WORKING GROUP ON ECOLOGICAL CARRYING CAPACITY IN AQUACULTURE (WGECCA; outcomes from 2021 meeting)

VOLUME 4 | ISSUE 11

ICES SCIENTIFIC REPORTS

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ISSN number: 2618-1371

ICES Scientific Reports

Volume 4 | Issue 11

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Recommended format for purpose of citation:

ICES. 2022. Working Group on Ecological Carrying Capacity in Aquaculture (WGECCA; outcomes from 2021 meeting).
ICES Scientific Reports. 4:11. 13 pp. http://doi.org/10.17895/ices.pub.10033

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i Executive summary

Management of aquaculture activities using ecological carrying capacity (ECC) is in accordance with an Ecological Approach to Aquaculture (EAA) as defined by the Food and Agriculture Organization of the United Nations (FAO). There are several ways in which EAA has been defined, calculated, and implemented across geographies. Existing methodologies and management schemes were reviewed for ICES areas. The review confirmed that ECC is not uniformly implemented. Many regions are not yet prepared to execute an ECC approach and are still in the data gathering phase to understand production at the farm level. Often implementation of ECC is limited due to existing policy and governance structures of that region. No information was found explaining if and how ECC might change with implementation of integrated multi-trophic aquaculture (IMTA) revealing many data gaps. A brief comment is included in this report on these data gaps. In addition, two manuscripts have been drafted for publication and seeing these products through to publication and distribution is WGECCA's priority for next steps.

ii Expert group information

Expert group name	Working Group on Ecological Carrying Capacity in Aquaculture (WGECCA)
Expert group cycle	3-year fixed term
Year cycle started	2019
Reporting year in cycle	3/3
Chairs	Jeffrey Fisher, USA
	Carrie J. Byron, USA
	Dror Angel, Israel
Meeting venues and dates	9–11 April 2019, ICES Secretariat, Copenhagen, Denmark, 8 attendees in person, none remotely
	27–29 May 2020, online meeting, 13 participants
	23 and 28 April; 3 May 2021, online meeting, 16 participants

1 List of outcomes and achievements of the newly formed WGECCA in their first delivery period (2019–2021)

The work of WGECCA during its first 3-year term focused on examining where ecological carrying capacity is recognized in national aquaculture policy among a host of ICES member states and other significant aquaculture producing nations, and how ecological carrying capacity modelling is (or is not) used in decision-making related to aquaculture developments. This work has resulted in two review papers that are being prepared for publication. These papers reflected aspects of the ToRs initially established for the working group during WGAQUA in 2018, with modifications that evolved the focus of the ToRs to provide concrete deliverables.

To address the ToRs, WGECCA determined it was necessary to start from a working definition of ecological carrying capacity and adopted the definition of McKindsey *et al.* (2006) for our work, where ECC is defined as, "the magnitude of aquaculture production that can be supported without leading to unacceptable changes in ecological process, species, populations, or communities in the environment."

1.1 Product 1: National Strategy and Policy Review

Largely addressing the concept of ToR c, WGECCA conducted an evaluation of national strategy and policy documentation to determine to what degree ecological carrying capacity—or carrying capacity by any definition—was identified in policy documentation, in the paper, 'Ecological carrying capacity in aquaculture: considerations and applications in national and regional strategies and policy'. The key findings of this review are summarized in the excerpted abstract below.

Fisher, J. *et al.* (in prep). ECOLOGICAL CARRYING CAPACITY IN AQUACULTURE: CONSIDERATION AND APPLICATION IN NATIONAL AND REGIONAL STRATEGIES AND POLICY. Prepared for submission to Reviews in Aquaculture.

