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Rights and representation support justice across aquatic food systems

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Injustices are prevalent in food systems, where the accumulation of vast wealth is possible for a few, yet one in ten people remain hungry. Here, for 194 countries we combine aquatic food production, distribution and consumption data with corresponding national policy documents and, drawing on theories of social justice, explore whether barriers to participation explain unequal distributions of benefits. Using Bayesian models, we find economic and political barriers are associated with lower wealth-based benefits; countries produce and consume less when wealth, formal education and voice and accountability are lacking. In contrast, social barriers are associated with lower welfare-based benefits; aquatic foods are less affordable where gender inequality is greater. Our analyses of policy documents reveal a frequent failure to address political and gender-based barriers. However, policies linked to more just food system outcomes centre principles of human rights, specify inclusive decision-making processes and identify and challenge drivers of injustice.

The global food system has supported the accumulation of vast quantities of wealth, most notably over the past half-century through the corporatization of agriculture and fisheries[1]. Food systems also support the livelihoods of nearly a third of the world's population and provide food—a basic need and human right—to all[2]. While global production, trade and consumption of food have escalated, these sectors have grown increasingly concentrated[2] and the number of people who are food insecure continues to rise, with one in four people now food insecure[3]. These food system inequities are further exacerbated by contemporary global crises—such as climate change, conflict and pandemics—a pattern laid bare by COVID-19 causing near-doubling of the number of people experiencing 'crisis level' hunger[3–5]. Consequently, the need for transformation towards a more just and sustainable food system is undeniable[3].

Social justice

Transformation towards a more just global food system requires broad-scale engagement with concepts of justice and equity. Justice broadly means 'parity of participation', based on the principle of equal moral worth[6]. Injustices are thus understood to exist where institutionalized structures create barriers that impede full participation across society[6], resulting in the greatest burdens or benefits falling on particular social groups[7]. Injustices in food systems manifest in diverse ways; from the egregious human rights violations associated with slavery at sea[8], to the negative health outcomes, such as malnutrition and maternal and child mortality, associated with a lack of food[4]. Struggles for justice have most often played out within territorial frames[6]. However, for globally connected systems, barriers to participation are increasingly constructed across national and international

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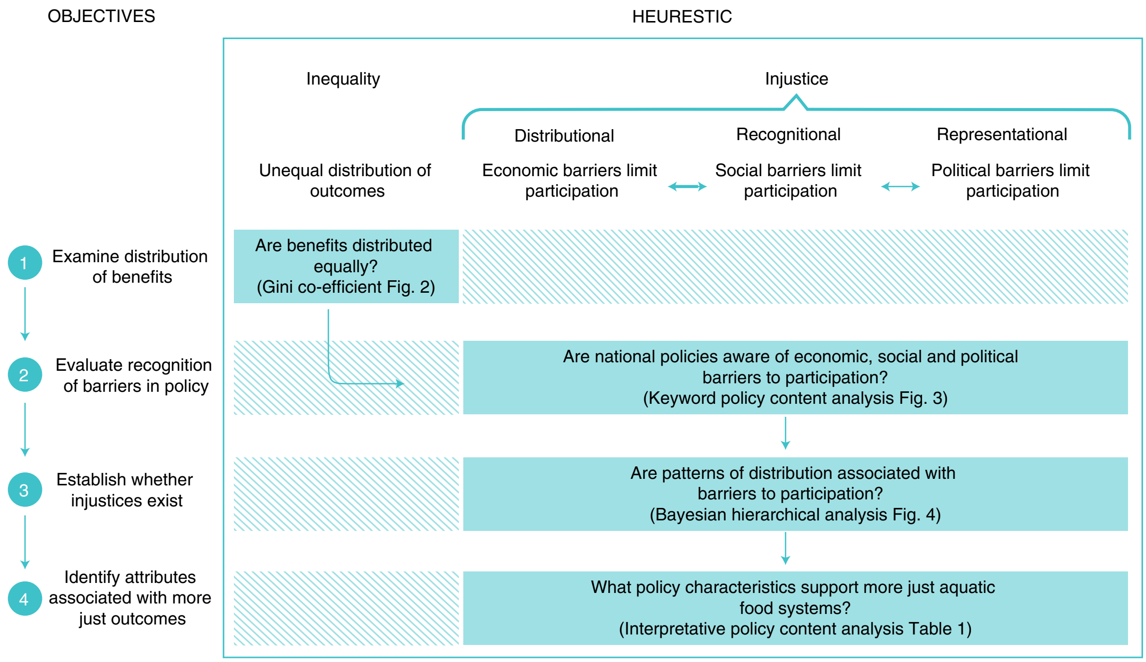

Fig. 1 | Heuristic showing the relationship between three dimensions of justice and the research framework followed. This diagram distinguishes between equality and justice and describes how the research questions draw on three dimensions of social justice[14,15] to guide the analysis and implications for aquatic food policy.

scales. The resulting global scope of injustice therefore necessitates global analyses[6,7,9].

Analyses of injustice tend to encompass three interdependent dimensions: distributional, recognitional and representational or procedural justice[6,7]. Distributional injustices emerge when economic structures, such as class, mean that some people lack the resources needed to fully participate. Recognitional injustices emerge when social or cultural structures, such as gender, do not value or recognize certain identities, making it harder for them to participate as equals. Representational injustices emerge when political structures, that establish whose voice counts in decision-making, prevent some people from participating fully[7]. All three dimensions are relational and interact with one another to create unequal distributions of benefits (and burdens) and exacerbate conditions such that some social groups lose out, in terms of resources and power, whereas others gain.

Here, we develop a mixed-methods approach (Fig. 1) that draws on a three-dimensional justice lens[6,7] and uses data from 2006 to 2016 on food system benefits and associated national policies of 194 countries, to evaluate inequalities and injustices. Such an approach, through its focus on barriers as the conditions of injustice, can also illuminate how injustices can be resolved. We focus on the highly traded[10], socially valuable[11–13], aquatic food system, which although characteristic of many food systems is only recently gaining attention.

