

Analysis of the replication potential of aquaculture structures in wind farms: Analysis for the North Sea and potential application to Portugal

Dissertação para obtenção do Grau de Mestre em
Engenharia do Ambiente, perfil de Ordenamento do Território e Impactes Ambientais

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Presentation layout

- COEXIST project
- Problem definition and aims:
 - Demographic pressures
 - Coastal area activities
 - Marine Spatial Planning
 - Food: Aquaculture and Fisheries
 - Energy production: prediction
- Case studies
- Methodology:
 - FARM data requirements
 - Culture practice
 - Adopted layout for a possible aquaculture structure within Horns Rev I
 - Adopted layout for a possible aquaculture structure close to WindFloat
- Results and Discussion
- Conclusions
- Further Research
- Acknowledgements

COEXIST project

- **COEXIST** - Interaction in European coastal waters: A roadmap to sustainable integration of aquaculture and fisheries. FP7, Cooperation, Food, Agriculture and Fisheries, and Biotechnology
- Multidisciplinary project which aims at:
 - evaluate competing activities and interactions in coastal areas.
 - provide a roadmap to better integration, sustainability and synergies across the diverse activities taking place in the European coastal zone.
- **Thesis** - European context of contrasting systems: North/South: Denmark - Portugal
- Knowledge transfer
 - Physical conditions; water quality; aquaculture, energy
 - Aquaculture modelling, energy
- Objective: Evaluate the co-use of marine space for aquaculture within offshore wind farms

Co-use of wind farms for aquaculture: Simulation analysis for northern and southern Europe, and assessment of overall potential

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Introduction

Because of the increasing world population growing competition for resources is occurring, leading to a lack of food, space and energy & pressure on coastal environment. As a result, moving to offshore aquaculture and energy could be a solution.

Over-exploitation of marine resources and other demands on the marine ecosystem are compromising the future use of the ocean.

Conflicts in marine space occur as a result of on-going and future activities leading to the necessity of marine spatial planning (MSP).

Co-use of certain activities such as offshore wind energy, fishing and aquaculture, shipping and marine protected areas may be an option to ease demands on space, energy and food.

Aims

- Evaluate the co-use of marine space for aquaculture and offshore wind farms areas as an optimization strategy for marine space occupation;
- Determine the culture practice and evaluate the potential production of shellfish aquaculture co-use.

Methods

Approach

The "Plant, People, Profit" approach was used to analyse two contrasting systems, in Northern Europe and Southern Europe, for scenarios of shellfish monoculture within wind farms.

Select contrasting sites

Two contrasting systems, with different physical condition, water quality and cultured species (Fig. 1):

- A: Denmark (DK), North Sea - Høns Rev - Case study 1;
- B: Portugal (PT), Atlantic Ocean - WindFloat - Case study 2.

Data acquisition for water quality

- Denmark: data were extracted from the validated BS coastal hydrodynamic 3D circulation model;
- Portugal: data were collected from the International Council for the Exploration of the Sea (ICES) (<http://www.ices.dk>).

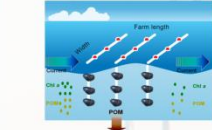
Tested species

- Mediterranean Mussel - *Mytilus galloprovincialis* (PT)
- Blue Mussel - *Mytilus edulis* (DK)
- Pacific oyster - *Crassostrea gigas* (DK and PT)

Model

- A dynamic model (FAFM - Farm Aquaculture Resource Management) was used to simulate shellfish growth (Fig. 2) in order to examine production, environmental impacts and economic viability.

Figure 1: Model conceptual diagram



Acknowledgements

The authors acknowledge financial support from the EU COEXIST Project. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007/2013) under grant agreement no. 246776. This publication reflects the views only of the author, and the European Union cannot be held responsible for any use which may be made of the information contained therein. We are grateful to Aquagem, Chosenberg and Pescaçã, Marine from DTU/Aqua for the access to Biscorn model.

Results

People - Production

- The harvestable biomass (TPP - Total Physical Product) was higher in case study 2 for the Mediterranean mussel production, in comparison with the production of blue mussels in the case study 1 (Fig. 3).
- Pacific oyster harvestable biomass was also higher in case study 2 (Fig. 4).

Figure 3: Mussel production of different densities in Denmark and Portugal

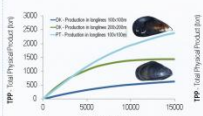
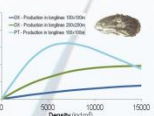



Figure 4: Oyster production of different densities in Denmark and Portugal



Profit - Marginal analysis

- FARM model provides data to carry a marginal analysis. An example is presented in Figure 5 for longline culture of blue mussel cultured for 550 days in case study 1 with different seeding densities.
- Profit maximization is based on marginal principles. Figure 5 indicates that maximum profit would occur for a seed density of 10 000 ind m², with an associated production of 235 tonnes per hectare. This high densities is comparable to other systems' but case studies have limitations in terms of physical carrying capacity.

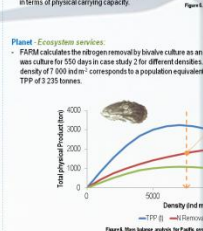
Figure 5: Marginal analysis for the most used longline on 2000m



Plant - Ecosystem services

- FARM calculates the nitrogen removal by bivalve culture as an ecosystem service. In Figure 6 Pacific oyster longline was cultured for 550 days in case study 2 for different densities. For instance, the nitrogen removal by oysters for a density of 100 000 ind m² corresponds to a population equivalent P/EQ of 19 488 individuals per year and an optimal TPP of 235 tonnes.

Figure 6: Nitrogen removal for Pacific oyster longline on 2000m



Discussion

Offshore aquaculture combined with other marine activities in particular energy systems, is a promising co-use according to the Brønnoerhus Declaration (2012), it has potential to bring global aquaculture production to a new level that contributes to future human needs and creates employment.

A legal framework to deal with offshore aquaculture is needed and should establish clear standards and thresholds, in order to harmonize sustainable aquaculture practices within different countries. The option of moving some activities offshore involves a sound marine spatial planning and requires active participation of all stakeholders.

Other conditions pose challenges for aquaculture production, due to strong waves and currents limiting access to sites and conditioning the culture structures to be fixed and not within the turbine areas. For these reasons, bivalves were appropriate species for the two case studies as opposed to fish, as they are fixed aquaculture.

Other challenges in co-use of marine space for aquaculture, and potential infrastructure and services, such as appropriate site selection in relation to distance to port, appropriate mooring technologies, permitting costs, safety, and insurance, need also to be addressed.

Conclusions

The different bivalve culture of mussels and oysters scenarios tested at both case studies, gave promising results for a one farm scenario of 10 kha. From a "People" and "Profit" perspectives, the optimal production between 500 - 3500 t y⁻¹ for 1 to 14 M€ y⁻¹ profit. From a "Plant" perspective, ecosystem service was provided by bivalves from the nutrient removal up to 10 500 P/EQ per year.

A scaling exercise to case study 1 (DK) would provide 210 000 P/EQ per year in a 80 turbines park, although this is assuming no food competition between the farms, and applying a large scale ecological modelling would address this issue.