Abstract

National and regional policies and strategic plans among ICES member states and other major aquaculture producing nations were reviewed for their incorporation of 'ecological CC' concepts as a management tool or permitting requirement for aquaculture development. Aquaculture ecological CC, considered here as, "the magnitude of aquaculture production that can be supported without leading to unacceptable changes in ecological process, species, populations, or communities in the environment," was not strictly applied in any jurisdiction's aquaculture policy documentation, so we broadened our search to consider other CC definitions (e.g. social, assimilative, production). Outreach to regional managers identified additional policy documentation not found through Google Scholar™. National documentation from over two dozen countries were reviewed included concepts of CC in their aquaculture policies, though none required CC modelling for aquaculture development, and the concept in policy documentation was rare. In contrast, regional or local modelling was required for permitting in some countries, typically where marine spatial planning had zoned certain areas acceptable for aquaculture development. Carrying capacity concepts could be enhanced as a management tool through broader incorporation at the policy and strategic planning level, and by reducing the variability of definitions applied among aquaculture producing regions.

1.2 Product 2: Review of ecological carrying capacity modelling applications in mariculture

Early on in discussions among the WGECCA active members on the TORs, it became clear that a review of ECC models, as defined in TOR a, was redundant to recently published works whose focus was on reviewing ECC models currently in application (e.g. Weitzman and Filgueira 2019). As such, WGECCA refined the focus of TOR a to consider how broadly carrying capacity analyses were being applied at the country level, which models were being applied and how, without critiquing the actual models being used. This review took the approach of a 'Horizon Scan', in which a formalized systematic search using the PRISMA approach was applied by WGECCA members assigned to specific regions and/or countries for their analyses. The abstract from this work is excerpted below.

Fisher, J., *et al.* (in prep). ECOLOGICAL CARRYING CAPACITY IN MARICULTURE PART 2: REVIEW OF MODELLING APPLICATIONS IN ICES MEMBER STATES AND BEYOND. Prepared for submission to ICES Journal of Marine Science.

Abstract
We conducted systematic searches of primarily English language literature using the PRISMA approach to evaluate how ecological carrying capacity modelling was applied in the evaluation and management of marine aquaculture operations within ICES member states and other significant global production areas. Modelling of ecological carrying capacity for aquaculture, considered in this paper as, "the magnitude of aquaculture production that can be supported without leading to unacceptable changes in ecological process, species, populations, or communities in the environment" was inconsistently applied in accordance with this definition, and the objectives of studies reviewed often represented an amalgam of study metrics related to production or social carrying capacity, and/or environmental thresholds with some, but often limited relevance to the definition of ECC applied in this study. The PRISMA search using Covidence returned 8,306 non-duplicate articles relevant to our search terms, and 217 were screened for consideration in our analysis. Relative to the definition of ECC we applied, 47 papers published through 2020 referenced or analysed ECC in a context reflective of our operating definition.

1.3 Product 3: Integrated Multi-Trophic Aquaculture (IMTA) data gaps

In its first incarnation as a working group WGECCA, ToR b identified integrated multitrophic aquaculture (IMTA) as a potential means for maximizing ecosystem services from aquaculture, and requested that the group evaluate IMTA applications to identify data gaps and future research emphasis. These discussions lead to a draft work product that identified a series of research questions revolving around 6 themes, including (1) economic viability, (2) marketability, (3) technical feasibility, (4) nutrient loading, (5) ecosystem services, and (6) regulation and governance (Table 1).

Table 1. IMTA Research Questions by Theme

Economic Viability	What assessments have been done on profitability, and how do economists make the case for or against IMTA?
Marketability	Is there a market for IMTA products? If so, where?