Results and discussion

Unequal distributions of aquatic food benefits

Focusing on three aquatic food system benefits associated with production (quantity of food produced), distribution (value of export revenues) and consumption (dietary supply of protein) of aquatic foods and using the Gini index[14], we found that aquatic food system benefits were distributed highly unequally across countries (Fig. 2). Distributions in the quantity of food produced (Gini = 0.76, where 1 is perfectly unequal) (Fig. 2a) and value of export revenues (Gini = 0.90) (Fig. 2b) were more unequal than income (Gini = 0.65)[15]. A few high-income countries, including Iceland and Norway, produced the most per worker (253 and 171 t worker^{-1} yr^{-1}, respectively) (Fig. 2a and Supplementary Data; ref. [16]) despite China, India and Indonesia, where most fish workers live[10,11], dominating total production (Supplementary Data; ref. [16]). High-income or island nations, including Iceland, Norway and Seychelles, dominate per capita export revenue (Fig. 2b and Supplementary Data; ref. [16]), whereas the quantities of aquatic foods exported are greatest in resource-rich countries, with large Economic Exclusive Zones (EEZ), such as China, Norway and Peru, which together account for 23% of global exports by volume (Supplementary Data; ref. [16]). As a group, aquatic foods are among the most highly traded food commodities, in part due to the increasing commodification of fishery products and the rise of foreign processing[17]. Between 1994 and 2012, global seafood trade nearly doubled[18], generating over US$164 billion globally in export revenues in 2018 (ref. [10]). This growth in seafood trade may have exacerbated inequalities[19], as globally traded aquatic foods interact with domestic markets and small-scale fisheries by diverting products to foreign markets and through competition with imported products[20]. However, these interactions are not universal and the impacts are context-dependent.

Consumption of aquatic foods (as protein supply) was more equally distributed than production or export revenues but still exhibited high inequality (Gini = 0.46; Fig. 2c). Aquatic food consumption comprises around 17% of animal protein consumption globally[10,16]. The highest levels of consumption were found in island nations across the Atlantic, Pacific and Indian Oceans, including the Maldives, Iceland and Kiribati (47, 27, 24 g capita^{-1} d^{-1} of protein, respectively) (Supplementary Data; ref. [16]). In comparison, for 100 countries (60%) consumption was below the global average of 5.5 g capita^{-1} d^{-1} of protein (Supplementary Data; ref. [16]). Because there are limits to how much someone can eat, the range of consumption values is smaller than the range of values for production and trade, which partly explains the more equal distribution. However, small increases, or decreases, in consumption of aquatic foods can substantially impact nutrition. This is particularly true in low-income countries[21,22] where up to 845 million people depend on aquatic foods as a critical source of essential micronutrients[12,13] but where supply is at, or close to, levels needed to meet requirements for a healthy diet[21]. The emerging emphasis on aquatic foods as a healthy and sustainable alternative to meat could undermine this potential if aquatic foods flow increasingly towards high- and middle-income consumers and countries[23].

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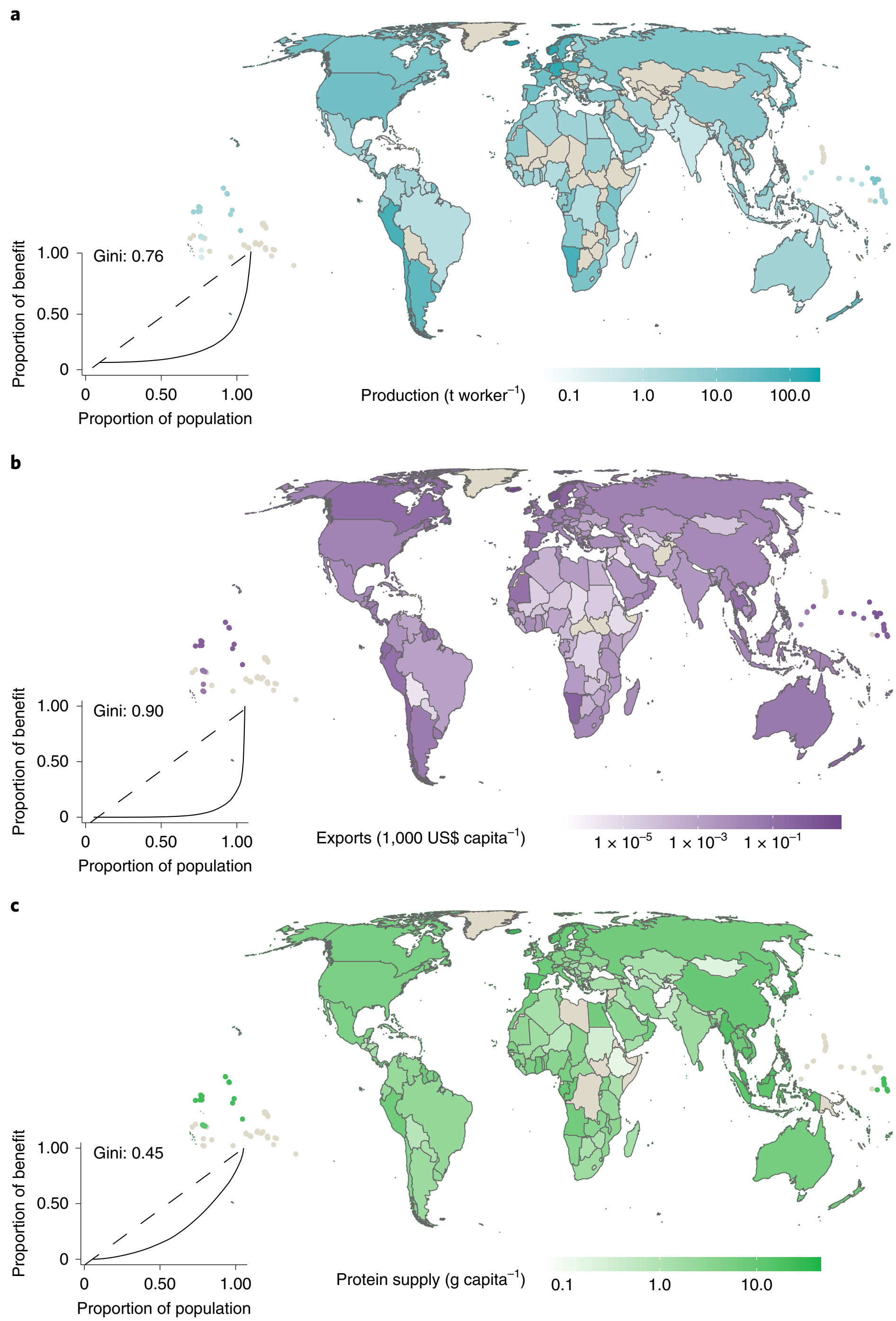

Fig. 2 | Global distribution of benefits from aquatic foods. a–c, Global distribution of production (t worker^{-1} yr^{-1}) ($n = 144$) (**a**), exports (US$ capita^{-1} yr^{-1}) ($n = 188$) (**b**) and aquatic protein supply (g capita^{-1} d^{-1}) ($n = 167$) (**c**), represented as global map with insert for Lorenz curves with Gini coefficients. Grey colour represents countries with missing data.

