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Multi-level agency and transformative capacity for environmental risk reduction in the Norwegian salmon farming industry

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This article analyzes the role of agency in reducing environmental risk in the Norwegian salmon farming industry. The theoretical starting point is recent literature on *change agency* which focuses on the different ways in which actors purposely act to renew existing and create new regional industry growth paths, and *reproductive agency* which focuses on how actors, explicitly and implicitly, maintain existing structures to uphold status quo. Departing from a current risk society ambiguity in the industry and an explorative multi-scalar study of industrial innovation processes, we analysis how *change agency* combined with *reproductive agency* play out. The analysis shows that change agency affecting transformative agency capacity reducing environmental risk is connected to *institutional entrepreneurship* in terms of a Development Licenses Program on the national level and to *Schumpeterian innovative entrepreneurship* in terms of Development Licenses Projects on firm level. Moreover, the study shows how *reproductive agency* also affects the capacity to cope with environmental risks in terms of risk reducing *place-based leadership* illustrated by cooperation and bottom-up, self-organized area cooperation on the regional level, and in terms of risk creation illustrated by a global growth logic across geographical levels. On this ground, it is argued that the theoretical contribution of the study is that the transformative capacity to reduce environmental risks of an industry rests on multi-scalar *change*- and *reproductive agency* and how these are combined.

KEYWORDS

change agency, reproductive agency, environmental risk, salmon farming, Norway, transformative capacity, multi-scalar

Introduction

Since open-net pen technology was introduced in 1969, Norway has grown to become the world's largest Atlantic salmon producer, and the Norwegian salmon industry now makes up one of Norway's biggest export industries (Fløysand and Jakobsen, 2017). Moreover, Atlantic salmon "is one of the most successful aquaculture species in terms of production growth and the second most valuable species in global aquaculture after shrimp" (Føre et al., 2022; p. 1, see also Garlock et al., 2020). However, while extremely profitable, this growth has not come without environmental risks that include: changes in the genetic characteristics of wild salmon populations caused by successful interbreeding with escaped farmed salmon; the risk of significant increases in wild salmonid mortality from salmon lice in fish farming; and the risk of unacceptable changes in sediment chemistry and faunal communities in production zones caused by industrial organic material emissions (Taranger et al., 2015). Thus, while the Norwegian salmon farming industry has enjoyed decades of economic growth, it is under increasing pressure from National Authorities, NGOs and others to introduce more sustainable production practices. Current technologies represent efficient salmon farming solutions but, according to scientific experts (Helland et al., 2012; Jansen et al., 2012; Serra-Llinares et al., 2014; Taranger et al., 2015), they also create new risks such as lice infections among farmed and wild salmonid populations.

Departing from this *empirical* backdrop of a risk ambiguity, i.e., simultaneous creation of, and attempt to limit, risks, our theoretical focus is on the literature on agency, which also is open to seeing environmental risks as opportunities for innovation. Grillitsch and Sotarauta (2020) argue that *Schumpeterian innovative entrepreneurship*, *institutional entrepreneurship*, and *place-based leadership*, which represent a trinity of *change agency*, are considered central contributors to renewal and new regional industry growth paths. However, it is also important to be aware of *reproductive agency* (Bækkelund, 2021), which focuses on how actors' agency maintains existing structures, industry practices and institutional logics that explicitly and implicitly uphold a status quo. Focusing on these analytical concepts, we analyze multi-scalar agency dynamics in Norwegian salmon farming by addressing the following research question: "How does current change agency and reproductive agency, affect the transformative capacity for environmental risk reduction in Norway's salmon farming industry?"

In answering this question, we apply an explorative and qualitative oriented research approach that started with interviewee recruitment *via* a national selection. The qualitative interviews revealed the importance of a national Development Licenses (DLs) in a Development Licenses program (DL program) for current *transformative capacity* introduced in 2015 (Hersoug et al., 2021). This added a new core issue to the interviews and led us first to several Development Licenses projects (DL projects) and a particular DL project in Northern Trøndelag. Here the interviews revealed that environmental risk reduction was driven by *place-based leadership* in terms of bottom-up area collaboration processes around the localization of fish farms, and *Schumpeterian innovative entrepreneurship* in terms of the DL project Aquatraz. Finally, the explorative study also revealed that environmental risk reduction is simultaneously hampered by a *reproductive agency* driven by a global institutional logic of economic growth, which for the salmon farming industry is intrinsically linked to increased biomass (which lead to unsustainable environmental and animal welfare issues) rather than e.g., value-adding through processing or product diversification. Thus, the study indicates that multi-scaler agency dynamics including both *change agency* and *reproductive agency* make up the transformative capacity affecting environmental risk reduction in Norway's salmon farming industry.

Theoretical framework

The trinity of change agency and reproductive agency

The geography of innovation literature has recently shifted from a dominant focus on the rate and determinants of innovation to tackle issues concerning its direction and societal relevance (Uyarra et al., 2019; Mazzucato, 2020). The emerging focus is not primarily on analysis of innovations and their processes *per se*, but rather on how these can help to solve 'wicked' problems or "grand challenges" (Mazzucato, 2020) and/or reduce environmental risks (e.g., global warming, pollution, threat of nuclear war), which, despite being caused by economic growth in modern societies (i.e., capitalism), are considered manageable by continuous scientific and technological development and innovation, or "technological fixes" (i.e., applying technology to solve problems). Moreover, while this literature has traditionally emphasized the roles of firms, academia, and government, it has recently begun attending to how new innovations are created by intentional actors with agency—defined as "the ability of people to act and have an effect" (Gregory et al., 2009, p. 347)—aiming to stimulate new economic activity and influencing and changing formal and informal institutions[1] (Carvalho and Vale, 2018, Grillitsch and Asheim, 2018). Isaksen et al. (2019) approach this dualism by arguing that regional actors have the capacity to enact both "firm agency" and "system agency," where the latter is how both nonindustrial and industrial actors aim to change system conditions (e.g., institutions) to stimulate regional development.

In line with this thinking, the main focus of this article is not to primarily explain institutions or gradual institutional change *per se* (see e.g., Mahoney and Thelen, 2009 for a discussion here), but rather agency processes where actors could influence technological *and* institutional change, either intentionally or unintentionally. Following up this ambition, we adhere to the assertion made by Grillitsch and Sotarauta (2020) that *institutional entrepreneurship*, *Schumpeterian innovative entrepreneurship*, and *place-based leadership*—the trinity of change agency—are important in regional innovation processes.

