Review

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Seafood Sustainability Challenges for Import-Dependent Nations

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Review

Seafood Sustainability Challenges for Import-Dependent Nations

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Abstract: Dependence on seafood imports is growing for many nations, effectively exporting the environmental and social impacts from consuming nations to producers. While countries have commitments to national regulations and global sustainability targets, such as the United Nations Sustainable Development Goals, sustainability standards for imported seafood are lacking. We examine the sustainability implications of high-income countries' reliance on seafood imports, using Australia as a case study. Australia imports around 60-70% of domestically consumed seafood, with 96.5% imported from 20 countries. Compared to Australia, these countries generally have lower environmental performance, higher vulnerability to slavery, and increased risk of illicit trade in their supply chains. Yet, biophysical limits on wild catch, low demand for underutilized species, social conflict, environmental concerns over aquaculture expansion, and low domestic production, suggest imports will likely remain an important source of seafood for Australian consumers. Other high-income countries in Europe and North America face similar challenges. These countries have a pivotal role in promoting responsible trade. Comprehensive sustainability assessments that integrate environmental and social considerations of production and trade, improved mapping of seafood production activities, and more granular trade data will be critical for informed and effective trade regulations that support sustainability commitments.

Keywords: seafood; sustainability; imports; international trade; impact displacement

Main

The international seafood market has experienced profound transformations in recent years and many countries now rely on imported seafood to meet domestic demand (J. L. Anderson et al., 2018). High-income countries, once major producers, increasingly rely on imported seafood to meet their growing demand while enforcing strict sustainability regulations and policies on domestic production (Anderson et al., 2019; FAO, 2024a; Swartz et al., 2010). For instance, the United States of America (USA), European Union (EU), and Australia have some of the strictest social and ecological regulations for seafood production (Kelemen, 2010), yet the USA imports 90% and the EU and Australia both report that 60% of their consumed seafood is imported (ABARES, 2022; European Commission, 2019; Gephart et al., 2019; Klein et al., 2022). To meet demand, high-income countries typically import relatively large volumes of seafood compared to low- and middle-income nations, where the need for imported products is more often due to limited production driven by

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overexploitation by domestic and foreign fleets (e.g., Marin et al., 2024; Watson et al., 2016, 2017). Thus, trade flows among nations carry asymmetrical implications for the sustainability of seafood products.

Seafood trade patterns are driven by a complex suite of ecological, socioeconomic and political factors, including resource availability, environmental and geopolitical shocks, telecoupled investments or market regulations (Anderson et al., 2018; Farmery et al., 2017; Godar & Gardner, 2019; Li et al., 2022; Subramaniam et al., 2023). Seafood imports can increase domestic availability and buffer supply against local production shocks (Asche et al., 2015; Nash et al., 2022; Smith et al., 2010; Walker et al., 2023). The production and export of seafood can offer economic benefits, including generating foreign exchange to alleviate poverty, importing lower-cost food for domestic markets, and increasing local seafood availability (Belton, Little, et al., 2020; Belton, Reardon et al., 2020; Béné et al., 2010). However, traded seafood can be associated with social, economic and environmental problems. For example, the export of seafood can have negative impacts in the producing country, such as compromised food and nutrition security (Belton, Reardon, et al., 2020; Belton & Thilsted, 2014; Farmery et al., 2015; Teh et al., 2019), labor exploitation, and/or the displacement of small-scale producers by large monopolies (Belton, Little, et al., 2020). Further, poorly regulated seafood production can be associated with illegal, unreported and unregulated (IUU) fishing practices, overfishing, or land-use changes and nutrient enrichment from aquaculture (Froehlich et al., 2021; Nakamura et al., 2018). Therefore, when a nation imposes strict regulations that limit domestic production for sustainability reasons but seafood consumption continues to increase, growing import-dependence may simply displace the environmental or social challenges of seafood production to their trade partners (Asche et al., 2016; Dorninger et al., 2021; Klein et al., 2022; Nash et al., 2022).

Numerous high-income countries, like Australia, have made domestic (e.g., Commonwealth Fisheries Policy, The National Fisheries Plan 2022 - 2030) and international commitments (e.g., UN Sustainable Development Goals - SDGs) to sustainable seafood production and consumption. However, Australia's governance of seafood is primarily limited to regulating domestic production, which in 2020 accounted for 40% of the seafood that it consumed (ABARES, 2022). Therefore, to improve the sustainability of domestically consumed seafood in import-reliant countries, focus must extend beyond sustainable domestic production to emphasize responsible sourcing (Anderson et al., 2019). High-income countries have both the means and the responsibility to guide the seafood market toward more sustainable products (Guillen et al., 2019). This is crucial for aligning trade practices with sustainability commitments and goals. We use Australia as a case study to highlight the sustainability challenges associated with growing import-reliance of seafood and discuss potential mitigation strategies. To do this we synthesize data from diverse sources to (1) describe historic and potential future trends in Australian seafood supply and (2) examine the socio-economic and environmental sustainability implications of seafood consumed in Australia.

Australia's Growing Seafood Import Dependence

Consumption of seafood in Australia has surged in recent decades. Since the 1960's, per capita apparent consumption of seafood has increased more than any other major food group, with the average Australian consuming 12.8kg of seafood in 1961 to a peak of 26.8kg in 2013 and 24.5kg in 2022 (Figure 1a; FAO, 2023). While domestic seafood production has steadily increased, it has lagged behind demand and the growth in per capita apparent seafood consumption has largely been met by imported products. While official reports state that 60% of the domestic supply is imported, we found that this number was closer to 70% in 2019 (Figure 1b). Our calculation is higher than official reports as it is based on live weight equivalents (i.e., biomass weight at production), rather than edible weight (i.e., product weight after processing; ABARES, 2022), the latter of which is prone to underestimating the biomass of seafood needed for consumption, and thus the embedded impacts of its production (Edwards et al., 2019; Love et al., 2015). To calculate the live weight equivalent, we matched the processed seafood products needed to meet Australian supply to conversion factors (EUMOFA, 2004) by the Harmonized System (HS) codes from trade data. As the conversion factor for non-edible products (e.g., pearls, coral) is zero, all non-edible products traded are excluded from our analyses.