National policies differ in awareness of barriers

To evaluate awareness of barriers to participation within national aquatic food policy, we conducted eight expert interviews to identify terms that reflect economic (for example, wealth), social (for example, gender) or political barriers (for example, voice) and policy concepts (for example, social security) that seek to address these barriers (Supplementary Table 2). We then used these terms and concepts in a summative content analysis[24] conducted on 173 countries aquatic food production-related (for example, fisheries and aquaculture) and consumption-related (for example, food and nutrition security) policy documents, comprising 306 enacted laws and policies in total (Methods). We found globally that policies were most likely to recognize or seek to address economic barriers, most often related to wealth and trade (Fig. 3 and Supplementary Table 3). This policy orientation was particularly true for southern Africa (Fig. 3), a region with some of the highest levels of income inequality in the world[25]. Overall, policies were least likely to recognize or seek to address political barriers (Fig. 3).

We found considerable variation in attention given to social barriers, including gender and age (Fig. 3 and Supplementary Table 3). Policies from eastern Africa and southern and western Asia, where

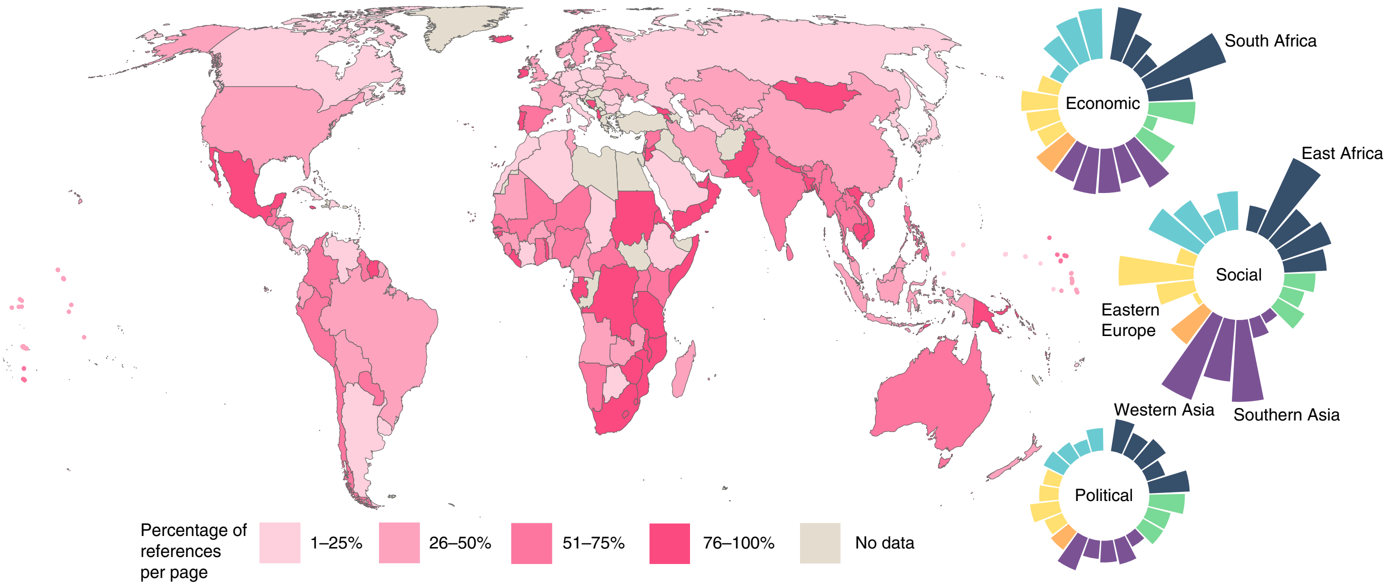

Fig. 3 | Recognition of barriers to participation in national policy documents. Average number of references made to economic, social and political barriers in enacted national policy documents ($n = 306$). Petal diagrams describe the average number of references per page across UN subregions. Colours: dark blue, Africa; light blue, Oceania; yellow, Europe; orange, Caribbean; green, Americas; purple, Asia. Grey colour represents countries with missing data.

prevalence of malnutrition is high and a particular concern for women and children[4], contained the most frequent references to social barriers, in particular age (Fig. 3). In contrast, policies from eastern Europe contained the fewest (Fig. 3). References to social barriers were particularly low across production-related policies where on average fewer than 0.1 references were made, per page, compared to over ten times more (1.2) in consumption-related policy documents (Supplementary Table 3). This suggests a broad failure within production-related policies to recognize and account for differences in social identity (for example, gender and age). Fifty-three and 84 (20% and 30%) countries' production policies made no reference to age or gender, respectively, compared to only three and nine countries' consumption policies (Supplementary Data), highlighting the slow progress in moving beyond gender-blind production-related policies[26]. Yet, global prevalence of child labour remains high[27] and ample evidence exists that gender norms and social constraints limit aquatic food system actors from participating equally[28].

Historical and sociocultural differences in how production and consumption sectors are perceived[26,29], have created little overlap between sectors in awareness of barriers, reflecting a lack of institutional coordination. Differences were particularly stark in some geographies. For example, production-related policies from Vietnam and the Democratic Republic of Congo made some of the most frequent references to economic barriers and least frequent to social barriers. Conversely, their consumption-related policies were amongst the least likely to reference economic barriers and most likely to reference social barriers. Consumption-related policies from Bangladesh and Australia similarly make some of the most frequent references to social barriers but their production-related policies make the fewest (Supplementary Data).This focus, on overcoming economic barriers in the production of aquatic foods and social barriers in the consumption of aquatic foods, rather than removing barriers to access, is likely to reinforce divisions of labour that are shaped by traditional social and cultural norms[29]. Greater investments in mother- and child-focused health probably account for differences between production- and consumption-related policies[30]. However, differences across sectors in awareness of, and efforts to address, barriers can also present an opportunity for cross-sector policy engagement to embed gender and broader socially sensitive strategies into production policies.

