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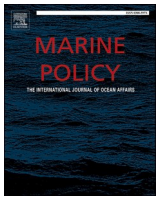

Leaving the niche: Recommendations for mainstreaming Low Trophic Aquaculture in countries around the Atlantic basin

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ABSTRACT

Low Trophic Aquaculture (LTA) is the farming of aquatic organisms such as primary producers (e.g., seaweeds) and primary consumers (e.g. bivalves). Despite recognition as a key pathway to the provision of sustainable food from the oceans, many forms of LTA around the Atlantic basin remain in the niche stage of socio-technical evolution. With governance regarded as a limiting factor to LTA development, aquaculture experts and stakeholders were surveyed to find, and interviewed to document, examples of implemented good practice in rules, regulations and processes that were seen as supportive of the sustainable development of LTA and related Integrated Multi-Trophic Aquaculture. A theoretical framework on socio-technical change under polycentric governance informed an analysis of the good practices, according to five core themes: regulation and legislation; resources and infrastructure; human and social capital; financial instruments and economic support; and, the overarching socio-economic environment. Recommendations for action were constructed both inductively (from interview evidence) and deductively (from the theory), and were organised in relation to the three spheres of governance: *Government* should: provide stable policy and legal frameworks within which developers can operate with commercial confidence; ensure public trust in LTA products; support LTA start-ups; ensure availability of researchers and public officials with LTA relevant skills and knowledge. *Market organisations* should: allow LTA to better access financial capital and insurance; develop consultancy services; inform the public about LTA. *Civil Society organisations*, including universities, producer organisations and NGOs, should: in some cases, lead development of LTA with arrangements for local control; help certify appropriate LTA as sustainable, healthy and socially equitable.

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1. Introduction

The cultivation of carnivorous fish such as salmon or sea-bass is called High Trophic Aquaculture (HTA), because in their natural state these fish feed on smaller fish that are two or more food-web steps away from primary production [41]. Although many currently-farmed fish strains have been bred to use a partly-plant-based diet, they still require some fish protein and oil [42], and they continue to excrete compounds of nitrogen and phosphorus with potential to cause eutrophication [52].

In contrast, seaweeds are primary producers, requiring only sunlight and mineral nutrients, and mussels (and other filter-feeding bivalve shellfish) feed mainly on natural phytoplankton. Thus their cultivation is called Low Trophic Aquaculture (LTA). Arguably, LTA has a higher efficiency of natural resource use and lower environmental impact, compared with HTA. Low trophic species can also be grown in systems that integrate species of different trophic levels, where some species use the inorganic or organic nutrients produced by other species, in what is known as Integrated Multi-Trophic Aquaculture (IMTA). Nutrients from other anthropogen sources can also be removed by freestanding LTA [9,30,32,36,51].

Expansion of LTA seems desirable on grounds of reducing emissions of green-house gases and nutrients per kilogram of food (and other products). However, such expansion encounters numerous obstacles, which can be theorized as confining most forms of LTA and IMTA to the *niche* stage of socio-technical change [22]. In 2022, following studies of the obstacles [11,43], a survey of 'Good Practice for policy development for low-trophic level aquaculture' was carried out by the EU Horizon 2020 project 'AquaVitae'. This paper reports examples of practices by government, market organisations, and civil society, around the Atlantic basin, that were seen as supportive of LTA and IMTA expansion by survey respondents, and integrates these with recommendations from other work in the AquaVitae project.

2. Theoretical framework

The growth path for LTA/IMTA may be seen in terms of change within a socio-technical system. Theories of such change [56] posit that new methods of producing goods become fully utilised only after changes in society. In a market economy, profit can be made from, for example kelp cultivation, only if there is a demand for kelp products and a means to make them available to consumers. More generally, LTA and its products need to become normalised, so that the industry and its products are a familiar part of everyday life and are governed by relevant laws.

One such theory of change is the 'Multi-Level Perspective' of Geels [21,22]. This posits that established industries are integrated into a *socio-technical system* that links technologies, popular culture, market preferences, and public policies into a network that is resistant to new forms of production. Thus the latter tend to remain as *niche innovations*, confined to small market segments. The system exists within a *landscape* that provides its boundary conditions, and which in some cases perturb the system so as to make it permeable to niche industries.

The application of this theory to LTA is exemplified in Table 1, where we have added an additional step, characterised by decline in market share. However a failing industrial sector might restart with new technology, as envisaged by theories of panarchy [24].

Aquaculture has also been seen [49] as a 'wicked problem' [31] in that there is no simple method for the sharing of the natural resources used by the industry, and the aim of developing LTA and IMTA for societal benefit thus relies on *governance*. i.e. the steering of society by governments, markets and civil society [25,26]. In most cases such governance is polycentric [39,50], involving hierarchies of organisations (corporate bodies) and institutions (rules, laws, norms). For example, spatial planning at Ostrom's *operational level* may constrain approvals for farm developments, while policy decisions at the *collective-choice level* (of national governments and markets) may provide a larger or smaller space for particular aquacultural sectors, and evolution at the *constitutional level* (of federal governments and bodies such as the European Union (EU) and the United Nations (UN)) may begin to reshape the socio-technical landscape.

Finally, the conditions for successful establishment and operation of a LTA/IMTA enterprise can be seen in terms of discrete logic as a requirement for economic, environmental, social and technical switches or licences (Fig. 1), requiring access to: physical equipment; financial, human and social capital; and conditions and services provided by the natural environment. The licences individually represent necessary conditions, at the operational level, for development of a LTA enterprise, and their joint fulfilment is seen as a sufficient condition for such development. At the level of an aquacultural sector, more favourable conditions result in additional viable enterprises. Geel's 'niche' is an analogue of an ecological niche for a rare endemic species. Energising the switches in Fig. 1 by means of socio-economic as well as technical change, should allow the LTA sectors to expand into the wider socio-technical system.