	What are the opportunities and constraints for marketing IMTA products regionally?
	How does land-based IMTA compare to sea-based models of IMTA? What are the major differences in these 2 models relative to costs of production, risks and product marketability?
	What species are most marketable for IMTA, by region? How is this marketability determined?
Technical Feasibility	How does land-based IMTA compare to sea-based models of IMTA? What are the major differences in these 2 models? (as above, but focused on aquaculture techniques)
	What lessons have we learned from the “IDREEM” project as regards the overall feasibility of IMTA?
	Do IMTA filter-feeders actually remove detrital particles released from fish farms or do they mostly prefer microalgae or bacteria in the water?
	What are the most common technical/engineering barriers to implementing IMTA?
	What decision support tools are used determine the most suitable biota for culturing on each IMTA farm? What are the biological, chemical and physical criteria involved, and how are they considered in the tools?
	Is IMTA a “fail-safe” practice, and if not, what problems do aquatic farmers need to consider in deciding whether to adopt IMTA over conventional aquaculture? Can IMTA effectively overcome limiting factors at play in a farmer’s monoculture production? Under which scenarios?
Nutrient Loading	How do benthic deposit-feeders fit into the models of inshore and/or offshore IMTA systems? Are there deposit-feeder IMTA solutions for very deep sites, like fjords?
	Do IMTA filter-feeders actually remove detrital particles released from fish farms or do they mostly prefer microalgae or bacteria in the water?
	Is IMTA able to reduce nutrient levels locally? Or is it mainly a means to address nutrification on a basin-wide scale? What empirical evidence exists, in either case?
Ecosystem Services and Mitigation	Can we identify and quantify direct and indirect ecosystem services that IMTA provides or enhances/supports compared with conventional mono-culture (e.g. salmon)?
	What are the ecosystem service benefits of multiple species use at the scale of the farm and at the scale of the embayment? For example, when multiple species are cultured in an embayment, but not on the same farm, are they working in synergy at the embayment scale? How is this best modelled/calibrated? (Should the environmental benefits of IMTA be considered from the standpoint of single farms, aggregations of farms or larger spatial units)?
	Are there any examples of LCAs (?) for IMTA farms? What do they show?
Regulation and Governance	What are the economic, regulatory and property rights implications of managing IMTA involving multiple firms (e.g.: zoning to allow farms growing extractive species to be located near fed fin-fish farms) or basins?
	Can we make the case that the ecosystem services provided through IMTA could/should enable the farm to comply with regulation (e.g. if carbon credits are imposed or there are limits to nutrient release)? What case study examples exist of this in practice? What would be the barriers in considering this within each ICES member state?

Although progress was made in defining research questions, the group did not reach consensus around prioritizing these areas of research, and concluded that addressing the full scope of IMTA as considered in ToR b was beyond the scope of what could be fully considered in its first term. WGECCA has recrafted a ToR for its next term to further address IMTA questions.

The Food and Agriculture Organization (FAO) of the United Nations (UN) has proposed the ecosystem approach to aquaculture (EAA) as a strategy for the integration of aquaculture within the wider ecosystem in such a way that it promotes sustainable development, equity and resilience of interlinked social and ecological systems (Soto, Aguilar-Manjarrez and Hishamunda, 2008). The EAA promotes the efficient use of nutrient resources as well as the opportunity of diverse products and benefits, while reducing impacts, and integrated aquaculture becomes a very important practical way to implement such an approach.

There is a dichotomous tension between the need for sustainable practices (e.g. integrated aquaculture) and intensive, highly efficient systems (monoculture). Whereas farm-scale IMTA probably cannot satisfy both of these criteria, diverse forms of aquaculture (cultivation of both fed and extractive species) practiced at the basin scale is probably a viable solution. There are, nevertheless, a number of gaps that need to be closed to enable integrated aquaculture.