Barriers that create injustice

We developed a series of Bayesian models (Methods) to establish whether unequal distributions of benefits in the global aquatic food system are associated with barriers to participation, reflecting injustices. We focus on seven economic, social and political barriers to participation and eight production, distribution and consumption benefits from aquatic food systems. Because food system distributions can also result from natural variations in resource endowments[9,31], in each model we control for relevant biophysical and geographic variables (for example, EEZ area and climatic zone) that are known to influence the overall size of benefits but are not relevant to our analysis of barriers.

We found that when economic barriers were lower, characterized by wealthier countries with greater levels of educational attainment, aquatic food consumption per capita and production per worker was higher (Fig. 4). Indeed, increases in fish consumption are often attributed to increases in income[32]. In contrast, when economic barriers are higher, characterized by lower educational attainment, we find that diets are more dependent on aquatic foods, aquatic foods are more nutritious and jobs more dependent on the aquatic food system (Fig. 4). Together, this suggests that economic barriers are associated with distributional injustices that limit wealth-based benefits but create welfare-based dependencies with livelihoods more dependent on the aquatic food system; dynamics that can lead to poverty traps[33].

Economic and political barriers often co-occurred to create distributional and representational injustices that reinforced a wealth–welfare divide across the aquatic food system (Fig. 4). Greater wealth-based benefits, including greater production, export and consumption of aquatic foods, were found where political barriers were lower, characterized by high levels of voice and accountability (that is, democratic processes and freedom of expression). In contrast, where political barriers, due to the lack of voice and accountability, were present, more jobs (including for women) and more affordable aquatic foods were evident (Fig. 4). Policies capable of addressing economic and political barriers to participation are desirable; however, global aquatic food system dynamics have created welfare-based dependencies that limit the potential to escape poverty[33]. Care is thus needed to ensure that the welfare functions, crucial to food and nutrition security, are not undermined[34].

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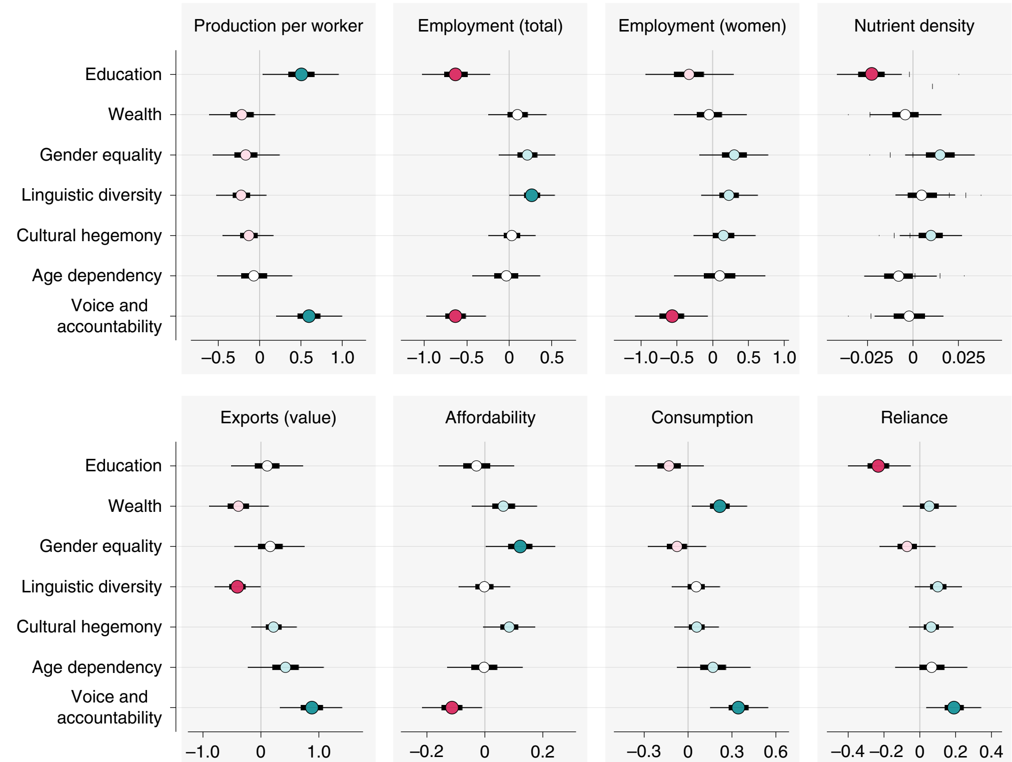

Fig. 4 | Bayesian hierarchical models establishing how economic, social and political barriers are associated with distributions of aquatic food benefits. Standardized effect sizes for the influence of economic, social and political barriers on aquatic food benefits. 'Employment (women)' refers to women's employment only in the direct sector. Parameter estimates are median values of Bayesian posterior distributions. Darker shaded circles indicate that 90% of credible intervals do not overlap 0 and that the estimate was either positive (blue) or negative (red). Lighter shaded circles indicate that 50% of credible intervals do not overlap with 0 and that the estimate was either positive (blue) or negative (red). White circles indicate that 50% of credible interval overlap 0. Thick and thin horizontal lines are 50% and 90% credible intervals. For all models, $n = 195$.

In contrast to economic and political barriers that limit wealth-based benefits, social barriers tended to limit welfare-sustaining benefits. For example, where gender-based barriers were lower (greater gender equality), aquatic foods were more affordable (Fig. 4). Indeed, gender and development research show that if women had equal access to productive assets and resources and were free from other gendered constraints, the number of food-insecure people could be reduced by up to 17% (ref. [35]). Similarly, where linguistic diversity, a proxy for cultural diversity[36], was higher aquatic food systems supported more jobs, although exported less (Fig. 4). Diverse cultures are more likely to reflect a diversity of practices[37] that support a larger workforce, whereas homogenous cultures may have more specialized production practices that support fewer jobs but, in the current system, have greater export potential[34]. Many low-income countries look to exports to generate economic growth[38]. However, trade-induced economic growth will only benefit domestic food and nutrition security if countries can absorb the excess labour force and have policies that redistribute export revenues in a just manner, domestically[34]. Indeed, the tensions between welfare-sustaining (for example, local jobs and affordable nutrition) and wealth-generating (for example, revenue and profit) contributions from aquatic foods have led global food justice and food sovereignty movements to push back against the increasingly global and lucrative trade in aquatic foods, to advocate for greater support for domestic markets, household production and local domestic consumption[39]. National food policy therefore needs to balance support for diverse production systems that sustain jobs and are likely to be more resilient[40] with export-led economic growth that risks undermining the welfare functions of aquatic food systems[41].

