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Supplementary information

Seafood businesses' resilience can benefit from circular economy principles

In the format provided by the authors and unedited

Supplementary Information for "Seafood businesses' resilience can benefit from circular economy principles"

Supplementary Methods: Identifying literature

In June 2019, we searched three databases, Scopus, Science Direct and Web of Knowledge, for relevant literature. Searches used the following Boolean search string: *(seafood OR aquaculture OR fisher*) AND ((business OR company OR economic) AND (model OR plan OR case)).* Here, it is noted that the search was limited to an article's title, abstract and keywords. In addition, a timeframe of 10 years (2009-2019) was applied to the search to ensure that only recent business models are included. Over three thousand (n=3,710) articles were identified, with the corresponding citations imported into the reference management software, EndNote X9 (Clarivate Analytics). Any duplicate citations, for example the same article identified by a different database, or a report later published as a peer-reviewed journal article, were first removed. Where an article was later published in a peer-reviewed source, we removed the original (non-peer-reviewed) article. For the remaining 2,845 references, we searched for and downloaded the full texts, both through open access and institutional access at the University of Manchester. Over two selection stages, we applied inclusion and exclusion criteria (Supplementary Table 1) to the 771 articles with full texts. The first selection stage applied the criteria to the titles and abstracts only and retained 376 articles, while the second selection stage applied the criteria to the whole paper retaining 73 articles (for full bibliographic details see Supplementary Table 2).

Supplementary Table 1: Inclusion-exclusion criteria.

Criteria used for selecting appropriate secondary sources when applied first to the title and abstract only, then to the full text.

	Inclusion criteria	Exclusion criteria
Applied to title and abstract	- Written in English language. - Focus on any geographic areas and scope. - Should concern commercial seafood sectors including aquaculture and wild-capture fisheries.	- Focus on the composition of seafood e.g. nutritional content or toxicity levels. - Focus on ecological or climate change impacts of physical activities, or value gained from ecosystems services. - Focus on recreational fishing or angling.
Applied to full text	- Present information about specific business models. - Inclusion of real-world case studies / scenarios.	- Focus on the introduction or assessment of initiatives or schemes e.g. MSC certification. - Purely theoretical, conceptual or modelled cased studies. - Focus on broader societal issues e.g. food security, poverty, health impacts, diets or food authentication.

Supplementary Table 2: Full bibliographic details of the reviewed literature.

The journal articles included in the reviewed sample.

Author(s), year	Title	Journal
Anna and Hindayani, 2018[1]	A welfare study into capture fisheries in Cirata reservoir: A bio-economic model	Asean-fen international fisheries symposium - 2017
Asche et al., 2014[2]	Price transmission in new supply chains-the case of salmon in France	Aquaculture Economics & Management
Aswathy and Kalpana, 2018[3]	Women's work, survival strategies and capitalist modernization in south Indian small-scale fisheries: The case of Kerala	Gender Technology & Development
Aura et al., 2018[4]	Integration of mapping and socio-economic status of cage culture: Towards balancing lake-use and culture fisheries in Lake Victoria, Kenya	Aquaculture Research
Avadí et al., 2014[5]	Coupled ecosystem/supply chain modelling of fish products from sea to shelf: The Peruvian anchoveta case	Plos One
Berrill et al., 2012[6]	Bio-economic costs and benefits of using triploid rainbow trout in aquaculture: Reduced mortality	Aquaculture Economics & Management
Beuving, 2015[7]	Spatial diversity in small-scale fishing: A socio-cultural interpretation of the Nile perch sector on Lake Victoria, Uganda	Tijdschrift Voor Economische En Sociale Geografie
Bela H Buck et al., 2010[8]	Mussel cultivation as a co-use in offshore wind farms: Potential and economic feasibility	Aquaculture Economics & Management
Buisman et al., 2009[9]	Evaluating economic efficiency of innovative management regimes	Comparative evaluations of innovative fisheries management: Global experiences and European prospects
Bukenya and Ssebisubi, 2014[10]	Price integration in the farmed and wild fish markets in Uganda	Fisheries Science
Campbell et al., 2014[11]	From vegetable box to seafood cooler: Applying the community-supported agriculture model to fisheries	Society & Natural Resources
Carlson et al., 2018[12]	Peruvian anchoveta as a telecoupled fisheries system	Ecology and Society
Chen, 2017[13]	Buyer-supplier relationship and optimisation model in a dynamic collaborative network with shortages allowed	International Journal of Computer Integrated Manufacturing
Cissé et al., 2013[14]	A bio-economic model for the ecosystem-based management of the coastal fishery in French Guiana	Environment and Development Economics
Dey et al., 2017 [15]	Market trends for seafood products in the USA: Implication for southern aquaculture products	Aquaculture Economics & Management
Doeksen and Symes, 2015 [16].	Business strategies for resilience: The case of Zeeland's oyster industry	Sociologia Ruralis
Engelseth and Felzensztein, 2012[17]	Intertwining relationship marketing with supply chain management through Alderson's transvection	Journal of Business & Industrial Marketing
Engelseth and Sandvik, 2017[18]	On complexity, ecosystems, and sustainability in local food supply: A case study on fresh seafood supply	International Journal on Food System Dynamics
Engle and Kumar, 2011[19]	The effect of cash flow and credit constraints on financial feasibility and stocking strategies on us catfish farms: A mixed-integer multi-stage programming approach	Aquaculture Economics & Management

