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Theme session Report

Sustainable aquaculture in a changing world

Conveners: Neil Ruane (Ireland), Julie Maguire (Ireland), Mike Rust (United States)

INTRODUCTION

Aquaculture (the production of finfish, mollusc and seaweed) has the potential to play an increasingly important role in global food security. In Europe and North America, development of aquaculture has been possible due to advances in technology and improved husbandry practices, making aquaculture not only a key industry in the provision of high-quality food, but one of the more sustainable and low carbon sources of animal protein. However, significant challenges remain in further reducing the impact of an expanding industry on the coastal environment and managing the increased competition for use of the coastal zone while meeting the challenges imposed by climate change.

This session looked at how aquaculture is meeting these challenges, how recent technological and best practice developments have transformed food production and how aquaculture can exist in harmony with other users of the coastal zone.

SESSION SUMMARY

The session focused on three key areas impacting the sustainable development of aquaculture, namely climate change, environmental impacts and production challenges. The session consisted of 13 oral and three poster presentations all of which were hosted on the conference app.

The session opened with a discussion on integrated multi-trophic aquaculture (IMTA) and the reasons why it is still not at a commercial scale within the ICES region, despite the potential benefits outlined in a number of the presentations. The majority of marine aquaculture within the ICES region is based on monoculture and is well developed and technically advanced. At present the impetus for IMTA comes from regulators & academics, and not the industry itself. There is still a need to quantify risks, highlight the advantages both environmentally and socioeconomically as well as a requirement for the provision of practical training in the cultivation of multiple species. Assessing the impacts of IMTA to meet strict environmental regulations is a challenge, and there is a role for the scientific community, potentially through ICES, to bring forward and convince the industry and the public that IMTA is a viable option. Previous studies have already shown that public opinion is more favourable towards IMTA than monoculture. One idea proposed was putting a monetary value on nutrients, such as nitrates, and quantifying the remediation potential of low trophic species to offset nutrient inputs.

Further discussions centred around the issue of climate change and how it is impacting on the aquaculture sector. A detailed example was provided in relation to harmful algal blooms (HABS) in Ireland where HABS show regional changes in population structure with some blooms e.g. *Alexandrium* sp., occurring over more prolonged periods in recent years resulting in extended closure periods for shellfish aquaculture. There is a need for many of the long-established monitoring programmes in place in many countries to include climate aspects. ICES is answering the challenge to ensure that climate-awareness is included in the advice products produced on a consistent manner. To this end the Workshop on Pathways to Climate-Aware Advice (WKCLIMAD) was convened and is working on this at present.

From a social perspective employment in aquaculture is not seen as attractive by young people who have more options available to them in other sectors. We often hear of fishing communities but not aquaculture communities. In many countries, the industry is dominated by a number of large multinational companies, however they can still play a role in providing employment and are key for the sustainability of isolated rural communities with important economic (employment) and social (schools, sports clubs) benefits.

The session wrapped up with a short discussion on what role ICES can play in developing independent advice on aquaculture related issues. The 2016 ICES WKCULEF report (workshop on possible effects of salmonid aquaculture on wild Atlantic salmon populations) was highlighted as a good example of this. ICES is also producing a range of aquaculture overviews which are seen as important documents containing a comprehensive review of aquaculture, including important socio-economic aspects, within the ICES regions. Finally, it was suggested that advice products looking at the positive aspects of aquaculture are lacking and an opportunity exists in this area.

Contents

CM 12: Environmental interactions with an offshore, long-line mussel farm and its conservation potential

Llucia Mascorda-Cabre, Phil Hosegood, Martin Attrill, Emma Sheehan

Bivalve aquaculture has traditionally been established in shallow, sheltered waters in inshore areas generating notable negative environmental impacts due to the accumulation of waste products. The recent global expansion of the offshore industry is perceived to have a lower environmental impact coupled with a higher growth potential. As ecosystem engineers, mussels can positively contribute to marine ecology through carbon storage, nutrient remediation, coastal defence and enhancing biodiversity. Hence, the development of offshore aquaculture has the potential to provide one of the most sustainable sources of protein to feed our growing population.

Since 2013, the University of Plymouth has been monitoring the UK's first large scale offshore mussel farm in Lyme Bay, UK. Using a range of underwater survey vehicles and sampling techniques (Towed Video Array, BRUV, ROV, PelagiCam, ADCP or sediment grabs), the study has been valuable in showing the farm's potential to increase ecosystem value and contribution to the production of the area. Results to date show large aggregations of benthic and pelagic organisms beneath and around mussel ropes relative to control sites. The farm is acting as a fish aggregation device (FAD), shelter, refuge, nursery, food source and increasing the integrity of the ecosystem by creating a hard-bottom reef-like habitat in historically heavily fished ground.

