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Food for Thought

Scenario analysis can guide aquaculture planning to meet sustainable future production goals

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Marine aquaculture holds great promise for meeting increasing demand for healthy protein that is sustainably produced, but reaching necessary production levels will be challenging. The ecosystem approach to aquaculture is a framework for sustainable aquaculture development that prioritizes multiple-stakeholder participation and spatial planning. These types of approaches have been increasingly used to help guide sustainable, persistent, and equitable aquaculture planning, but most countries have difficulties in setting or meeting longer-term development goals. Scenario analysis (SA) for future planning uses similar approaches and can complement holistic methods, such as the ecosystem approach to aquaculture framework, by providing a temporal analogue to the spatially robust design. Here we define the SA approach to planning in aquaculture, outline how SA can benefit aquaculture planning, and review how this tool is already being used. We track the use of planning tools in the 20 International Council for the Exploration of the Sea member nations, with particular attention given to Norway's development goals to 2050. We conclude that employing a combination of an ecosystem framework with scenario analyses may help identify the scale of development aquaculture goals over time, aid in evaluating the feasibility of the desired outcomes, and highlight potential social-ecological conflicts and trade-offs that may otherwise be overlooked.

Keywords: aquatic farming, EAA, ecosystem management, futures planning, MSP, SDGs

Introduction

As both human populations and per capita demand for protein continue to grow, aquaculture is seen as a key food sector to support rising global demand (Delgado *et al.*, 2003; The World Bank, 2013; FAO, 2018a; Froehlich *et al.*, 2020). Aquaculture has huge potential for further growth in the oceans (Froehlich *et al.*, 2017; Gentry *et al.*, 2017), and can be less resource intensive than production of animal-based protein on land with proper planning and management (Tilman and Clark, 2014; Hilborn *et al.*, 2018; Poore and Nemecek, 2018). Despite improvements in fisheries management (Free *et al.*, 2020; Hilborn *et al.*, 2020), global wild fisheries production has remained relatively stable over the past decades (FAO, 2020); therefore, the majority of seafood growth will likely have to come from aquaculture. Aquaculture continues to be the dominant source of global seafood, but marine aquaculture currently only makes up about 35% of total marine production (FAO, 2020).

With adequate planning and regulatory frameworks, growth in the marine aquaculture sector can be achieved with a potential for comparatively lower environmental impact, including decreased greenhouse gas emissions, freshwater, and energy use, and increased ecosystem services when compared to expansion of other animal production methods (Gephart *et al.*, 2014; Tilman and Clark, 2014; Hilborn *et al.*, 2018; Poore and Nemecek, 2018; Theuerkauf *et al.*, 2019a). Much work has focused on designing farms that minimize negative impacts to local ecosystems, and best management practices have been developed to maintain healthy practices. Strategic siting of ocean farms helps reduce user conflicts and environmental impacts by placing farms in places that facilitate dispersal of wastes and avoiding highly impacted areas (Theuerkauf *et al.*, 2019b). Climate change is increasing and intensifying storm events, so developing rapid response mechanisms is crucial for mitigating and responding to damage or disasters at sea. At the same time, gradual shifts in productivity and ocean conditions make adaptive management an important part of marine industries best practices. Given resource limitations, potential to reduce food production impacts, and a changing climate means marine aquaculture has an increasingly important role in sustainable development goals (Boyd *et al.*, 2020) and thus requires strategic and comprehensive planning to meet those goals.

Enhanced sustainable production from the aquaculture sector will require increased policy focus on a set of human-animal-environmental health (One Health) metrics that enable production of high-quality food without undue detriment to people, cultured animals, or the environment (Stentiford *et al.*, 2020). To this end, the ecosystem approach to aquaculture (EAA) is a key framework developed by the Food and Agriculture Organization of the United Nations (FAO) and industry collaborators to help guide aquaculture planning and implementation with an emphasis on ecosystem health and management, human well-being, and conflict mitigation. Inspired by the earlier ecosystem approach to fisheries in promoting sustainable fisheries development—which has seen some levels of uptake and success since its introduction in the early 2000s (e.g. Marshall *et al.*, 2019)—the EAA provides a framework for both industry and managers to develop the aquaculture sector in "a way that promotes sustainable development, equity, and resilience of interlinked social and ecological systems" (Soto *et al.*, 2008). Arguably, all aquaculture accounts for some level of ecosystem considerations, but EAA explicitly articulates the sustainability trade-offs and lends particular focus to marine aquaculture systems (Soto *et al.*, 2008; Aguilar-Manjarrez *et al.*, 2017). In particular, marine spatial planning and multi-stakeholder participation are prioritized so as to minimize conflicts between competing interests, measures, which have been adopted by some around the world (Aguilar-Manjarrez *et al.*, 2017; Brugère *et al.*, 2019). Yet, planning into the future and the uncertainty therein is minimally addressed in EAA, with a brief mention of precautionary and adaptive management strategies (Soto *et al.*, 2008; Ross *et al.*, 2013). Spatial considerations and cross-sector inclusion are important to sustainable and equitable planning, but the trajectories of these tools tend to be relatively short (Figure 1). Unsurprisingly, many countries appear to lack longer-term goals for aquaculture (e.g. 10+ years), even those, which have long and continued histories with wild fisheries management and seafood consumption (Froehlich *et al.*, 2020). Greater ownership of national aquaculture strategy by national governments responsible for the waters in which production occurs is fundamental to sustainable aquaculture development (Young *et al.*, 2019; Stentiford *et al.*, 2020).