3. AquaVitae and constraints on LTA

3.1. AquaVitae

AquaVitae (aquavitaeproject.eu) was a four-year (2019–2023) EU Horizon 2020 project that focused on increasing the production of value chains around the Atlantic basin involving LTA. Project members included producers as well as researchers.

In addition to biotechnical studies, AquaVitae also investigated the socio-economic barriers to increased production and the ways in which governance could improve the market share of LTA and IMTA. This related to UN Agenda 2030 [60], especially Sustainable Development Goal 12 'Responsible consumption and production', and the EU's 'Farm to Fork' strategy [15]. A 'Stakeholder Platform', which was set up to inform and engage the aquaculture industry, policy-makers, non-governmental organisations, and certification bodies [12], provided a resource used by the Good Practice survey.

Table 1
Phases [1-4 after [22]) of socio-technical change, exemplified from aquaculture and fisheries. Phase 5 is additional to the Geels model.

Phase	Description	Examples
1	*experimentation and trial-and-error learning with radical niche-innovations*	kelp farming for research purposes in Scotland
2	*innovations establish a foothold in one or more market niches, which provides a more reliable flow of resources*	kelp farming in Faroes, with marketable product but not fully economically self-sustaining; seaweed *Kappaphycus alvarezii* adding to economics of bivalve mollusc farms in some states in Brazil; abalone-seaweed in France and S. Africa
3	*the radical innovation diffuses into* [and destabilises] *mainstream markets, on the one hand driven by niche-internal drivers …and, on the other hand, taking advantage of structural windows of opportunity created by landscape developments …*	fin-fish farming in Europe, partly displacing wild fishery products in markets, but remaining controversial in society [19]
4	*the new socio-technical system replaces (parts of) the old one, and becomes institutionalized and anchored in regulatory programmes, user habits, views of normality, professional standards, and technical capabilities*	many commercial fisheries, even if unsustainable
5	existing socio-technical system in decline, i.e. sector decreasing as a fraction of GDP and of food markets	mussel farming in EU [3]

3.2. Constraints on LTA and IMTA

Compared to the situation in east Asia, most forms of LTA and IMTA around the Atlantic basin have small market shares. They appear to be kept in the niche stage of socio-technical development by several sorts of constraint. Amongst these are the laws and regulations linked to the switches in Fig. 1. Legislation on food safety, in particular, is essential for consumer trust in aquacultural products. Environmental and planning laws control farm size and location. AquaVitae studies [11] in Europe, Brazil and South Africa showed that relevant laws and regulations were well-developed for the farming of salmonids and shellfish where these were established industries, but immature for seaweed farming and IMTA. In addition there were differences between countries in the balance of environmental regulation and economic stimulation. In many cases LTA producers reported that they found licence application time-consuming and complex; they also mentioned the need for financial support for R&D, innovation and start-up [43]. The next subsections provide more details of the LTA and IMTA sectors featured in responses to the Good Practice survey.

3.3. Kelp in Northern Europe

Laminarian seaweeds grow well in cool nutrient rich waters around the northern coasts of the Atlantic Ocean. Cultivation of some of these, especially sugar kelp, *Saccharina latissima* and winged kelp, *Alaria esculenta*, has begun in recent decades, typically using long-lines, with sporelings put out in Autumn and harvested in late Spring before fouling becomes excessive. Laminarians alternate gametophyte (small, haploid) and sporophyte (large, diploid) generations, and hatcheries are needed to maintain gametophytes and provide young sporophytes for cultivation at sea [10]. Kelp production remains small compared with east Asia [33,63], and in many cases reliant on research funding. Amongst significant developments in Europe are larger and more robust structures for use under exposed conditions in Faroese fjords [5,6]. Potential markets are culinary, agricultural (cattle feed additives), pharmaceutical, and for biofuels [63]. Although held up as good for employment for coastal communities, profitability requires both local infrastructure [13] and the cultivation of social licence for large-scale farming [53].

3.4. Seaweed in Brazil

Seaweed production in Brazil is recent. There are no restrictions on cultivation of native seaweeds, but most interest has been shown in the introduced red algae, *Kappaphycus alvarezii*. Commercial cultivation of this fast growing producer of carrageenan is increasing, despite being permitted only in Santa Catarina state and portions of Rio de Janeiro and São Paulo states. The commonest method is to grow the seaweed in the traditional tie-tie method or tubular nets hanging from long-lines, harvesting between 45 and 60 days depending on the region and season. The main challenge comes from the lower winter sea-temperatures in these more southerly parts of Brazil, which may kill the seaweed [27]. In Santa Catarina state, a few farmers of bivalve molluscs are beginning to include *Kappaphycus* in IMTA systems in order to increase economic return and reduce market risks from the effects of toxic algae blooms and the low prices for mussels and oysters in some seasons [54]. Products from *K. alvarezii* have a range of uses, and the market is promising; currently most attention is being given to the extraction of liquid to be used as agricultural biostimulants.

3.5. Filter-feeding bivalves in Europe

Bivalves (e.g. mussels and oysters) are extractive filter feeders that extract natural suspended food particles from the seawater. The bivalves are the most important group of low trophic species cultivated around the Atlantic Ocean [58]. Within this region, mussel cultivation methods include bottom culture and suspended cultivation on longlines and rafts. Within the European Union, the aquaculture production of mussels has declined by 20 % since the 1990s due to environmental problems, access to space for farms, and low market price [3]. Solutions to lack of inshore space have been sought in offshore cultivation and co-use of areas such as those in wind parks, which creates new technical requirements. Mussel cultivation in the EU might, thus, fall into the 5th category in Table 1, if its decline can be reversed by the provision of hatcheries for seeding [55], new technologies for offshore cultivation [28], and improved attention to marketing.