Offshore mussel farms such as the Lyme Bay present the exclusion of fishing activities (mobile and static gear) from farmed grounds, which may not only provide the potential to enhance both commercial and non-commercial species producing a spill over effect but, present the prospect for benthic habitats to be restored to previous state, serving as a de facto MPAs.

As marine biodiversity continues to decline, it is paramount to reconcile nature conservation and the sustainable development of the oceans. If we want to meet international marine conservation targets such as Aichi and the SDGs, the Blue Economy and in particular, aquaculture as the fastest growing food industry, must move forward together. Offshore mussel farming might be preferable to other destructive extractive activities happening in multi-use MPAs and PPAs whilst it presents as a sustainable alternative to overfishing. With the prospective to recover damaged habitats, boost ecosystem services and provide effective *in-situ* conservation of biodiversity if effectively managed, offshore mussel farms may have the ability to become part of a wider marine conservation strategy. With this in mind, the Lyme Bay mussel farm was used as a case study on the ICES/IUCN-CEM-FEG Workshop on testing OECM practices and strategies. Improving our understanding of offshore aquaculture–environment interactions is crucial to identify the priorities needed for future research to inform aquaculture conservation policy and management practices as well as its role as part of the Blue Growth Agenda and their potential as OECMs.

Keywords: Offshore aquaculture, mussel farm, ecology, oceanography, food security, OECM, conservation

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CM 61: The potential of IMTA (Integrated Multi-Trophic Aquaculture) for sustainable aquaculture development?

Frank Kane, Pauline O'Donohoe, Joanne Casserly, Neil Ruane

Aquaculture is recognised as a promising source of seafood and plays a key role in providing valuable employment in rural communities. However, aquaculture faces future challenges to meet this demand and to minimise environmental impacts. It is recognised that the environmental performance of the EU aquaculture sector can be improved by promoting the development of IMTA. IMTA, involves the farming of multiple aquaculture species, from different trophic levels, in an integrated system. IMTA mimics the functioning of natural ecosystems, and elements of the externalities of fed mono-culture are internalised in the IMTA system, improving the overall sustainability and economics of farms. IMTA allows a reduction in the environmental impact; a diversification of produce; an increased biomass production from the same area; reduced investment risks; job creation; improved consumers perception; as well as supporting sustainable aquaculture and the circular bio-economy.

There is currently significant interest in the concept within the ICES region, from research and industry, and IMTA has received considerable attention through a series of international projects funded through the EU Framework and INTERREG programmes. IMTA offers potential for the eco-intensification of aquaculture, utilising available space and infrastructure more optimally, enabling an increase in biomass production under a lowered environmental footprint. However, IMTA development is challenged by regulatory and administrative burdens as well as site management, economic, and investment backing with the result being that there has been very little commercial adoption.

These issues will be discussed along with an outline of how we can change the paradigm in order to bring IMTA to a commercial reality and meet the requirements of sustainable development to successfully diversify aquaculture, and implement the Green Deal and Blue Growth strategies.

Keywords: integrated multi-trophic aquaculture, circularity, low trophic, seafood

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CM 77: New sustainable and profitable value chain systems for IMTA production in the Atlantic region - ASTRAL

Pauline O'Donohoe & Joanne Casserly

ASTRAL (All Atlantic Ocean Sustainable, Profitable and Resilient Aquaculture) seeks to increase value and sustainability for Integrated Multi-Trophic Aquaculture (IMTA) production by developing new, resilient, and profitable value chains. In IMTA production, multiple aquatic species from different trophic levels are farmed together. Waste from one species is used as inputs (fertilisers and food) for another species. The IMTA process will be used at 4 'labs' in Scotland, South Africa, Brazil and Ireland. A prospective IMTA lab will also be assessed for future production in Argentina.

Potential climate risks and emerging pollutant (micro-plastics, HABs, pathogens) will be assessed, together with the development of production techniques and innovative technology to monitor the production and the interactions from/to the surrounding environment (sensors and biosensors, IoT, and AI data analytics). ASTRAL goals include the increase of circularity and the achievement of aquaculture systems towards zero-waste.

Objectives of ASTRAL IMTA Labs:

BRAZIL → Explore the feasibility of the integration of *Litopenaeus vannamei* (white shrimp), *Oreochromis niloticus* (tilapia), *Crassostrea gasar* (oyster), *Ulva fasciata* (seaweed) and *Salicornia neei* (sea asparagus) in with a biofloc system.