The International Council for the Exploration of the Sea (ICES), and the 20 nations which participate, is an intergovernmental organization that conducts marine research to meet societal needs, sharing methods, tools, and data across the north Atlantic region. In part due to this network, the 20 member nations tend to be long time leaders in fisheries management leading to improved fisheries sustainability (Duarte *et al.*, 2020; Hilborn *et al.*, 2020). Despite successes in fisheries management and science, ICES nations also report large seafood deficits due to an increasing reliance on seafood imports (FAO, 2020; Froehlich *et al.*, 2020). This dependence can lead to a number of unintended consequences for both importing and exporting countries, particularly concerning social sustainability outcomes (Krause *et al.*, 2020).

An increase in imports is not necessarily a problem per se, but it can create greater uncertainty and complex traceability challenges in ensuring sustainable seafood practices (Costello *et al.*,

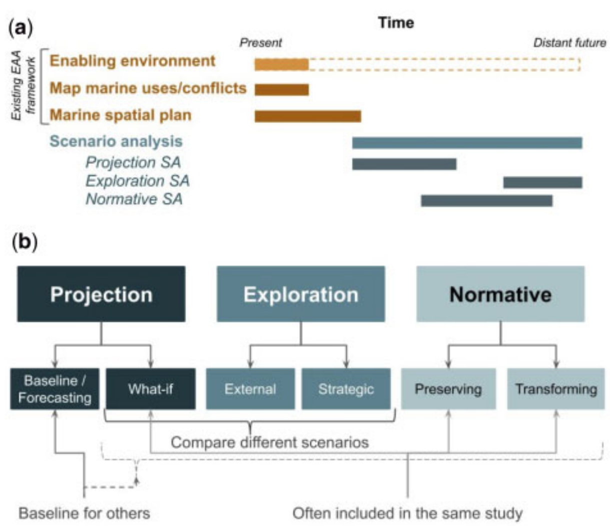

Figure 1. SA in planning. (A) Time scales of EAA and SA management and planning tools. (B) Comparison of SA methods for food systems.

2016; Gephart *et al.*, 2019; Kroetz *et al.*, 2020). In addition to existing and known dependencies, the current global COVID-19 pandemic is leading to a multidimensional crisis in all sectors of society, highlighting the vulnerability of our current food systems under adverse conditions. Sustained interruptions in global trade from pandemics and other unforeseen climate change-induced catastrophes threaten food security in countries dependent on imports (Gephart *et al.*, 2016; FAO, 2018b; Mbow *et al.*, 2019; Davis *et al.*, 2020; Erokhin and Gao, 2020). For these reasons, ICES nations, and other countries around the world have expressed interest in expanding domestic marine aquaculture industries, but are often unclear how to meet proposed development goals (Froehlich *et al.*, 2020; Szuwalski *et al.*, 2020). EAA guidelines set the stage for strong collaborative marine planning, but perhaps do not look far enough into the future. *Scenario analysis* (SA) is a method that does just that: considers and compares multiple possible futures to inform planning and decision-making in a long-term context. This approach can act as a supplement to the EAA by building off the groundwork laid by the EAA, including multi-sector relationships and communication, trade-off analysis, and a comprehensive understanding of internal priorities.

Here we review and assess how SA can be used to improve, and potentially help meet, sustainable national aquaculture goals into the future. First, we provide an overview of general planning approaches used in the marine space and review the three central types of SA, which can build on initial steps in marine development and planning (e.g. marine spatial planning). We then assess how scenarios have been employed in fisheries and aquaculture. Finally, we use ICES nations as case studies of progress, and the potential for duplicating successful methods in scenarios for aquaculture, with a particular emphasis on Norway due to its successful development of marine aquaculture industries. This paper provides a case for using SA in aquaculture planning to help set and meet longer-term strategic development goals with methods that align with, support, and build on the FAO's EAA and One Health Aquaculture approaches.

Making space for marine aquaculture

In the EAA and subsequent documents, the FAO shows that optimal governance for facilitating aquaculture development should focus on creating an enabling environment for the industry, while prioritizing sustainability and stability (Soto *et al.*, 2008; Hishamunda *et al.*, 2014). Enabling environments refer to ensuring effectiveness, efficiency, and predictability in all aspects of commerce. Economic and political stability, secure property rights, enforcement of contracts, dissemination of technological advances, and maintenance of other public goods and infrastructure, are necessary to marine aquaculture development.