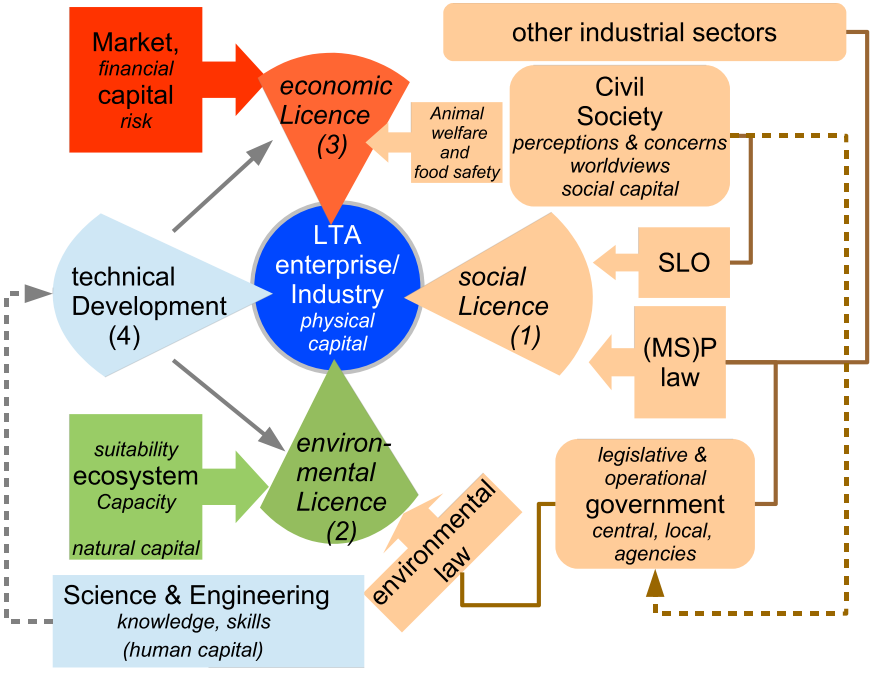

Fig. 1. Four switches or licences needed for the development of LTA. The numbers are those used in Table 3. SLO = Social Licence to Operate; (MS)P = (Maritime Spatial) Planning.

3.6. Abalone-seaweed as example of IMTA

A number of aquaculture systems integrate different trophic levels. One example is combining abalone and seaweed in the same system. Abalones are large sea snails in the Haliotidae family. In the wild they live in the intertidal zone and feed on seaweeds, including kelp. They are a luxury product in many cultures and markets, especially in parts of Asia [17]. The global wild harvest has fallen over the years, mainly due to overfishing and disease [18], and aquaculture now dominates the global supply, with 98 % produced in China and Korea [29]. In the AquaVitae project there were two case studies of abalone aquaculture with seaweeds [28]. One was in South-Africa, combining abalone with seaweed production in a land-based aquaculture plant. The seaweed was fed to the abalones, together with feed pellets. The producers export abalones mainly to Asia, either fresh (live), dried or canned. The other case study was a sea-based plant in France that sells fresh abalone to high-end restaurants in France. There, the abalone is mainly fed wild harvested seaweed. However, issues with seaweed supply have led the producers to test co-cultivation with seaweed in order to use the latter as abalone feed. The European abalone production is currently very small.

4. Methods

The Good Practice survey was ethically approved by the University of the Highlands and Islands, with reference number ETH2122–0643, and had two parts. The first part was quantitative and used an on-line questionnaire (in English, Portuguese and Spanish) to establish whether AquaVitae (AV) project members, plus others who had signed up to the AquaVitae Stakeholder Platform, had knowledge of such good practice. Table 2 lists practical topics identified during earlier work in AquaVitae [11,43,44] and included in the questionnaire; respondents were invited to identify those to which they could contribute.

148 potential respondents (of whom about 20 were AquaVitae project members) were emailed a copy of the questionnaire and directed to the on-line version, which was open from 5 July 2022–30 September 2022 on the Online Survey platform.

The second part was qualitative, and involved semi-structured interviews, carried out in English or Portuguese during September through December 2022, and lasting up to an hour. These interviews typically commenced with questions relating to the topics that the respondent had identified during the on-line survey. Each interview was guided by a standard protocol, which led the interviewer to seek more details of the good practice and to understand why it was seen as successful and if it might be transferable to other countries.

Interviews were recorded, transcribed manually, and analysed in relation to five hypotheses about favourable conditions for the start-up and operation of enterprises, and with the expansion of the LTA and IMTA sectors. The hypotheses (Table 3) were developed inductively from the theory presented above and each was associated with a theme. The themes LAW, TECH(nical), H(uman and)S(ocial)CAP(itals) and ECON(omics), whilst influenced by higher levels of government, markets and society, mainly concerned the operational level of polycentric governance [39,50]. In contrast, S(ocio-economic)ENV(ironment) concerned the broader context for LTA and IMTA, and corresponds to the socio-technical system.

Table 2
Practical topics and associated main question for researching Good Practice in LTA and IMTA. The questions were those asked during the first, on-line, part of the survey, and explored in more depth during interviews.