1 As conceptualized by North (1990).

However, as emphasized by Bækkelund (2021), this perspective has been less able to account for the contribution of agency to path dependence, suggesting that *reproductive agency* (i.e., how agents and their actions contribute to incremental change that maintain existing structures, industry practices and institutional logics) is also important. Thus, *change agency* need not be defined at the individual level, but can also be a form of collective agency enacted by formal or informal networks or actor groups (Geels, 2020).

Institutional entrepreneurship is conceptualized by Grillitsch and Sotarauta (2020, p. 708) as "actions that are directed toward transforming existing or creating new institutions", and describes how actors work to leverage "particular institutional arrangements and mobilize resources, competences, and power to create new institutions or to transform existing ones" (Sotarauta and Pulkkinen, 2011, p. 98). Moreover, the literature has increasingly focused on how actors work with 'missions' in industry restructuring (Simmie, 2012; Steen, 2016; Miörner and Trippl, 2017; Hassink et al., 2019), particularly in relation to environmental sustainability (Fløysand et al., 2022). Institutional entrepreneurs can be found both within the public and private sector and generally involves the development of broader socio-political engagement and alignment around both informal and formal institutional change (Pacheco et al., 2010). This can for example occur through "framing" or "lobbying" processes (Woolthuis et al., 2013), which can help legitimize and empower emergent regional paths or technologies (Grillitsch and Sotarauta, 2020). However, *reproductive agency* is also present both insofar as it is in many actors' interests to resist institutional change due to hegemonic positions in the regional economic system (MacKinnon et al., 2019) and because *reproductive agency* related to *institutional entrepreneurship* for green industrial restructuring can unintentionally carry practices that (de)legitimize greening (Fløysand et al., 2022).

The trinity of *change agency* also includes *Schumpeterian innovative entrepreneurship*, defined as "willful attempts to realize novel combinations of knowledge and resources coupled with the search for a not-yet-realized potential" (Grillitsch and Sotarauta, 2020, p. 708). This agency is thus initiated by firms, either alone or cooperatively, that engage with "innovation" and "technological development" to introduce new products and services to the market (Shane and Venkataraman, 2000). This can occur when new products or processes come about, or not, through upscaling successful demonstration projects toward more sustainable solutions for reducing environmental risk. *Reproductive agency* in this case would be defined as incremental changes that follow a path-dependent innovation trajectory in which firms replicate existing innovation. When creating new paths to reduce environmental risk, replicative innovations will not drive new paths. However, an industry with the ability to quickly absorb and reproduce innovation when new paths are created is considered positive for path evolution. Thus, change and reproductive agencies caused by *Schumpeterian innovative entrepreneurship* have different roles, depending on the path evolution stage.

Finally, the trinity of *change agency* also includes *place-based leadership*, defined as agency that aims "at transforming particular places by pooling competencies, powers and resources to benefit both agents' individual objectives and a region more broadly" (Grillitsch and Sotarauta, 2020, p. 708). According to Sotarauta et al. (2017, p. 212), place-based "leaders as individuals, and groups of individuals, tend to possess a greater range and depth of assets–including commitment to advancing the region–than other actors". This individual- or collective-based leadership form coordinates regional development efforts among stakeholders. Place-based leaders can be individuals or actor collectives working to inspire and direct heterogenous actors toward a shared vision or direction. This means that *place-based leadership* can be connected to both formal authorities and "informal leaders" (e.g., philanthropic business leaders who lead through charisma and inspiration rather than through "formal" means). It can also be connected to reproductive agency if *place-based leadership* processes can maintain regional agency patterns that uphold existing production or innovation practices, or, at best, very little change from the status quo. Thus, societal pressure to advance regional sustainability does not necessarily lead to radical changes in leadership orientation and industrial practices. However, path-dependent (i.e., reproductive) *place-based leadership* can also decrease environmental risks in those instances where such processes lead to e.g., sustainable governance (by regulatory and industrial actors) which can prevent a "tragedy of the commons" (Ostrom, 1990).

In sum, we define transformative capacity as an outcome of the interplay between *change agency* and *reproductive agency* among all three layers of the trinity of change, which play out on different scalar levels; Institutional entrepreneurship on the *national* level, Schumpeterian innovative entrepreneurship on the *firm* level and place-based leadership on the *regional* level. We therefore structure our analysis around both a vertical dimension (how the change agencies interact with each other over multiple spatial scales) and a horizontal dimension (how change agency and reproductive agency interact with each other at each scale). While such a dynamic or transformative capacity can also be found in regional industry clusters (see e.g., Njøs et al., 2017), our focus on the interplay on multi-scalar agency still merits an application of our theoretical framework.

Methodology

This qualitative multi-scalar case study (George and Bennett, 2005) was based on 24 semi-structured interviews conducted primarily *via* Zoom and Teams (due to the COVID-19 pandemic) during the first half of 2021. Interviewee recruitment started *via* a national selection, as part of an overarching research project[2] to extensively explore perceptions about environmental risks linked to innovation processes among the largest Norwegian salmon producers and other key stakeholders within the salmon farming industry. Interviewees were representatives of 13 of the 20 largest salmon producers in Norway in 2019 (*industry representatives*), including everything from project- and group managers, directors, production leaders, business developers, CFOs and CEOs. We also interviewed 11 other stakeholders connected to this industry (*regulatory authorities, R&D institutions, and NGOs*), e.g., represented by CEOs, directors, managers and advisors While we targeted firms based on size, snowball sampling (Morgan, 2008) was used to recruit other stakeholders. We also used document studies, including firm strategy documents, industry project documents, research reports and newspaper articles. On a general level, the intention of using various documents was to collect as much background data as possible with regard to the perception of risk and strategies with regard to environmental and animal welfare issues for various stakeholders (e.g., industry, regulatory stakeholders, R&D and NGOs) connected to the Norwegian salmon farming industry. However, documents also revealed more detalied data or accounts of e.g., change agency and reproductive processes on the firm level, regional level and national level. Finally, we also base our study on previous research (e.g., Fløysand and Jakobsen, 2017; Hersoug et al., 2019; Tveterås et al., 2020). During the data collection process, we became intrigued by the importance of the DL program linked to current agency. Moreover, the interviews revealed that regional actors connected to the salmon farming industry had engaged in voluntary area cooperation with the aim of reducing, among other things, salmon lice. Our informants turned our attention to the voluntary area cooperation in Northern Trøndelag and how this region "coincided" with the DL-project Aquatraz, which was seen as a very promising project by both regional endogenous and exogenous informants. Therefore, albeit our study is operating within the context of the Norwegian salmon farming industry, it is representing a qualitative research approach exploring current multi-scalar *change agency* and reproduction agency in the Norwegian salmon farming industry, rather than a case study of a focal region.