Field et al., 2013[20]	Cooperation between scientists, NGOs and industry in support of sustainable fisheries: The south African hake *Merluccius spp*. Trawl fishery experience	Journal of Fish Biology
Fox et al., 2018[21]	The seafood supply chain from a fraudulent perspective	Food Security
Gammage et al., 2017[22]	A case study from the southern cape line fishery 2: Considering one's options when the fish leave	South African Journal of Science
Gasalla and Gandini, 2016[23]	The loss of fishing territories in coastal areas: The case of seabob-shrimp small-scale fisheries in Sao Paulo, Brazil	Maritime Studies
Glavee-Geo and Engelseth, 2018[24]	Seafood export as a relationship-oriented supply network: Evidence from Norwegian seafood exporters	British Food Journal
Greenfield et al., 2019[25]	Economically viable aquaponics? Identifying the gap between potential and current uncertainties	Reviews in Aquaculture
Guillen Garcia et al., 2012[26]	A bio-economic evaluation of the potential for establishing a commercial fishery on two newly developed stocks: The Ionian red shrimp fishery	Scientia Marina
Guy et al., 2009[27]	Economic assessment of an intra-specific cross of silver perch (*bidyanus bidyanus mitchell*) for commercial farming	Aquaculture Economics & Management
Haghiri, 2014[28]	An evaluation of consumers' preferences for certified farmed Atlantic salmon	British Food Journal
Hardy et al., 2016[29]	Viability and resilience of small-scale fisheries through cooperative arrangements	Environment and Development Economics
Havice and Campling, 2017[30].	Where chain governance and environmental governance meet: Interfirm strategies in the canned tuna global value chain	Economic Geography
Herrero, 2017[31]	Family involvement and sustainable family business: Analysing their effects on diversification strategies	Sustainability
Hutton et al., 2016[32]	Trade-offs in transitions between indigenous and commercial fishing sectors: The Torres strait tropical rock lobster fishery	Fisheries Management and Ecology
Iotti and Bonazzi, 2015J[33]	Profitability and financial sustainability analysis in Italian aquaculture firms by application of economic and financial margins	American Journal of Agricultural and Biological Science
amilah and Najib, 2019[34]	Business model identification in vannamei shrimp (*litopenaeus vannamei*) mariculture commodity (case study: Sea farming project in Semak Daun island, Indonesia)	IOP Conference Series: Earth and Environmental Science
Johns et al., 2016[35]	Evaluating the outcomes of vca-led improvement projects a case study of an Australian prawn fishery	British Food Journal
Joyce and Satterfield, 2010[36]	Shellfish aquaculture and first nations' sovereignty: The quest for sustainable development in contested sea space	Natural Resources Forum
Kamiyama et al., 2015[37]	The impact of distribution change on fisheries in southeast Asia: A case study in the Batan estuary, Aklan, central Philippines	Fisheries Science
Kankainen et al., 2012[38]	Modelling the economic impact of welfare interventions in fish farming a case study from the UK rainbow trout industry	Aquaculture Economics & Management
Kareen and Williams, 2009[39]	A techno-economic analysis of aquaculture business in Ogun state, Nigeria	Chinese Journal of Oceanology and Limnology
Khan, 2012[40]	Understanding global supply chains and seafood markets for the rebuilding prospects of northern gulf cod fisheries	Sustainability

Kumar and Engle, 2014[41]	Optimizing catfish feeding and stocking strategies over a two-year planning horizon	Aquaculture Economics & Management
Kuo and Chuang, 2017[42]	Salmon importation and consumption in Taiwan	Aquaculture Economics & Management
Lasner et al., 2017[43]	Establishing a benchmarking for fish farming - profitability, productivity and energy efficiency of German, Danish and Turkish rainbow trout grow-out systems	Aquaculture Research
Leadbitter and Benguerel, 2014[44]	Sustainable tuna - can the marketplace improve fishery management?	Business Strategy and the Environment
Lim-Camacho et al., 2015[45]	Facing the wave of change: Stakeholder perspectives on climate adaptation for Australian seafood supply chains	Regional Environmental Change
Maravelias et al., 2010[46]	Stochastic bioeconomic modelling of alternative management measures for anchovy in the Mediterranean Sea	Ices Journal of Marine Science
Marvasti and carter, 2016[47]	Domestic and imports sources of supply to the us shrimp market and anti-dumping duties	Journal of Economic Studies
Maynou et al., 2014[48]	Bio-economic analysis of the Mar Menor (Murcia, SE Spain) small-scale lagoon fishery	Journal of Applied Ichthyology
Miller and Atanda, 2011[49]	The rise of peri-urban aquaculture in Nigeria	International Journal of Agricultural Sustainability
Molina et al., 2012[50]	Simulation model of the scallop (*argopecten purpuratus*) farming in northern Chile: Some applications in the decision-making process	Latin American Journal of Aquatic Research
Murata et al., 2017[51]	Modelling a supply chain network of processed seafood to meet diverse demands by multi-branch production system	Proceedings of the eleventh international conference on management science and engineering management
Ndraha and Hsiao, 2019[52]	Exposure assessment and sensitivity analysis for chilled shrimp during distribution: A case study of home delivery services in Taiwan	Journal of Food Science
O'Gorman and Evers, 2011[53]	Network intermediaries in the internationalisation of new firms in peripheral regions	International Marketing Review
O'Neill et al., 2018[54]	Socioeconomic dynamics of the Ghanaian tuna industry: A value-chain approach to understanding aspects of global fisheries	African Journal of Marine Science
Onjong et al., 2014[55]	Current food safety management systems in fish-exporting companies require further improvements to adequately cope with contextual pressure: Case study	Journal of Food Science
Palm et al., 2018[56]	Towards commercial aquaponics: A review of systems, designs, scales and nomenclature	Aquaculture International
Plagányi et al., 2013[57]	Integrating indigenous livelihood and lifestyle objectives in managing a natural resource	Proceedings of the National Academy of Sciences of the United States of America
Plagányi et al 2014[58]	A quantitative metric to identify critical elements within seafood supply networks	Plos One
Plotnek et al., 2016[59]	From unsustainability to MSC certification: A case study of the artisanal Chilean south pacific hake fishery	Reviews in Fisheries Science & Aquaculture
Puduri et al., 2011[60]	Consumer attitude towards pricing of live aquatic products	Aquaculture Economics & Management