References

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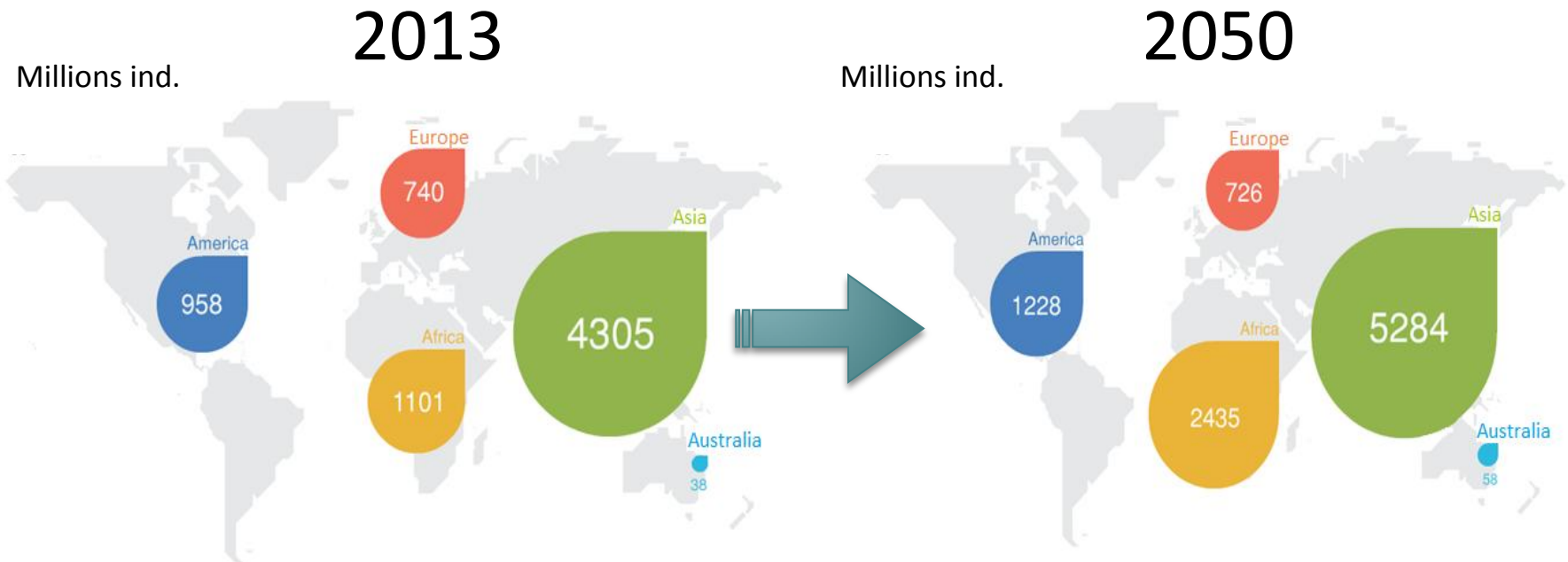
7. Ferreira, J.G., Saurer, C., Stenborg, C., Estanqueiro, A. (2015) *Journal of Applied Aquaculture* 27(2): 10-18.

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Problem definition

Population

- Current world population: 7.2 billion people
 - projected to increase by 1 billion over the next 12 years;
 - 9.6 billion people by 2050

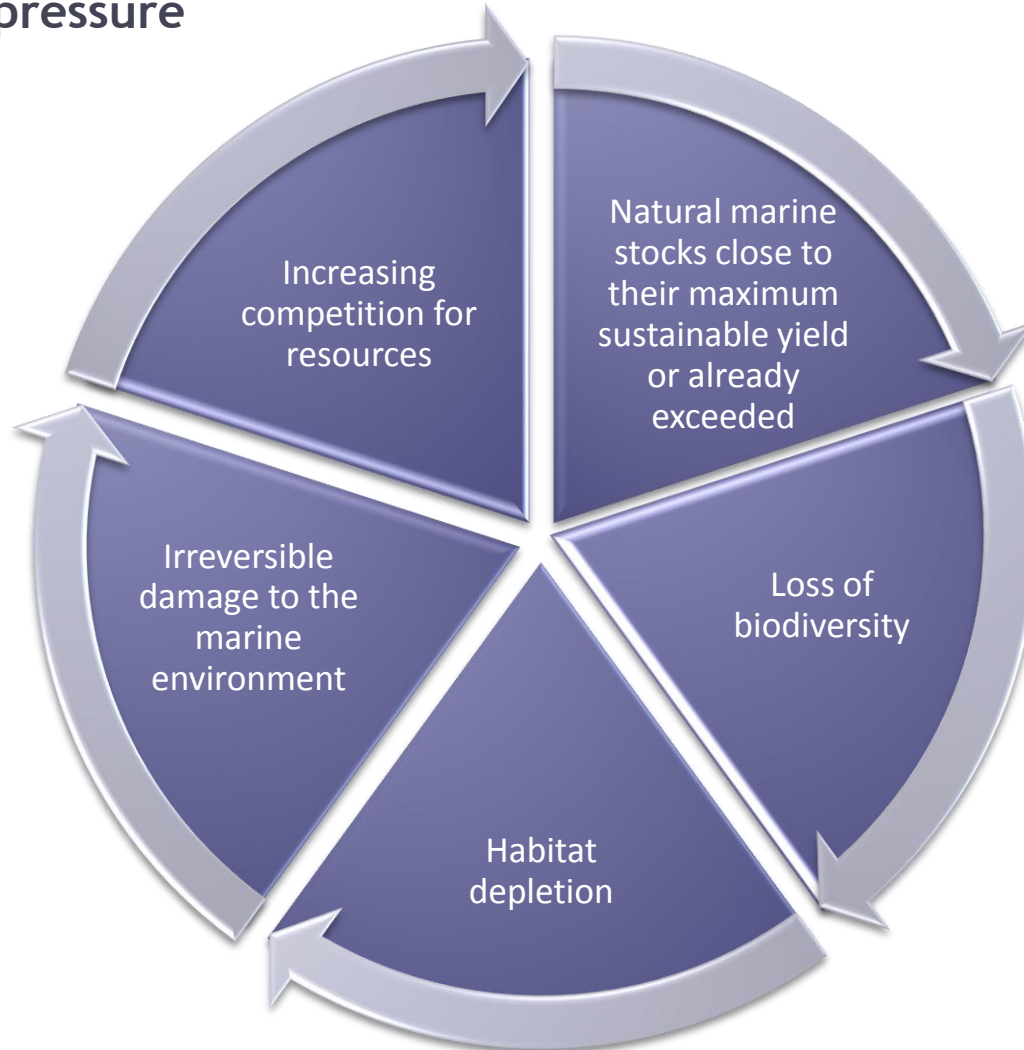


Coastal ecosystems are some of the most impacted and altered worldwide

"The key problem facing humanity in the coming century is how to bring a better quality of life without wrecking the environment entirely in the attempt." E.O. Wilson

Problem definition

Demographic pressure



These present exploitation patterns are unsustainable

Problem definition

Coastal area activities

- Resources exploitation, renewable energies and aquaculture are moving to the maritime space as a result of the competition for resources in European coastal areas.
- Offshore development has become a rising interest:
 - renewable energy sources, such as offshore wind farms and aquaculture integration
- Offshore wind projects and aquaculture could be co-locate:
 - fishing, and military manoeuvres can be combined in space, but not in time.



Activities in the coastal areas

"The sea, the great unifier, is man's only hope. Now, as never before, the old phrase has a literal meaning: we are all in the same boat"

Jacques Yves Cousteau

Problem definition

Marine Spatial Planning

- Increasing pressures on the maritime environment as a result of ongoing activities, coupled with:
 - expansion of new uses;
 - potential of conflicts between both;
 - necessity of Maritime Spatial Planning (MSP).
- These developments address:
 - Europe's 2020 strategy target of 20% of energy from renewable energy;
 - Development of aquaculture as a priority for:
 - conservation (protection of wild fish);
 - societal well-being (increase of fish consumption in Europe);
 - economics (over 70% of aquatic products are imported).



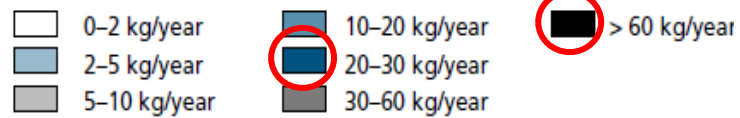
Cartoon from the Baltic Sea Plan:
 "Become a Maritime Spatialist Within 10 minutes"

"The sea, the great unifier, is man's only hope. Now, as never before, the old phrase has a literal meaning: we are all in the same boat"

