WORKING GROUP ON ECOLOGICAL CARRYING CAPACITY IN AQUACULTURE (WGECCA; OUTPUTS FROM 2024 MEETING)

VOLUME 7 | ISSUE 13

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
CIEM CONSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

ISSN number: 2618-1371

ICES Scientific Reports

Volume 7 | Issue 13

WORKING GROUP ON ECOLOGICAL CARRYING CAPACITY IN AQUACULTURE (WGECCA; OUTPUTS FROM 2024 MEETING)

Recommended format for purpose of citation:

ICES. 2025. Working Group on Ecological Carrying Capacity in Aquaculture (WGECCA; Outputs from 2024 Meeting).
ICES Scientific Reports. 7:13. 37 pp. https://doi.org/10.17895/ices.pub.28263971

Editors

Dror L. Angel • Carrie J. Byron

Authors

Antonio Agüera • Dror L. Angel • Daniele Brigolin • Carrie J. Byron • Myriam Callier • Lynne Falconer • Ramon Filgueira • Bobbi Hudson • Frank Kane • Lotta Kluger • Sophie J. I. Koch • Chris McKindsey • Heather Moore

ICES CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Contents

i Executive summary

The ICES Working Group on Ecological Carrying Capacity for Aquaculture (WGECCA) aims to advance understanding and science for sustainable development and management of aquaculture across species, scales, and regions. From 2021–2024, WGECCA focused on three Terms of Reference (ToR) with the aim of advancing three topics on (ToR A) low trophic level species (LTL), (ToR B) farm-environment interactions (FEI), and (ToR C) development of indicators for ecological carrying capacity (ECC). Each of these aims corresponds to an individual ToR; however, there is considerable overlap in our outputs across all ToRs.

The products of these ToRs are varied. The process and outputs from our discussions on LTL (ToR A) are articulated in this report. ToR A is further integrated into the outputs prescribed to ToR B and ToR C. Both ToR B (FEI) and ToR C (indicators) include analysis on LTL, thereby integrating the aim of ToR A into the other two ToRs and their respective outcomes and products.

The work for ToR B is mostly complete and currently being drafted for a peer-reviewed publication; the title and abstract of which is are copied into this report. ICES ASG will be updated when this work is finalized in a peer-review publication.

The outcome for ToR C is a peer-reviewed published paper, the link to which is included in this report. Part of the work process for ToR C included hosting a Networking Session at the ICES ASC 2023 in Bilbao, Spain on Ecological Indicators for Shellfish and Seaweed Aquaculture.

ii Expert group information

Expert group name	Working Group on Ecological Carrying Capacity in Aquaculture (WGECCA)
Expert group cycle	Multiannual
Year cycle started	2022-2024
Reporting year in cycle	3/3
Chairs	Carrie J. Byron, US
	Dror L. Angel, Israel
Meeting venue and dates	2022 (monthly meetings), Online
	2023 (monthly meetings), Online
	2024 (monthly meetings), Online

1 Term of Reference A

1.1 Background

The cultivation of lower trophic level (LTL) species has been proposed as the most sustainable approach to optimize biomass extraction from the ocean. Many of the LTL species, e.g. macroalgae, invertebrates are not widely cultivated in Europe and the Americas. This review will identify social, economic and environmental barriers, priorities, advantages, and knowledge gaps within LTL aquaculture.

1.2 Objective

Estimate the development potential of underutilized lower trophic level aquaculture species in ICES countries including (i.e. macroalgae, invertebrates, detritivores) towards meeting carrying capacity thresholds. Identification of social, economic and environmental advantages, barriers and knowledge gaps; recommendations for research.

1.3 Methodology

We approached ToR A in a few ways. First, we took a cross-species approach. Members of the Working Group on Ecological Carrying Capacity for Aquaculture (WGECCA) spent considerable time sharing with each other information on the topic of LTL across geographic regions. We looked for opportunities and barriers for advancing LTL in each region. Second, we took a species-specific approach. A detailed analysis on seaweed aquaculture was performed using the Delphi method. This work was led by WGECCA member Sophie Koch as part of her dissertation research. The Delphi survey included experts around the world, and beyond members of WGECCA. Finally, we took an integrated approach. Recognizing that bivalve shellfish and seaweed are the primary LTL farmed species, we integrated these species into the analysis and outputs for ToR B on FEI and ToR C on indicators of ECC. In this way, ToR A is also captured in the outputs for ToRs B and C, described later in this report. Here, we focus on Part 1 – the cross-species information sharing analysis, and Part 2 – the species-specific Delphi survey on seaweed.

ToR A, Part 1; Cross-species Regional Information Sharing

Members of WGECCA took turns presenting their own professional knowledge of the LTL species in their geographic region. We aimed to address the following research questions (RQ):

RQ1. What is the LTL species utilization in the different regions (of the group members)?

RQ2. What are the barriers, opportunities, and knowledge gaps across social, economic, environmental, cultural, and governance systems?

This information was summarized in ppt format and in table format, copied into this report.

ToR A, Part 2; Delphi Survey on Seaweed Aquaculture

The Delphi survey method extended beyond members of WGECCA, across the globe. It consisted of three rounds aimed at consolidating knowledge of relevant limiting inputs to seaweed culture and negative outputs of seaweed culture as well as indicators. In the survey, *inputs* were conceptualized as an influence originating in the environment and society influencing the cultivation site (barriers for seaweed aquaculture expansion), and *outputs* were defined as negative impacts or pressures on the environment and society originating in the cultivation site (critical carrying capacity variables). Associated with each input and output, *indicators* were defined as metrics that can inform these inputs and outputs. Furthermore, associated with each indicator, a corresponding *barrier* and *threshold* were identified. A barrier was defined as the process that becomes a bottleneck for expansion, and a threshold was the limit (tipping point) that defines the carrying capacity of the system. Accordingly, barriers were associated with inputs and thresholds with outputs, defining the optimal production window (unpublished and in preprint, Koch *et al*., 2024).

The survey was intended to capture responses to the research questions:

RQ3. How can we assess ecosystem services and carrying capacity of seaweed aquaculture?

RQ4. What are the socio-economic and environmental advantages and barriers of seaweed aquaculture?

1.4 Results

1.4.1 Part 1. RQ1:

Region	Expert	Established LTL spp	LTL spp in development
Canada	Ramon Filgueira and Chris McKindsey	*Mytilus edulis* *Mytilus galloprovincialis* *Crassostrea virginica* *Magallana gigas* *Placopecten magellanicus* *Argopecten irradians* *Panopea generosa* *Clinocardium nuttalli*	*Saccharina latissima* *Alara marginata* *Porphyra corallicola* *Parastichopus californicus* *Mesocentrotus franciscanus* *Strongylocentrotus droebachiensis*
Faroe Islands	Sophie Koch	*Saccharina latissima* *Alaria Esculenta*	*Mytilus edulis*

Region	Expert	Established LTL spp	LTL spp in development
France	Myriam Callier	*Magallana gigas* *Mytilus edulis* *Clams and cockles*	*Saccharina latissima* *Ostrea edulis* *Arenicola marina* *Hediste diversicolor* *Holothuria tubulosa* *Holothuria forskali*
Germany	Lotta Kluger	*Mytilus edulis* *Ostrea edulis*	*? Saccharina latissima*
Ireland	Fank Kane	*Magallana gigas* *Mytilus edulis* *Pecten maximus* *clam* *abalone* *urchin*	*Laminaria digitata* *Alaria esculenta* *Saccharina latissima* *Palmaria palmata* *Porphyra umbilicalis* *Ulva spp.*
Northern Ireland	Heather Moore	*Mytilus edulis* *Magallana gigas* *Ostrea edulis* *Pecten maximus* *Aequipecten opercularis*	*Ruditapes philippinarum* *Alaria esculenta* *Saccharina latissima* *Palmaria palmata*
Mediterranean	Dror Angel / Daniele Brigolin	*Grey mullets* *Mytilus galloprovincialis* *Magallana gigas* *Ruditapes philippinarum*	*Sea urchins:* *Paracentrotus lividus* *Sea cucumber:* *Holothuria tubulosa* *Polychaetes:* *Sabella spallanzanii* *Sponges: Dysidea avara, Chondrosia reniformis*
Norway	Antonio Agüera	*Mytilus edulis* *Pecten maximus* *Ostrea edulis* *Saccharina latissima* *Alaria esculenta*	*Palmaria palmata* *Porphyra umbilicalis* *Laminaria digitata* *Ciona intestinalis* *Strongylocentrotus droebachiensis* *Echinus esculentus*
Peru	Lotta Kluger	*Litopenaeus spp.* *Argopecten purpuratus* *Penaeus vannamei*	*Chondracanthus chamissoi* *Macrocystis pyrifera* (Avila-Peltroche and Padilla-Vallejos, 2020)

Region	Expert	Established LTL spp	LTL spp in development
Scotland	Lynne Falconer	*Mytilus spp.* *Magallana gigas* *Ostrea edulis* *Aequipecten opercularis* *Pecten maximus*	seaweeds
Eastern USA	Carrie Byron	*Crassostrea virginica* *Mytilus edulis* *Saccharina latissima*	*Ensis directus* *Placopecten magellanicus*
Western USA	Bobbi Hudson	*Mya arenaria* *Mytilus spp.* *Magallana gigas* *Crassostrea virginica* *Crassostrea sikamea* *Ostrea lurida* *Ruditapes philippinarum* *Panopea generosa*	*Red sea cucumber* *Crassadoma gigantea* *Saccharina latissimi* *Alaria marginata* *Nereocystis luetkeana*

Cultured species in the Celtic Seas ecoregion is summarized in a published report – ICES Aquaculture Overviews, Celtic Seas Ecoregion, published 05 October 2022.

1.4.2 Part 1. RQ2:

CANADA	Barriers	Opportunities	Knowledge gaps
Social	Social acceptance (property value, aesthetics, recreation, sense of place....) (Wood and Filgueira, 2022)	Rural employment and other indirect benefits related to "community building" (Krause *et al.*, 2022)	Site-specific perspectives are critical (Wood and Filgueira, 2022)
Economic	Labour, capital, no market (and processing facilities), perceived limited contribution from the government	Job diversification, jobs and income. Strongly linked to social opportunities	Profitability of new species (business plan!)
Environmental	Ocean warming and mussel mortality (Steeves *et al*., 2018), interactions with wild species (mammals, particularly for offshore operations), ocean acidification (mostly at hatchery? not so obvious for adults)	Nutrient extraction (Bivalves - Guyondet *et al.,* 2015, 2022, but also for seaweeds)	Poor understanding about negative effects of growing seaweeds (e.g. fall-offs)
Cultural	There is no market for seaweeds. No vision that it could be a business (artisanal operations)	Also related to social	

CANADA	Barriers	Opportunities	Knowledge gaps
Governance	Bureaucracy is demanding (slow and costly - specialized knowledge is required to fill paperwork). Triggered by knowledge gaps (i.e. application of precautionary principle)	Opportunities to overcome barriers	Regulatory thresholds that could be applied at the national level

FAROE ISLANDS	Barriers	Opportunities	Barriers
Social	Seaweed and shellfish are not really eaten there, seaweed is seen as a ‘poor people’s weed’.	There are some job opportunities, social acceptance is higher than in other regions, there is a general acceptance for aquaculture	Seaweed and shellfish are not really eaten there, seaweed is seen as a ‘poor people’s weed’.
Economic	Other aquacultures are very strong compared to LTS, high processing costs (Eriksen *et al.,* 2024), market fluctuation (personal communication with employees from Sjókovin)	Strong tradition: The Faroese lived of the ocean for centuries. The aquaculture industry today accounts for >40% of total export value (90% in total export) lower trophic species are on the 10th spot of aquaculture species, opportunities for development, seaweed is a developing industry, blue mussels are abundant in the local waters, but not yet an industry. Trials show good farming potential (Danielsen *et al.,* 2022), mechanizing harvest to increase harvest speed (Eriksen *et al*., 2024), Since 2012 non-Faroese companies or persons cannot own more than 20% of the commercial licenses /this applies to salmon cultivation at sea), which allows non-Faroese persons or companies to operate in all other aquaculture production seaweed farming (Agnalt *et al*., 2023)	Other aquacultures are very strong compared to LTS, high processing costs (Eriksen, *et al.,* 2024), market fluctuation (personal communication with employees from Sjókovin)
Environmental	Toxicology is not yet up and running.	Clean, nutrient rich oceanic waters, with cool steady temperatures Strong currents in the fjords (Agnalt *et al.*, 2023; Bak *et al.,* 2018)	Toxicology is not yet up and running.
Cultural	Eating preferences, market?	Strong tradition: Faroese lived of the ocean for centuries Aquaculture industry today accounts for >40% of total export value (90% in total export)	Eating preferences, market?

FAROE ISLANDS	Barriers	Opportunities	Barriers
Governance	Prior to 2019 the legislation only allowed single species farming in each of the 22 management areas, all occupied with salmon farming.	Aquaculture sector is very flexible, there is easy dialogue with authorities. To find a solution, one can ask, and it is likely that there will be a solution. Seaweed cultivation company is in dialogue with the authorities to get more licenses. These shorter distances between authorities and operators are helpful. It's a strength of the sector (personal communication with employees from Sjókovin). In 2019 the legislation allowed more than just single species farming and allocated 3 licenses to seaweed companies from 2020 (Agnalt *et al*., 2023).	Prior to 2019 the legislation only allowed single species farming in each of the 22 management areas, all occupied with salmon farming.

FRANCE	Barriers	Opportunities	Knowledge gaps
Social	Social acceptability of seaweed. Social acceptability for sea cucumbers.	Rural employment 2938 shellfish farms	
Economic		700 M euros, shellfish	
Environmental	Oyster and mussel mortality: diseases (virus, bacteria), anoxia, picoplankton. Growth rate for sea cucumbers.	Nutrient extraction from shellfish. Restoration, ecosystem services for seaweed. Restoration, ecosystem services for sea cucumbers.	Production and selection for seaweed. Production for sea cucumbers.
Cultural	No market (exportation) for sea cucumbers.	Well established for shellfish	
Governance			

GERMANY	Barriers	Opportunities	Knowledge gaps
Social	Low social acceptance, lack of knowledge of the use of products (in the case of seaweeds), lack of markets	Growing interest in using seaweeds for different purposes, social awareness of its potential	
Economic	Economic feasibility; labour, no market	Growing global demand, opportunity to diversify coastal livelihoods, circular economy initiatives	
Environmental	Low saline environment of Baltic and North Sea = low species diversity of seaweeds, harsh environment (large tidal amplitude) for any aquaculture	Nutrient extraction, circular economy initiatives	Optimum growth conditions in the German environment; social and ecological externalities of culture
Cultural	No local market for seaweeds	Small-scale projects emerging for the use of seaweeds for paper and fertilizer production, cosmetics, food	How to alter consumer preferences towards the increased consumption of low trophic species
Governance	Regulatory processes unclear or lacking, high bureaucracy		

IRELAND	Barriers	Opportunities	Knowledge gaps
Social	Social acceptance for licensing; use of space conflicts; visual impacts;	Employment in local communities	
Economic	No significant market; no standards and certification;	Employment in rural locations; hatchery opportunities	
Environmental	Carrying capacity of certain bays;	Low impact foods; extractive aquaculture; low carbon footprint	Carry capacity potential
Cultural	No tradition of eating many of the LT or seaweed species; No significant market; aquaculture not seen as a desirable/lucrative job;		Food opportunities
Governance	Regulation (novel food regulation; iodine/metals levels in seaweeds; slow licensing process;	Extractive aquaculture reduces impact;	Multispecies regulation
Technical	Seed supply (lack of hatcheries); mechanization; scale of production; breeding/selection;	Upscaling; stock/genetic selection;	Seed production; upscaling;

NORTHERN IRELAND	Barriers	Opportunities	Knowledge gaps
Social	Social license to operate (SLO); conflict with other stakeholders, space conflicts; visual impacts;	Local rural employment. Community projects. Marine spatial plans (MSPs) to include LTL species	Poor public perception of the value of LTL species. Site-specific issues – all very different.
Economic	Labour and investment. Processing and hatchery / nursery requirements for sustainability. Greater investment required for offshore development. Small domestic demand. Market development for seaweed products and shell waste.	Rural employment – artisanal products; Nutrient credit trading. Increased demand for nature based solutions (NBS). Circular economy, hatchery / nursery and valorisation opportunities.	Increase domestic demand for LTL species. Impact of scaling up LTL species. Novel species impacts.
Environmental	Poor water quality; increased vulnerability to existing and emerging contaminants and disease. Interactions with wild species; introduction of NIS. Reduced wild mussel seed availability.	LTL species nutrient bioextration capacity to mitigate against eutrophication – NBS. High protein, low carbon footprint foods; Ecosystem services; and restoration projects, e.g. native oysters in the UK.	Environmental impacts not always considered. Increasing awareness. Disease control measures; effect of up-scaling. Future species selection considering biosecurity concerns. Ecological Carrying capacity not widespread consideration.
Cultural	No tradition of eating many of the LT or seaweed species. Acceptance of artisanal products but need for commercial products. Processing and market development required. Current government support to promote seaweed aquaculture.	Community based projects, supporting co-location with shellfish and seaweed cultivation, Câr y Môr in Wales.	Improve public perception of species, by-products and potential for re-use. Promotion of LTL ecosystem services Novel food opportunities
Governance	Slow licensing process Changing goals on environmental impact assessments and increased biosecurity planning. Need to future proof Guidelines and regulations for contaminants in novel products.	Streamline all associated licencing processes. Bio-extractive aquaculture reduces impacts of excess nutrients	Regulatory thresholds that could be applied at the national level, promote clarity. Multispecies regulations Feasibility of offshore aquaculture, co-location with offshore energy. Novel species
Technical	Mussel seed supply (lack of hatcheries); Spat collector up-scaling. Seaweed nursery and biosecure fertile seeded lines.	Upscaling; stock/genetic selection.	Mussel hatchery Seaweed nursery.

ITALY	Barriers	Opportunities	Knowledge gaps
Social	Limited interest on LTL: Seaweeds are commonly perceived as an environmental issue and not as a resource; Mullets appreciated only in specific regions, limited market	Small-scale applied research projects focusing on LTL species (sea urchins, seaweeds) and IMTA are enhancing communication	Better knowledge of biology needed (e.g. diseases, reproduction); optimization of farming technology
Economic	Lack of proper knowledge of the seaweed market	Biorefinery approach to valorize seaweed bio-based products (e.g. Armeli Minicante *et al.*, 2022)	Quantification of total economic value of ecosystem services related to LTL species (e.g. Pacifico *et al.*, 2024)
Environmental	Decreasing trophism of the cultivated systems (lower riverine inputs); Predation by invasive species (e.g. blue crab on Manila clam juveniles); More frequent summer heat waves	Ongoing research improving knowledge of the potential of LTL species for restoration and ES (sea cucumbers, seaweeds, sea urchins)	
Cultural	Low tendency towards diversifying the productions Historically there was no interest from the shellfish farmers to grow seaweeds	Current pressures on shellfish industry imposed by the blue crab invasion may stimulate the diversification of productions towards seaweeds and other LTL species	
Governance	Complex and time consuming licensing Lack of harmonization/potential conflicts with nature conservation efforts (Natura 2000 network and Nature restoration law)		Including considerations on seaweed sector in aquaculture sectorial planning (AZA – Allocated Zones for Aquaculture) and in maritime spatial planning (MSP)

NORWAY	Barriers	Opportunities	Knowledge gaps
Social	Low social acceptance due to pass experiences. Lack of knowledge of the use of products (in the case of seaweeds) and lack of market for seaweed products.	Growing interest in using LTL species for different purposes, social awareness of the potential use and ecosystem services	
Economic	High production costs with a potential market demanding low value products (e.g. feed ingredient market). Low local demand	New markets with a very large demand (finfish feed industry), circular economy initiatives.	
Environmental	Low primary production and cold, dark winters. Short production cycles for seaweed and long production cycles for suspension-feeders (~2 years). Deep fjords or exposed coastal areas.	Limited nutrient extraction in fjords around major cities, circular economy initiatives, IMTA at basin scale to mitigate finfish output of dissolved nutrients	Optimum growth along the environmental gradients (salinity, latitude and nutrients/primary production. Impacts on a mesotrophic pelagic foodweb.
Cultural	No local market for seaweeds and small local market for bivalves.	Several projects to produce seaweed as sustainable food/feed source. Small projects with bivalves oriented to finfish demands for ingredients.	Uses for seaweed in the food industry. Or alternatives that provided a market for high value product.
Governance	Regulatory processes are complex, requiring similar procedures than finfish aquaculture. Several governance bodies are involved. High liability fee to cover cleanup in case of bankruptcy.	Association of small producers in coops and other groups. Interest in the development of the industry by policymakers.	

PERU	Barriers	Opportunities	Knowledge gaps
Social	Social inequalities (small-scale producers vs. Large-scale exporting companies), cultures increasingly dominated by large-scale actors	Promotion of cooperatives and their capabilities to process and export; aquaculture dynamics allow alternative work; macroalgae culture as an opportunity for small-scale fishers	
Economic	Depending on international market dynamics	High profitability of scallop aquaculture, social opportunities	Economic feasibility of macroalgae

PERU	Barriers	Opportunities	Knowledge gaps
Environmental	Capture-based aquaculture, source of seeds not secured and exposed to environmental dynamics and overharvesting; ENSO dynamics potentially scallop (culture) dynamics, the last event (coastal El Nino 2017) has caused an almost complete die-off of scallops in the North (Kluger *et al.,* 2020), summer heat events	Long-term planning should include environmental dynamics and potential harvest losses	
Cultural	Scallops not linked to food security but being produced mainly for international markets.	Promotion of sector in last 10-15 years as economic /work force. Seaweeds (as other seafood) with a long tradition of being consumed	
Governance	Scale mismatch between regulations, but also hybrid governance structures with the sector being shaped by informal-formal rules and practices (Damonte et at. 2023); culture concessions in the hand of few actors (Kluger *et al*., 2022, Schlüter *et al*., 2023)		

SCOTLAND	Barriers	Opportunities	Knowledge gaps
Social	Conflict with other marine activities/users (Tett *et al*., 2012, 2025)		Community acceptance is location specific
	Few employment opportunities		
	Poor communication affects social acceptance (Billing *et al*., 2021)		
Economic	Very small domestic demand for shellfish	Use of low trophic species for non-food purposes	How to increase domestic demand.
	Brexit adding additional costs and burdens		What future trade will look like
	Fluctuating and uncertain market puts financial strain on producer		Potential and feasibility of non-food uses of low trophic species
	Competition from other LT producing countries		Competition from other low trophic producing countries
	Start-up costs		Profitability of production
	Supply chain and infrastructure requirements		

SCOTLAND	Barriers	Opportunities	Knowledge gaps
Environmental	Mussel spat mortality (Broughton *et al*., 2019)	Nutrient offsetting	Causes of mussel spat mortality (Broughton *et al*., 2019)
	Risk – increasing temperatures may affect disease outbreaks (Murray *et al*., 2012).		Effects of seaweed production on environment.
			Environmental interactions when operating at larger scales.
			Connectivity between farms
Cultural	Very small domestic demand for shellfish	Restoration of native oyster populations	How to increase domestic demand for shellfish
Governance	Licensing and regulation is complex and time consuming.	Policy and regulation across entire aquaculture sector is being revised in 2022/2023 (Griggs, 2022).	Feasibility of new production technology and environments, e.g. offshore shellfish farms
	Slow decisions		

USA (eastern US and western US)	**Barriers**	**Opportunities**	**Knowledge gaps**
Social	Social acceptance (Wood and Filgueira, 2022) Industry shift in response to climate change (Cleaver 2018) Insufficient research on seaweed SLO	Rural employment (Krause *et al*., 2022) Increase gender equity in working waterfronts (McClenachan and Moulton 2022) Designing a human and natural model for seaweed aquaculture using Maine as example (Grebe *et al*., 2019) How do people perceive aquaculture in Atlantic states? Consumer based survey, includes aquaculture mapping tool (Bouchard *et al.,* 2021)	Site-specific perspectives are critical (Wood and Filgueira, 2022) What is the social perception of aquaculture in Maine (Britsch *et al*., 2021) Using stakeholder perceptions of offshore mussel farming to understand social and governance barriers and opportunities for the industry (Fairbanks, 2016)

USA **(eastern US and western US)**	**Barriers**	**Opportunities**	**Knowledge gaps**
Economic/ Technology	No processing infrastructure for seaweeds (Noll, personal comm.) Offshore mussel farming should be supported for economic and social reason, although governance may be challenging (Mizuta and Wikfors 2019, 2020)	Economic opportunities for Seaweed Aquaculture in the US (Piconi and Chase 2020) Analysis of economic opportunities for Maine bivalve aquaculture (Gulf of Maine Research Institute, 2016) Consumer market for seaweed (Li 2021) Design of accessible kelp farm system, Maine (St-Gelais *et al.*, 2022) Overview of seaweed aquaculture development in the US (Kim *et al.*, 2019) Commercial uses for Seaweed in US and beyond (Leandro *et al.*, 2020) Depth Selection and In Situ Validation for Offshore Mussel Aquaculture in Northeast United States Federal Waters (Mizuta and Wikfors 2019, 2020) Modelling nitrogen bioremediation of bivalves at the municipal level (Dvarskas *et al.*, 2020)	Scaling up and offshore technology for seaweed Offshore technology for mussels
Environmental	Ocean warming and mussel mortality (Steeves *et al.* 2018)	Nutrient extraction (Guyondet *et al.*, 2015, 2022) Nutrient extraction (Grebe *et al.*, 2021)	Production carrying capacity of seaweed? Impact of mussel farms on lobster behaviour (Lavoi *et al.*, 2022)
Cultural	There is no market for seaweeds	Advertising strategies based on seaweed qualities and consumer trends (Aquaculture Shared Waters, Piconi *et al.,* 2020)	
Governance	Analysis of governance affect aquaculture through different policy strategies in the US (Lester *et al.*, 2022)		Thresholds that could be applied at the national level (Lester *et al.*, 2022)

Significant work has been undertaken in recent years to expand Alaska mariculture, especially seaweed. A summary, including barriers and opportunities, is maintained, here: https://alaska.seaweedinsights.com/seaweed/future-outlook

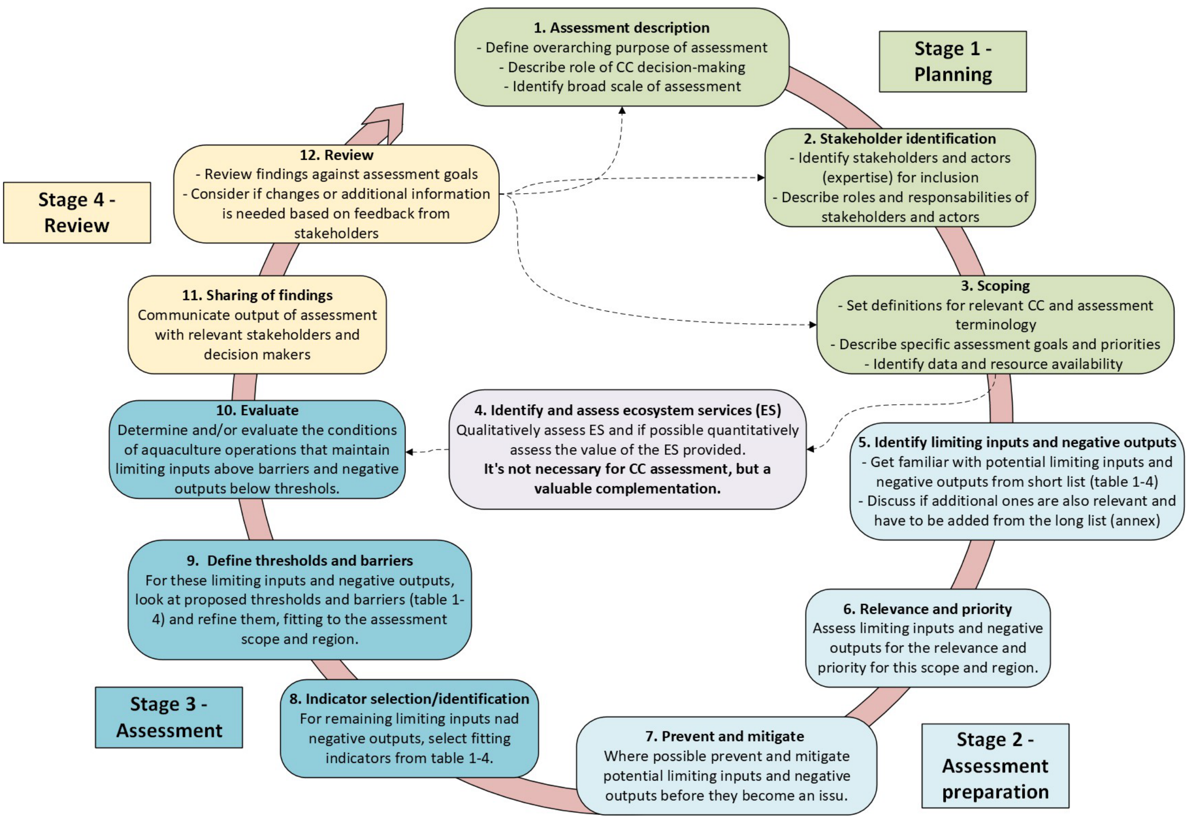
Challenges and strategic interventions for the future of LTL in Bangladesh as reported in publication (Asaduzzaman *et al.*, 2025).

Please see supplemental file that includes several slides supporting the information presented in the above tables (Annex 3).

1.4.3 Part 2. RQ3:

A manuscript entitled "**Into the wild: how farm-derived nutrients and energy flow through marine ecosystems - consequences and management perspectives**" was prepared and already submitted with Sophie Koch being the lead author, with the help of the co-authors: Ramon Filgueira, Jóhanna Alberg, Dror L. Angel, Carrie J. Byron, Mariana Cerca, Leeann B. Ennis, Urd Grandorf Bak, Frank Kane, Jonne Kotta, Stefan Kraan, Myron Peck, Marnix Poelman, Patronella M. Slegers, Kristian Spilling, Jean-Baptiste E Thomas, Lotta C. Kluger.

Delphi survey results suggest that barriers and impacts should be assessed at both the socio-economic and ecological dimensions. It is important to include government, scientists and local stakeholders in this assessment. It should be a universal approach that is adaptable to each location. Indicators and thresholds might vary, just as relevant barriers and impacts vary from site to site.



1.4.3.1 Barriers (socio-economic and environmental mixed, but can be separated)

Barriers were separated into limiting barriers to seaweed aquaculture and negative impact coming from the aquaculture activity. This distinction is necessary, as for the latter, management practices can help mitigate some of the impacts as the cultivation is the cause. However, to limiting factors from the environment or the society, a cultivation unit doesn't have much power over and needs to adapt to or need support on a larger scope (for socio-economic negative impacts).

1.4.3.2 Limiting inputs

Limiting Input
Operating costs are too high (not yet economically viable), need for costly infrastructure close by (hatchery, processing, harvesting, clean water, etc.)
Underdeveloped market (not enough demand and high export host, too small or too large volumes, specific processing demands)
Difficulties with licenses, permits, and certificates (administrative burden, expensive, cultivation license framework not in place)
Costly practice with low value product leading to possibly unprofitable businesses
High price of seaweed products can't compete with cheaper seaweed form Asia or other sources of biomass that are cheaper
Lack of investment for technology required for reaching large-scale in an economical way (e.g. more automation of deployment, harvesting and processing)
Uncertain impacts from climate change (adaptivity to warmer oceans, less meteorological predictability, less crop resilience and growth, more disease)
Epifauna, fouling, grazers
Specific farming design needed
Lack of government support, no zoning for seaweed in marine spatial plans
Investors are hesitant as there are no established seaweed cultivation business cases (risks for capital), lack of capital for entrepreneurs
Large-scale farming not yet ready (needs proof of concept, has unknown impacts and risks)
Temperature increase
Social acceptance, social license to operate, lack of trust in the aquaculture industry
NIMBY, people are against the use of the sea
Access to sea in difficult weather conditions
Heavy metal uptake leads to higher than acceptable levels
Limited permits, locations on coasts

Limiting Input
Sunlight and nutrient availability
Not enough hydrodynamic activity
Available and suitable area (e.g. close to the coast, sheltered, not too deep, enough nutrients and light etc.)
Lack of workforce that wants to do the work (hard working, manual work, specified academic work, remote areas, seasonal work)
Short time window for cultivation
Lack of federal guidance around food safety
User space needed, potential conflicts with other economic activities
Poor regulatory/community understanding
Possible negative ecological impacts or misinformation on possible ecological impacts
Lack of science for optimization of cultivation and biosecurity
Diseases
Low salinity
Storms and waves (damage to infrastructure or no access to see possible)
Space limitation by seaweed monoculture
Lack of education, skills and algae farming traditions
No high salaries and good working conditions possible, due to low value of product
Willingness of entrepreneurs to start a seaweed business
Predation (e.g. sea urchins)
Lack of genetic diversity
Conservation objectives
There may be limited Mondial growth in production
Absorption of synthetic compounds
Multi-use poses challenges (insurance risks/cost, designated windfarm areas are not all good locations

1.4.3.3 Negative outputs

Negative outputs
Overhyped unrealistic view and expectations of seaweed cultivation, with potentially being less profitable and les jobs created than expected
Potential poor social license and image due to over-promising/hype but under delivering of touted benefits
User space needed, potential conflicts with other economic activities (tourism, fishing)
Opposition from fisheries if their fishing grounds are being converted to seaweed farms
Potential monopolisation by larger multinational companies, leading to imbalance of benefit share
Pollution (plastic, ropes)
Input of or spread of non-indigenous or invasive species
Input of or spread of genetically modified or selected bred species and translocation of native seaweed species (threat to genetic diversity)
Disease (Input of microbial pathogens and parasites and disease proliferation)
Release of reproductive material from domesticated seaweed species (and potential native local retention of reproductive material)
Economically unviable compared to (unsustainable) productions from Asia
Sunlight and nutrient competition
Input of organic matter (DOM and POM)
Changes in siltation, sedimentation, turbidity
Physical disturbance to seabed (temporary or reversible)
Impacts on hydrological processes (Water flow and wave energy changes)
Fuel used and carbon emission from the boats
Consumer safety issues such as heavy metals or iodine content
Competition over space with natural seaweed beds (cultivation vs. restoration)
Changes to biodiversity and food we structure
Impacts on biochemical processes
If seaweed businesses fail (bankruptcy), it will negatively affect the community
Introduction of synthetic compounds
Nitrogen emission and deposition
Risk of entanglement of megafauna
Overharvesting of wild sorus tissue to produce nursery seed

Negative outputs
Visual amenities
Disturbing the rural areas with ocean activities, can impact an unspoiled culture/rural society
CO2 emissions
Nitrogen emission and deposition
The attraction of species to the farm through the artificialization of habitat
Disturbance to species (anthropogenic sound, visual disturbance, barrier to movement)
Busier coastal areas
Introduction of non-synthetic substances and compounds

1.4.3.4 Advantages

Again here, the experts decided to divide between factors from the environment favouring the aquaculture cultivation (favouring inputs) and positive impacts, being outputs from the aquaculture having a positive effect on society and environment.