SOUTH AFRICA → Develop IMTA in land-based pump ashore system for abalone (*Haliotis midae*) and Ulva spp. Develop culture technology to produce sea urchin *Tripneustes gratilla*. Develop the use of waste from Cape sea urchin (*Parechinus angulosus*) as a feed/probiotic of juvenile abalone.

IRELAND → Produce Atlantic salmon (*Salmo salar*); lumpfish (*Cyclopterus lumpus*); native oyster (*Ostrea edulis*); great scallop (*Pecten maximus*); kelp (*Saccharina latissima, Alaria esculenta*); spiny sea urchins (*Paracentrotus lividus*) and European lobster (*Homarus gammarus*) to mimic the natural ecosystem where different animals and plants/seaweed benefit from growing in proximity to each other.

SCOTLAND → Develop new IMTA value chains by conducting cultivation trials to improve productivity and inform best practice for kelp *(Alaria esculenta, (Saccharina latissima)*; Oarweed *(Laminaria digitata)*; Dillisk (*Palmaria palmata)*; European flat oyster *(Ostrea edulis)*; and *Mytilus spp.* (*Pecten maximus).*

ARGENTINA → Investigate the best combination of native species from the Beagle Channel to be used in IMTA: biological aspects, local market, legal regulations, and social acceptability.

The ASTRAL project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 863034

Keywords: IMTA, circularity, seafood, production technology

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CM 125: How does rearing regime shape the metabolic phenotype of Atlantic salmon in commercial aquaculture?

Elizabeth Ryder[A], Karl P. Phillips[B,D], Philip McGinnity[A,B], Fintan Egan[A], Jamie Downes[C], Alan Drumm[A], Neil Ruane[C].

Individual organisms vary in their metabolic rates. This variation, in turn, may underpin variation in life-history strategies. Many traits associated with these strategies, such as specific growth rate, feed conversion rate, body mass, and general health, are of high value to commercial farming, including commercial aquaculture. Understanding how different aquaculture regimes shape metabolic phenotype thus has the potential to enhance productivity and improve fish welfare. Here, we investigate how two different rearing regimes – Recirculation Aquaculture System (RAS) technologies and the conventional flow-through methods – may shape fish standard and maximum metabolic rate in commercial aquaculture Atlantic salmon. RAS allows for full environmental control of the water in which the fish are produced for limited water exchange, with water quality maintained through a series of mechanical and bio-filtration units. Such control over parameters enables fish growth and production to occur in optimal conditions. In contrast, the traditional flow-through system extracts water directly from a water source (Lough Feeagh) and is gravity-fed through circular rearing tanks in a single pass before circulating and discharging from the tanks. The flow-through production system is subject to the influence of the external environment which cannot be controlled. By understanding the metabolic response of individual fishes within a controlled environment versus conventional rearing methods, will inform strategic frameworks for the sustainable development of the finfish aquaculture industry in the future.

Keywords: respirometer, metabolism, aquaculture, rearing regimes.

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CM 208: Novel sustainable aquafeeds for improved fish stocks

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AquaTech4Feed is a project that aims to formulate novel fish feeds from alternative proteinaceous biomass sources in order to improve fish production and quality. The aquatic freshwater plant Lemna gibba farmed in aquaculture wastewater, the macroalga Alaria esculenta, the microalga Nannochloropsis gaditana and the black soldier fly larvae Hermetia illucens are the novel ingredients tested on Salmo salar smolts. In a first experiment, 7% of the four ingredients were added to the standard feed in four different dietary treatments. Fish growth, mortality, feeding behaviour and feed conversion rate were assessed in fish fed with the feed containing the alternative ingredients and compared with the fish fed with standard feed (control). Viscerosomatic and hepatosomatic indexes were also assessed. There was no difference among the dietary treatments tested in any of the parameters assessed. In a second experiment, conventionally used diet was supplemented with A. esculenta biomass to test its bioactive potential. In this trial, four different dietary concentrations of A. esculenta (0.5,1, 2 and 3%) were tested. Moreover, fishmeal content in the feed was reduced from 17 to 4.25%, and it was replaced with L. gibba and H. illucens. Those feed formulations were tested on rainbow trout Oncorhynchus mykiss.

AquaTech4Feed was funded by ERA-NET BioBlue Cofund.