Gaps:

1. How do we define a "basin" (bay? lagoon? cove?); is it a function of hydrodynamics (should probably consult with phys. oceanographer) as well as physical (geographical) dimensions?
2. Integrated aquaculture practices in marine environments must be understood, both by practitioners and by managers / decision-makers.
    - Need to create a short, simple description of the IMTA concept, preferably with graphics to illustrate the concept.
    - Need to also describe environmental & social implications of integrated aquaculture (such as carrying capacity) to counter negative attitudes (educating as a tool against bias based on misconceptions & ignorance) toward these practices.
3. Ecosystem services (ES's) provided by integrated aquaculture need to be described and quantified, and the production cannot exceed the ecological carrying capacity of the basin.
    - Need to define the terminology used & the relevant ES's (not all are relevant) and describe how these ES's may be impacted if we exceed ECC. It will be necessary to emphasize the distinction between Ecological and Production CC as this will reflect on which of the ES's are affected.
4. Risks, financial details (e.g. returns to investment) and economics of integrated aquaculture systems must be fully described and quantified to enable investors, farmers, decision-makers to consider adopting these practices, to include and consider ecosystem carrying capacity – this will be challenging to encompass, but is a worthwhile undertaking, seeing as there are clear benefits in the adoption of this technology, but there are also risks that must be described and recognized.
5. Likelihood (risk) of disease transmission (this may also be defined in terms of carrying capacity) between different aquaculture systems needs to be defined to convince stakeholders to adopt integrated practices – may want to consult with someone in the ICES Working Group on Pathology and Diseases of Marine Organisms (WGPDMO)
6. Legislative and regulatory aspects of basin-scale aquaculture need to be assessed on a country by country level in order to establish an EAA in "aquaculture basins" (zones) – this will necessitate a review of relevant literature; probably outside the scope of this paper, but we could provide a case study to illustrate how this is done.
7. The proper balance of fed and extractive aquaculture species and biomasses (AKA Carrying capacity) in each basin needs to be determined ad hoc, in accordance to local environmental (and ecosystem) conditions – this is a modelling exercise, and we need to

search for a basin where this may be done. It will be good to describe the process using a case study (with sufficient bio-phys-chem data) to illustrate the approach.

8. Markets for the IMTA products are essential before producers and investors can consider integrated practices – an example of market assessment for key IMTA products (e.g. *Saccharina sp., Mytilus sp.*) will be given to illustrate this aspect of financially sustainable integrated aquaculture.
9. Incentives such as eco-labelling of IMTA products will be explored to encourage adoption of IMTA, and these may include language related to carrying capacity – this should involve interaction with such certification schemes as the Aquaculture Stewardship Council (ASC), and understanding what is involved in compliance with ASC and other certification standards.
10. Technological gaps need to be closed, where necessary, to enable integrated aquaculture – the technological challenge exists mainly for species that have not been farmed before, or if they have, the challenge may involve how to do it better, more efficiently and more sustainably so that the principles of ecological carrying capacity are upheld.

2 Progress report on ToRs and workplan

ToR a – Review existing and developing methodologies for predicting and assessing the carrying capacity of the ecosystems at different geographic scales and strategies for environmental sustainability of aquaculture.

A comprehensive review of if and how ECC is applied to aquaculture management is included in the Horizon Scan paper (product 2). A second paper focused on the policy around implementation of ECC helps to explain some of the hurdle in implementation of ECC in different geographies (product 1).

ToR b – Considering divers aquaculture production methodologies, including IMTA, explore those which provide enhanced ecosystem services and or may impact carrying capacity for aquaculture.

Insufficient data and research has been done to fully address this ToR as articulated. A short comment has been drafted to identify the research and data gaps that need to first be filled before addressing this larger issue across space and geography.

ToR c – Develop international guidelines on loads and combinations of loads (indicators) from aquaculture and its possible remediation.

The Horizon Scan paper acknowledges that environmental indictors can be and have been used to assess ecological carrying capacity for aquaculture and these are discussed where identified.

ToR d – Analyse and describe current monitoring practices related to environmental concerns.

Much of this work has already been done outside this working group and was recognized as the key focus of WGEIA. Though monitoring aspects applied are detailed in the Horizon Scan paper for some regions where it is relational to carrying capacity, a detailed analysis of national environmental monitoring components was not conducted.