Practical topic	Main question: "Do you have examples of …"
Marine Spatial Planning	"… planning law, planning policy, or zoning or consenting decisions that are good for the development of LTA or IMTA?"
Leasing of public space or use of private space	" … laws, policies, markets or other mechanisms, that make it easy to find and pay for space that is suitable for LTA or IMTA?"
Control of environmental impact	" … legislation, regulation, policy, or decision-making that perform well and efficiently to minimise the environmental impact of LTA or IMTA?"
Food safety and quality	"… voluntary or mandatory schemes that are successful in assuring the public of the safety and quality of the products of LTA or IMTA?"
Public attitudes and SLO	" … public policy or producer actions that have improved public education or public opinion about LTA/IMTA, or brought about better stakeholder engagement?"
Risk management and insurance	" … schemes for risk management that benefit LTA/IMTA? They might include public laws or policies to reduce risk, (public or private) insurance to share its costs, or improved risk management by the sector."
Taxes and subsidies	"… schemes involving taxes, subsidies, or transfer payments, that help to level the playing field amongst different economic sectors and thus benefit LTA/IMTA?"
Access to finance	" … public or private funding schemes or mechanisms or policies that support investment in LTA/IMTA?"

5. Results

5.1. Quantitative results

There were 32 responses to the on-line survey, with a total of 18 examples of good practice (Table 4). The most frequently mentioned topics were those directly relevant to consumers and communities, such as addressing LTA product safety concerns and the need for public engagement.

On the basis of the on-line survey, 12 in-depth interviews were conducted, 7 in English and 5 in Portuguese. Although this number is small, it was not intended to be a representative sample of opinion but an elicitation of positive experiences that would be worth copying. The interviews drew on expertise from LTA enterprises, producer organisations, and academic researchers, in the regions and organisms listed in Table 5.

5.2. LAW: legislation/regulation including spatial planning

Interviewees pointed to situations where leases were available for small as well as large farms: '*It's not only in communities but also now*

Table 3
Themes and hypotheses relating to creating good conditions for LTA and related IMTA.

Theme	Hypothesis: the following will be associated with Good Practice:
	... at the operational level (of a single enterprise)'
LAW	an environment of applicable, supportive, but flexible/adaptive law, enabling actors to know the possibilities for lawful action, and allowing for new circumstances such as those associated with LTA and IMTA
TECH	provision of technical support, with information, tools, etc, allowing good monitoring and forecasting, so reducing the unknowns for communities, investors and operators
HSCAP	adequate human and social capital [46] – i.e. sufficient people with appropriate skills to staff industry and regulators; sufficient existing, or potential for, bridging capital [35] between local communities and industry, i.e. for Social Licence to Operate [8]; facilitation of communicative action [25] by co-engagement of stakeholders, especially in Action Situations [39,50];
ECON	availability of financial capital and insurance from market organisations or government
	... at the level of LTA sectors
SENV	public economic policy that provides a level playing field for LTA/IMTA, alongside other forms of sea use, in taxes, subsidies, charges for licences and rent for sea-space; and, in some cases provides positive financial support for socially and environmentally beneficial forms of aquaculture through, for example, transfer payments and public education

Table 4
Quantitative results from the Good Practice survey. 'Hispanic' includes Spanish, peninsular Portuguese and Brazilian Portuguese. 148 persons were invited by email to access the Online Survey platform. Positive responses often referenced several topics.

	English	Hispanic
(Total online views)	47	35
(Total online responses)	19	13
Topics eliciting positive responses		
Marine Spatial Planning	5	6
Use of public or private space	5	7
Control of environmental impact	4	3
Food safety & quality	7	7
Public attitudes & SLO	8	7
Risk management & insurance	4	1
Taxes & subsidies	3	4
Access to finance	5	5
Other examples	3	3
(Total online responses offering examples)	8	10
(Interviews in English or Portuguese)	8	5

Table 5
Summary of organisms and regions discussed in Good Practice semi-structured interviews.

Main organisms discussed	Region
kelp, shellfish	N.E. states of USA
kelp	Faroes
mainly oysters	Sweden
urchins in RAS, urchins and young kelp	W. coast N. America; Norway
mussels	Sweden
mussels and oysters	Sweden
shellfish	Denmark
oysters	Brazil - Santa Catalina
bivalves	Portugal
shrimp (in freshwater)	Brazil
bivalves	Brazil - Santa Catalina and Maranhão
oysters	Brazil - Santa Catalina

private people that can just go out and make a line for 10 or 20 m with mussels or seaweed.' In Brazil, legal frameworks protect and engage indigenous communities and their wisdom: *'we need permission from the communities (…) saying they allow us to use their associated traditional knowledge'* and *'the community decides together with that authority what can or cannot be done in that area'*. There were examples of streamlined and fast licensing: *'Until 2020 the process was all physical. Today we submit the process in the government database. (…) this was an advance, because as an applicant I put together a single process and this (…) goes to all the authorities.'* Also, *'It will not take you forever; I think it's around three, six months, from when you apply to have either a permit or they reject your application'*. And examples of licences considered sufficiently long: *'the applicant gets a permit for 20 years, which can be renewed for another 20 years'*.

Several countries had designated marine areas for specific forms of aquaculture: in the Faroes, *'in each fjord you have specific areas for fish aquaculture, for mussel farming, for seaweed farming'*, and in the N.E. United States *'the federal government, 10–15 years ago, created the Marine Aquaculture Areas, which are areas to facilitate the licensing for aquaculture'*. [1] In some cases there was a clear public strategy and vision for aquacultural development: *'for us, who will actually work with the plans, it was very clear what the politicians wanted us to prioritise'* and consultation processes in which a proposed law or policy *'goes to public consultation, where everyone has access, can read and give an opinion'*. In Sweden, a high level of trust in the government to regulate aquaculture transparently was seen as important: *'I think the openness in the data and to send out through Facebook to the public the information, I would say that that is very … a very Swedish way to do it. That is also culturally a lot of Swedes trust the authorities and trust the Government'*.