During the interviews and our document analysis it became apparent that the DL program and subsequent emergence of DL projects have been heavily focused on reducing the presence of salmon lice as an environmental risk. To facilitate interviewees sharing their views, experiences, and reflections, we used a semi-structured interview guide with topic-based, open-ended questions. These could be tailored to deliver targeted questions to different informants, depending on their position and organizational membership. In line with our qualitative research approach, our aims shifted from a general focus on elucidating environmental risk among our informants *per se* (for example how they engaged with environmental risks, and how their innovation practices were incentivized by national and international regulations and broader discourses on sustainability), to elucidate the motivation(s) for engaging with new technology development and innovation by including a specific focus on DL projects.

After interviews were transcribed, primary and secondary data were thoroughly analyzed to identify *change agency* and *reproductive agency* related to environmental risk mediation. Accordingly, in the analysis phase, we switched to a research design focused on interpreting the interviews and documents to identify similarities and differences in how actors' innovation practices contribute, or not, to reducing environmental risk. Next, our analysis concentrated on identifying claims and story lines representative of ongoing environmental risk perceptions, and processes of *change agency* as *institutional entrepreneurship*, *Schumpeterian innovative entrepreneurship* and *place-based leadership*. Data concerning *Schumpeterian innovative entrepreneurship* (e.g., on how they work with technological development and innovation) was primarily identified through interviews and documents; data concerning *place-based leadership* and *institutional entrepreneurship* was identified in the interviews, documents and former research. Moreover, our analysis has focused on processes of *reproductive agency* found within each of these three forms of agency. We have also here drawn on interview and document data which show that both industry and regulatory stakeholders maintain an economic growth-oriented institutional logic. These issues were both looked for and revealed through the data collection.

Data were produced through the saturation principle. This included stopping additional stakeholder interviews after the same themes recurred and no new insights were forthcoming from additional data sources (Bowen, 2008). Saturation was also applied in manual interview data coding, to ensure that quotes were sufficiently generic to cover multiple stakeholders (i.e., a consensus across views).

Results

Institutional entrepreneurship

Our interviews quickly revealed an awareness of environmental risk and related challenges. However, while the risks assessments among our informants from the public sector and NGOs focused on risks such as infectious diseases and parasites that affect both farmed and wild salmon, water quality degradation from farm discharges, and carbon footprint issues related to soil degradation and deforestation in soya feed production regions abroad (see also Norwegian Ministry of Fisheries Coastal Affairs., 2009; Rainforest Foundation Norway Future in Our Hands., 2018; Føre et al., 2022), the informants

2 This paper is part of the research project "Responsible Innovation in the Norwegian Salmon Farming Industry: Grand Societal Challenges, Dilemmas and Improvements" (SALMANSVAR).

Percentage of salmon mortality per production area and year					
Area	Area names	2018	2019	2020	2021
1	Svenskegrensen til Jæren	6,0	10,8	11,3	10,4
2	Ryfylke	16,3	15,7	14,4	19,8
3	Karmøy til Sotra	20,8	19,1	19,9	19,9
4	Sotra til Stadt	18,0	19,4	27,2	22,5
5	Stad til Hustadvika	13,7	15,0	15,2	18,7
6	Nordmøre og Sør-Trøndelag	16,4	12,1	13,5	14
7	Nord-Trøndelag og Bindal	8,2	7,9	10,5	10,8
8	Helgeland til Bodø	13,3	10,2	9,7	12,1
9	Vestfjorden og Vesterålen	12,9	28,8	9,6	13,6
10	Andfjorden til Senja	8,4	23,0	10,2	10,9
11	Kvaløya til Loppa	9,6	10,7	15,7	12,6
12	Vest-Finnmark	11,6	8,2	11,1	13
13	Øst-Finnmark	9,4	16,1	6,7	10,2

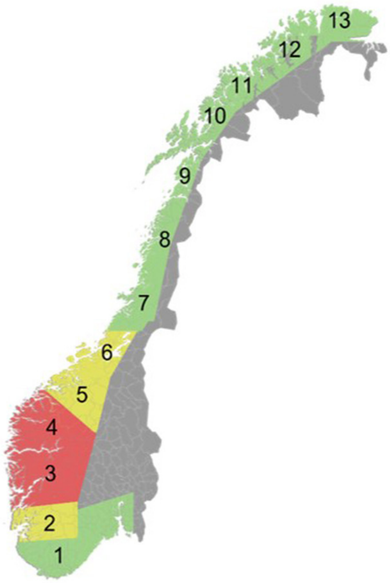

FIGURE 1
Map with production zones in traffic light colors and mortality rates in the Norwegian salmon farming industry. Credits: own elaboration with information taken from Veterinærinstituttet 2022: http://apps.vetinst.no/Laksetap/.

from the industry sector focused on innovations challenging the risk such as those linked to electrification of production processes and supply boats, more sustainable feeding systems, etc. (see section Schumpeterian innovative entrepreneurship).

Nevertheless, the interviews revealed how the environmental risk situation had triggered *institutional entrepreneurship* in the form of policy experimentation on the national level, as also emphasized by others (e.g., Hersoug et al., 2019; Jakobsen et al., 2021), in terms of new national regulations including the "Traffic light system" (2017) (Tveterås et al., 2020) and the DL program (2015) aimed at inducing new industrial technology development (Hersoug et al., 2019; Jakobsen et al., 2021). The traffic light system assigned production zones a red, yellow, or green light based on the lice levels of farmed salmon[3] (Figure 1).

In 2015, the Norwegian government issued Development Licenses (DLs) (Føre et al., 2022), i.e., temporary development concessions that promote technology. The purpose of introducing these licenses was to incentivize industrial actors to innovate new sustainable technological solutions; as described by the Directorate of Fisheries (n.d.a):

> "The development licenses are a temporary program with special permits that can be awarded to projects that contain significant innovation and significant investments. The purpose is to facilitate technology development that can contribute to solving one or more of the environmental or acreage challenges faced by the aquaculture sector, for example, through constructing prototypes and test facilities, industrial design, equipment installation, and full-scale test production" (Author translation).

Although lice reduction is not a specific DL program priority, nearly all approved DL projects aimed to reduce lice levels. A total of 104 applications for 892 licenses[4] were submitted to the Directorate of Fisheries (Hersoug et al., 2021),

3 The traffic light system is designed to protect the wild salmonoid population in the zones. "Green = Can lead to an increase of 6% production. In this category, it is assumed that less than 10% of the salmon smolt die due to salmon lice. Yellow = No change in production. In this category, it is assumed that 10–30% of the salmon smolt die due to salmon lice. Red = Can lead to a production decrease. In this category, it is assumed that over 30% of the salmon smolt die due to salmon lice. Salmon farmers that end up in this category can apply for an exception to the production decrease if they can display low lice numbers" (https://www.hi.no/hi/nyheter/2020/februar/trafikklys) (author translation).