Policy attributes for change

A positive deviance approach has been used previously in nutrition and marine research to identify and learn from places performing better than expected[42]. We drew on this approach to identify, for each of five benefits and given barriers present, the 12 countries securing considerably more and considerably less aquatic food benefits than expected. Selections were based on the largest standard deviations from our Bayesian models (Methods). We then qualitatively analysed the content of the resultant policies of countries to establish how barriers are addressed and consequently how national policy can better support justice in aquatic food systems. Although the content of policy documents does not always reflect practices on the ground[43], it can help to create the conditions for more positive change.

Policies differed considerably in how (Table 1) and how often (Fig. 3) they engaged with social barriers. Since social barriers limit welfare-based production and consumption benefits (Fig. 4), differences in policy engagement with barriers were associated with outcomes (Table 1). For example, in Bangladesh and Gambia where aquatic food outcomes were greater than expected, nutrition policies clearly centred principles of justice and human rights, often starting with a declaration such as 'Nutrition also is a basic human right' (Table 1). These policies also endorsed wider responsibility for change by challenging unequal gender norms and envisioning new ones; such as promoting 'male participation in the provision of nutritional care and support for women and their families' (Table 1). In contrast, policies from countries with lower-than-expected aquatic food outcomes tended to interpret social barriers narrowly or in ways that risked reinforcing unequal social norms and harmful stereotypes. For example, policies that stated "[these] risks may then be compounded […]; which

Table 1 | Aquatic foods policy attributes and example quotes

	Common policy failings and examples	Parallel best practises and examples
Addressing social barriers (recognitional justice)	**Policies fail to acknowledge social difference or recognize structural barriers. When they do, they inadvertently blame the disadvantaged**. "These risks may then be compounded …; which will lead to another generation of malnourished mothers, who will in turn replicate the cycle" (Sudan Nutrition Policy 2009)	**Policies acknowledge social difference, that structural barriers exist and that challenges are intersectional**. "[The] nutritionally vulnerable (pregnant women, lactating women, infants and young children 0–23 months old) and nutritionally-affected (those who are already malnourished), from poor families and communities have less access to resources and services …" and " … the problem for achieving optimum complementary feeding is not simply rooted in income" (Philippine Plan of Action for Nutrition 2017–2022s) **Policies centre justice, equity and human rights**. "Nutrition also is a basic human right, with both equity and equality related to eliminating malnutrition and ensuring human development" (Bangladesh Nutrition Policy 2015). "Support the food rights approaches" (Gambia Nutrition Policy 2010–20). "Government's actions will be guided by the principle of equity in all aspects of the sector" (Liberia Food Security & Nutrition strategy 2008)
Addressing economic barriers (distributional justice)	**Policies inadvertently place the burden of change on the disadvantaged**. "Identify opportunities where women can provide useful inputs to the development of the fishery. Identify opportunities for women to add value to fishery products. Increase the number of women employed by the support agencies and develop their linkage with women" (Bangladesh Fisheries Strategy 2006)	**Clear redistributive policies that state what, to whom and how redistribution applies**. "Small-scale commercial fisherfolk shall be granted incentives … priority access [e]specially as to rural credit, with preference being given to fisheries cooperatives" (Philippine Fisheries Code 1998). "Zoning of protected areas and fishing areas for the development of the artisanal fishing activity" and "05 sea miles as a reserve zone for artisanal fishing" (Peru Fisheries Policy) **Policies clearly articulate the context of how structural barriers drive injustice and strive to avoid bias**. "Provision in the household and community of time, attention, support and skills to meet the physical, mental and social needs of the socio-economically deprived and nutritionally vulnerable groups" (Gambia Nutrition Policy 2010–20) "It will support efforts to address structural injustices in the allocation of resources necessary to give access to food. Actions planned under the strategy will pay close attention to whether there is any bias or perceived bias in the targeting of these programmes along potentially volatile social dimension, be they ethnic, income, geographic, or religious" (Liberia Food Security & Nutrition Strategy 2008) **Polices broaden the responsibility for change and open spaces to challenge stereotypes and social norms**. "Promotion of male participation in the provision of nutritional care and support for women and their families" (Gambia Nutrition Policy 2010–20)
Addressing political barriers (representational justice)	**Policies lack or do not specify, how different groups can participate in decision-making processes (for example, through cooperatives, other procedural means) nor guarantee any public accountability**. There was no evidence found of a recognition of political barriers or a clear articulation of what processes are to be followed to gain representation in the policies reviewed for Sudan, Ethiopia or Finland.	**Policies highlight political voice and representation as core principles to be protected, and commit to downward accountability**. "Strengthening of local democratic decision-making and implementation processes …. Key elements … include ensuring that women, youth, and those historically excluded from political decision-making participate and take action so that their particular needs are addressed …. Government and its leaders at all levels are held accountable by the households and communities that they serve for producing the results towards which this strategy aims" (Liberia Food Security & Nutrition Strategy 2008) **Policies commit to engaged governance and equitable decision-making processes that enable marginalized groups to confront power structures**. "The administration will provide access to information so that the same information base is available to all parties interested in fisheries management and development" (Liberia Fisheries & Aquaculture Strategy 2014). "It means seeking balance in the participation of men and women, closing the gaps of inequality" and "To this end, the participation of both genders in decision-making should be promoted" (Peru National Strategy for Food & Nutrition 2013–2021)

National production (for example, fisheries and aquaculture) and consumption (for example, food and nutrition) policy document attributes drawn from countries with more negative and more positive aquatic food outcomes than expected, given the existence of barriers, to illustrate policy failings (on the left) and in parallel, best practice (on the right). Consumption-related policy documents were only included if they referred to aquatic foods. Select examples are included below.

will lead to another generation of malnourished mothers, who will in turn replicate the cycle" (Table 1), implicitly position women at the centre of cycles of intergenerational undernutrition and poverty and risk repeating widespread policy failures that inadvertently lay the blame[44] or place the burden for change[45] on women, the marginalized or poor. Policies that centre principles of justice and human rights and open up spaces to challenge norms that create constraints, without reinforcing stereotypes, can support more just food systems; strategies that are now recognized as effective levers of change[28].