Additionally, strong policies, governance, and communication systems facilitate development and sustainability in industries, including ocean farming. Meanwhile, expanding industries in the ocean environment also brings unique challenges, such as harsh and changing environmental conditions and conflicts with wildlife and other human uses (Hishamunda *et al.*, 2014). In order to administer equitable and sustainable aquaculture development, the EAA promotes holistic and participatory approaches, including community and stakeholder involvement. Several tools have been developed to address spatial conflicts that arise as oceans become busier, which can help support better and more inclusive planning. Integrated Coastal Zone Management (ICZM) and Marine Spatial Planning (MSP) are GIS-based tools used to reconcile multiple marine uses and environmental conditions, increasing predictability, transparency, and ideally equity in ocean planning (Aguilar-Manjarrez *et al.*, 2017; Theuerkauf *et al.*, 2019b). The process of data collection, compilation, and application of these frameworks can vary widely in scope and scale but is vitally important for describing and mapping use conflicts and opportunities to inform planning and management design (Buck *et al.*, 2004; Krause *et al.*, 2015; Krause and Stead, 2017). Once the various uses are identified, defining the context of these interactions (ecological/economic/social/physical/legislative/regulatory and positive/neutral/negative) helps highlight which interactions to prioritize in decision-making. Finally, there are several support tools to help make these important decisions (Lester *et al.*, 2013; Klinger *et al.*, 2018; NOAA, 2020). While this process is valuable and effective, it can be costly and data and/or time intensive, which may limit its use. In short, strategic growth in aquaculture requires an environment that enables industry to operate while accounting for stakeholder conflicts, guided by clear targets for aquaculture expansion. But a sustainable industry implies persistence into the future. Shifts in consumer preferences, climate change, and regulation, to name a few, cause increasing uncertainty further into the future. Therefore, additional tools are needed to inform planning for the longer term and ensure perpetuity of these essential food industries.

A Brief review of SA

The broad field of future-based studies has evolved over time, with several methods typically used to project into the future. SA is a process of modelling several possible futures to help predict and plan for outcomes of different decisions or scenarios in an uncertain future. Instead of estimating a discrete future with boundless uncertainty, the practitioner proposes several scenarios to envision how specific decisions or external changes might impact their defined goals. Like the EAA approach, the journey is as important as the destination. Much of the learning occurs over the course of data gathering, communicating between sectors and interests, assessing potential conflicts, determining priorities, setting goals, and gauging and incorporating uncertainty. In fact, SA can be a valuable addition to the EAA because scenarios development can build on EAA groundwork. Final estimates of how each constructed scenario will impact prescribed metrics can inform decision-making within a company or agency tasked with planning for the future (Reilly and Willenbockel, 2010; Tourki *et al.*, 2013). SAs are commonly used in economics, business, social political systems, and increasingly to study environmental systems (Tourki *et al.*, 2013). This broad application also comes with a wide spectrum of methods. Comparable futurist methods including horizon and environmental scanning, use analogous data collection, curation, and/or initial assessment steps as a full SA (Bengston, 2013), but lack the construction and comparison of multiple scenarios or choices, which motivate establishment of priorities and goals and are key to informing actionable decision-making.

We discuss three main types of SAs used in food systems and industries: *projection*, *exploration*, and *normative* assessments (Reilly and Willenbockel, 2010). Projection SAs ask what *will* happen, whereas exploration SAs ask what *can* happen. Normative analyses are more directed but are backwards facing, asking how a specific target can be reached. Projection uses a narrow lens and a shorter time horizon to ask explicit questions about how the future will look. The short-time horizon allows for a quantitative approach, using real data and constructive assessments of uncertainty to project business as usual (baseline/forecasting) or single "what-if" scenarios that test the effects of a single decision or external change (The World Bank, 2013). In quantitative approaches, uncertainty becomes limiting in the longer term. Exploration SAs combine both quantitative and qualitative data to project further out into the future: perhaps several decades to centuries (Figure 1a). Due to the longer time scale, results are more general than projection SA results, but can incorporate longer scale changes or goals. These SAs are further broken down into "strategic" or "external" assessments based on whether the practitioner is considering different internal decisions or external changes, respectively, and compare several scenarios side-by-side (usually 3–4 at a time). Often two scenario axes are selected and varied along a gradient (e.g. high and low costs of an important input), creating a 2 × 2 matrix of scenarios to be tested (Carpenter *et al.*, 2005; World Economic Forum, 2017). For normative analyses, the practitioner sets a target and back calculates how the target might be reached. This analysis is applied to moderate- to longer-term cases and thus combines qualitative and quantitative data inputs. Instead of looking externally and internally, the focus is completely internal and the different approaches consider how big of a change is to be considered. Preserving normative analyses assume there will be no changes to the larger system being assessed, whereas transforming normative analyses allow for system-wide changes to occur.

These three approaches to SA carry their own strengths and weaknesses and therefore fill unique roles in planning and are often used in conjunction (Figure 1b) (Molden *et al.*, 2007; Froehlich *et al.*, 2018). Normative approaches often employ a what-if type SA to test discrete approaches to reaching the determined goal. This approach may be most helpful in decision-making and planning because it constructs specific paths and tests how each performs compared to outlined goals. Projection methods can be helpful on a smaller scale, such as company or farm-levels, to inform specific operational decisions. Exploratory methods are commonly used on a general or global scale and thus tend to be less directly applicable in decision-making and planning, but can be used to guide high-level discussions or investigate pervasive stressors such as climate change. Although, due to the complexities of climate change, its impacts have been considered using each of these methods; projection using estimates of temperature change into the future, exploratory methods considering general higher occurrences of disease and disasters, for example, and combinations of these used in normative methods (Merino *et al.*, 2010b; Hermansen and Heen, 2012).