1.4.3.5 Favouring inputs

Socio-economic
Better environmental reputation than other aquaculture industries
Employment (regional opportunities, job creation, for indigenous communities)
Interest from food processing industry for sustainable biomass
Many valuable components for food industry
Provides ecosystem services
Low capital investment
Potential for niche market
Income, new opportunities and improvement of livelihoods to coastal areas
High quality seaweed for specific markets/industries
Healthy biomass
IMTA possible (favourable for social acceptance and profitability)
Need for traceable seaweed production from industry and consumers
Potential for organic certification

Socio-economic
Current hype over seaweed
Greenwashing
Provides alternative for fishers and shellfish farmers who have access to gear and equipment
European consumption is increasing (e.g. sushi, market development)
Green jobs, jobs in sustainable sector
Additional income to existing ocean farmers or wild harvesters
Social acceptance, social license to operate
Trickle down benefits to local communities is essential to establish/guarantee
Recognized as eutrophication mitigation tool in Marine Spatial Planning
Current emphasis on blue growth, the "Blue Acceleration" - the ocean as the next frontier for capitalism
Farm to Fork support expansion of the industry
Can be adapted to coastal small communities
Limited environmental impacts
New interesting industry with local feedstock for industry
Green image of seaweed, Sustainable production
Existing processing facilities that could be converted to process seaweed on coasts
People are supportive of and demand local, climate-positive food sources, recyclable/regenerative products and industries
Local community 'buy-in' (e.g. profit-sharing arrangements with local community)
Lots of traction from EU Commission
More seaweed companies are getting attention
Government stimulates innovative projects
Consumers are less hesitant to use seaweed products
The focus is not only on food anymore (biomaterials, biostimulants, feed, food, pharmaceuticals and medical purposes.)
New source of food contributing to food security
Expansion of start-up focusing/demanding seaweed in their activities/products
Short growth cycle and possibility to farm multiple species, means potential for favourable cash flow
More and more awareness on seaweed as food of the future
High investment in research by for example the EU

Socio-economic
Companies view seaweed as an opportunity to achieve ESG goals
Consumer trends towards and increasing demand for vegan/ vegetarian diets and products
Potential for multi-use of sites and space, development of offshore wind farms
Greater understanding by individuals and companies of biodiversity loss, climate change, the negative impacts of meat consumption offer space to posit seaweed aquaculture as a solution
Theoretically unlimited area for seaweed cultivation
Extractive species, does not require food
New investment routes
Seaweed is an additional marine resource
Biomass with various potential applications
Awareness of and positive perception of society around the benefits and sustainability potential of seaweed (low-carbon and environmentally friendly product)
Monetized ecosystem services can be beneficial to the business case
Halo effect
Policy emphasis on lower trophic species aquaculture
Space availability
Low impact production
Circularity of nutrients
Support from investors

Ecologic
Water availability
Diverse species option for cultivation
High nutrient flux (moderate nutrients, high current velocity)
Eutrophication mitigation
Light availability
CO_2 availability
Excess nutrients
High current velocity
Exposure
No nutrient limitations

Ecologic
Favourable water temperature
Nutrient availability
Fast growing species
Clean water
Low turbidity
Medium current velocity
Low temperature
No seagrass forests below the cultivation
Optimal attachment of the seaweed
Water depth more than 3 m
No grazing animals
Halo effect
Full mixing of the water column

1.4.3.6 Positive outputs (impacts)

Socio-economic
Job creation (in coastal regions with often limited opportunities)
Economic development
Returns to (remote coastal) communities from economic activity, local livelihood development and increased economic resilience
Skills development and education
New source of food contributing to food security
Methane reduction in cattle when adding seaweed to their feed
Seaweed biostimulant makes agricultural products more resilient (e.g. potatoes are more resilient to salt intrusion)
Economic diversification in rural communities, for working waterfronts
Healthy food source, proteins
New industry offers fishers an opportunity who lost their job, or additional income
Sustainable and low impact feedstock production (food and other products), which doesn't require freshwater, arable land and feed
Ecosystem benefits

Socio-economic
Discover lost and old knowledge
Nature-based solution in nutraceuticals or pharmaceutical compounds
Diversification of aquaculture activities (decreasing risks to broader industry)
Conductive to new types of business concepts, with shared (material and immaterial) ownership
Diversified economies and industries, with local engagement and focus
Indigenous involvement and leadership
Increased water transparency and recreational value for humans due to removal of nutrients
Local production may reduce the need to import goods from other countries
Support to other related businesses
Increased production of food and non-food products
Substitution of fossil fuel value chains, and having the benefits from using seaweed-based products (carbon emissions avoided, health, etc.)
Provide a livelihood
Facilitates dietary diversity
Utilizes coastal resources
Healthy animal feed
Jobs in sustainable sector, meaningful jobs
Sustainable use of the ocean
Aquaculture could act as a wave breaker
Relieve pressure on agriculture/forestry for food and biomass
Gives a role for coastal communities in the transition economy
Habitat enhancement / rejuvenation / restoration that supports other economically important fisheries
Climate and biodiversity positive product
Improves water quality (filters pollutants, removes excess nutrients)
Locally produced food
Attractive fishing and diving grounds next to seaweed cultivation sites

Ecologic
Nutrient uptake (Eutrophication mitigation)
Provision of shelter, hatchery
CO2 uptake/sequestration
Biodiversity increase
Photosynthetic activity (CO2 uptake and O2 release)
Reduced turbidity
Wave dampening
Filtering pollutions
Water quality improvement
Current speed reduction
Reef effect benefits
Provision of POC and DOC for foodwebs
Acidification mitigation
Attraction of species
Provision of food for juvenile species

1.4.3.7 Discussion

Knowledge gaps identify and justify new research that is needed to overcome barriers to industry advancement. Some of the identified high-level knowledge gaps and barriers for LTL aquaculture include:

- Barriers to sustainable developments
- Knowledge gaps, e.g. optimized feed, cultivation protocols
- Labor shortages, i.e. workers with experience
- Worker safety and risks in labour
- Predation on farmed animals
- Available markets

For each LTL species examined, specific knowledge gaps include:

- Seaweeds -
    - Regulations. Gaps from how seaweeds are going to impact other species in IMTA and ecosystem dynamics.
    - Food safety guidelines (also supplements and pharmaceuticals, cosmetics).
    - Nursery and seed spore source re: biosecurity.
    - Scaling for commercial viability and impact of upscaling on receiving environment

  - Existing producers, where is that product going.
  - Sustainable processing and reliable food products, at least for European markets
- Oysters -
  - Introduction and transfer of non-native species, (although *M. gigas* is naturalized) in western US, Canada, and Europe.
    - E.g. Sweden and Norway, where *M. gigas* is naturally occurring but there is no cultivation due to the status of invasive species
  - Triploidy.
  - Managing for faecal coliform from birds, in US and Canada. Growing areas certification based on water quality and total coliform.
  - Climate change impacts emerging diseases and increasing vulnerability to existing contaminants. For *Vibrio* spp. , Norovirus.
- Mussels -
  - Movement of seed stock and genetic integrity.
  - Mussel industry in Northern Ireland declined compared to oyster industry, due to wild mussel seed stock availability.
  - Considerable amount of west coast mussel populations come from Northern Ireland. Spread quite widely. Driven by mussel industry in Scotland because worried about seed supply so want to know where wild seed coming from. Still need to do some genetic testing to demonstrate hydrographic models are correct. Natural seeding and distances (Corrochano-Fraile *et al.,* 2022).
  - Hatchery production in Washington State, US, of *Mytilus spp.:* There are multiple farms producing seed via hatcheries in WA, including Taylor Shellfish, Penn Cove (aka Pacific Seafoods partial ownership) and Kamilche Sea Farms.
  - Duck predation on mussels and mussel spat collectors.
  - HABs effects.
  - Diseases, parasites and responses to multiple stressors: large mortality events across Europe (Baden *et al*., 2021)
- Scallops -
  - Biotoxins in scallops, which hold onto saxotoxins for long time. Need different management. Convert to more toxic derivates in adductor mussels (Houle *et al*. 2023). Rock scallops (*Crassodoma gigantea*) convert it and move it into adductor over time. Different from Atlantic scallops.
  - Grow-out strategies: scallops from suspended culture Likely to have a lower biotoxin loads; bottom culture economically more profitable
- Clams -
  - With rarer *spp* species, seed will be issue, though have it figured out for *Panopea generosa.*
  - Clams require a lot of space. Need of space which will be limiting factor.
  - Netherlands, problem with oyster drilling *spp* species.
  - Tunicates, ascidians.
  - Markets. Which needs to be developed first - market or production?
- Echinoderms -
  - Sea cucumber for IMTA is a candidate LTL species in several areas.
  - Aquavitae has project dedicated to produce food for sea urchins.
    - Remove urchins from barrens but then need to feed them.
    - Ireland and Scotland had have done carried out research on urchins.

    - Abalone and sea urchins, varied levels of success. Need to grow food for them. Need to create own a market and market is small. Cover entire value chain, which is a lot for a small company. Sea urchin has a market in Europe.
- Worms -
    - Polychaetes have been farmed at pilot level in a few locations, including Italy, Netherlands, and Norway.
    - Uses for the polychaetes - Circular economy and potential of IMTA with fin-fish (Svensson *et al*., 2023)

1.5 Literature cited

Agnalt, Ann-Lisbeth ; Cooper, Anne; Dam, Rúni; Gaard, E., Jensen, Katrin H.; Laksáfoss, Magni, Laksá, Unn; Mørkøre, B. á, & Nordi, Gunnvør; Henn, O. (2023). *WORKSHOP ON THE FAROES ECOREGION AQUACULTURE OVERVIEW (WKFaroesAO)*. https://doi.org/10.17895/ices.pub.21551541

Armeli Minicante, S., Bongiorni, L., and De Lazzari, A., (2022). Bio-Based Products from Mediterranean Seaweeds: Italian Opportunities and Challenges for a Sustainable Blue Economy. Sustainability, 14(9), 5634; https://doi.org/10.3390/su14095634

Asaduzzaman, M., Nahiduzzaman, M. Chowdhury, M. T. H., Rahman, M. M., Mamun, A. Hossain, M.M. (2025) Advancing low-trophic extractive mariculture (LTEM): Strategies for a thriving blue economoy in Bangladesh. Marine Policy 173. 106557. https://doi.org/10.1016/j.marpol.2024.106557

Avila-Peltroche & Padilla-Vallejos (2020). The seaweed resources of Pero. Botanica Marina 63(4) 381-394. https://doi.org/10.1515/bot-2020-0026

Baden, S., Hernroth, B., & Lindahl, O. (2021). Declining populations of Mytilus spp. in North Atlantic coastal waters—A Swedish perspective. Journal of Shellfish Research, 40(2), 269–296.

Bak, U. G., Mols-Mortensen, A., & Gregersen, O. (2018). Production method and cost of commercial-scale offshore cultivation of kelp in the Faroe Islands using multiple partial harvesting. *Algal Research*, *33*(April), 36–47. https://doi.org/10.1016/j.algal.2018.05.001

Billing, S., Rostan, J., Tett, P. (2021) Handbook on social license to operate for seaweed cultivation. GenialG H2020 Project. Scottish Association for Marine Science. https://www.sams.ac.uk/t4-media/sams/pdf/publications/Handbook-on-Social-License-to-Operate-for-Seaweed-Cultivationv4(2).pdf

Bouchard, D., Camire, M.E., Davis, C., Shaler, G., Dumont, R., Bernier, R., Labbe, R. (2021) Attitudes toward aquaculture and seafood purchasing preferences: Evidence from a consumer survey of Atlantic States. Aquaculture Economics and Management. 25(4):411-429. https://doi.org/10.1080/13657305.2020.1869859

Britsch, M., Leslie, H., Stoll, J. (2021) Diverse perspectives on aquaculture development in Maine. Marine Policy. 131. 104697. https://doi.org/10.1016/j.marpol.2021.104697

Broughton, C., Baily, J., Green, D., Weidmann, M., Carboni, S. 2019. Spat mortality in farmed blue mussels (Mytilus edulis) in Scotland. European Aquaculture Society Conference. Dubrovnik, Croatia

Cleaver, C., Johnson, T., Hanes, S.P., Pianka, K. (2018) From fishers to farmers: Assessing aquaculture adoption in a training program for commercial fishers. Bulletin of Marine Science. 94(3): 1215-1222. https://doi.org/10.5343/bms.2017.1107

Corrochano-Fraile,. A., Adams, T.P., Aleynik, D., Bekaert, M., Carboni, S. (2022). Fronteirs in Marine Science. 9.

Damonte GH, Kluger LC, Gonzales IE (2023). Intertwined realities — hybrid institutions in the Peruvian fisheries and aquaculture sectors. Maritime Studies 22, 20. https://doi.org/10.1007/s40152-023-00309-1

Danielsen, Eirikur; á Norði, G. (2022). *Blue Mussel spat availability and settlement on longlines in a Faroese fjord*. https://aquavitaeproject.eu/reports_presentation/blue-mussel-spat-availability-and-settlement-on-longlines-in-a-faroese-fjord/

Dvarskas, A., Bricker, S.B., Wikfors, G.H., Bohorquez, J.J., Dixon, M.S., Rose, J.M. (2020) Quantification and valuation of nitrogen removal services provided by commercial shellfish aquaculture at the subwatershed scale. Environmental Science and Technology. 54, 16156–16165. https://pubs.acs.org/doi/10.1021/acs.est.0c03066

Eriksen, Katrine; Laksá, Unn; Laksáfoss, Magni; Kochanska, Adrianna; Herceglic, Nera; van den Burg, Sander; Hendricksen, Josien; Mikkelsen, E. (2024). *SEAMARK DELIVERABLE 8.3: PRELIMINARY TECHNO-ECONOMIC ASSESSMENT*. https://seamark.eu/about/deliverables/

Fairbanks, L. (2016) Moving mussels offshore? Percpetions of offshore aquaculture policy and expansion in New England. Ocean and Coastal Management (130): 1-12. https://doi.org/10.1016/j.ocecoaman.2016.05.004

Grebe, G., Byorn, C.J., St.Gelais, A., Kotowicz, D.M., Olson, T. (2019) An ecosystem approach to kelp aquaculture in the Americas and Europe. Aquaculture Reports. 15. 100215 https://doi.org/10.1016/j.aqrep.2019.100215

Griggs, R. 2022. A review of the aquaculture regulatory process in Scotland. Marine Scotland, Edinburgh. 59pp.

GMRI. 2016. Farmed shellfish market analysis. 47pp. https://d3esu6nj4wau0q.cloudfront.net/documents/GMRI_Farmed_Shellfish_Market_Report_2.0.pdf

Guyondet T., Comeau L. A., Bacher C., Grant J., Rosland R., Sonier R., et al. (2015). Climate Change Influences Carrying Capacity in a Coastal Embayment Dedicated to Shellfish Aquaculture. Estuaries Coasts 38, 1593–1618. doi: 10.1007/s12237-014-9899-x

Guyondet, T., Rilgueira, R., Pearce, C.M., Tremblay, R., Comeau, L.A. (2022) Nutrient-loading mitigation by shellfish aquaculture ein semi-enclosed estuaries. Fronteiers in Marine Science. 9. https://doi.org/10.3389/fmars.2022.909926

Houle, K.C., Buill, B.D., Christy, A. Davis, J.P., Leighfield, T.A., Morton, S.L., Shumway, S.E., Trainer, V.L., Vadopalas, B., Hudson, B. (2023) Biotoxin uptake, retention, and depuration trends in purble-hinged rock scallops, *Crassadoma gigantea* (Gray 1825). Journal of Shellfish Research, 42(2), 265-279.

Kim, JK, Stekoll, M., Yarish, C. (2019) Opportunities, challenges and future directions of open-water seaweed aquaculture in the United States. Phycologia, 58(5):446-461. DOI: 10.1080/00318884.2019.1625611

Kluger LC, Schlüter A, Garteizgogeascoa M, Damonte G (2022). Materialities, discourses and governance: scallop culture in Sechura, Peru. *Journal of Environmental Policy and Planning* 24(3): 309-324. DOI: 10.1080/1523908X.2022.2047620

Koch, S., Filgueira, R., Alberg, J., Angel, D., Byron, C., Cerca, M., Ennis, L., Bak, U., Kane, F., Kotta, J., Kraan, S., Peck, M., Poelman, M., Slegers, P., Spilling, K., Thomas, J.-B., & Kluger, L. (2024). *Identifying an Optimal Operating Window for Seaweed Aquaculture: Balancing Expansion Barriers and Carrying Capacity*. https://doi.org/10.2139/ssrn.5003456

Schlüter A, Kluger LC, Garteizgogeascoa M, Damonte G (2023). Resource Grabbing and the Blue Commons: The Evolution of Institutions in Scallop Production in Sechura Bay, Peru. In: Neef A, Moreda T, Mollett S, Ngin C (Ed.). Routledge Handbook of Global Land and Resource Grabbing p. 300-317. DOI: 10.4324/9781003080916-26

Krause, G., Vay, L.L., Buck, B.H., Costa-Pierce, B.A., Dewhurst, T., Heasman, K.G., Nevejan, N., Nielsen, P., Nielsen, K.N., Park, K., Schupp, M.F., Thomas, J., Troell, M., Webb, J., Wrange, A.L., Ziegler, F., Strand, A. (2022) Prospects of low trophic marine aquaculture contributing to food security in a net zero-carbon world. Fronteirs in Sustainable Food Systems. 6:875509. doi: 10.3389/fsufs.2022.875509

Lavoi, M.F., Simard, E., Drouin, A., Archambault, P., Comeau, L.A., McKindsey, C.W. (2022) Movement of American lobster *Homarus americanus* associated with offshore mussel *Mytilus edulis* aquaculture. Aquaculture Environment Interactions 14: 189-204. DOI: https://doi.org/10.3354/aei00437

Leandro, A., Pereira, L., Gonçalves, A.M.M. (2020). Diverse applications of marine macroalgae. Marine Drugs. 8, 17; doi:10.3390/md18010017

Lester, S.E., Gentry, R.R., Lemoine, H.R., Froehlich, H.E., Gardner, L.D., Rennick, M., Ruff, E.O., Thompson, K.D. (2022) Diverse state-level marine aquaculture policy in the United States: Opportunities and barriers for industry development. Reviews in Aquaculture. 14: 890-906. DOI: 10.1111/raq.12631

Li, T., Ahsanuzzaman, Messer, K.D. (2021) Is there a potential US market for seaweed-based products? A framed field experiment on consumer acceptance. Marine Resource Economics 36(3). http://dx.doi.org/10.1086/714422

McClenachan, L., Moulton, A. (2022) Transitions from wild-caught fisheries to shellfish and seaweed aquaculture increase gender equity in Maine. Marine Policy. 146. 105312. https://doi.org/10.1016/j.marpol.2022.105312

Murray, A., G., Marcos-Lopez, M., Collet, B., Munro, L.A. (2012) A review of the risk posed to Scottish mollusc aquaculture from Bonamia, Marteilia and oyster herpesvirus. Aquaculture, 370-371: 7-13

Mizuta, D.D., Wikfors, G. (2019) Depth selection and in situe validation for offshore mussel asquacultur e in northeast united States federal waters. Journal Marine Science Engineering. 7(9), 293; https://doi.org/10.3390/jmse7090293

Mizuta, D.D., Wikfors, G. (2020). Farmed mussels in the northeastern U.S. Excluseive Economic Zone; An opportunity too good to ignore. 45(4): 207-213. https://doi.org/10.1002/fsh.10365

Pacifico, A.M., Brigolin, D., Mulazzani, L., Semeraro, M., Malorgio, G., 2024. Managing marine aquaculture by assessing its contribution to ecosystem services provision: The case of Mediterranean mussel, *Mytilus galloprovincialis*. Ocean and Coastal Management 259 (2024) 107456

Piconi, P., Veidenheimer, R., Chase, B. (2020) Edible Seaweed Market Analysis. Island Institute. 56pp.

Steeves, L.E., Filgueira R., Guyondet, T., Chasse, J., Comeau, L. (2018) Past, present and future: Performance of two bivalve species under changing environmental conditions. Frontiers in Marine Science. 5. https://doi.org/10.3389/fmars.2018.00184

St.Gelais, A., Fredriksson, D.W., Dewhurst, T., Miller-Hope, Z.S., Costa-Pierce, B.A., Jondrow, K. (2022) Engineering A Low-Cost Kelp Aquaculture System for Community-Scale Seaweed Farming at Nearshore Exposed Sites via User-Focused Design Process. Frontiers in Sustainable Food Systems. 6:848035. doi: 10.3389/fsufs.2022.848035

Svensson, S.G.B. Strohmeier, T., Rastrick, H., Garcia, A.A., Lock, E., Sveier, H., Jansen, H.(2023). Life history traits for *Ophryotrocha craigsmithi*, a candidate species in integrated multitrophic aquaculture. Frontiers in Marine Science. 10.

Tett, P., B. Valcic, T. Potts, C. Whyte, F. Culhane and T. Fernandes 2012. Mussels and yachts in Loch Fyne, Scotland: a case study of the science- policy interface. Ecology and Society 17(3): 16.

Tett, P., Charalambides, G., Franco, S.C., Hughes, A.D., Mikkelsen, E., Nielsen, K.N., Routledge, E.A.B., Nielsen, P. James, P. (2025) Leaving the niche: Recommendations for mainstreaming Low Trophic Aquaculture in countries around the Atlantic Basin. Marine Policy 171. 106475 https://doi.org/10.1016/j.marpol.2024.106475

Wood, S.E., Filgueira, R. (2022). Drivers of social acceptability for bivalve aquaculture in Atlantic Canadian Communities. 27(3):9. https://doi.org/10.5751/ES-13358-270309

2 Term of Reference B

2.1 Background

It is not clear if energy and nutrients derived from aquaculture sites is a net benefit or detriment to wild populations. There is a need to provide an overview of the transfer of energy between farm sites and the surrounding environment and the implications of this to the greater ecosystem and associated organisms. The review will include the identification of knowledge needs and priorities in this ToR.

2.2 Objective

A review of the transfer of energy and nutrients between farm sites (e.g. algae, bivalves, finfish) and the surrounding ecosystem to maintain production within carrying capacity limits; Identification of knowledge gaps and recommendations for research.

2.3 Methodology

Three conceptual diagrams representing generalized ocean farming systems for finfish, bivalves, and seaweed were developed. Energy flows leaving the farm and entering the surrounding ecosystem were identified and described for each of the three farming systems. These flows outward into the environment were discussed at the individual level, population level, and ecosystem level. Management implications and recommendations were made based on WGECCA expertise and published literature.

2.4 Results

A manuscript is in preparation with the title **"Into the wild: how farm-derived nutrients and energy flow through marine ecosystems – consequences and management perspectives"**. Myriam Callier is the lead author and facilitating the advancement of this manuscript to publication, together with the assistance of coauthors: Ramon Filgueira, Carrie J. Byron, Daniele Brigolin, Dror L. Angel, Sophie J. I. Koch, Bobbi Hudson, Frank Kane, Heather Moore, Antonio Aguera, and Christopher W. McKindsey. This manuscript will likely be submitted to either ICES Journal of Marine Science or Reviews of Aquaculture.

Abstract: A review of the transfer of energy and nutrients between farm sites (algae, bivalves, and finfish) and the surrounding ecosystems relevant to maintain production within carrying capacity limits. This publication further identifies knowledge gaps and makes recommendations for research and implication in terms of management (Fisheries, MPA). We carried out a narrative review (appr. 90 studies) to illustrate all the fluxes coming from the farm and the corresponding direct and indirect trophic transfers. We reviewed the consequences at individual, population, and ecosystem levels and illustrate the interactions in case studies. Consequence and on management perspectives.

Keywords: trophic transfer, aquaculture, shellfish, finfish, macroalgae, mariculture

3 Term of Reference C

3.1 Background

Given the current levels of understanding and experience in the implementation of ECC monitoring, there is now a need to explore the possibility of developing guidelines for more cost-effective, less data intensive ECC monitoring techniques. It is important that these guidelines draw on expert knowledge to provide (i) for the identification of the environmental drivers relevant to the types of aquacultures being monitored and the waterbody they occur in (ii) guidance on the choice of proxy for ECC and (iii) guidance for the establishment of the ECC thresholds.

3.2 Objective

Review Ecological Carrying Capacity (ECC) monitoring techniques with potential to identify more efficient applications to support ECC as a management strategy.

3.3 Methodology

This work included organizing and hosting a networking session on Indicators for Ecological Carrying Capacity at the ICES ASC 2023in Bilbao, Spain. The outcomes of this networking session were incorporated into the resulting manuscript.

3.4 Results

A manuscript has been published capturing the work for ToR C:

Indicators for ecological carrying capacity of bivalve and seaweed aquaculture
Carrie J. Byron, Sophie J. I. Koch, Myriam D. Callier, Lotta C. Kluger, Dror L. Angel, JanVanaverbeke, Ramon Filgueira

First published: 27 June 2024
https://doi.org/10.1111/raq.12945

Abstract
Within the framework of Ecosystem Approach to Aquaculture (EAA), ecological carrying capacity (ECC) is a key concept that helps to determine the upper limit of production without compromising ecosystem functioning. The implementation of ECC is complex as ECC differs between type of farms and location and standardized methods should be developed for management. There is therefore a clear need for operational indicators. The objectives of this paper were: (1) to carry out a systematic literature review on shellfish and seaweed aquaculture-environment interactions to list the most used environmental indicators, (2) to classify the indicators according to the effects they measure (i.e. benthic, water quality, foodweb interactions, cultured organism health, resource use) and the scale on which they are applied, and (3) to assess their potential based on four indicator criteria categories: sensitivity, accuracy and precision, feasibility and utility, and ecosystem-level scalability. Overall, indicators describing benthic effects were the most highly cited and scored. Indicators identified for bivalve and seaweed culture were

discussed and compared to previous work on salmon aquaculture indicators to highlight similarities and differences across trophic levels. In addition, questions related to the challenges of ECC indicators implementation were presented to a panel of experts. The scoring and consultation provided the source of discussion on environmental management consistent with EAA.

4 Conclusion

WGECCA will continue its work in a new term (2025–2027) with new ToRs:

- Assessment response of ecological carrying capacity of aquaculture from climate change drivers and with recommendations for sustainable management and adaptation strategies.
- Monitor trends and trajectories in research and application of ecological carrying capacity of aquaculture.

Annex 1: List of participants

Name	Institute	Country (of institute)
Antonio Aguera Garcia	Institute of Marine Research	Norway
Bobbi Hudson	Pacific Shellfish Institute	US
Carrie Byron	School of Marine and Environmental Sciences	US
Chris McKindsey	Fisheries and Oceans Canada	Canada
Dan Cheney	Pacific Shellfish Institute	US
Daniele Brigolin	Ca'Foscari University of Venice	Italy
Dror Angel	University of Haifa	Israel
Elisa Ravagnan	NORCE	Norway
Francis O'Beirn	Marine Institute	Ireland
Frank Kane	Marine Institute	Ireland
Heather Moore	Agri-food and Biosciences Institute	UK
Jeffrey Fisher	City of Seattle	US
Lotta Kluger	Christian-Albrechts-University of Kiel	Germany
Lynne Falconer	University of Stirling	UK
Myriam Callier	Palavas-les-Flots Station	France
Nicole O'Shea	Department of Agriculture, Food and the Marine	Ireland
Ola Luthman	Aquaculture Stewardship Council	Sweden
Rakel Gudmundusdottir	Marine and Freshwater Research Institute	Iceland
Ramon Filgueira	Dalhousie University	Canada
Reinier Nauta	Wageningen University and Research	Netherlands
Sophie Koch	Wageningen University and Research	Netherlands
Trevor Telfer	University of Stirling	UK

Annex 2: Resolutions

WGECCA – Working Group on Ecological Carrying Capacity in Aquaculture

2021/FT/ASG01 A **Working Group on Ecological Carrying Capacity for Aquaculture** (WGECCA), chaired by Carrie J. Byron, USA, and Dror Angel, Israel, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2022	26 September (monthly meetings)	Online		
Year 2023	Monthly	Online		
Year 2024	TBD	TBD	Final report by Date to ASG	

ToR descriptors

ToR	Description	Background	Science Plan Codes	Duration	Expected Deliverables
a	Estimate the development potential of underutilized lower trophic level aquaculture species in ICES countries including (i.e. macroalgae, invertebrates, detritivores) towards understanding carrying capacity thresholds. Identification of social, economic and environmental advantages, barriers and knowledge gaps; recommendations for research.	The cultivation of lower trophic level (LTL) species has been proposed as the most sustainable approach to optimize biomass extraction from the ocean. Many of the LTL species, e.g. macroalgae, invertebrates are not widely cultivated in Europe and the Americas. This review will identify social, economic and environmental barriers, priorities, advantages, and knowledge gaps within LTL aquaculture.	5.5	year 1-2	ICES report to inform future research proposals.

b	A review of the transfer of energy and nutrients between farm sites (e.g. algae, bivalves, finfish) and the surrounding ecosystem as it influences carrying capacity limits; Identification of knowledge gaps and recommendations for research.	It is not clear if energy and nutrients derived from aquaculture sites is a net benefit or detriment to wild populations. There is a need to provide an overview of the transfer of energy between farm sites and the surrounding environment and the implications of this to the greater ecosystem and associated organisms. The review will include the identification of knowledge needs and priorities in this new ToR.	5.6, 1.3, 1.4	Year 1-2	Manuscript for publication
c	Review Ecological Carrying Capacity (ECC) monitoring techniques with potential to identify more efficient applications to support ECC as a management strategy.	Given the current levels of understanding and experience in the implementation of ECC monitoring, there is now a need to explore the possibility of developing guidelines for more cost-effective, less data intensive ECC monitoring techniques. It is important that these guidelines draw on expert knowledge to (i) identify the environmental drivers relevant to the types of aquacultures being monitored and the waterbody they occur in (ii) provide guidance on the choice of proxy for ECC and (iii) guide the establishment of the ECC thresholds.	6.1	Year 3	ICES report of identified knowledge gaps for future research

Summary of the Work Plan

YEAR 1	GATHER BACKGROUND INFORMATION AND BEGIN TYPING SUMMARIES OF FINDINGS FOR TOR A & B.
Year 2	Write report and manuscript for ToR a & b. Begin preliminary work for ToR c.
Year 3	Synthesize information and write report for ToR c.

Supporting information

Priority	The current activities of this Group will inform ICES on issues related to the ecological carrying capacity for differeent aquaculture species in different regions. Consequently, these activities are considered to have a very high priority.
Resource requirements	None at this time.
Participants	The Group is normally attended by a dozen members.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	There are no obvious direct linkages.

Linkages to other committees or groups	There is a very close working relationship with all the working groups in ASG.
Linkages to other organizations	

Annex 3: Appendix

Includes ppt. slides supporting information provided in ToR A, Part 1.

Center for Ocean and Society

KIEL MARINE SCIENCE CONNECTED RESEARCH

CAU Christian-Albrechts-Universität zu Kiel

Aquaculture of low trophic level species

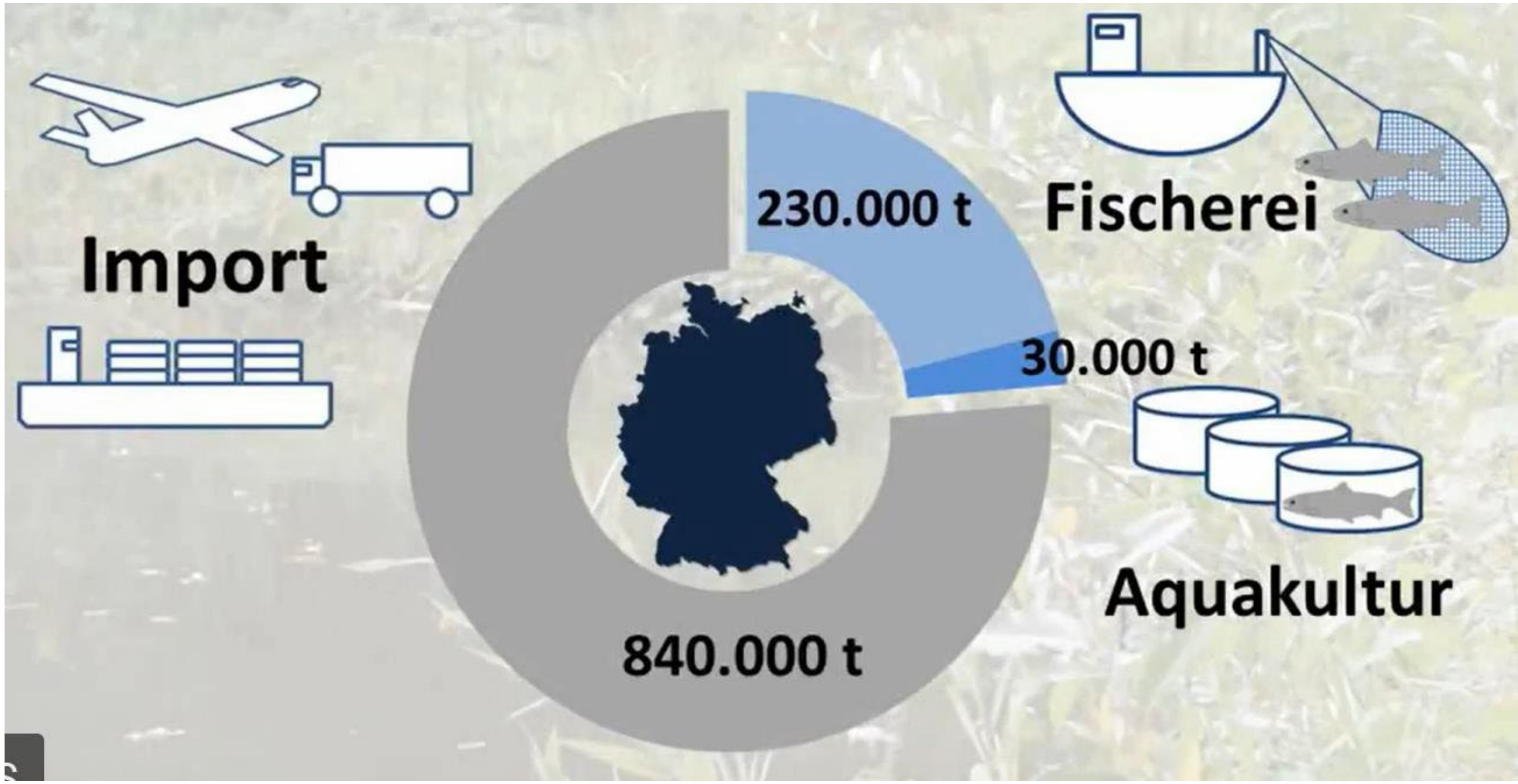
GERMANY

October 31st 2022

Center for Ocean and Society

The German fisheries and aquaculture sector of Germany

- Total seafood volume: 2.2M tons (88% imports)
- Human consumption: 12.7 kg /capita

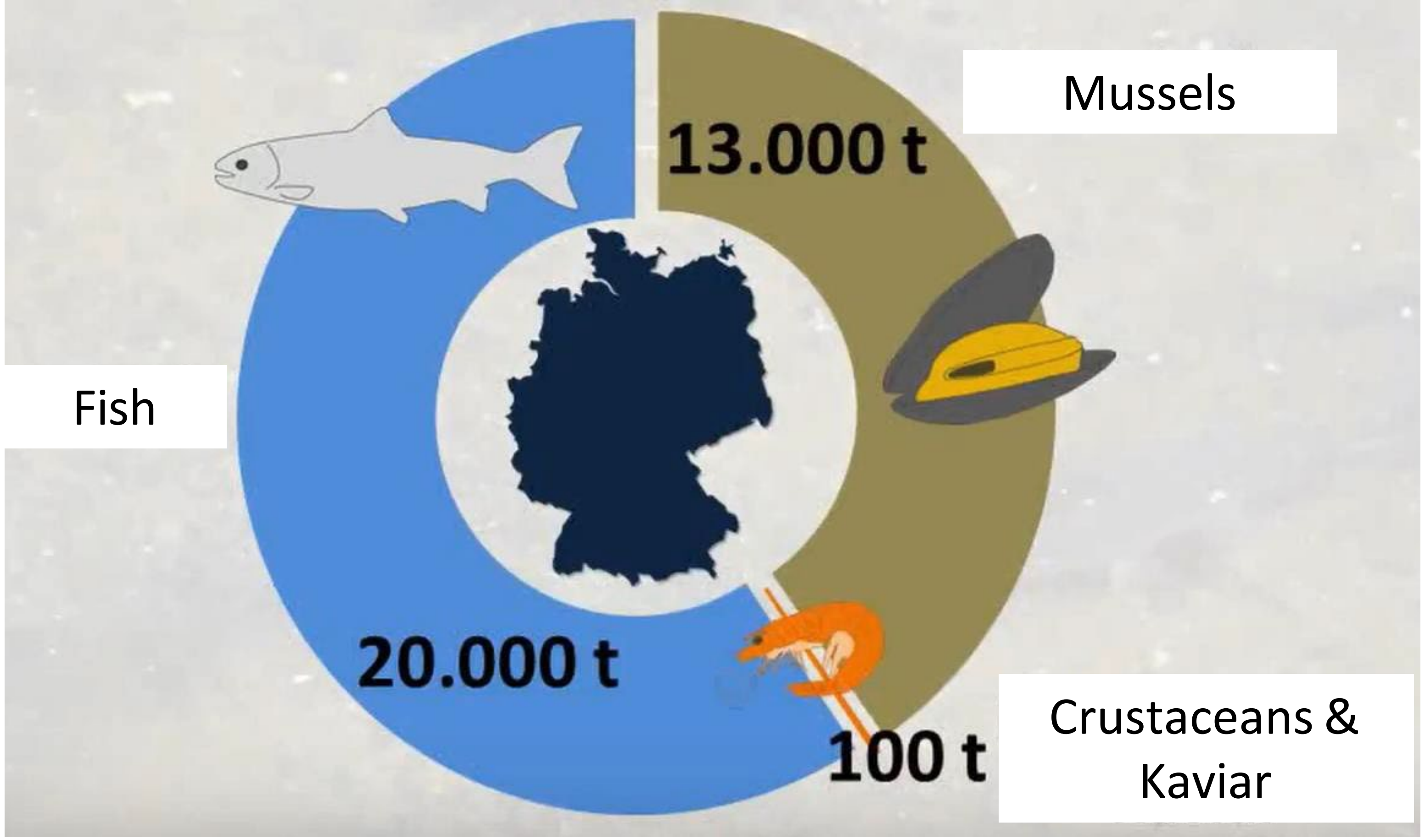


Values for 2016

Source: Statistisches Bundesamt; Fig.: https://www.aquakulturinfo.de/aquakultur-deutschland

Aquaculture in Germany

Aquaculture farms: 2281



Values for 2016

Source: Statistisches Bundesamt; Fig.: https://www.aquakulturinfo.de/aquakultur-deutschland

Aquaculture production

	2019	2020	2021
Fish	18.548	18.596	18.267
Crustaceans	k. A.	k .A.	k. A.
Mollusks	19.413	13.490	14.274
Kaviar	76	76	85
Algae	k. A.	k. A.	k. A.
Gesamt[2]	**38.074**	**32.204**	**32.671**

[1] Und sonstige aquatische Organismen. [2] Einschließlich geheim gehaltener Angaben. k. A.: keine Angaben

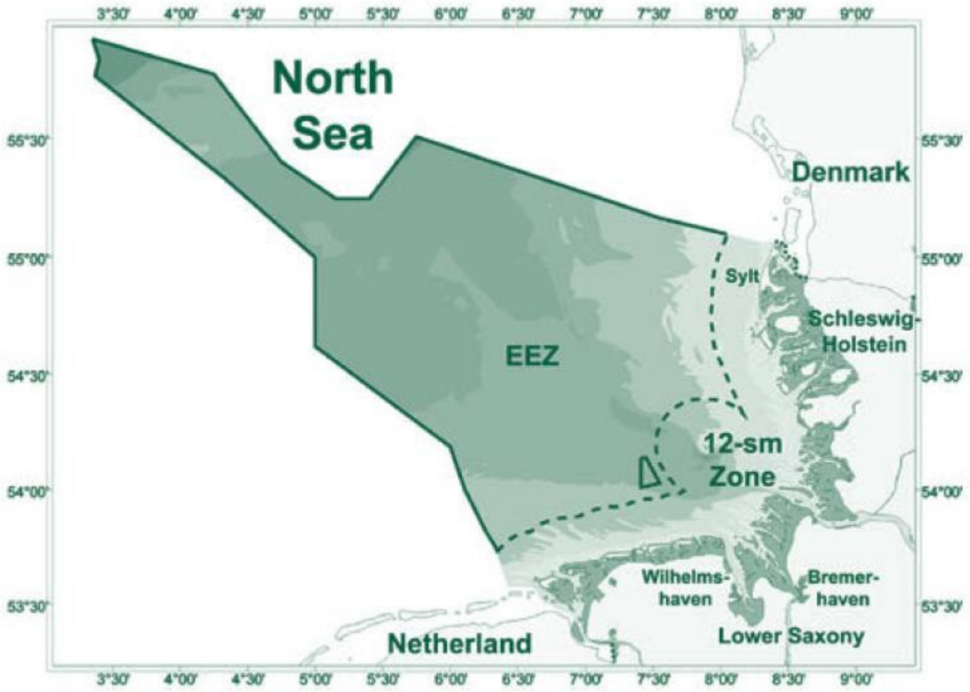
Values in in tons

Source: FIZ (2022), p. 17

Center for Ocean and Society

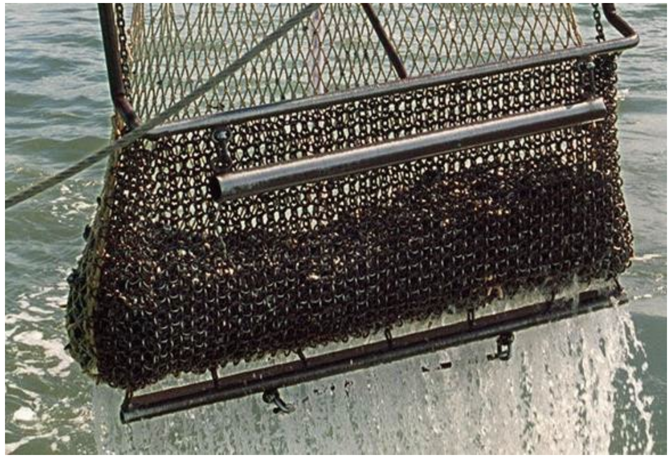
(Marine) Aquaculture in Germany

- German coast = relatively short (in relation to total landmass) & harsh conditions (tidal range)
- Focus on trout & carp culture (inland) in the past & present



Source of Fig.: Buck et al. (2006)

(Marine) Aquaculture in Germany



- Long tradition of blue mussel (*Mytilus edulis*) and oyster (*Ostrea edulis*) harvesting
  → *M. edulis*: bottom-culture, (long-lines)
  → *O. edulis* ‘replaced‘ by *Crassostrea gigas*