Redistributive approaches were frequently used to address economic barriers, that limit wealth-based benefits. For example, the fisheries policies of the Philippines, Peru and Liberia, grant small-scale fisheries and aquaculture workers preferential access to credit or exclusive access to fishing grounds (Table 1). Although economic barriers are most frequently addressed in national policies (Fig. 3), nations securing more aquatic food benefits than expected went further in their redistributive policies to make the case for justice claims, clearly outlining how structural drivers such as poverty and gender norms shape, intersect and reinforce unjust outcomes. For example, the Philippines nutrition policy acknowledged that women who were "nutritionally vulnerable [and] from poor families and communities have less access to resources and services" (Table 1). Such redistributive justice claims that clearly acknowledge the causes of injustice can avoid inadvertently promoting destructive notions such as the 'undeserving poor'[46]. Political barriers, which also limit wealth-based benefits (Fig. 3), were in contrast least likely to be mentioned, particularly in consumption-related policies; however, the nutrition policy of Liberia was an exception, exemplifying downward accountability (Table 1). Other exceptions were from countries that secured more aquatic food benefits than expected, whose fishery policies outlined clear processes for inclusive decision-making that looked to support equal opportunities and build accountability (Table 1), highlighting the potential for inclusive decision-making processes to support more just food systems.

Aquatic foods are critical to health, economies and livelihoods[10,12] but economic, social and political barriers mean their benefits are unevenly accessed, leading to costly unmet nutritional needs. Policies can steer food systems towards more parity in access to productive, affordable and nutritious foods. Five policy recommendations emerge from this work that can help support justice across aquatic food systems. These recommendations are not exhaustive and, because injustices are intersecting, multidimensional and cross-scale[6], apply both nationally and beyond national boundaries. Overall, we found that more just aquatic food policies:

(1) Centred principles of justice and human rights[47] and challenged existing social norms[28]; in doing so, these policies seek to minimize social barriers and support welfare-based benefits of aquatic foods without placing the burden of change on the disadvantaged[45]
(2) Provided clear guidance on inclusive decision-making processes and downward accountability to address political barriers and support more equal access to wealth-based benefits of aquatic foods
(3) Identified and specified the structural drivers or conditions, of injustice, so that redistributive policies that address economic barriers and support more equal access to wealth-based benefits, can do so without inadvertently disempowering or 'moralizing', the disadvantaged[46]
(4) Built strong cross-sectoral engagement between production and consumption sectors[48] and supported colearning to develop policies that support more inclusive production practices and more representative consumption practices and in doing so avoid reinforcing harmful social norms
(5) Recognized the inherent tensions between wealth-generating and welfare-sustaining benefits, appreciating that this requires coordination and concession across scale, underscoring the importance of pan-national efforts, such as the Committee on World Food Security, to inform global negotiations and agreements[47]

Moving towards a more just aquatic food system will require both a renewed emphasis on justice in policy formulation and increased investment by states and their development partners in supporting governance reform in the sector[23,48]. These actions will help to ensure that the benefits of aquatic foods are more equitably distributed and accessible to populations that need them most.

Methods

We develop a mixed-methods approach to examine aquatic foods through a three-dimensional justice lens[6,7] (Fig. 1). We first use a Gini coefficient[14] to quantify how (un)equally benefits are distributed (Fig. 2). Next, we combine expert interviews with a summative content analysis[24] of national production and consumption-related policies[49] to quantify the extent to which policies recognize economic, social and political barriers to participation (Fig. 3). Third, we develop a series of Bayesian hierarchical models[50] to establish whether economic, social or political barriers are associated with the unequal patterns of distribution (Fig. 4). Finally, we combine a positive deviance (or positive outlier) approach[42,51], to identify countries securing considerably more (and less) aquatic food system benefits than expected given the barriers present, with an interpretative policy content analysis[24], to qualitatively analyse the content of their national production- and consumption-related policies and identify policy actions likely to support more just food system outcomes (Table 1).

Distribution of benefits using Gini coefficient

We focus on three aquatic food system benefits (quantity of food produced, value of exports and quantity of food consumed (Supplementary Methods)) and use a Gini index[14] to examine how unequal the distributions of benefits are across country. For each variable we plot the Lorenz curve and calculate the unweighted Gini coefficient using the R package reldist (Fig. 2). Gini coefficients represent the area between a line of equality and a curve of the benefit distribution when plotting the cumulative share of the population versus the cumulative share of the benefit. The unweighted Gini coefficient applied to per capita estimates of benefits measures between-nation inequality in the distribution of benefits, aligning with the response variables in our subsequent Bayesian models below. We plotted values for production (t worker^{-1}), distribution (US$ capita^{-1}) and consumption (g capita^{-1} d^{-1}) by nation to visualize patterns globally.

Policy engagement with barriers

Expert interviews. We first conducted eight guided expert interviews with academics and practitioners working in aquatic food systems to: (1) identify policy (and legal) documents; (2) identify terminology, which when used in policy documents suggests recognition of or engagement with economic, social or political barriers to participation; and (3) conceptualize policy attributes likely to be used in efforts to overcome barriers faced by different social groups in accessing benefits associated with aquatic food systems. Academics and practitioners (some of whom are co-authors) were identified through our networks to cover a range of geographies (South America, Africa, United States, Asia and Global) and areas of expertise (fisheries, aquaculture, public health, development and trade). Ethics was granted through the Lancaster University ethics board to C.C.H., approval number FST18132.

All concepts identified in the interviews that either recognized or attempted to overcome a barrier were grouped thematically into the categories of barrier they were most closely associated with (Supplementary Table 2). Economic barriers were thematically grouped as wealth, safety net policies and policies to improve market access and domestic trade. Social barriers were thematically grouped as gender, age and policies to support access to health for vulnerable populations. Political barriers were thematically grouped as human rights, access rights and participatory processes (Supplementary Table 2). Although terms capturing cultural identity were specified (for example, groups capturing differences in ethnicity, religion, caste and race), these were not included in subsequent analyses as they tended to be geographically specific, making selection of representative terms, for a global analysis, impossible.