The combination of normative/what-if SA methods limits analysis to a moderate time projection since what-if analyses are confined to shorter time scales (years to decades) and normative analyses operate on moderate to long time scales (a few to several decades, Figure 1a). The moderate time scale is ideal for planning, allowing time for real changes to be made and felt but not so far out that uncertainty is too high to make confident predictions. This moderate level is consistent with recommended levels of management (Klinger *et al.*, 2018) and should also be applied to the spatial extent of the analysis. A moderate spatial scale similarly permits realistic application of results with broad enough reach for changes to have significant impacts. For planning, a country-level assessment is ideal for setting broad supporting management policies and development strategies, but effort should also be dedicated to understanding and accounting for differences among sub-country municipalities. Sub-country level can be too narrow a focus for strategic planning because financial support and capacity tend to be larger at the country scale, especially long term, and of course country-level regulations still apply. Although the larger the country, the more relevant sub-country level analyses become, as differences between production, ecosystems and management increase. For example, the US marine ecosystems range from arctic to tropical, which by necessity are managed differently across US sub-regions (Theuerkauf *et al.*, 2019b). Analysis on a scale larger than country level (super-country) invites high variation and results become too ambiguous for direct application. Additionally, country-level analyses can call on existing national governance structures to apply and manage changes, whereas super-country level would require international coordination structures. In cases where these structures exist (i.e. the European Union [EU], or ICES organizations), larger-scale planning can be similarly beneficial especially when resources are shared across borders. Finally, the focus of the SA should also be intermediate, targeting significant but specific changes, decisions, or scenarios to provide the greatest benefit, without losing applicability.

The process of SA often helps identify internal and external constraints and opportunities. Internally, the practitioner (e.g. manager) must evaluate their own structures (e.g. domestic policy, demand and/or production capacity) to understand the status of in-house systems (e.g. current import/export rates or production levels) and determine what they desire for their futures. This exercise on its own can be valuable in highlighting procedural inefficiencies or inconsistencies. Identifying known unknowns and key hurdles in growth or progress are valuable intermediate products of the SA process. With this knowledge alone, governments or industries can adjust to address these issues, collect additional data, or fund directed research to fill knowledge gaps. In addition to these internal benefits, reaching outside the system, company, or country to assess conflicts, synergies, and collaborations can similarly be a helpful process on its own. Data collection should be dynamic and interdisciplinary, incorporating data, input and interviews across agencies and sectors. Conversations discussing hurdles and priorities among different stakeholders increases transparency in the process, fosters trust across potentially conflicting parties, and builds connections between potential collaborators (Tourki *et al.*, 2013).

SA in seafood planning

SA has been commonly used in seafood planning, mainly for fisheries planning specifically. A Web of Science search (date: 16 December 2020) of "fisher*" and "scenario" returned 3621 publications. All searches were conducted as "Topic" terms, which search the title, abstract, and keywords, for the indicated words among publications from 1900 to the present. When aquaculture was added to the search ("fisher*" and "scenario" and "aquaculture") only 189 results were returned, ~5% of the fisheries publications. This is evidence that aquaculture and fisheries are rarely considered together in seafood futures' planning. When just "aquaculture" and "scenario" were searched, 808 citations were returned, but only 30 publications used futurist SA methods in their approaches (see Supplementary information for the full list of the publications discussed here). Each of the 808 references were individually reviewed and removed if scenarios were only discussed loosely and/or lacked structured scenario formation procedures, scenarios were considered only for uncertainty analysis with no temporal component, or did not explore aquaculture in the scenarios. Horizon and environmental scanning studies that omit full scenario construction, forecasts or comparison were also excluded. While these works are essential to informing SA and decision-making, this review focused on studies that include projections of future conditions. The Web of Science search was supplemented by a Google search for “scenario analysis aquaculture” to account for studies published in the grey literature during which 8 additional studies were added, based on the same criteria as above, for a total of 38 studies. Our results are also limited to studies conducted in or translated to English.

Use of SA in aquaculture research is increasing, although use of these methods varies (Figure 2a). The majority of these 38 studies use either exploratory (20) or projection (15) approaches to SA; only three use a normative/what-if combination. Almost half of the studies (13) are conducted at the global scale, using either exploratory or projection methods (Figure 2b). Four of the 13 focus on global fishmeal supply to aquaculture feeds alone (Merino *et al.*, 2010a, b, 2012; Froehlich *et al.*, 2018). Another six assess seafood within a broad food supply context with high level global exploratory SAs that are difficult to apply in any specific regional planning context, but can be helpful for generalized or higher-level comparisons (Delgado *et al.*, 2003; Alcamo *et al.*, 2005; Merino *et al.*, 2012; The World Bank, 2013; FAO, 2016; Gephart *et al.*, 2020). Three strong examples of intermediate scale SA tracked nutrient loading (Bouwman *et al.*, 2011, 2013) and energy use (Kim and Zhang, 2018) from different global aquaculture production scenarios. Here the analyses are applied at the global level, but the authors use focused metrics and derive realistic scenarios to apply real existing data to project impacts. So, while the spatial scale is broad, the bounded focus makes the results more easily applicable. At the sub-global (super-country) level, two publications consider aquaculture in the context of food security in Africa and provide direct suggestions for policy prioritization. However, given the diversity of government structures throughout Africa, application would likely be difficult due to the large spatial scale and heterogeneity (Chan *et al.*, 2019; Tran *et al.*, 2019). Two exploratory SAs consider climate change impacts on aquaculture in Europe (Kreiss *et al.*, 2020; Peck *et al.*, 2020) using similar approaches to a global exploratory SA, while a third with the same spatial scale takes a closer look at specific product markets employing projection methods (MacAlister Elliot & Partners Ltd., 1999). Results at these scales can be informative to managers and policymakers but as is outlined for the African studies, direct application is likely difficult.