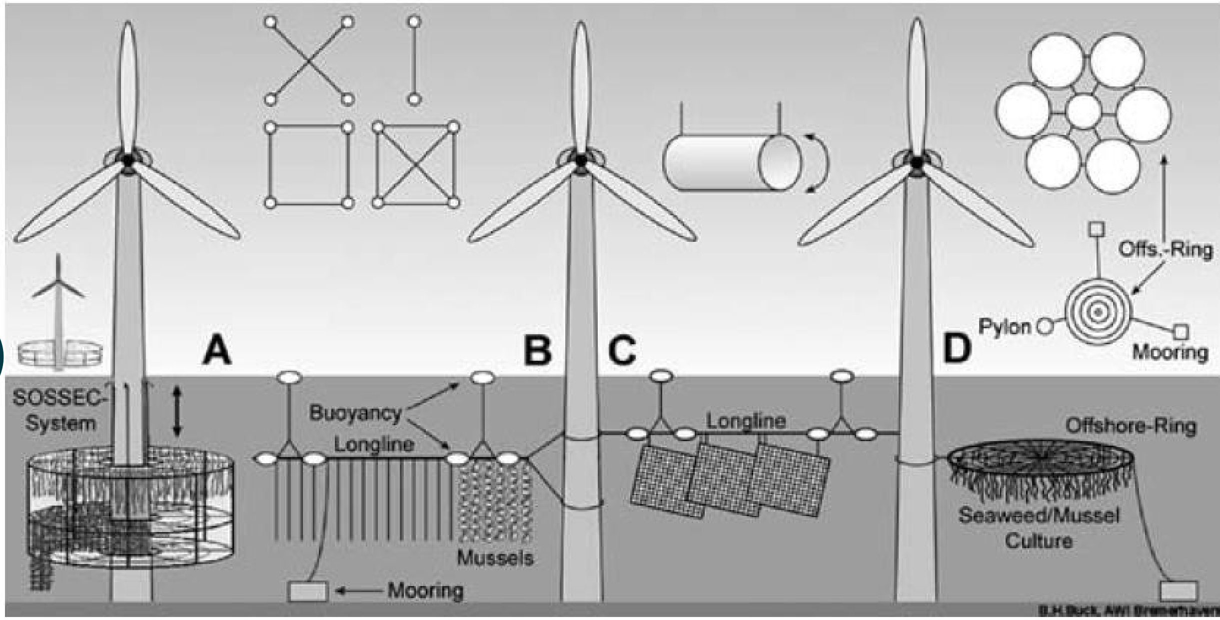
European oyster (*Ostrea edulis*)

Pacific oyster (*Ostrea edulis*)

Sources of Figs.: Wikipedia; Planet-wissen.de Pogoda (2019)

(Marine) Aquaculture in Germany

- Experimental open-ocean culture (windfarms!) since the 2000's, IMTA experiments



Source of Fig.: Buck et al. (2006)

References

FIZ - Fisch-Informationszentrum e.V. (2022). Daten und Fakten 2022. https://www.fischinfo.de/index.php/verbraucher/broschueren?cf=5081#Flyer5081

https://www.aquakulturinfo.de/aquakultur-deutschland

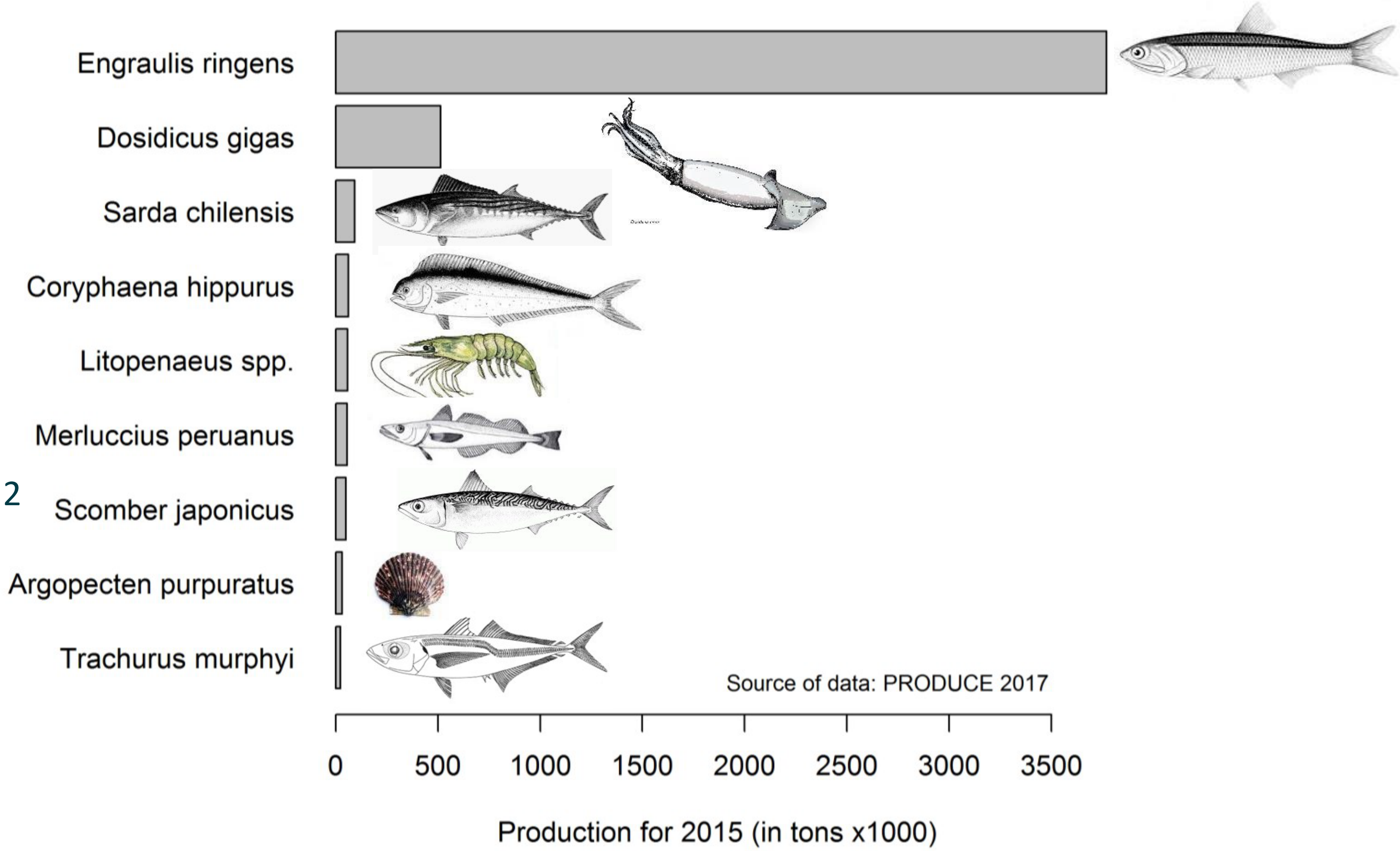
Buck et al. (2006)

Aquaculture of low trophic level species

PERU

The Peruvian fisheries and aquaculture sector

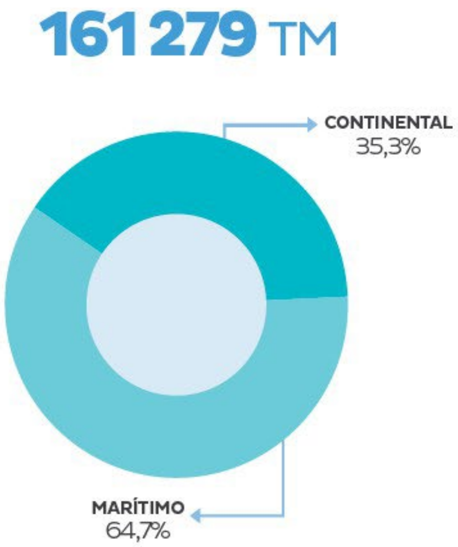
- World's 2nd fisheries producer (>7M tons /yr) [1]
- Industrial fishery: 91% of production
- Anchoveta (*Engraulis ringens*) accounts for up to 80% of catches [2]

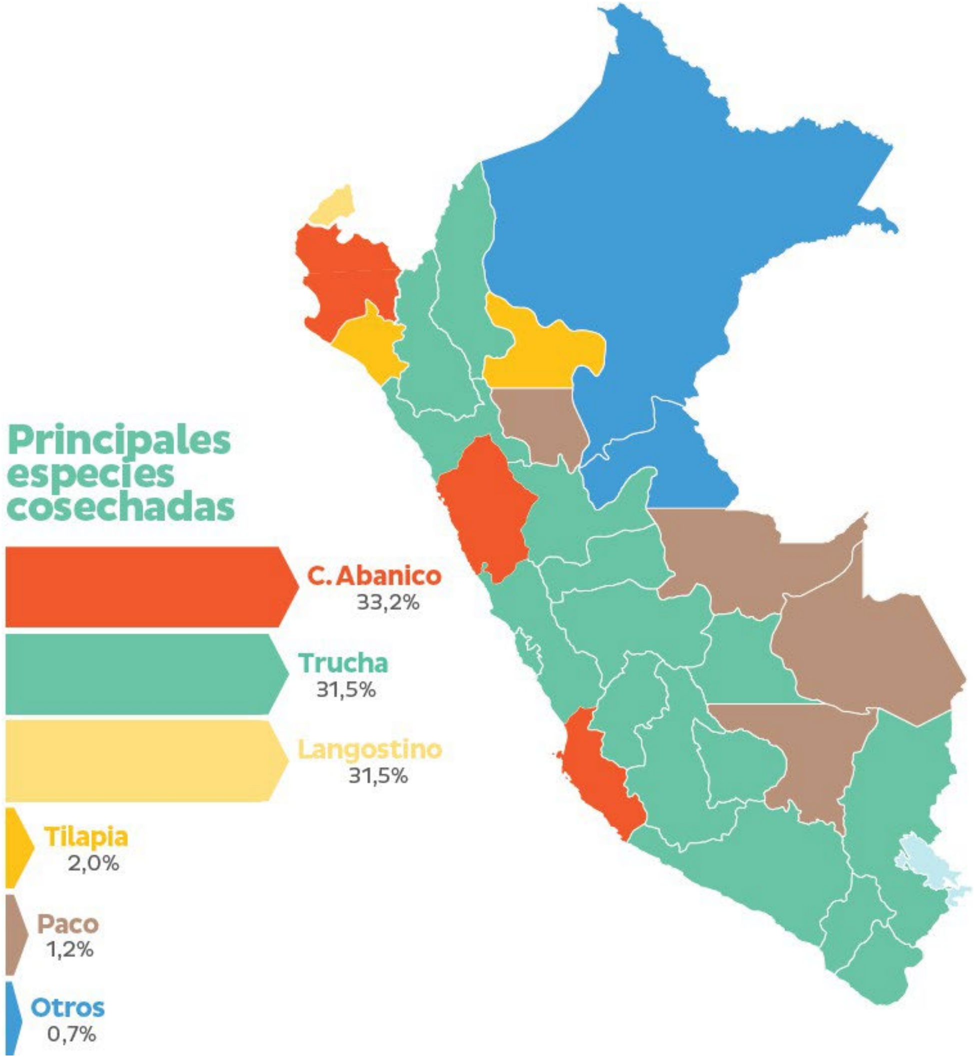


Sources: 1 FAO; 2 Mendo & Wosnitza-Mendo (2014)

Aquaculture in Peru

Total harvest





Source: PRODUCE (2020), p. 130

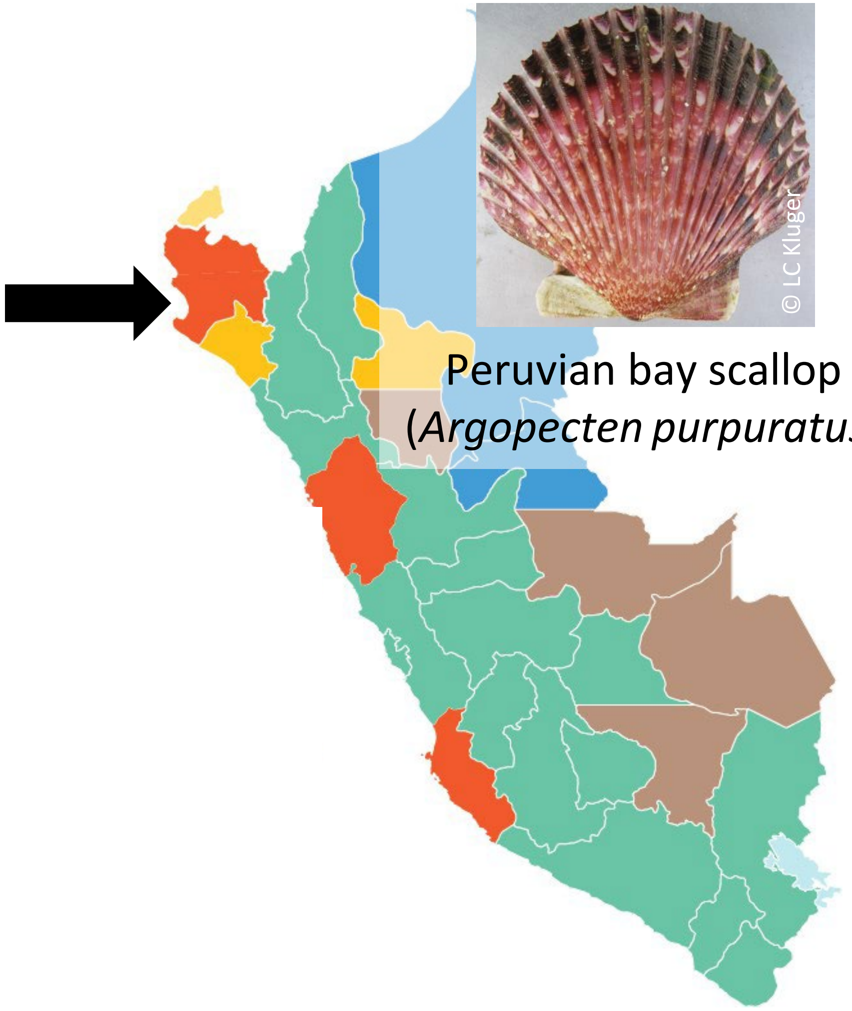
Scallop production in Peru

From open-access fisheries…

- Artisanal diving fishers since 1990‘s
- Until 2006, landings <1% of all catches [1]

… to aquaculture:

- First cultures (informally) established in early 2000‘s
- By now, 158 fishermen cooperatives registered [2], and
  41% of bay‘s area occupied by aquaculture [3]
- 5 000 fishers and 20 000 personnel [4]
  → influx of migrants

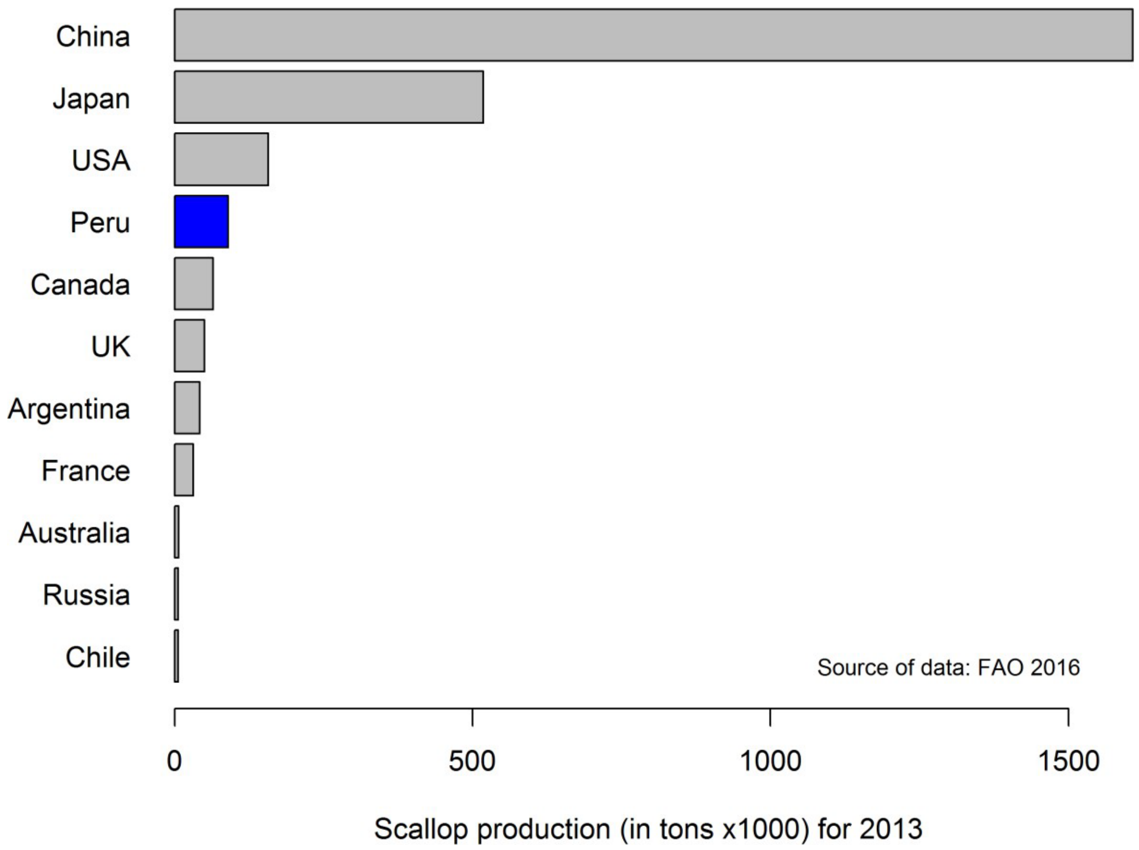


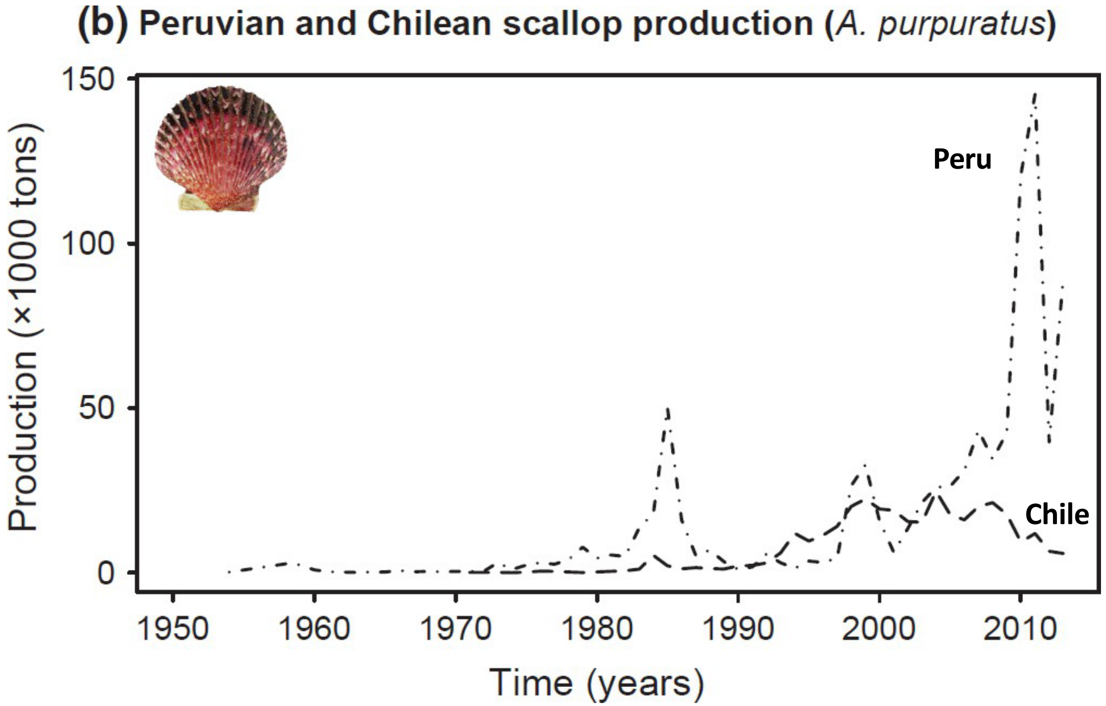
Peruvian bay scallop (*Argopecten purpuratus*)

Source:1 IMARPE (2007); 2 Mendo (2015); 3 PRODUCE (2015); 4 J. Proleon (pers. comm.)

Scallop production in Peru

Sechura in the context of world scallop production

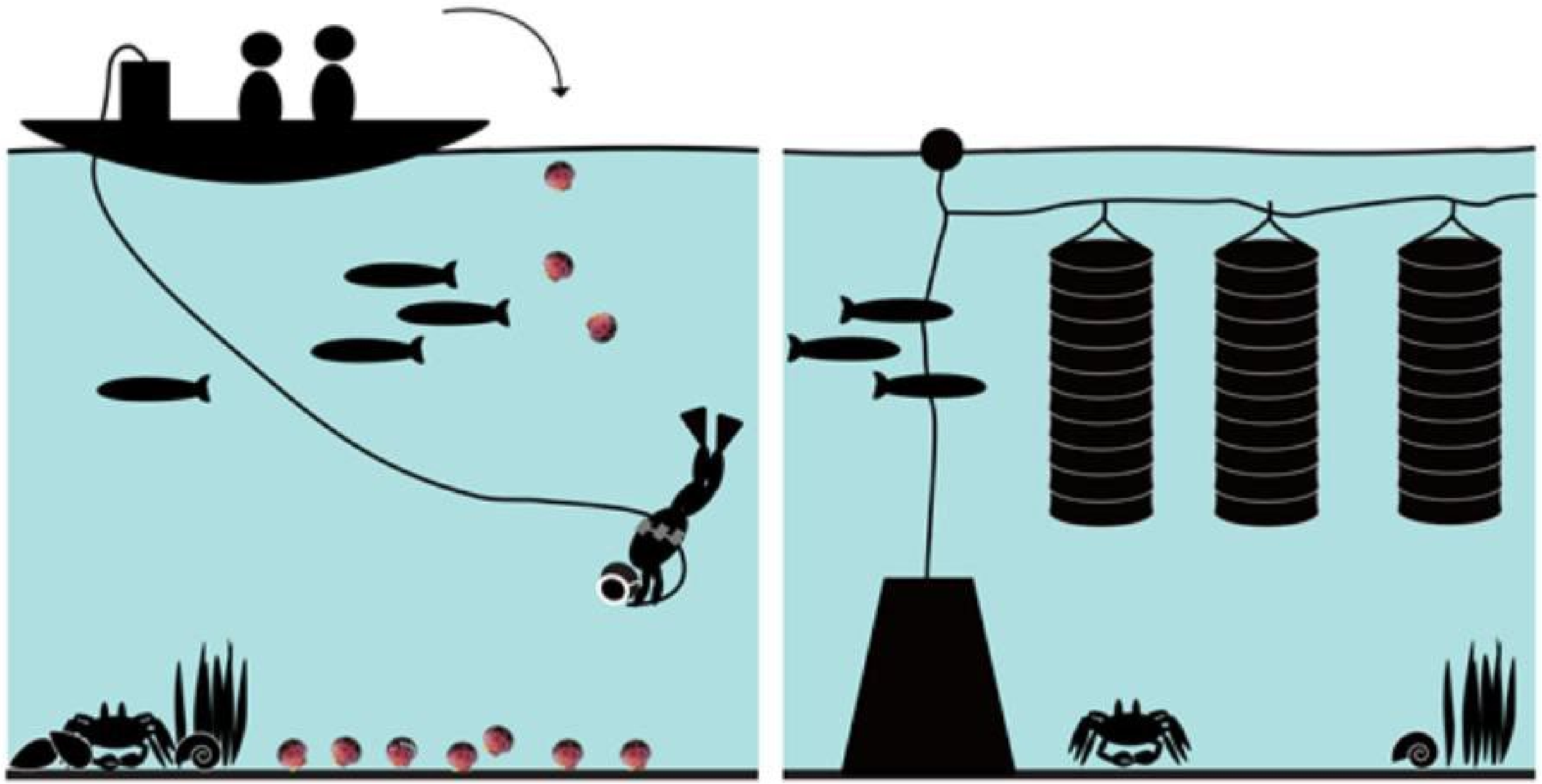




Source: Kluger et al. (2019); FAO data

Scallop production in Peru

Bottom vs. suspended aquaculture

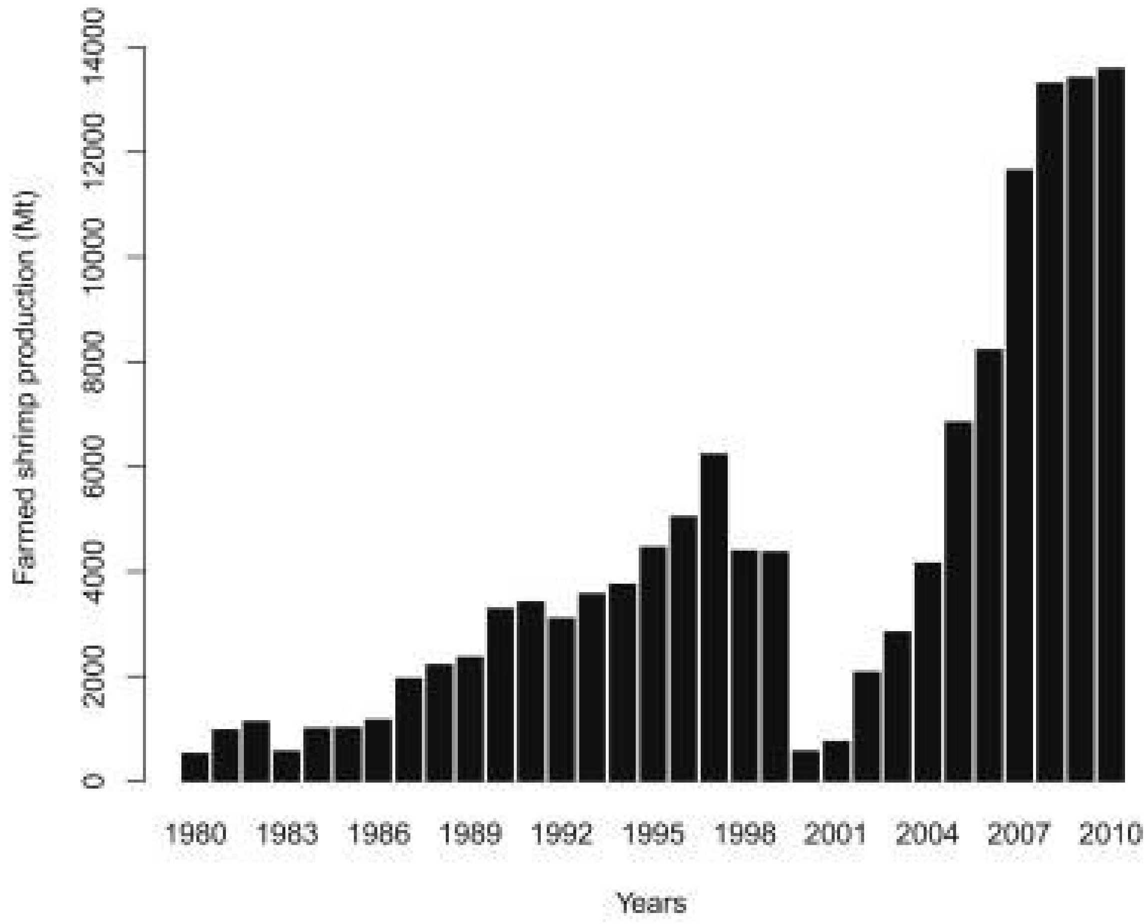


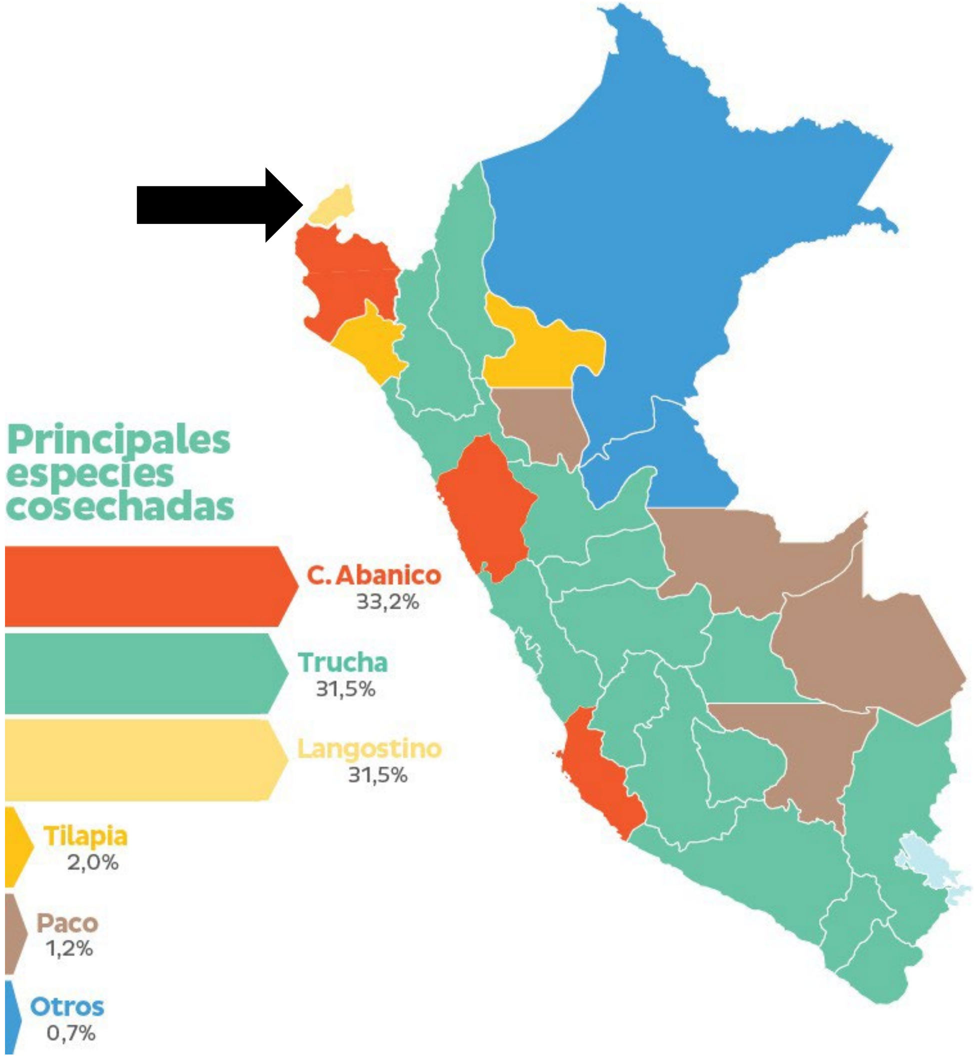
Source: Fig: Kluger et al. (2020)

Center for Ocean and Society

Shrimp farming in Peru

- Ermerged in the late 1970s (export-oriented)



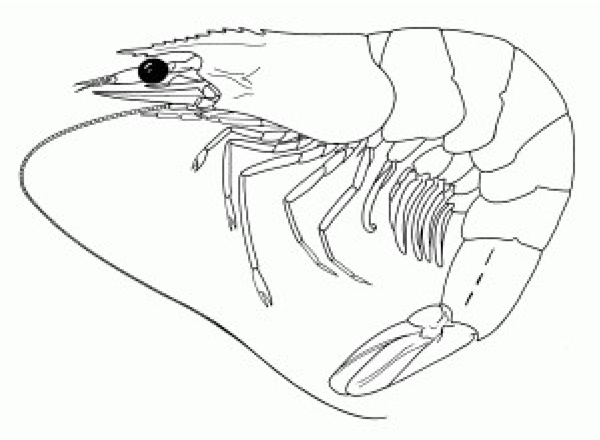


Source (also of Fig.): Mialhe et al. (2013)

Shrimp farming in Peru

- Semi-intensive and intensive monoculture of shrimps (*P. vannamei*).

  → Converted 17% of the Peruvian mangroves
- Provides work for ca. 10000 persons (influx of migrants)



Penaeus vannamei

Source of Fig: FAO

Source: Mialhe et al. (2013); Picture: own

Center for Ocean and Society

References

Mendo & Wosnitza-Mendo (2014)

PRODUCE (2020)

IMARPE (2007)

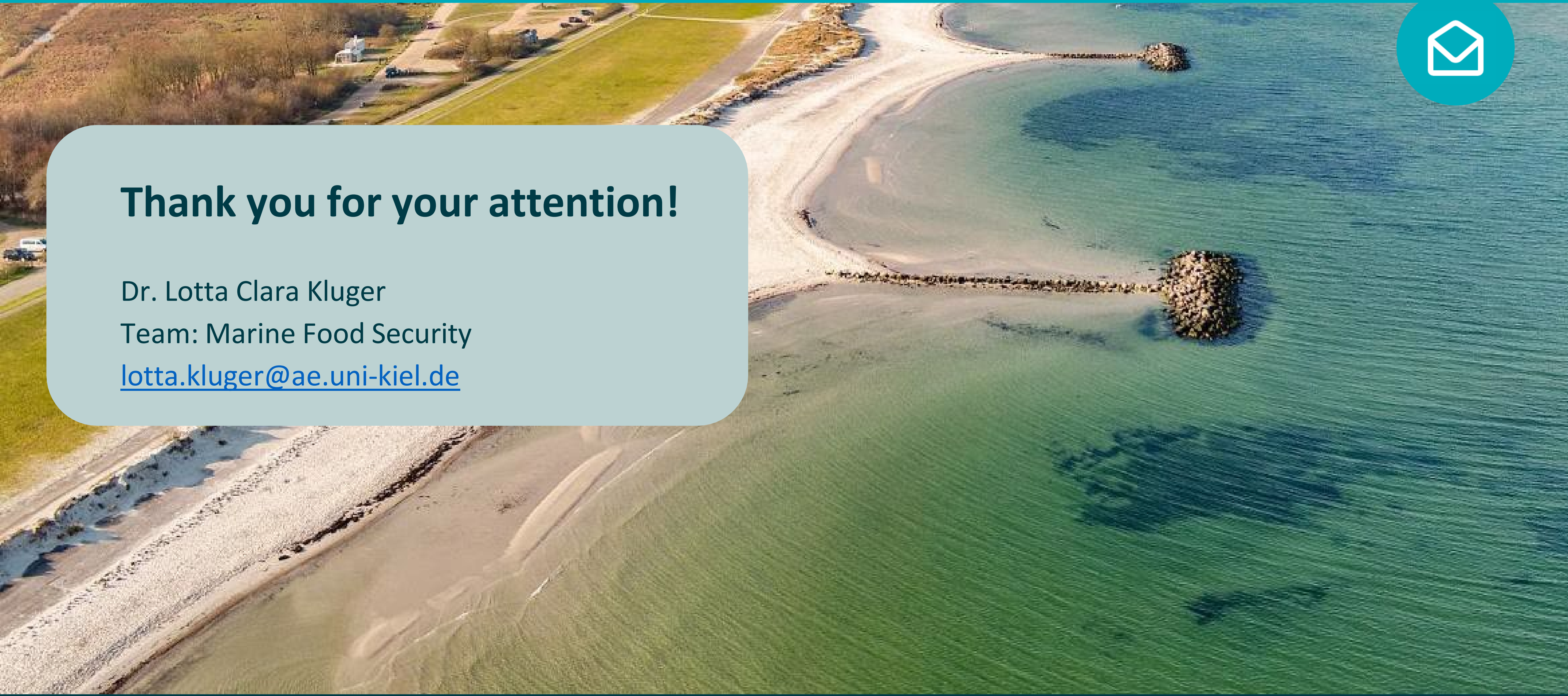
Mendo (2015)

PRODUCE (2015)

Kluger et al. (2019)

Kluger et al. (2020)

Mialhe et al. (2013)



Thank you for your attention!