Jacques Yves Cousteau

Problem definition

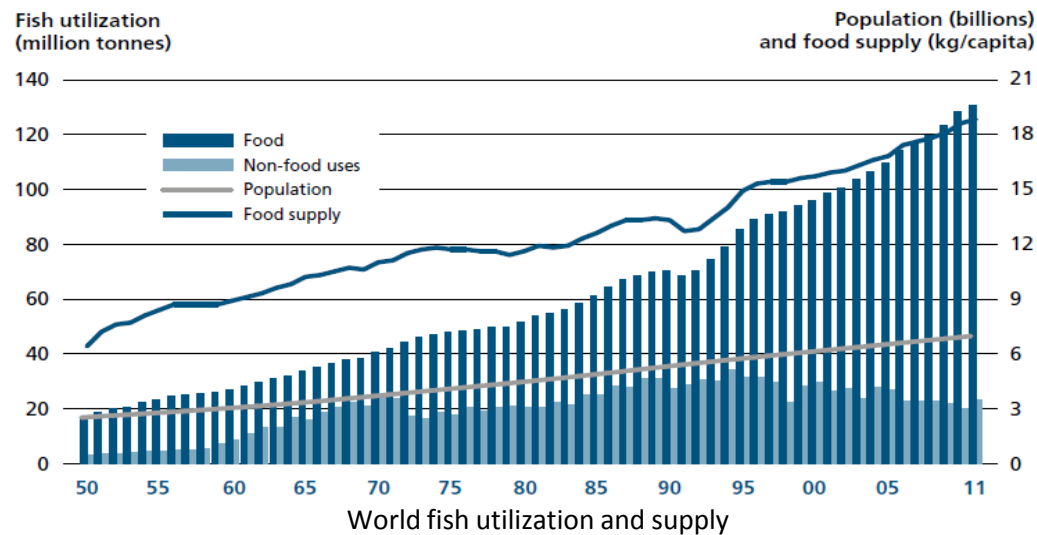
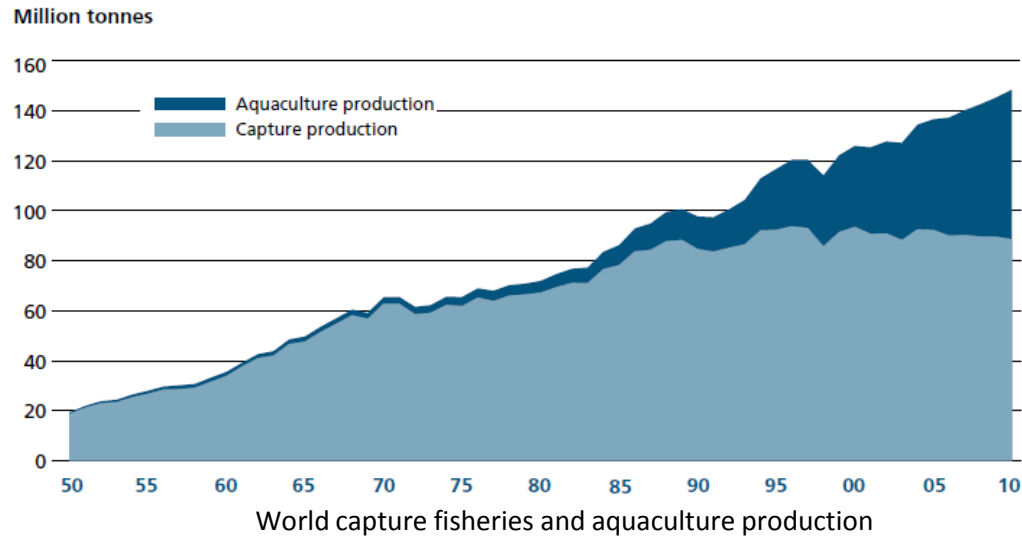
Aquatic products as food



Per capita supply (average 2007–2009)

Problem definition

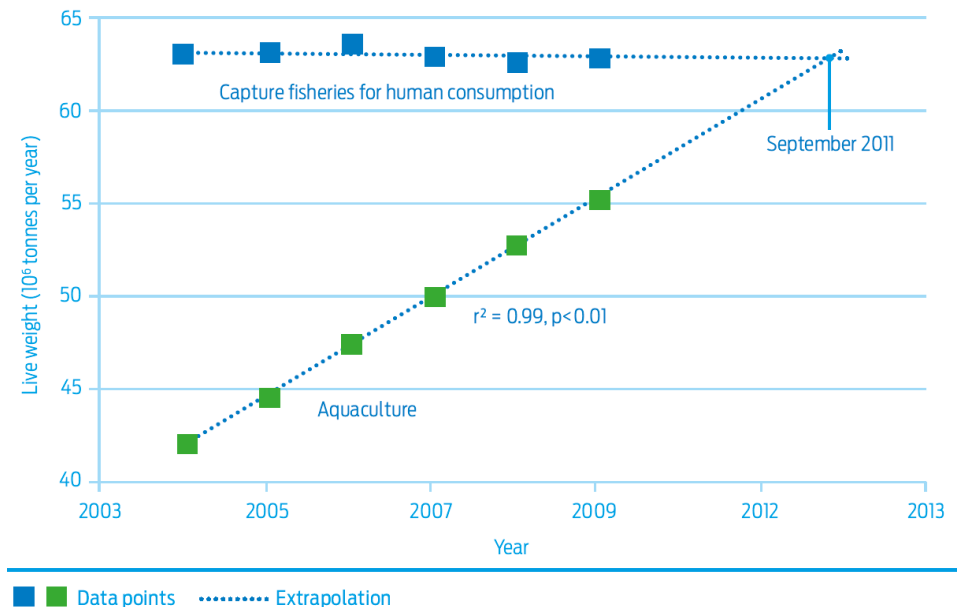
Aquaculture and Fisheries



Problem definition

Aquaculture and Fisheries

- Aquaculture and fisheries production:
 - two major activities interacting in the coastal area;
 - potential spatial and resource use conflicts, since they share two principal goals:
 - provide seafood protein mainly for human consumption and;
 - generate employment using the ocean as a common area.
- Aquaculture: annual production of 60 million tonnes, is equal in volume to capture fisheries.