Thirteen of the 38 aquaculture SA studies were conducted at the country level (Figure 2b). Four of these 13 focus on aquaculture in Norway specifically, five in Asian countries, three in Oceania, and one in the United Kingdom. Six of the studies employ exploratory methods to explore the potential for aquaculture broadly by comparing priority axes. One Indonesian and one Australian study each look into aquaculture in a broader seafood portfolio (Lim-Camacho *et al.*, 2015; Henriksson *et al.*, 2019), while three additional studies focus on general considerations such as climate change, social responses and acceptance, and environmental impacts (World Fish Center, 2011; Tran *et al.*, 2017; KPMG, 2020). The UK-based study (while the United Kingdom is not a single country, it has an established collaborative governance system in place and moderate total size) focuses narrowly on how two specific axes might affect aquaculture expansion: energy costs and social acceptance, in an exploratory SA (Black and Hughes, 2017). As such, the narrow focus means results are relatively actionable but may ignore other key influences that would likely affect outcomes. Similarly, a recent Tasmanian study uses exploratory approaches to investigate the expansion of recirculating aquaculture systems specifically (King, 2016). While exploratory SA is helpful at the country level for broad exploration of aquaculture introduction or expansion, perhaps the most directly applicable of all of the studies reviewed here are three normative what-if SAs, two based in Norway and one in Singapore. The Norwegian Ministry of Fisheries and Coastal Affairs set progressive aquaculture growth goals to 2050 (Norwegian Gov., 2013). Two SAs use these production targets in normative SAs that include what-if scenarios to test how specific decisions or external impacts will influence aquaculture growth trajectories in Norway (Finne, 2017; PwC, 2017). The spatial extent here is large enough to motivate significant change, but small enough for consistency

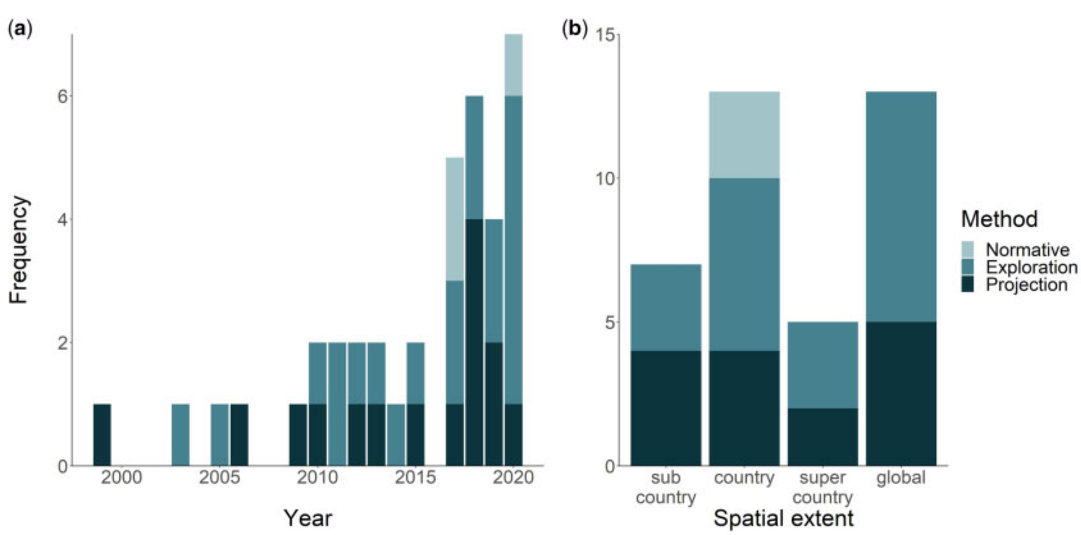

Figure 2. Publications of SA in aquaculture (A) over time by analysis method and (B) by spatial extent and analysis method.

in regulatory frameworks. The timelines are similarly moderate, with enough time to enact changes but not cloud results with excessive uncertainty. Each of the studies assesses different axes of aquaculture growth: industry responses to sustainability requirements and external influences, contribute unique lessons to stakeholders, and include specific action plans based on analysis results. The Singapore study similarly uses established growth targets and test strategies to reach these goals within 10–20 years (Bohnes *et al.*, 2020). Two additional Norway-based studies use projection approaches, which limits the temporal reach of predictions, but the confined focus on how sea temperature changes might affect fish growth and yields results in actionable lessons (Lorentzen, 2006). Studies such as these can help Norway reach their ambitious growth targets.