Dr. Lotta Clara Kluger
Team: Marine Food Security
lotta.kluger@ae.uni-kiel.de

Shellfish

La conchyliculture regroupe principalement :

L'ostréiculture (élevage d'huîtres)

La mytiliculture (élevage de moules)

La vénériculture (élevage de palourdes)

La cérastoculture (élevage de coques)

Total aquaculture production in France= 200 000 T

Shellfish farming = 155 000 T (in comparison: 49 000 T fish, only 5000 T marine fish)

- Pacific Oyster= 77 000T
- Mussel=75 000T
- Clams and cokcel = 3000 T

	Barriers	Opportunities	Knowledge gaps
Social		Rural employment 2938 farms	
Economic		700 M euros	
Environmental	Oyster and mussel mortality: diseases (virus, bacteria), anoxia , picoplankton	Nutrient extraction	
Cultural		well establish	
Governance			

France. Myriam Callier

European flat oyster (*Ostrea edulis*)

a)

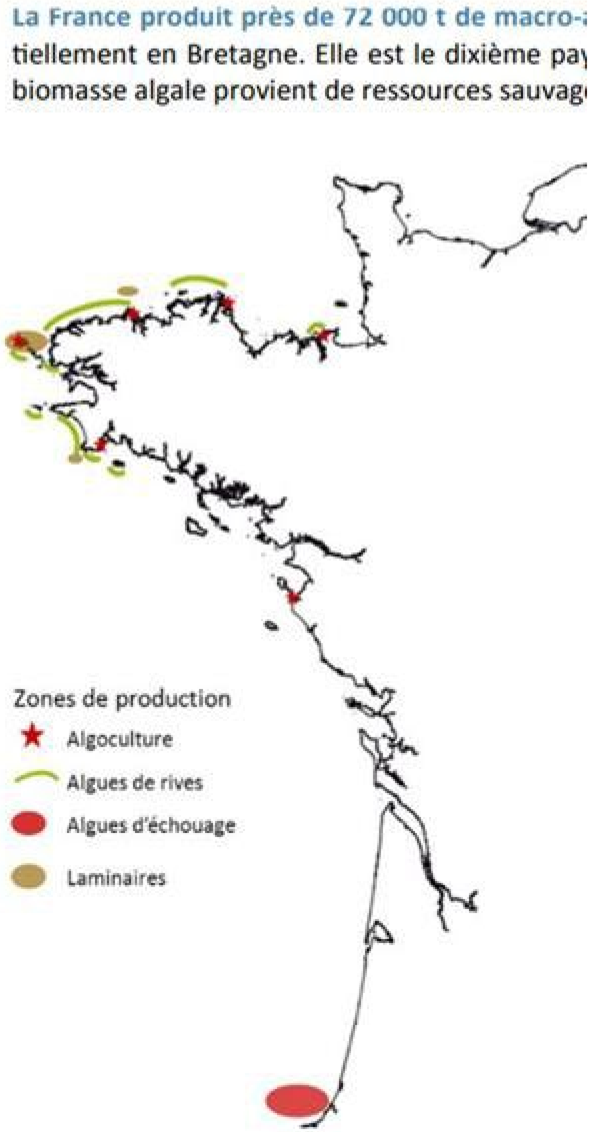

1500 T

+	-
• Good image • european species • Ecological Restoration	• Parasit • Predatory snail: European sting winkle • Predation: seabream

Ifremer research

France. Myriam Callier

Seaweed



Zones de production des macro-algues en France (Netalgae, 2012)

- ALGAE (in the world algae production dominated by aquaculture but not in France!
- 90 000 T = collect
- 10 farms = 100 T/year,
- *Undaria pinnatifida*,
- Japan species: *Saccharina latissima*.

https://www.idealg.org/fr/la-production-francaise
https://www.idealg.org/fr/les-algues-dans-la-presse

Research: CNRS, IFREMER

France. Myriam Callier

Seaweed

	Barriers	Opportunities	Knowledge gaps
Social	Social acceptability		
Economic			
Environmental		Restoration, ecosystem services	production, selection
Cultural			
Governance			

France. Myriam Callier

Seacucumbers: « pilot scale projects »

- *Holothuria tubulosa*
- *Holothuria forskali*
- Https://www.youtube.com/watch?v=G-nFj23At0I

	Barriers	Opportunities	Knowledge gaps
Social	Social acceptability		
Economic			
Environmental	Growth rate	Restoration, ecosystem services	production
Cultural	No market (exportation)		
Governance			

France. Myriam Callier

Polychaetes

Arenicola marina = (the first universal oxygen carrier for therapeutic purposes)

https://www.hemarina.com/hemarina/la-ferme-aquacole/

https://www.sciencesetavenir.fr/videos/reportage-dans-la-ferme-de-vers-marins-dhemarina_m8zmxv

Hediste diverscicolor

France. Myriam Callier

Some examples of LTL initiatives in the Eastern Mediterranean

Dror Angel
University of Haifa
Israel

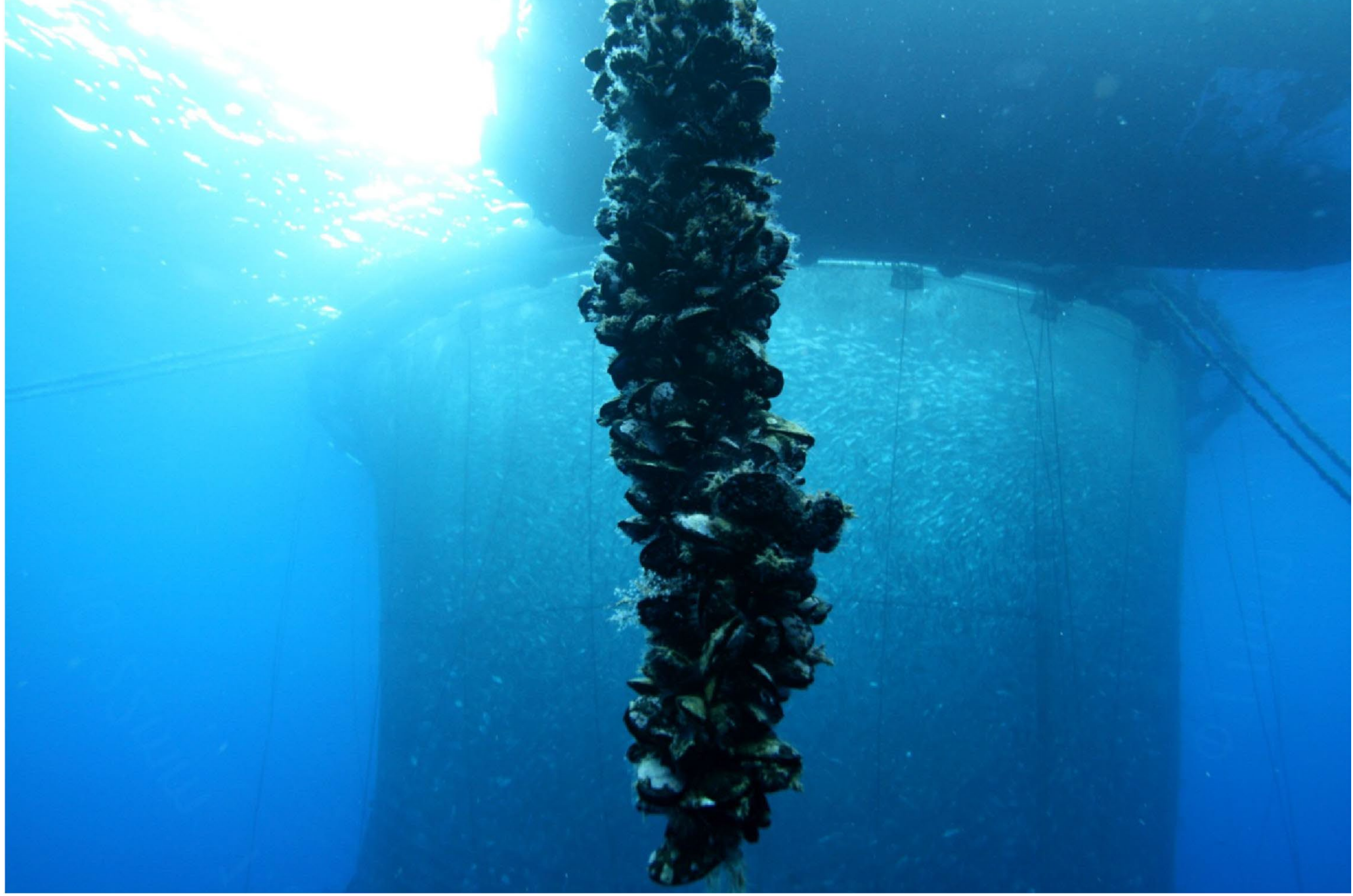
Unlike most of the groups that focus on cold water AQ, the E Med is warm, oligotrophic, hi-salinity systems

- in Med & Red Sea’s
  - conventional extractive biota (bivalves, algae) do not grow naturally in large quantities, because:

1. Naturally low background levels of **nutrients** & biomass
2. Delivery of farm effluents to extractive species is inefficient due to:
   - **Dispersive** sites - best for FFs – good water quality

For example:

In IDREEM project - mussels, oysters, sea urchins, crabs were tested at commercial fish farm in Cyprus…



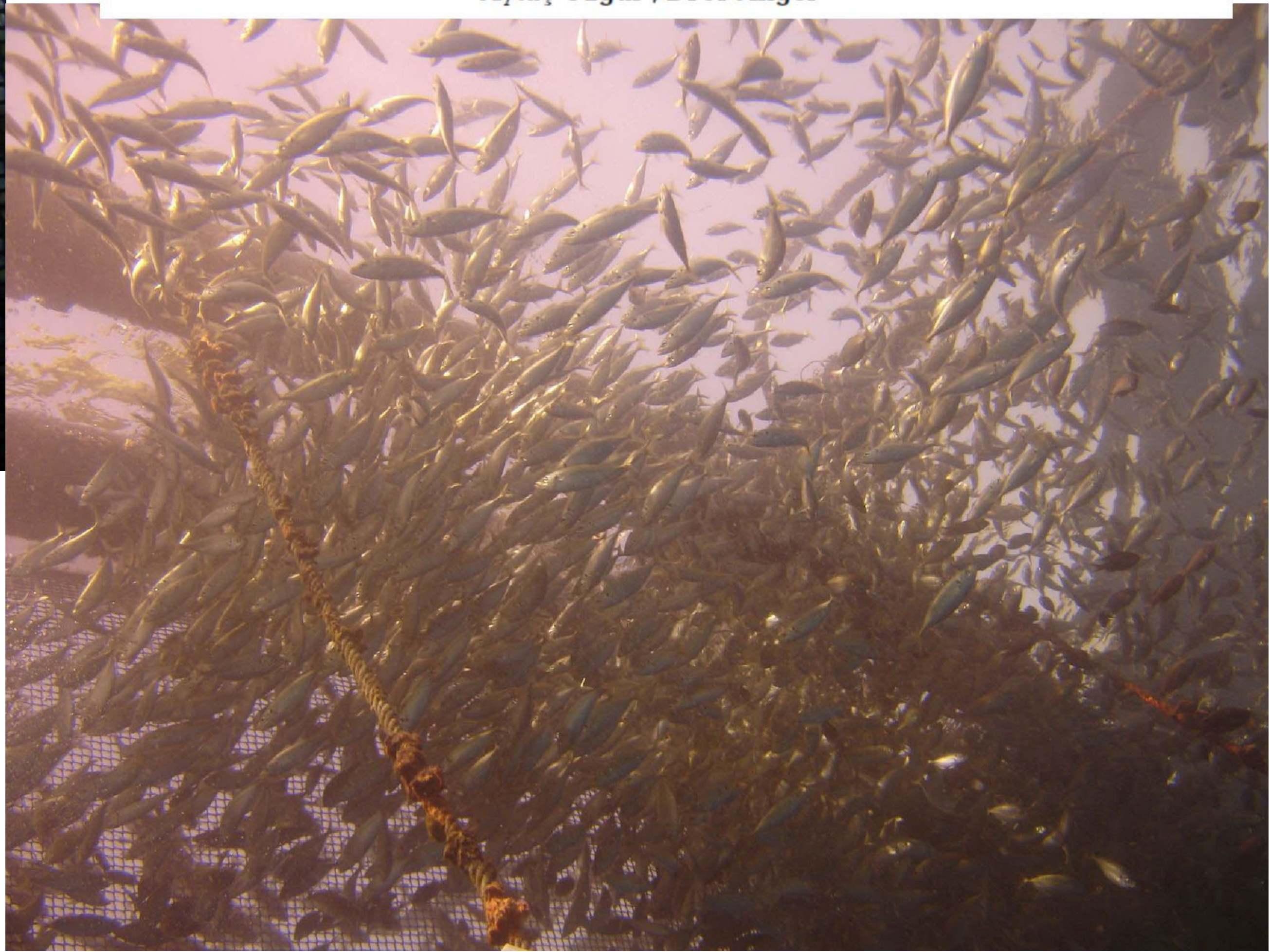
but these extractive species **did not grow**…

…yet the same Fish Farms harbor massive <u>aggregations</u> of **Wild Fish, Algae & Invertebrates**

Vol. 4: 135–145, 2013
doi: 10.3354/aei00076
AQUACULTURE ENVIRONMENT INTERACTIONS
Aquacult Environ Interact
Published online July 25

Wild fish aggregations around fish farms in the Gulf of Aqaba, Red Sea: implications for fisheries management and conservation

Aytaç Özgül[1], Dror Angel[2,*]



**** Many papers by Dempster & colleagues on wild fish @ Med fish farms**


and when we deployed artificial reefs
near these fish farms…


Lots of reef fish inhabited these

Wild fish around Fish Farms

- Wild fish may provide a variety of (ecosystem) services
  - **Ecotourism** (divers, recreational fishers)
  - Uptake of particulate **effluents**
  - **Stocks** for the aquarium sector
  - Fisheries for **artisanal fishers**
  - Wrasse & lumpfish feeding on **sea lice**

In oligotrophic waters, dissolved farm effluents

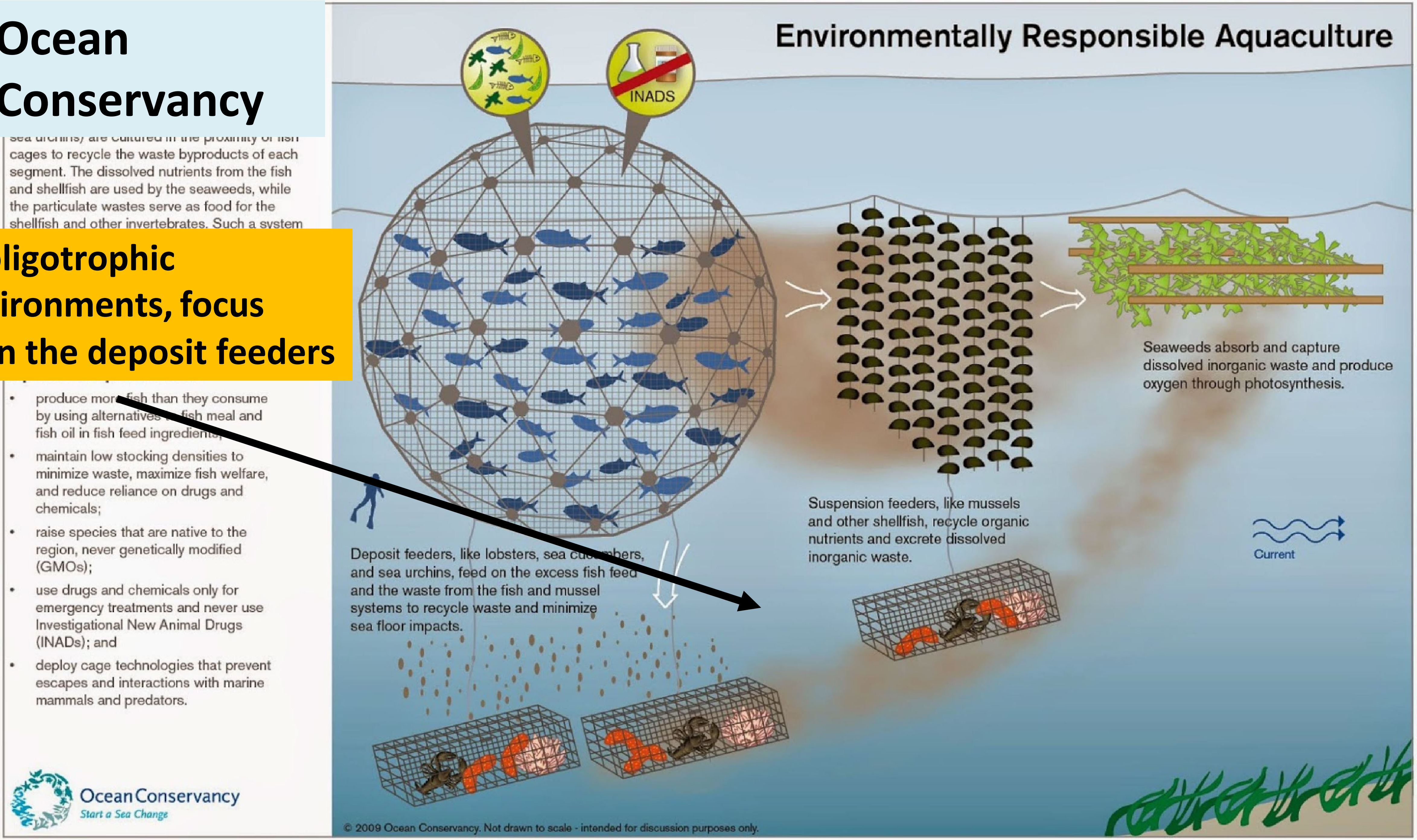
are taken up rapidly by microbes (phytoplankton,

bacteria), so – emphasis is generally directed

toward particulate effluents and the benthos

Ocean Conservancy

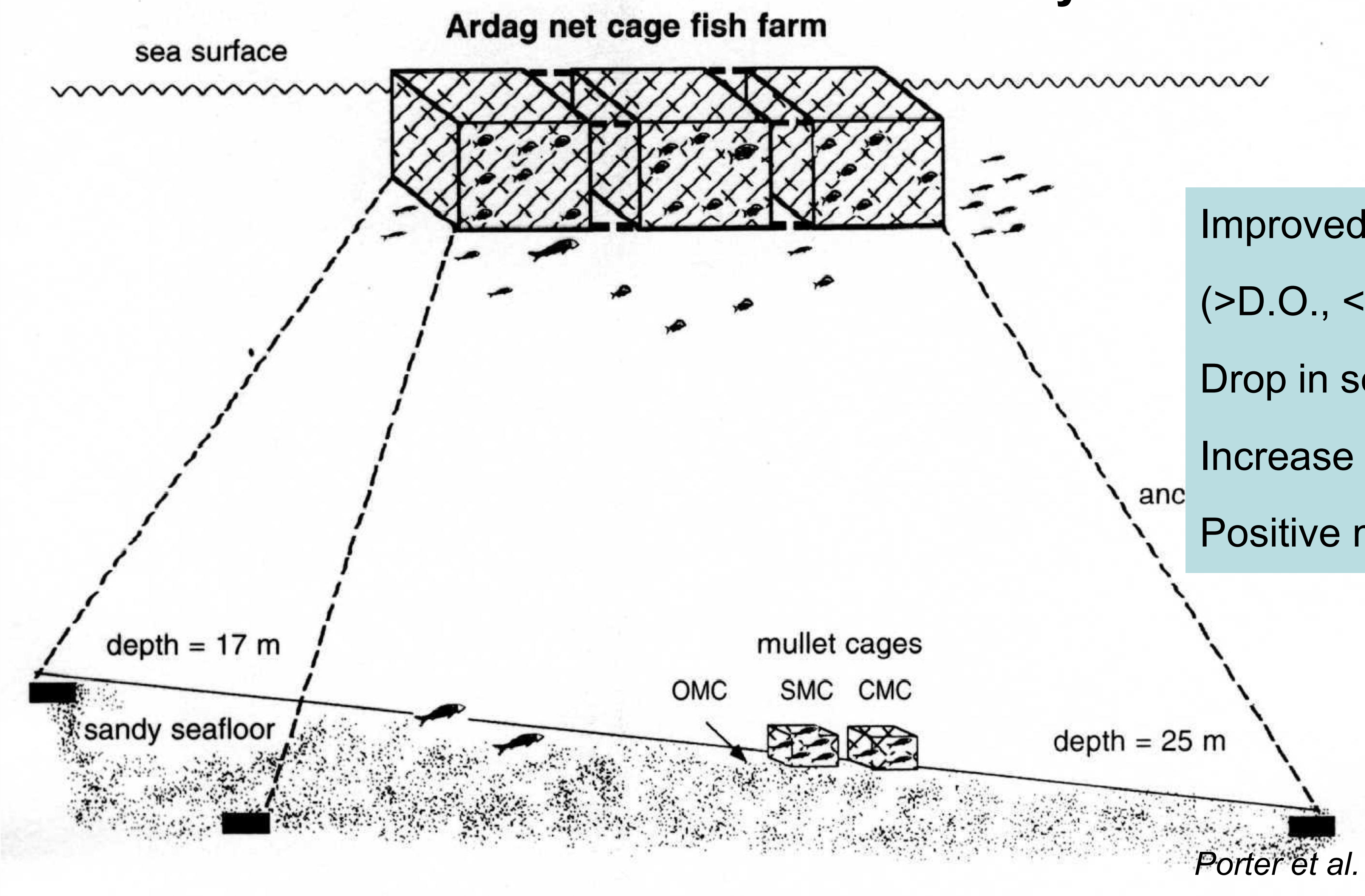
In oligotrophic environments, focus is on the deposit feeders



Warm water LTL – some examples

- Mullets
- Echinoderms
- Sponges
- Corals
- Polychaetes

Grey mullets under Seabream farm



Improved sediment geochemistry

(>D.O., < H_2S)

Drop in sediment OM

Increase bioturbating macrofauna

Positive mullet growth

Katz et al 2002
Lupatsch et al 2003

Porter et al. 1996

Aquaculture Research, 2003, **34**, 1367-1377

Assessment of the removal efficiency of fish farm effluents by grey mullets: a nutritional approach

Ingrid Lupatsch, Timor Katz & Dror L Angel

Israel Oceanographic and Limnological Research, National Center for Mariculture, Eilat, Israel

Correspondence: I Lupatsch, National Center for Mariculture, POB 1212, 88112 Eilat, Israel.E-mail:Lupatsch@ocean.org.il

Sea Urchins

- *Tripneustes gratilla* in the Red Sea
- *Paracentrotus lividus* in the Mediterranean

Aqua.culture 510 (2019) 364-370

Contents lisrs available at &tenceDirect

Aquaculture

journal' hom,epage: www.elsevier.com/locate/aquaculture

Testing the digestibility of seabream wastes in three candidates for integrated multi-trophic aquaculture: Grey mullet, sea urchin and sea cucumber

Dafna Israel\ Ingrid Lupatsch\ Dror L Angela•*

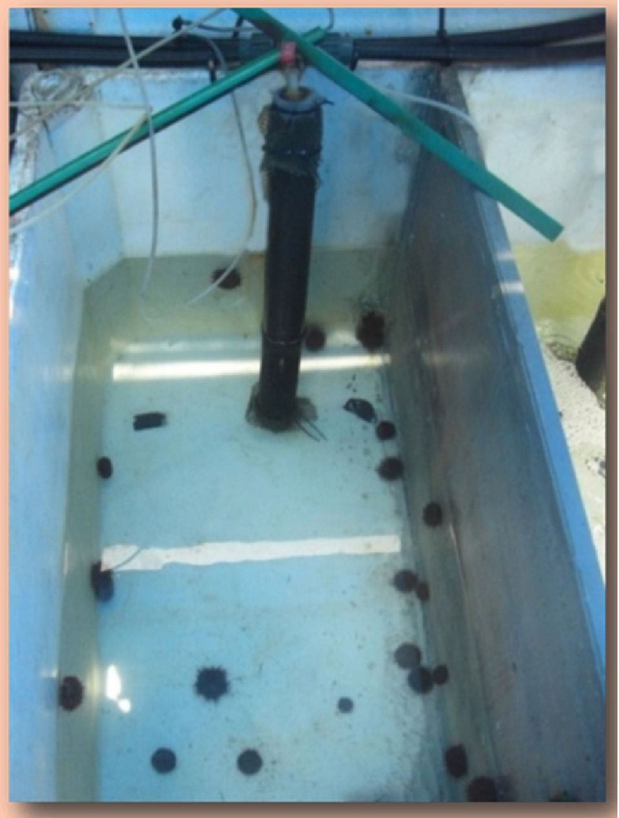
"l.6an Rf'oomm *bisumte- for Maritime St:udies and* »epmtmem *fer* MimmJif' Cill!?izarums, Cii1uney *Schaol of Mmme Sciez:u:e-., UniYersity oj Haifa,, Haifa, lsmel*

b *Assacmud British Ag;,u,l.Hlw:'i!;;,Pf'll!rbomugh, UK*

Use of echinoderms in IMTA

IDREEM (IMTA) project

- **Sea urchins** can digest seabream wastes
- **Sea cucumbers** are even better at it than the urchins!



Sea urchins & sea cucumbers feed on seabream wastes - IMTA

Digestibility coefficients (%) of seabream wastes offered to sea urchin, *Paracentrotus lividus*

	(Mean ± SD)
Dry Matter %	3.8 ± 1.4
Organic Matter %	**13.9** ± 3.3
Protein %	**11.2** ± 2.8
Phosphorus %	3.5 ± 9.4
Lipid %	**16.3** ± 6.8
Energy %	**13.8** ± 4.4

Digestibility coefficients (%) the seabream wastes fed to sea cucumber, *Actinopyga bannwarthi*

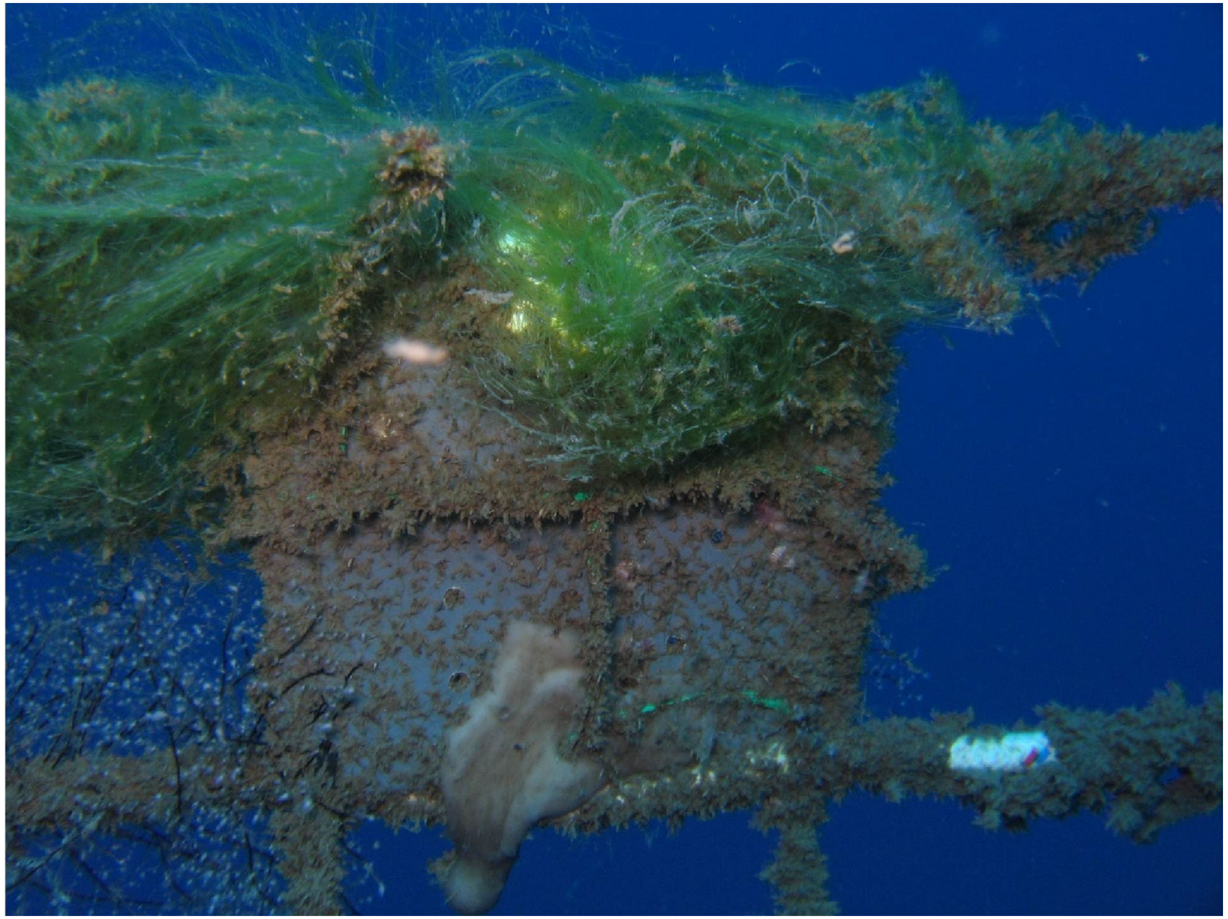
	(Mean ± SD)
Dry Matter %	11.72 ± 1.0
Organic Matter %	**26.7** ± 2.0
Protein %	**16.6** ± 2.2
Phosphorus %	2.3 ± 3.0
Lipid %	**45.9** ± 2.3
Energy %	**24.1** ± 1.7


What about Sponges as IMTA species?

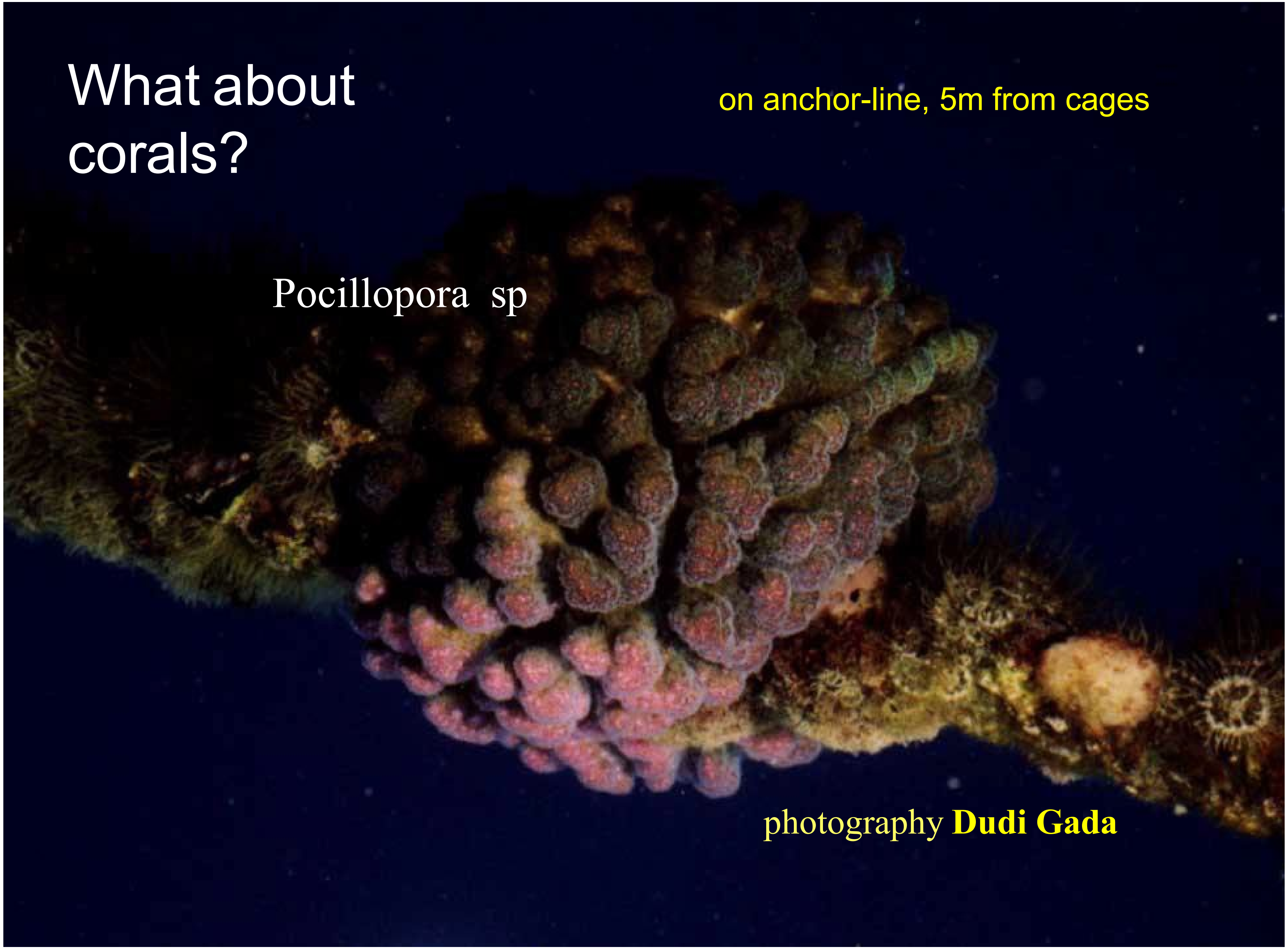
Sponge aquaculture & IMTA

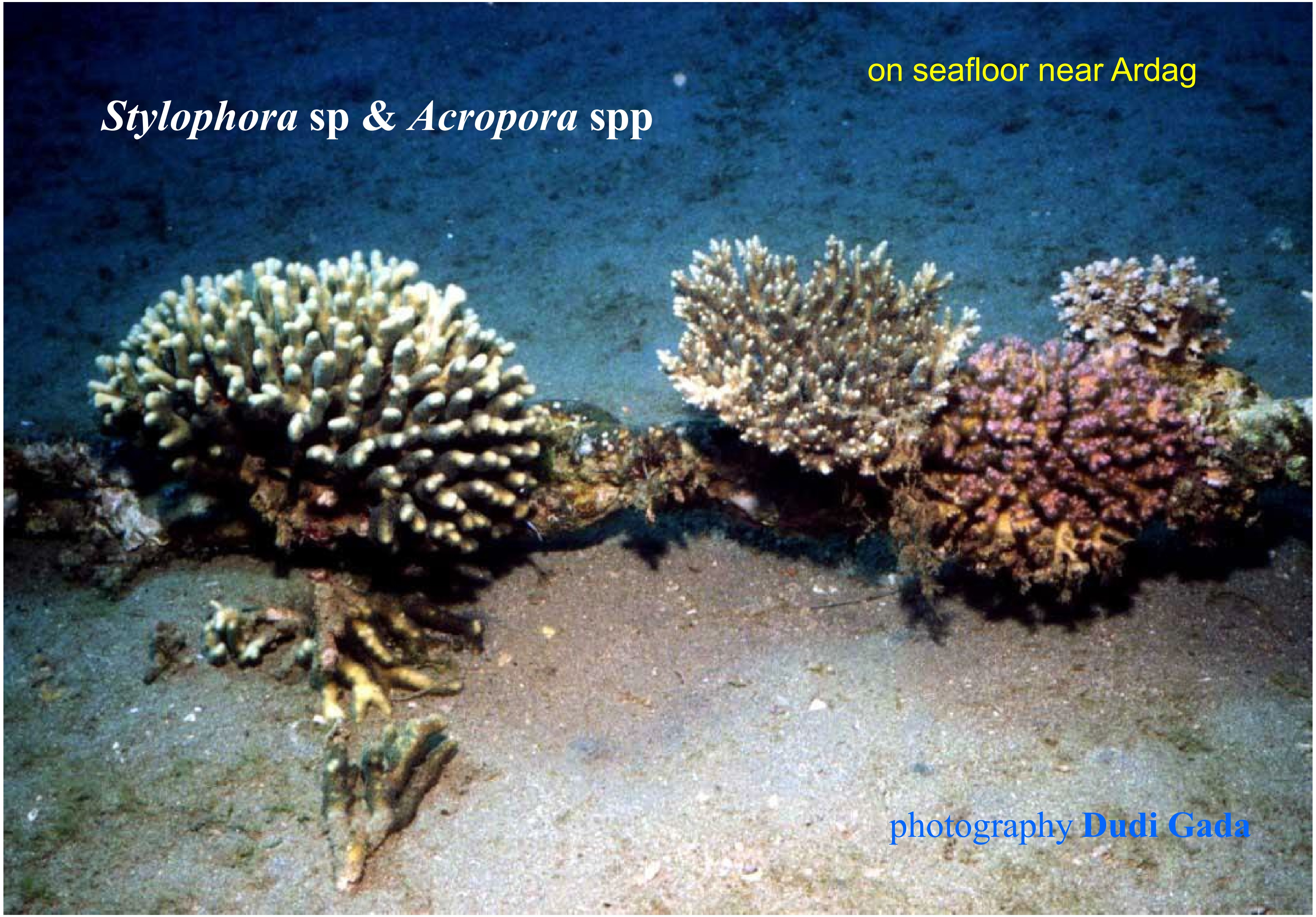
- Sponges
  - have high filtration rates
  - can feed on both particulate AND dissolved Fish Farm effluents
  - produce bioactive molecules (economic value)
- But, surprisingly…
  - sponges grow slowly
  - challenging to work with

Sponges grown near fish farms in E Med

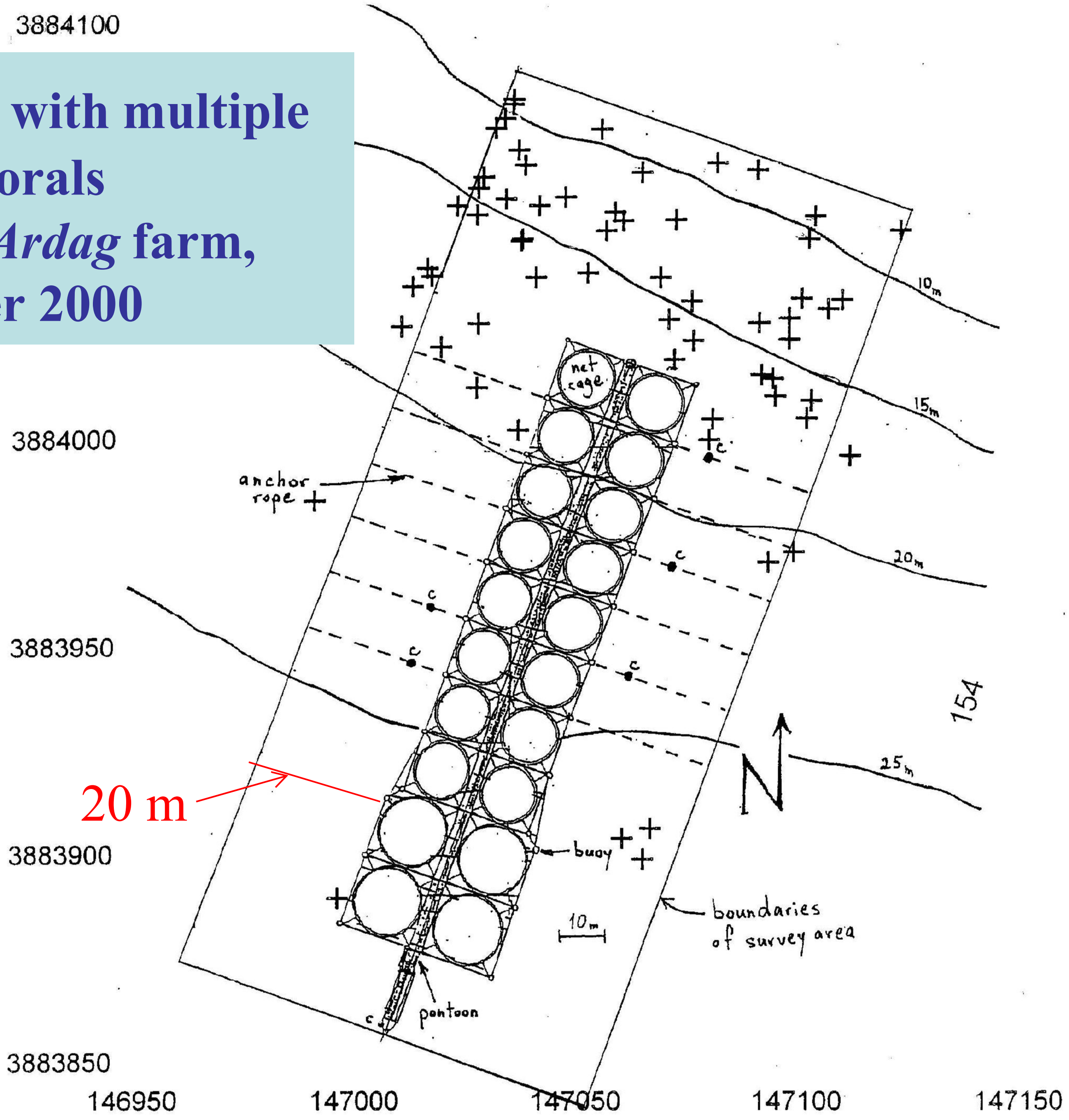


- Slow growth
- Biofouling
- Species selection is key

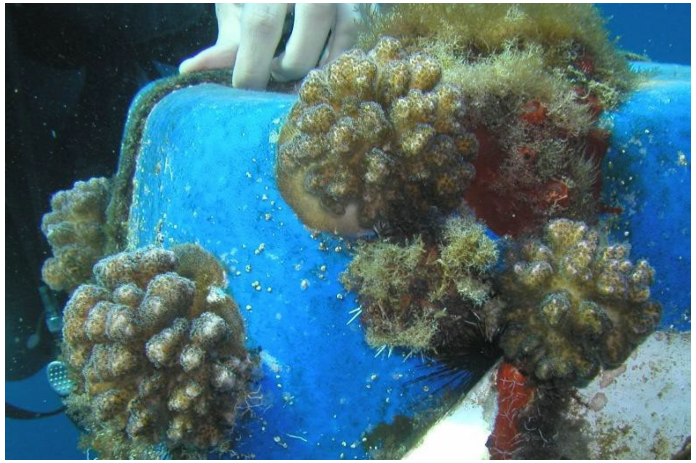

What about corals?
on anchor-line, 5m from cages
Pocillopora sp
photography Dudi Gada


on seafloor near Ardag
Stylophora sp & *Acropora* spp
photography **Dudi Gada**

Substrates (+) with multiple live corals around the *Ardag* farm, summer 2000



Corals recruit and grow on substrates around fish farms at <u>amazing rates</u>



(E. Spanier, S. Breitstein & A. Yurman)

ery at fish farm

Additional product plus potential compatibility with conservation

Bongiorni et. al. (2003), Shafir et al. (2001, 2006)

Aquaculture & polychaetes

- Organically enriched sediments below net pens are teeming with **polychaetes**
- Polychaetes process the organic matter efficiently, producing marketable biomass