ToR e – Review stats and potential for low trophic level (LTL) aquaculture

LTL species are addressed in the IMTA comment as all successful models of IMTA include at least one LTL. In this way ToR b and e are linked. LTL species are a focus of our new TORs for the next term.

3 Revisions to the work plan and justification

WGECCA would like to continue this work into the next 3–year term. There is still additional work that can be done to more fully address ToRs c–e at this time. We will need to see the above-mentioned products through the revision and publication process. We would like to invite additional members with varied expertise from other WGs to help us more fully address our ToRs.

Annex 1: List of participants

WGECCA 2021 Meeting

Name	Institute	Country (of institute)	Email
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WGECCA 2020 Meeting

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WGECCA 2019 Meeting

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Annex 2: WGECCA resolution

Working Group on Ecological Carrying Capacity in Aquaculture (WGECCA)

2018/MA2/ASG07 A **Working Group on Ecological Carrying Capacity in Aquaculture (WGECCA)**, chaired by Jeff Fisher, Ireland, and Carrie Byron*, United States, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2019	9-11 April	ICES HQ, Copenhagen, Denmark	Interim report by 1 August	
Year 2020	27-29 May	Online meeting	Interim report by 26 June	Additional Chair in 2020: Carrie Byron, United States
Year 2021	26, 28 April; 3 May	Online meeting	Final report by 21 June	

ToR descriptors

ToR	Description	Background	Science Plan codes	Duration	Expected Deliverables
a	Review existing and developing methodologies for predicting and assessing the carrying capacity of the ecosystems at different geographic scales and strategies for environmental sustainability of aquaculture.	Building on work carried out by WGAQUA on benthic impacts on soft bottoms, it was appreciated that a review on drivers of ecological impacts, habitat sensitivity and current assessment methodologies is required. It will also be important to define the different carrying capacities approached (i.e. carrying capacities for what? Single species, multiple species, ecosystem based?), as well as to define which indicators can be used to assess these. Models may need to be created, or existing models applied, to balance different loads in any given system, and the working group will attempt to resolve and rationalize how such loads should be balanced.	5.5, 5.6	year 1	Review paper
b	Considering diverse aquaculture production methodologies, including IMTA, explore those which provide enhanced	Integrated Mult-Trophic Aquaculture (IMTA), both as an aquaculture production method and as a means to consider the use of different trophic componants in	5.5, 5.6, 5.8	Year 1	Prioritized list of research to elucidate knowledge gaps as part of WGECCA's

	ecosystem services (nutrient/carbon management, habitat value, etc) and/or may impact carrying capacity for aquaculture. Conduct an analysis of the effect on carrying capacity at the basin-scale, where trophic level interactions of different species occupying the same marine area may impact carrying capacity for aquaculture. WGECCA, through international cooperation and the shared experiences of its members will focus on prioritizing thematic areas that would be highly beneficial to address in future research.	an ecosystem as mitigation, or to provide enhanced ecosystem services (nutrient/carbon management, habitat value, etc.) is high on the agenda in several aquaculture producing countries. Analysis of the effect on carring capacity from Basin Scale Integrated Multi-Tropic Aquaculture (BSIMTA), where trophic level interactions of different single species trophic level industries produce different trophic level products yet occupy the same marine area is needed. WG ECCA, through international cooperation and the shared experiences of its members, will focus on prioritizing thematic areas that would be highly beneficial to address in future research.			annual reports in 2019
c	Develop international guidelines on loads and combinations of loads (indicators) from aquaculture and its possible remediation.	The concept of carrying capacity is a measure to describe how a high biological load of single or multiple species may affect production of the cultured species and/or other species using the same habitat. It must be calculated within a specific spatial area—either locally or regionally, and uncertainty of measurement can be greatly affected by the spatial area to which the calculations are applied. WGECCA will need to define the different types of loads that could/should be considered, and how—recognizing that the answers to these scenarios will vary by the spatial scale of analysis, and in different geographic areas. In any given area at any given time, there will be a balance between different loads present, but often one being dominating.	5.5, 2.1	5.6, Year 2	Deliver final report in 2020 as part of annual WGECCA report.
d	Analyse and describe current monitoring practices related to environmental concerns. Review mass balance and other modelling of nutrient flow between multi trophic levels (farmed and wild) and in circular systems to consider how such	An analysis of current monitoring practices used by ICES member states would help to reveal geographic trends in environmental concerns related to local aquaculture activities. This analysis would indicate if monitoring objectives are consistent and would help to identify any commonality in the setting of regulatory thresholds for	5.5, 3.2	5.6, Year 2 & 3	Deliver progress report in 2020 and final report in 2021 as part of the WGECCA annual report