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CM 259: Capturing climate conversations & concerns with the US aquaculture industry through farm-level discussions, some preliminary survey results, and how they might be used in the decision-making process and policy development

First author: Daniel Wieczorek

Co-author: Sally McGee

While aquaculture production continues to grow and take more of the global seafood market, so do the concerns for potential impact and interruptions to that growth from climate change. We intend to show that industry is aware and concerned about their becoming increasingly vulnerable to warming waters, diseases and harmful algal blooms, acidifications, and more frequent storm events, and in some cases, ready to act. Information contributing to decisions can come from a variety of sources. Currently, decision-making, policy development, or fund allocation is supported mainly by research conducted by government agencies, academics, or industry scientists in the form of science advice products. These can also be driven by industry coalitions that partake in lobbying activities. Additionally, boundary organizations, interagency organizations, non-governmental organizations (NGOs), and industry contribute synthesized information. Journalists, NGOs, industries, and governmental agencies also contribute information about the human consequences of climate change by focusing on the personal experiences of coastal resource users and the economic impacts of their work. Ideally, we should have ecosystem-scale, spatially explicit projections of climate change's effects on specific geographic regions and species, as well as production and market impacts for both industry and decision-makers to utilize. And while climate forecasts are forthcoming for particular times and places, not all possible consequences on specific marine populations, ecosystems, and species can be predicted accurately. Without that kind of inclusive end-to-end information, decision-making must proceed with the best and most applicable information possible. Here we intend to describe additional pathways information can take in the form of direct communication through on the ground, person-to-person contact with farm-level producers, as well as focused surveys to collect data directly. For the past six months, we have been engaging the US aquaculture industry through visits, conferences, and a survey to capture their aquaculture industry farm-level concerns for climate change. Our survey was designed to capture their concerns but also their actions and overall understanding and readiness level in regards to climate change. Through these efforts and participation through collaborating agencies, we can put these concerns and actions directly in the hands of those who can translate them to the format policymakers and resource managers need to address them.

Keywords: Industry Engagement, Aquaculture, Climate Change, Decision Making

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CM 264: Implications of the ICES workshop on pathways to climate-aware advice (WKCLIMAD) to aquaculture - a call to action!?

First author: Michael Rust

Co-authors: Kirstin Holsman, Mark Dickey-Collas, Seth Theuerkauf, Michelle Rub, Clifford Cosgrove.

How do we make sure climate-awareness is consistently included in ICES advice products across fisheries, aquaculture and ecosystems, and develop a system to repeat this input over time? The Workshop on Pathways to Climate-Aware Advice (WKCLIMAD) tested a Delphi-based approach to gather ICES experts' opinions on the impacts of climate change (negative and positive) on fisheries and aquaculture, and to articulate possible mitigation and adaptation strategies. The Delphi method is a structured communication technique that allows for arrival at a quantitative group decision through surveying a panel of experts, providing a snapshot of the group average opinion and a measure of variability. It is both a robust process and a relatively straightforward one. It also proved to work well in a virtual format with existing online tools. Participants advanced 28 impacts for fisheries and 33 for each segment of aquaculture (finfish, shellfish and algae). Adaptation and mitigation options were approached differently by each sector as they addressed different impacts and considered different time horizons. Final data submission for fisheries experts ranged from an n = 17-19 for impacts, adaptations and mitigations out of about 45 fisheries workshop attendees, however only an n = 5-7 were recorded from the 7-10 aquaculture attendees. It was also noted that the diversity of expertise needed for aquaculture was underrepresented. Obtaining meaningful data for sub-topic areas such as climate change impacts or potential adaptation measures on aquaculture diseases separate from genetics or feeds for example, was not possible due to a lack of more than one or two experts in each of those fields. Likewise expertise in finfish, shellfish and algae was uneven. No expertise in key areas such as industry, economics and social impacts was represented. Thus this presentation is a call to action for aquaculture focused expert groups. We hope to discuss the options for expert groups to use this methodology to produce aquaculture specific climate awareness for their own sub topics (health, genetics, economic, social systems, feeds, risk, engineering, etc) that can be aggregated to cover aquaculture more completely. We will also discuss the option to form a new climate focused aquaculture expert group to assist in this process and develop additional Terms of Reference.