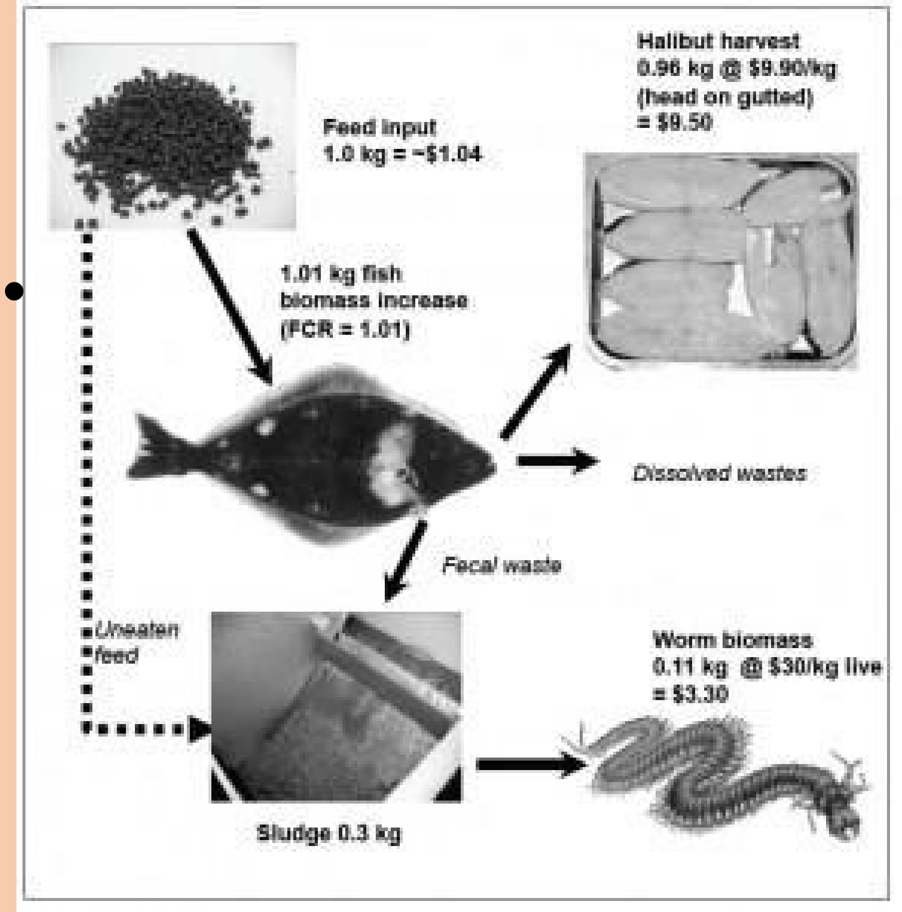
J. Ocean Univ. China (Oceanic and Coastal Sea Research)
DOI 10.1007/s11802-017-3256-1
ISSN 1672-5182, 2017 16 (2): 294-304
http://www.ouc.edu.cn/xbywb/
E-mail:xbywb@ouc.edu.cn

Applicability of *Perinereis aibuhitensis* Grube for Fish Waste Removal from Fish Cages in Sanggou Bay, P. R. China

FANG Jinghui[1), 5)], JIANG Zengjie[1), 5)], JANSEN Henrice M.[2), 3)], HU Fawen[4)], FANG Jianguang[1), 5), *], LIU Yi[1), 5)], GAO Yaping[1), 5)], and DU Meirong[1), 5)]

Polychaetes & IMTA

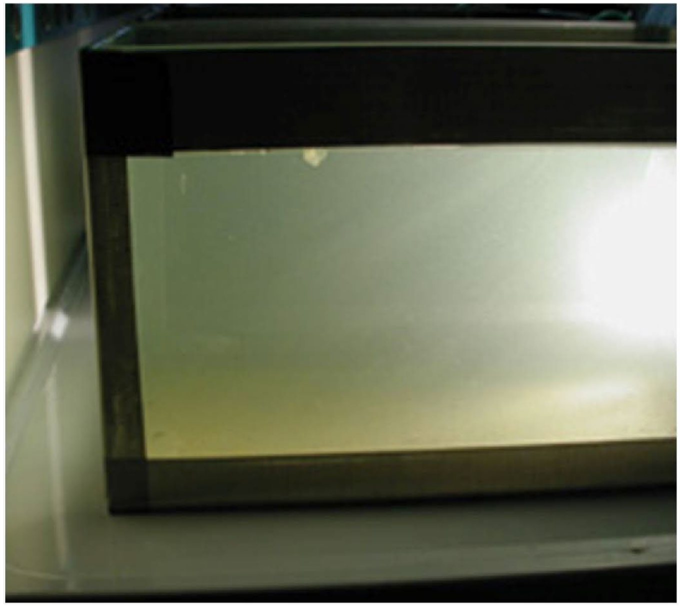
•



Growing polychaetes on fish wastes, University of Maine … land based system

Brown et al. 2011

Preparing polychaetes for seeding in sediments, below commercial salmon pens



Wastes from fish farm

Adriana Giangrande
Lecce, Italy

Polychaetes on lines in lagoon, adjacent to fish farm

Sabella spallanzanii

polychaetes have cleared the water

Bottom Line

- LTL species generally driven by bottom up processes; if the "bottom" is oligotrophic, won't work

- In the Med, there are meso/eu trophic exceptions to the rule: Albania, N Adriatic, N Greece, Sardinia, Corsica, S French lagoons, Italian lagoons – mussels & other shellfish are cultivated

- Future: benthic extractive species, e.g. sea cucumbers, clams, polychaetes, sea urchins, demersal/omnivorous fish (e.g. mullets) – potential LTLs

Acknowledgements

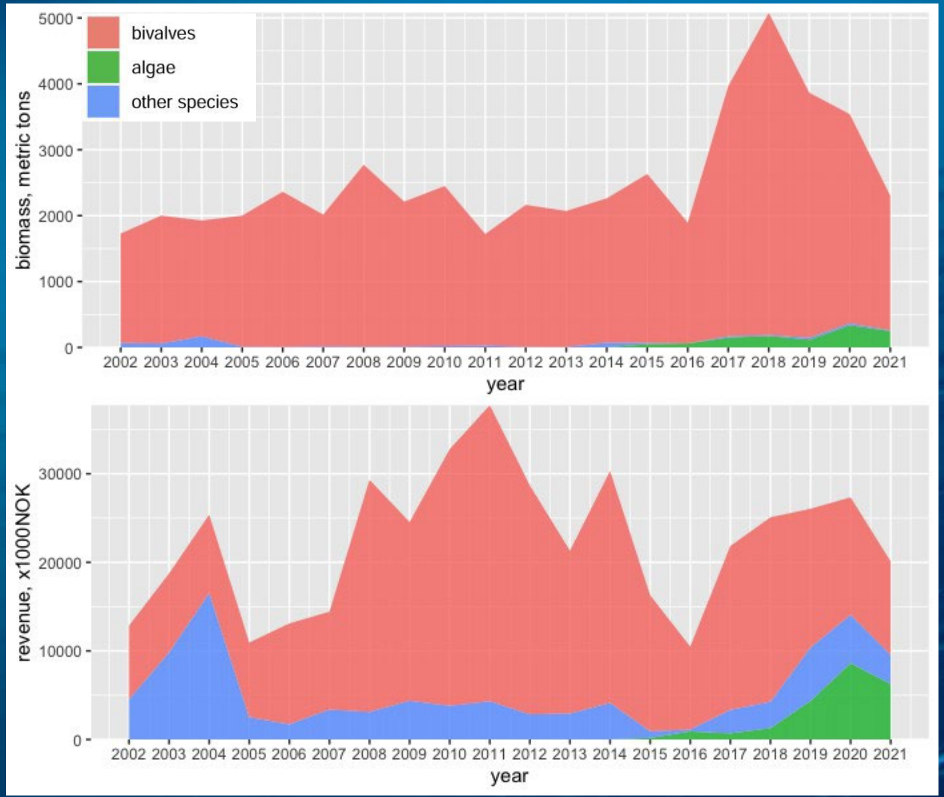
- Dafna Israel
- Aytac Ozgul
- Philip Nemoy
- Peter Krost
- Ehud Spanier
- Timor Katz
- Noa Eden
- Ingrid Lupatsch
- Steve Breitstein
- Adam Hughes
- Demetris Kletou
- Johan Johansen
- IDREEM project
- University of Haifa
- FutureEUAqua project
- European Union

Low Trophic Aquaculture
in Norway

Antonio Agüera
Bentiske Ressurser og Prosesser
Institute of Marine Research

Low Trophic Aquaculture in Norway: Overview

- LTL spp. production is comparably small in Norway
- Serving mainly the local demand
- Only a handful of species are cultured in commercial scale
- Several others are produced at experimental scale or still under research

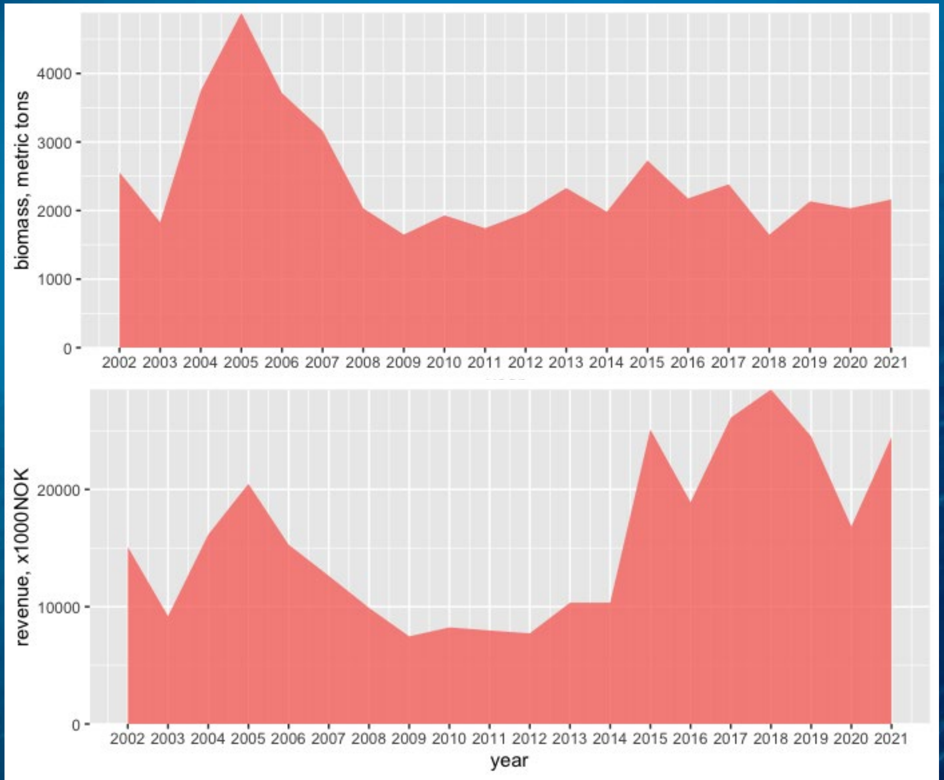


Source: Fiskeridirektoratet @ fiskeridir.no

Norway. Antonio Agüera

Low Trophic Aquaculture in Norway: Blue mussels

- The primary LTL spp produced. Stable localized production destined to local market
- Mussels recognized as potential source of feed ingredients for salmon aquaculture and other species.
- Experimental production for use as feed.
- Need to upscale production.
- Opportunities arise from the co-use of concessions and IMTA.

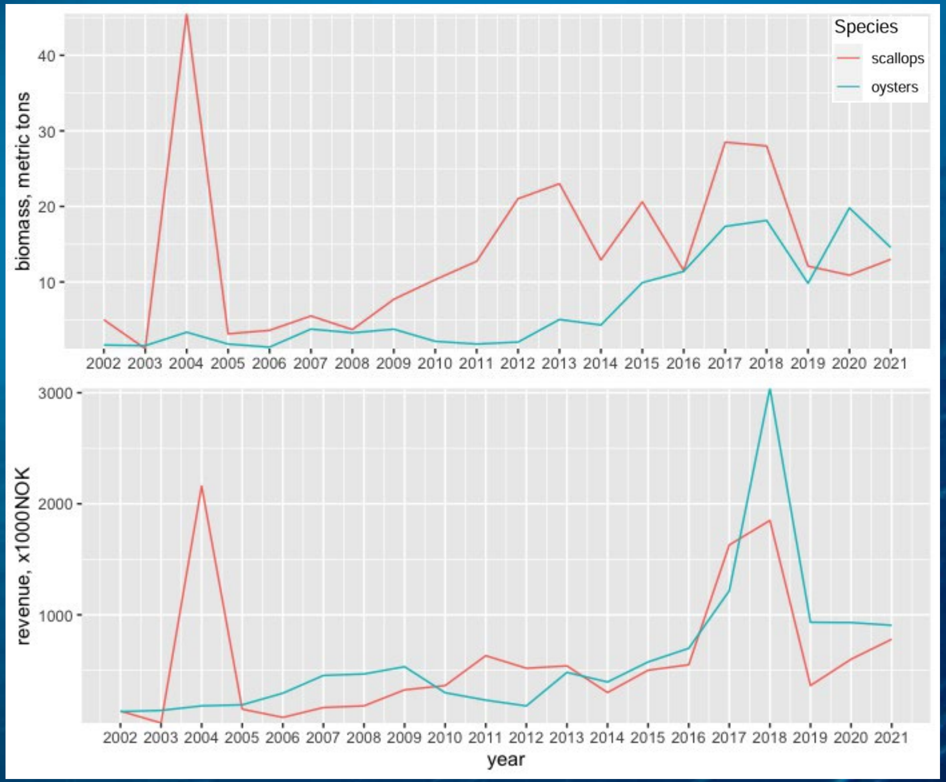


Source: Fiskeridirektoratet @ fiskeridir.no

Norway. Antonio Agüera

Low Trophic Aquaculture in Norway: Other Bivalves

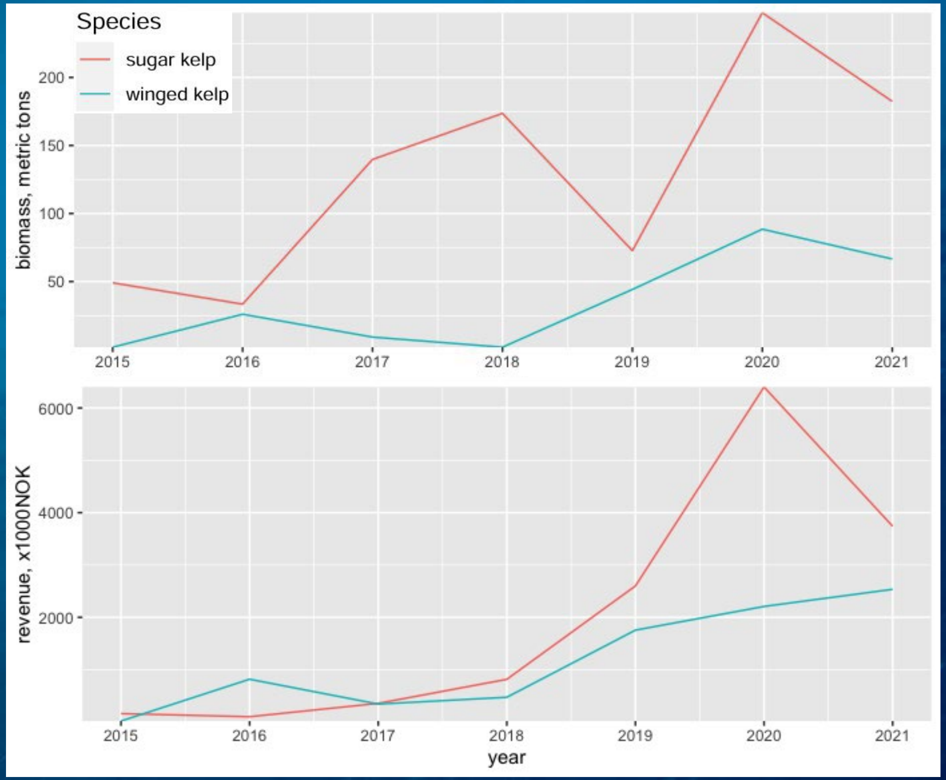
- Scallops (*Pecten maximus*) and flat european oysters (*Ostrea edulis*)
- Scallops hatcheries for small scale sea ranching.
- Small land based oyster production
- Barriers to upscaling by costs/revenue.
- Scallop culture competes with a profitable fishery.



Source: Fiskeridirektoratet @ fiskeridir.no

Low Trophic Aquaculture in Norway: Macroalgae

- Mainly two species produced: Sugar kelp (*Saccharina latissima*) and winged kelp (*Alaria sculenta*)
- Occasionally small-scale production of other species: nori, dulse, laminaria
- Uses include human consumption, feed ingredients and source of natural products.
- Culture needs large areas for significant production
- Integration in co-use of concessions and potential IMTA with other LTL spp
- Extensive fishery on wild populations affects cost and revenues.



Source: Fiskeridirektoratet @ fiskeridir.no

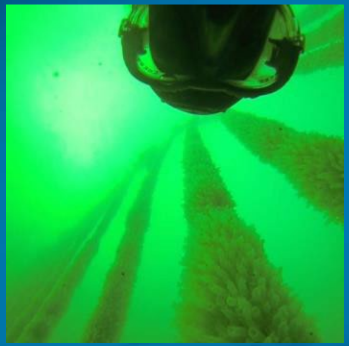
Norway. Antonio Agüera

Low Trophic Aquaculture in Norway: Other species

- There are no separated statistics for other LTL spp but a handful of species are produced at different experimental and marketing levels.

- Sea urchins (Urchinomics + Nofima)
  - Land based conditioning of sea urchins with artificial feeds.
  - High revenue potential.
  - Collection from natural population, barrens.
  - Aiming international markets for human consumption.
  - Research on artificial feeds.

- Tunicates (Ocean Bergen + Ocean Tunicell)
  - Longline production of *Ciona instestinalis*
  - Natural products (cellulose) with medical applications
  - Research on production potential and upscaling.
  - Research on potential uses of other natural products and feed ingredients


Source: oceantunicell.com


Source: nofima @ nofima.com

Low Trophic Aquaculture in Norway: Barriers

- Economic costs of production and revenue.
- Competition with larger international markets
- Upscaling limitations.
- Competition of use coast space for different activities.
- Lack of knowledge on environmental impacts of and on cultured species

Low Trophic Aquaculture in Norway: Opportunities

- Increase interest in the use of LTL spp for feed ingredients and food.
- Use of Norwegian fjords to upscale the production of LTL species.
- Technological advancements to open new areas for LTL aquaculture.
- IMTA and concession co-uses.
- Research on novel species and their natural products potential.

INSTITUTE OF MARINE RESEARCH

Norway. Antonio Agüera

Low Trophic Aquaculture in Norway: Knowledge gaps

- Production potential.
- Revenue vs costs and production scale
- Impact on the ecosystems of culturing activities.
- Impact of environmental conditions on production activities.

Norway. Antonio Agüera

Foras na mara
marine Institute

Low Trophic Aquaculture

Ireland

Frank Kane

Aquaculture in Ireland

- 319 aquaculture operations
- Value of aquaculture €175million (-2% growth in 2022)
- 1,984 employed directly (+ processing)

BIM National Seafood Survey Aquaculture Report 2019
The Business of Seafood – A snapshot of Ireland's Seafood sector 2021 (www.bim.ie)

A,OUIA,CUILTUIREPRODUICTIONI
BY VALE

Foras na mara
marine Institute

Aquaculture productiorn by value (€M)

Salmo,n

€109M

-14%

Ilrish Rock Oysters

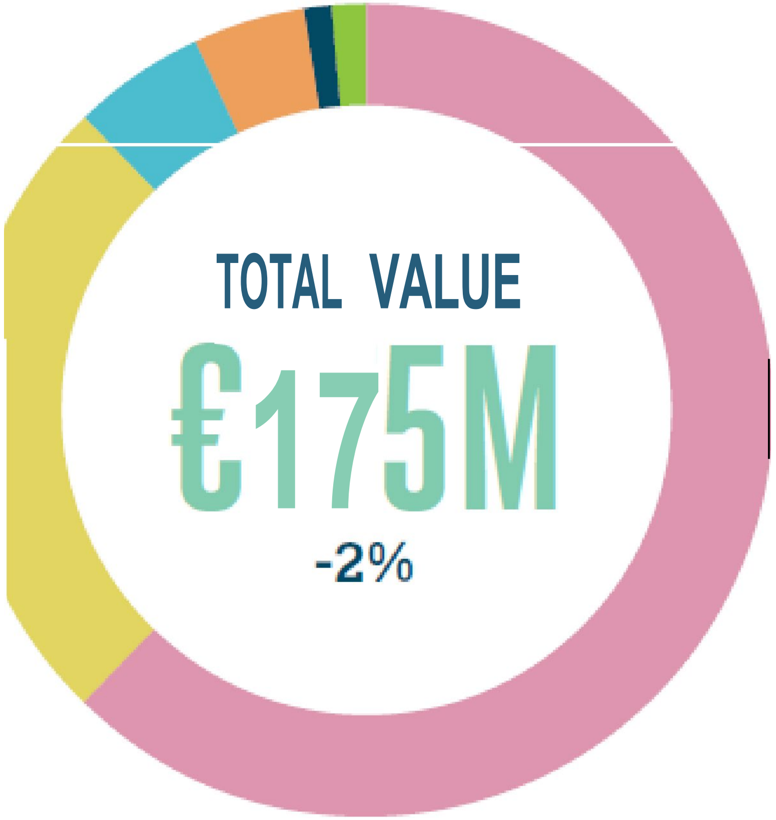
€45M

+22%

Seabed Cuitur1ed Musse,fs

€9M

+24%



Ropes Mussels

€8M

+31%

Othe,r Finfish

€2M

-9%

Other Shellfish

€2M

123%1

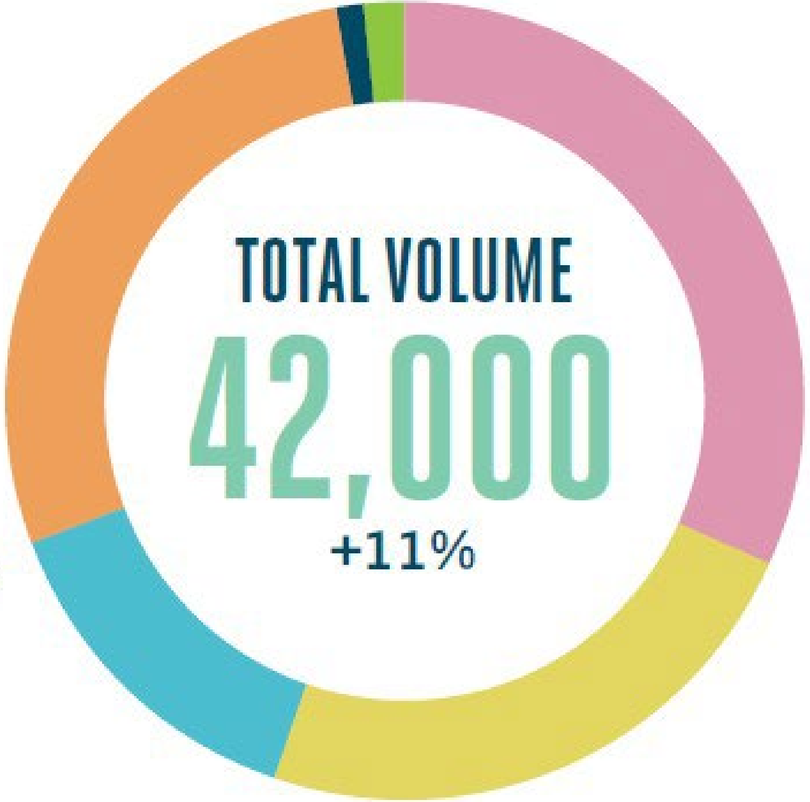
Foras na Mara
Marine Institute

Aquaculture production by volume (Tonnes)

Salmon
13,400
0%

Irish Rock Oysters
9,900
+13%

Seabed Cultured Mussels
5,800
+33%



Ropes Mussels
11,800
+14%

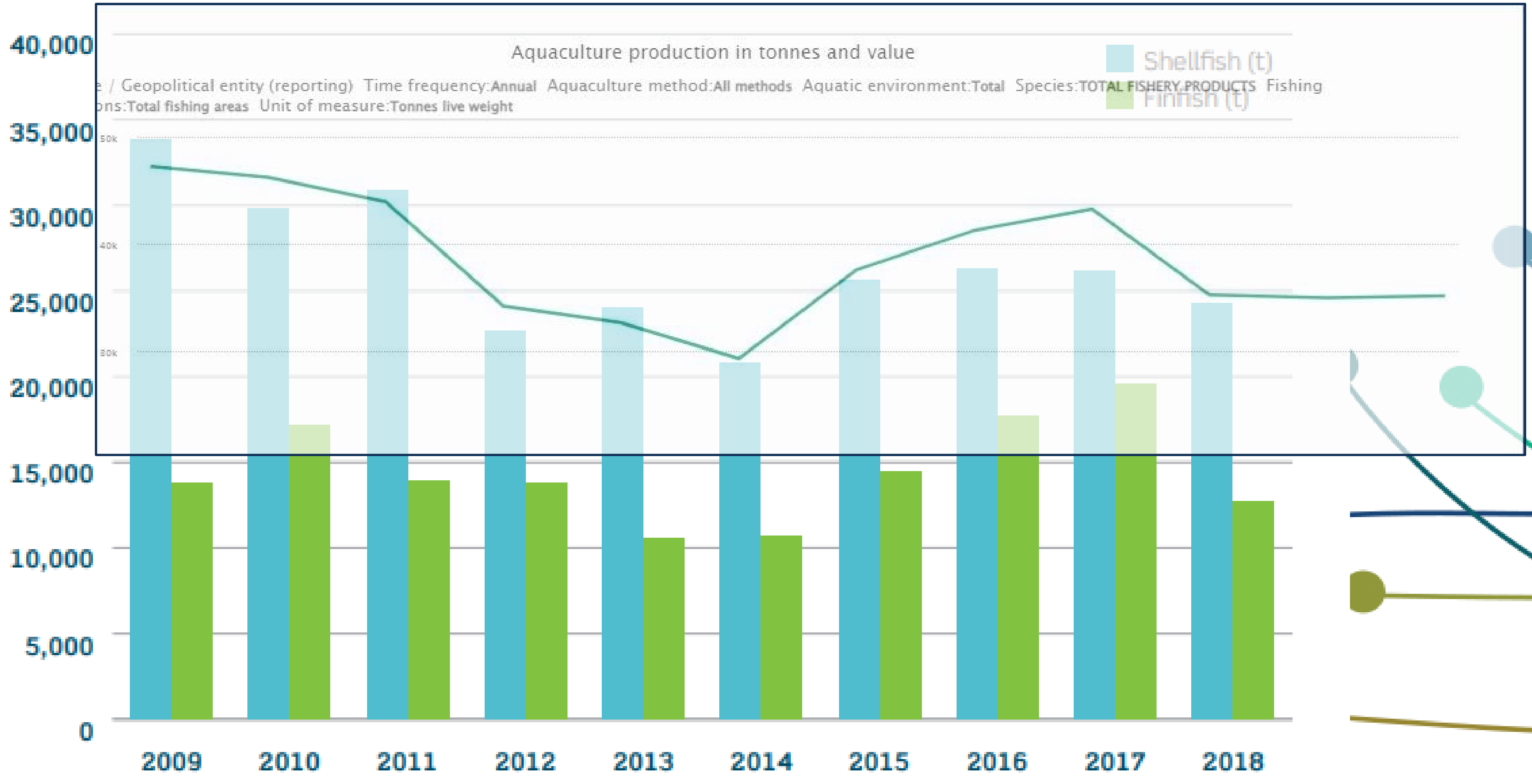
Other Finfish
500
-11%

Other Shellfish
600
+80%

Scallop, Clams, Abalone and Urchin, Trout, Perch

Aquaculture Production

Figure 2: Finfish & Shellfish Production Volumes – 10 Year Trend

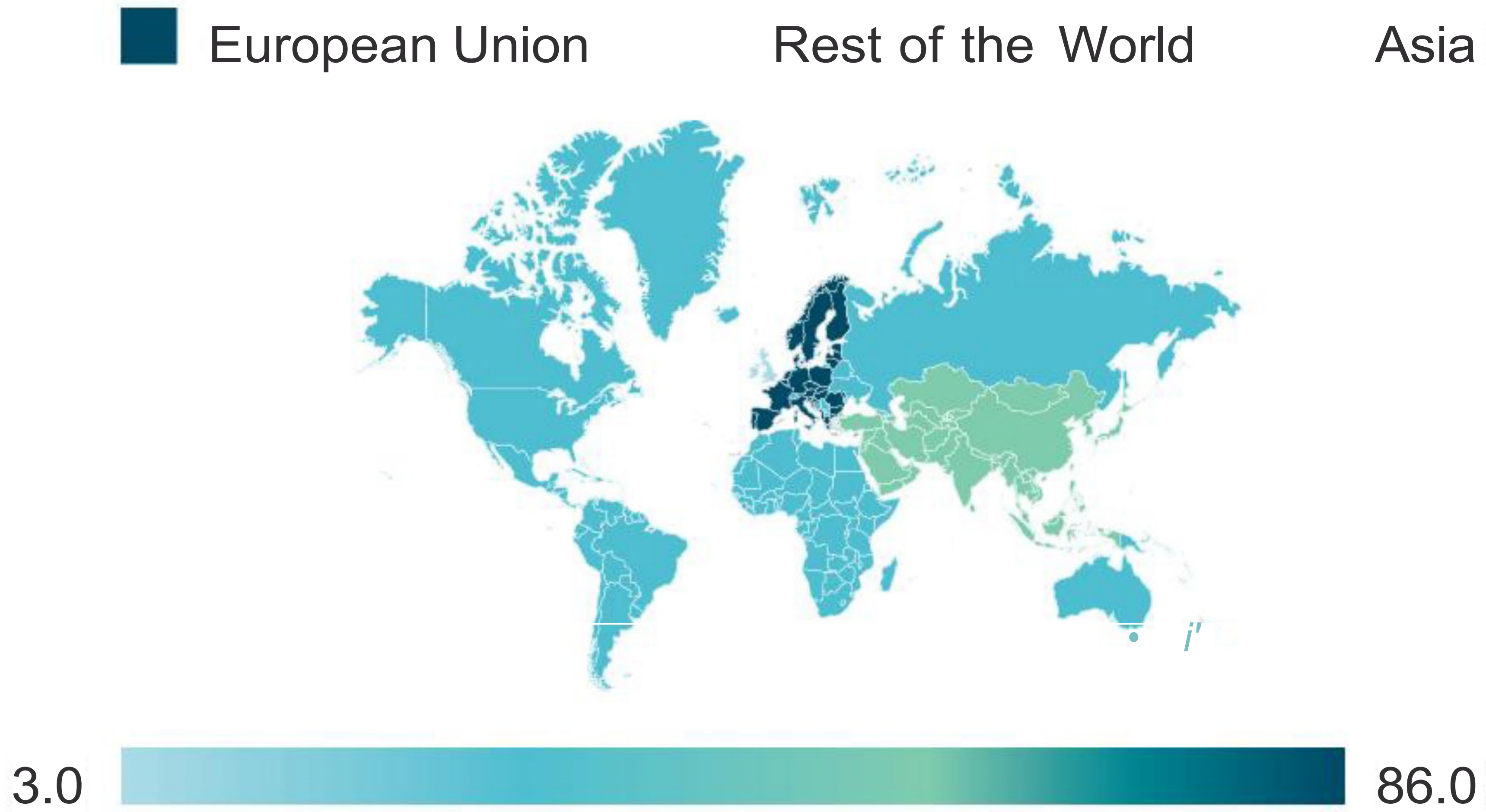


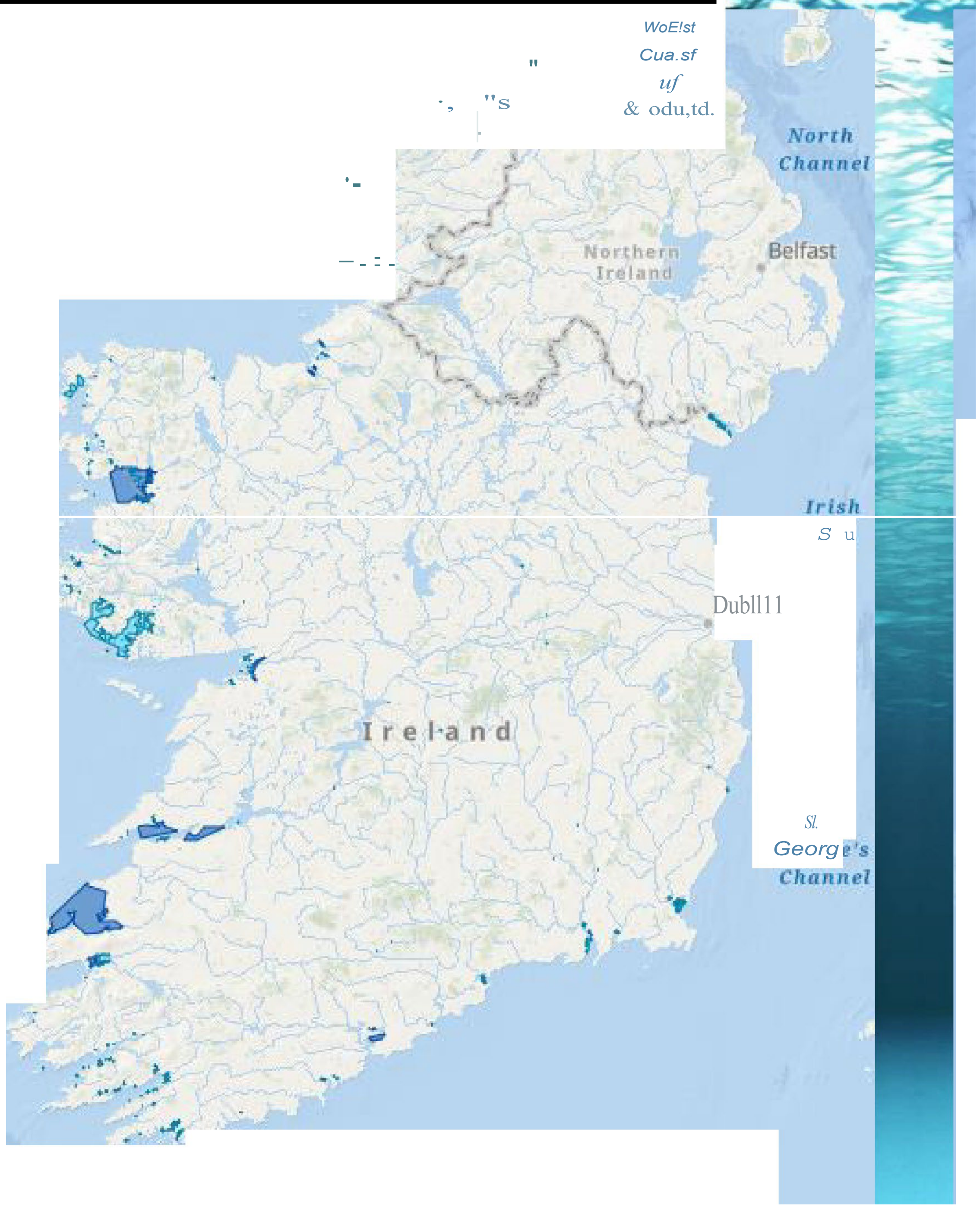
42,000 in 2021

Foras na Mara
Marine Institute

Employment by sector 2020

- Mussels, Oysters and other shellfish account for 90% of employment in the sector.
- Nearly 90 percent of those directly employed in the sector tend to live within 10km from their place of work
- There were close to 80 oyster farming units spread across the 11 bays.


European Union
Rest of the World
Asia
3.0
86.0


North Channel
Northern Ireland
Belfast
Irish
Ireland
George's Channel


North Channel
Northern Ireland
Belfast
Dublin
Ireland

Seaweed Development

- BIM has led a seaweed development programme in Ireland since 2004
- Work has concentrated on developing and perfecting cultivation methods for the brown seaweeds (*Laminaria digitata*, *Alaria esculenta* and *Saccharina latissima*) and more recently the highly sought after red weeds (*Palmaria palmata* and *Porphyra umbilicalis*).
- Farming of brown seaweeds, specifically *Alaria esculenta*, takes place at licensed marine sites.

Foras na mara
marine Institute

Seaweed Development

- A substantial number of new licences for seaweed cultivation were granted in 2018 and 2019.
- BIM estimates the licensed seaweed hectarage in Ireland to be 150 hectares.
- The yield of brown weeds is 6 tonnes fresh product/ha (based on best known performance and varies with water depth and long line density).
- This equates to 900 tonnes fresh harvest if all the sites are fully operat10 nal. (This is anticipated within the next 5 years).

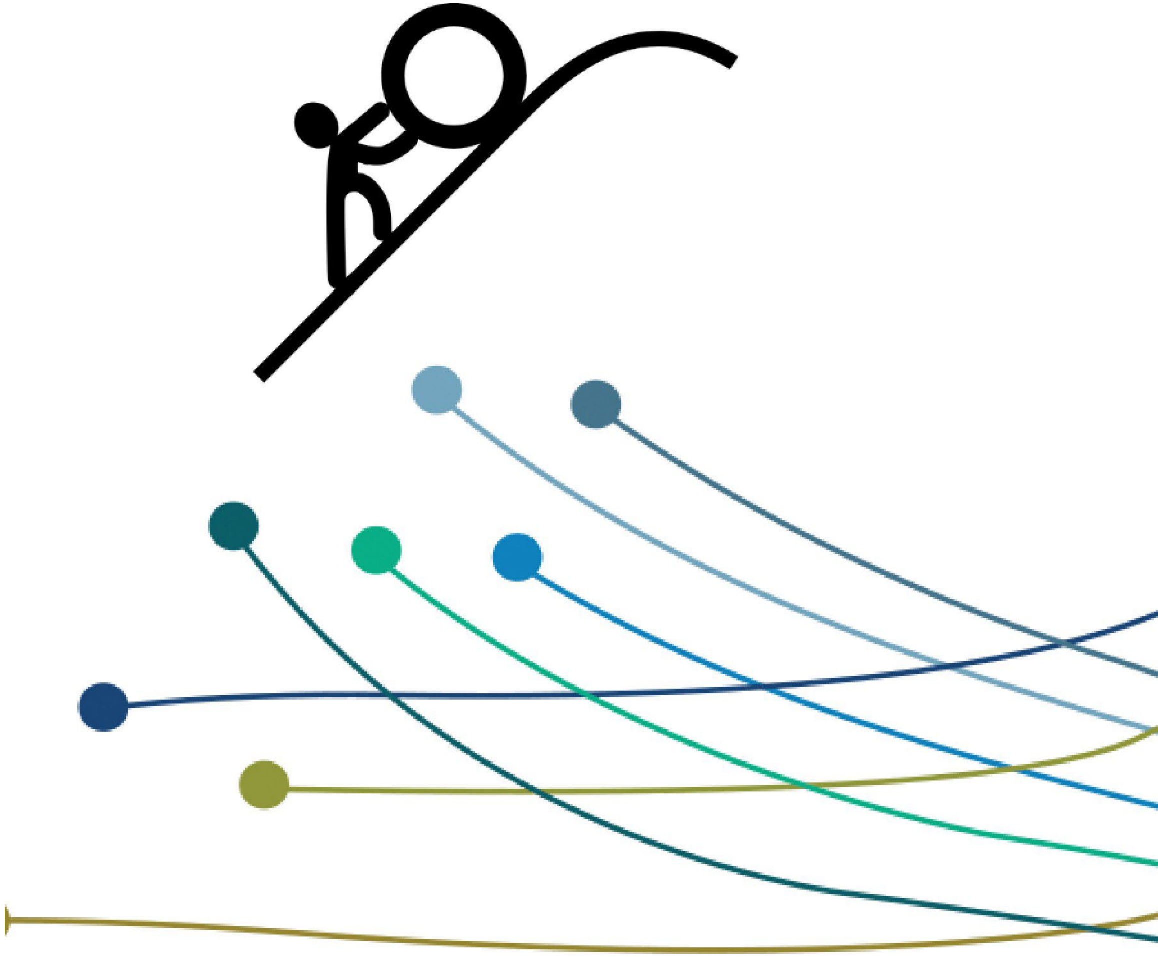
SCOPING A SEAWEED BIOREFINERY CONCEPT FOR IRELAND – 2020
BIM

Seaweed

- Farmed seaweed production in Ireland from licensed aquaculture sites was recorded at 40 tonnes in 2018 - worth €40,000 at farm gate
- This product was destined for further value adding for sale into high end niche markets
- There are an estimated 43 **seaweed related companies** in Ireland ranging from:
  - farming companies,
  - sea vegetable production (~15 Irish companies are processing seaweed fort' @ sea vegetable market),
  - companies producing high end, value added products such as
    - plant biostimulants,
    - soil amendments,
    - animal health and nutrition products,
    - cosmetics.