4 The industry could submit applications until November 2017.

Nr.	Company	Innovation	Nr.	Company	Innovation
1	Ocean Farming AS (SalMar)	"Ocean pen" - Based on offshore technology	13	Nova Sea AS	"Spidercage" - Offshore farming
2	Nordlaks Oppdrett AS	"Ocean farm" for ocean-based farming	14	Stadion Laks SUS	"Stadionbassenget" – Closed floating pen (basin)
3	Seafarming Systems/MNH Produksjon AS	"Aquatraz" - semi-closed pen	15	Salaks AS	"Fjordmax" – Semi-closed integrated farming platform
4	AkvaDesign AS	Closed-pen technology	16	Fishglobe AS	"FishGLOBE" – Closed-pen technology
5	Marine Harvest Norway AS	"Egget [The Egg]" – Closed-pen technology	17	Lerøy Seafood Group AS	"Pipefarm" – Closed floating pen
6	Atlantis Subsea Farming AS	Submersible farming	18	Reset AS	Sustainable closed land-based farming
7	NRS ASA / Aker ASA	«Arctic Offshore Farming» - Semi-submersible offshore farming	19	Nekst AS	"Havliljen [The Ocean Lily]"- Submersible farming
8	Hydra Salmon Company AS	Closed-pen technology	20	Eide Fjordbruk AS	"Salmo Zero" - Closed sea facilities with recycling of water
9	Mariculture AS	"Smart Fishfarm" – Complete solution for open sea offshore farming	21	Grieg Seafood Rogaland AS	"Blue farm" – Anchored concrete pen
10	Cermaq Norway AS	«iFarm» - IT technology for individually-oriented fish-farming	22	Albatros Technology B.V.	"Nereus" - Floating RAS facility
11	Mowi Norway AS	"Marine Donut" – Closed units	23	Astafjord Ocean Salmon AS	"ØyMerd [Island pen]" – Triangular floating facility
12	Måsøval Fiskeoppdrett AS	"Aqua Semi" - Semi-submersible farming	24	Eidsfjord Sjøfarm AS	"Eidsfjord Giant" – Closed production and treatment facility

FIGURE 2
Table of projects that have received development licenses [Source: https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Saertillatelser/Utviklingstillatelser/Status-ja-nei-antall-og-biomasse (accessed March, 2022)].

of which 24 from all over Norway were approved (Directorate of Fisheries, n.d.b). The fact that a total of 892 licenses "equals 85% of the total number of ordinary licenses" (Hersoug et al., 2021, p. 7) demonstrates the program's popularity and degree to which competition was stimulated among industry actors (Hersoug et al., 2019; Vormedal et al., 2019; Aarset et al., 2020; Føre et al., 2022; Osmundsen et al., 2022). All awarded licenses included measures against sea lice (Føre et al., 2022). As of September 2022, 24 applications for 119.5 licenses, covering a total of 88.919 tons of maximum allowed biomass, have been granted (Directorate of Fisheries, n.d.b).

In relation to the trinity of change agency, the emergence of DLs came about as a process of *institutional entrepreneurship* on the national level; the effect on reducing environmental risk is clear, as DLs have changed the rules of the game for industry actors toward developing more sustainable production technology:

> There are several technology companies that are applying for DL projects… What are we looking at then is production technology equipment… is it possible to build the construction?... the applicant claims, for example, that this concept should be more escape safe… Then they must have done some analysis that shows it for this steel structure or the concrete structure or whatever it may be. […] But one does not develop technology just for the sake of developing technology; in the end, it is a biological organism that lives and grows in the pens… The technology must take fish welfare into account, this is important for the assessments (Regulatory authority).

Most of DL projects in the program are thus technological expressions of environmental risk reduction. Several of them have emerged within offshore, semi-closed, and closed salmon farming technology (Figure 2). However, while DLs have the potential to stimulate green technological development, they do not necessarily lead to industry greening. Nevertheless, if companies attaining DLs accomplish their projects, their licenses can be converted to "normal" licenses even if the project fails at commercialization. This creates additional conditions for growth in total produced biomass within existing technologies (Hersoug et al., 2021) and is thus an unforeseen consequence of *institutional entrepreneurship*, because it can lead to actors "reproducing" environmental risk. It is important to note that producers have always sought "special purpose licenses" (Hersoug et al., 2021) and that this incentive represents a major firm subsidy, despite high investment costs (Vormedal et al., 2019), given that the cost of a new license today is almost NOK 200 million (NOK 171.4 million in 2020) (Osmundsen et al., 2022). A recent proposition to create "eco-technology licenses" is also worth mentioning, as these would specifically stimulate developing closed or semi-closed technologies (Osmundsen et al., 2022). This is a potential criticism of the DL program, which so far has failed to successfully divert salmon producers' practices away from the open-net pen technologies that play a major role in upholding the very environmental and animal welfare risks the program originally sought to eliminate.

Place-based leadership: Change and reproductive agency

While the emergence of DL projects has contributed to significant technological development in the industry, this does not paint the whole picture of environmental risk reducing efforts that are taking place. Evidence of *place-based leadership* reducing environmental risk on the regional level was also reported as important for environmental risk reduction by several informants. Exemplifying this, several informants turned to the region of Northern Trøndelag. This region hosts several salmon farming firms, most of which were historically classified as small-and-medium sized businesses (SMBs). These are family firms with a strong community commitment and engagement in regional industry cooperation, who historically have tended to follow collective rather than individual strategies (Jakobsen, 1999). Regional cooperation between firms is common, as emphasized by this informant:

> I would perhaps say that we in Northern-Trøndelag are in a special situation. We must cooperate due to the fact that we are seen in many instances as a fire gate between southern and northern Norway, a buffer (Industry representative).

Another informant argued that these patterns of cooperation have created firm economic benefits:

> Until recently we cooperated with [X firm]. We cooperated for 16 years I think, so we started cooperating quite early… When we started the cooperation, we had two licenses and [X firm] had six. Today, we have 10 and they have 16, 17. The reason for this cooperation was to spread risk and exploit the licenses we had in a better way in terms of scale (Industry representative).