Keywords: Advice, Aquaculture, Climate Change, WKCLIMAD

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CM 282: Assessing the risk of climate change to aquaculture in Oman

Georg H. Engelhard, Ella L. Howes, John K. Pinnegar, Will J.F. Le Quesne

Aquaculture is is crucial for world food security, yet climate change causes substantial risks. These may impact through a variety of mechanisms varying by location and aquaculture type with implications for future productivity. Understanding the risks that climate change poses on different culture systems in different locations is important to enable the design of targeted adaptation and resilience building actions. We provide a framework for assessing risks from climate change to aquaculture, applied to the aquaculture sector of the Sultanate of Oman, that identifies the sensitivity and exposure of different components of the sector to climate change risk. Oman has aspirations to significantly expand aquaculture but is also situated in one of the hottest regions on earth. The focus is on coastal shrimp ponds, finfish sea cages, land-based recirculating aquaculture systems, and ponds and raceways. We quantify overall climate risk as the combination of four risks: (1) species' temperature sensitivity, (2) flooding and storm surge exposure, (3) low-oxygen hazard and (4) disease vulnerability. Shrimp culture is identified as highest risk due to high exposure of shrimp ponds to flooding and storm surges, and high disease vulnerability. Seabream cage farming also faces high risk due to high thermal sensitivity and high potential of low-oxygen levels affecting sea cages. Following the risk assessment a stakeholder workshop was conducted to identify targeted adaptation measures for the different components of the sector. The framework for assessing climate risk to aquaculture demonstrated here is equally applicable elsewhere in the world at regional, national or sub-national scales, to support design of targeted resilience building actions and enhance food security.

Keywords: climate adaptation, aquaculture, climate resilience, climate risk assessment, food security, Sultanate of Oman, seabream culture, shrimp culture

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CM 342: An innovative approach to sustainable aquaculture planning: Case study - Canary Islands

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In this contribution, we define and test a novel methodological approach for introducing or extending marine aquaculture facilities within a maritime space. A methodology was defined for implementing maritime spatial planning (MSP) processes and applied in the Canary Islands archipelago, in Eastern Atlantic Ocean, tested along almost 2000 km of the coastline and across the coastline more than 50.000 km^2 of related offshore areas.

The innovative methodological approach was designed to identify marine areas suitable for aquaculture considering 5 clusters analyses:

1. Identify significant potential considering physical oceanographic parameters (temperature, depth, currents, …) obtained by Copernicus Marine system;
2. Minimize the impact on the marine environment (spatial information structured following Good Environmental Status defined by Marine Strategy Framework Directive 2008/56/EC);
3. Search for (in)compatibility with marine conservation (analyzed marine protected areas under the Natura 2000 and related European Environment Agency database);
4. Analyze coastal land use for Land-sea interactions, avoiding conflicts and searching compatibilities with coastal sectors using CORINE data set provided by Copernicus Land Monitoring Service) and
5. Analyze operative maritime activities, avoiding conflicts and searching multiuse compatibilities potential with aquaculture (EMODnet Human activities data portal and local databases).

We have identified marine areas with significant oceanographic potential, minimal impact on the marine environment, compatibility with marine conservation, and conflict avoidance with other maritime and coastal sectors. To find a balance and superpose all the five clusters analyses, reflecting on Ecosystem Based Management components, we introduce a series of weights to reflect optional trade-offs regarding sectorial growth, conflict prevention, and environmental protection and conservation.
Aquaculture suitability maps were developed based on the outputs of the INDIMAR decision support system, adjusting the aquaculture site relation to each considered parameter/cluster, and related weight that we calculated using an analytical hierarchy process.
Finally, results are compared with the aquaculture designated areas included in the recently approved Spanish National Maritime Spatial Plan, and the Canarias Regional Plan of Aquaculture Zoning approved in 2018.

Keywords: aquaculture, suitability maps, maritime spatial planning, decision support system, analytical hierarchy process.

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CM 431: Combining population models and larval dispersal – a tool for sea lice management

John P. Phelan, Michael T. Burrows, Keith Davidson, Alexander G Murray, Philip A Gillibrand, Thomas Adams

Control of sea lice, *Lepeophtheirus salmonis,* is one of the key management priorities for salmon aquaculture operators. The dispersal of sea lice larvae is driven by local hydrodynamic conditions. Understanding this movement is essential when looking at how aquaculture sites may be connected, with consequent impacts on the population dynamics of sea lice on their farmed salmon hosts.

We developed a sea lice population model which integrates on-farm dynamics with dispersal driven by local hydrodynamics, with the goal of investigating and disentangling the many factors affecting population development. Connectivity between sea lice populations on farms is driven in part by dispersal patterns and biological constraints. Infection rates derived from this dispersal model have been included in models of sea lice populations at farms at three interconnected sites as an example of a small network. The abundances of sea lice at each stage on farm sites were used to calculate the daily number of viable larvae being released from each site. The total number of larvae and the relative abundances of infective lice arriving in the vicinity of each site were used to infer an absolute infection pressure. Analysis of deviance gives insight into model performance, estimating development rates of stages, mortalities, and successful attachment rates for sites. Understanding the rates of arrival (and subsequent attachment) of larvae using quantitative predictions will help identify key points in the production cycle where preventative measures would be best applied.

