquaculture should not only be guided by technological and ecological advances but also by the development of robust governance frameworks, well-targeted policies, strategies and proper planning, and transparent, knowledge-based, predictable and enforceable legislation, underpinned by effective capacity building. Furthermore, sustainable aquaculture proactively considers social and economic factors, such as long-term profitability and competitiveness, fair labor practices and community involvement, and gender and racial equality, to ensure that the industry is not only environmentally sustainable but also socially responsible and economically viable in the long term.

The thematic reviews presented in this important special issue of this journal provide greater detail and further key messages on the issues that need to be addressed to deliver on the GCA +20 vision and the Shanghai Declaration for the future of sustainable aquaculture. FAO looks forward to convening, with key partners, the next global conference in this series to measure progress and identify further the impacts of the various initiatives being promulgated in support of sustainable aquaculture development.

<sup>2</sup>For more information please see [www.fao.org/in-action/gsa](http://www.fao.org/in-action/gsa)

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## DATA AVAILABILITY STATEMENT

No data included.

## KEYWORDS

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.