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Food for Thought

Contribution to the Themed Section: '*Marine aquaculture in the Anthropocene*'

Thinking outside the box: embracing social complexity in aquaculture carrying capacity estimations

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With ever-expanding marine aquaculture, calls for sustainable development become louder. The concept of aquaculture carrying capacity (CC) emerged 30 years ago to frame development, though so far, most studies have focused on the production and ecological components, leaving aside the social perspective. Often, estimations are carried out *a posteriori*, once aquaculture is already in place, hence ignoring relevant voices potentially opposing the onset of aquaculture implementation. We argue that CC should be multidimensional, iterative, inclusive, and just. Hence, the evaluative scope of CC needs to be broadened by moving from industry-driven, Western-based approaches towards an inclusive vision taking into consideration historical, cultural, and socio-economic concerns of all stakeholders of a given area. To this end, we suggest guidelines to frame a safe operating space for aquaculture based on a multi-criteria, multi-stakeholder approach, while embracing the social-ecological dynamics of aquaculture settings by applying an adaptive approach and acknowledging the critical role of place-based constraints. Rather than producing a box-checking exercise, CC approaches should proactively engage with aquaculture-produced outcomes at multiple scales, embracing complexity, and uncertainty. Scoping CC with the voices of all relevant societal groups, ideally before aquaculture implementation, provides the unique opportunity to jointly develop truly sustainable aquaculture.

Keywords: aquaculture, aquaculture management, carrying capacity, seafood farming, sustainability

Introduction

The culture of marine resources provides valuable nutrition and livelihoods to humans around the world. With an annual growth rate of 5.8% (for the period 2001–2016), the sector is expanding faster than other food producing industries (FAO, 2018). In 2016, 110.2 million tonnes of seafood was produced from aquaculture, including 54.1 million tonnes of fish, 31.1 million tonnes of aquatic plants, 17.1 million tonnes of bivalves, and 7.9 million tonnes of crustaceans, overtaking the 90.9 million tonnes originating from wild fisheries (FAO, 2018). In fact, 37 countries now produce more farmed than captured fish (FAO, 2018). In the discourse of "Western" societies, aquaculture is being promoted as a solution to meet the growing gap that collapsing fisheries have created in nutrient provisioning—and to solve the world's hunger problem (Ahmed and Lorica, 2002; Duarte *et al.*, 2009; Lovatelli *et al.*, 2010; Barange *et al.*, 2014; Froehlich *et al.*, 2018). However, a large portion of aquaculture production—including that of developing countries—is explicitly designated for these Western markets, namely North America and the European Union, and not for feeding local populations (Garlock *et al.*, 2020).

Farming aquatic organisms in marine and coastal environments is not without consequences. Depending on the species cultured, aquaculture facilities interact with the surrounding environment in many ways, generating both costs and benefits at different social, economic, and ecological levels. Ecological aspects are usually limited to the local spatial scale, understanding by local scale the body of water where the aquaculture facility is placed (e.g. organic loading in the vicinity of a farm) (for a review of aquaculture–environmental interactions, see Edwards, 2015). Contrarily, due to the globalization of the seafood market (e.g. Deutsch *et al.*, 2007; Subasinghe *et al.*, 2009), complex social and economic externalities of aquaculture implementation and expansion emerge at both the local (producing) and international (consumer) scales (e.g. in Ireland, imported salmon is usually more affordable than the locally produced product, which is organically certified; Krause *et al.*, submitted). Although these social and economic implications have often been overlooked in the past, a growing body of literature acknowledges the need to tackle environmental and social consequences of aquaculture on a range of scales (e.g. Little *et al.*, 2013; White *et al.*, 2013; Edwards, 2015; Asche *et al.*, 2016).