Currently, local industry stakeholders and those from the regional public sector have created new forms of self-organizing, bottom-up collaborations around area cooperation, defined as "a cooperation between two or more private or public actors connected to aquaculture within a defined geographical area" (Karlsen et al., 2019, p. 1). This is because local natural conditions and regional farm agglomerations have created, quite literally, negative "spillover" effects of salmon lice between farms. This effect was revealed by one of our informants:

> If we go back 10 years, give or take, there were great challenges in parts of Trøndelag. We saw that we had to act to shift the production model, with regard to coordinating deploying [salmon] and fallowing, not in the production areas… [but] in coordination areas. So there was a long process here, which started in 2012 or 2013, especially in Northern Trøndelag, where good forces from both administration and industry tried to divide sea areas into so-called coordination areas… with joint deployment and fallowing within focal coordination areas, which then was defined based on current models and local knowledge about place-specific conditions, in order to reduce the interaction between these areas to the extent this is possible based on the coast in this area. […] To make this happen, all firms operating in that area must be willing to pull together. This means that some must be given new localities, and others again must give up some localities. In that process, many changes in the use of localities were undertaken, and many firms, or several firms, there are not so many in total… gave up localities and others gained localities. Some had to expand certain localities and there was a great understanding between the industry and the administration that this was a process that we had to see through. Everyone wanted to see it through, to structure the production model in such a way that you reduced the lice problems, and, through that, reduced the need for both chemicals and mechanical treatment (Regulatory authority).

As a solution, the firms in the region have taken the initiative to swap locations to better control lice spread, creating a self-organized, bottom-up initiative that sought better governance of the commons by applying scientific models and measurements of factors such as how lice spread in currents and in proximity to other fish pens:

> This was something that was local, a joint initiative from both industry and administration. Because everyone wants this. The administration wants to reduce the footprint and the problems connected to sea trout and wild salmon, problems connected to the use of chemicals and the influence on crayfish and all this. That is the administration's angle. But the industry's angle is also to reduce the problems that cost large sums and that create loss of production. All had an interest in it. And then there was an initiative from the industry together with the administration, without it being a [regulatory] demand as such (Regulatory authority).

Thus, this area cooperation among regional firms occurred along with the regulatory authorities. Another interesting aspect is that this self-organization does not seem to have been forced on the industry. While Karlsen et al. (2019) point out in their nationwide study that some area cooperation is required by law, most cooperation is nonetheless voluntary. They stress that Northern Trøndelag is particularly engaged in area cooperation, underline the presence of a clustering milieu consisting of smaller companies with common challenges as a reason behind this (Karlsen et al., 2019). The long-term collaborative strategies in this region are thus path-dependent and serve as an example of *reproductive agency* insofar as regional actors' agency maintains existing collaborative structures and explicitly and implicitly upholds incremental changes toward seeking better common governance and, consequently, environmental risk reduction. In this region, *reproductive agency* can be seen as positive with regard to environmental risk reduction because the collaborative milieu in the region has a history of interdependence and trust. Yet this form of reproductive agency-as-*place-based leadership* can be challenged on the basis that several merger and acquisition processes have occurred since the 1970s, ultimately leading to the merger of Midt-Norsk Havbruk and Salmonor in 2021, and, most recently, a further merger with Norwegian Royal Salmon and Salmar—one of the largest salmon producers in Norway (Intrafish, 2022). Accordingly, the regional conditions seem to be changing toward an ownership structure in which a concentration of larger companies gains power at the expense of smaller companies. This indicates that the *place-based leadership* observed to date may be challenged by *change agency* that does not necessarily seek to improve common governance.

Schumpeterian innovative entrepreneurship

The industry's adaptation to the United Nation's Sustainable Development Goals to reduce undesirable salmon production outcomes has become a common strategy among industrial players. Most firms point to several innovation initiatives that address what the industry perceives to be environmental risks. These include innovations linked to electrification of production processes, supply boats, and more sustainable feeding systems:

> We want to reduce the footprint, and this of course involves fossil fuels, where we do a lot of things, in relation to switching to electrification of rafts, power fusion. . . fuel on boats. We participate in a hydrogen project, to investigate the possibility of operating with hydrogen on boats (Industry representative).

> We have been what we call "first movers" on several pre-raw materials, i.e., oil from microalgae instead of fish oil, or insect meal, made from insects that grow on waste from the agricultural industry (Industry representative).

> We have for many years tried to reduce our footprint, our carbon footprint... so we chose to go through that certification scheme so that we are classified as a carbon-neutral company. In parallel, we developed a carbon-neutral product (Salmon producer).

Nonetheless, *reproductive agency* is observed insofar as path-dependent innovation trajectories produce new environmental risks as by-products of an otherwise rather successful development trajectory. *Reproductive agency* is present in those innovations that carry observable and thoroughgoing environmental risks, and in related fish welfare impacts within the geographical areas hosting salmon farming production:

> The industry has done many good things. For example, when they reduced the escapes from 14 to 7%, it's great. But in the same period, they have tripled their volume, which means that they have increased the discharge into the fjord. So all the good environmental changes that we have seen, there are a good number, they are in a way eaten up by the increase in biomass. So the footprint in total becomes larger. So yes, at the level of detail a lot of things happen that get better, but the footprint gets bigger and the negative effect from fjord to fjord gets bigger (NGO).

In the next quote, the dynamics between change agency to eliminate environmental risks and reproductive agency to increase industrial growth and environmental risk (i.e., an awareness of an underlying risk ambiguity) is evident:

> The fivefold [growth] goal is the most catastrophic in the history of the fishing industry in Norway. It is so devoid of critical analysis of the bottleneck that we are facing, it is just embarrassing… I am angry and disappointed, because it points to an impossible goal that has enormous environmental consequences… [The fivefold growth goal] does not take into account feed sources, salmon lice, the disease problem, the use of the Norwegian coast, potential markets—there is nothing to indicate that the market can withstand five times as much salmon… nothing (Industry representative).

The lice problem is a particular focal environmental risk in the industry and is considered by some as a persistent and "wicked" problem (Osmundsen et al., 2017). Many have argued that the greatest environmental risk of lice is not directly related to increased mortality rates among farmed salmon, but rather the risk it poses to the wild salmon population in Norway if farmed lice-infested salmon escape. For farmers, this environmental risk has necessitated increased treatment of the farmed salmon, which *then* leads to higher mortality rates among these penned salmon (Norwegian Ministry of Trade Industry Fisheries., 2021 p. 15):

> [Salmon lice has not in itself been a fish health-related problem for farmed salmon. However, the need to reduce the effect of salmon lice on wild salmon has led to an increased need for the treatment of farmed salmon. This, in turn, has led to the development of drug resistance and the introduction of nonmedical treatment [e.g., mechanical treatment] […] In total, this has affected the welfare of farmed salmon and is one of the main reasons for death among fish in the sea phase (Author translation).