Rivera-Ferre, 2009[61]	Can export-oriented aquaculture in developing countries be sustainable and promote sustainable development? The shrimp case	Journal of Agricultural & Environmental Ethics
Schernewski et al., 2012[62]	Zebra mussel farming in the Szczecin (Oder) lagoon: Water-quality objectives and cost-effectiveness	Ecology and Society
Schmitt and Brugere, 2013[63]	Capturing ecosystem services, stakeholders' preferences and trade-offs in coastal aquaculture decisions: A Bayesian belief network application	Plos One
Sengupta et al., 2012[64]	Wastewater aquaculture by the Mudialy fisherman's cooperative society in Kolkata, west Bengal: An example of sustainable development	Journal of Applied Aquaculture
Simioni et al., 2013[65]	Detecting asymmetric price transmission with consistent threshold along the fish supply chain	Canadian Journal of Agricultural Economics-Revue Canadienne D Agroeconomie
Simons et al., 2014[66]	Integrating stochastic age-structured population dynamics into complex fisheries economic models for management evaluations: The North Sea saithe fishery as a case study	ICES Journal of Marine Science
Stoll et al., 2015[67]	Local seafood: Rethinking the direct marketing paradigm	Ecology and Society
Trondsen, 2012[68]	Value chains, business conventions, and market adaptation: A comparative analysis of Norwegian and Icelandic fish exports	Canadian Geographer-Geographe Canadien
Truong and Ariyawardana, 2015[69]	Small-scale shrimp grower-collector relationships: The case of Thua Thien Hue province, central Vietnam	Aquaculture Economics & Management
Vormedal, 2017[70]	Corporate strategies in environmental governance: Marine harvest and regulatory change for sustainable aquaculture	Environmental Policy and Governance
Wati, 2018[71]	Analysing the development of Indonesia shrimp industry	Asean-fen international fisheries symposium - 2017
Wetengere, 2011[72]	Constraints to marketing of farmed fish in rural areas: The case of selected villages in Morogoro region, Tanzania	Aquaculture Economics & Management
Yang et al., 2011[73]	Analysis on business model of Chinese aquatic e-business	Proceedings - 2011 4th International Conference on Business Intelligence and Financial Engineering, BIFE 2011

Supplementary Methods: Determining resilience mechanisms as a lens of analysis

Within existing food systems, several vulnerabilities have been acknowledged that may make disturbances more pronounced such as the homogeneity of products, a high dependence on imported food and diets that are increasingly unvaried, calorie-rich and land-intensive [74] (see column 'Vulnerability in Supplementary Table 3). To overcome these vulnerabilities, Schipanski et al (2016) [74] suggested strategies across the supply chain (see column 'Strategy' in Supplementary Table 3). These mechanisms respond to system-level vulnerabilities and, as such, relate to general - rather than specified – resilience, which aims to increase systemic capacity to respond to shocks or uncertainty [75,76].

To determine the resilience measures used within our Circular Economy-Resilience Framework for Business Models (CERF-BM), we grouped the suggested strategies into four categories; (1) diversification across the value chain, (2) utilise ecosystem services, (3)

promote local system and (4) knowledge exchange between stakeholder. The colour-coding of Schipanski et al (2016)'s strategies within Supplementary Table 3 shows how we allocated their strategies to the four resilience mechanisms.

Supplementary Table 3: Development of the four resilience mechanisms.

Vulnerabilities identified across the food supply chain, and strategies suggested to overcome them [74]. Colour coding has been added by the authors and refers to resilience mechanisms under the table.

	Vulnerability	Strategy
Production	Immense homogenisation and specialisation (monocultures) reduced diversity --> increased vulnerability to climate variability, pest and disease, food price volatility.	Increase use of ecological processes in place of chemical-based inputs. Restore biodiversity and ecosystem functions. Crop diversity / multi-trophic species
Distribution	Dependency on international food imports. Dominated by livestock feed and more processed foods. Increased distance between consumer and producer, geographically and in access to information. Growing interconnectedness but with less transparency. Displaced environmental impacts.	Source food from multiple scales of distribution and diverse markets. Diversifying distribution networks. Increase emphasis on local and regional food systems. Create social embeddedness. Acknowledge nested nature of food systems (local, regional and global).
Consumption	Vertical integration of production, marketing, and distribution systems has contributed to an increasingly homogenous, calorie-rich, and land-intensive global diet.	Sustaining viable, diversified local and regional food systems can improve human health.
General	Underlying drivers of vulnerabilities (inequity, environmental degradation, global distribution networks, and homogenised energy dense diets) are not fully addressed in current food security policy.	Resilient systems incorporate internal feedback mechanisms, maintain redundancy, and promote responsive governance and diversification at almost all levels.

Colour code key:

Resilience mechanisms	(1) Diversification across value chain	(2) Utilisation of ecosystem services	(3) Promotion of local systems	(4) Knowledge exchange between stakeholders

Supplementary Methods: Combining the concepts of resilience and circular economy

To support a shift towards sustainable seafood production at the business level, while acknowledging and connecting with the wider food system, we propose the integrated use of the resilience mechanisms with the circular economy principles. Complex inter-relationships between economic, social and environmental factors are thereby considered [18,77]. An example is the development of the iReSOLVE checklist, which offers specific, structured actions for improved circularity [78], and is drawn upon and applied specifically to business models analysed here (see Supplementary Table 4).

Some fisheries already embrace circular economy principles [79]. Day-to-day materials, such as nets, engine oil and plastics can be recycled [80,81]. The energy needs of buildings can be met using renewable sources [82]. Plastic materials used for nets and ropes can be replaced by other materials such as cork, flax fibres, and Balsa wood [83]. The adoption of marine protected areas and closed seasons also accounts for circularity. While some measures are beyond the control of individual businesses, the cooperation of companies within the seafood sector is vital for the development and implementation of such measures. Businesses, therefore, play a key role in adopting circular economy principles within the seafood system, which can be enhanced through collaboration with other key actors across

the value chain, such as governments, international development organisations, and consumers, to share resources, access and knowledge [84].

Supplementary Table 4: Application of iReSOLVE checklist to the seafood sector.