Sub-country studies largely use projection methods because the smaller spatial scale makes data collection easier (Figure 2b). Three of the seven publications at this scale use exploration methods, likely because the quantitative specificity of projection results was not needed. SA at this scale is most easily conducted and implemented, but application is limited likely due to the time and cost-intensive methods of SA with a potentially lower overall impact at this smaller spatial scale.

ICES member nations

Although nearly all ICES member nations have set targets for aquaculture growth (exception, Estonia), nearly all have been far below what would be needed to meet seafood demand within the country; thus, the domestic seafood deficit has been expanding (Bostock *et al.*, 2016; Froehlich *et al.*, 2020). With the production from ICES nations' well-managed fisheries appearing to have stabilized, increasing demand for seafood is being met with imports rather than expansion of domestic aquaculture. While the majority of the 20 nations have expressed interest in expanding aquaculture, only three have proposed growth goals beyond a 10-year time horizon, and only Norway set clear targets out to 2050 that would result in their aquaculture production surpassing their wild capture landings (Froehlich *et al.*, 2020).

To better understand why these nations might be falling short of their needs or interests, we explore the role that planning and SA may play in enabling countries to set appropriate targets, a critical step for aquaculture, especially during initial stages (Soto *et al.*, 2008; Ross *et al.*, 2013; Brugère *et al.*, 2019). The status of the 20 ICES nations was tracked along the marine planning workflow outlined above. Specifically, we focused on three concrete products that can be easily assessed, measured, and compared between countries: (i) maps of marine uses, a necessary input into planning decisions that require understanding a given context and the potential for conflict, (ii) completed marine spatial plans that are explicit strategic planning documents, and (iii) at or near country-level aquaculture SAs.

Of the 20 member nations, nearly all have publicly available maps of marine uses (17 countries). Although 17 nations produce marine aquaculture, only 14 of these have marine uses mapped, and only 12 countries include marine aquaculture in these maps. The EU (of which 14 of the 20 nations are ICES members) has called for EU member countries to produce full MSPs, where the member states shall aim to contribute to the sustainable development of aquaculture sectors by 2021; yet, as of this writing, only five ICES nations had full MSPs (four of which are EU members). Six additional countries have drafted MSPs, all also EU nations. Of the five nations with full marine spatial plans, four include marine aquaculture in those plans (Table 1).

The four plans that include marine aquaculture in the full MSPs vary in their goals. For instance, in Germany, the Federal Maritime and Hydrographic Agency (BSH) produces marine utilization maps for the country's exclusive economic zone, but out of necessity, attention has focused on the rapid expansion of offshore wind farms (BSH, 2020). Marine aquaculture is included in

Table 1. Use of planning and management tools for each of the 20 ICES nations.

		Uses mapped		Marine spatial plan			SA
	Existing mariculture	Marine activities	Aquaculture included	Completed plan	Aquaculture included	Aquaculture mgmt. area	Aquaculture
Belgium		✓	✓	✓	✓		
Canada	✓	✓	✓				
Denmark	✓	✓	✓				
Estonia	✓	✓	✓	*Draft*			
Finland	✓	✓	✓	*Draft*			
France	✓						
Germany	✓	✓	✓	✓	✓		
Iceland	✓						
Ireland	✓	✓	✓				
Latvia		✓		*Draft*			
Lithuania		✓		✓			
The Netherlands	✓	✓		✓	✓		
Norway	✓	✓	✓	✓	✓	✓	✓
Poland		✓		*Draft*			
Portugal	✓	✓	✓				
Russia	✓						
Spain	✓	✓	✓	*Draft*		✓	
Sweden	✓	✓		*Draft*			
United Kingdom	✓	✓	✓	*Draft*			✓
United States	✓	✓	✓	*Draft*			
Totals	16	17	12	5	4	2	2

Where confirmed, drafts of completed marine spatial plans were noted by "draft". Drafts were not tracked for any other tools.

marine exploitation maps, and efforts are ongoing to define future suitability areas for offshore aquaculture that are consistent with the expansion of other uses, with an emphasis on multi-use scenarios in the safety zones of offshore wind farms (Schupp *et al.*, 2019). The Netherlands is investigating placement of potential marine aquaculture management areas, but has yet to define specific locations or plans. Similarly, Belgium is specifically investigating co-location of marine aquaculture with wind farms, likely due to the relatively small and impacted coastline that limits available space and creates large potential for conflict with other existing uses (especially fisheries), but has yet to establish commercial marine operations. Norway's plan sets aside areas into which marine aquaculture can expand. Allocating defined marine spaces for future marine aquaculture to move into is important in establishing marine aquaculture expansion as a national priority, as well as increasing efficiency and conveying predictability and commitment to potential investors (Sanchez-Jerez *et al.*, 2016; Aguilar-Manjarrez *et al.*, 2017).