To treat salmon lice, the industry applies mechanical delousing, which causes substantial salmon death in the fish farms. As shown in Figure 1, a high mortality rate is a general problem for the industry. In addition, there are large variations in mortality levels across production zones. In Zones 3 and 4, we observe particularly high mortality. In contrast, Zones 1 and 7–13 stand out for their low salmon mortality levels, among which the lowest is Northern Trøndelag (Zone 7; Figure 1). Over time, this zone has displayed low salmon death numbers[5].

In the following, we argue that these low salmon mortality levels in the region can be partly linked to firm-level *Schumpeterian innovation entrepreneurship*, exemplified by the regionally embedded DL project Aquatraz. This project was granted four concessions and the right to farm 3,120 tons of farmed salmon per year (Directorate of Fisheries, n.d.b). The new technology in this project has been developed by Seafarming Systems, who in 2016 agreed to build several new semi-closed containment pens for the salmon farming company Midt-Norsk Havbruk (Sandstad et al., 2022). The main aim of this project is to significantly reduce the environmental risk of salmon lice growth by "shielding" the salmon through increased pen water circulation and decreasing salmon escape through sturdier construction or architecture (Figure 3). In so doing, the project has also applied many solutions from the maritime and offshore industry and has had to develop new verification standards for the technology in cooperation with DNV (Sandstad et al., 2022).

Aquatraz and its stakeholders received praise from the media (Hernes, 2021) and interviewed informants, and has delivered on all areas of the project's initial goals, namely to reduce salmon lice, increase growth, improve salmon coloration, eliminate escaped salmon, eliminate personal injuries, and maintain a good work environment (Salmonor, n.d.). It has therefore generated much knowledge on how to reduce environmental risk among involved actors over several project generations (Kyst.no, 2020). The third Aquatraz generation to operate in Eiterfjorden (Northern Trøndelag) also showed significant positive results in 2021 compared with the control pen (Table 1) (with respect to, e.g., costs, sales price, delousing numbers, mortality rates) (Aunsmo and Aunsnmo, 2021)[6]. Now in the fourth generation, involved actors are more focused on commercialization. This long-standing emphasis—in addition to aspiring to future convert of DLs to normal licenses—distinguishes the Aquatraz project from most other DL projects. According to one industry informant connected to the project:

> [The big carrot… in addition to of course creating better technology that can shield us against lice, is that the development licenses will be converted to normal licenses. And to do that we must finish the development course… What is also genius… was that we have applied for one development course where we will build several generations, and find a technology that is commercial. When we have finished that course, we can apply for conversion. That has an enormous value for us]. […] Looking back, this was genius, or a combination of flair, skill, and a bit of luck. If we had not contracted four [Aquatraz pens] when we did,

5 Although the most recent traffic light system update for Northern Trøndelag (Zone 7) was 'yellow light', mortality numbers in 2018–2021 (Figure 1) remained among the lowest in the country and have proven stable in light of significant regional production.

6 Although Aunsmo and Aunsnmo (2021) do not show clear data on the number of rounds of delousing, extracts from their report show that in 2021 Aquatraz 3 needed zero rounds of delousing compared with five rounds in the control pen (https://aquatraz.com/resultater-fra-aquatraz-i-drift/).

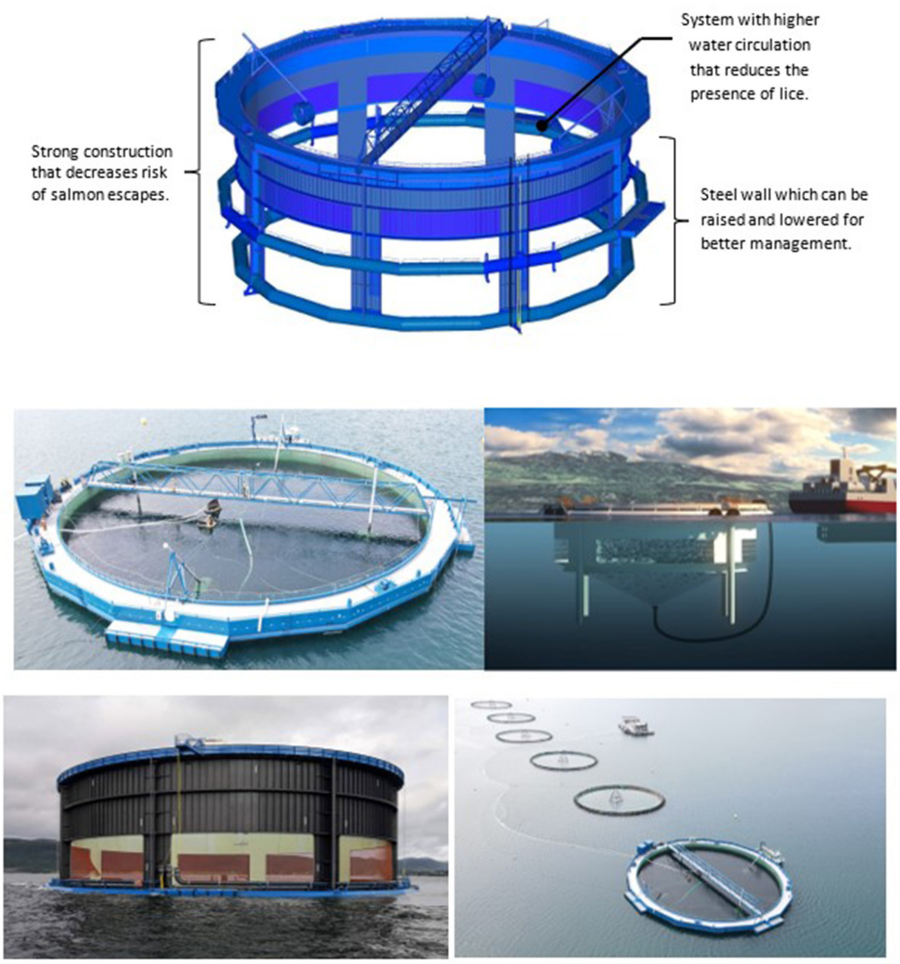

FIGURE 3
Aquatraz illustrations courtesy of Midt-Norsk Havbruk AS published in Sandstad et al. (2022). Aquatrazprosjektet—Sluttrapport. Utvikling av semi-lukket st+Ñlmerd fra konsept til kommersielt produkt. Seafarming Systems, SalmoNor, Aqua Kompetanse. Dokumentnummer: AQT-MNH-RA-01-22.

> we would not have come so far so fast in developing a third generation and a fourth generation we now think is ready for the market (Industry representative).