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CM 439: Understanding Climate Change - effects on Harmful Algal Blooms and impacts on aquaculture sustainability

Dave Clarke, Henrik Enevoldsen, Elisa Berdalet, Eileen Bresnan, Tsuyuko Yamanaka, Caroline Cusack

Climate change effects on marine ecosystems is an ever-increasing concern, particularly on the future sustainability of aquaculture practices involved in the production of finfish and shellfish. Aquaculture is considered as an important protein source that can help meet the increasing demands of the growing global human population. An array of climate change effects is anticipated including those associated with physical, biological and chemical changes affecting stratification, temperature, ocean acidification, and salinity. These parameters can influence alterations in phytoplankton distribution, composition and growth season ranges, including species which cause Harmful Algal Blooms (HABs) and produce toxins affecting aquaculture harvesting. Other climate change effects can impact on shellfish species settlement and growth rates.

Recent research projects have focused on the prediction of climate change variables which affect the occurrence and abundance of primary production in the future. For example, the JPI Climate funded CoCliME project recently developed a number of model outputs that estimate the abundance and probability of presence/absence for several toxin producing phytoplankton species (which cause closures of shellfish harvesting) off southwest Ireland in the near future (2017-2035). The bespoke, proof-of-concept, climate service developed, will now help generate discussion informing the aquaculture industry and regulators of the potential impacts of climate change in the future. Such tools can also assist with the development of mitigation and risk management strategies needed to ensure the future sustainability of aquaculture practices and development of the industry.

The recently (2021) published IOC UNESCO Global Harmful Algal Bloom Status Report concluded that the commonly perceived idea that HAB trends and events are increasing globally, is unsupported by a meta–analyses. Improved awareness, technology and monitoring efforts (linked to increased aquaculture e.g.) have resulted in more reports of HAB events and impacts through the last 40 years, rather than a documented increase in the actual global occurrence of HABs.

The 2021 GlobalHAB Scientific Committee report (IOC UNESCO/SCOR), Guidelines for the Study of Climate Change Effects on HABS, concluded that more comprehensive time series data are required on environmental parameters surrounding HAB events to improve HAB modelling and prediction. These guidelines aim to provide standardised strategies, tools and protocols to researchers in studying the effects of climate change drivers in aquatic environments.

Concurrent information on the socioeconomic impacts of HABs on aquaculture as well as on the farmed organisms are required to ascertain the risks attributed to climate change.

Keywords: harmful algal blooms, aquaculture, modelling, forecasting, prediction, seafood safety,

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CM 485: Towards more sustainable parasite management in aquaculture: depopulation can complement drug-based strategies

Duo Xu, Mikko Heino

Here we use a model mimicking the salmon louse–farmed salmon system to test the hypothesis that depopulation of heavily-infested farms can be used to complement drug-based strategies to reduce drug use and combat anti-drug resistance. Combating parasites – a serious challenge in aquaculture – with drugs suffers from two setbacks: (1) drugs released to the ambient environment may have adverse environmental effects, and (2) because of evolving drug resistance, the efficacy of drugs will deteriorate over time. Therefore, there is need to supplement drug-based strategies with alternatives. Our model suggests that factors favoring the resistant-type parasites are (1) effectiveness of the anti-parasite treatment in killing the normal-type parasites, (2) the effectiveness of drug resistance in protecting the resistant parasites, and (3) low of fecundity cost of resistance. If higher temperature means faster developmental rates but lower survival of the parasites, we expect the resistant-type parasites to do less well under increasing temperatures. Nevertheless, under the conditions when the resistant types are successful, the drug loses its efficacy in controlling the parasite population. As an alternative approach, we then evaluated threshold-based depopulation of farms. When used alone, depopulation is effective in reducing the drug use to the minimum and keeping both the parasite population and drug resistance in check but can imply frequent depopulation, which could be economically devastating. However, our model suggests that a regime combining drug treatment triggered by a lower threshold and depopulation triggered by a higher threshold can offer a good compromise: drug treatment takes most of the burden of the parasite control, while depopulation helps to reduce the spread of resistant parasites, and thereby keeps the drug treatment effective and helps to reduce drug use. Our results suggest that depopulation should play a more integral role in disease and parasite management in aquatic production systems, not only by contributing to direct control of parasites but also by reducing prevalence of drug-resistant forms, therefore helping prudent use of drugs.