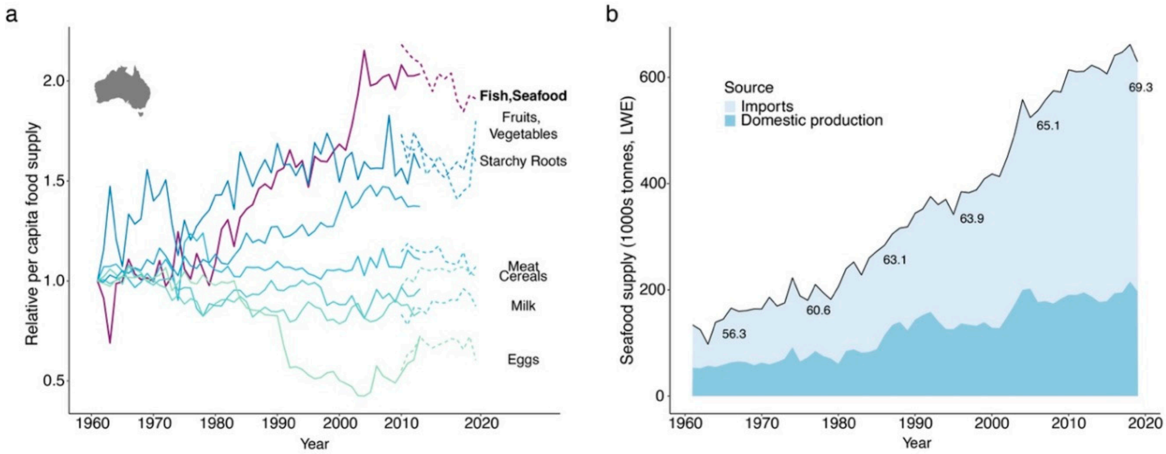

Figure 1. Australia's food consumption trends. (a) Per capita supply of food commodities relative to 1961 values. Solid and dashed lines represent old and new FAO error distribution methodologies, respectively. We used the United Nations Food and Agriculture Organization (FAO) data, adjusting for seafood items in the Food Balance Sheets (FAO, 2020; 2023), considering exports, re-exports (Supplementary Figure 1) and excluding aquatic products not used for food. (b) Seafood supply by source in live-weight equivalent (LWE). We validated our calculations by matching volumes with the Food Balance Sheets' "Total Food Supply" category. We used temporal production trends from the "FAO Global Fishery and Aquaculture Production Statistics v2024.1" dataset (FAO, 2024b).

Increased seafood imports into Australia were facilitated by policy reforms in the mid-1980's that ended market protectionism, along with trade agreements and the establishment of the World Trade Organization (WTO), which boosted international trade (Anderson, 2020; Banks, 2005; FAO, 2024a). However, reports of fraud (Cundy et al., 2023), forced labor (Selig et al., 2022; Tickler, Meeuwig, Bryant, et al., 2018; Tickler, Meeuwig, Palomares, et al., 2018), and the harvesting of endangered species (Roberson et al., 2020) are proliferating in global seafood supply chains. As a result, Australia's growing reliance on seafood imports heightens its risk of being implicated in environmental and social harm, which has received scant attention in Australia.

Sustainability Implications of Australia's Imported Seafood

Seafood sustainability indices that simultaneously encompass social, economic, and environmental factors do not exist (Gephart & Golden, 2022)(Gephart and Golden, 2022). To estimate sustainability challenges associated with imported seafood in Australia, we couple seafood import data (FAO, 2024c) with three publicly available metrics relevant to understanding how aquatic systems are regulated in producing countries (Figure 2). The Environmental Performance Index (EPI; Wolf et al., 2024) encompasses numerous indices relevant to all wild-caught and farmed, inland and marine seafood products, including composite measures of fisheries management, biodiversity and habitat protection, climate mitigation strategies, waste management, and agricultural pollution. The Vulnerability to Slavery Index (The Walk Free Foundation, 2023), synthesizes governance effectiveness, access to basic services, inequality, and propensity for conflict. The Illicit Trade Environment metric (The Economist Intelligence Unit, 2018) evaluates the risk of illicit trade, involving counterfeit, mislabeled, or illegally smuggled products in a country's supply chain - underpinned by a lack of sufficient policies or initiatives to prevent these activities.

We focus our analysis on Australia's top 20 seafood trade partners as they supplied 96.5% of the 1.2 million tons of imported products from 2019 to 2022 (Supplementary Table S2; FAO 2024c). Nearly all of these trade partners scored lower than Australia on all three sustainability metrics (Figure 2). When looking at individual metrics, all but four countries (Norway, Denmark, Poland, and the United Kingdom) exhibit lower national Environmental Performance Index scores; only two

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countries (Denmark and Norway) have lower vulnerability to slavery; and all but three countries (New Zealand, the USA, and the United Kingdom) have a higher risk of illicit trade within their supply chains than Australia (Figure 2; Supplementary Table S2). These trends raise concerns about the social and environmental sustainability of the majority of seafood supplied to Australians.