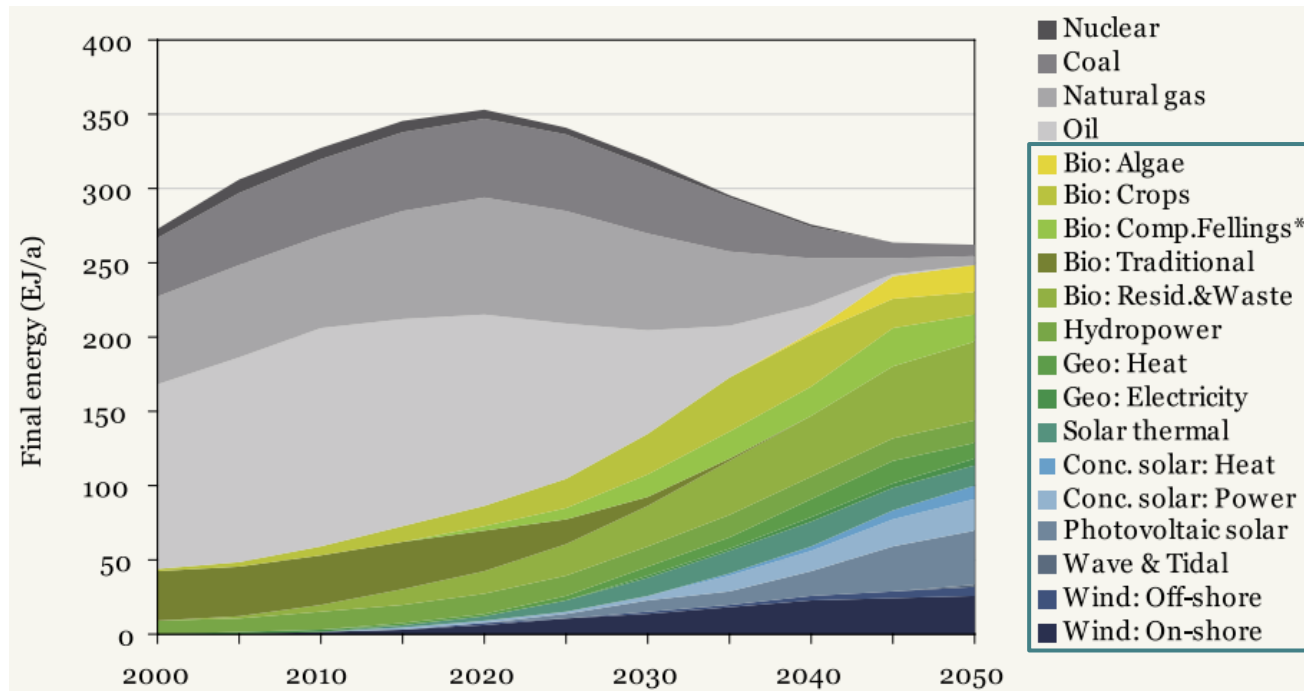


Projection of capture fisheries for human consumption and aquaculture

Problem definition

Energy production: prediction

- Increase by up to three times by 2050

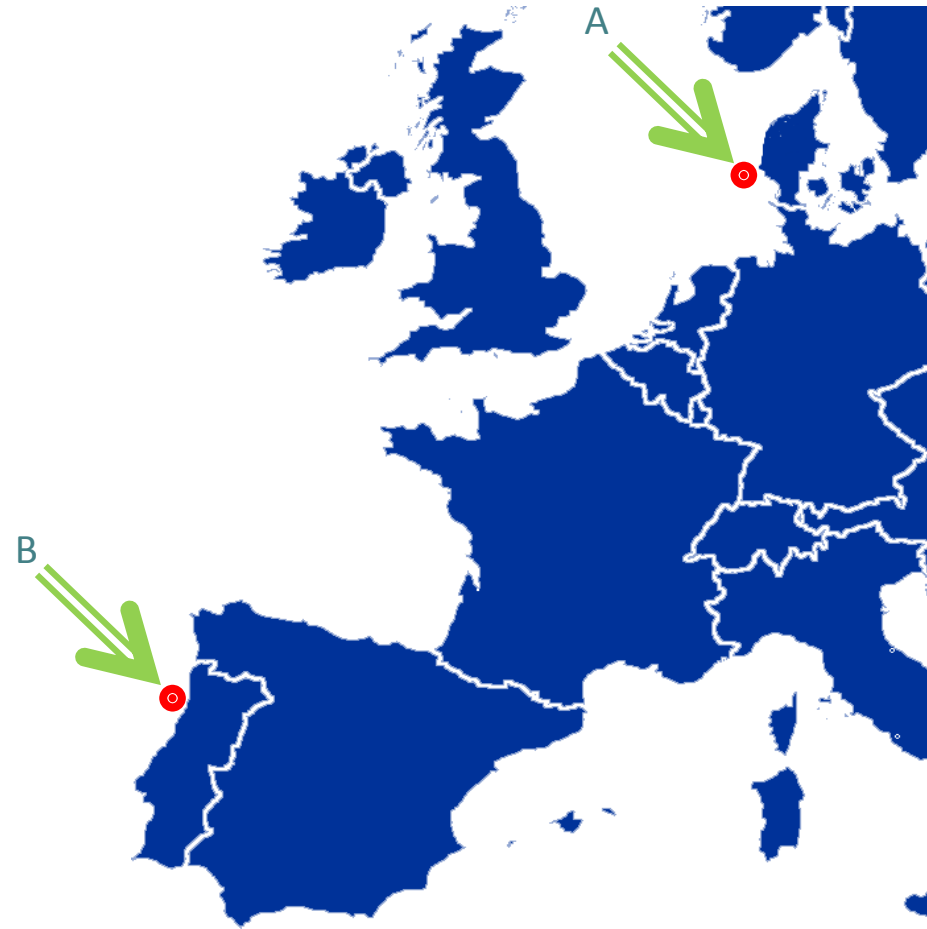


World energy supply by "The Ecofys Energy Scenario, December 2010"

Renewable energy will play a vital role in meeting this demand

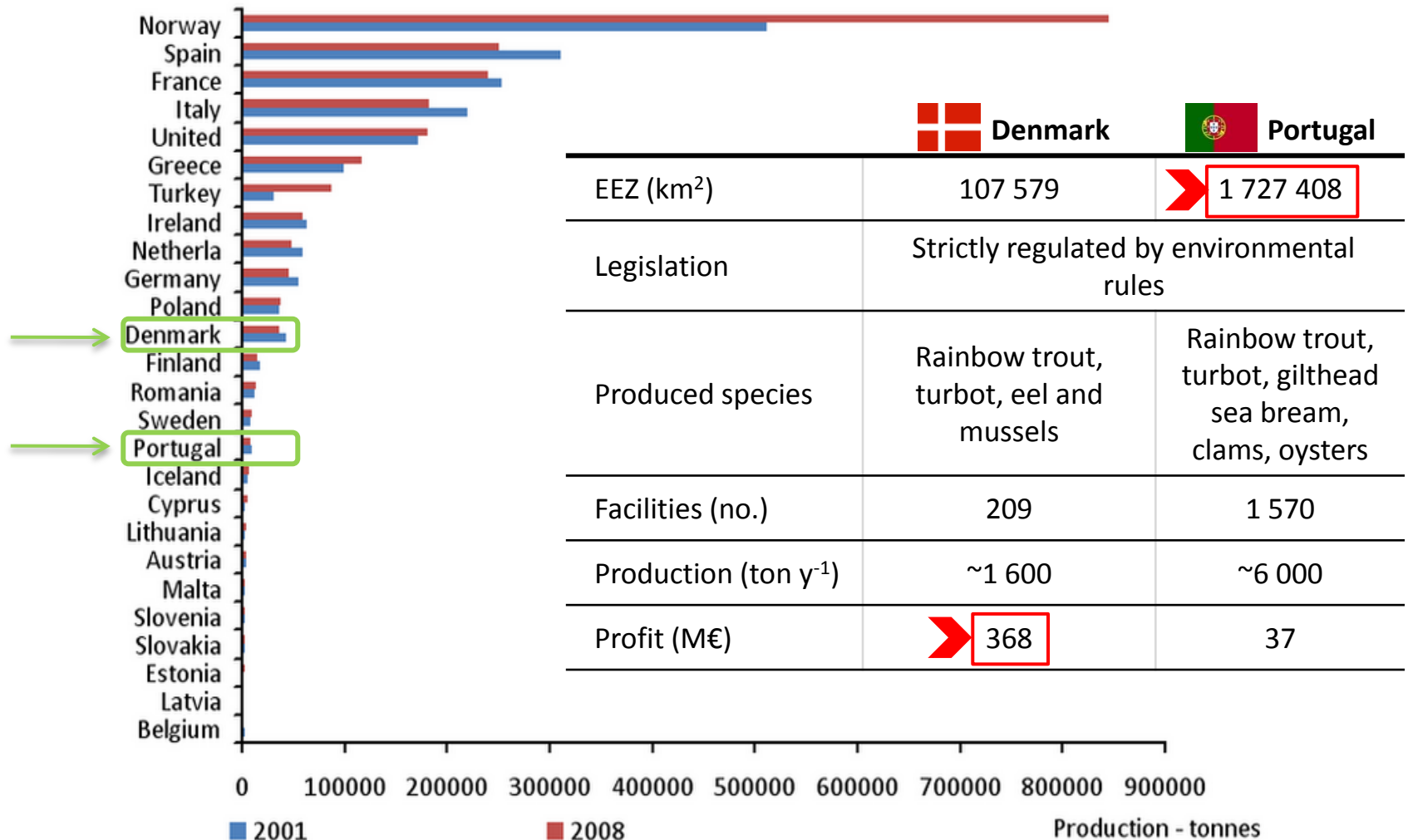
Aims

- Analyze two contrasting systems with different physical conditions, water quality and cultivated species:
 - A: Denmark (DK), North Sea – Horns Rev I;
 - B: Portugal (PT), Atlantic Ocean – WindFloat;
- Aquaculture: Apply a dynamic model to simulate shellfish growth, and examine production, environmental impacts, and economic viability and optimization;
- Determine the culture practice and evaluate the co-use of marine space for aquaculture within offshore wind farms.