The iReSOLVE checklist [78] and its application to the seafood sector [84]. Examples within the literature that align with the individual iReSOLVE categories are also given.

iReSOLVE categories - Actions	Application to seafood sector	Examples for capture fishery	Examples for aquaculture
Implement			
- Have a vision or target to achieve - Engage with stakeholders - Employ systems thinking	By recognising the wider context that companies operate in, social and environmental issues can be addressed. Engaging with stakeholders e.g. local communities, other companies, consumers and authorities Considering the lifecycle of species / products sold, acknowledging impacts across value chain.	Establishing a sustainable ethos that engages with stakeholders, protects the environment and addresses value chain impacts.	
e.g. Application of a community-supported agriculture model to fisheries, where collaboration across the value chain (including fishers, processors, restaurants and individual consumers) ensures increased consumer access to fresh local fish, especially in inland areas [11].			
Regenerate			
- Use renewable resources - Ensure a healthy ecosystem - Return biological resources	Utilising renewable energy sources to power properties and transport products to the consumer. By managing the waters in which seafood is sourced or grown sympathetically, the sector can help enhance ecosystem health. The seafood sector can use (biological) wastes to support other systems.	Facilities used to process seafood could be powered by renewables.	Biological waste can be collected and utilised as fish meal.
e.g. Successes of a local fishing cooperative, based in Kolkata, that use waste-water fed aquaculture to commercially produce vegetables and fish whilst improving the water quality and thus regenerating the local ecosystem and creating a nature park [64].			
Share			
- Share assets - Reuse items or use second hand	Using common resources, sharing physical infrastructure (and maintenance) with other parties. Repurposing existing infrastructure and using second-hand equipment.	Use of second-hand equipment.	Sharing physical infrastructure.
e.g. The co-use of offshore wind farms for mussel cultivation, where the mussel cages are anchored to the wind turbine bases. In this scenario, trips to monitor mussel growth / collection and regular infrastructure maintenance can be combined, thus saving fuel and the need for two vessels [8].			
Optimise			
- Prolong the life span of products - Increase product efficiency - Remove waste in value chain - Leverage big data	The seafood sector can promote actions that prolong shelf-life of products and reduce mortality rates of (non) target species. Using business tools to improve economic efficiency, streamline inputs and maximise outputs. By introducing specific measures, damage or waste in production, distribution and consumption can be reduced. Utilising trends, managing production networks and enhancing traceability across value chain.	Processing and packaging products to minimise food waste, maximise shelf-life and make production/distribution more efficient.	
e.g. A small Norwegian fresh seafood retailer that supplies both fresh and processed fish (such as fishcakes using offcuts therefore reducing waste) and maintains a competitive edge by maintaining supplier relations and ensuring excellent product quality [18].			
Loop			
- Remanufacture - Recycle - Anaerobic digestion - Extract nutrients	Using equipment that has been remanufactured. Recycling biological nutrients produced during production, traditional recycling of materials / products. Using anaerobic digestion in waste management e.g. sludge treatment Enabling the reuse of water, by promoting the removal of nutrients and allowing for denitrification.	Use of recycled materials or remanufactured equipment.	Use of IMTA system, where the waste from one species feeds another.

e.g. The expansion and success of peri-urban aquaculture systems that repurpose and collectively manage abandoned aquaculture infrastructure [49].			
Virtualise			
- Direct dematerialisation - Indirect dematerialisation	*Not applicable* – The seafood sector is based on the physical transaction of seafood. Using online platforms, and social media in marketing and automated distribution.	Products can be marketed and distributed using online systems.	
e.g. The potential of future e-business models with respect to Chinese aquaculture products. It suggests using mature e-business platforms that provide e-store functionalities to sell direct to the consumer, and also virtual wholesale market that incorporate third-parties [85].			
Exchange			
- Use new efficient technology - Design dew products and services - Utilise advanced materials	Utilising more efficient, newer technology e.g. vessels, fishing gear, aquaculture equipment / methods. Diversifying products, moving away from single-species and reducing reliance on monocultures. Replacing traditional materials with advanced non-renewable materials.	Use of gear made from advanced materials to favour durability or reduce weight.	Capitalising on IMTA systems, offering more species as products.
e.g. The benefits of employing aquaponic systems that combine aquaculture and plant production. It is argued that as the water and nutrient efficiency of an aquaponic system can enable off-grid production, it may become a valuable tool in enabling the security of food supplies in remote areas [25,56].			

Supplementary Methods: Mapping content of literature to the Circular Economy-Resilience Framework for Business Models (CERF-BM)

This study used a spreadsheet to map the contents of the literature sample. To begin with, we extracted bibliographic information including the name(s) of the author(s), date of publication, article title and the name of the journal or source that published the article. Then we extracted contextual information, including the aim of the article, unit of analysis, methodology or approach employed by the article and any conclusions and recommendations given (as full quotes with page numbers). Information regarding business models was then extracted (as full quotes and page numbers) and mapped against the nine building blocks of the business model canvas.

The presence of circular economy principles within each article, based on the seafood specific application of the iReSOLVE checklist, was recorded as binary data ("1" for present and "0" for not present). To highlight examples of good practice, we also recorded examples of where business models aligned with iReSOLVE actions. We also searched the literature sample for keywords related to resilience (resilient/resilience, adapt/adaptable/adaptive, shock, vulnerable/vulnerability, diversify/diversification/diversified, and flexible/flexibility) and extracted the surrounding text when found as full quotes with page numbers.

Supplementary Methods: Analysis of extracted data

Publication data and contextual information helped to understand what parts of the seafood sector were represented within the reviewed articles. Distribution of publication dates identified any temporal trends, with respect to business models within the seafood sector. Assessment of publication outlets determined whether the study of business models within the seafood sector was predominantly in topic-specific outlets or also included outlets with a broader topic area. To do this, we assigned each publication outlet to either one of two topic-specific themes: Seafood and Food systems or Business and Economics, or the broader theme of Sustainability and the Environment. The title of the publication outlet, e.g. journal name, and the scope of the outlet, e.g. journal scope (as described on the outlet's website) informed allocation to the three categories. Finally, we used contextual information i.e. aim, unit of analysis, methodology, conclusions, to infer geographical location and which type(s) of seafood, i.e. finfish, shellfish or both, are considered.

We determined the types of business models within the seafood sector from the data extracted using the business model canvas. Four elements—source of seafood, business model type, scale of operation and length of value chain—were considered. Source of seafood, i.e. from wild capture fisheries, farmed in an aquaculture system or a mixture of both, for each business model was first determined from the data extracted as value proposition, key activities and key resources.

Then we used data extracted as value proposition, key activities, key resources, customer segment, and customer relationships to assign each company to one of four business model types. This approach is based on the business models presented by Baden-Fuller et al [86], which draw on marketing, strategy and entrepreneurship literature. Other approaches to classifying business models, include the five archetypes of circular business models identified by Rosa et al [87] and the six business model strategies developed by Bocken et al [88] that seek to slow or close resource loops. These approaches consider the use of business models either fully aligned to the circular economy or integrating resource-efficiency innovations i.e. during or after transition to the circular economy. As this study aims to assess existing, and potentially non-circular, business models, we have not adopted these approaches.