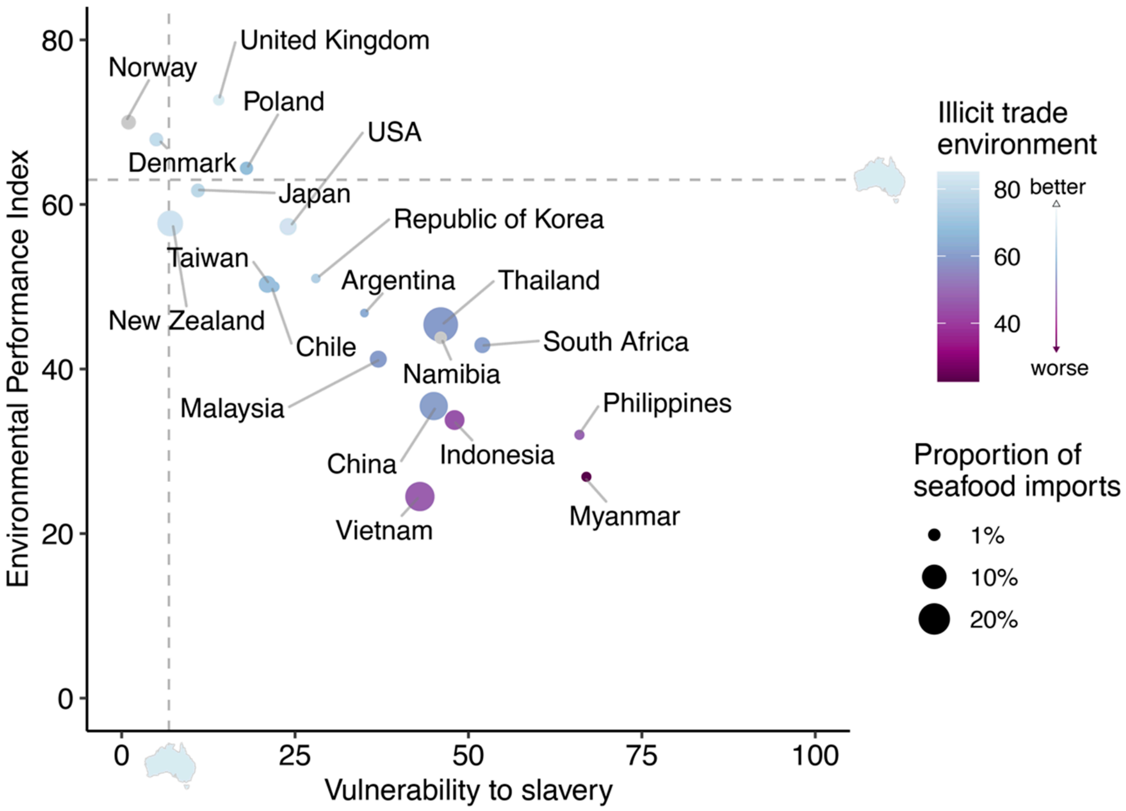

Figure 2. Sustainability challenges within supply chains of Australia's top 20 trade partners, by proportion of Australia's total seafood imports. Environmental Performance Index (Wolf et al., 2024), Vulnerability to Slavery (The Walk Free Foundation, 2023), Illicit trade environment (The Economist Intelligence Unit, 2018). We use data for seafood imported into Australia in 2019-2022 from the Food and Agriculture Organization (FAO, 2024c). The intersection between the dashed horizontal and vertical lines represents Australia's score for Environmental Performance Index and Vulnerability to Slavery, respectively.

Opportunities to Reduce Import-Reliance for Seafood in Australia

Uncertainty about the social-ecological risks embedded in imported seafood products raises the question of whether Australia *could* or *should* increase dependance on domestic production to meet its seafood consumption needs. Theoretically, this *could* be achieved through a combination of three different approaches: 1) increasing domestic wild-capture production, 2) expanding domestic aquaculture production or 3) redirecting seafood exports to domestic markets. We explore the feasibility and their implications for sustainability of each approach to help guide future decisions about the sustainable consumption of seafood.

1) Increasing domestic wild-capture production

Australia's domestic seafood production is primarily dominated by marine wild-capture fisheries which account for about 60% of the national total (150 thousand tones in 2022; Figure 3a). These fisheries are generally recognized as being well-managed relative to other countries (Alder et al., 2010; Mora et al., 2009). Although Australia's fisheries have been previously criticized for limited efforts in stock restoration and insufficient stock assessments (Harrison et al, 2021), efforts to improve stock assessments are increasing. The latest estimates (503 individual stocks assessed in 2023) indicate that 62.8% of fisheries stocks are at sustainable biomass levels, 3.2% recovering, but a further 14.7% still undefined (Figure 3b; Roelofs et al., 2024).