The concerns related to the ever-expanding aquaculture industry and its potential ecological consequences and spill-over effects on social and economic dimensions have triggered a whole range of approaches focusing on aquaculture impact analysis. The concept of aquaculture carrying capacity (CC), popularized in the 1990s (Chapman and Byron, 2018), is generally framed as the maximum aquaculture intensity a (eco)system can support within *limits of acceptable change* (*sensu* McKindsey, 2013, p. 458). This broad definition can be applied with a holistic perspective by breaking down CC into four sub-categories: physical (maximum area available for aquaculture), production (stocking densities allowing for maximum harvests), ecological (maximum stocking densities not causing ecological externalities), and social (maximum culture intensity not causing social externalities) (e.g. Inglis *et al.*, 2000; McKindsey *et al.*, 2006). Although most CC studies and applications have focused on production and ecological CC, with a focus on bivalve aquaculture (Weitzman and Filgueira, 2019), the general concept of CC has recently been suggested to be appropriate to operationalize the ecosystem approach to aquaculture (EAA; e.g. Ross *et al.*, 2013; Chapman and Byron, 2018; Weitzman and Filgueira, 2019).

This work argues that the current scientific discourse on aquaculture CC estimates remains very much industry focused and seen through "Western" glasses. In other words, CC has been commonly explored as a tool for *a posteriori* regulation of the existing industry, with emphasis on aspects related to culture production and ecological consequences. This focus has inherently limited the potential for improving aquaculture management. We argue for a multi-stakeholder approach for CC assessment that recognizes the dynamic nature of social-ecological systems hosting aquaculture, one that incorporates ecological, social, and economic costs and benefits of aquaculture development. We propose that these CC assessments need to be rooted in the values of local communities, while acknowledging international drivers such as the reality of globalized seafood markets, and urge for the development of additional tools to ensure the sustainability of aquaculture at local and global scales. Furthermore, a proactive adoption of a dynamic framework that recognizes complexity and uncertainty and embraces the different voices of concerned stakeholders in an inclusive and just way is envisioned to allow for truly sustainable aquaculture development.

Social CC—the potential for an underrated concept

Although the earliest attempt to use a CC concept to estimate limits to aquaculture expansion dates back to the 1960s (Yashouv, 1963; cited in Weitzman and Filgueira, 2019), the modern understanding of CC emerged from the foundational work published by Inglis *et al.* (2000), which provided ecological, social, and to some extent economic perspectives to the concept. Despite this holistic nature, so far the greatest emphasis has been given to ecological and production capacities (Weitzman and Filgueira, 2019), while social CC has historically received less attention. The reason for this could be that CC studies have usually been driven by industry or regulators, e.g. low meat yields in bivalve crops, or the need for indicators to evaluate the impact of this activity on the ecosystem. Accordingly, many CC approaches looked at single indicators that are relevant for monitoring the growth and performance of the cultured species, e.g. oxygen (Uribe and Blanco, 2001; Tam *et al.*, 2012), phytoplankton availability (Dame and Prins, 1997), or culture density that optimizes annual yield (e.g. Carver and Mallet, 1990; Bacher *et al.*, 1997; Smaal *et al.*, 1997). More recently, ecosystem-modelling tools were used to estimate limits to aquaculture expansion based on trophic flow limitations (e.g. Jiang and Gibbs 2005; Byron *et al.*, 2011b; Xu *et al.*, 2011; Kluger *et al.*, 2016). These aspects are often most relevant to industry operators and regulators, focusing on the aquaculture activity itself rather than on a broader consideration of the social-ecological system. By neglecting socio-economic considerations and favouring aspects relating to resource and ecological functioning impacts, aquaculture research has so far prioritized the profit-driven, private-dominated sector (Krause *et al.*, 2015).