Keywords: disease management, parasite management, drug resistance, salmon louse

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CM 493: Socioeconomic opportunities and challenges to seaweed multi-trophic aquaculture: case of pond culture in Brebes, Indonesia

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Seaweed contains high nutritional values, including fiber, protein, omega 3 and 6 unsaturated fatty acids, vitamins and minerals, as well as low-calorie consumption. These nutritional values make seaweed a nutritious and low-cost alternative protein source. As a potential source of environmentally friendly food, seaweed has the potential to improve world food security. Indonesia is the second-largest seaweed producer globally after China, especially the Kappaphycus, Eucheuma and Gracilaria species are cultivated there. Seaweed cultivation is one of the few opportunities available to generate income for Indonesian coastal communities, including Brebes. Integrated Multi Trophic Aquaculture (IMTA) proposes to combine the production of multiple trophic levels of aquaculture species under a circular economy concept, reducing energy loss and environmental impact. The use of seaweed in IMTA brings many benefits, such as reducing nutrient load, increasing product diversity and increasing cash flow. This study aims to understand what opportunities exist to support Indonesian seaweed farmers in contributing to secure global food availability and barriers impede the use of IMTA to be less widespread by seaweed farmers in Brebes. To explore these opportunities and challenges, one hundred seaweed farmers were interviewed regarding their demographics, socioeconomic conditions, technical, financial, and institutional abilities, and perception to risks.

Keywords: seaweed aquaculture, socioeconomic analysis, IMTA, Indonesia

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CM 498: A theoretical framework to evaluate the circular journey of aquaculture companies in Italy

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Aquaculture has experienced the fastest expansion among the world's food production sectors over the past 30 years (FAO, 2020), leading institutions and researchers to suggest actions for sustainable intensification (Little et al., 2018). The European Commission (2013) has recognized the need to accelerate this transition for the aquaculture sector, emphasizing the need to shift to circular business models fostering the regeneration of production systems (Ruiz-Salmón et al., 2020). Circular economy (CE) strategies have the potential to provide the path toward a better use of natural resources, reducing waste production (Strazza et al., 2015). Recently, the EU launched the new Circular Economy Action Plan (2020) as a pillar of the European Green Deal (European Commission, 2019), which opens a new perspective for the application of CE in aquaculture.

Scholars have proposed several approaches to assess different aspects of circularity, however, providing partial results, mainly focused on the analysis of environmental sustainability performance (Regueiro et al., 2021). Beyond the attempts of measuring the firm's performance circularity, what is lacking is an approach that can assess the circular maturity status of a company (Roos Lindgreen et al., 2020; Sacco et al., 2021). The circular maturity assessment might represent a preliminary investigation to aquaculture firm performance evaluations, with the goal of identifying a target that can potentially make the transition.

Lacy et al. (2020) attempted to make a contribution by defining the companies' degree of circularity through the assessment of four dimensions in which circular actions could be implemented: operations, product and services, culture and organization, and environment. This allows us to understand the extent to which companies are implementing circular business models across different dimensions, and thus where they are still lacking.

The present study, through the review of the literature on the subject, is aimed at developing a theoretical framework to assess the degree of circular maturity of the Italian aquaculture companies.

This framework could represent a method to classify aquaculture firms from a state where they have just started the transition (emerging) to the accomplishment of it (ultimate).

Keywords: circular economy, aquaculture, micro-level assessment, maturity

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CM 502: Defining the role of Seaweed Aquaculture in Marine Biodiversity and Ecosystem Function

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Seaweed aquaculture is rapidly developing as an alternative to harvesting wild macroalgal resources, minimising environmental impacts and boosting the Blue Biotechnology Economy (BBE). In Europe, the industry is still young, hence the need to streamline and upscale it to satisfy market demands in an environmentally sustainable manner. While negative impacts from monoculture or integrated multi-trophic aquaculture (IMTA) systems are generally regarded as low, the presence of seaweed biomass can provide valuable ecosystem functions. However, to-date, studies on the ecological importance of seaweed aquaculture are mostly desk-based with very few observational studies. Some exceptions include the recently completed EU project GENIALG, which identified and quantified potential impacts of seaweed farms on the surrounding environment finding mostly positive effects on benthic primary producers, water quality and local biodiversity, and provided tangible evidence of the role of seaweed farms as nursery areas for commercial fish species. The current research follows up on the steps of GENIALG by providing evidence on the effects organic inputs from seaweed farms might have on underlying seabed biodiversity and determine the pathways of farm-grown seaweed into local food webs. The work presented includes preliminary results of a two-year survey conducted in 2018/19 at an existing medium-sized licensed aquaculture site growing kelp species *Saccharina latissima and Alaria esculenta* in the southwest coast of Ireland. The comprehensive Before-After-Control-Impact (BACI) seabed survey suggested low spatial and temporal variability in grain size composition and organic matter content and no evidence of direct effects from the farm operation. While the full characterisation of the benthic assemblages is still underway preliminary results suggest the presence of an invertebrate community typical of sandy habitats influenced by the presence of seagrass beds. Using stable isotope analysis (δ13C and δ15N) at two experimental seaweed farms, including an IMTA experimental site, the present work will provide new insights into the role of cultivated seaweed in local food webs, supporting biodiversity and the development of multi-species aquaculture. Ultimately, the evidence will help understanding the environmental implications of scaled-up seaweed aquaculture to develop evidence-based guidance that can inform site selection and contribute to the licensing process.