Seaweed Challenges

- Growing
  - Seed supplies
  - Labour/ scale/ mechanisation
  - Species/ growth cycles
  - Breeding and selection
  - Fouling/epiphytes
- Regulation
  - Novel food regulation
  - Iodine/metals
- Market
  - Market size /costumers - Market value
  - Standards and certification



IMTA

- Few IMTA in Ireland
- RAMPS - Recirculating Aquaculture Multi trophic Pond System
- Growing Perch in RAS and ponds, where the wastewater is treated by algae, duckweed, and reed-beds.
- Projects –
  - Biopuralg project (Interreg IIIC)
  - Sudevab project (FP7)
  - IDREEM
  - TAPAS
  - IMPAQT
  - ASTRAL
  - INEVAL
  - AQUAMONA

IMTA

- Incidental IMTA
- Atlantic salmon, blue mussels, scallops and seaweed are all cultivated in relatively close proximity, Mulroy Bay, Co. Donegal,
- During an extensive fallowing of some of the salmon sites there were claims of decreased yields from the mussel farmers (pers. comm.).
- Exploring the concept further.

THANK YOU

Foras na mara
marine Institute

www.marine.ie

@marineinstituteireland

@marineinstitute

@MarineInst

@marineinstituteireland

@marineinstituteIRL

Lower trophic species on the Faroe Islands

Sophie Koch, WEcR, PhD candidate

WAGENINGEN
UNIVERSITY & RESEARCH

In the heart of the North Atlantic

Located in the Northeast Atlantic, the Faroe Islands comprise 18 small islands, characterised by steep cliffs, tall mountains, narrow fjords – and a population of approximatly 50,000.

Context

Ideal climate and water conditions ideal for aquaculutre

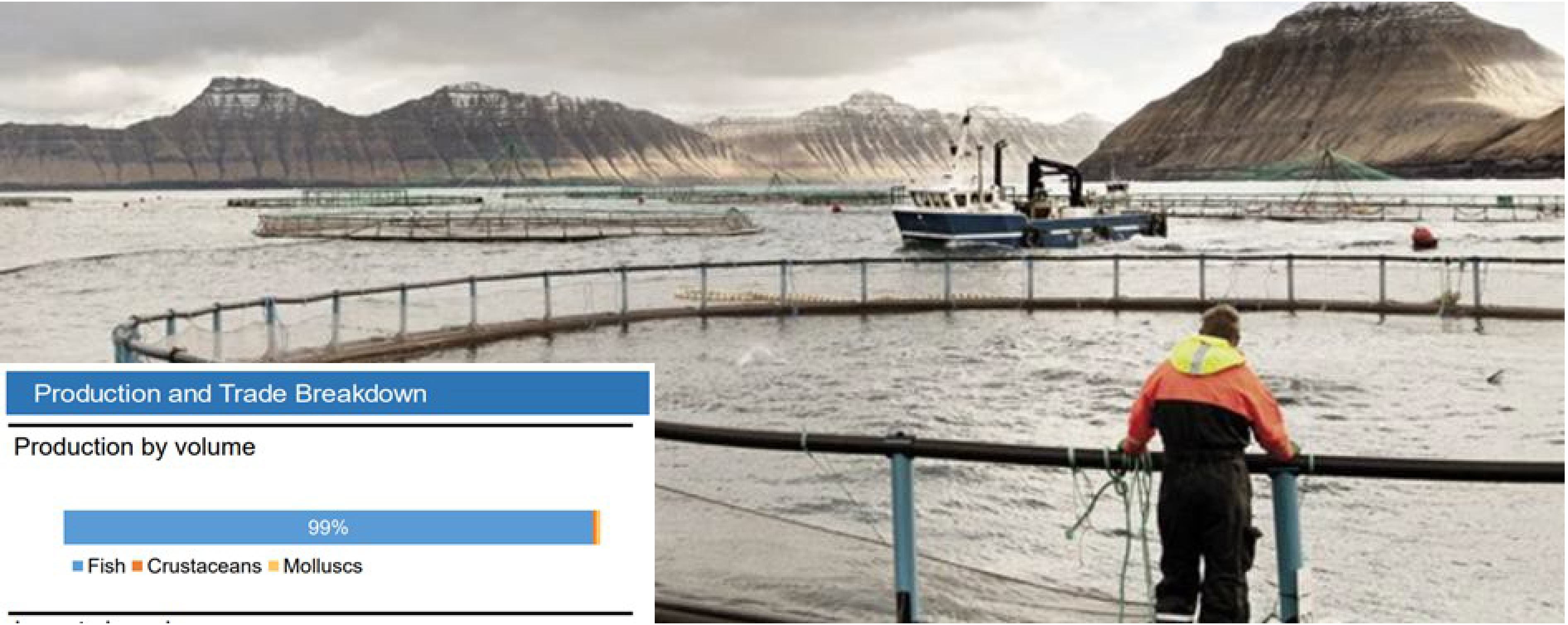
- Clean oceanic waters, with cool steady temperatures
- Strong currents in the fjords

Strong tradition

- Faroese lived of the ocean for centuries
- Aquaculture industry today accounts for >40% of total export value (90% in total export)

Faroe Islands. Sophie Koch

Highly developed salmon farming industry



https://www.fao.org/3/cb9708en/cb9708en.pdf

WAGENINGEN UNIVERSITY & RESEARCH

Faroe Islands. Sophie Koch

Other species (LTS)

- 10th place: Queen scallop
- Also cold water shrimp

Faroe Islands 2019

Production - Top 10 Species (Volume)

		Tonnes
1st	Blue whiting (Poutassou)	339 697
2nd	Atlantic herring	117 563
3rd	Atlantic salmon	95 000
4th	Atlantic mackerel	63 224
5th	Atlantic cod	52 038
6th	Saithe (Pollock)	23 340
7th	Argentines	12 518
8th	Haddock	11 578
9th	Ling	6 173
10th	Queen scallop	5 530

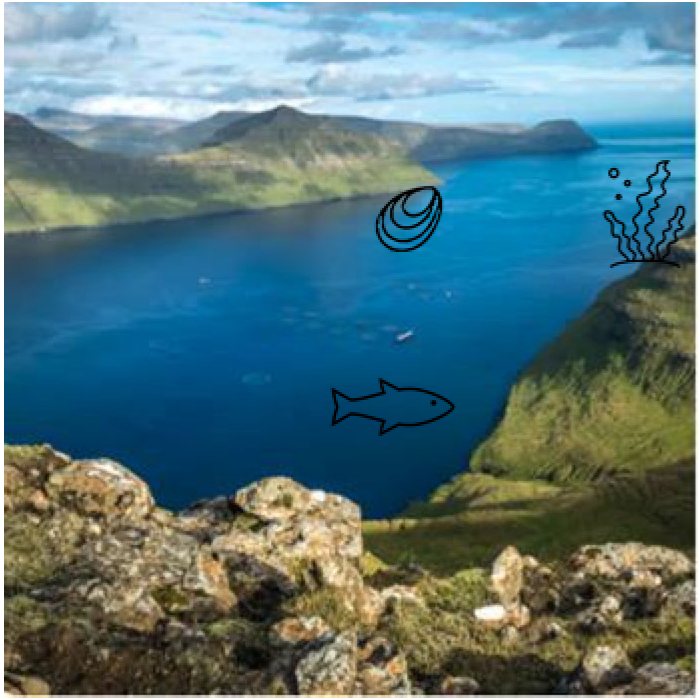
Other species (LTS)

Blue Mussels

- Currently not an industry
- Abundant in the coastal waters
- Trials show good farming potential
    - Aquavitae report: https://aquavitaeproject.eu/reports_presentation/blue-mussel-spat-availability-and-settlement-on-longlines-in-a-faroese-fjord/

Faroe Islands. Sophie Koch

Aquavitae Project



Picture by James Currie Photography – own edits

IMTA site in in Sørvágsfjørður, Faroe Islands – *Photos: Mayleen Schlund*

Faroe Islands Sophie Koch

Slide from Gerardo Diaz, Aquaculture Europe conference 2022

Farms characteristics

Salmo salar	*Saccharina latissima*	*Mytilus edulis*
10 cages	6 rigs	20 rigs
Area: 23 Ha	Area: 39 Ha	Area: 12 Ha
18 months growth cycle	2 harvest per year	36 months growth cycle
Fully technified process	Partially mechanized process	Partially mechanized processes
2,500 MT/year	600 MT/year	5000 MT/cycle
Optimized production	Production in development	Production in development
All-in, all-out	3 partial harvests from 1 seeding	Natural spat
Fallowing (3 months)	First year of deployment	Re-seeding to reduce self-

Conclusions

- RIMTA profitability still heavily relies in salmon farms
- Traditional aquaculture could cover ES (N) expenditure without a considerable compromise in profitability
- Increased value for ES + higher yields/volumes can push low-trophic species profitability “into the black”

Slide from Gerardo Diaz, Aquaculture Europe conference 2022

Other species (LTS)

Developing industry: Seaweed (Saccharina Latissima)

- Tari seaweed (also wild species)
- Ocean Rainforest

Urd Bak and Floor Masman on their cultivation vessel on the Faroe Islands.

Image credit: Sophie Koch

WAGENINGEN UNIVERSITY & RESEARCH

Faroe Islands. Sophie Koch

Ocean Rainforest

- Saccharina Latissima
- Considered exposed (offshore)
- Multiple harvests
- Harvesting device -> vertial lines more efficiently on offshore sites
- MACR
- Upscaling
- Selective breeding (50% more efficiency)
- 150 T ww (but calculated double)

Faroe Islands. Sophie Koch

https://seamark.eu/

SEAMARK
Seaweed-based Market Applications

Co-funded by the European Union

- ES quantification
- ES valuation
- Monetized ES into business exploitation plans
- PhD on carrying capacity for seaweed ecosystems

Faroe Islands, Sophie Koch

Carrying capacity for seaweed cultivation

- Theoretical framework defining boundaries
- Interdisciplinary: socioecological context
- Where are the limits of unacceptable change?
- Where are bottlenecks that can be changed to help develop the industry?
- Can social limits be changed? Is social license variable?
- What are tradeoffs in the discussion about sustainably developing hte industry?

Faroe Islands. Sophie Koch

Thanks!

Sources:

https://www.faroeseseafood.com/fishery-aquaculture/sustainable-aquaculture

https://www.fao.org/3/cb9708en/cb9708en.pdf

https://aquavitaeproject.eu/reports_presentation/blue-mussel-spat-availability-and-settlement-on-longlines-in-a-faroese-fjord/

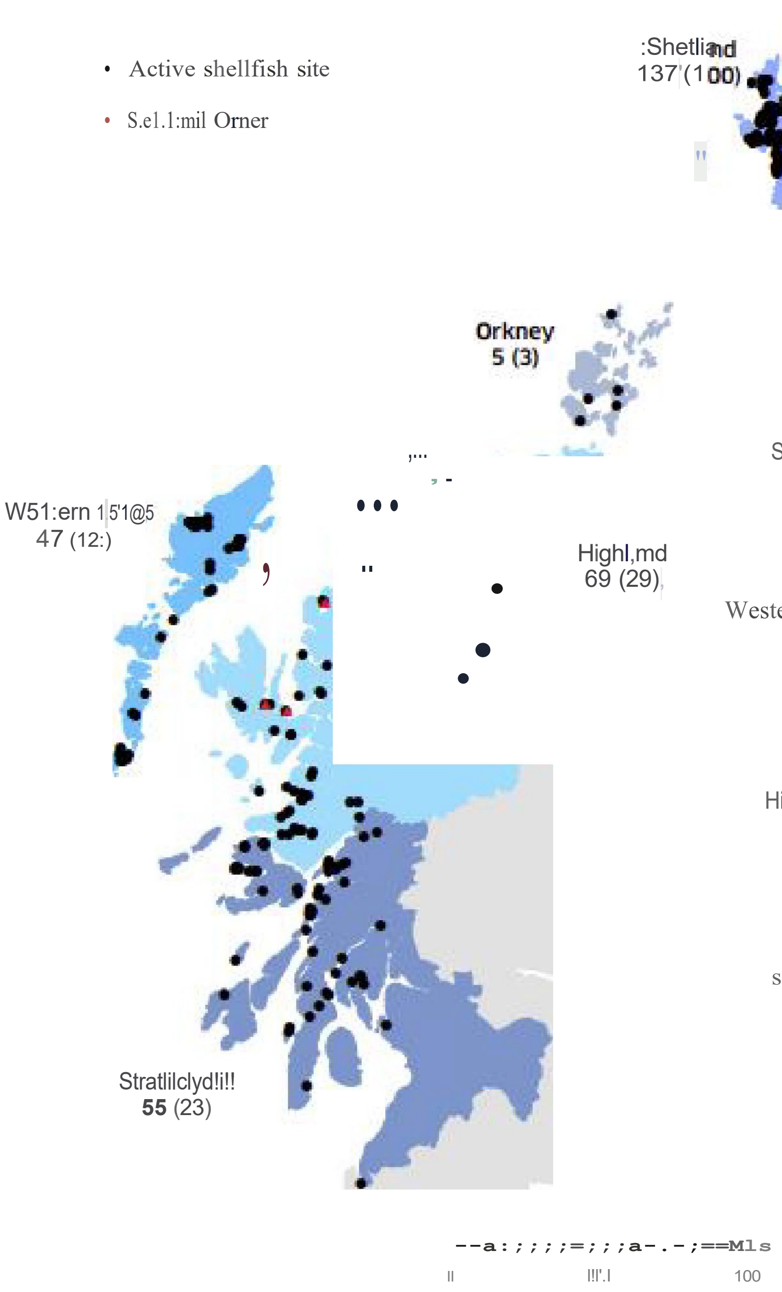
Faroe Islands: Sophie Koch

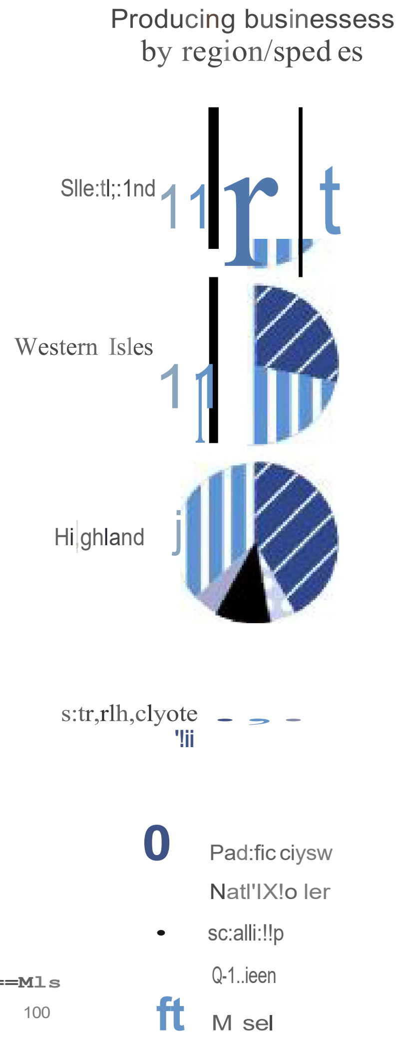
Sophie.Koch@wur.nl

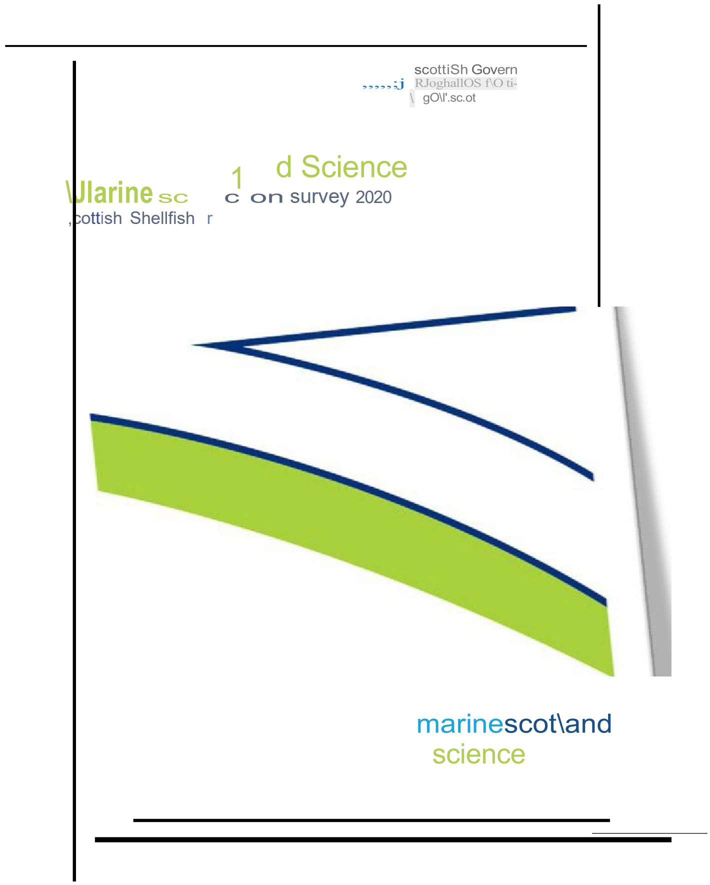
Scotland: Shellfish

Mussel:	*Mytilus spp.*
Pacific oyster:	*Crassostrea gigas*[1]
Native oyster:	*Ostrea edulis*
Queen scallop:	*Aequipecten opercularis*
Scallop:	*Pecten maximus*

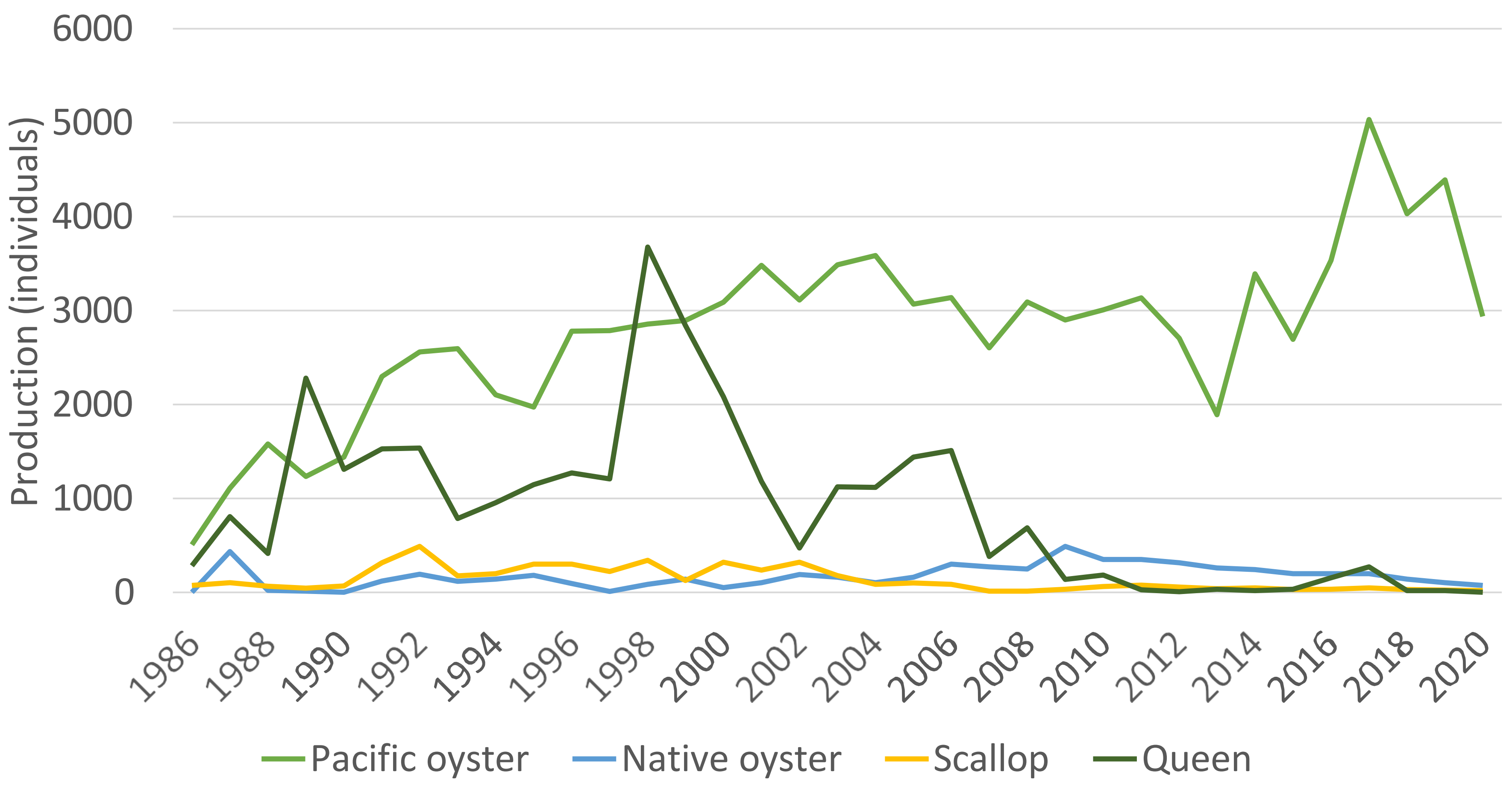
Industry worth about £6 million first sale value in 2020 f.C!0N.AL DtrS:TRIIBILI1'10N OF AITIrVE S:HEl..UISH 5JTeSIN 201'9 (NUMIBE IPlmDILIOINC GIVE IN BRACKETS:} AND UMBEROF PRODUCINGBUSI ESSES:BY RBGION/SPiE.CIES.





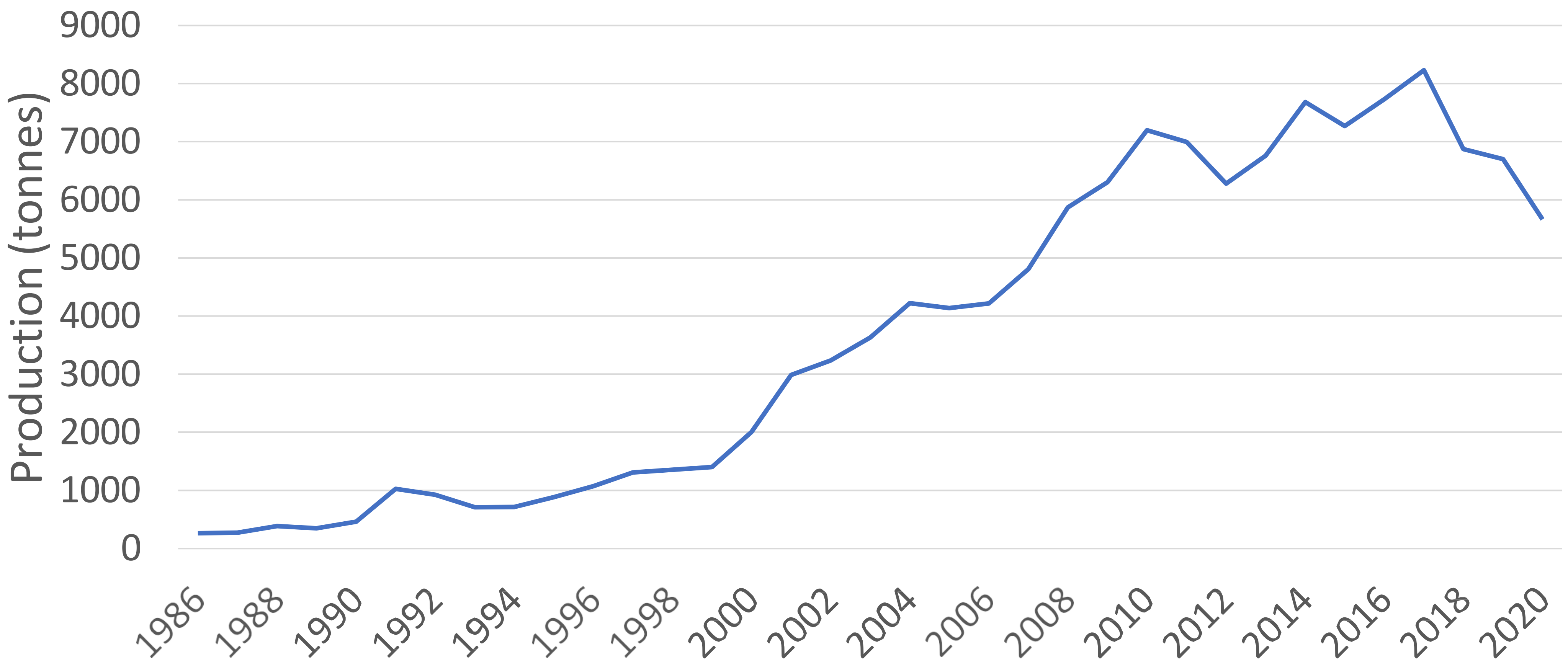


Scotland: Oysters and scallops (1986 – 2020)



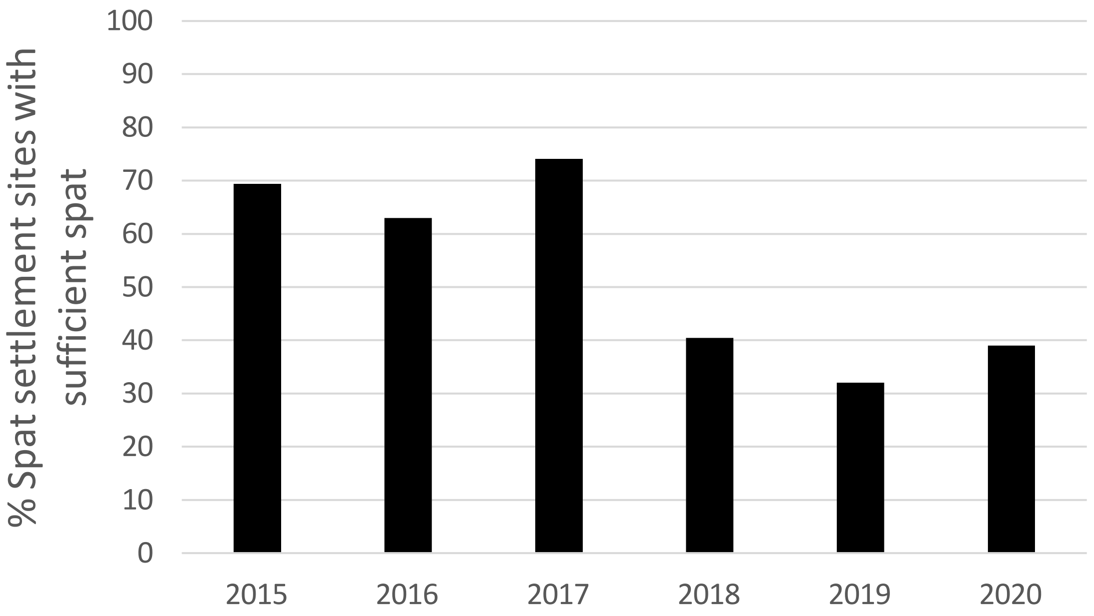
Covid-19 is a major reason for decline in 2020

Scotland: Mussels(1986 – 2020)



Scotland: Mussel spat settlement

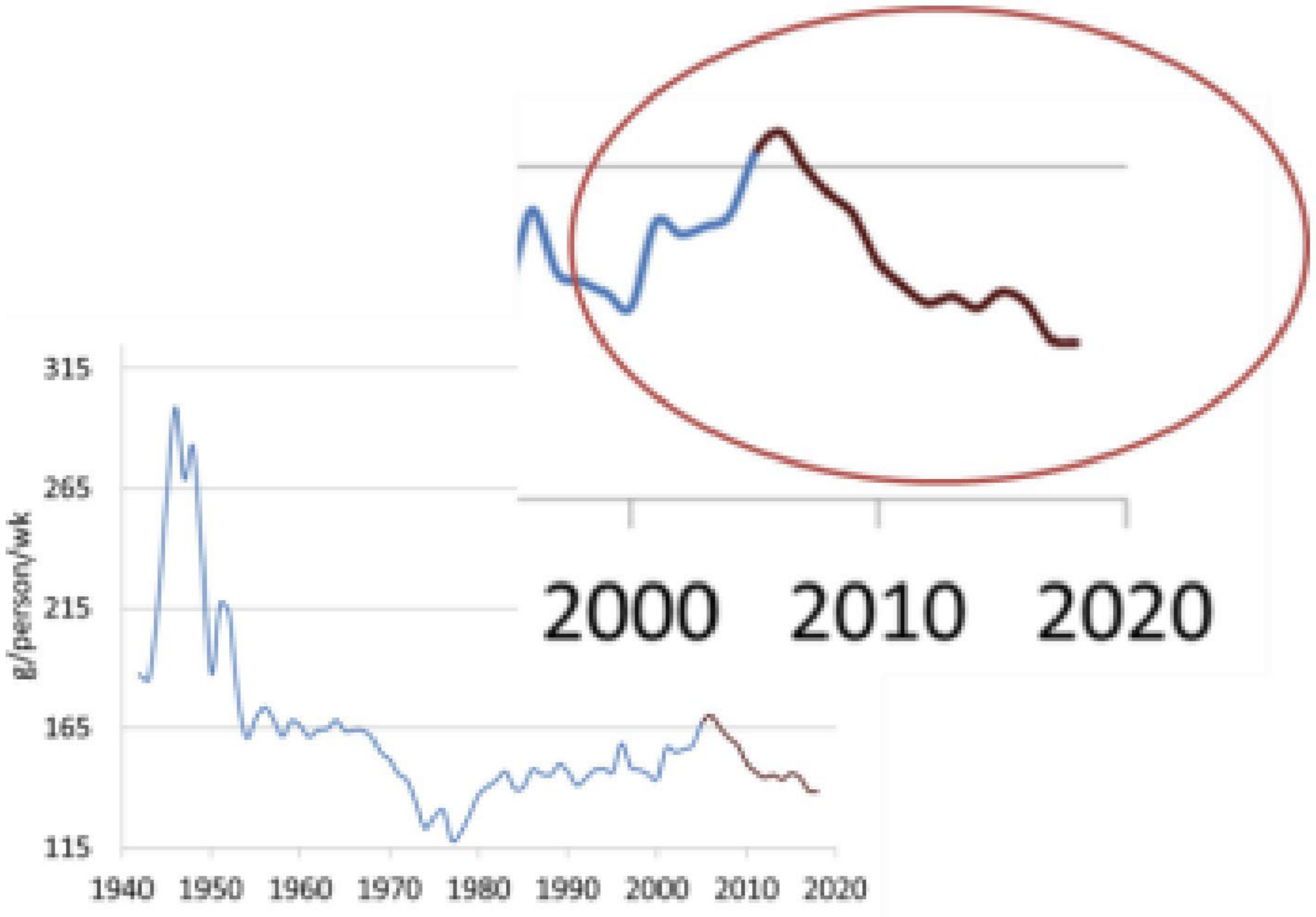
- From 2010 - anecdotal industry reports of poor spat settlement and mortality, so Marine Scotland survey about spat settlement
- Trying to establish mussel hatchery – some challenges
- Industry funded research to investigate what is going on



Demand?

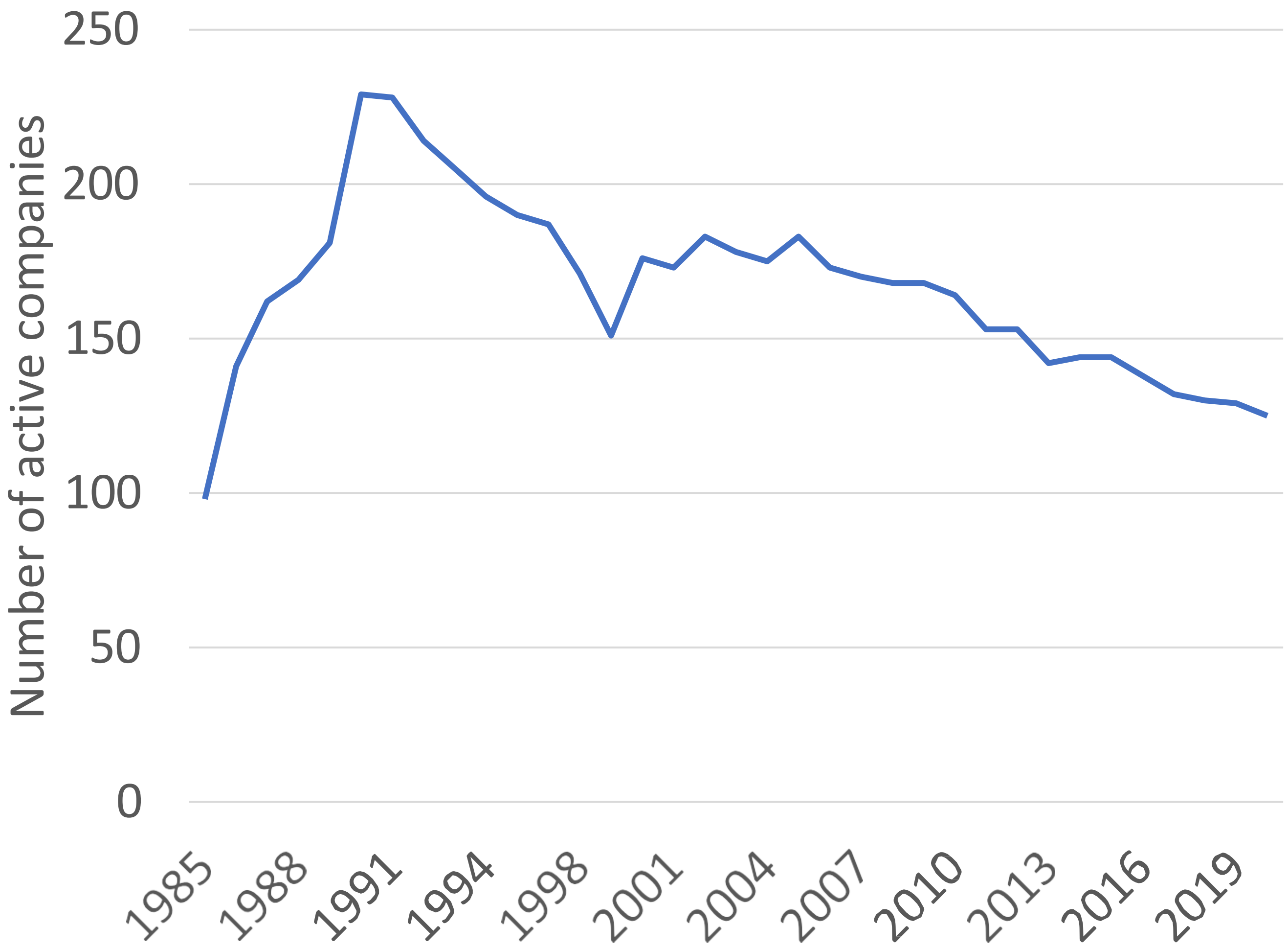
- Seafood is not a major part of the UK diet
- Most shellfish exported
  - Brexit challenges

Long Term in Home Seafood Consumption Trends (1940 to 2018)



Seafish: Market Insight Factsheet Seafood Consumption (2019)

Scotland: number of active companies

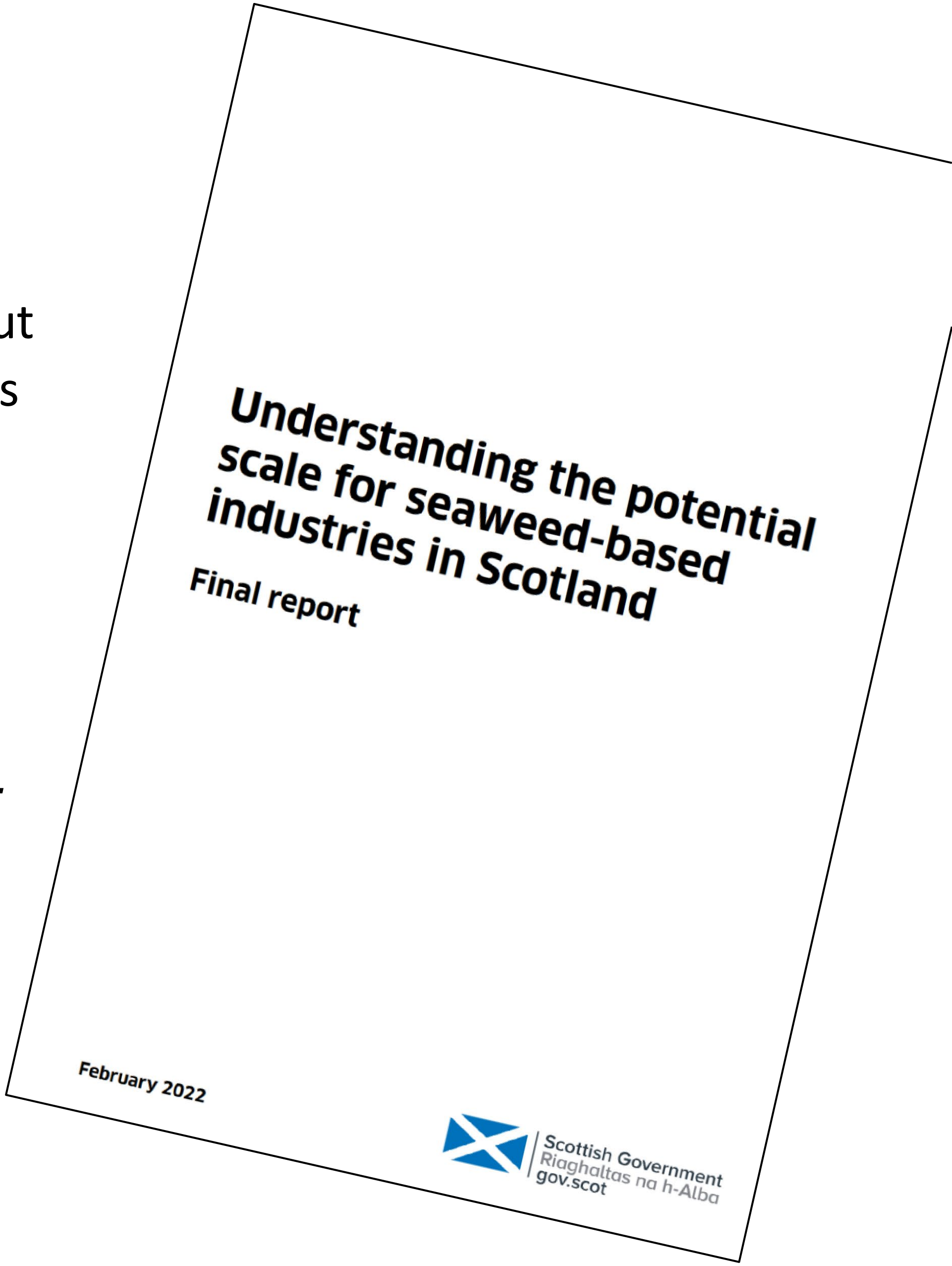


Scottish Shellfish

Association of Scottish Shellfish Growers

Scotland: Seaweed

- Seaweed farming is an emerging industry throughout the UK but it is difficult to obtain data on levels of production at present as this is not recorded in the same way that fish and shellfish production is.
- *In 2020, a maximum of approximately 15,000 tonnes of seaweed (all species combined) was consented for harvesting on Crown Estate Scotland owned land/seabed.*
  - Consented does not mean that amount will be produced
- *In 2020 the Scottish seaweed-based industry as a whole had an estimated Gross Value Added (GVA) of £510,000 per annum and employed a total of 59 people.*