The historically narrow focus on the aquaculture activity has called for production and ecological rather than social CC, despite early discussions of social CC claiming that society needs to define variables of interest and acceptable limits of change (McKindsey *et al.*, 2006; McKindsey, 2013), handing over responsibility to society to define the acceptability of aquaculture (Byron *et al.*, 2011b). Reducing the use of CC to a single dimension, as done in the past, has been criticized as of little use for decision-making processes and rendering successful implementation of modern management frameworks difficult (McKindsey *et al.*, 2006). The need for societal responsibility to establish multidimensional CC limits inherently increases the complexity of CC estimations, as there is a need to holistically balance multiple activities, sectors, and uses, as well as the integrity of the ecosystem—all of which depend on human values. This complexity is also reflected in the lack of available methods for social CC estimations. While there are many different methods to estimate the other CC categories (see Filgueira *et al.*, 2015), few social CC methods exist that are specifically designed for application in the aquaculture context (McKindsey, 2013). One early idea for estimating social CC suggests the use of fuzzy expert systems that assign functional relations between production levels and acceptability rather than precise numbers (McKindsey *et al.*, 2006). Kite-Powell (2009) presented an economic model of social CC based on a cost–benefit analysis of bivalve aquaculture and other activities and values such as recreational use and aesthetics. More recently, the need for meaningful engagement, and not a simple "box-ticking exercise", with all relevant stakeholders to estimate (social) CC, was emphasized (Little *et al.*, 2013); although the lack of frameworks or case studies to move this forward has been highlighted as a limitation (Weitzman and Filgueira, 2019). This critique is aggravated by the timing at which CC is usually estimated. Rather than before aquaculture implementation, CC estimations are often initiated after cultures are already in place and could—if anything—only buy social licence, unless drastic and controversial measures are implemented, such as the banning of finfish (including salmonids) aquaculture in Alaska (Gross, 2019), or more recently, salmon aquaculture in Washington (Ryan, 2018). Moreover, the majority of all CC approaches follow a steady-state approach, i.e. looking at a single point in time. This, however, neglects the dynamic nature of both ecosystems—responding differently to the pressure of aquaculture development over time due to changing environmental parameters—and human perceptions and values.

Historically, aquaculture development has been carried out without prior systematic planning or any zoning framework (Ferreira *et al.*, 2013), reflecting "old-fashioned" governmental policies that did not include multiple stakeholders, as is now "encouraged" in the decision-making progress (Weitzman and Filgueira, 2019). Acquiring a licence to operate traditionally did not include a social licence, but social acceptance is today given greater consideration, particularly in the Western world (Mather and Fanning, 2019); for example leasing processes usually require community consultations. So far, only a few studies have attempted to adjust CC models and frameworks to target EAA principles (Byron *et al.*, 2011a; Kluger *et al.*, 2016) or to be integrated into broader decision-support systems (Silva *et al.*, 2012; Hermawen, 2018), although those approaches are grounded in the traditional natural science approach and do not fully embrace the need for community engagement. In general, addressing social CC is hindered by a lack of models or frameworks that allow for the exploration of alternative scenarios—a common method for ecological and production CC. A key bottleneck for the development of broadly applicable methodologies is the high relevance that case-specific socio-economic settings play in the decision-making process.

Integrating local dynamics of human uses and values

Local socio-economic settings such as the heterogeneity of a community and the degree to which it depends on aquaculture are relevant to fully understand the position of a community regarding aquaculture. Marine coastal waters are used for shipping, recreational and cultural purposes, harvest of non-living resources (oil, gas, minerals), as well as fishing, among many others activities. Despite the global interactions and effects, aquaculture externalities are mainly felt by local communities (Asche *et al.*, 2016). However, few studies have examined the interactions of aquaculture with other human uses (for examples see Teixeira *et al.*, 2018; Holden *et al.*, 2019). In particular, the physical exclusion imposed by tenure systems can render the societal acceptance of aquaculture complicated (Holden *et al.*, 2019). Based on the nature of a (potential) aquaculture externality, different sectors of society might be concerned, but it should be the human communities that make decisions and set thresholds. Any framework for CC estimations ultimately requires input and approval from all relevant stakeholders and is, hence, *social* in the end (Figure 1).

A first step towards a true stakeholder approach could be defining how nature, i.e. the ecosystem in which aquaculture is proposed, benefits local communities, while identifying all (potentially) affected user groups. The quantification of negative externalities was suggested to represent an important step towards improved management (Ferreira *et al.*, 2013), while benefits (societal, community and individual level) emerging from aquaculture activities should be identified and weighed in as well. At the same time, it is important to analyse whether (potential) aquaculture expansion would cause the exclusion of any actors, be it internal (e.g. excluding certain stakeholders from the decision-making process) or external (e.g. degradation of ecosystem service provisioning) to the aquaculture sector (Krause *et al.*, 2015). This is because, depending on specific local socio-economic settings, history and societal preferences, perception of aquaculture and limits to its expansion might be defined very differently. For example, a community in a Western country whose economy does not completely rely on aquaculture could not be affected by the change in the price of a commodity. In contrast, the high price of the farmed species could be an incentive for a poor community in a developing country to expand the limits of acceptable change from a social CC perspective, i.e. placing less emphasis on potential "side effects" of aquaculture in favour of increased production or economic profit. One example for this is Chilean salmon (Atlantic salmon *Salmo salar*, rainbow trout *Oncorhynchus mykiss*, and coho salmon *Oncorhynchus kisutch*) aquaculture that has grown exponentially since its offset in the late-1980s to peak volumes in 2008, despite severe environmental incidents (e.g. virus outbreaks, eutrophication and harmful algae blooms, specimen escapes) (Niklitschek *et al.*, 2013; Quiñones *et al.*, 2019). A second example is the culture of the Peruvian bay scallop (*Argopecten purpuratus*) in Peru, where aquaculture expansion is motivated by high prices, although deadly accidents of divers working in the production cycle are not uncommon (Kluger *et al.*, 2019).