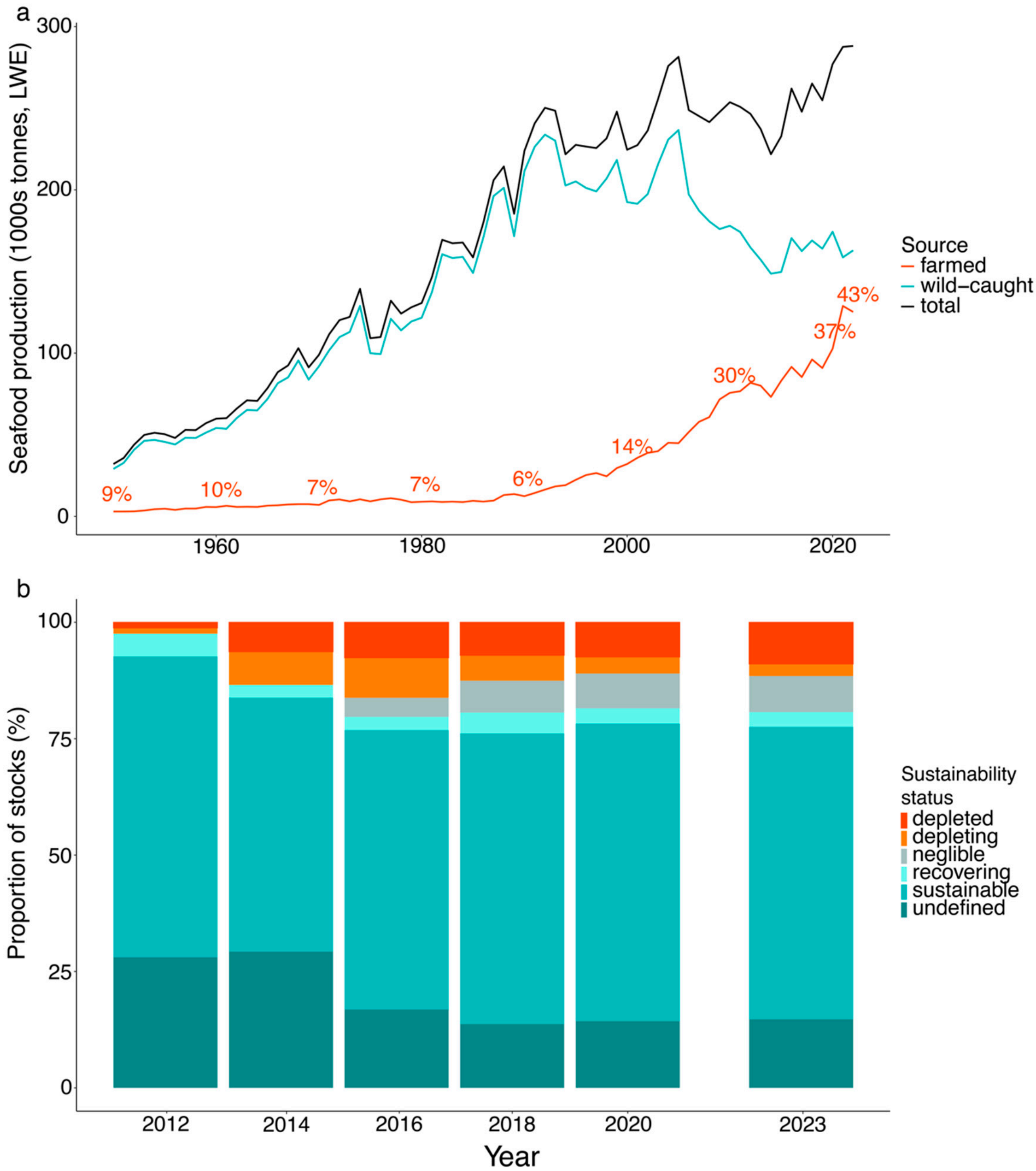

Figure 3. Trends in Australia's seafood production systems. Temporal trends in a) Australia's seafood production across sectors (FAO 2024b), numbers in plot represent the proportional contribution of aquaculture to total seafood production in Australia; b) the sustainability status of Australian wild fish stocks from the Fisheries Research and Development Corporation (FRDC; Roelofs et al., 2024).

Australian wild-caught fisheries could increase production by targeting non-target or small pelagic species like sardines (Smith et al., 2021; van Putten et al., 2019; Ward et al., 2023). However, market demand for these species remains low (Smith et al., 2021; van Putten et al., 2019; Ward et al., 2023). Moreover, overfishing has led to declines in some coastal fish populations (Edgar et al., 2018, 2019), and increased market competition and rising operational costs have resulted in decreased landings from domestic fisheries in recent years (Australian Government Department of Agriculture and Water Resources, 2016; Figure 3a).

The environmental consequences of increasing wild-caught fisheries production on marine ecosystems remain uncertain, and the economic effects of shifting production from over-exploited to

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under-exploited species have yet to be explored (Smith et al., 2021). Additionally, stock assessments often overestimate the health and sustainability of fish populations (Edgar et al., 2024). This, combined with limited productivity in Australian marine waters (Department of Aquaculture, 2015) and anticipated threats from climate change (English et al., 2022) may further limit the potential for sustainably increasing wild-caught seafood to meet domestic demand. Therefore, a comprehensive analysis of Australia's ability to sustainably increase wild-caught seafood production, considering implications for ecosystem health, social acceptance and market opportunities, is urgently needed (Smith et al., 2021).

2) Expanding aquaculture production

In contrast to the barriers to increase wild-fisheries production, aquaculture production has steadily increased in recent years. This growth was driven primarily by the expansion of salmonid farms in Tasmania (Figure 3a; Curtotti et al., 2023). Aquaculture products are predicted to provide 64% of the total gross value of seafood production by 2027, and the government's goal to double the value of domestic aquaculture from 2017 - 2027 was met in 2023 (Curtotti et al., 2023; Department of Agriculture and Water Resources, 2017). Australia has one of the world's largest marine Exclusive Economic Zones (Flanders Marine Institute, 2023) and has huge potential for mariculture growth based on biophysical potential for species growth (Gentry et al., 2017). This has spurred a wave of investment in exploration of Australian onshore, nearshore and offshore 'blue economies,' including aquatic food production (Spillias et al., 2022; see https://blueeconomycrc.com.au/).

Yet, there are considerable challenges to expanding the Australian aquaculture sector enough to substantially substitute currently consumed imported products. Broad-scale social acceptance of the aquaculture industry remains a limiting factor. Poor farm siting decisions and interactions with rare species in some locations in Tasmania have sparked a highly mediatized conflict between the public and aquaculture industry stakeholders, leading to heated debates about the sustainability of marine farming (Condie, Vince, et al., 2022). High-profile resignations from the Marine Farm Planning Review Panel in 2018 further undermined confidence in the sector's development process. While this conflict has largely been restricted to Tasmanian salmon farming, there is potential for other aquaculture sectors to inherit poor public perceptions by association, and pose challenges for growth (Spillias et al., 2022). This may be particularly important for plans to expand southern bluefin tuna ranching and prawn farming, the next two most important sectors of the Australian aquaculture industry (Tuynman et al., 2024). Furthermore, disparate regulations for aquaculture expansion among states and territories (Department of Agriculture and Water Resources, 2017), the technical challenges of moving the industry to offshore or onshore environments away from social conflict (Chu et al., 2020), continued pressure from marine heatwaves and climate change (Fleming et al., 2014; Laubenstein et al., 2023; Lim-Camacho et al., 2015), and the comparative economic advantage of imported products (Hoshino et al., 2021; Pascoe et al., 2022; Schrobback et al., 2019) will continue to pose challenges for the sector.

