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Food for thought: A realistic perspective on the potential for offshore aquaculture in the Dutch North Sea

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1. Why offshore aquaculture?

1.1. Recent trends in (sea)food systems

Rethinking of our food systems is required under conditions of climate change, ecosystem degradation and increasing food demand. Food production in Europe must therefore transform to achieve the United Nations' Sustainable Development Goals, increase its level of self-sufficiency and be resilient to external shocks. Part of the future's food and nutrition demand can be met by seafood products. Compared to livestock production, aquaculture is an efficient way of protein production with relatively low environmental costs (Hilborn et al., 2018). This has set international agendas for increasing aquaculture (EC, 2012; European Union, 2017; SAPEA, 2017) and in parallel initiatives to develop climate smart bio-based economies including marine resources (EC, 2019a, 2019b, 2020).

1.2. Towards seafood production in the North Sea

Various policies such as the EU Blue Growth Strategy (EC, 2019b) and the EU Strategic Guidelines for a more sustainable and competitive EU aquaculture (COM/2021//236 final) and the funding mechanisms including Interreg, the European Maritime, Fisheries and Aquaculture Fund, Horizon Europa and their precursors, seek to stimulate the aquaculture sector in Europe. The EU Member states have formulated multiannual national plans that outline ambitions for sustainable aquaculture development. The Dutch plan aims for a modest growth objective of 3% growth in value of production in the period 2014–2023 (Rijksoverheid, 2015). The plan also refers to the development of offshore cultivation, including multi-use platforms at sea. Driven by climate objectives, the Dutch government recently, for the first time, explicitly allocated large areas for marine food production in the future vision of the North Sea (National Climate Agreement; Rijskoverheid, 2019). This suggests we are now at a turning point in the development of offshore aquaculture in The Netherlands.

We argue that to define and achieve (realistic) ambitions for aquaculture production a shift in policies and knowledgebase is required. In this essay we discuss how to align the ambition of large-scale aquaculture with sustainability and climate goals, and outline the knowledgebase and governance required to develop policies for sustainable growth of aquaculture production.

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2. Conditions for development of sustainable aquaculture

2.1. Governance and adaptive management

The mismatch between policy ambitions and achieved results in bringing about offshore aquaculture can be understood by applying a governance perspective. Governance refers to all forms of social coordination and patterns of rule, whether undertaken by a government, market, or network, whether over formal or informal organization, or territory, and whether through laws, norms, power or language (Bevir, 2012). A governance perspective challenges us to look beyond the role of the government only in realizing growth ambitions for offshore aquaculture.

The policy instruments so far deployed by the European Union, and through that by Member States, are top-down instruments, focussing on the allocation of space for aquaculture (through Marine Spatial Planning), development of knowledge (Horizon 2020) of financial support to innovation (EMFF). When it comes to aquaculture in the North Sea, it is clear that the top-down state-efforts to develop aquaculture, unlike the offshore wind sector, are not mirrored by the private sector initiatives (Soma et al., 2019). In the Netherlands, a Community of Practice North Sea was set up by government to bring together public and private actors to discuss and work on technical and policy innovations, including offshore aquaculture (Steins et al., 2021). This has facilitated existing and new pilot initiatives for seaweed cultivation and offshore mussel production. While the government provides funding for the Community of Practice and short term pilot projects though innovation grants, it should also focus on allowing room for experimentation with long term perspectives. The development to offshore aquaculture requires a turn in policy-making towards an adaptive approach which creates room for learning through practice, failure and improvement.

2.2. Viable business models

The biological and economic feasibility for offshore cultivation in the North Sea have been evaluated for a range of species, and highest potential was identified for shellfish (mussels and oysters) and seaweed (kelp) production rather than for fish culture (reviewed in Jansen et al., 2016). This is in line with van der Meer (2020) who challenges the optimistic views on the future role of marine fish culture, and instead argues that important steps in raising global production of protein-rich animal seafood can only be expected from aquaculture of low-trophic organisms such as shellfish and seaweed.