While local perceptions and social-ecological settings shape the local definition of social CC, national political agendas as well as international prices and international consumer demands can also interact with local aquaculture production and the broader SES (Kluger *et al.*, 2019) and consequently are an intrinsic part of CC definition. Accordingly, one of the key aspects for estimating CC is to incorporate the different stakeholder visions in the definition of limits to acceptable change, which includes a detailed description of uses and non-use values of the ocean, as well as the actual and perceived effects of aquaculture on the receiving environment and human users. The introduction of allochthonous species such as Pacific oyster and Nile perch for culture is a good example for prioritizing economic aspects over environmental. Since the early 20th century, bivalves (in particular the Pacific

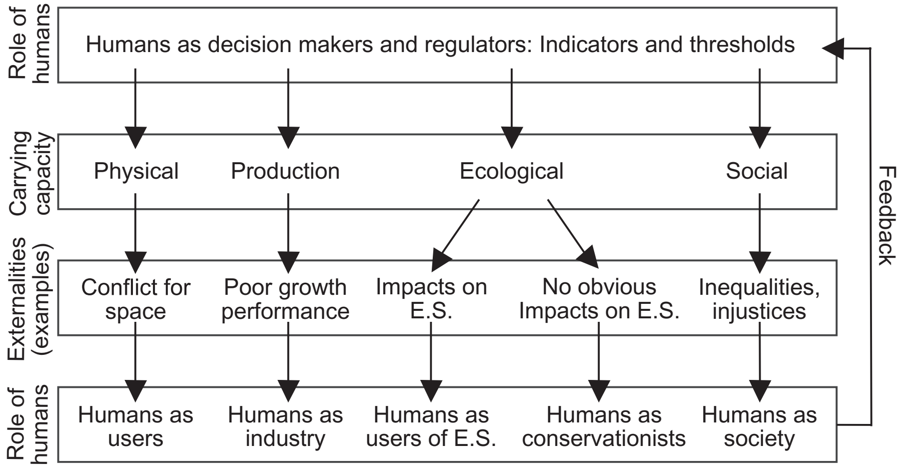

Figure 1. Humans play an integral role in aquaculture carrying capacity estimations and the definition of indicators and thresholds, since any of the diverse social or ecological externalities can produce concerns and feedback for different parts of society that in turn produce outcomes for individual humans. E.S., ecosystem services.

oyster *Crassostrea gigas*) have been transplanted to new countries as to enhance fishery output or to stipulate the development of a new industry (Cognie *et al.*, 2006). But even if a farm causes a minimal impact on the environment, the perceived negative effects on aesthetics could reduce the social CC. Particularly in Western countries, these potential conflicts among uses and values could lead to "Not In My Back Yard" perspectives in some aquaculture sites (Froehlich *et al.*, 2017). The fact that marine aquaculture is carried out in the commons exacerbates the implications of perceived uses and values on determining the CC of the system, making aquaculture management a clear example of a wicked problem (Rittel and Webber, 1973) with no objectively clear and straightforward solution. A wicked problem has "no true or false answers" (Rittel and Webber, 1973, p. 161), e.g. when different parties represent diverging judgments of what is good or bad to tackle a consensual solution to a problem.