The environmental implications of meeting rising seafood demand with domestic aquaculture production are also uncertain. Comprehensive and comparable measures of aquaculture's environmental sustainability measures across different archetypes are currently insufficient (Garlock et al., 2024). However, the resource intensiveness of farmed aquatic taxa can be evaluated, in part, by quantifying their feed dependence and feed conversion efficiency. Aquaculture feeds are manufactured from a range of agricultural and fisheries products sourced globally and typically account for the majority of embedded environmental impacts in the life cycle of fed aquatic species (Gephart et al., 2021; Henriksson et al., 2013; Hilborn et al., 2018; Newton & Little, 2018). The proportion of fed to non-fed aquaculture production in Australia has risen sharply from 8% in the 1980s to 89% in 2021 (Figure 4a; FAO, 2024b) due to a shift in the industry from oysters to finfish. Therefore, feed is an increasingly important component of Australian aquaculture's environmental sustainability.

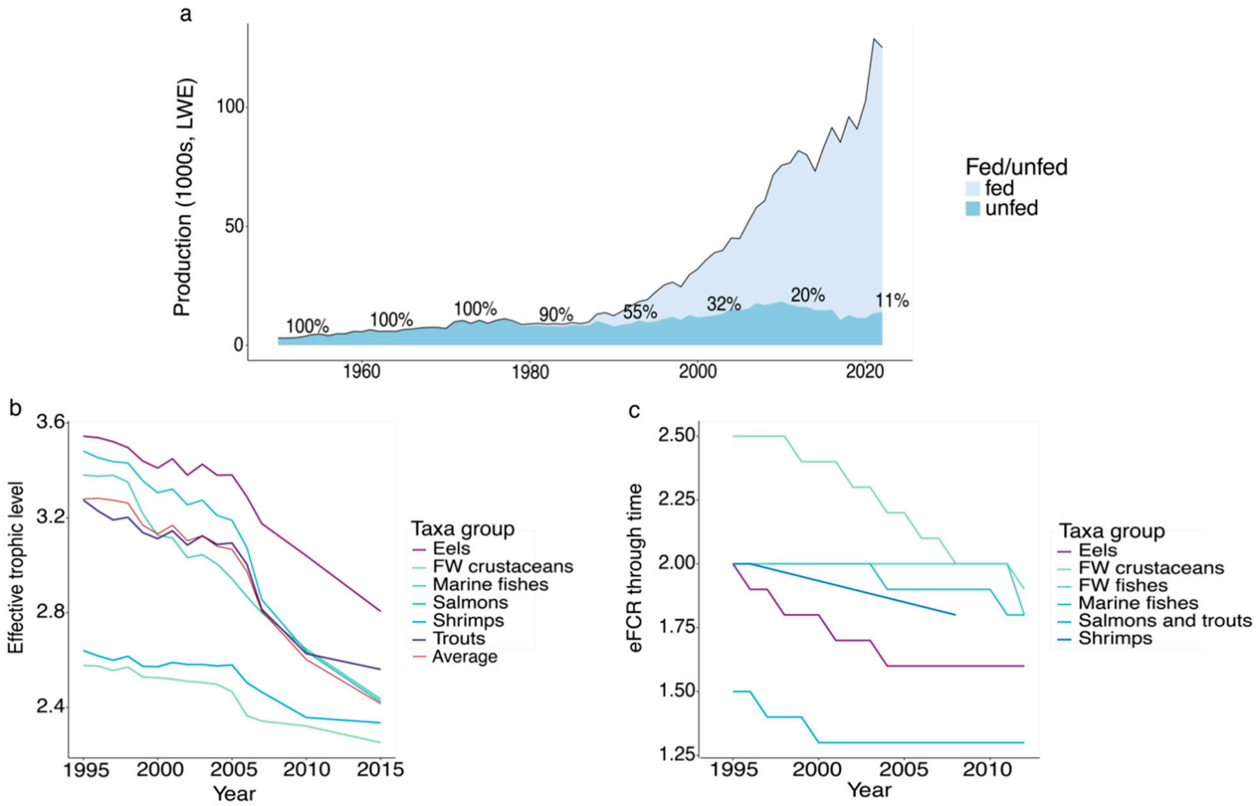

Figure 4. Trends in Australia's aquaculture production systems. Temporal trends in: a) fed and unfed farmed aquatic species production (fed = dependent on manufactured feeds), percentages represent the proportion of fed aquaculture production; b) the typical effective trophic levels that major aquatic taxa in Australian aquaculture are fed at; c) typical economic feed conversion ratios (feed in:fish biomass out) of major aquatic fed taxa in Australian aquaculture. We assumed that all species in Australia are fed during the farming process except for bivalves and seaweeds and took values for average feed conversion ratios for each taxon from Tacon & Metian (2008, 2015), effective trophic levels from Cottrell et al., (2021), and production data from FAO (2024b).

There are a number of considerations for understanding the environmental impact of feed practices for the species farmed in Australia (Truong et al., 2023), but the trophic level at which species are fed and their economic feed conversion ratio (eFCRs; i.e., the feed biomass required to produce one unit of animal biomass inclusive of feed waste) provide generalizable and open source indicators of resource intensiveness. The weighted average effective trophic level and eFCRs of fed species in Australian aquaculture have decreased through time (Figures 4b and c, respectively), indicating a reduction in the ecosystem energy embedded in feeds and more efficient feed-to-food ratios. These trends reflect the continued research and investment in selective breeding, nutrition, feed technology, and on-farm practices that have reduced reliance on marine ingredients (i.e., fishmeal and oil) and continue to improve the efficiency in which farming inputs and outputs are managed, contributing to sustainability advances (Cottrell et al., 2020, 2021; Gephart et al., 2021; Hua et al., 2019; Turchini et al., 2019).