Understanding the potential scale for seaweed-based industries in Scotland

Final report

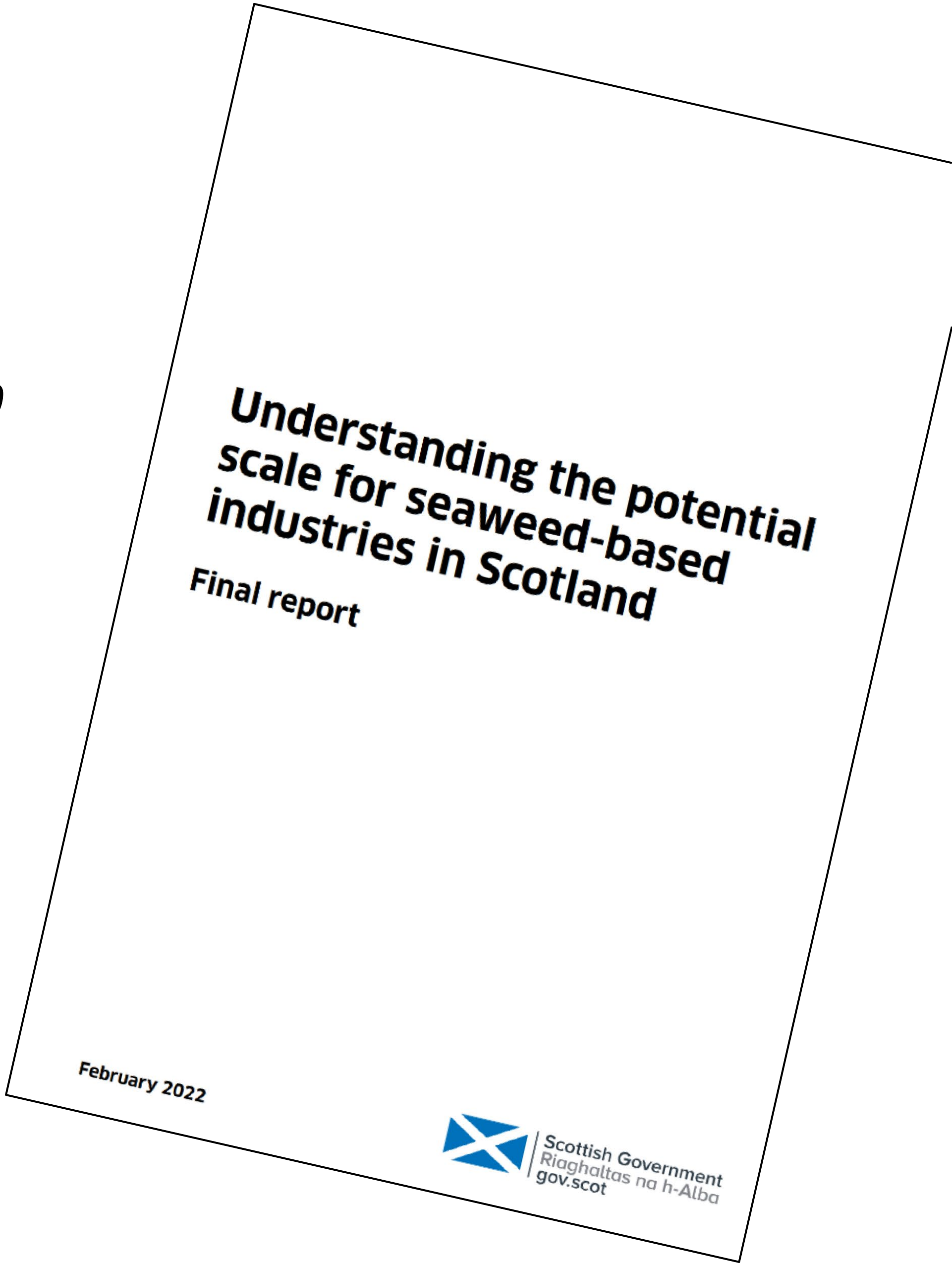
February 2022

Scottish Government
Riaghaltas na h-Alba
gov.scot

Scotland: Seaweed

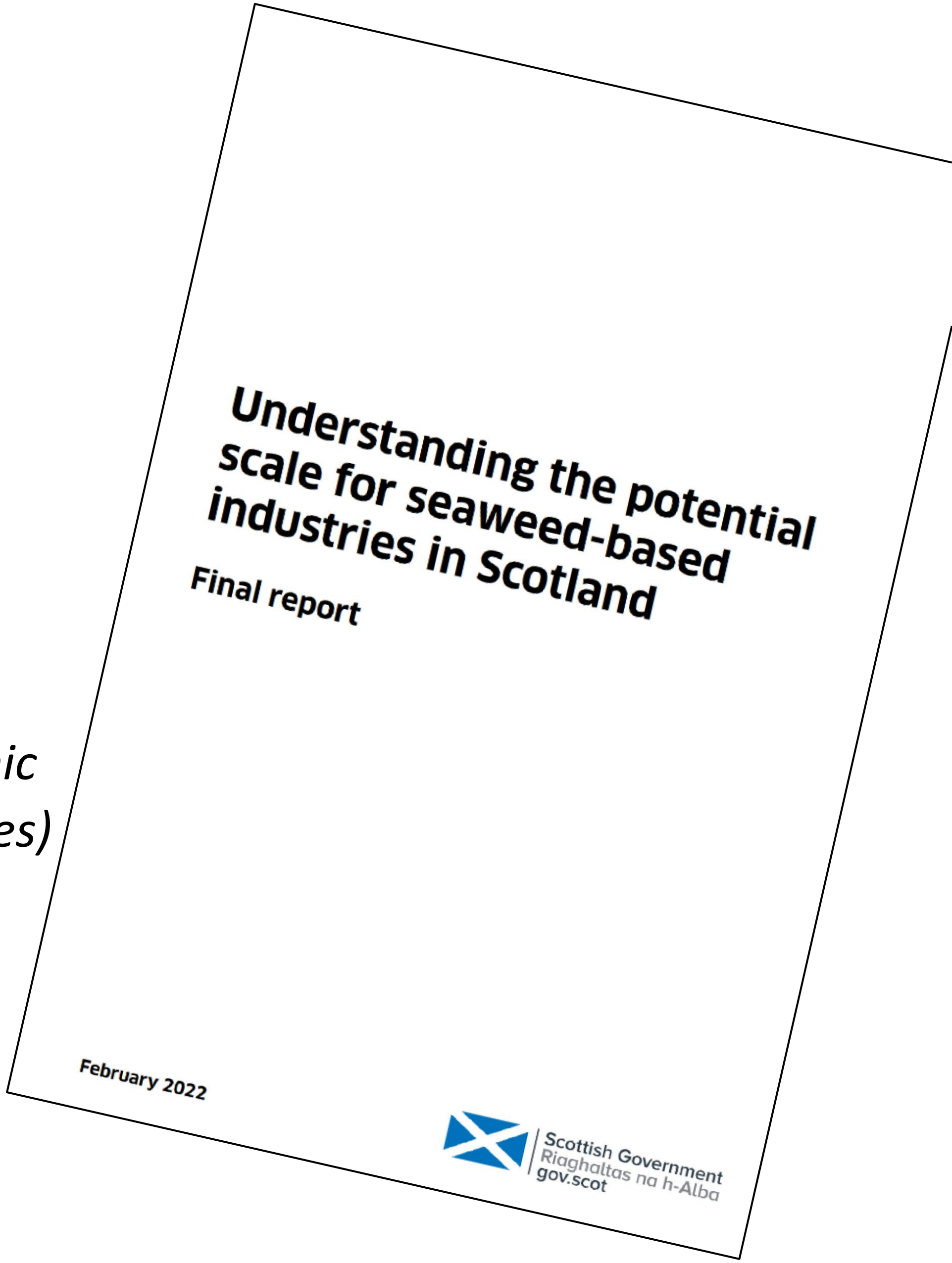
- ***Business as usual scenario***
    - *Generate a total turnover of £22.1 million per year by 2040*
    - *This activity is estimated to support 130 FTE jobs by 2040 and a further 30 FTE in the wider economy once induced impacts are included*

- ***Higher Growth scenario***
    - *Total turnover of £71.2 million per year by 2040*
    - *This activity is estimated to support 400 FTE jobs by 2040 and a further 90 FTE in the wider economy once induced impacts are included.*



Scotland: Seaweed

- Barriers
  - *Large start-up investment costs, access to finance and financial risk*
  - *Relatively low value and uncertainty regarding markets for species that can be cultivated*
  - *Scale of cultivation potentially required to achieve economic viability (and need for mechanization to achieve these scales)*
  - *The need for supply chain and infrastructure development within Scotland*


Understanding the potential scale for seaweed-based industries in Scotland

Final report

February 2022

Scottish Government
Riaghaltas na h-Alba
gov.scot

Scotland: Seaweed

- Stakeholders highlight poor communication a concern and potential development constraint
- Licensing system needs improved.
- Many knowledge gaps, particularly around scale of operation and impacts.
  - Lack of knowledge recognized in Scottish Government's Seaweed Policy Statement
    - Supportive of small/medium scale (0-50 x 200m line) subject to meeting regulatory requirements
    - Uncertainties about large scale (> 50 x 200m lines)


Marine Policy 83 (2017) 29–39
Contents lists available at ScienceDirect
Marine Policy
journal homepage: www.elsevier.com/locate/marpol
ELSEVIER

UK macroalgae aquaculture: What are the key environmental and licensing considerations?

Daniel Wood[a,*], Elisa Capuzzo[a], Damien Kirby[a], Karen Mooney-McAuley[b], Philip Kerrison[c]

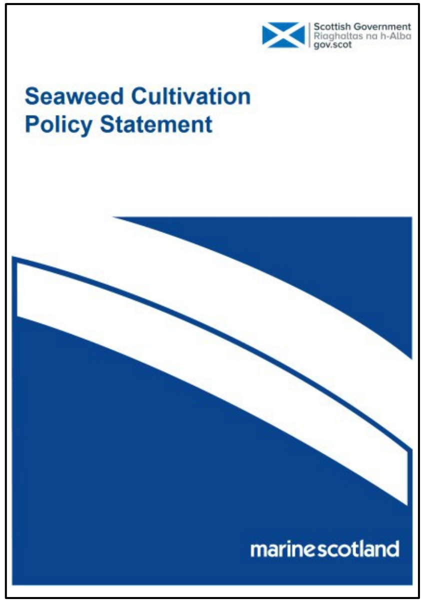
[a] Centre for Environment, Fisheries and Aquaculture Science (Cefas), Pakefield Road, Lowestoft NR33 0HT, UK
[b] Queen's University Belfast, Queen's University Marine Laboratory, 12-13 The Strand, Portaferry, Co. Down BT22 1PF, UK
[c] SAMS, Scottish Marine Institute, Oban, Argyll PA37 1QA, UK


Aquaculture 534 (2021) 736203
Contents lists available at ScienceDirect
Aquaculture
journal homepage: www.elsevier.com/locate/aquaculture
ELSEVIER

Is social license to operate relevant for seaweed cultivation in Europe?

Suzannah-Lynn Billing[a,*], Julie Rostan[a,b], Paul Tett[a], Adrian Macleod[a]

[a] Scottish Association for Marine Science, Oban PA37 1QA, Scotland, UK
[b] The Bryden Centre, University of the Highlands and Islands, Scotland, UK



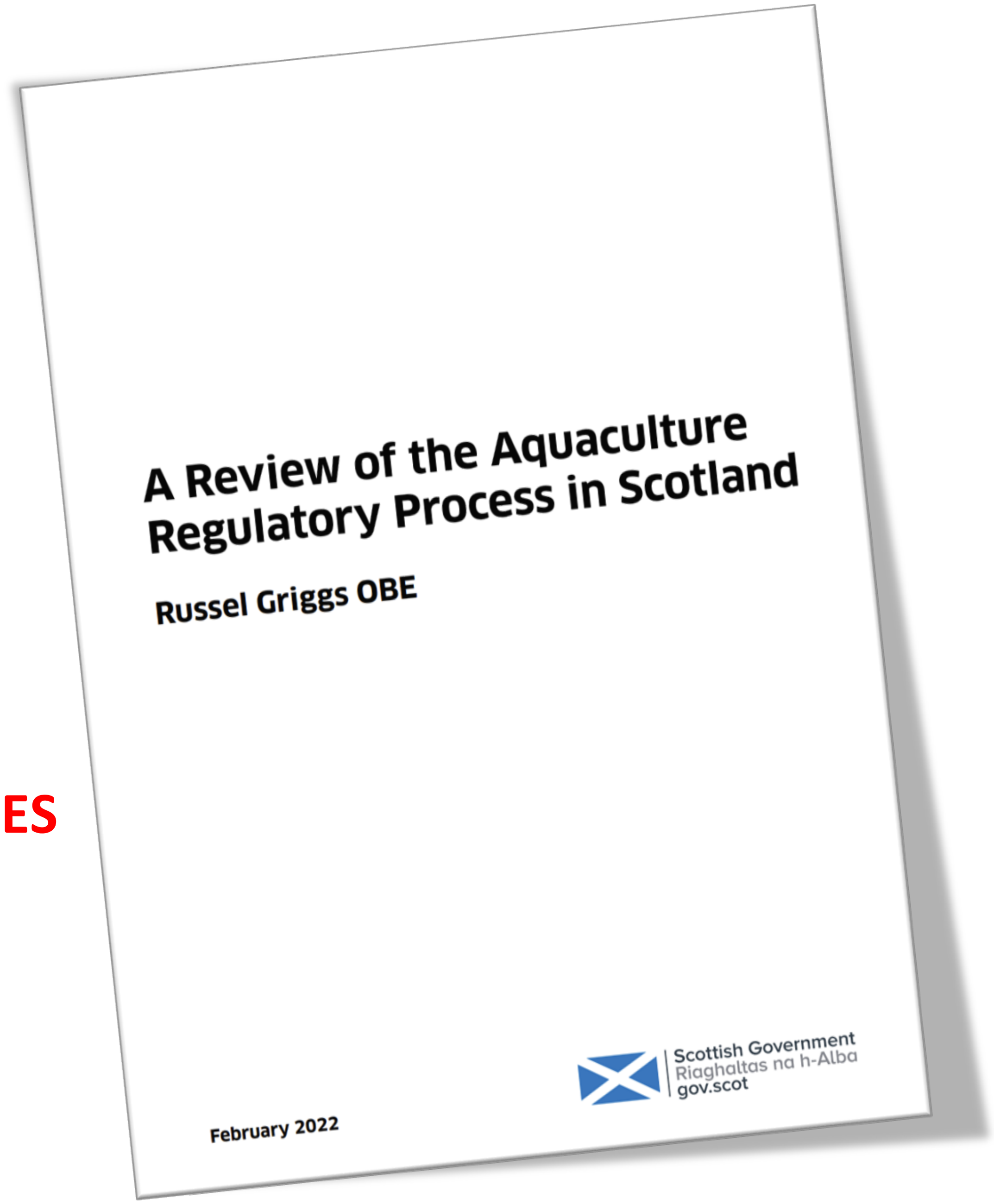
The LTL future – who knows?!

LIFE OUTSIDE EU

COVID-19 RESPONSE

COMPETITION FROM OTHER LT PRODUCING COUNTRIES

NEW POLICY/REGULATIONS



A Review of the Aquaculture Regulatory Process in Scotland

Russel Griggs OBE

February 2022

Scottish Government
Riaghaltas na h-Alba
gov.scot

New Seafood Strategy to be published later this year

	Barriers	Opportunities	Knowledge gaps
Social	• Conflict with other marine activities/users (Tett et al., 2012) • Few employment opportunities • Poor communication affects social acceptance (Billing et al., 2021)		• Community acceptance is location specific
Economic	• Very small domestic demand for shellfish • Brexit adding additional costs and burdens • Fluctuating and uncertain market puts financial strain on producer • Competition from other LT producing countries • Start-up costs • Supply chain and infrastructure requirements	• Use of low trophic species for non-food purposes	• How to increase domestic demand. • What future trade will look like • Potential and feasibility of non-food uses of low trophic species • Competition from other low trophic producing countries • Profitability of production
Environmental	• Mussel spat mortality (Broughton et al., 2019) • Risk – increasing temperatures may affect disease outbreaks (Murray et al., 2012).	• Nutrient offsetting?	• Causes of mussel spat mortality (Broughton et al., 2019) • Effects of seaweed production on environment. • Environmental interactions when operating at larger scales. • Connectivity between farms
Cultural	• Very small domestic demand for shellfish	• Restoration of native oyster populations	• How to increase domestic demand for shellfish
Governance	• Licensing and regulation is complex and time consuming. • Slow decisions	• Policy and regulation across entire aquaculture sector is being revised in 2022/2023 (Griggs, 2022).	• Feasibility of new production technology and environments, e.g. offshore shellfish farms

References for Table

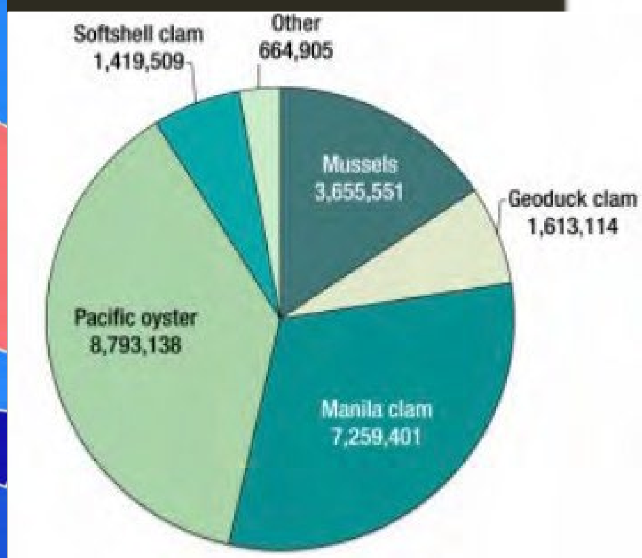
- Broughton, C., Baily, J., Green, D., Weidmann, M., Carboni, S. 2019. Spat mortality in farmed blue mussels (Mytilus edulis) in Scotland. European Aquaculture Society Conference. Dubrovnik, Croatia.
- Griggs, R. 2022. A review of the aquaculture regulatory process in Scotland. Marine Scotland, Edinburgh. 59pp.
- Murray, A., G., Marcos-Lopez, M., Collet, B., Munro, L.A. 2012. A review of the risk posed to Scottish mollusc aquaculture from Bonamia, Marteilia and oyster herpesvirus. Aquaculture, 370-371: 7-13.
- Tett, P., B. Valcic, T. Potts, C. Whyte, F. Culhane and T. Fernandes 2012. Mussels and yachts in Loch Fyne, Scotland: a case study of the science-policy interface. Ecology and Society 17(3): 16.

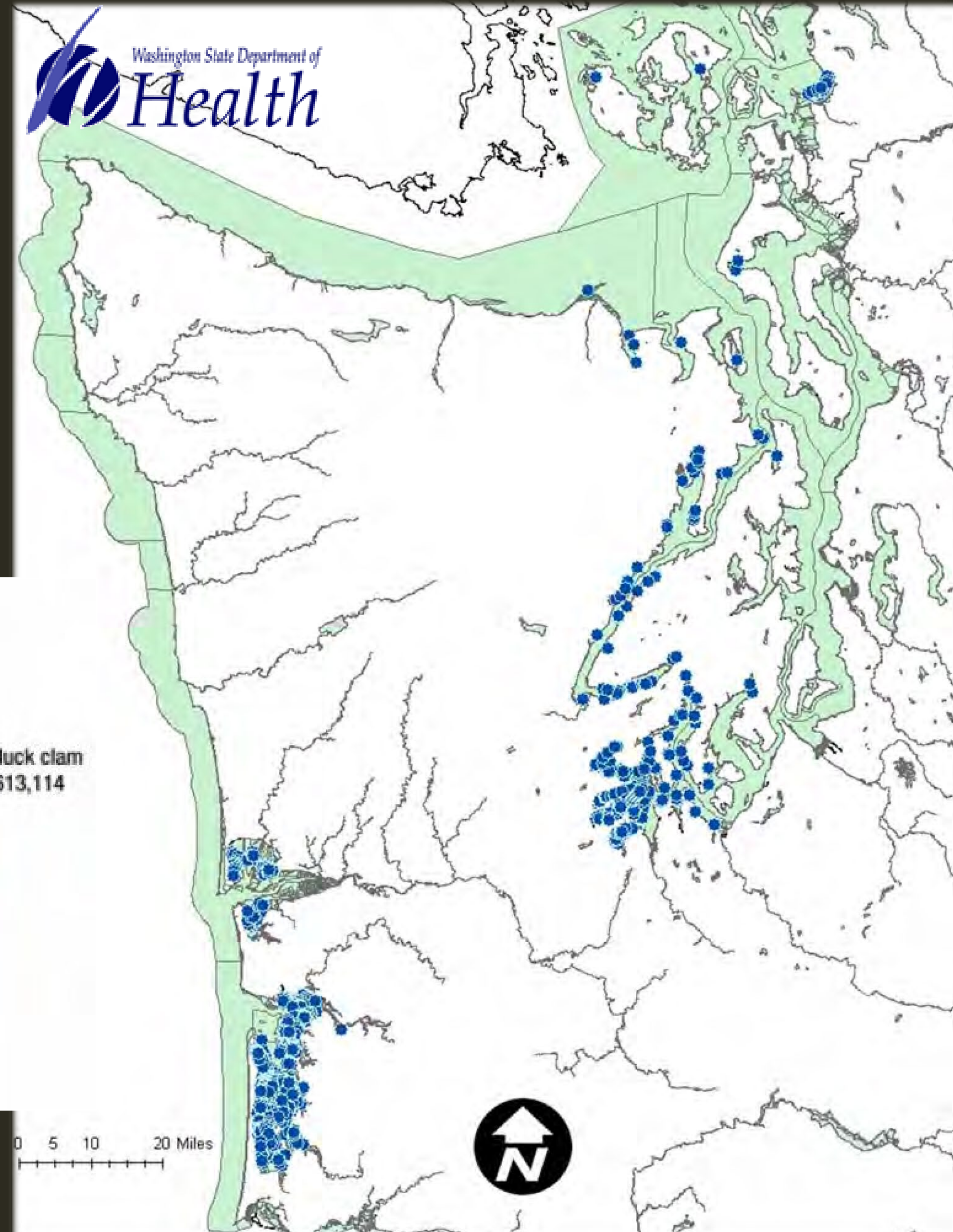
UNITED STATES WEST COAST MARICULTURE PRODUCTION & EMERGENT SPECIES DEVELOPMENTS

Bobbi Hudson, Exec Dir
Pacific Shellfish Institute
WEGCCA
August 29, 2022

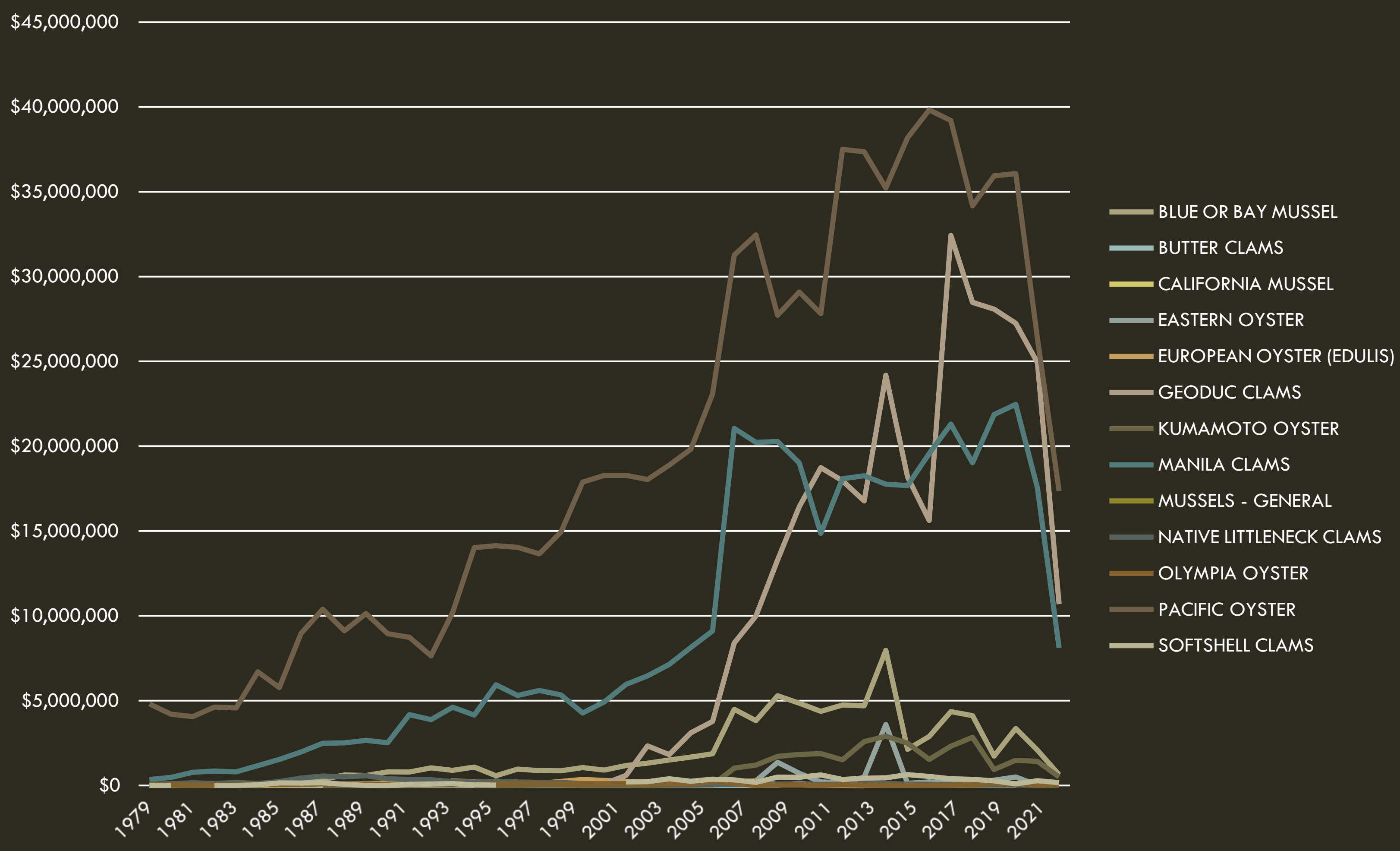
WEST COAST SHELLFISH FARMS

Total production WA
10,500 metric tons
$150 million

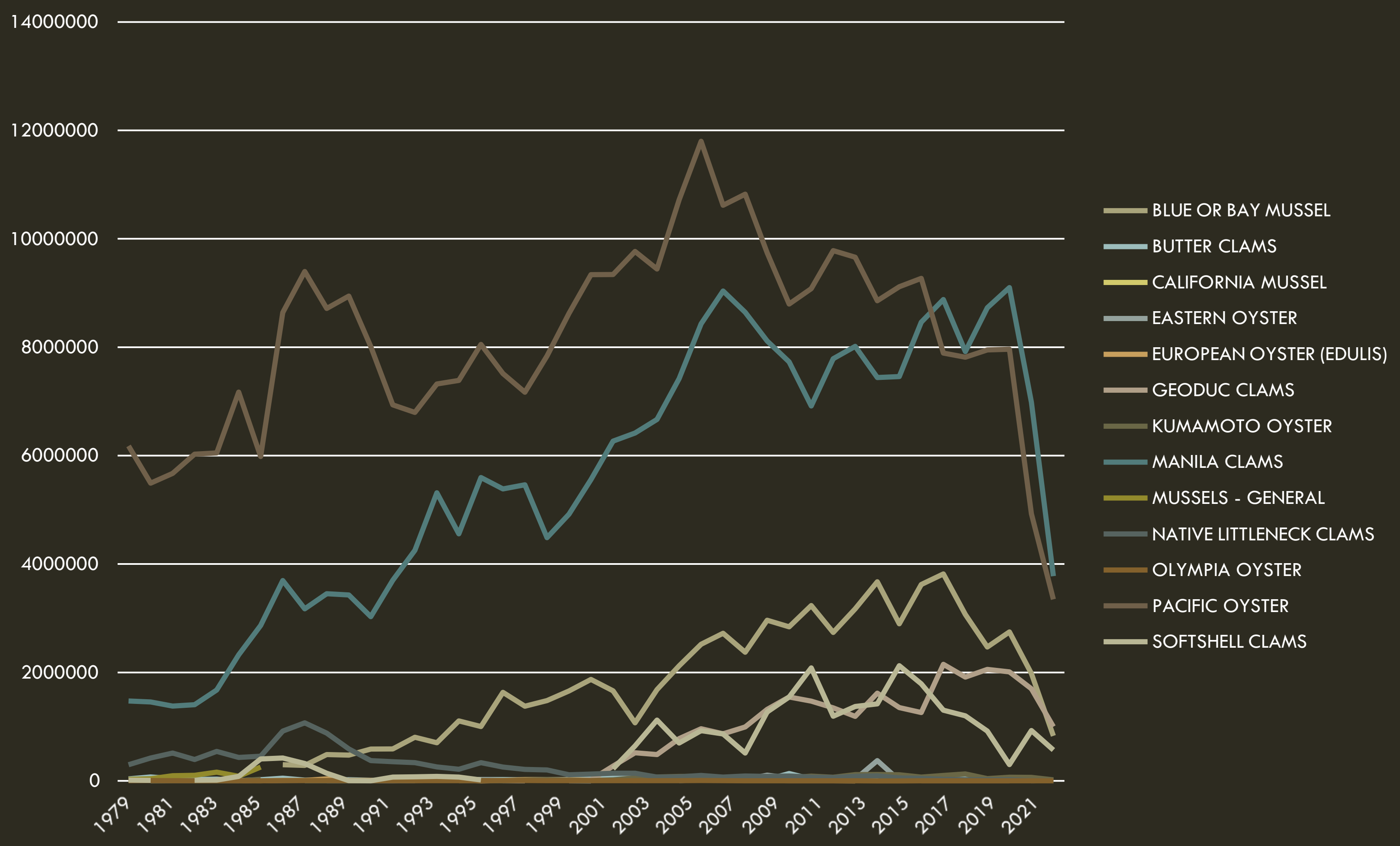




WA AQUACULTURE VALUE (WDFW DATA)



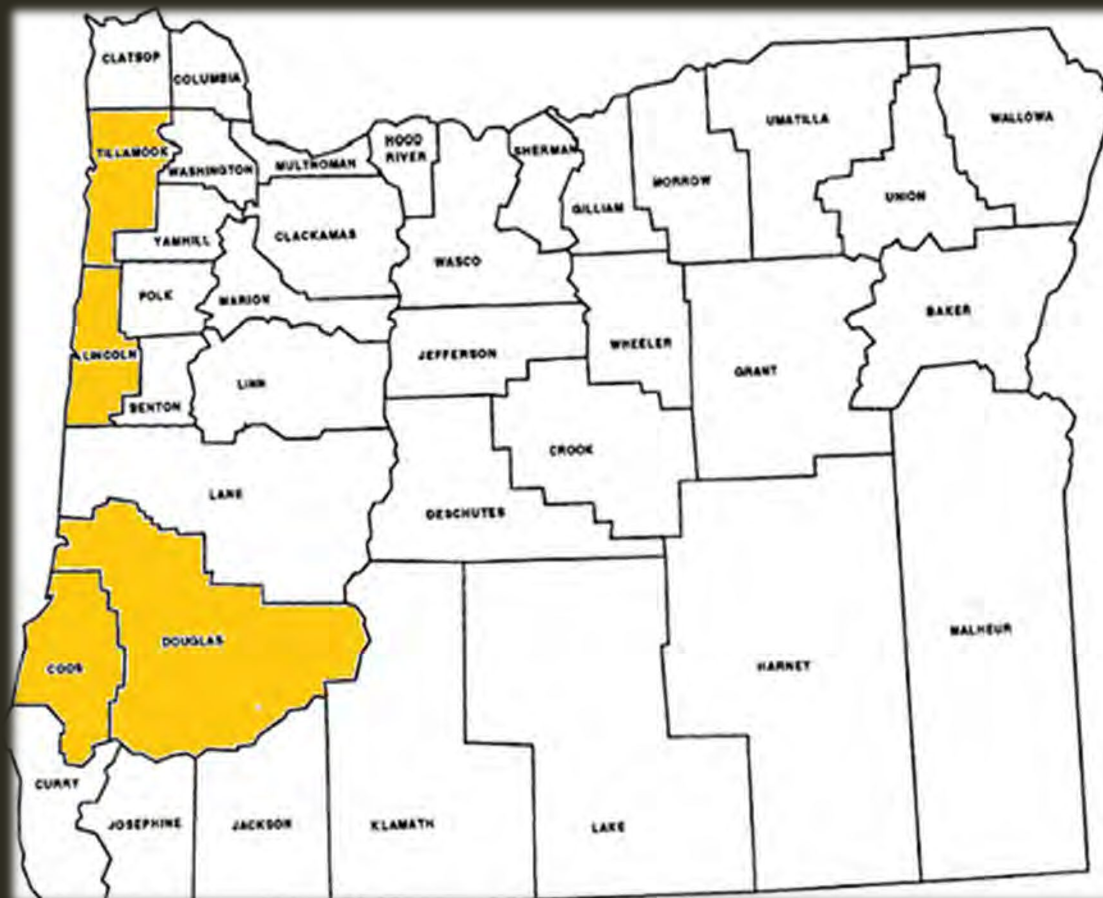
WA AQUACULTURE POUNDS (WDFW DATA)



OREGON

Growers (23)
Shellfish Processors (8)
Shellstock Shippers (37)

Oregon Department of Agriculture



CALIFORNIA

30 Marine Aquaculturists
16 active bivalve producers

WA, C. GIGAS GROUND CULTURE

WA, BAG CULTURE ON BOTTOM

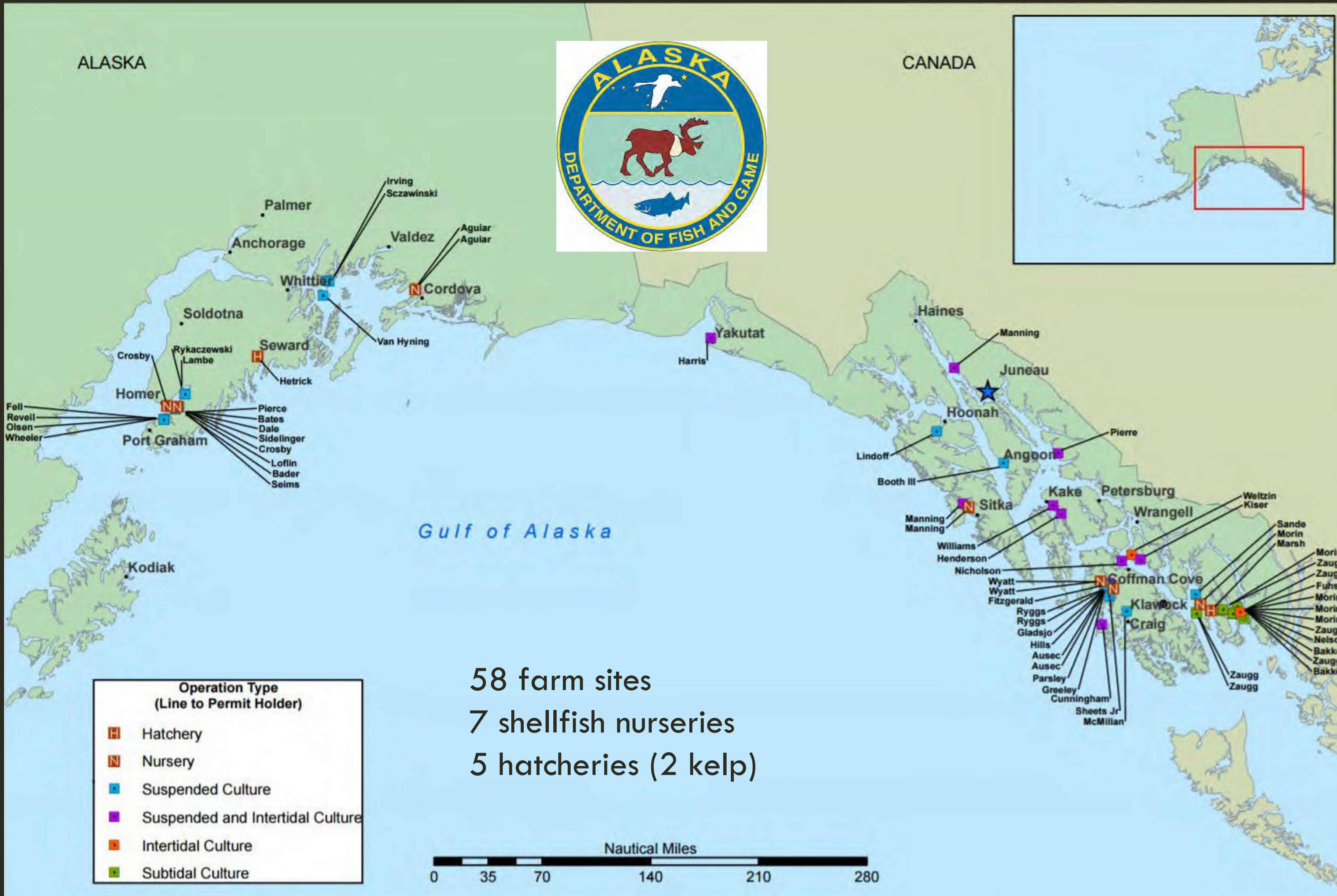
WA, LONGLINE WITH C. GIGAS

WA, LONGLINE WITH C. GIGAS

CA, SEAPA™ BASKETS

WA, FLIP BAGS

WA, C. GIGAS BOTTOM CULTURE



58 farm sites
7 shellfish nurseries
5 hatcheries (2 kelp)

www.adfg.alaska.gov

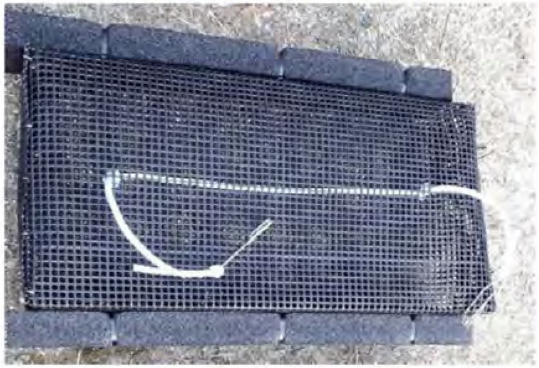
ROCKY BAY OYSTERS, SE ALASKA

ROCKY BAY OYSTERS, SE ALASKA

FREE OYSTER GEAR - 2016

Alaskan Mariculture Diversification, Innovation and Technology Transfer Project:
Alternate Species and Gear

Each participating oyster farm will receive *all* of the following, at *no cost*:

Maine Style Container	Zapco Bag with Floats	Seapa Container
		
Vexar container with closure 9mm mesh; 29 x 15.5" x 5" deep box Foam floats (or round or square plastic) Hog rings & clips & zip ties *44 per oyster farm*	Vexar bag with closure 10mm mesh; 30 x 18" x 3" deep pouch Foam floats 10mm poly aqualine & assembly *44 per oyster farm*	34L tube with end cap & door 12mm mesh; 33.5" x 10" No floats provided 20mm flexi clip, 11mm clamps & pins *22 per oyster farm*

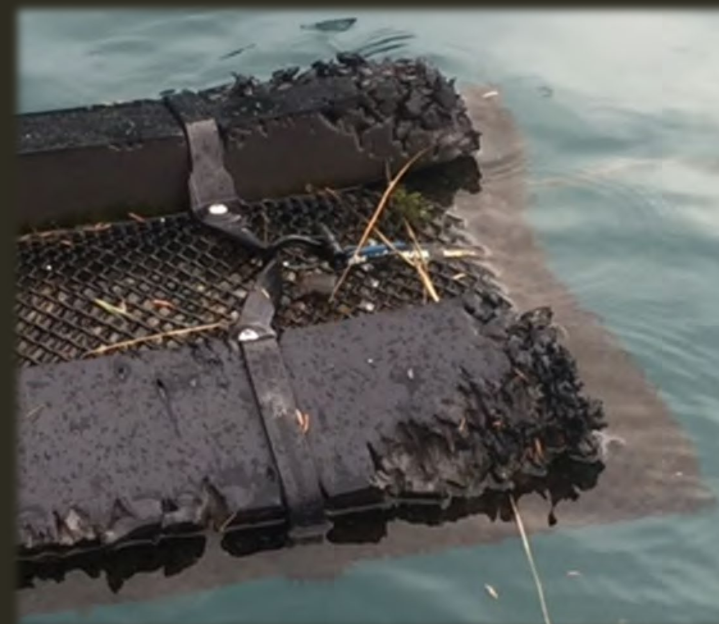
Shipping: All gear is initially being shipped from Seattle to Ketchikan on Alaska Marine Lines. SE farm gear will be pulled in Ketchikan, and the remainder will be shipped to Anchorage. Farms will need to coordinate pick-up of gear from these locations. Alaska Marine Lines shipping is covered by this grant, but shipping to individual farms is *not* covered.