Recently an increasing interest from industry is observed, which resulted in operational pilot sites for kelp production (NSIL, 2020) and the first license applications for commercial mussel cultivation. The small-scale activities explored the on-site technical and biological feasibility. So far, these systems did not reflect commercial production units, leaving various technical questions for cultivation under rough offshore conditions unresolved.

Unsurprisingly, new aquaculture production processes cannot compete directly with established production on production cost alone (Burg van der et al., 2017; Burg van der et al., 2019). Rough environmental conditions and high costs for labor make it difficult to compete on price only. This is of particular relevance for the relatively low value products as proposed here. If aquaculture in the North Sea is to grow, the economic dimension does require further scrutiny. The following three pathways can be instrumental in achieving economically feasible aquaculture:

- A substantial reduction in the costs of production is deemed achievable by mechanization and in case of seaweed production the development of high-performing strains specifically adapted for offshore conditions. This allows to compete with other national and global production areas
- Increasing consumer demand can increase retail prices. Starting points for this are the positive image of seaweeds or the low environmental impact of shellfish. Still, reaching and teaching a large group of consumers to use these products requires a concerted effort of producers, intermediary organizations and retailers
- The production of low trophic marine species can benefit the ecosystem. Rewarding the positive impact through payment for ecosystem services can provide an additional source of income for producers and strengthen stakeholder incentives

Further exploration of avenues for increasing the competitiveness of North Sea aquaculture is required and, more importantly, should be a joint effort of the public and private sector. Creating a competitive aquaculture sector is not only to the benefit of private entrepreneurs but also key to achieving societal objectives, including food security and sustainable management of the North Sea. In this context it is relevant to weigh the value-biomass pyramid (e.g. Chopin and Tacon, 2020) against the Food Recovery Hierarchy (Steves et al., 2018) and principles for circular production (Muscat et al., 2021). In a situation when aquaculture production is limited, for example by environmental constraints (see Box 1), this may lead to prioritization of the production of food over non-food items, despite potentially higher market prizes for non-food items.

2.3. Resilient and climate robust production

For marine spatial planning as well as for a realistic outlook of the scope for business, it is imperative that we get an idea regarding the ecological boundaries of the North Sea for food cultivation. This will ultimately define spatial requirements, prime locations and production outlook. Low trophic aquaculture, such as shellfish and seaweeds, is generally considered a sustainable form of food production (Hilborn et al., 2018) and delivers various ecosystem services (Smaal et al., 2019; Weitzman, 2019). A well-known example is the potential to stimulate biodiversity by attracting sessile and mobile species to the cultivation structures (Callier et al., 2018), thereby having the potential to contribute to resilient ecosystems and nature ambitions as outlined in marine frameworks directives. Aquaculture-ecosystem interactions are characterized by inputs to (artificial material, habitat creation, plastics, genetic resources, noise) and extraction from (nutrients, kinetic energy, light) the ecosystem (Campbell et al., 2019). Whether these lead to services or negative impacts depends on the cultivated species, area-specific conditions but also the scale of production. For example, nutrient extraction can control eutrophication (Petersen et al., 2019), and thus act as a ecosystem service, but when exceeding sustainable production limits, even low trophic aquaculture may negatively affect ecosystem functioning (see Box 1). In general terms a number of aquaculture-ecosystem interactions have been identified but quantification and thresholds, especially for offshore conditions, are lacking. The (gu)estimates for maximum production based on ecological carrying capacity (several hundred km^2; Box 1), for example, highlight that potential production levels are considerable lower than the initial ambition foreseen in policy documents (several thousand km^2; Rijksoverheid, 2019). Such a simple scaling exercise may guide spatial planning and discussions on area allocation, and demonstrates the need for quantification, even in early stages of development when methodology only allows for ballpark guestimates. ‘Learning by doing’ also implies that knowledge and insights will be refined and improved along the way. Development of aquaculture that meets the sustainability goals therefore needs investment in the knowledgebase, in terms of empirical and modelling studies. Moreover, methodologies to evaluate the contribution to climate and natural capital requires further scrutiny.

For the evaluation of environmental opportunities and risks associated with aquaculture, we recommend establishing a generic cumulative effect assessment (CEA) comparable to frameworks currently developed the evaluate other marine activities in the North Sea (Piet et al., 2019).