5.3. TECH: resources and infrastructure

Interviewees pointed to the benefits of industry collecting data that government could use, for example reporting that: *'we also (…) did a more detailed mapping of suitable sites around the Faroe Islands'*, information that was fed back to the government's MSP; and *'the government is monitoring [the algae blooms in] areas all around Denmark, so in that way we have all the information we need'*. Technical support could be provided by government: for example the *'Swedish Food Agency has a course in how you sample your products before sending it to them. And it's compulsory for the farmers to send their farm manager once a year to this course.'* Or by consultants or researchers: *'everything that was developed as a research project, was born out of direct demand by the industry.'* And industry organisations might provide codes of good practice. Government could require the use of specialised technicians when applying for a licence: in Brazil, *'the producer cannot undertake the application process on its own: you have to hire a specialised technical lead. (…) This is to ensure environmental responsibility, because on what regards environmental legislation the producers may argue lack of knowledge, whilst the technical lead cannot, because they must have a licence from IBAMA'*.[2] Finally, social media was helping to maintain stakeholder networks: *'Before WhatsApp and mobiles what they [the government] would do was that everything was done by invitation (…) You had the associations, producers would meet, you would go door by door calling people for the meeting. Today we have a forum on WhatsApp.'*

5.4. HSCAP: human and social capitals

Respondents highlighted good practice in terms of individual knowledge, skills and competencies (human capital) and co-operation between stakeholders, public engagement, and networks of trust (social capital). Companies invested in human capital to help secure research funding: *'we have human resource in the company (…) with great experience in EU proposals and also national proposals. So we have (…) a high success rate to get funding.'* 'Key agents' were important: *'what I see is that the success is in the people involved. As much as the government wants action, if the person in front of it does not have that willingness, (…) it will not move forward'*.

Stakeholder consultation and engagement with government and community was widely seen as critical. In the Faroe Islands, kelp farmers had *'meetings with the minister and we were present in the local societies, we talked about what we were doing, we talked with the other aquaculture industries [i.e.] the salmon farmers'*. Businesses would *educate and tell all stakeholders, like local people and Government, about what we are doing'* on top of what is legally required. In Sweden, stakeholder consultation for minimising conflicts was the main good practice addressed, and was said to explain why they *'get a very high acceptance for our businesses'*. Additionally, when the government collects samples from farms, the results are not only sent back to the farm in question, it's also sent to *'researchers that might want it, (…) all the other farmers and (…) the county administrative board. So all the data is very open access and very, very public'*. Due to this openness, *'culturally a lot of Swedes trust the authorities and trust the Government'*. Additionally, the use of farmed seafood in school meals encouraged children to eat more fish and aquaculture products and to educate them on the practices of LTA. Danish coastal communities can gain licenses for small-scale non-commercial aquaculture farms, schemes that encourage people to consume more local seafood as *'they grow their own mussels there and they use them for like events where they invite all other citizens … to come and visit and taste mussels'*. On a

[1] May refer to US 'Aquaculture Opportunity Areas' [45].

[2] IBAMA is *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis*, the Brazilian Ministry of the Environment's administrative arm.

commercial-scale, farmers work together: *'we have a society that is collecting samples and trying to minimise the costs to do it in a network, community network together with other companies. So the skills, if you don't have them you can pretty much, it's easy to learn it and have access for experts to tell you or learn how to do this'*. In the Northeast United States, public hearings are part of the process of obtaining a lease, and this public forum was seen as a good practice *'for people to express their concerns or ask their questions before a lease can be considered'*.

In the cases of good practice reported from Brazil, social factors were hard to dissociate from human factors, and processes of stakeholder cooperation were often presented as interlinked with networks of trust and shared values, the role of key agents and individuals' competences. For instance, when producers were engaging with government to change the current legislation *'we took the solution, because the government technician does not live the day-to-day [in a farm]. Is not that he does not want to [help], he does not know how'*. When researchers were dealing with local communities in area management measures *'we take into account the communities' knowledge'*. The success of these networks of trust was often linked by interviewees to underpinning relational approaches, existing alignment of interests, but also to the role of specific people involved (and the knowledge, competences, or commitment they brought to the table). For example, during recent changes in aquaculture legislation in Brazil,*'what happened in previous governments is that that person [the minister] had always been a politician, or a technical person, this time we had a professional, who had owned a fisheries business. He was a person that understood it and that made it easier for us, in the sector of mariculture and fisheries, to communicate with him'*. When exploring the development of the mariculture sector in the Brazilian state of Santa Catarina, a respondent noted *'a very strong interaction between producers, academia, extension services and mariculture producers. What happens is that one year there is a problem with seed production, the next on the environment (…) in Brazil, we don't have mariculture insurance, so when these things happen, there are large losses, and these are very significant for producers … so what is seen is that this interaction with the universities and the support it provides helps lift the producer'*. However, such interactions are less well developed in other Brazilian states.

5.5. ECON: financial instruments and economic support

Economic challenges to LTA are those faced by its sectors as niche industries and by the costs of starting as well as operating a farm. Respondents in Denmark, Faroes, Norway and Portugal emphasised the importance of access to national and EU funds for innovation. In Portugal, for example, access to public R&D funding allowed companies *'in a phase when they are not attractive to investors, to become more attractive'* because the commercial investors can *'trust the R&D is being built up, and they can invest in other areas of the business. This allows us to give more safety to investors, as it covers the higher-risk activities'*. In Norway, processing time for funding applications was fast: *'the government can give very precise and concise feedback within 10 business days, and approval of that funding could be within those timelines'*.