Opening up: embracing global social complexity

One common narrative frames aquaculture as the ultimate solution to meeting the growing protein demands of the world's growing human population, particularly when the farmed species belong to lower trophic levels (Olsen, 2011; SAPEA, 2017). Moreover, the booming of the middle class in developing countries such as China has dramatically increased the demand for seafood, boosting even more the so-called Blue Revolution (Whitehead, 2012). The level of aquaculture development varies greatly, however, among and within regions, with the five most important aquaculture producers (China, India, Indonesia, Vietnam, Bangladesh) located in Asia (FAO, 2018, p. 28). A key critique of this development has emphasized that a major share of this production is exported to wealthier consumers in Western markets (Asche *et al.*, 2016), hence not contributing towards local consumption demands. With the exception of Norway, the only developed country in the top ten producers (ranking seventh; FAO, 2018), production and trade data suggest that developed countries have not embraced the Blue Revolution (Garlock *et al.*, 2020). According to the FAO, 59% of global export volumes of fish and fish products (in live weight equivalent) are from developing countries (FAO, 2018, p. 57). An example for this is marine shrimps, typically farmed in coastal areas, with countries of Latin America and East/Southeast Asia accounting for the major share of production by far, while a large proportion of the product is consumed in developed markets (FAO, 2018). Some authors argue that governments in many developing countries have prioritized capital-intensive aquaculture devoted to global markets as a basis for national economic development over more labour-intensive operations characteristic of traditional, extensive, and family-run aquaculture companies (e.g. Krause *et al.*, 2015). As a result, aquaculture development has reportedly marginalized poor people from coastal communities (e.g. Toufique and Gregory, 2008), such that they are being prevented from taking part in this Blue Revolution.

Global value chains of aquaculture products introduce an important complexity into CC estimation processes: scale. Theoretically, CC implies an estimation of the limits of acceptable change at the local scale, with local communities being the ones concerned with and affected by aquaculture externalities. However, globalized markets introduce interactions of value chain actors and consumer demands beyond the aquaculture production system. Restricting the CC analysis to local communities "neglects the organizational reality in a modern globalized world" (Moffat *et al.*, 2016, p. 483). Societal perception (and acceptance) of aquaculture can vary greatly between countries and regions (Froehlich *et al.*, 2017; Kluger *et al.*, 2019), as do the principle arguments around the Blue Growth agenda. At the same time, global trade conceals the social and ecological implications of consumption as production areas and supporting ecosystems are located far away from consumer realities (Deutsch *et al.*, 2011), with little incentive to question local conditions of aquaculture production (Krause *et al.*, 2015). Since aquaculture development is usually driven by local or regional political agendas, limits to its potential expansion ultimately represent a balance between supporting local livelihoods and meeting requirements of other activities and local economies (Kluger *et al.*, 2019). For example, society might support aquaculture growth beyond ecological thresholds if the priority is on food production rather than ecosystem integrity (Kluger *et al.*, 2019), emphasizing the need to construct local limits of acceptable change through a joined societal discourse. In contrast, in parts of the Western world, other uses and values could have a higher weight in the decision-making process than food production (Ferreira *et al.*, 2013). Ultimately, acknowledging the multi-scale nature of aquaculture can set the basis for inclusive decision-making and the construction of relevant policies that embrace potentially important processes (Krause *et al.*, 2015) of local societies in global contexts.

Since aquaculture externalities are mainly felt on the local scale, final markets should ultimately hold no authority to define local social CC thresholds. Coming back to the examples of shrimp aquaculture in developing countries and scallop farming in Peru, negative impacts of these activities in local ecosystems (e.g. mangrove destruction) and societies (e.g. diver casualties) have to be accommodated (and paid for) by local societies. Consequently, CC has a limiting power to capture these global interactions, while other tools such as social licence to operate (SLO, Mather and Fanning, 2019) could play a key role for a socially accepted aquaculture at the global scale. Hence, a comprehensive assessment of sustainable and accepted aquaculture might have to be conducted across a continuum, i.e. considering all relevant stakeholders at local, regional, and global scales (Dare *et al.*, 2014), using a variety of tools ranging from CC to SLO.