Despite the apparent lack of forward movement, almost all ICES member nations identified a target for growth in aquaculture industries, largely for marine systems (Froehlich *et al.*, 2020). Only two of the 20 ICES member nations had SAs that included domestic aquaculture production. The United Kingdom addressed potential for aquaculture under a narrow lens, which may facilitate application but may overlook other influences. Scenario building exercises have been conducted in France but full analyses have yet to be implemented (Rey-Valette, 2014). Similarly, in Finland several scenarios for possible futures of the operating environment in Finnish maritime areas until 2050, including aquaculture, have been drafted and await completion of the MSP. In the United States, scenario planning is expected to be a component of the recently announced efforts to develop Aquaculture Opportunity Areas along the coastlines where large investments in MSP are being used to identify the opportunity areas (United States, Executive Office of the President [Donald Trump], 2020). Norwegian aquaculture has received the focus of a number of studies using both normative and projection methods. The benefits of these works to Norwegian aquaculture and their roles in the larger planning framework are discussed further below.

Norway

Norway has a long history of prioritizing marine aquaculture production, and as a result has achieved rapid growth (Hersoug *et al.*, 2019; Froehlich *et al.*, 2020). Given this continued expansion of marine aquaculture, Norway is one model against which to investigate the use and efficacy of the frameworks outlined above; particularly for commercial-level, intensive production systems (Taranger *et al.*, 2015). In 2013, the Norwegian Ministry of Fisheries and Coastal Affairs (Ministry) set a goal to expand aquaculture to 5 million tonnes, ambitious given annual production at the time was already 1.2 million tonnes. Can proper systems and planning help Norway meet this target? While criticisms of the Norwegian governance and marine aquaculture frameworks exist (Sandersen and Kvalvik, 2015; Bailey and Eggereide, 2020a), this study found that while the Norwegian approach is imperfect, it incorporates many of the recommended elements for industry sustainability and growth and so makes a strong case for the employment of an EAA+SA framework. The Norwegian government is focused on sustainability and providing an environment that enables industry operations and expansion. They integrate governance at several scales and employ spatial management and planning tools to coordinate the various marine uses, and SAs to predict further into the future in order to plan approaches to effectively meet growth targets (Figure 1b).

Economic, social, and ecological sustainability are addressed in salmon marine aquaculture by the Ministry with a combination three key initiatives: permit allocation, the *Traffic Light* system, and development licenses. Permit allocation is managed by local municipalities who control spatial permitting of new marine aquaculture enterprises and can vary greatly in their priorities and aquaculture endorsement (Sandersen and Kvalvik, 2015). This gives communities more power over their local ocean spaces, thus promoting social sustainability. In contrast, development licenses are granted by the national government to companies providing innovations to improve sustainability and efficiency in aquaculture. These licenses promote advancements towards economic as well as ecological sustainability. The Norwegian coastline is divided into 13 production areas, which each receive a growth allotment score in the form of traffic light colours (green, yellow, red) based on the mortality risk to wild salmon populations from salmon ectoparasites (sea lice), which in turn dictate regional growth concessions. Regions are slated to be evaluated every 2 years (Norwegian Gov., 2015). These measures aim to promote ecological sustainability by incentivizing decreasing ecological impacts of salmon farming, the metrics (currently sea lice threat) of which are designed to be adaptable to evolving threats. The transparency and versatility of this system were devised in response to a lack of public trust in the permitting process, so aim to strengthen confidence in marine aquaculture governance and the salmon industry to enhance social sustainability (Hishamunda *et al.*, 2014; PwC, 2017). Norway's advanced social infrastructure, such as ports, roads, and social services facilitates industry growth by providing the means to conduct business and help support local workers.

Norway also employs ICZM and MSP tools to reconcile the various marine activities at a fourth spatial scale. Permitting and monitoring occur on smaller, local level to promote coordination and cooperation between farms and engagement between the public and industry. The traffic light system is applied at a larger scale, dividing the coast into 13 "production areas" to capture proximal ecosystem impacts, but large enough for efficiency in regular assessments and monitoring. MSP acts on an even larger scale breaking up the extensive coastline into three regions (Barents Sea, North Sea, Norwegian Sea), for which MSP harmonizes conflicts within each, at intermediate time scales. Benefits from these diverse governance scales can only be successfully integrated through strong communication, cooperation, and adaptability as outlined in the EAA. Although none of the approaches do well to inform growth further than several years into the future, and therefore fail to advise how to reach growth targets to 2050. The two normative SAs outlined above serve this very purpose.