Some countries give economic support to LTA through low-cost licence fees and by government provision of quality assurance. In Sweden, the cost of product safety tests is subsidised, *'as the Government want to have these tests taken quite regularly'*, and otherwise *'it would be a huge cost for the businesses'*. Additionally, the Swedish government monitors for toxic algae without charge to shellfish farmers.

5.6. SENV: the socio-economic environment

Only in Faroes and Norway was government policy seen as positive. Because much of *'the income in the Faroe Islands [is] made from either fishing at sea or the aquaculture'* the islands' government is keen to expand current or develop new related activities. In Norway, much governmental decision making is de-centralised to the point where local organisations *'don't even have to call in Oslo to make pretty decisive financial calls from loans and credits'*. Specifically, this was in reference to Innovation Norway which is a government entity that helps stimulate and catalyse innovative ventures.

As already mentioned, trust in governmental institutions was high in the Nordic Countries, and this conditions both expectation and behaviour. It is lower in Brazil, and here the central government uses interventions that link market and law. Thus, access to financial services is dependent on being fully licenced to operate: *'there is finance for small producers, but they need to be operating lawfully. I think the licencing of the production areas was a great advance for the [mariculture] sector'*, because it did away with unregulated aquacultural developments that were common at the end of the twentieth century.

Interestingly, it was in respect of the very different societies of the Faroes and Brazil that our respondents emphasised the important role of communities of trust within civil society.

6. Discussion

In general, empirical evidence from the interviews supports the theory-based hypotheses in Table 3. However, some discussion and caveating is necessary, leading to the synthesis of results in Fig. 2.

6.1. Governance

How the generalised good practices might be implemented in different countries, likely depends on characteristics of each polity (Table 6). The optimum balance of steering by governments through laws and policies, by market processes, and by civil society networks and organisations, is also likely to be polity-specific. At one extreme, informal networking seems important in the Faroes, with its small population and high reliance on fisheries and aquaculture. At the other extreme, in Brazil, somewhat similar networks in civil society, involving producers, local communities and universities, also seem important, because relevant law may be weak [34] and trust in government low. In between, high levels of trust in Nordic public authorities, and efficient public administration, seems to support a major rule for public law.

Law is particularly important in relation to allocating common-pool [50] resources of the sea, through both Marine Spatial Planning (MSP) and the licensing of use of Natural Capitals. In many European countries, competition for marine space close to shore is restrictive of both finfish and shellfish aquaculture [20], and this is likely to be an increasing constraint on LTA as an extensive form of aquaculture. FAO have already recommended [1] that marine planners identify and allocate marine zones for aquaculture on the basis of suitability for organisms and gear, access to harbours and land-based facilities, and equitability of provision to industrial sectors competing for sea-space.

Two strategic challenges to licensing LTA have been widely identified [11,43]: the complexity of the requirements arising from multiple overlapping public authorities, and the tardiness of law in catching up with new forms of aquaculture. Because of the need to retain public trust, excessive de-regulation of licensing should be avoided; the GP solution is that of providing a central point for contact with the authorities, backed by rapid response systems. Adaptive governance has been seen [44] as a solution to the need for law to evolve rapidly. However, the flexibility of regulatory systems required to adapt to new species, gear, climates or markets requires a careful balance between freedom of regulators from over-rigid constraints and the need to control environmental impact, maintain social licence and fairly distribute use of common-property resources in the sea. Furthermore, it isn't clear how much adaptiveness and flexibility should be built into each level in the hierarchy of polycentric government. EU Directives (devised at the constitutional-choice level) specify a set of aims that each member state implements (at the collective-choice level) in ways appropriate to its own traditions of governance and national sovereignty, and some federal states have constitutions that allow the lower collective-choice levels the necessary capacity for adaptiveness. In some cases the