Moving forward: framing safe operating spaces from a multi-criteria perspective

We argue that the previously discussed focus of CC approaches on harvest optimization and ecological impact reduction is industry- and regulatory-centred and does not include social externalities of aquaculture development. To address this, we propose (Figure 2): (i) to identify all ecological and social costs and benefits of an aquaculture project as well as all potentially affected stakeholders, (ii) to define the set of site-specific indicators relevant to local societies through a stakeholder process, (iii) to evaluate all stakeholder perceptions and limits of acceptable levels of change for each criteria, and then (iv) to frame a safe operating space for aquaculture operations based on this multi-stakeholder, multi-criteria approach, while (v) applying an adaptive approach, i.e. continuously revisiting, and potentially readjusting, thresholds.

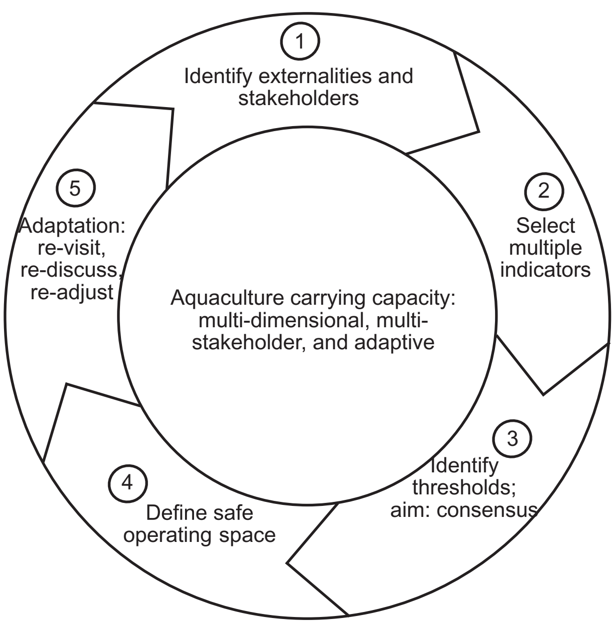

Figure 2. Carrying capacity approaches for aquaculture should follow an adaptive, multi-dimensional, multi-stakeholder approach based on site-specific ecological, economic, and social processes.

Identifying social and ecological externalities of the aquaculture project represents a great challenge (Ferreira *et al.*, 2013), but it is a indispensable process to ultimately identify potential key issues and all relevant stakeholders, and hence set the scale for the CC assessment. Once stakeholders are identified, meaningful engagement measures are required to start the conversation. It is important to reiterate that stakeholder engagement is often criticized as superficial, lacking consideration of marginal voices (e.g. informal groups and institutions that exist in complex real-world settings) and being "more consultative than collegiate" (Little *et al.*, 2013, p. 110).

Based on local priorities, site-specific indicators of ecological, economic, and social processes must be identified following an inclusive process with representatives of literally all stakeholder groups. Moreover, this process needs to be just: power relations, (contrasting) political interests, and different economic constraints between actors must be considered. For example, the voices of small-scale holders, such as small-scale fishers, who share the same physical space than aquaculture operations, often remain unheard (Krause *et al.*, 2015). This implies that stakeholder engagement cannot be a simple "all-in-one" meeting, at which those who dare may raise concerns. Rather, stakeholders must be asked individually and anonymously, to facilitate the free expression of opinions. A key component of this process is trust. The process needs to be led by a respected institution and/or leader who are trusted by everyone. This is important because in some cases, the government has been seen to have a dual and conflicting role as promoter and regulator of aquaculture (Rigby *et al.*, 2017; Milewski and Smith, 2019), though they most often hold decision-making power over such processes. Accordingly, in those situations, a third independent party, a knowledge broker that is trusted and facilitates the communication among different stakeholders, could be a preferred avenue to guarantee the legitimacy of the CC assessment—especially if this broker was a permanent figure, i.e. accompanying the communication process through all relevant steps. The concept of knowledge brokers has been studied in different contexts, e.g. agricultural expansion (Klerkx *et al.*, 2012), land-use planning (Leino *et al.*, 2018), and international development (Cummings *et al.*, 2019), acknowledging that these processes require the contribution from a variety of actors from "diverse fields of knowledge" (Leino *et al.*, 2018, p. 121). Providing such a "linkage building" environment was claimed to facilitate "effective policy formulation and implementation, development and innovation" (Klerkx *et al.*, 2012, p. 53). We would argue that this broker needs to embrace interdisciplinarity and be carefully selected according to site-specific needs as to move beyond normalizing industry action.