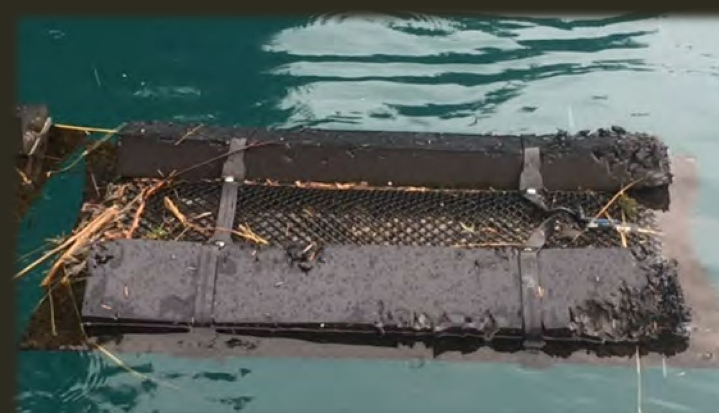
ZAPCO STYLE BASKETS

Abandoned immediately due to sea otter vandalism

Other observations:

- Hooks released too easily, especially catching on things when deploying or retrieving
- Bags have no depth at all constraining the oysters
- Oysters float too close to the surface causing significant surface debris fouling

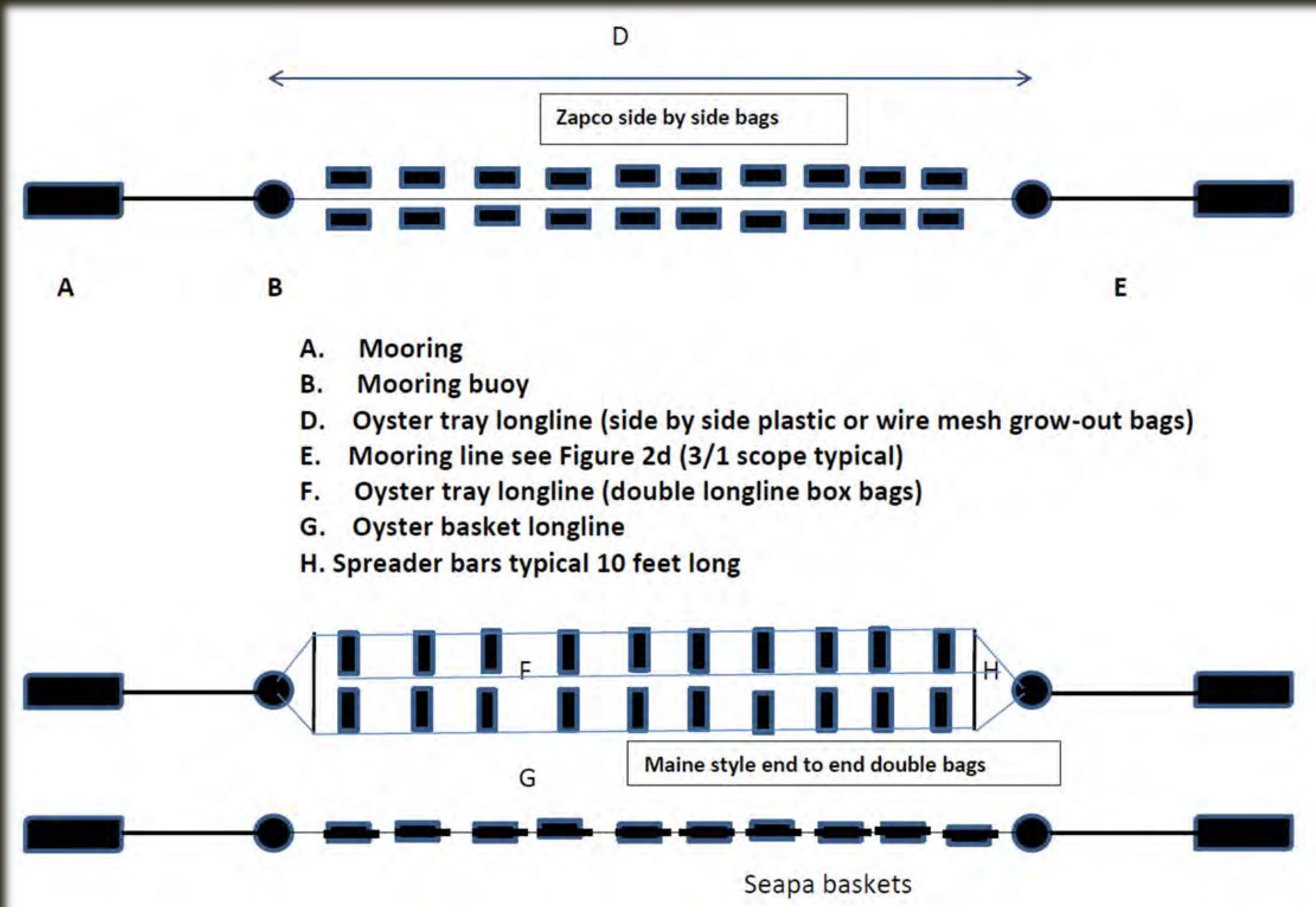




JAKOLOF BAY OYSTER CO.
SWEETSPOT FOR OYSTERS IN KACHEMAK BAY

ADFG DFG-91-22A-AF-SC
DNR ADL 225292
ADEC AK-6972-SP
ADFG SA 13-V-0100-SA
OA POA-1990-454

PLACEMENT & PERMIT DIAGRAMS



MAINE STYLE BASKETS

Abandoned immediately since floats had a tendency to leak

Other observations:

- **SIDE** mounting kept oysters too close to the surface, collecting surface debris, and leaving oysters nearly dry.
- **TOP** mounting presented same problem as existing beach bag where *bags tend to tip on end if wildlife land or lounge on top*, requiring frequent visits to resettle the oysters. Significantly worse when floats leaked!

Photos by Jakolof Bay Oyster Co.

SEAPA 35L ON LONGLINES

Cannot be stretched on poles due to special area habitat restrictions

Other observations:

- Baskets are very easy to work (empty, sort, pack, repack etc.)
- In-water movement with tide changes and surface rocking makes a nice shape to the oyster.
- Shape and meat to shell ratio was excellent even in juvenile (1 year old) oysters.

Photos by Jakolof Bay Oyster Co.

LANTERN NET

#1 Best use of a lantern net!

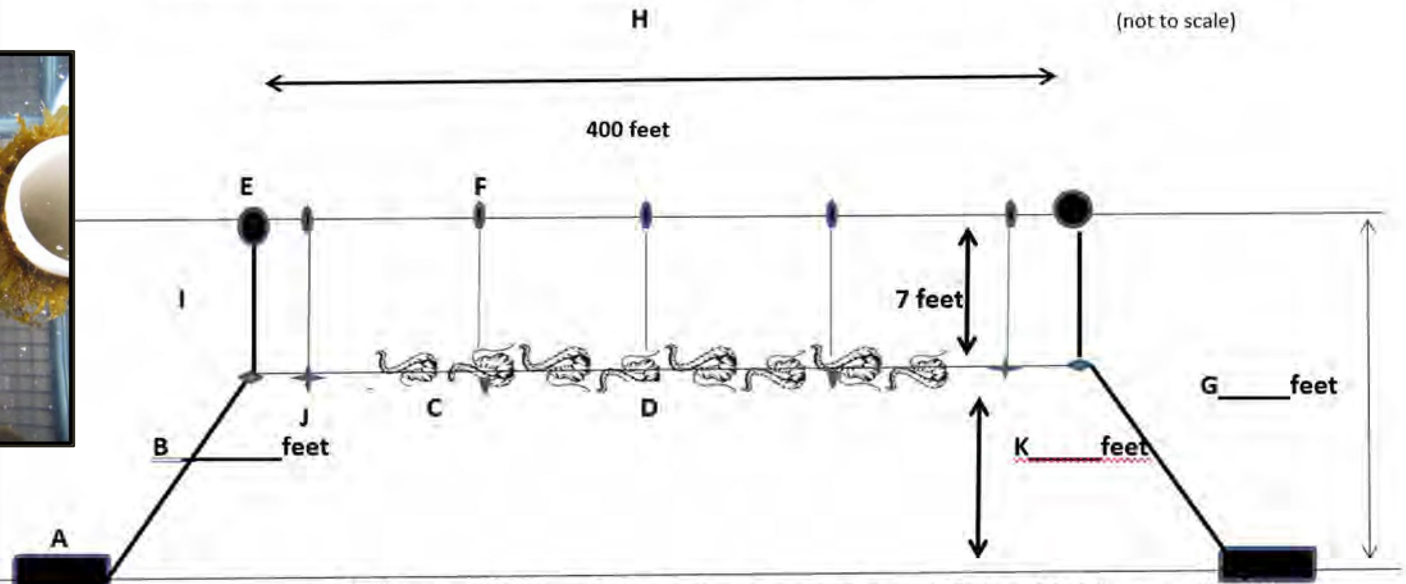
JAKOLOF BAY OYSTER CO.

SWEETSPOT FOR OYSTERS IN KACHEMAK BAY

ADFG	DFG-91-22A-AF-SC
DNR	ADL 225292
ADEC	AK-6972-SP
ADFG: SA	13-V-0100-SA
OA	POA-1990-454

PERMITTING & GEAR $ ASSISTANCE

Figure 1A. Cross-sectional view Alaskan Sugar Kelp Longline (grower fill in depth G and L)



A. Mooring (200 lb. mushroom anchor or auger or granite block or 2000 lb. cement block)[1]
B. Grower fill in anchor line length and materials (3/1 scope typical)
C. 7/16 inch seeded kelp poly line 400 feet long and 7 feet below the surface
D. 5-10 lb. cement weights or three holed bricks to keep kelp 7 feet below surface
E. Surface mooring ball 18 inch diameter 100 lb. displacement
F. 5/16 inch poly depth 7' control line (dropper) , 6x14 inch foam surface buoy and weight (D)
G. Water depth at low tide H. Longline section (400 feet typical, grower fill in if different)
I. 7 feet ½ inch chain to shackle. J. Line holdfast K. Distance from kelp longline to bottom

[1] Mooring detail to be filled out by grower in Figure 5.

1ST ALASKA COMMERCIAL KELP HARVEST

10/26/2016 Seaweed farming begins in Sou

JuneauEmpire.com

Seaweed farming begins in S

Posted: October 12, 2016 - 12:02am

By MARY CATHARINE MARTIN

Capital City Weekly

A year ago, Trevor Sande wasn't thinking much about seaweed.

Early this November, however, he and the employees at Hump Island Oyster Company in Ketchikan, which Sande founded and owns, will plant five acres of bull kelp and ribbon kelp, all originating from local seaweed.

Seaweed isn't yet a big part of commercial mariculture in Alaska — but researchers at the University of Alaska Southeast and seaweed product company Blue Evolution are working to change that.

UAS professor of chemistry and biochemistry Mike Stekoll has been researching the viability of different kinds of seaweed grown commercially in Alaskan waters, recently funded by Premium Oceanic (Blue Evolution's parent company) and grants.

GIANT RED SEA CUCUMBER R&D

Speed up Growth in Nursery

- Different Feeds
  - Mussel Waste
  - Nursery diet of seaweed and detritus
  - Experimental Diets
- Increase Temperatures
- Shorten time to outplant
- Increase food availability

PUGET SOUND RESTORATION FUND

Taylor Pride Shellfish Hatchery

OceansAlaska MARINE SCIENCE CENTER

IMTA RESEARCH

Integrated Multi-Tropic Aquaculture (IMTA) with two farmed species (WA)

- Blackcod
- Mussels

Quantify sedimentation and water chemistry characteristics (WA)

- Carbon chemistry - OSU
- Nutrient analysis – UW
- Sediment traps under & inside raft
- Food availability, Total Organic Matter

ROCK SCALLOP *Crassadoma gigantea*

- ISSC approval of Receptor Binding Assay (RBA) for PSP detection
- uptake, retention & detoxification of rock scallop to saxitoxins (STX) in:
  - adductor muscle
  - digestive gland
  - Viscera

Photo by Katie Houle, PSI

$: NOAA-OAR-SG-2016-2004807

GEODUCK
PANOPEA GENEROSA

1. PSP – monitoring critical to siting farms in WA & AK
2. Predator exclusion mandatory
3. Growth rate challenging
4. Seed supply & improve survival
5. Wild fishery
6. Trade issue: Arsenic, China

Photograph: Taylor Shellfish

SEAFOOD news.COM

Washington Seafood Broker Lands Jail Time; Company Hit "itb $25K Fine for Illegal Geoduck Shipments

May 18, 2022

A seafood broker based in Burie11 Washington was sentenced in U_S_District Court m Seattle to 90 days in prison and three years of supervised release for sm.uggling seafood from. the u_s_

The Department of Justice (DOI) said that Jeffrey Hallin Olsen. 52, owner of Absolute Seafoods LLC, falsified docume11t£ and lied to authorities about disposing of 46 cases of potentially tainted geoduck &om Alaska_

u_s District Judge John C_ Coughenour also sentenced Oken's com.pany, Absolute Seafoods LLC, to probation and was ordered to pay a $25,000 fine.

Mr_Olson chose to gamble with the lives of customers across the globe - putting them at risk of shellfish poisoning,= said u_s_ Attorney Nick Br-own_ "We'11 likely never know if any of the Chinese customers becatlle ill &om thesedams, but a prison seutence .is justified by the danger of his conduc t and h.is repeated lies to authorities, claiming he had destroyed the potentially harmful ge-oduck_"

Case records .show that on Febmary 20 or 21, 2019, Olsen purdiased 2,500 pounds of geoduck from a few A]aska divers_The geodnck was mixed together in crates for .shipping, and was picked up at Sea-Tac A.irporl, and headed to British Columbia for shipping to Hong Kong.

Concerns remain over tribe's oyster farm in Dungeness Bay

By Michael Dashiell Sequim Gazette • February 2, 2022 1:30 am

Contact before you start:

- Alaska Native entities in your area (tribes and village corporations) as appropriate.
- Your local government/city planners
- Nearby property owners
- Other area users (commercial fishermen, subsistence users, etc.)

SHPO

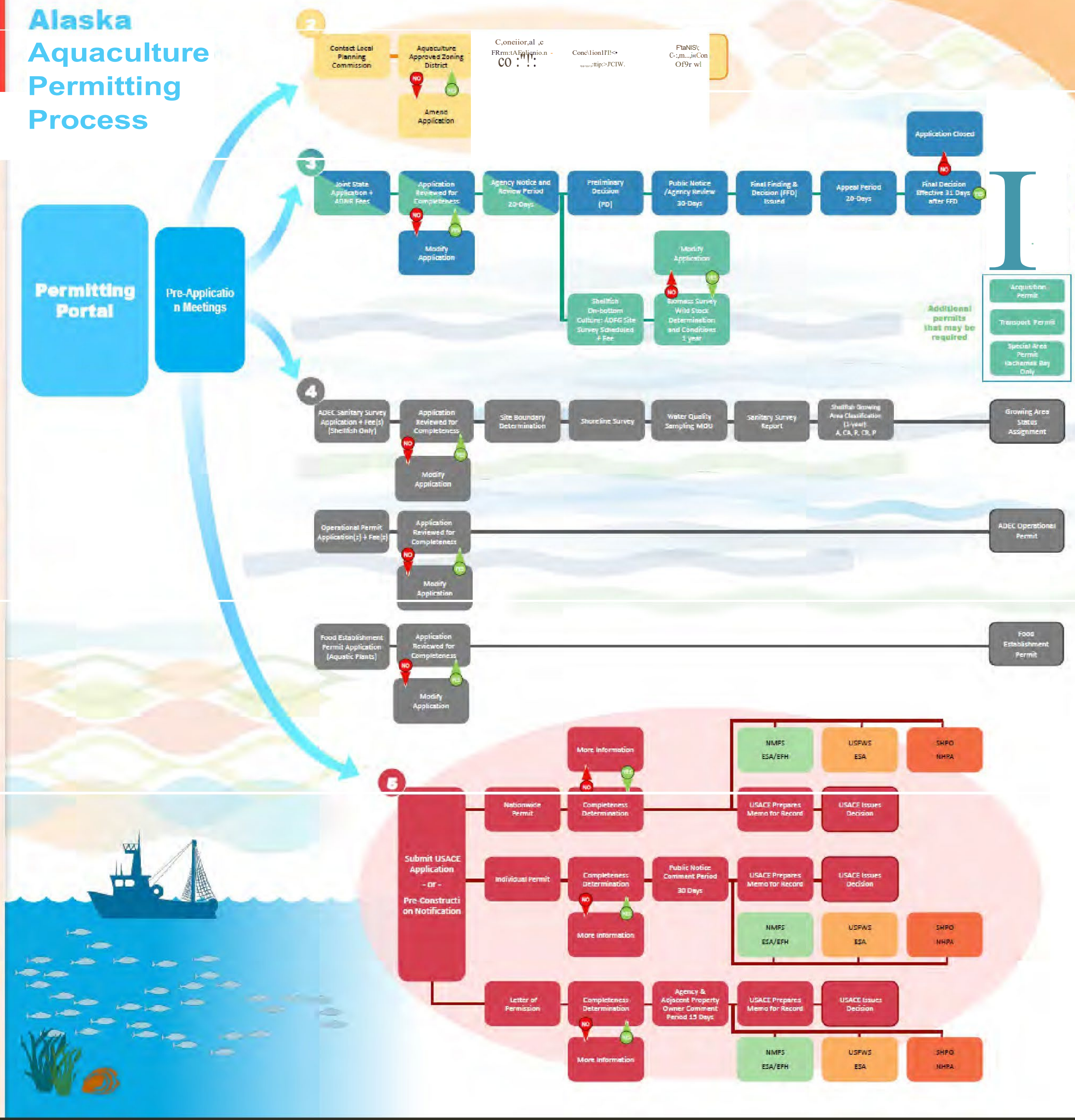
USFWS

Local GOV

ADEC

NMFS

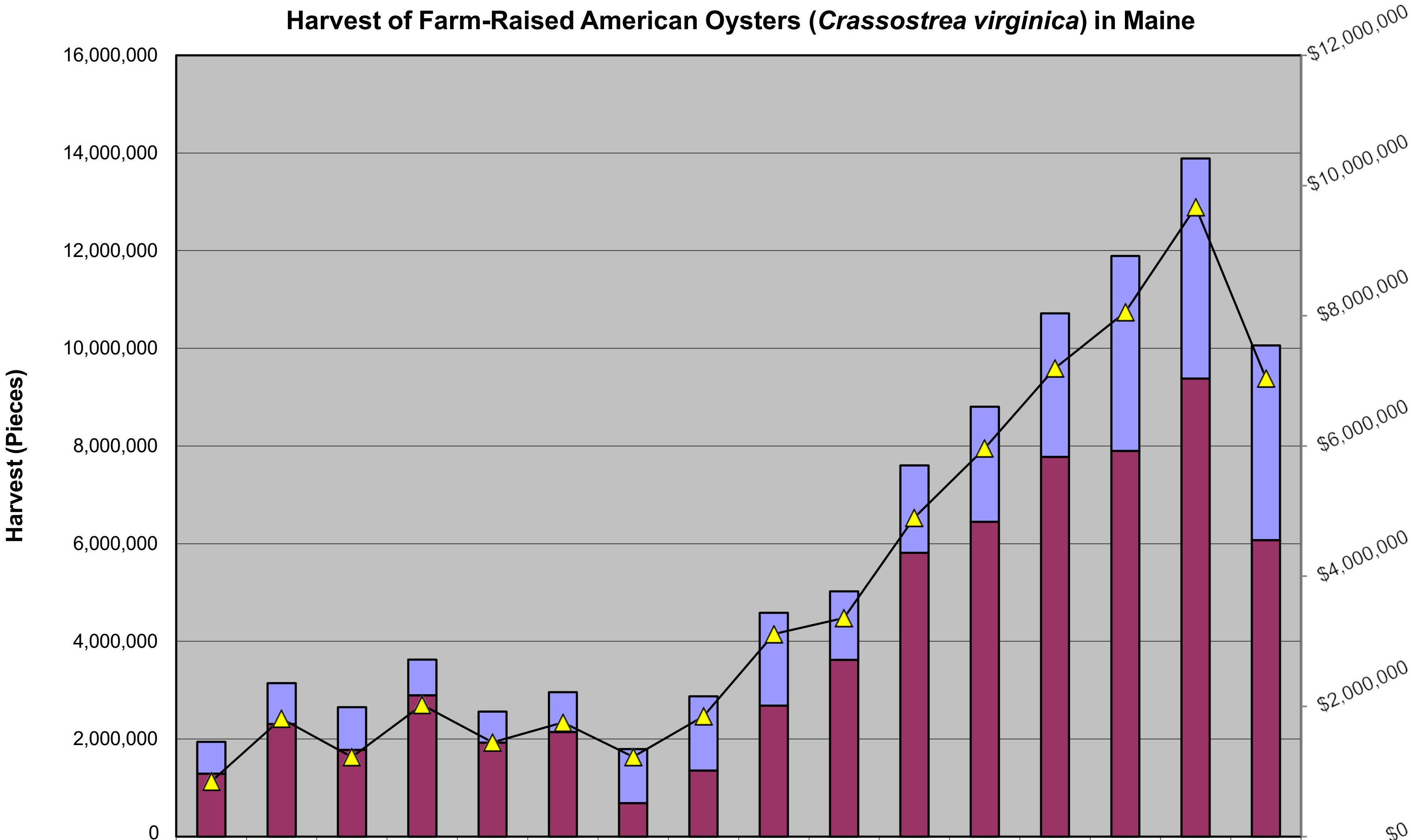
Alaska Aquaculture Permitting Process



QUESTIONS?

Bobbi Hudson, *Executive Director*
Pacific Shellfish Institute (PSI)

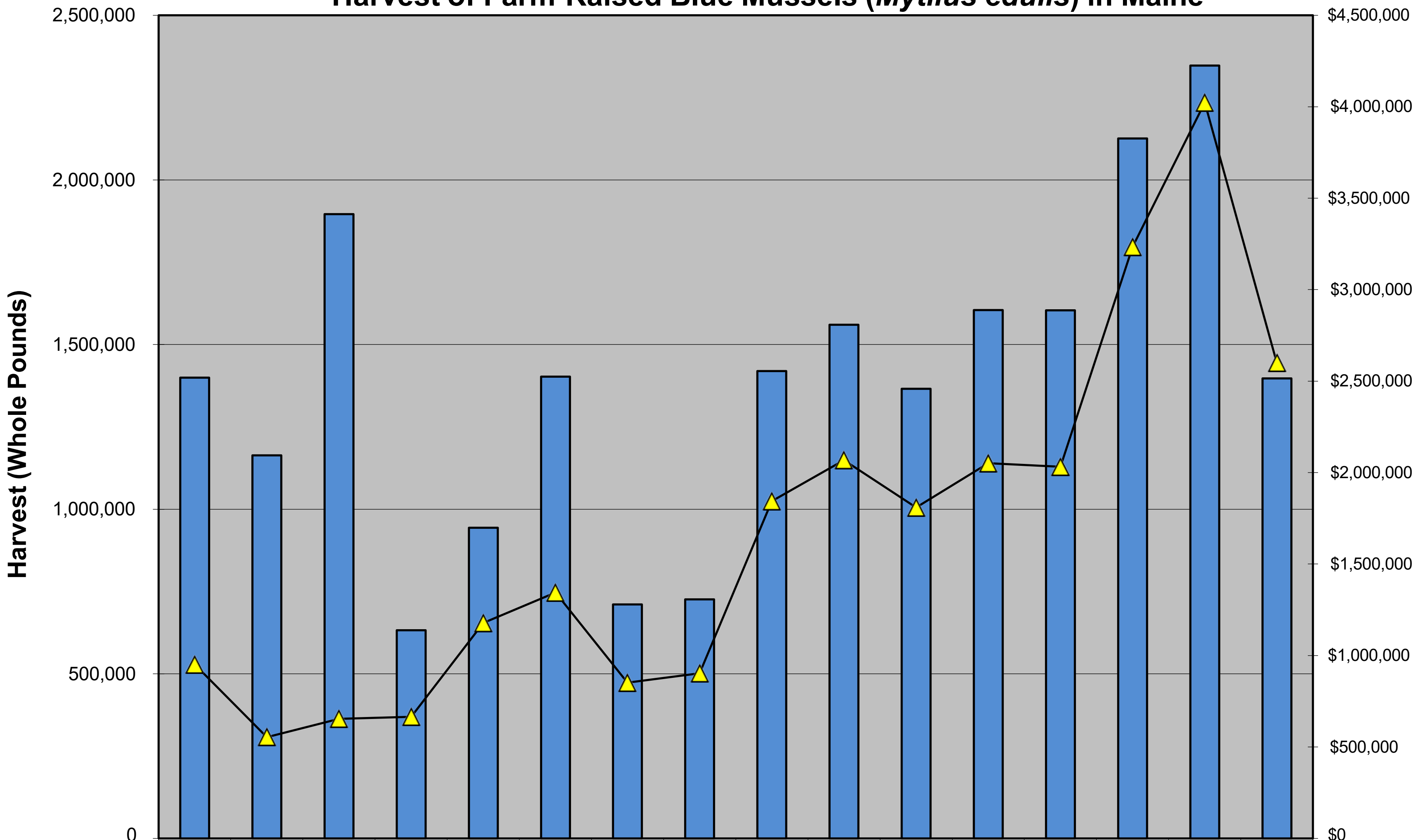
Harvest of Farm-Raised American Oysters (*Crassostrea virginica*) in Maine



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015*	2016	2017	2018	2019	2020
Other Location	650,044	837,138	875,067	728,073	633,894	820,047	1,103,901	1,522,652	1,900,640	1,404,861	1,788,685	2,356,755	2,941,792	3,992,948	4,507,768	3,990,144
Damariscotta River	1,291,494	2,306,290	1,777,798	2,896,714	1,925,700	2,140,279	687,500	1,353,162	2,681,997	3,618,669	5,811,629	6,447,636	7,774,405	7,898,517	9,381,531	6,070,775
Total Harvest	1,941,538	3,143,428	2,652,865	3,624,787	2,559,594	2,960,326	1,791,401	2,875,814	4,582,637	5,023,530	7,600,314	8,804,391	10,716,197	11,891,465	13,889,299	10,060,919
Total Value ($)	$848,338	$1,812,677	$1,220,531	$2,024,575	$1,447,378	$1,754,744	$1,225,472	$1,851,331	$3,113,775	$3,359,665	$4,898,154	$5,964,214	$7,193,925	$8,054,957	$9,670,100	$7,041,070

** DMR began collecting LPA harvest data in 2015.*

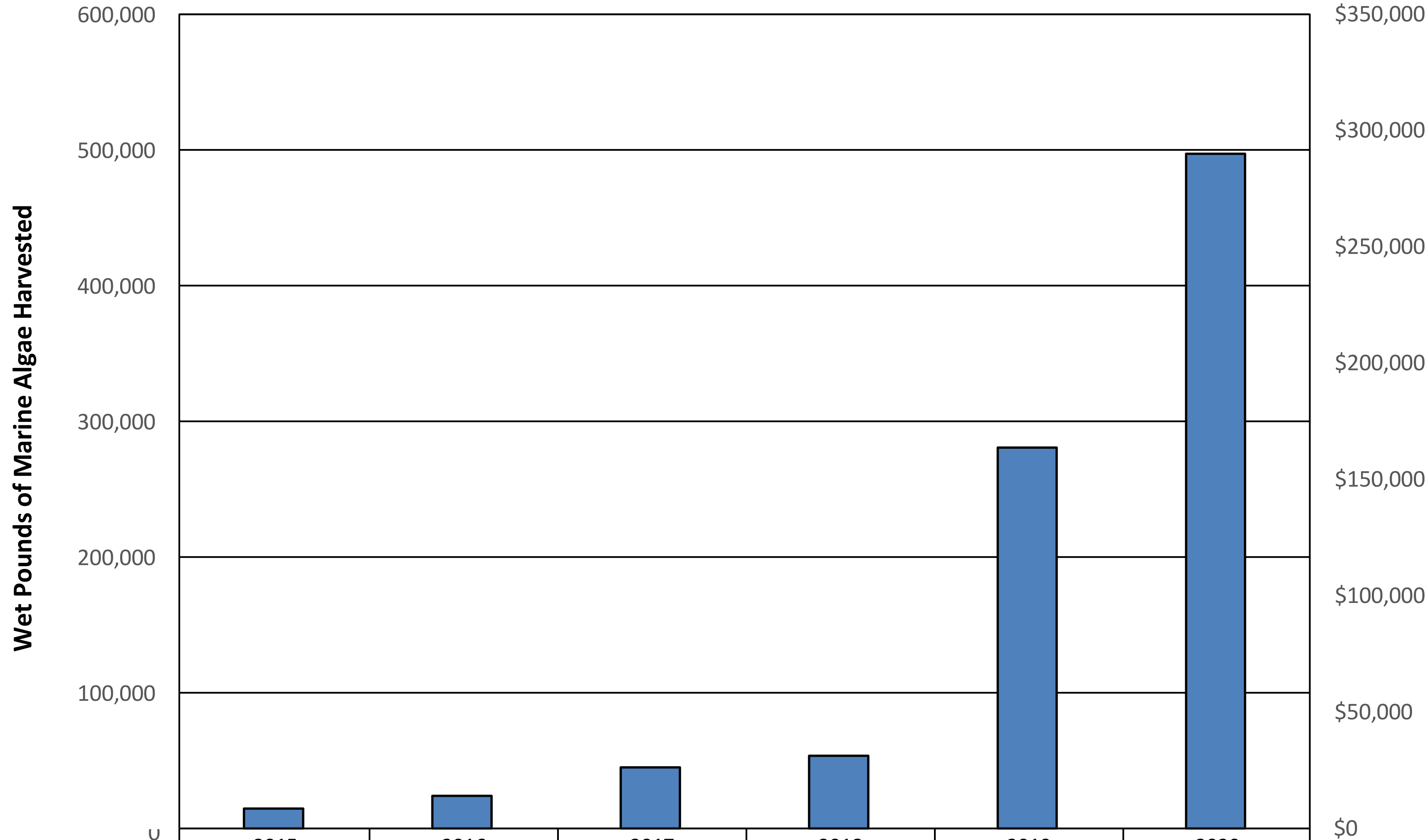
Harvest of Farm-Raised Blue Mussels (*Mytilus edulis*) in Maine



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015*	2016	2017	2018	2019	2020
Total Harvest	1,399,508	1,163,763	1,896,160	632,330	943,504	1,402,608	710,879	726,108	1,419,188	1,560,056	1,365,593	1,604,648	1,603,793	2,126,250	2,347,146	1,397,023
Total Value ($)	$951,269	$553,520	$653,867	$664,822	$1,177,738	$1,344,652	$851,814	$903,045	$1,843,353	$2,067,979	$1,808,899	$2,051,194	$2,031,376	$3,234,580	$4,022,825	$2,598,649

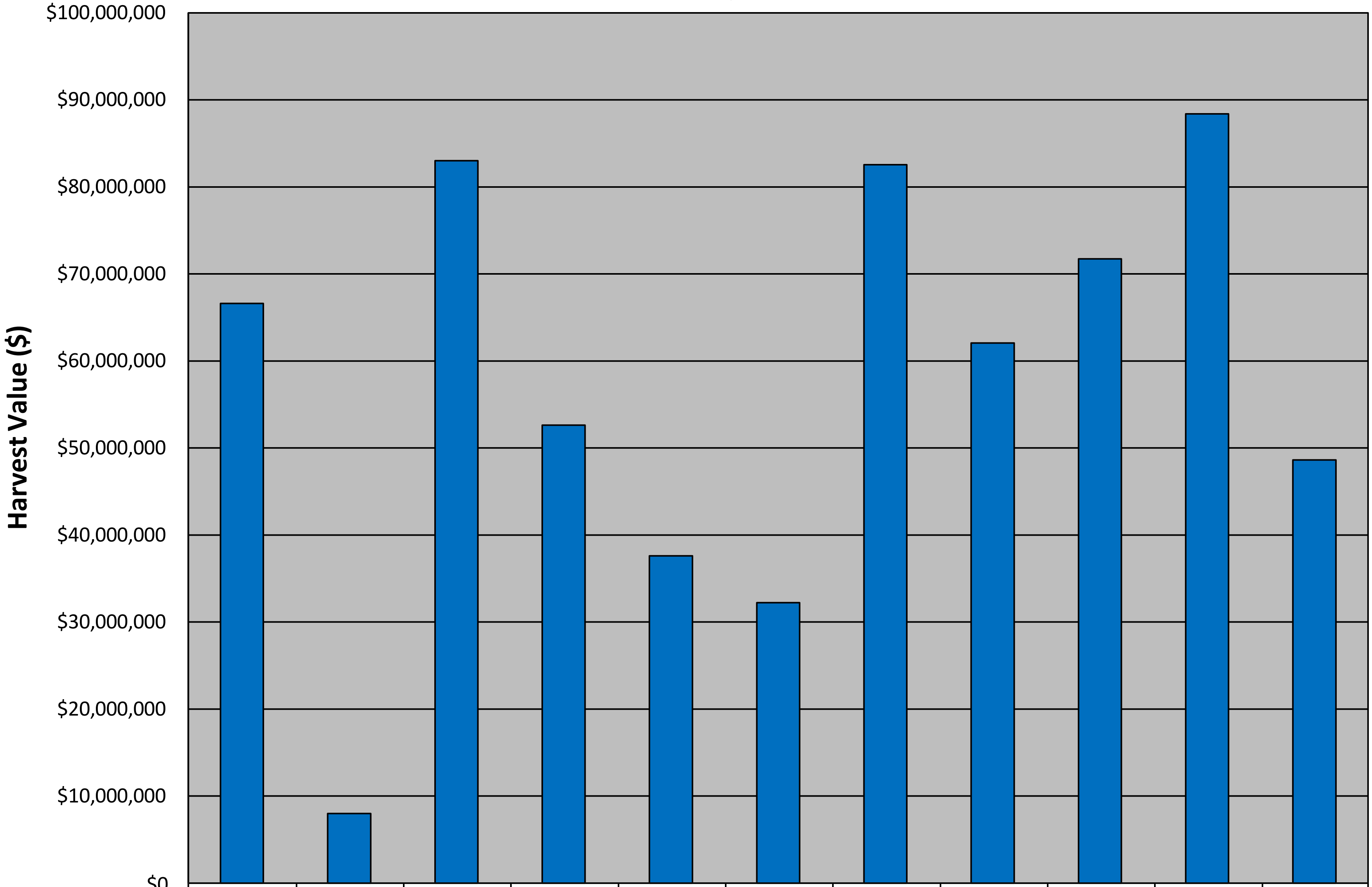
** DMR began collecting LPA harvest data in 2015.*

Harvest of Farm-Raised Marine Algae in Maine



	2015	2016	2017	2018	2019	2020
Marine Algae Harvest	14,582	24,004	45,023	53,564	280,612	497,146
Harvest Value				$37,897	$176,132	$301,285.60

Total Maine Aquaculture Harvest Value



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total Harvest Value	$66,602,539	$8,008,847	$83,003,459	$52,624,276	$37,612,339	$32,221,580	$82,550,294	$62,058,671	$71,750,076	$88,408,714	$48,638,549