	modelling can be applied to carrying capacity estimations in a multi-trophic landscape.	managing environmental status and impacts. Similarly, models, where applied for consideration of environmental concern, energy transfer, etc., should be analysed for their accuracy and their value as decision support tools.			
e	Review status and potential for low-trophic aquaculture.	A substantial increase in sustainable marine aquaculture production may be enhanced by further development of low trophic level aquaculture. WGECA aims to evaluate this potential in the shared waters of ICES member states including sea urchins, bivalve shellfish, macroalgae, polychaetes. Opportunities and constraints by regional sea will be the focus of the analyses.	5.5, 5.8	Years 2&3	Deliver progress report in 2020 and final report in 2021 as part of the WGECCA annual report

Summary of the Work Plan

Year 1	One term of reference a) review existing and developing methods for assessing carrying capacity and will be finalized and b) Recommendations for prioritized research to elucidate knowledge gaps in use of IMTA and other mitigating practices will be initialized.
Year 2	Term of reference b) and c)Development of international guidelines on loads and combinations of loads (indicators) will be finalized and terms of reference d) monitoring practices and e) low trophic aquaculture will be initalised.
Year 3	Term of reference d) and e) will be finalized and the final report will be submitted.

Supporting information

Priority	The activities of this Group will continue to lead ICES into the key scientific issues related to aquaculture – ecological carrying capacity including lower trophic aquaculture, use of aquaculture to enhance ecosystem services etc., with a main focus to lay the scientific foundations for further sustainable aquaculture growth. The subject of ecological carrying capacity, and how to address it appropriately, has become fundamental to permitting decisions. Permitting decisions affect the potential for aquaculture to realize its potential in member states waters where ICES operates. ICES, and the expert working group framework it has developed, is particularly well poised to develop the international best practices for considering ecological carrying capacity in aquaculture permitting and its relationship with spatial planning. Such guidelines are needed if the sustainable aquaculture goals identified by respective ICES Member States are to be realized. Consequently, the activities of WGECCA are considered to have a high priority.
Resource requirements	Meeting logistics
Participants	The Group is normally attended by approximately 10 -20 members and guests.
Secretariat facilities	Meeting rooms at the Secretariat will be required
Financial	No financial implications envisaged for ICES.

Linkages to ACOM and groups under ACOM	Products produced will establish an example of the types of advice countries will need to manage aquaculture to maximize ecosystem services and growth targets sustainably. Outputs may also have direct implications for governments working on nutrient and/or carbon trading systems. Habitat creation and nutrient management will have positive implications for wild capture fisheries.
Linkages to other committees or groups	There is a very close working relationship with all the groups of the Aquaculture Steering Group. We will seek to form links with the Working Group on Socio-Economic Dimensions of Aquaculture (WGSEDA) Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM), Working Group on Environmental Interactions of Aquaculture (WGEIA), and the Working Group on Scenario Planning on Aquaculture (WGSPAQ). It is also very relevant to the Working Groups, WGHABD, WGITMO, and WG Benthic Ecology.
Linkages to other organizations	OSPAR, NASCO, EAFP, EFARO, EATiP, FAO, EU (EUMAP regulation), NOAA, DFO