The selection of a multidimensional set of indicators by all relevant stakeholders that define a "safe operating space" for aquaculture (*sensu* Tett *et al.*, 2011) is, in our opinion, the way to ensure that all voices can contribute to the conversation and to ensure to holistically embrace all relevant aspects of CC. Even embracing social complexity into CC approaches does not, however, guarantee equity. Ecological and social costs at multiple scales might be identified, but depending on the economic interests of differently influential stakeholders and political agendas, not all voices might be heard in the ultimate decision-making. Again, the figure of a knowledge broker could be key to ensuring the saliency of the CC estimation for all voices. The most controversial step is to define the thresholds of these indicators, in other words, to define how much is too much. Given that some of these thresholds cannot be calculated using a natural applied science approach, mainstream in CC estimations, and rather fit under the realm of human perception and preferences, reaching a consensus could be complicated (McKindsey, 2013). More importantly, uncertainties on these indicators are inherently part of the problem. For example, keeping aquaculture within the resilience of the system according to the ecosystem approach to aquaculture promoted by the Food and Agriculture Organization of the United Nations (Soto *et al*., 2008) was necessary to create awareness for the topic but may be limited in its operationalization (Brugère *et al*., 2019). Given the complexity of social-ecological settings producing aquaculture, the incomplete knowledge of externalities, the stakes of a decision regarding this economic activity, and the uncertainty on indicators and respective thresholds, CC estimations fit within the realm of post-normal science (*sensu* Funtowicz and Ravetz, 1995, 2018). In other words, science for policy advice should embrace complexity by engaging interdisciplinary perspectives and also embrace uncertainty that should be mitigated through transparency, which in turn will ensure credibility.

Whatever approach is ultimately used to define the above-mentioned steps, we believe that the process of CC estimations needs to be framed around the pillars for successful policy and decision-making defined by Cash *et al.* (2002): salience, credibility, and legitimacy. Hence, CC estimations must be relevant to the needs of end users and/or decision-makers (salient) and based on convincing information and analysis (credible), while operating with the endorsement and ideally participation of the main target audience (legitimate). Following these steps, policy objectives and management mechanisms need to integrate socio-economic aspects to achieve politically transparent and socially legitimate aquaculture development (Krause *et al*., 2015). Finally, to cope with these challenges, communication and transparency throughout the process are key (Fox, 2007; Hale, 2008), as is the openness of different players to iteratively revisit agreed-upon indicators and thresholds. Embracing social-ecological dynamics of aquaculture production systems requires dissolving static visions into approaches that proactively take into considerations all potential outcomes these interactions might produce over time.

Conclusion and final remarks

This work contributes to the discussion on CC for aquaculture development by emphasizing how industry-driven (CC approaches have resulted from farmer's concern on growth) and regulator-driven (CC estimations have been explored as a regulatory avenue) approaches to CC potentially exclude other user groups from the outset onwards. Although social CC has gained conceptual momentum, few methods have been proposed in the literature thus far, raising concerns about the general applicability of the concept (Social carrying capacity—the potential for an underrated concept). Approaches need to embrace local socio-economic complexity and the perception of an inclusive set of stakeholders (Integrating local dynamics of human uses and values), while acknowledging international forces (Opening up: embracing global social complexity) that could be explored complementary to local CC approaches, e.g. through SLO. Social-ecological dynamics require interdisciplinary research teams to engage with a multitude of directly and indirectly influenced stakeholders, potentially embracing post-normal science (Moving forward: framing safe operating spaces from a multi-criteria perspective).

When discussing aquaculture development, social CC should be considered not as a priority, but as a necessity. Independent of aquaculture CC, or whether estimation is to be done *a priori* or *a posteriori*, approaches to aquaculture should acknowledge social complexity, as well as the dynamics of social-ecological systems in the context of international forces. Aquaculture operations cannot be considered independent of their surroundings, social and ecological, recognizing the *wicked* nature of this economic activity. The view on their development or expansion is neither white nor black and requires a continuous back and forth and a willingness to reach compromises on the part of the full range of CC estimates.

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