We determined the scale of operation for each business model from the data extracted as key activities, customer segment, and customer channels. Here, we allocated business models to one of three scales: local, national or international. Where companies performed at more than one scale, we took the largest scale.

We determined the final business model element, value chain length (short, medium or long) from the data extracted as key resources, value proposition, customer segment, customer channels, cost structure, and revenue stream. A short value chain was interpreted as the single transaction between the producer and consumer. A medium value chain allowed for up to two intermediary steps between the producer and consumer i.e. processor, retailer, wholesale etc. Any operation that had more than two intermediary steps was interpreted to have a long value chain.

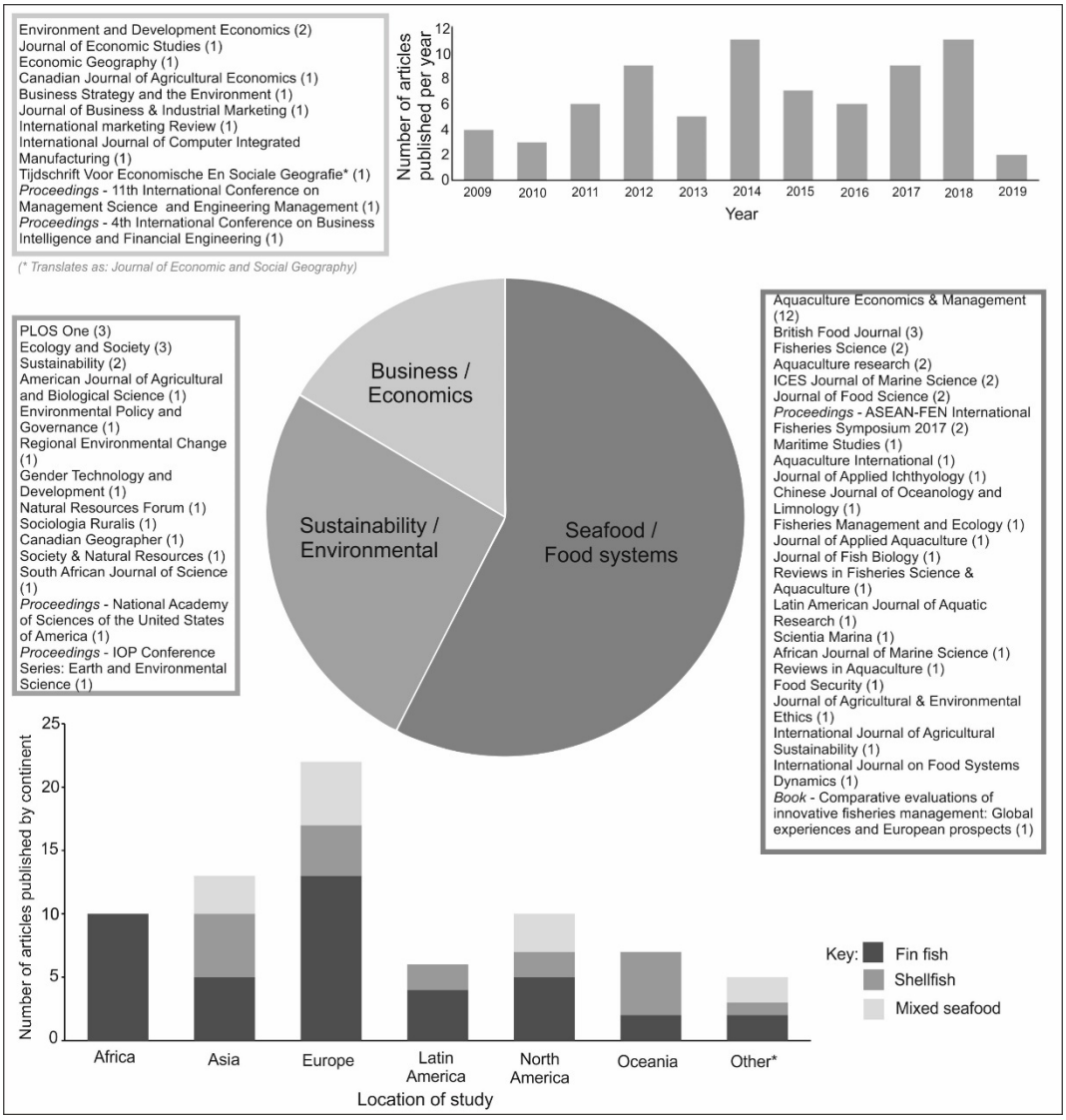
From the binary data concerning the presence of circular economy principles, overall alignment to circular economy principles was determined, and specific circular economy gaps identified. We considered data at both the level of iReSOLVE *categories* and more specific iReSOLVE *actions*. We also compared the data across the reviewed articles, where the average, maximum and minimum number of actions per article was discussed.

While the comprehensive inclusion of circular economy principles implies an enhanced level of resilience, this study also explored the level at which the reviewed articles explicitly consider resilience. Extracted text from the resilience keyword search was analysed following Ingram [89] definition of food resilience, using the operational framework developed by Helfgott [90]. Ingram [89] highlights three food system outcomes that contribute to resilience: food security, environmental welfare, and social welfare. With social, economic and environmental themes, this definition highlights the connections between resilience and sustainability.

The operational framework of resilience includes ‘resilience of what’, ‘resilience to what’, ‘resilience of whom’ and ‘over what timeframe’ [90]. For example, in relation to ‘resilience of whom’, we considered three levels of ‘actor’, as described in the main article: the main actor, downstream stakeholders, and upstream stakeholders. We combined ‘resilience to what’ and ‘timeframe’ by considering shocks, i.e. short-term interruptions such as extreme weather events and price fluctuations, and stresses, i.e. long-term disruptions such as changing environmental conditions and consumer diet [89].

Supplementary Discussion: Research trends by year, seafood type and location

The articles reviewed represent studies from across the seafood sector (see Supplementary Figure 1). Articles spanned 2009-2019 and were published by a range of outlets that were both topic-specific (e.g. seafood sector or business model) and more general (e.g. with a sustainability or environmental focus). Compared with other fields of research such as operations management [91] and general circular-economy business models [87], the expected year-on-year increase in the publication of business model studies has not occurred within seafood sector research so far. This lack of growth may be because the study of business models within the seafood sector is still an emergent topic – a reason supported by the breadth of publication outlets.