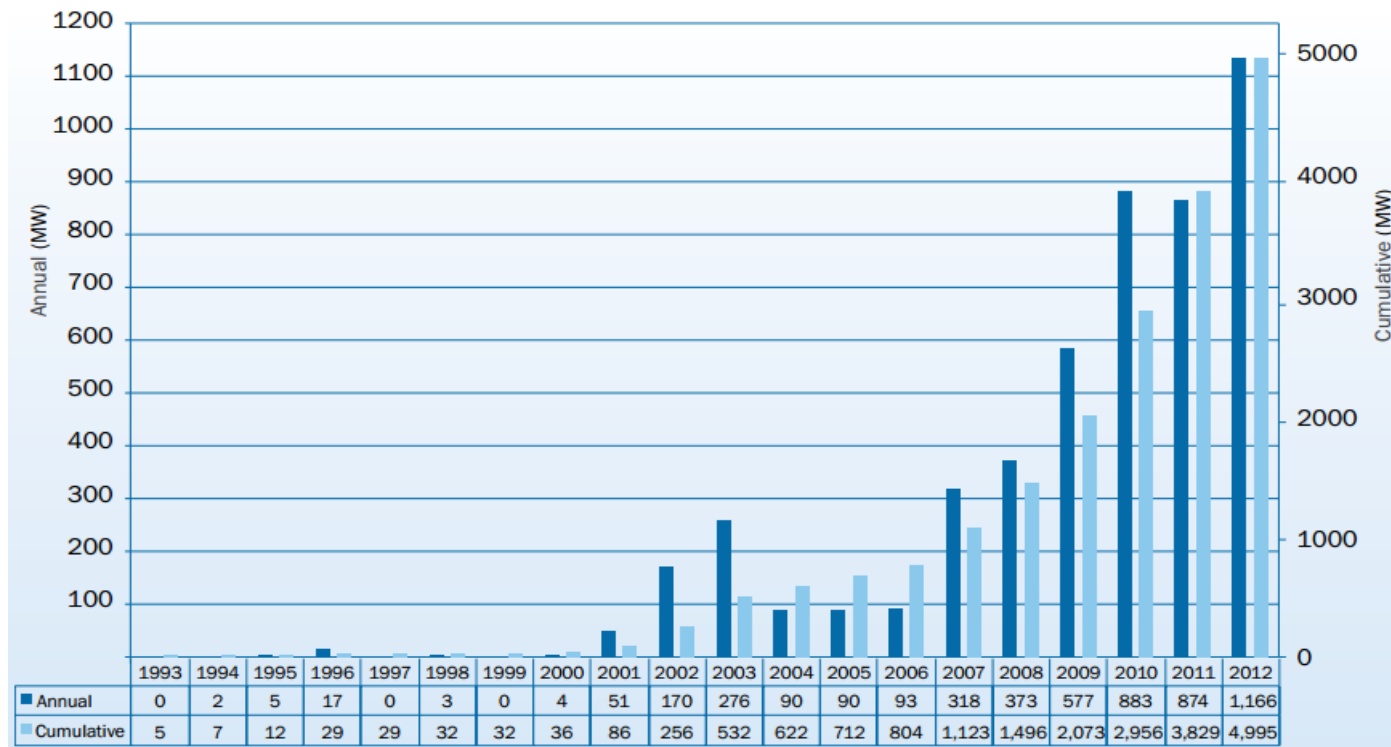
Location of both contrasting systems

Aquaculture in Europe



Annual aquaculture production by country, 2001 and 2008

Energy from offshore wind farms



Country	UK	DK	BE	DE	NL	SE	FI	IE	NO	PT	Total
No. of farms	20	12	2	6	4	6	2	1	1	1	55
No. of turbines	870	416	91	68	124	75	9	7	1	1	1,662
Capacity installed (MW)	2,947.9	921	379.5	280.3	246.8	163.7	26.3	25.2	2.3	2	4,995

Cumulative and annual offshore wind installations (MW)

Offshore wind farms: types

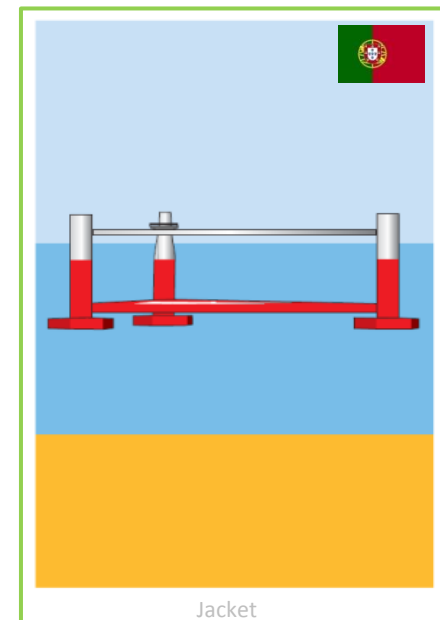
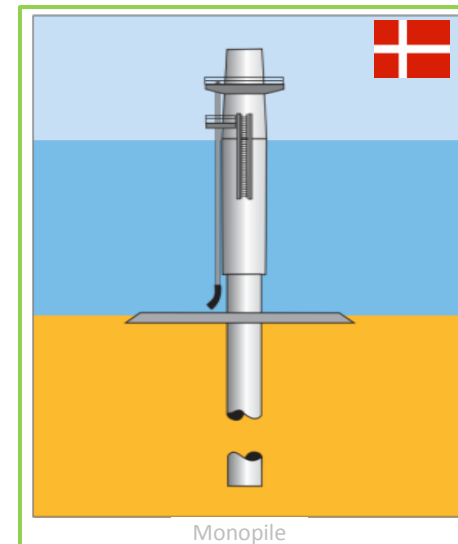
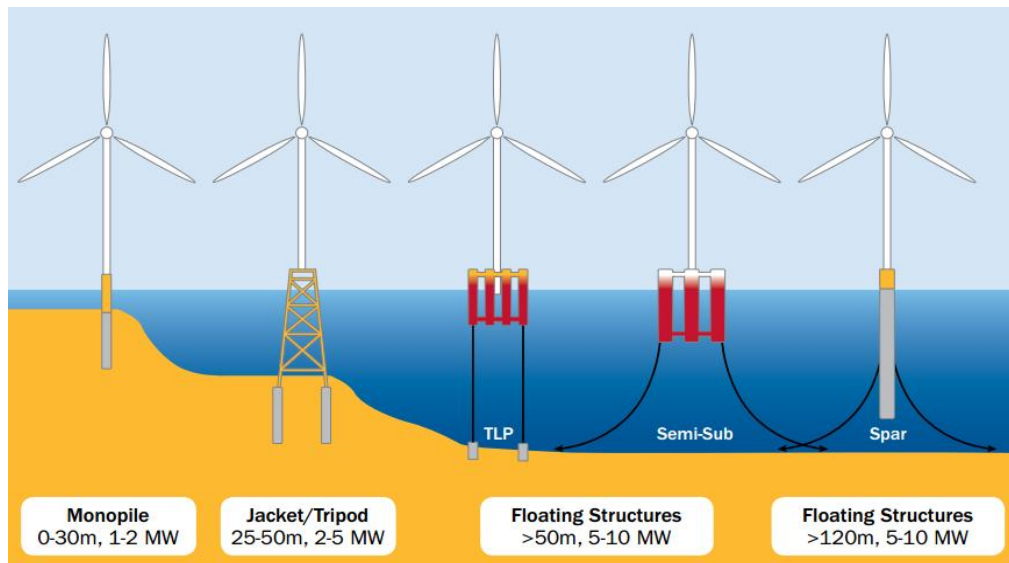
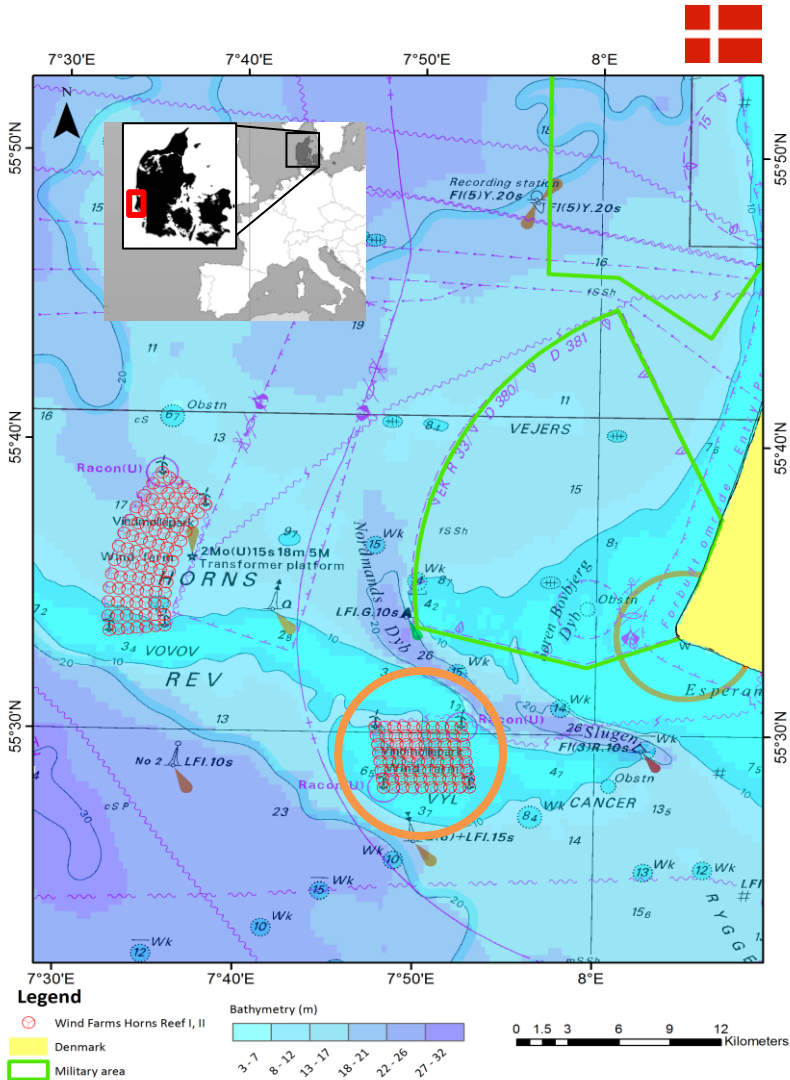
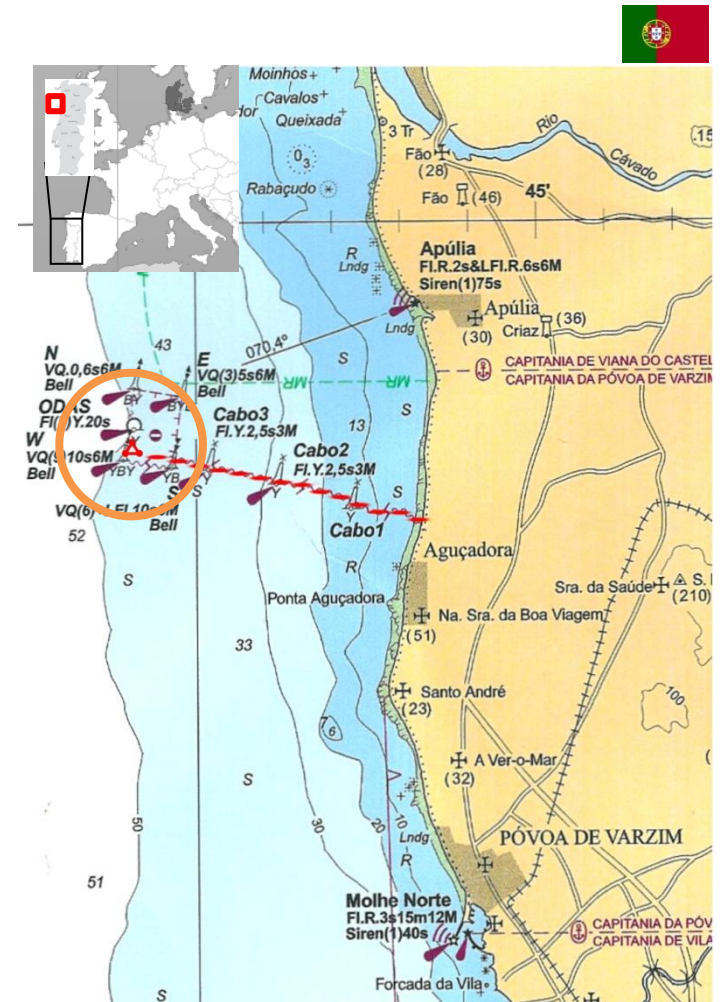