Although the environmental efficiency of Australian aquaculture in terms of feed is improving, there are other consequences of substantially upscaling the sector to help meet seafood demand. For example, a dramatic increase in aquaculture production in its present form, dominated by coastal sea cages, would heavily impact the near-shore environment and likely create conflict with other stakeholders (Condie, Alexander, et al., 2022; Sanchez-Jerez et al., 2016). An increased demand for aquaculture feed would also inflate the global footprint of Australian farmed seafood, increase food-feed resource conflict, and potentially undermine the benefits of reducing seafood import-dependence and the displacement of environmental and social impacts associated with it. A better

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understanding of the ecosystem impacts associated with feeds for marine aquaculture, both at farm and global scales, is needed before it can sustainably expand to substitute the seafood currently supplied by imports.

3) Redirecting seafood exports to domestic markets

Redirecting exports as a strategy to displace import reliance is limited by both the quantity of total exports and the types of products that are imported and exported. Australian seafood exports, although valuable, are relatively small, equivalent to around 10% of total apparent consumption in 2019 (64,296 tones of live weight equivalent, FAO, 2023; Supplementary Figure 1.). Most Australian seafood exports are of high value (e.g., rock lobster, abalone, tunas and salmonids) while imports consist primarily of lower value seafood products, like white fish, small pelagic species, squid, or mussels (FAO, 2024d; Figure 5.). Salmonids and tunas are important in Australian diets, but they only represent around a third of per capita apparent consumption (ABARES, 2022). Moreover, the average prices of exported products are higher than those of imported counterparts for all groups (Figure 5.). To support the redirection of exports, Australian consumers would need to be willing and able to pay for these premium seafood products and potentially adjust their consumption choices. Thus, the reallocation of these seafood products toward domestic markets would displace very little imported biomass, and still leave unfulfilled demand for more affordable seafood.

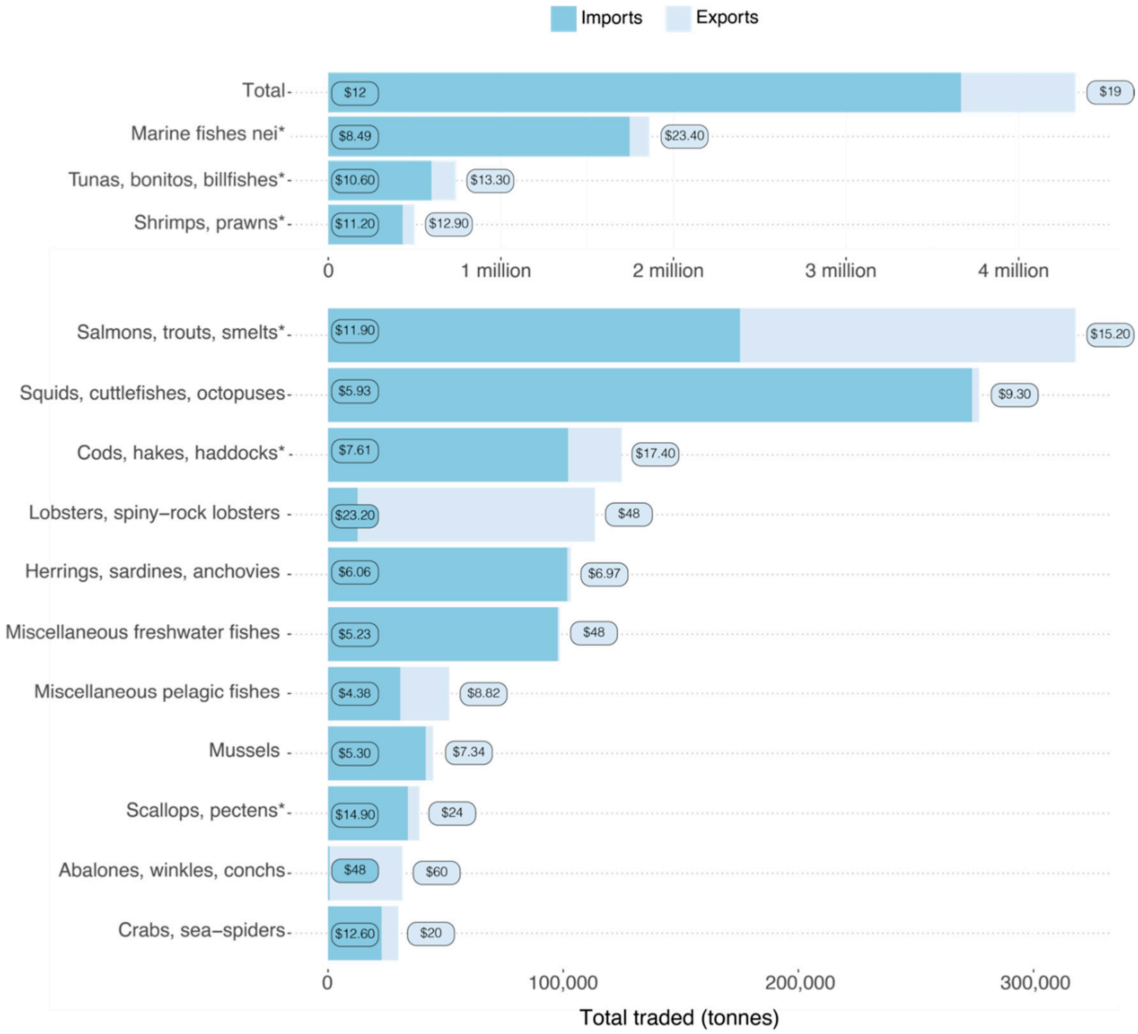

Figure 5. Top seafood products imported into and exported from Australia from 2010 - 2022 (FAO 2024d). Dark and light shaded boxes indicate the average value (AUD) per ton of imported and exported products, respectively, within each commodity group. Groups marked with * are within the top 10 commodity groups imported and exported from 2010 to 2022 (by value and volume; FAO 2024d).