Supplementary Figure 1: Overview of publication outlets.

*Year of publication, theme of outlet, location of study and type of seafood included. Number of articles per outlet is shown in brackets. * 'Other' locations include articles with an international focus and those that do not explicitly refer to a location.*

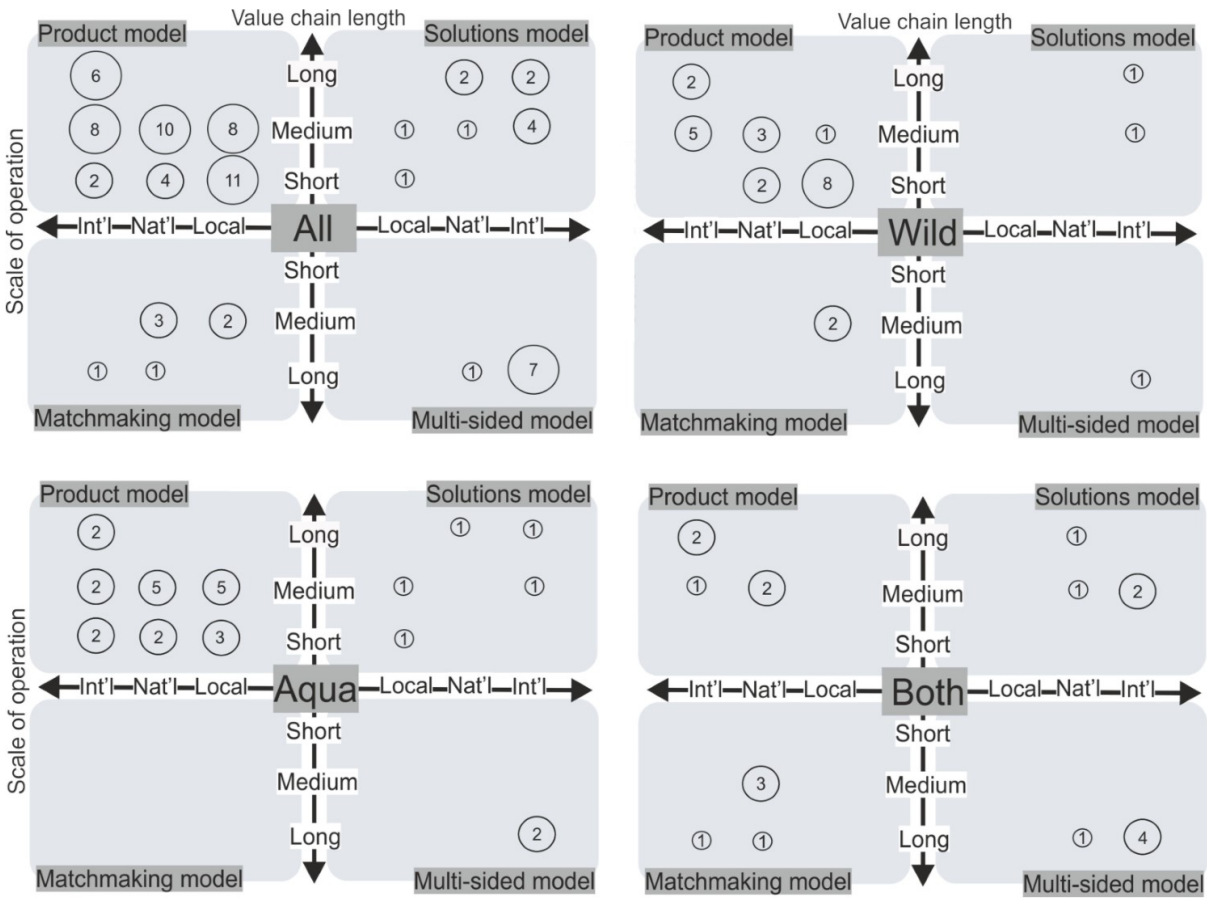
The majority of sources (n=42; 57.5%) aligned with Seafood and Food Systems. However, inclusion in Business and Economics, and Sustainability and the Environment, show that the use of business models to study the seafood sector is gaining attention outside seafood and food systems literature – and could grow in the future. The articles covered diverse geographical locations and seafood types, representing six continents (Antarctica excluded) and a mixture of seafood (categorised as fin fish, shellfish or mixed seafood). This diversity highlights both the global scale of, and individual niches within, existing research in this area.

Supplementary Discussion: Applying the CERF-BM

Analysing existing business models. The first stage of assessing business models against the principles of the circular economy and resilience mechanisms is to map the current business models using the business model canvas. We extracted information on seafood companies from the literature, mapped it to the business model canvas, and then assigned each company to one of four business model types.

Drawing on marketing, strategy and entrepreneurship literature [86], the four business model types were: the product model, the solutions model, the matchmaking model and the multi-sided model. The most common business model type, the product model, describes an operation where a customer purchases a product from a producer for personal consumption (e.g. a fisher selling their catch to a consumer). If the producer engages with the customer before purchase such that they co-create the product, the operation follows the solutions model (e.g. seafood is processed to match a customer's individual requirements). Where a company organises the market and facilitates a connection between the producer and the customer as a third-party intermediary, the company follows the matchmaking model (e.g. a seafood brokerage company that links producers with consumers). Companies that follow the multi-sided model establish relationships between two or more otherwise disconnected groups, where the product and/or service provided to each of the groups can be different (e.g. companies that provide a vertically integrated service that is bespoke to a range of customers such as seafood exporters).

The business models identified within the literature predominantly follow the product model type (n=49; 67.1%), where business models represent all scales of operation and all value chain lengths (Supplementary Figure 2). Business models that operate on an increasingly international scale favour longer value chains. Here, we define a short value chain as an interaction between two actors (e.g. between a fisher and the consumer), where medium value chains include one intermediary actor, such as a processor or wholesaler, and long value chains include two or more intermediary actors.



Supplementary Figure 2: Types of business models within the reviewed articles.