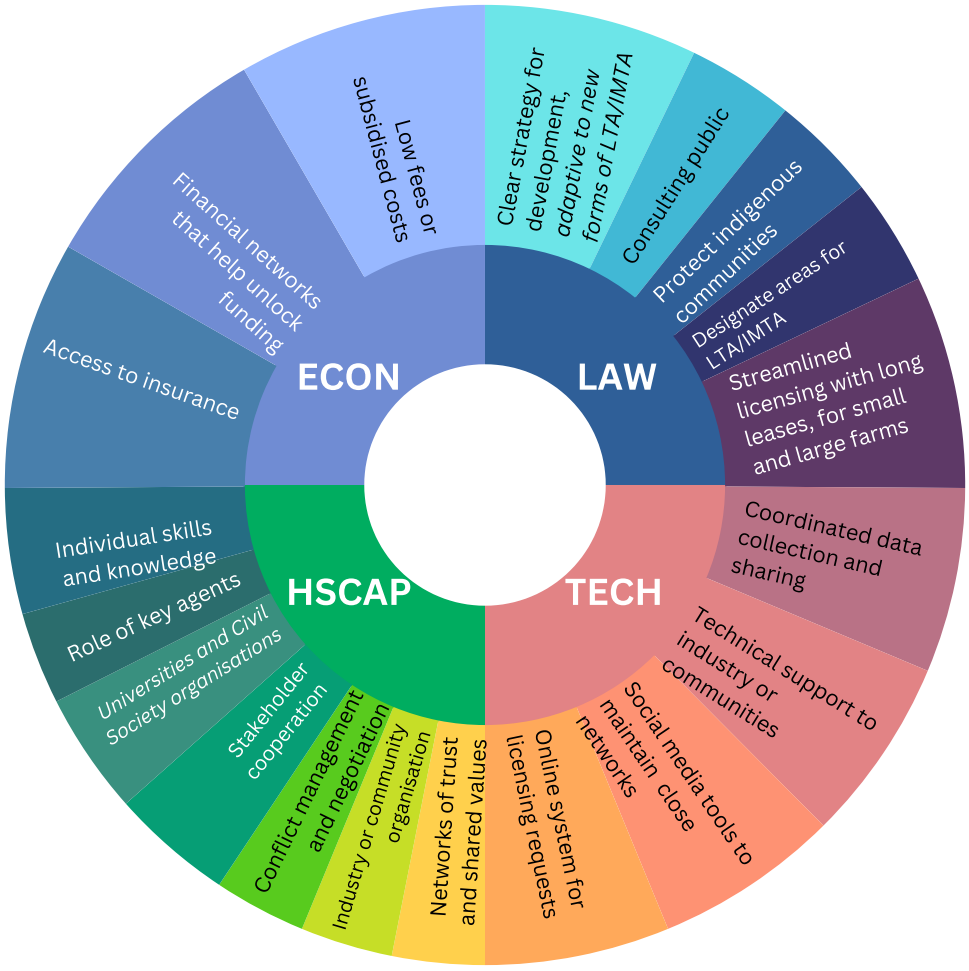

Fig. 2. Summarising findings by themes. Italicised text from section 6, all else from section 5.

Table 6
Countries featured in the Good Practice survey. F&Aq is fisheries and aquaculture as parts per thousand of GDP, circa. 2020 (‡in 2003), based on OECD.stat and *FAO - facp. Trust is percent of population expressing confidence in national government in 2020 (OECD.stat and †pewreserach.org).

Country	type of polity	F&Aq	Trust
Brazil	Federal constitution. Aquaculture licences are issued at Federal level, while environmental licensing is a State responsibility.	*5	36 %
Denmark	Denmark proper is an EU member state with a unitary constitution	2.8	72 %
Faroes	The Faroe Islands are an autonomous region of Denmark and are outside the EU	* > 200‡	n.a.
Norway	Member state of the European Economic Area with unitary constitution. Production licences are granted nationally; site licences involve national authorities and local government	11.9	83 %
Portugal	EU member state with unitary constitution. Aquaculture regulated by national organisations	6.8	61 %
Sweden	EU member state with unitary constitution. Aquaculture is regulated by national Fisheries laws, sites consented by local government	0.8	67 %
USA	Federal constitution. States and local governments licence aquaculture in territorial waters; the federal government is responsible in the offshore part of the US exclusive economic zone and also for environmental impact and food safety throughout	1.2	†24 %

ability and willingness of local government to adapt, is open to abuse by concentrations of power by special interests [40]; in other cases local government is not given sufficient powers. The Faroes example evidences effective governance involving communicative action amongst all interested parties.

6.2. *Capitals*

As summarised in Fig. 1, starting and operating farms requires adequate financial, human and social capitals. Several interviewees noted the importance of the availability of financial capital, for the costly large-scale or high-tech developments that may well be necessary for the growth of LTA, and pointed to the role of public funding of research in order to generate investor confidence in an industry. According to OECD [46], **human capital** is the "knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being" and **social capital** is "the networks, norms, values and understandings that facilitate co-operation within or among [between] groups". Especially relevant are networks of trust within communities (bonding capital) and amongst groups (bridging capital) [35] especially, in the present context, trust between communities and developers and regulators. The development of human and social capitals is expensive. The former is usually regarded as requiring public support, since it is a benefit to society as a whole. Less attention has been paid to the latter, except in relation to SLO, which is now widely seen [38] as something in which developers need to invest.

The level of social acceptance for aquaculture in general, and farm activities in particular, can influence the granting of licences and the

smooth operation of a farm. Most research has concerned fin-fish cultivation, and shown important factors are community engagement, individual world-views, perceived fairness in the distribution of benefits and harms from the industry's operations, and confidence in the authorities' regulation of the industry [4,7,38,47,62]. In the case of seaweed cultivation in north-western Europe, it has been found that interpersonal relationships, perceptions of environmental risk, scale of decision-making and of operations, and communication, are key to local perceptions of the cultivation operations [8,23,53].

6.3. Budgets and markets

Typical LTA is a spatially-extensive form of cultivation and tends to operate on lower economic margins [59] than spatially-intensive HTA [48]. The challenge of low profitability per hectare of LTA farm could be addressed in several ways: through public subsidy on the grounds of maintaining employment in coastal communities or the greater sustainability of LTA production of food; transfer payments for ecosystem services provided by LTA [30,36] or economies of scale. Limited space, competition from other sectors, and social constraints on farm size inshore [20] means that larger farms will require offshore sites, perhaps in co-use with wind turbines [14], and will thus need the level of investment that is most likely to come from large companies. However, local communities prefer local ownership [8,53], and an alternative is the formation of locally-controlled producer or marketing co-operatives [61], aggregating activities over numerous small or medium-sized farms. Finally, the GP interviews suggest that government can support LTA by providing access to public funding for start-ups and for applied research, which could help leverage private funding, and support of consumer confidence in LTA products by public funding of product quality monitoring and HAB monitoring.