Two projection SAs examine productivity of salmon marine aquaculture in the face of climate change. Using existing estimates of climate change effects on ocean temperatures, calculating impacts on salmon growth can inform the siting of future farms and production adaptations (Lorentzen, 2006; Rey-Valette, 2014). Extensive latitudinal coastlines give industry particular flexibility when it comes to planning for impacts of climate change, so such results can benefit both industry as well as management. Both of the normative SAs address 2050 production goals. The PwC analysis looks inward, taking a strategic preserving approach (Börjeson *et al.*, 2006; PwC, 2017) that focuses on how the domestic industry might respond to traffic light legislation, and how innovations might help boost production and mitigate environmental impacts. PwC compares different combinations of industry responses and growth allocation potentials to calculate how production targets can be met. Only the most optimistic scenario achieves this goal, predicting a need for significant growth in land-based recirculating aquaculture systems, compliance and success with the traffic light regulations (and therefore optimal offshore growth), as well as efficiency benefits from "green light" innovations that improve environmental performance. The baseline case emphasizes growth from the traffic light system and some boost from innovations, but estimates fall short of the 5 million tonne production goal, estimating production at 3.3 million tonnes (PwC, 2017). Finne (2017) takes a more external and transformative approach, looking beyond domestic behaviours to include impacts of public perception and global markets to predict demand trends for Norwegian salmon. Again, only the most optimistic scenario reached the 5 million tonne target and highlights that the traffic light initiative's existing focus on sea lice metrics to curb salmon lice issues is key to reaching 2050 targets. Finne (2017) also highlights monitoring demand for Norwegian salmon as a priority. For Norway, both analyses engage directly with industry and other stakeholders and include action plans for each scenario, which help decision-makers directly apply lessons learned from the results.

While these are both strong outcomes, their benefit can only be as strong as the information given. Critics of the traffic light approach claim that permitting is too narrowly focused on salmon lice impacts and may ignore other policy considerations and potential dangers (Bailey and Eggereide, 2020b). The Norwegian Ministry treats salmon lice impacts as a "canary in the [marine aquaculture] coal mine", indicating generally unhealthy conditions, but this narrow focus may overlook additional risks, such as ecosystem degradation or disease transmission. In this case, lessons from baseline and pessimistic cases are helpful for understanding how to maintain the industry, even if growth targets cannot be met. The projection SA is limited temporally, but provides actionable lessons that farmers can use to protect against environmental stressors, such as adjusting harvest schedules. Serving a different purpose than the normative SA, projection SA approaches can be helpful at the farm level by providing actionable results.

The Norwegian case exemplifies how these management and planning tools can be used together to move marine aquaculture development forward and guide decisions to promote a sustainable industry. The EAA promotes communication, collaboration, sustainability, and equity in the aquaculture industry, and when combined with ambitious planning goals and policies can facilitate industry growth, but its application has mostly focused on spatial considerations with little attention to long-term planning. SA can build on the EAA to assess the potential for growth and industry sustainability into the future given selected criteria, and inform how to reach defined goals. Industry and managers can then adjust siting and growing schedules based on SA outcomes about the impacts of climate change on productivity. While lessons from these specific SAs might not be directly applicable to other countries hoping to expand aquaculture production, the demonstrated benefits of the outlined framework can guide policy development, management, and planning to create a system that best serves the conditions and goals of a given country or region. Indeed, several aspects of the Norwegian governance, policy priorities and social infrastructure, as well as use of EAA components, have also contributed to Norway's successes in development of marine aquaculture industries. In Norway, policies focus on controlling disease risk and promoting growth of salmon farming, goals which will likely differ elsewhere depending on species and production type (e.g. intensive vs. extensive). A fundamental step in both EAA and SA is to understand the politics, resources, and priorities of the various stakeholders to set relevant and progressive goals. A strength of SA is the ability to assess the impacts of elements that might otherwise be overlooked in order to highlight their potential effects on a given system. For example, Finne (2017) identifies that in addition to sea lice risks, maintaining high global demand for Norwegian salmon products is also important to meeting growth goals and in this way can also be used to test potential limitations of existing governance. At the same time, SAs are limited in scope as is demonstrated by the normative SAs, which are limited by sea lice development restrictions; as such, changes to this legislation, novel pests, or other limitations are along the supply chain not considered.

Conclusions

In order to meet goals, needs, and demands for marine aquaculture growth, stronger planning and clearer holistic policy is needed. Through targeted laws, regulations, and associated management reforms, many wild commercial fisheries stocks have seen improved industry sustainability globally (Hilborn *et al.*, 2020). The EAA has set the groundwork for similarly robust aquaculture industries, but fails to address long-term development goals or planning into the future. SA can be used to design and test strategies for reaching long-term goals and therefore can be critical in planning for aquaculture growth. Although many nations are keen to expand marine aquaculture industries to enhance blue economies and increase food production, most have planning and policy structures that are too limiting to industry, short term, and/or fragmented to facilitate expansion. Norway has modelled the steps to aquaculture development outlined here and has benefitted from the structure and transparency they provide to the industry and society. However, sustainability is a moving target and as the industry grows so do social and ecological issues, such as disease, making adaptive feedbacks even more important. Demonstrating sustainability in aquaculture (including marine) will increasingly require read-across to other major food sectors considered by national governments as the means to feed their people or to create export income (Stentiford *et al.* 2020). Employment of mapping tools, adaptive management, and planning techniques have made Norway a dominant producer of marine aquaculture products, and SAs can help guide advancement towards their next set of goals. This work highlights where and how SA can add to existing frameworks (i.e. EAA) to help move aquaculture development forward. Further investigation into measurable impacts of the SA process and use will help improve understanding of the value and efficacy of these tools. Moving production offshore and adding activities to already highly impacted marine spaces is difficult, which leaves many countries to languish in the goal-setting stage. With proper planning and efficient and adaptive management systems, we can all benefit by allowing these emerging industries to grow sustainably into the future.

Data availability

There are no new data associated with this article.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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