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Seafood Sustainability for Import-Reliant Futures

Given the challenges in meeting seafood demands with increased domestic production, imported products will likely remain an important, and possibly increasing, source of seafood in Australia. The same holds true for other nations. For example, in the USA, sustainability concerns limit the increase in wild fishery production (Froehlich et al., 2021; Hilborn et al., 2020), and although the country has huge potential for increased aquaculture production (Gentry et al., 2017), regulations and public concern hinder its expansion (Fong et al., 2022, 2024a, 2024b; Lester et al., 2022). If current consumption trends continue and production goals are met, all International Council for the Exploration of the Sea (ICES) member countries (predominantly high-income countries in Europe and North America), except Norway, are predicted to increase their reliance on imports by 2050 (Froehlich et al., 2021).

Governments can enhance seafood sustainability by developing and implementing supportive trade policies, such as policies that aim to restrict IUU seafood imports (Bellmann et al., 2016; Kittinger et al., 2021; Roberson et al., 2024). However, market-based regulations (e.g., sustainability certifications) and local seafood sustainability legislation generally focus on production (Kittinger et al., 2021), overlooking the impacts of displacement through international trade. Expanding trade measures to address broader sustainability concerns, like contributions to financial equality or ecosystem health, could advance progress toward global sustainability goals, including the SDGs. Australia is already party to treaties like the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and supports the biodiversity beyond national jurisdiction treaty for the sustainable use of resources in the high seas (Commonwealth of Australia, 2017). Moreover, the Australian government is developing a trade policy similar to those in other high-income countries such as the USA, the EU and Japan (Roberson et al., 2024). These policies aim to prevent IUU seafood products from entering the domestic market (DAFF, 2023a, 2023b; Dominguez-Martinez et al., 2023; Roberson et al., 2024), but do not include measures to establish sustainability standards for imported seafood. Catch documentation schemes allow information on a product (e.g., where it was caught, vessel number) to travel through the supply chain as it gets traded and processed (FAO 2017; Roberson et al., 2024). Policies akin to catch certification schemes could be used to ensure socio-economic and environmental sustainability across the supply chain.

However, three research priorities are necessary to inform these new trade policies: more comprehensive sustainability assessments, spatially specific aquaculture location data, and improvements in publicly available trade data.

(1) More comprehensive sustainability assessments

While there are assessments of economic, social and environmental sustainability aspects of seafood production, they are often siloed rather than integrated into comprehensive sustainability assessments. For example, ecosystem- or area-based management approaches in wild fisheries offer a chance to include social sustainability aspects, but they mostly focus on the industry's economic inputs and outputs (Hornborg et al., 2019). Similarly, social factors like inequality and food security driven by seafood exports have received less attention than other economic or environmental aspects, especially in the aquaculture sector (Brugere et al., 2023). The impacts of the seafood sector on equality and other social factors contribute to several SDGs and need to be considered in sustainability assessments and trade policies and regulations. A positive development is the growing recognition of adverse working conditions and modern slavery in wild-caught fisheries from both scientists (Hicks et al., 2016; Kittinger et al., 2017; Tickler, Meeuwig, Bryant, et al., 2018; Tickler, Meeuwig, Palomares, et al., 2018) and media (e.g., Lawrence & Booth, 2010).

Although aquaculture is now the main source of seafood globally (FAO, 2024a), less attention has been devoted to the socio-economic sustainability of this industry compared to wild fisheries. There have been isolated reports highlighting benefits such as improved nutrition and food security (Golden et al., 2021), increased employment and overall wellbeing (Larson et al., 2021). However, these benefits might not be equitably distributed (Gonzalez Parrao et al., 2021), particularly in areas where rapid economic growth is prioritized for the industry (Belton, Reardon, et al., 2020; Brugere et al., 2023; Farmery et al., 2021). Additionally, although some isolated instances of forced labor have

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been reported (*Fisheries and Aquaculture*, 2024.; Sutton & Siciliano, 2016), the prevalence of such practices remains unknown due to limited research to date (Troell et al., 2023). Moreover, sustainability certifications in aquaculture production (e.g., Aquaculture Stewardship Council or Friends of the Sea) often emphasize health and safety of workers, while overlooking crucial ethical issues such as human rights, exploitation, harassment, and the impacts on local and indigenous communities (Saha, 2024). Understanding the trade-offs associated with the growth of aquaculture production - driven by both domestic demand and international exports - and integrating these insights into comprehensive sustainability assessments is crucial to ensure that the industry's expansion aligns with broader sustainability objectives.

Recent disruptive events like the COVID-19 pandemic, geopolitical tensions, and extreme weather events highlight the importance of integrating resilience into sustainability assessments. Resilience and sustainability research has historically focused on the production phase of agriculture supply chains (Davis et al., 2021). However, sustainability must be recognized as an integral characteristic of project, policy, or system resilience, rather than a desirable result (Marchese et al., 2018). Integrating these concepts is crucial for ensuring the sustainability of the seafood market system (including ecosystems, resources, and social benefits) and its ability to recover, adapt or cope with stressors in a context of climatic and market change (Mason et al., 2022).