Figure 15 – Offshore wind foundations regarding the depth of water
Source: Arapogianni *et al.*, 2013

Offshore wind farms in case studies

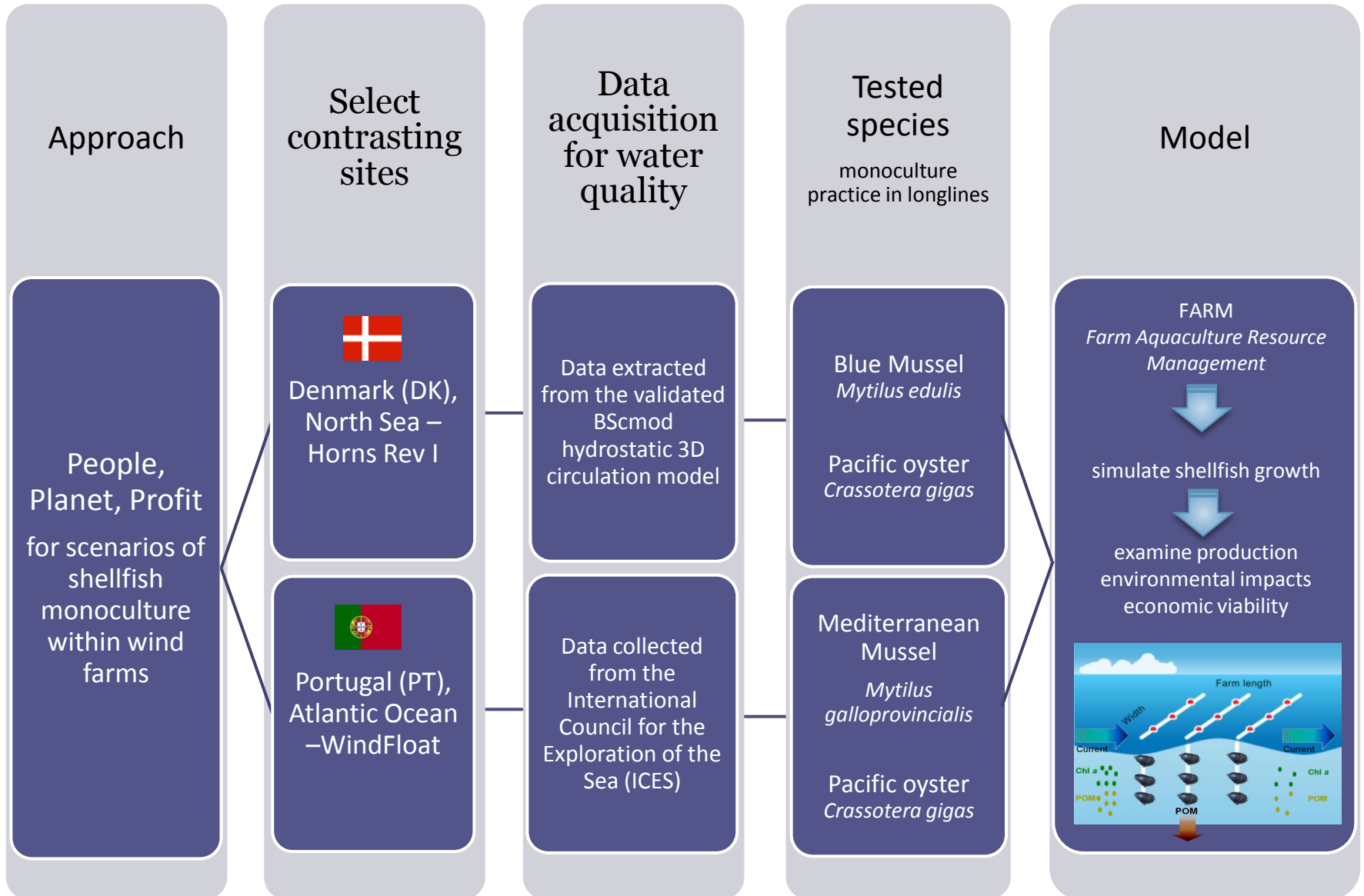


Horns Rev I – orange circle



WindFloat - orange circle

Methodology



Methodology

FARM data requirements

FARM - Farm Aquaculture Resource Management

Shellfish model live | Finfish model off | Run FARM | Exit

FARM drivers | FARM shellfish outputs | FARM shellfish mass balance

Farm layout

Farm location 30° 0' North
 Length (m) 3000 | Depth (m) 10.0
 Width (m) 20 | Nº Boxes 3

Culture structures

Bottom culture Trestles
 Longlines Rafts
 Other
 Intertidal culture Height above datum 1.0

Drivers

Load model | Save model

	A	B	C	D	E	F	G	H	I	J	K
1	Julian day	Temperature (oC)	Salinity (-)	Chlorophyll a (ug L-1)	POM (mg L-1)	TPM (mg L-1)	Dissolved oxygen (mg L-1)	DIN (umol L-1)	Wind speed (m s-1)		
2											
3	15	7	35	2	4	15	8	10	2		
4	75	12	35	3	5	12	7,5	9	2		
5	135	16	35	10	7	16	6	4	2		
6	195	20	35	5	2	20	6,5	1	2		
7	255	14	35	8	6	25	8	7	2		
8	305	10	35	3	8	15	8,5	8	2		

Environment

Peak current at spring tide (m s-1) 0.20
 Peak current at neap tide (m s-1) 0.10
 Spring tidal range (m) 3.0
 Neap tidal range (m) 2.0
 Mid-tide height above datum (m) 2.0
 Use wild species
 Wild species density (ind. m-2) 100
 Wild species filtration rate (L h-1) 1.5

Semi-diurnal tide
 Current inverts with tide
 Use seaweed fouling

Shellfish economics and finance

Seed cost per kg (USD) 1.00
 Sale price per kg (USD) 5.00

Shellfish cultivation

Species AquaShell Pacific oyster | Culture period (days) 365
 Mortality (percent cycle-1) 10 | First seeding day 1
 Seed weight TFW (g) 0.65 | Seed length (cm) -
 Harvest weight TFW (g) 90.00 | Harvest length (cm) -