Box 1
Maximum level of seaweed production based on the ecological carrying capacity

Simple assumptions and first order calculations were used to provide ballpark figures for sustainable seaweed production scenarios at the North Sea (based on Duren et al., 2019). We emphasize that these numbers are guestimates, nonetheless, they provide projection for the growth ambitions and aid policy discussions in early stages of development.

Assumptions & Definitions

- *Carrying capacity*: maximum seaweed production that has no/limited impact on the pool of dissolved nutrients available for phytoplankton growth
- *Nutrient availability*: 50% new input (25% via Atlantic Ocean, 25% via rivers), 50% regenerated
- *Nutrient removal levels:* sustainable exploitation can never be higher than the input of 'new' nutrients. Here we calculate two scenarios: seaweed cultivation uses 5% or 50% of 'new' nutrients
- *Limiting nutrients:* Calculations are based on Nitrogen (N). Average N concentration in winter is 15 μmol l^{-1}, given a depth of 25 m and total area of 58.000 km^2 this equals to $21*10^9$ mol N for the entire North sea
- *Seaweed Production (Saccharina latissima):* Assuming a production of 10 tons DW ha^{-1}, C:DW = 0.4 g and C:N = 9 mol results in $3.7*10^6$ mol N being harvested per km^{-2}

Conclusions

Scaling the available nutrients under the scenarios of 5% and 50% of 'new' nutrients harvested in seaweed biomass, suggests that 145 to 1000 km^2 seaweed can be exploited. Larger ambition requires innovations in production systems, such as fertilization with external nutrient resources. These guestimates are considerable smaller than initial policy ambitions (Rijskoverheid, 2019), suggesting a smaller areal requirement and production potential than foreseen.

To improve these guestimates, research in the near-future should include spatio-temporal dynamics in environmental conditions and seaweed growth through the development of simulation models (e.g. as shown by Jiang et al., 2022 for an inshore area in the Dutch delta). Such analysis should further consider the interplay between the joint exploitation of seaweed and shellfish, given the numerous synergistic, antagonistic and facilitative interactions between them.

This includes prioritization of key knowledge gaps and highlight directions for policy and research. Boundaries for sustainable exploitation cannot be defined a priori which implies that upscaling aquaculture activities should go hand in hand with evaluation of ecosystem interactions.

3. Looking ahead: perspective for development

To secure the long-term food security, sustainability and climate ambitions for the North Sea, it is essential to provide a clear perspective for (innovative) aquaculture production. Definition of realistic ambitions in terms of desired scale is however a process rather than a fixed value and would greatly benefit from a 'learning by doing' approach. As such, we advise to start with (commercial) experimenting at sea on a scale realistic for entrepreneurs, to evaluate business models. These sites do not only aid technical and economic feasibility but also helps to define ecological impact assessments and allows adaptive policy making.

It seems evident that environmental sustainability goals largely define the boundaries to the ambition of large scale aquaculture. In case of seaweed production the areal requirement is likely limited to a maximum of several hundred km^2, for shellfish production this has not yet been defined. Scale of pilot sites should be large enough to measure (local) interactions with the environment as on-site measurements are essential for development of the knowledgebase, to parameterize ecosystem models and to establish evaluation frameworks. Only then realistic goals can be set, based on ecological boundaries, economic projections and in agreement with other emerging and existing maritime functions. Throughout the process involvement of stakeholders from the outset is essential and should not be considered as an add-on. The Community of Practice North Sea could play an important role in this process.

With the expected increase in offshore wind and its associated claim for space, it is argued that the most likely areas for expanding offshore aquaculture is within wind farms (Buck and Langan, 2017), and cumulative impact assessments become relevant. Although potentially attractive, multi-use sites have a number of limitations including operational risks making both wind farm operators and insurers of the turbines hesitant to embrace co-use with aquaculture. In addition, whether these sites are also prime locations from an aquaculture perspective is to be seen. Managing risks and optimizing operational procedures for all activities in one location, will be an important aspect of future management.

Declaration of Competing Interest

There is no conflict of interest.

Data availability

No data was used for the research described in the article.

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