Legal and policy documents. We next compiled 344 production- and consumption-associated policy and legal documents from 173 countries, written between 1991 and 2020 (Supplementary Methods; ref. [49]). All documents were produced by national fisheries, agricultural, environmental and health agencies themselves or in conjunction with United Nations organizations including the World Health Organization and the Food and Agriculture Organization. These documents are not necessarily evidence of policies in practice but reflect prerequisite enabling conditions, recognizing that policy development and implementation take time and acknowledging that policies de jure are not necessarily de facto practices[43]. Furthermore, these documents are not exhaustive of all aquatic food policies but represent a comparable and nationally representative global sample of production and consumption policies to provide an indication of the levels of awareness of the challenges associated with social difference.

Summative keyword analysis. We finally, conducted a summative qualitative content analysis[24] to quantify the extent to which national policies recognize barriers to participation. We scanned all consumption-related policies in NVivo 2020 for terms that relate to aquatic foods (for example, fish and fisheries) (Supplementary Table 2). Consumption policies that made no reference to aquatic food terms were removed from subsequent analysis. We autocoded the remaining

306 production and consumption policy documents in NVivo 2020 for terms (Supplementary Table 2) capturing economic, social and political barriers identified through the expert interview. Analyses were conducted in five languages, covering 98% of all countries. For each policy, the number of references to each keyword was extracted and divided by the number of pages in the policy. For each theme (that is, wealth, safety nets, access to markets, age, gender, health- and nutrition-sensitive policies, human rights, access rights and representation), references per page were calculated by summing across all keyword references within a theme (for example, woman + maternal = gender) and averaging across policy type (consumption and production) (Supplementary Table 3). The summarized keyword theme references per page were then merged with global shape files in the sf R package[52] (Fig. 3; Supplementary Fig. 5).

Associations between barriers and benefits

We draw on social justice theory, based on the principle of 'equal moral worth'[6], to evaluate whether economic, social and political barriers to participation are associated with the unequal distributions of aquatic food systems benefits (Fig. 2). To do so, we developed a series of Bayesian hierarchical models to establish whether seven indicators of economic (wealth and education), social (gender inequality, linguistic diversity, cultural hegemony and age) and political (voice and accountability) barriers, explain patterns of distribution for eight benefits—production (quantity, quality, employment and women's employment), distribution (export revenues and affordability) and consumption (quantity and reliance) (Fig. 4)—while controlling for environmental, geographical and economic factors, that do not constitute barriers to participation but are likely to influence the benefit of interest (Supplementary Methods, Supplementary Figs. 1 and 2 and Supplementary Table 1).

Although differences exist in how the production, distribution and consumption of aquatic foods have evolved across different countries associated with history, religion and culture that influence current production, distribution and consumption, these are beyond the scope of this study. Our analyses are therefore limited to an evaluation of current practices and not to disentangling historical patterns of evolution or their role in driving policy changes.

Bayesian hierarchical model development. Before model development and for each of the eight aquatic food system benefits, we built a series of expert-informed directed acyclic graphs (DAGs)[53] (Supplementary Fig. 2) to explore interactions between our dependent, independent and control variables. The purpose of using DAGs in this exercise is to identify otherwise invisible confounding, particularly collider, bias where two variables simultaneously act on a third and induce correlation among them[53–55]. Where colliders were found, they were removed to avoid inducing collider bias (see Pearl's DAG-based approach[53]) and remaining variables were checked for correlations between variables (Supplementary Fig. 3). This DAG-based approach was developed to be more transparent about the underlying assumptions than including nuisance variables without checking for the range of confounding issues that they can induce. Because of the transparency of this approach, DAGS are often used for causal analyses; however, we do not use formal causal inference in this study.

Our final DAGs, after removing colliders and highly correlated variables included 9 environmental, geographic and economic control variables (EEZ area, primary productivity, maximum inland water, climatic zone, capture production, aquaculture production, imports, exports and affordability) across 8 models (production, employment, women's employment, nutrient density, exports, affordability, consumption and reliance) (Supplementary Figs. 1 and 2).

Aquatic food production is likely to be affected by natural productivity and the water available to produce aquatic foods. We therefore included EEZ area (km^2), primary productivity ($mg\,C\,m^{-2}d^{-2}$) and maximum inundation area (1,000 km^2) in the model for production per worker. The nutrient quality of aquatic foods is likely to be influenced by climatic zones[2], we therefore included climatic zones[1] in the model for nutrient quality. Employment, export revenues and affordability are likely to be affected by the size of the sector, we therefore included total capture production (t) and total aquaculture production (t) as the sum of marine, freshwater and brackish aquaculture production (t) in the models for total employment, women's employment, export revenues and affordability. Affordability of aquatic foods is in addition likely to be influenced by unit value of imports and exports. We therefore added unit export revenues (exports in US$1,000 divided by exports in tonnage) and unit import costs (imports in US$1,000 divided by imports in tonnage) to the model for aquatic food affordability. Consumption and reliance of aquatic foods are likely to be influenced by the relative affordability of aquatic foods, we therefore added fish relative caloric price (affordability) into the models for consumption of, and reliance on, aquatic foods.

After we identified and selected our 8 dependent, 7 independent and 11 control variables (maximum of 4 for any given model) on the basis of the descriptions above and before the analysis, we first log-transformed highly skewed independent and control variables (wealth, EEZ area, maximum inundation area, capture production, aquaculture production, unit exports and unit imports). Then, we standardized all independent and control variables by centring at the mean with a unit standard deviation. Finally, we scaled all dependent variables by dividing by an interquartile range and multiplying by 100, so that we could use the same parameterization for prior distributions across all models.