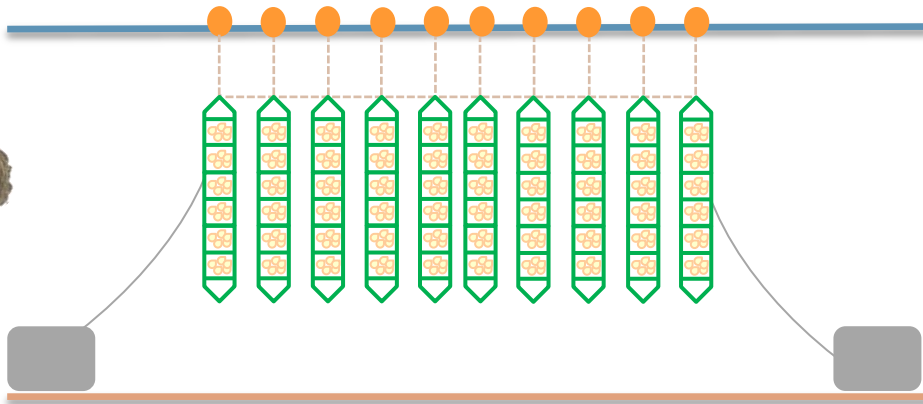
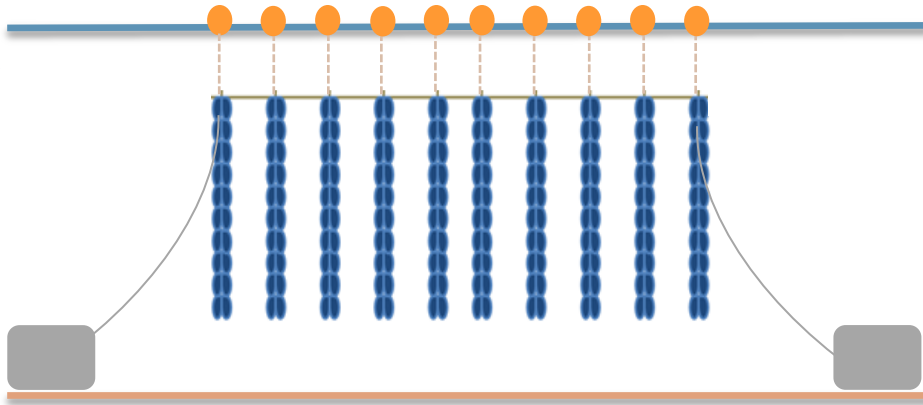
Biodeposition