*Business models within **all** the literature (n=73) reviewed based on source of seafood (**wild** caught: n=26, farmed via **aqua**culture: n=28 or **both**: n=19). Alignment to business model type (product, solutions, matchmaking or multi-sided), scale of operation (local, national: Nat'l or international: Int'l) and length of the value chain (short, medium or long) is also shown. Size of circles reflect the number of studies within each category.*

When analysed by source, the majority of business models identified within the reviewed literature source seafood either exclusively from wild capture (n=26; 35.6%) or exclusively from aquaculture (n=28; 38.4%), with the vast majority following the product model type. A comparison between business models sourcing wild capture products vs. aquaculture products shows differences in scale of operation and length of value chain. Business models that source seafood via wild capture tend to favour a local scale of operation and corresponding short value chain. In contrast, business models that source seafood from aquaculture tend to be broader, with all scales of operation present along with value chains that are short and medium in length.

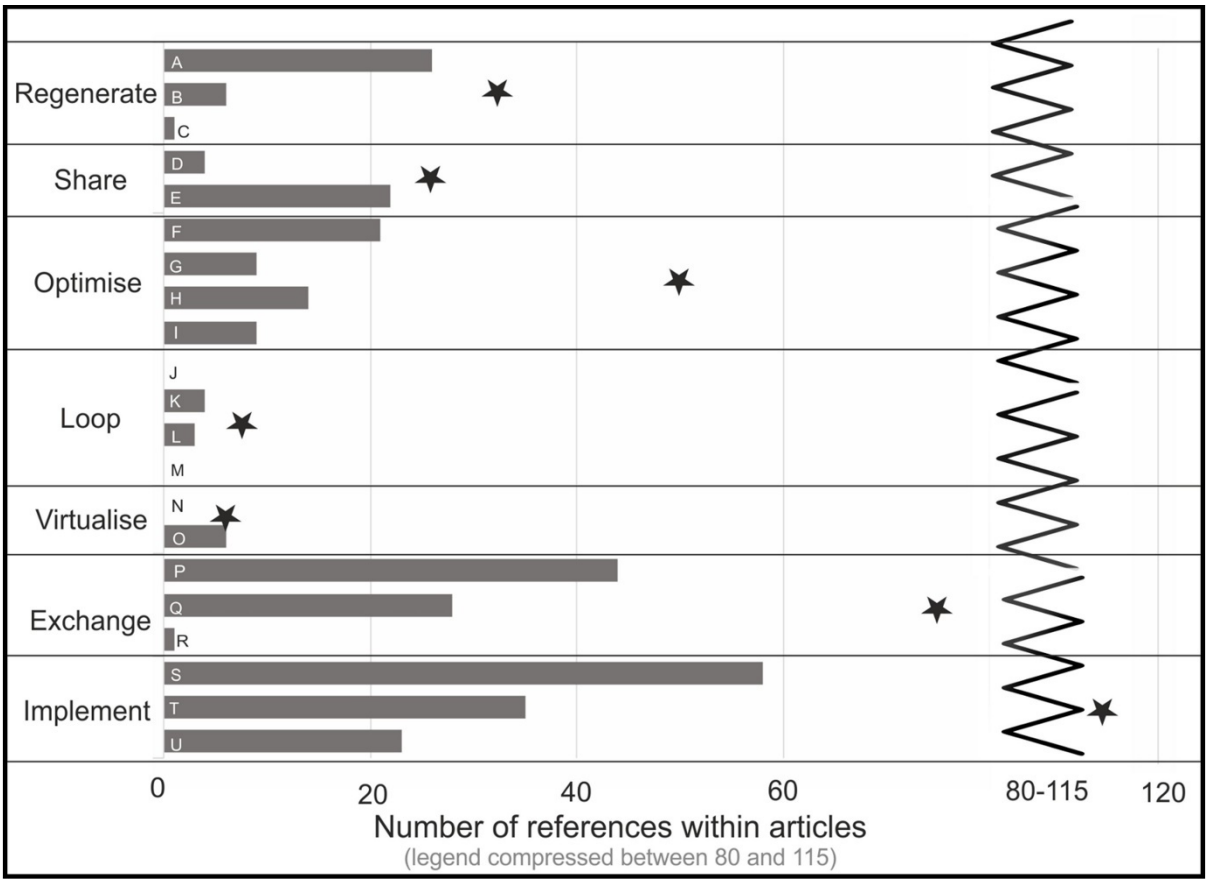
Value chain length has implications for the circular economy and resilience – each company within a value chain can either amplify or absorb the effect of a risk [92]. Longer value chains create more areas of weakness, but have more potential to produce a solution. With respect to resilience, while the likelihood of risk affecting a longer value chain is higher, the impact of that risk would be lower. The opposite is true for shorter value chains – the likelihood of risk

is lower due to fewer areas of potential weakness, but the impact would be greater due to the reduced capacity to produce a solution.

Business models that source seafood from both wild capture and aquaculture are distributed evenly across the four business model types (Supplementary Figure 2), favouring operations at a national and international scale along with value chains that are medium and long. No business models that source a mixture of wild-caught and aquaculture products align with a local scale of operation or employ short value chains, although this is not necessarily reflective of the sector as a whole.

There are obvious gaps in the literature reviewed concerning matchmaking and multi-sided models, particularly for single-source business models, where aquaculture lacks matchmaking companies and capture fisheries lack multi-sided companies. It is unclear whether these gaps are due to an absence of such companies within the sector or a lack of research including these business models. Trends in the sector towards fewer, higher volume operations [93] would suggest that it is the latter – however, further research would be needed to clarify this gap.

Aligning business models with iReSOLVE actions. Next, we assessed the level of alignment to the circular economy through the iReSOLVE categories and, at a more detailed level, the iReSOLVE actions (Supplementary Figure 3). The categories of Implement (n=116), Exchange (n=73) and Optimise (n=53) receive the greatest coverage. However, these categories would also be present within the lifecycle of a conventional (i.e. non-circular) business model [94]. For example, companies routinely optimise activities to increase profit margins (i.e. Optimise), introduce new technologies and products to adapt to changing markets (i.e. Exchange.), and use relationships to react to threats and opportunities (i.e. Implement).



Supplementary Figure 3: Number of references to iReSOLVE actions, within the reviewed articles.