6.4. Civil society

The organisations of Civil Society include churches, community groups, campaigning NGOs, and universities. Strictly, these are not part of governmental or market systems, although there may be overlaps, exemplified in public universities that receive government funding and/or charge student fees. Whereas the 'Humboltian University' has the two major functions of contributing, through higher education, to the reproduction of society, and, through research, to the growth of knowledge, it is becoming appreciated [2,57] that 21st-century universities can and should perform other social functions. One GP respondent from Brazil pointed to the importance of this social role, in which universities may act, independently of government, as development stimulators. Other Civil Society organisations can help or hinder social acceptability of different forms of aquaculture, both at the operational level by supporting SLO or opposing development at a new site, and at higher levels of governance by advocating for or against the different types of production or by setting up schemes for certifying environmental sustainability or social justice. An example, at the highest level of governance, is the 'Seaweed Manifesto' [37] originating from the UN Global Compact aimed at "international donors, intergovernmental organizations, non-governmental organizations, research centres and international companies" to support an "upscaled, responsible and restorative seaweed industry, playing a globally significant role in food security, climate change mitigation, and support to the marine ecosystem, as well as contributing to job-creation and poverty alleviation."

7. Recommendations

The recommendations that follow were reached both inductively (from interview evidence) and deductively (from the theory in section 2 and the hypotheses in Table 3). They are organised in relation to the three spheres of governance distinguished by Habermas [26]:

Government,. operating through impersonal power-steering, involving elected and appointed makers and implementers of laws and policies at *collective-choice* and *constitutional* levels [39,50] that impact both the social-economic environment for LTA/IMTA, and the operational level of public licensing of enterprises.

Market organisations,. operating through impersonal money-steering, with mechanisms that include: returns on invested financial capital; payments for services including nutrient or carbon sequestration; and efficiencies from co-use.

Civil Society,. operating through interpersonal communication. Organisations, which may have a larger part to play where trust in government is low, include church congregations, community groups, environmental NGOs, and universities [57]. However, some of these organisations also perform in the market sphere.

7.1. Recommendations for public policy-makers

1. Provide stable, clear, and as far as possible simple, **policy and legal frameworks** within which developers of LTA and IMTA can operate with commercial confidence. This includes: making explicit provision for each type of cultivated organism; identification of suitable zones for their cultivation, taking account of climate change; and a fast, transparent and adaptable site-licensing process within such areas.
2. Sustain **public trust** in the producer activities and products of LTA and IMTA by: protecting the environment; protecting farmed organisms from other sea-users; warranting that a farm's products are safe to eat by monitoring for quality and against HAB; educating the public about the costs and benefits of different forms of, and ownership models for, aquaculture; and facilitating public engagement in licensing decisions.
3. Provide an **economic environment** favourable to LTA/IMTA, with a diversity of easily-accessible funding types for start-ups, and which is financially equitable towards all forms of aquaculture in terms of charges or payments for ecosystem services used or provided;
4. Ensure availability of **researchers and public officials** with good knowledge of technical, environmental and social aspects of LTA and IMTA.

7.2. Recommendations for commercial organisations

5. Organisations in the **financial sector** could profit by developing expertise and mechanisms to allow LTA and IMTA to better access investment capital and operational insurance.
6. Organisations in the **consultancy sector** could profit by developing expertise and services: to advise LTA developers on financing, budgets, and environmental, social and technical matters; and to provide monitoring under contract to government or industry.
7. Organisations in the **LTA and IMTA sectors** should engage and inform the public about these forms of aquaculture and their products in order to expand their markets and to acquire SLO.

7.3. Recommendations for civil society

8. **Universities, community groups and producer organisations** should in appropriate cases lead or support the development of new forms of production such as LTA, should educate about its benefits, and could help steer the sector towards producing or marketing co-operatives in order to benefit from economies of scale whilst retaining profits locally.
9. **Civil Society organisations** should participate in operational Action Situations relating to LTA and IMTA, in order to prevent

dominance by more powerful governmental or commercial actors, and to help development of SLO.

10. **Environmental NGO**, by certifying LTA methods and products for environmental sustainability and social equity, and pressurising aquacultural sectors to improve processes, could help sustain public trust in the sector.

8. Conclusions

This paper has aimed to identify good practices in relation to the governance of LTA and IMTA, so as to help this more sustainable form of aquaculture to expand beyond the niche stage of socio-technical development in countries around the Atlantic basin. Our recommendations are based deductively on theory and inductively on interviewees' accounts of what already works, and should help in levelling the playing field for LTA in relation to HTA.

At EU level, the recommendations are relevant to multiple policy areas, with sustainable LTA development not only contributing towards the ambition of the European Green Deal and Farm to Fork Strategy, but also recognised in the EU's new strategic guidelines for aquaculture [16], and reflected in Member States' multi-annual National Strategic Plans for the development of sustainable aquaculture. Furthermore the recommendations are relevant not only to aquaculture and fisheries policy, but also to policy and regulatory frameworks for marine spatial planning, integrated coastal zone management, water management, environmental impact assessment, common markets organization, food safety, and animal health and welfare. Our recommendations contribute not only to UN Sustainable Development Goal 12 on responsible consumption and production, but also to SDG13 on climate action and SDG14 life below water.

CRediT authorship contribution statement

Pernille Nielsen: Writing – original draft. **Eric Arthur Bastos Routledge:** Writing – original draft. **Philip James:** Funding acquisition. **Adam D. Hughes:** Funding acquisition. **George Charalambides:** Investigation, Formal analysis. **Kåre Nolde Nielsen:** Writing – review & editing. **Eirik Mikkelsen:** Writing – original draft. **Sofia C. Franco:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis. **Paul Tett:** Writing – original draft, Methodology, Conceptualization.

Data availability

Data are available from Zenodo, doi: 10.5281/zenodo.14002377

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