Keywords: Seaweed aquaculture, IMTA, biodiversity, food webs

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CM 537: Environmental effects of seaweed farms on local ecosystems: evidence of their role as biodiversity reservoirs and facilitation of habitats of high conservation importance

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The role of macroalgae in the functioning of coastal ecosystems is well known, contributing to nutrient cycling and supporting diverse faunal communities. With growing demand for raw and derived seaweed products, aquaculture offers a more environmentally friendly and reliable alternative to mechanical harvesting of wild resources, along with the promise of contributing to local ecological functions and the provision of ecosystem services replicating those of wild seaweed.

However, although general principles on the interactions between seaweed cultivation and biodiversity are easy to visualize, it remains unclear to what extent these activities affect local ecosystem functioning due to a lack of observational data. To cover that gap, and over the course of three years, monitoring programs established in 2017 as part of the EU funded project GENIALG gathered a broad range of abiotic and biological data at two tests farms, in Ireland and The Netherlands. The results of this study provided clear evidence for predictions of low intensity impacts largely being compensated by beneficial effects. No negative impacts were detected on abiotic seafloor condition other than seasonal variability in organic carbon linked to primary production and within site spatial variability in sediment composition. Biodiversity within cultivated seaweed was high, with species numbers similar those recorded in natural kelp beds and no significant differences in the habitat provision role for the two cultivated kelp species studied. Of note was the role of these kelp farms as essential habitats for commercially important fish and crab species. Reduced water flow and turbidity recorded within the seaweed farm was likely responsible for higher irradiance recorded under the seaweed farm compared to distant controls and were linked to significantly higher seagrass shoot abundance and coverage under the farm. We hypothesise that these effects coupled with their de-facto role as exclusion zones against physical disturbance from anchoring or bottom trawling is evidence of quantifiable, positive effects from medium scale seaweed farms on the environment, facilitating the conservation of habitats of high conservation value such as seagrass. The outputs from the project represented a comprehensive account of biotic and abiotic effects of seaweed aquaculture to further support evidence-based licensing of new seaweed aquaculture sites and the management of existing ones using an ecosystem-based approach. Ultimately this study broadens our understanding of the ecosystem impact and potential benefits this novel form of aquaculture could have under the current climate and biodiversity crisis.

Keywords: biodiversity, ecosystem services, seaweed aquaculture, kelp, macroalgae, seagrass.

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CM 566: Biomonitoring planktonic threats in salmon aquaculture: eDNA metabarcoding analyses

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Salmon aquaculture loses c.20% of annual production as a result of gill challenges from the plankton, including jellyfish, harmful algal blooms and amoebic fill disease. Current methods of plankton monitoring lack sensitivity and specificity and data generated fail to provide actionable information to aquaculture managers. We have previously provided proof-of-principle that environmental DNA (eDNA) metabarcoding may be deployed to identify and quantify multiple planktonic threats around salmon farms. In the current study we present a c.200-day longitudinal planktonic eDNA survey of salmonid aquaculture on the west coast Scotland (UK). For seven months (March – October), daily eDNA sampling and metabarcoding was undertaken at two sea cage sites and complemented with microscopic plankton surveys. eDNA data were benchmarked against microscopic surveys and linked to abiotic variables (e.g. temperature, salinity, pH, turbidity) to assay their value in predicting salmon mortality. Data analysis is underway, and we hope that our approach a step change in mitigating losses caused by planktonic threats, improving both the sustainability and productivity of the salmonid aquaculture industry.

Keywords: biomonitoring, eDNA, plankton community, jellyfish blooms, salmon aquaculture, gill disease