Regenerate: *Reclaim, retain, or restore ecosystem health (A); Return biological resources to the biosphere (B); Shift to renewable energy and materials (C).* ***Share****: Reuse or second-hand use (D); Share assets (E).* ***Optimise:*** *Increase product performance and efficiency (F); Leverage big data (G); Prolong product lifespan (H); Remove waste from production or supply chain (I).* ***Loop:*** *Anaerobic Digestion (J); Extract chemicals from organic waste (K); Recycle (L); Remanufacture (M).* ***Virtualise:*** *Dematerialise directly (N); Dematerialise indirectly (O).* ***Exchange:*** *New product or service (P); New technology (Q); Use advanced non-renewable materials (R).* ***Implement:*** *Stakeholder engagement (S); Systems thinking (T); Introducing a vision or target (U). Stars denote the total number of references across all actions within each iReSOLVE category.*

The majority of articles reviewed align with at least one iReSOLVE action; the majority (n=52; 71.2%) align with one to five different actions. Palm, et al. [56] include the most actions (14); however even their article does not align fully with the circular economy as it lacks Virtualise actions. Across the articles reviewed, Virtualise is included the least (n=6), with other gaps in the coverage of circular economy principles including Loop (n=7) and, to a lesser extent, Regenerate (n=33) and Share (n=26). It is unclear whether these gaps highlight a poor level of implementation within the seafood sector or a lack of research.

Some articles provide examples of good practice where the business model in question aligns with one or more iReSOLVE actions. Campbell, et al. [11] and Stoll, et al. [95] report on

community-supported fisheries where direct marketing reduces the social and physical distance between producer and consumer and allows the companies to capture a price premium. These examples align with Optimise, Exchange and Implement actions. Other articles that align with Exchange actions, through the introduction of new services are: Yang, et al. [85], presenting a supply-demand platform with aspects of e-commerce, e-store and e-mail, and Ndraha and Hsiao [96], which studies a novel logistics system, a home delivery service for chilled shrimp, to meet consumer demand and expectations. As well as Exchange, these examples align with Virtualise and Implementation actions, respectively. Activities such as e-commerce and home delivery, which can be trialled at small scale by SMEs, would contribute towards both circularity and resilience. These actions have to some extent been tested by companies for survival during the COVID-19 crisis [97,98].

Buck, et al. [99] and Schernewski, et al. [62] describe companies cultivating mussels for consumption alongside other functions. Buck, et al. [99] suggest utilising offshore windfarm infrastructure to grow mussels. Offshore mussel production reduces the mortality rate of the produce due to lower storm damage and reduces stakeholder conflict, as competing sectors can use the same area simultaneously and share operational assets – windfarm engineers can perform maintenance checks from the mussel cultivation vessel. Positioning the activities of the two sectors side by side would align with the Share and Implement iReSOLVE actions. Schernewski, et al. [62] suggest that mussel cultivation can decrease the eutrophication of a degraded coastal ecosystem. Here, the production of the mussels would be a secondary benefit and align with Regenerate and Implement actions.

In fisheries management, Field, et al. [100] highlight the importance of multi-stakeholder representation. Stakeholder representation, whether that be family members or small-scale cooperative and collective arrangement, contributes to Regenerate, Share, Exchange and Implement actions. For example, Herrero [101] identifies how family-run businesses can diversify their product lines and share knowledge and assets in light of environmental instability, whereas Hardy, et al. [102] identify broader stakeholder inclusion to maintain system viability with potential gains to subsistence, profitability and ecological performance.

Aligning business models with resilience mechanisms. The prominence of Optimise, Exchange and Implement actions within the reviewed literature demonstrates some alignment to resilience mechanisms. Through Optimise and Exchange actions, companies demonstrate ‘diversification across the value chain’ (second resilience mechanism, Figure 2 in the main article). However, as these actions predominantly focus on the production end of the value chain rather than on the whole chain, full alignment to this resilience mechanism is lacking. ‘Increased knowledge exchange’ (fourth resilience mechanism) is demonstrated with Implement, Optimise and Exchange actions. Implement actions also ‘promote the use of local systems’ (third resilience mechanism), but perhaps focus more on the broad engagement with local systems rather than on the specific actions – alignment to this resilience mechanism is limited. Despite their prominence within the analysed companies, these three iReSOLVE actions do not show any alignment to the utilisation of ecosystem and ecological functions (first resilience mechanism).

When assessed against the resilience operational framework [90], around half (n=37; 51%) of the 73 articles reviewed contained text with one or more of the resilience key words. Figure 3 in the main article shows how the text from the reviewed articles aligns with the three elements of resilience: (a) resilience of what, (b) resilience to what and (c) resilience for whom. The majority of the text extracted aligns with Food Security and/or Social Welfare, with a limited consideration of environmental elements (Figure 3a). This finding is surprising, given the close linkages between the seafood sector and the environment i.e. the primary

source of the sector's raw material. Furthermore, the seafood sector must adhere to international policy e.g. the EU Common Fisheries Policy (EU 2019/1241) (EU, 2019) and is the subject of local stewardship, particularly with respect to artisanal fisheries [104]. The limited consideration of environmental elements does, however, mirror the lack of alignment found through the CERF-BM for the 'utilisation of ecosystem and ecological functions' (first resilience mechanism).

Of the text extracted (n=37 articles), the majority referred to stresses (n=26; 70%), while around half (n=20; 54%) referred to shocks (Figure 3b). Eight articles refer to both stresses and shocks in combination. Price fluctuations and policy changes are the most frequently mentioned shock and stress respectively within the articles reviewed. The prominence of these two factors is expected, as the sector is highly regulated, albeit subject to often fragmented and decentralised regulation regimes, and dependent on a resource that follows seasonal patterns [105,106]. Five articles referred to shocks and stresses without providing specific themes. Several articles focused on more than one type of shock or stress.

Almost all articles consider resilience from the perspective of the main actor (n=35; 97%; Figure 3c). Almost half (n=16; 44%) also consider downstream stakeholders (e.g. customers, consumers) – but few articles (n=7) consider upstream stakeholders (e.g. suppliers, outsourced services, regulators). This finding reflects our CERF-BM analysis showing that diversification is not equally spread across the whole value chain and that the focus on production indicates a disposition towards the main actor, as opposed to e.g. the actor's supply chains or customers.

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