Improving both resilience and sustainability across the entire supply chain has substantial implications for food security, nutrition, ecosystem health, and financial progress of producing countries (Mason et al., 2022), all of which align with SDG goals. High-income, import-reliant countries should focus on their responsibility and commitment to responsible consumption (SDG 12 - Ensure sustainable consumption and production patterns) and support the development of comprehensive sustainability assessments that incorporate socio-economic and environmental aspects of the seafood they consume. These assessments should consider resilience factors such as response diversity - the variety of responses available within a system to cope with change - to maintain system stability. For instance, Australia's relatively high response diversity for traded goods enhances its resilience (Walker et al., 2023), while countries like the United Kingdom could benefit from improving the resilience of their seafood imports (Ching-Pong Poo et al., 2024).

Comprehensive sustainability assessments that consider multiple metrics are essential for creating objective tools to guide decision-making in import-reliant nations and ensure the seafood sector's long-term sustainability. Increased production for international markets can lead to negative impacts in the producing country, including overexploitation (Eisenbarth, 2022) and reduced nutrient availability (Nash et al., 2022), but it can also drive economic development (Tran et al., 2023), benefiting communities by enhancing food security (Belton et al., 2018) or women's empowerment (Larson et al., 2021), therefore fundamentally contributing towards several SDGs. For instance, aquaculture production in Vietnam has increased dramatically in the last few decades (Nguyen Thanh et al., 2021), driving an increase in incomes and reducing inequality (Tran et al., 2023). We need to understand the trade-offs, costs and benefits of international seafood trade across multiple sustainability domains (i.e., environmental, social, economic) to ensure truly sustainable development of the seafood sector.

(2) Spatially specific data for the location of seafood production

Ecosystems and species have different sensitivities to similar pressures, making the spatial context of seafood production crucial for accurate sustainability assessments (Halpern et al., 2022; Kuempel et al., 2020). In recent years, there has been an increase in attention to the spatial patterns of fishing (Watson et al., 2016). As a result, global estimates of fishing effort now include both industrial and artisanal fisheries (Rousseau et al., 2024), though the data remains spatially limited. Global Fishing Watch have improved the spatial resolution of industrial fishing activities using AIS (see https://globalfishingwatch.org/), but this technology can be disabled to obscure vessels activities and locations (Bunwaree, 2023; Long et al., 2020; Park et al., 2023). Small-scale fisheries contribute significantly to global catch, and are often underreported, leading to gaps in catch data and stock assessments (Teh & Sumaila, 2013). Understanding where both industrial and small-scale fishing occurs is essential for assessing impacts of fishing and the status of marine resources on which seafood imports depend.

Available data for the location of fish farming is even more poorly resolved. A major challenge in accurately estimating the impacts of aquaculture production is simply locating aquaculture facilities. Maps for reported marine aquaculture sites exist but they under-represent the number of farms needed to meet the global volume of reported production (Clawson et al., 2022). As a result, numerous efforts have been made to map aquaculture sites, relying on methods such as remote sensing for location detection, suitability mapping to model farm siting, or estimating the number of farms needed based on reported national production (e.g., Clawson et al., 2022; Dorber et al., 2020; Peng et al., 2022; Spillias et al., 2023; Sun et al., 2024). Despite significant advances and ongoing efforts (e.g., Liu et al., 2024), we still lack harmonized approaches to map aquaculture production across different archetypes (e.g., finfish, shellfish, seaweed) in freshwater and marine environments. As the global volume of aquaculture production continues to grow, understanding the industry's impact on local ecosystems would allow for more strategic location of new farms to expand the industry and reduce resulting environmental pressures in producing countries.

(3) Improving data on international seafood trade

Trade data lack the granularity needed for accurate sustainability assessments. In 2018, 40% of wild-caught global landings were reported as broad taxonomic groupings (such as 'Marine fish'), rather than species, genus, or even family (Blasco et al., 2020). Because of the low resolution of initial reports by producing countries, compounded by additional aggregation before the information is made available to the public, a large proportion of traded seafood is categorized as "fish generic", "marine animals", or "freshwater fish" (FAO 2024b, 2024c, 2024d; Gephart et al., 2024). Adding to this challenge, the coordination between production and trade data is inadequate, making it unclear whether trade partners are the producing country or intermediary processors, or whether products are wild-caught or farmed. Moreover, masking the original source country and production method makes it impossible to understand the embedded environmental or social considerations needed for sustainability assessments.

Recent efforts have focused on increasing transparency through traceability initiatives (Bharathi et al., 2024; Lewis & Boyle, 2017; Shamsuzzoha et al., 2023), and advanced modeling techniques for improved data resolution. These models aim to disaggregate broad categories and estimate species-specific trade flows by integrating multiple data sources, including catch data, trade statistics, and market information (Gephart et al., 2024). Continued development and implementation of novel modeling approaches, supported by improved reporting practices, are crucial for enhancing the resolution and reliability of trade data in support of sustainable fisheries management.

Conclusions

We use Australia to illustrate the disparity between the sustainability of locally produced seafood and imported products in high-income nations. There is an urgent need for well-informed policies and effective regulations to improve the sustainability of internationally traded seafood in Australia and beyond. The globalization and commoditization of seafood is complex and demands deeper exploration. As the global population grows, the sustainability of food systems becomes essential for both nourishing people and mitigating socio-environmental impacts, in line with sustainability targets such as the SDGs.

High-income countries, as major importers and influential economies, bear an important responsibility and opportunity to lead sustainability efforts. While increasing wild-caught production and expanding aquaculture could diminish reliance on imports, the trend toward greater import dependence is likely to persist (Froehlich et al., 2021) (Froehlich et al., 2021). Establishing trade regulations and sustainability standards for imported products is therefore a potential avenue to enhance global seafood sustainability. However, the effectiveness of these regulations relies on an accurate assessment of seafood sustainability both in its production and through its trade. Here, we propose three key recommendations for progress: developing more comprehensive sustainability assessments, enhancing the granularity of data on seafood production locations, and improving the accuracy and resolution of trade data. These measures are essential for fostering the sustainable development of the international seafood market.

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