This industry informant also argued that “we have come so far in the run that we are in the last phase and that this actually is a commercial product”. Another unique aspect of the project dynamic is the strong ties between the technology developer (Seafarming Systems) and the salmon producer (Midt-Norsk Havbruk). In contrast to most of our industry informants, this case highlights a particularly strong identification and joint commitment among the project participants—expressed here as “we”—in their efforts to upscale the technology to the market:

> We have challenges with lice like the rest of the industry, so we want to acquire technology that allows us to produce the fish in a better way, and, in the long run, is more cost effective. That is our goal and that is a bit special. It is a joint project but there are very coinciding goals for [both of us], so there is no conflict with regard to what one wants to achieve here. We have a common goal and work very well toward that, together… We want them to succeed because that makes us succeed (Industry representative).

Moreover, many extra-regional industry actors hail Aquatraz as a promising solution to persistently difficult industry problems, as emphasized by a key representative for the Norwegian salmon farming industry:

> If I were to upgrade a fish farming facility today, I would have bought Aquatraz. Fantastic combination of closed and open [technology] where you gather the strengths from both […] It is robust and strong and developed by fish farmers who “understand the pain” (Industry representative).

TABLE 1 Difference in various factors related to costs, profits and mortality rates between the Aquatraz demonstration project in Eiterfjorden (2021), Northern Trøndelag, and a control pen.

	Aquatraz	Control pen	Difference
Production costs including depreciations	36.37 kr/kg	38.78 kr/kg	−2.31 kr/kg
Sales price	56.39 kr/kg	54.65 kr/kg	1.74 kr/kg
Margins	19.92 kr/kg	15.87 kr/kg	4.05 kr/kg
Weight when slaughtered (round)	5.36 kg	4.83 kg	0.53 kg
Maximum density	17.3 kg/m3	17.7 kg/m3	−0.4 kg/m3
Times needed to delouse	None	5	−5
Mortality rate	2.08 %	10.97 %	−8.89 %

Source: Aquatraz.com (2022).

Aquatraz is thus a good example of a technological fix, a solution envisioned by industry actors which can mediate environmental risks. Not only does it exemplify how industrial actors have developed a technological demonstration project that significantly reduces the environmental risk of salmon lice and escaped salmon, it is also an example of how such a fix has the potential to move beyond testing and into a commercial market application stage. Nevertheless, as the interviews revealed, stakeholders connected to Aquatraz are also driven to convert the project DLs to normal licenses. While it remains to be seen whether Aquatraz will represent an emerging change in the dominant industry standard (farming salmon in open pens), it shows significant promise of becoming a viable commercial product. It also shows a high degree of legitimacy in that several industrial (wharf and suppliers who needed to develop, test and coordinate the solutions) and R&D stakeholders (e.g., NIVA measuring water quality, NOFIMA measuring product quality, and SINTEF Ocean providing test and verification data and analyses) have been quite involved, and have had healthy discussions with Midt-Norsk Havbruk. Finally, the main stakeholders connected to the project have in a recent report (Sandstad et al., 2022) suggested that future regulatory specifications should emphasize "functional demands", for example qualitative assessments with regard to the risk of escaped salmon from sea farming installations (e.g., semi-closed pens), rather than "absolute restrictions for salmon density in pens" (Sandstad et al., 2022). This, it is argued, can (p. 8, our translation): "stimulate to development of new technology which contributes to good animal welfare…and reduces the risk for escaped salmon", whilst simultaneously allowing the industrial actors to increase (or at least not restrict) their production volumes. As such, this illustrates an emerging attempt by industry stakeholders to influence regulatory stakeholders—"bottom-up"—based on a demonstrated technology.

Interrelated trinity of change and reproductive agency

While the *change agency* processes described herein represent a departure from conventional salmon farming practices, *reproductive agency* elements are echoed in many firm-level innovation activities. Although, these have created both Schumpeterian innovations to reduce environmental risk, and incremental innovations to reduce environmental risk, their main target seems to be to increase growth. Accordingly, reproductive agency is an inherent ambition in Norwegian firms' business strategies:

> There is an ambition for growth, and we are growing through DL permits. When we convert them, we add four new production units to our portfolio… so yes, there is an ambition for growth (Industry representative).

> We absolutely believe that this can be scaled up, that is the reason why we have done this pilot [DL project], and looking at new pilots, because we believe this is the way to go in the future to have growth… our ambition is to have a series production… In that case, it will only be the start of further growth and development… We believe that this is the best development, the most sustainable development if we are to produce salmon on a larger scale in Norway (Industry representative).

This "inherent tension" between change agency, which attempts to reduce environmental risk, and reproductive agency, which maintains and stimulates economic growth through increased biomass rather than e.g. value-adding through processing or product diversification, has led to several protests and NGO activism. It has also led to a court case in which several salmon farming companies sued the Norwegian state for, in their opinion, wrongly depicting the cause of high pen lice levels that halted salmon production. Most stakeholders (e.g., researchers, NGOs, environmentally conscious politicians) claim that the lice problem is an inherent consequence of a volume-oriented production system that deprioritizes environmental risks. On the one hand, salmon farming is considered important for economic growth, through increased volumes; on the other hand, the volume-oriented growth strategy leads to stakeholder environmental risk concerns:

> It may be said in a way that's a little ragged, but what is certain is that the tendency is that… [the firms] want growth. They must get it in one way or another, and then they have to come up with something to get that growth, I think many applicants think that way, without saying it out loud (Regulatory authority).

In sum, it appears that both *institutional entrepreneurship* and *Schumpeterian innovative entrepreneurship*, involves both implicit change and reproductive agency. *Reproductive agency* can also be seen in actions that reduce environmental risk, such as sustainable commons governance through *place-based leadership*. However, this may be challenged by foreign ownership and leadership constellations that might steer in a direction where the consequences for particular places is at core. This can be explained by an overarching industrial growth logic (i.e., reproductive agency) in an industry that does not "accept" biomass reduction that would otherwise go a long way toward reducing the lice problem.

Discussion

The Norwegian salmon farming industry is characterized by environmental risks that have led to different forms of change agency, including new DLs and a DL program call for DL project technological fixes. The study has shown that several industry actors in Norway's salmon farming sector have created new technologies through 24 DL-projects. Accordingly, the DL initiatives set in motion both national-level *institutional entrepreneurship* (the DL-program) and firm-level Schumpeterian entrepreneurship (the DL projects).