All hierarchical models were specified with three levels: global, regional and national. For regions, we extended subregions defined by the United Nations into 22 finer regions (Australia and New Zealand, Polynesia, Northern Africa, Western Europe, Middle Africa, Southern America, Northern America, Eastern Africa, Southern Europe, Southeastern Asia, Eastern Asia, Northern Europe, Central America, Southern Asia, Western Africa, Eastern Europe, Caribbean, Melanesia, Micronesia, Central Asia, Southern Africa and Western Asia) to take into account cultural differences. In region i, intercept β_{0i} was drawn from a normal distribution (equation (1)) and standard deviation σ_i was drawn from a gamma distribution (equation (2)) as:

$$\beta_{0i} \sim \text{Normal}\,(\mu{=}\mu_0, \sigma{=}\sigma_0) \tag{1}$$

$$\sigma_i \sim \text{Gamma}\,(\alpha{=}\alpha_0, \beta{=}\beta_0). \tag{2}$$

In nation j, intercept β_{0ij} was drawn from a normal distribution (equation (3)) with a regional mean and standard deviation as:

$$\beta_{0ij} \sim \text{Normal}\,(\mu{=}\beta_{0i}, \sigma{=}\sigma_{\text{i}}). \tag{3}$$

These intercepts were passed into a linear model (equation (4)):

$$\mu_{ij} = \beta_{0ij} + \boldsymbol{\beta}\mathbf{X}, \tag{4}$$

where β is a vector of coefficients and X is a design matrix with independents. Finally, the logarithm of the observed value y_{ij} was modelled using a t-distribution, with $\mu = \mu_{ij}$, $\sigma = \sigma_{\text{error}}$ and $\upsilon = 5$. The data likelihood was chosen by checking leave-one-out probability integral transform (LOO-PIT)[55]. LOO-PIT diagnoses whether future unobserved data will follow the same distribution of the observed data by applying probability integral transform to leave-one-out cross-validation and estimating a cumulative density distribution of the posterior predictive. Our results show uniform distributions (Supplementary Fig. 4; also see Code availability), indicating proper model specifications. Global parameters were specified using weakly informative priors, with a normal distribution with $\mu = 0$ and $\sigma = 100$ for μ_0 and with a half-Cauchy distribution with $\beta = 5$ for $\alpha_0, \beta_0, \sigma_0$ and σ_{error}. Missing independent and control variables were imputed from a covariance matrix with LKJ Cholesky covariance priors. For LKJ Cholesky distribution, we used

$\eta = 2$ and standard deviation specified as an exponential distribution with $\lambda = 1$. Log-transformed population was also included in the matrix, as it was correlated with some of the independent variables. For each model, the parameters were sampled using the NUTS algorithm over two chains with 5,000 sampling each in PyMC3 v.3.10.0 (ref. [55]) under Python v.3.8.0. Model convergence was supported by Gelman–Rubin statistics ($\hat{R}$) all close to 1 (ref. [56]).

Attributes associated with more just outcomes

Positive deviance approach. Focusing on production, employment, affordability, consumption and reliance as the outcomes most likely to be influenced by production- and consumption-related policies, we identified, for each, 12 outliers defined as the nations with the greatest (positive and negative) standard deviations. Positive outliers thus represent areas with better-than-expected aquatic food outcomes (for example, aquatic food is considerably more affordable than expected) given the barriers present and negative outliers are places with worse-than-expected outcomes (for example, aquatic food is considerably less affordable than expected). We used outputs from the Bayesian models on the standard deviation of each nation's intercept from the expected regional distribution (equation (2)). For each benefit, six 'positive' and six 'negative' outlier countries were identified (Supplementary Table 4).

Interpretative qualitative policy content analysis. We then qualitatively analysed, in depth, the content of five randomly selected positive outlier country policies (Bangladesh, Gambia, Liberia, Peru and the Philippines) and three randomly selected negative outlier country policies (Ethiopia, Finland and Sudan) to understand how countries experiencing fewer injustices use terms that capture economic, social and political barriers in policy. We looked for evidence, depth and sophistication of engagement with distributional, representational and recognitional dimensions of justice and further coded for emergent themes demonstrating engagement across dimensions of justice and across sectors relevant to aquatic foods. Drawing on our guided interviews and iterative readings, we identified ten themes: three representing inadvertently damaging language, likely to translate to policy failings; and seven representing progressive language and context, likely to translate into policies capable of overcoming economic, social and political barriers (Table 1).

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

All data used to produce the results of our analysis are available in the Supplementary Information and on GitHub (https://github.com/zachkoehn/aquatic_food_justice_model), with the published version archived (https://doi.org/10.5281/zenodo.7035795).

Code availability

All code used to produce the results of our analysis are available in the Supplementary Information and on GitHub (https://github.com/zachkoehn/aquatic_food_justice_model), with the published version archived (https://doi.org/10.5281/zenodo.7035795).

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Author contributions

C.C.H., J.A.G. and J.Z.K. contributed equally to the study. C.C.H. and J.A.G. conceived of the idea and designed the overall study with J.Z.K. J.A.G., J.Z.K., K.D.G., E.F.-C., E.M., H.P. and E.R.S. compiled the data. C.C.H., J.A.G., J.Z.K., H.J.P., E.H.A., D.B., P.J.C., J.F., S.G., M.I., R.L.N., J.N., N.R. and C.C.C.W. designed the policy analysis. C.C.H., J.Z.K., H.J.P., S.G., P.J.C. and C.C.C.W. analysed the policy documents. C.C.H., J.A.G., J.Z.K., S.N. and M.A.M. developed the model and analysed the data. All authors reviewed the results and developed the main conclusions. C.C.H., J.A.G. and J.Z.K. wrote the manuscript draft and all authors contributed to and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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Study description	Mixed methods involving quantitative cross sectional and qualitative content analyses
Research sample	Data collected from all nations,
Sampling strategy	Quantitative data collection was conducted for all nations, we succeeded in covering approximately 95% and 90% of countries in the bayesian and policy analysis respectively. Qualitative analysis was selected using a bright spots or positive deviance approach.
Data collection	The majority of data collection involved secondary data. The interviews were recorded on an encrypted audio device
Timing	Data collection took place between April and October 2020, but secondary data dated back to 2014
Data exclusions	no data were excluded in this study
Non-participation	no participants dropped out or refused participation
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Policy information about studies involving human research participants

Population characteristics	There were no population relevant covariate characteristics of the respondents. Eight academics and practitioners working across aquatic food systems were interviewed to help guide the development of the summative approach to policy content analysis.
Recruitment	Key informant interviews and snowball recommendations. Interviews were exploratory, and not intended to be representative.
Ethics oversight	Lancaster University

Note that full information on the approval of the study protocol must also be provided in the manuscript.