Returning to the trinity of *change agency* concept, the study illustrates multi-scalar agency dynamics combining *institutional entrepreneurship* in terms of developmental licenses on national level, *place-based leadership* in terms of bottom-up collaboration processes around the localization of fish farms on regional level, and *Schumpeterian innovative entrepreneurship* in terms of the Development Licenses project on firm level. First, concerned politicians prompted national-level policymakers to engage in *institutional entrepreneurship* and policy experimentation processes regarding environmental sustainability and animal welfare, which, in turn, stimulated DL program creation (Jakobsen et al., 2021). This is interesting because it also shows that national regulatory authorities are initiating industrial innovation processes, rather than merely restricting production during unfavorable conditions (e.g., the goal of the traffic light system). We also find emerging examples of *institutional entrepreneurship* processes that are characterized by "bottom-up" processes, albeit with a different agenda in mind.

The effort by industry stakeholders connected to the Aquatraz project to influence regulatory stakeholders to focus on "functional demands" of sea farming installations (based on their perception of a proven technology in a demonstration project), rather than "absolute restrictions for maximum amount of allowed biomass per pen" (Sandstad et al., 2022) illustrates this. Nevertheless, the multi-scalar agency dynamics combining *institutional entrepreneurship* (DLs), *Schumpeterian innovative entrepreneurship* (the DL project Aquatraz), and *place-based leadership* (bottom-up collaboration processes surrounding fish farm locations) in Northern Trøndelag, have currently reduced environmental risks. Still, it is worth reflecting on whether increased consolidation of ownership in the region (e.g., fewer family-owned firms and more mergers, leading to larger firms) will impact regional *place-based leadership* dynamics and farmed salmon mortality rates. This is likely an important issue for future research.

However, *place-based leadership*, expressed through a collective agency among regional industry representatives and regulatory authorities, has also been activated to reduce environmental risks. Since 2012, several industrial representatives and regional authorities have begun to address, in a bottom-up manner, the production zone's lice problems, which was achieved by voluntarily switching locations among industrial actors. The ability to create an "area cooperation"—which has also been recommended in a recent report (Sjømat Norge., 2020)—is seemingly based on a tradition of collaboration and trust, building on previous practices of helping each other. Moreover, while Karlsen et al. (2019) point out that area cooperation is primarily voluntary in Norway, it appears to have been pursued strongly in Northern Trøndelag.

Finally, there are reasons to argue that *change agency* is hampered by *reproductive agency* that maintains a growth orientation in Norwegian salmon farming (Helland et al., 2012; Jansen et al., 2012; Serra-Llinares et al., 2014; Taranger et al., 2015). The industry has enormous growth and commercial potential, for example, by—in the industry's own words—"feeding the world" and contributing to global shifts from beef to healthier seafood protein consumption (Fløysand and Jakobsen, 2017). This has led to companies farming as large a volume of fish as possible, within current regulations. In turn, increased penned salmon density increases the environmental risks of higher salmon lice levels, leading to more treatment and ultimately higher mortality rates and worse fish welfare. For example, it is evident from our analysis of "Aquatraz" that although this project can decrease several risks and, at the same time, be commercial viable, its technology is still intended to maintain an economic growth orientation—which is intrinsically linked to increase in biomass rather than, for example, value-adding of existing salmon stock through processing or product diversification—and is compatible with the industry's fear of losing its competitive advantage if land based closed-containment system with recycled water take over as they can potentially be built closer to market and be based on technology developed outside Norway.

Concluding remarks

In this study, our objective was to analyze the role of agency in reducing environmental risk in the Norwegian salmon farming industry by addressing how *change agency* and *reproductive agency*, affect the transformative capacity for environmental risk reduction in Norway's salmon farming industry. Scrutinizing this, we found that *change agency* affecting the transformative capacity for environmental risk reduction need not be tied to a regional level (Grillitsch and Sotarauta, 2020). Rather, it seems to be a multi-scalar process combining *institutional entrepreneurship* in terms of developmental licenses on national level, *place-based leadership* in terms of bottom-up collaboration processes around the localization of fish farms on regional level, and *Schumpeterian innovative entrepreneurship* in terms of the DL-projects such as the Aquatraz on firm level. Regarding *reproductive agency*, it is also evident that the DL program upholds an institutional logic of economic growth as it incentivizes firm applications for normal licenses after project completion. Accordingly, we observe a danger that *change agency* in the industry aiming to reduce salmon lice and lower farmed salmon mortality rates is halted by *reproductive agency* with a continuous growth logic. While a desire to grow economically itself is natural for any industry, it is apparent that economic growth in the salmon industry is intrinsically linked to growth in biomass (which lead to unsustainable environmental and animal welfare issues) rather than e.g. value-adding of existing salmon stock through processing or product diversification.

As such, this study of how *change agency* and *reproductive agency* affect the transformative capacity for environmental risk reduction in Norway's salmon industry contributes with three observations. First, it shows that the interplay of *institutional entrepreneurship*, *Schumpeterian innovative entrepreneurship*, and *place-based leadership* comes with a potential that positively can affect the transformative capacity for environmental risk reduction. Second, it shows the ambiguities within both *change agency* and *reproductive agency* that halt and/or hamper risk reduction efforts, which cumulatively make up the actual transformative capacity in the industry. Third, echoing Bækkelund (Bækkelund, 2021), it shows that *change agency* and *reproductive agency* are interconnected and that their logics must build on one another.

This stated, although we do not possess similar primary data on other geographical locations where salmon is produced such as Chile and Canada, we believe that our theoretical and analytical approach could be of relevance for future studies. In so doing, however, it is likely that issues of power, "marginalized" knowledge and meaning systems, spillovers in local economies and income distribution would need to be explored further, as there are several examples how international salmon farming firms have marginalized indigenous groups in Canada (see e.g., Gerwing and McDaniels, 2006; Page, 2007; Young et al., 2019) and led to environmental, livelihood and labor conflicts in Chile (Aguayo and Barriga, 2016; Riedemann et al., 2021). It for example remains to be seen if marginalized groups, which are heavily affected by environmental risks related to the salmon farming industry, can mobilize the resources and power needed to enact impactful *institutional entrepreneurship* and *place-based leadership* leading to responsible or sustainable salmon farming practices, e.g., in the form of *Schumpeterian innovative entrepreneurship*. The contribution of this study is that the transformative capacity to reduce environmental risks of an industry also in such circumstances rests on how multi-scalar *change agency* and *reproductive agency* are combined.

Data availability statement

Restriction apply to protect the confidentiality of the informants. Requests to access the datasets should be directed to ssj@hvl.no.

Author contributions

SS and AF: main theoretical development, analysis, and data collection. HW: important input on theory development and contributed to some data collection. JZ: created figures, looked through references, and contributed to some data collection. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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