Biodeposit diameter (mm) 0.0156
 Sinking speed (cm s-1) 0.0173

Smaller | Larger
 6 5 4 3 2 phi

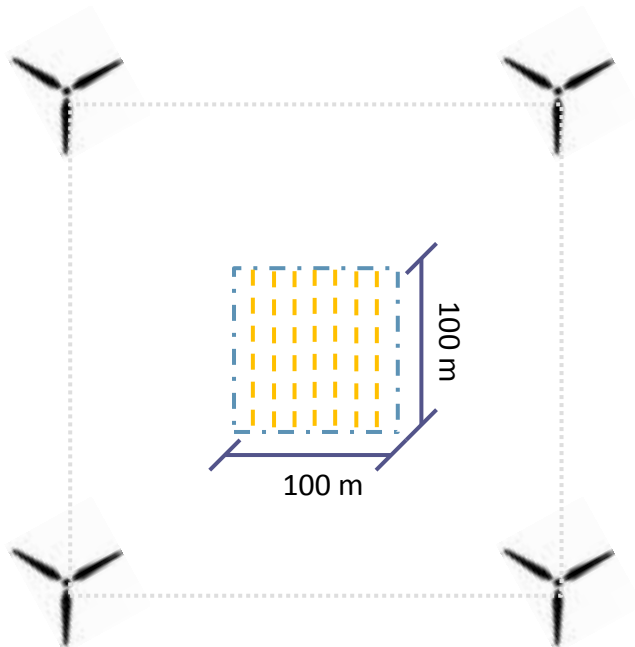
Methodology

Culture practice

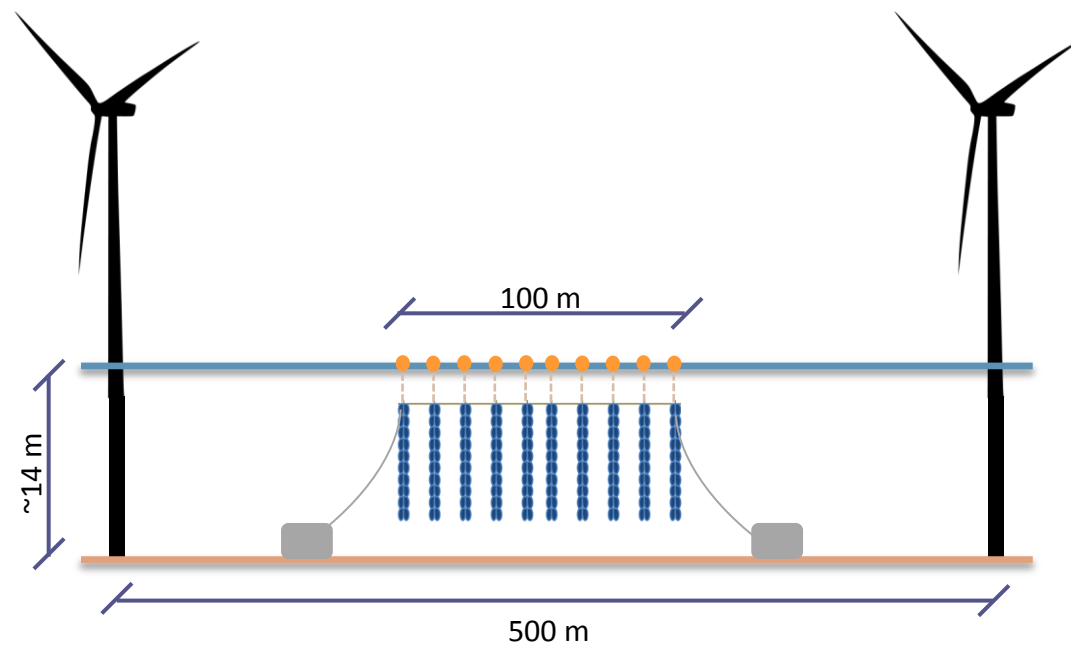


Methodology

Adopted layout for a possible aquaculture structure within Horns Rev I

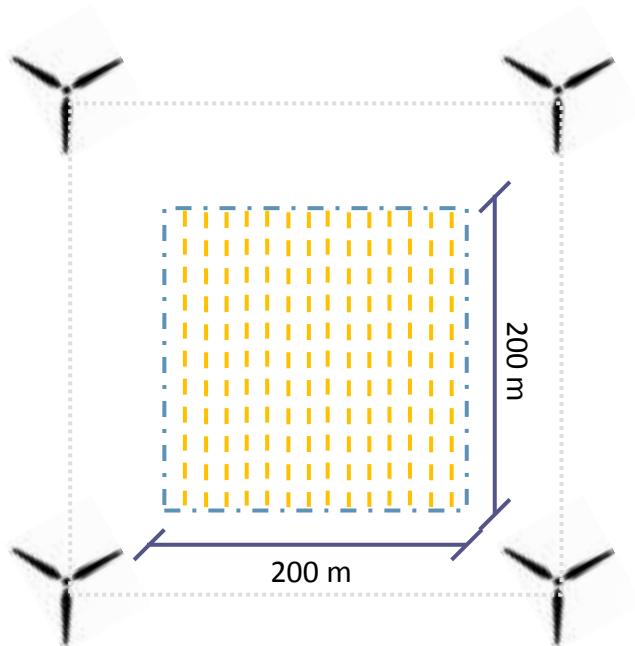


Aquaculture area: 1 ha

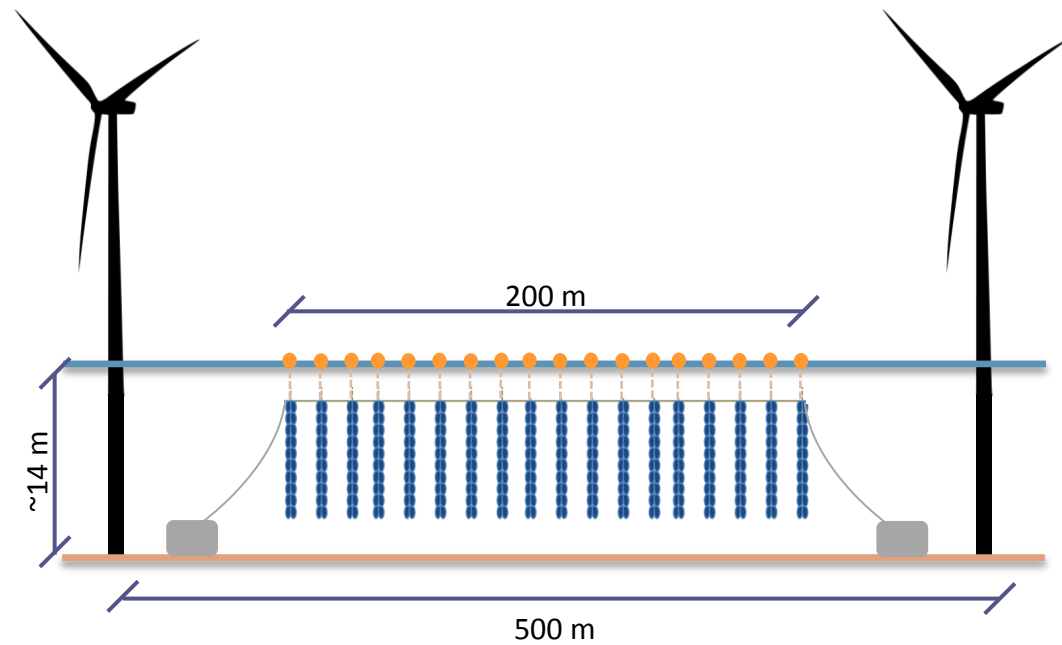


Methodology

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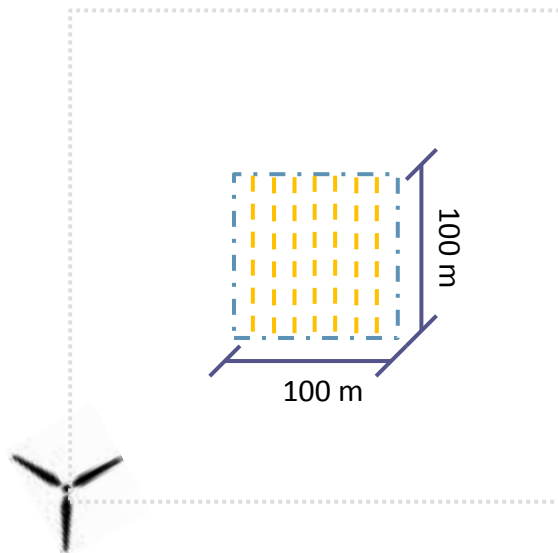


Aquaculture area: 4 ha

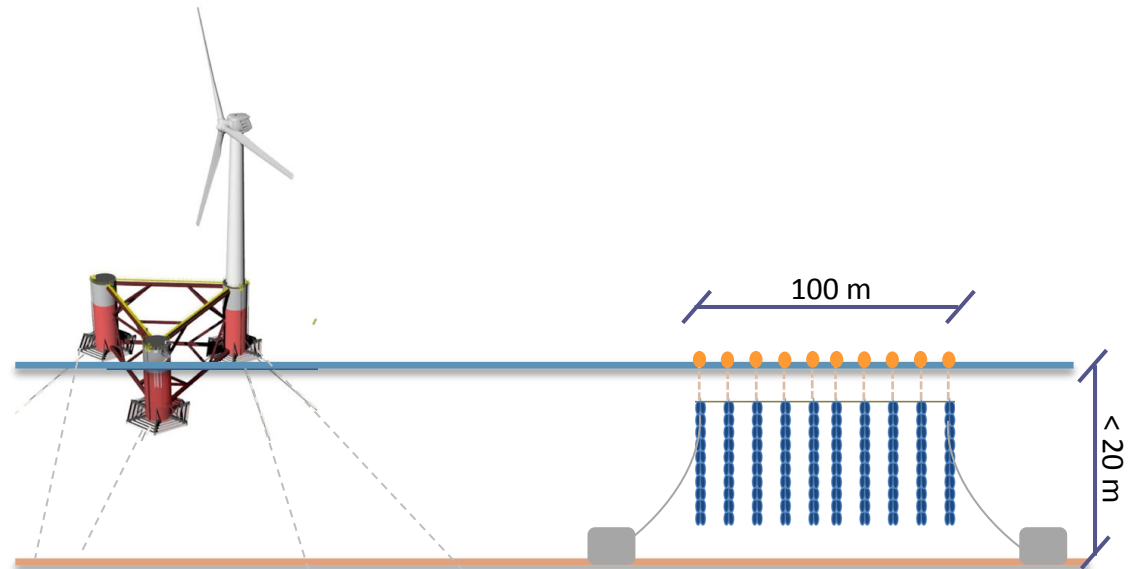


Methodology




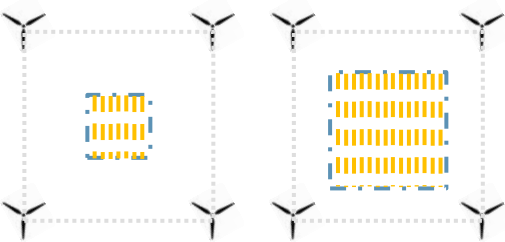



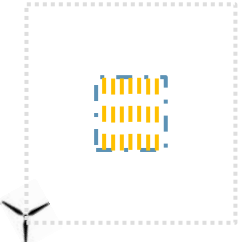
Adopted layout for a possible aquaculture structure close to WindFloat



Aquaculture area: 1 ha

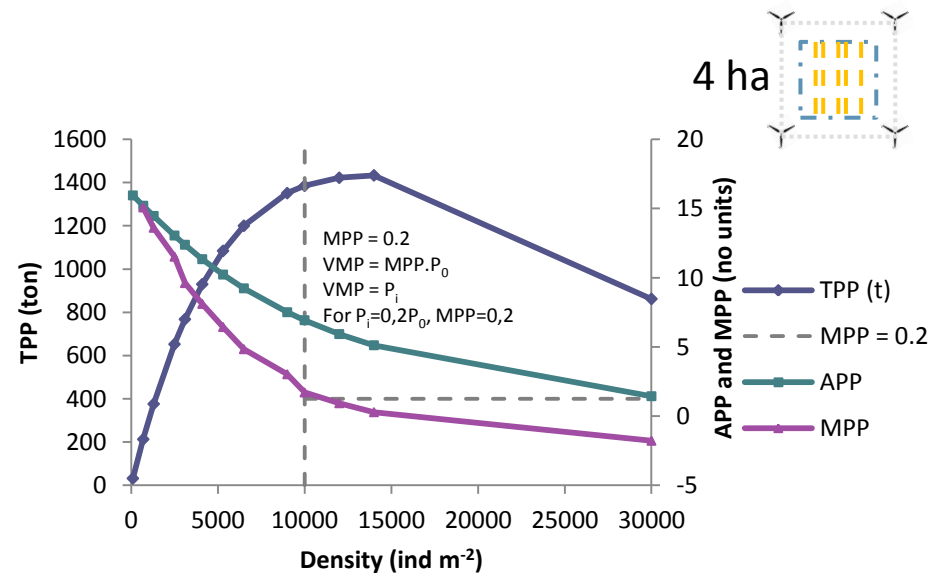
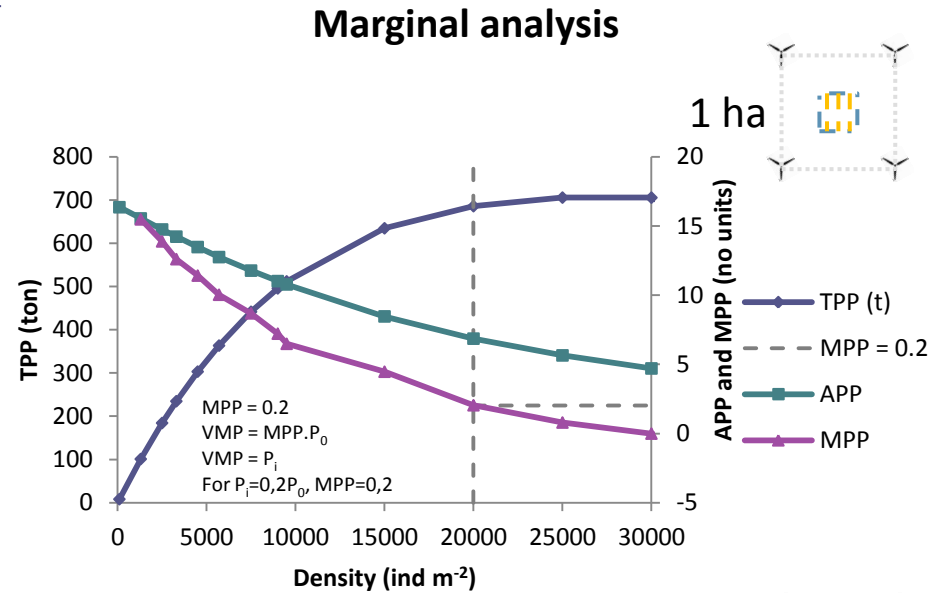
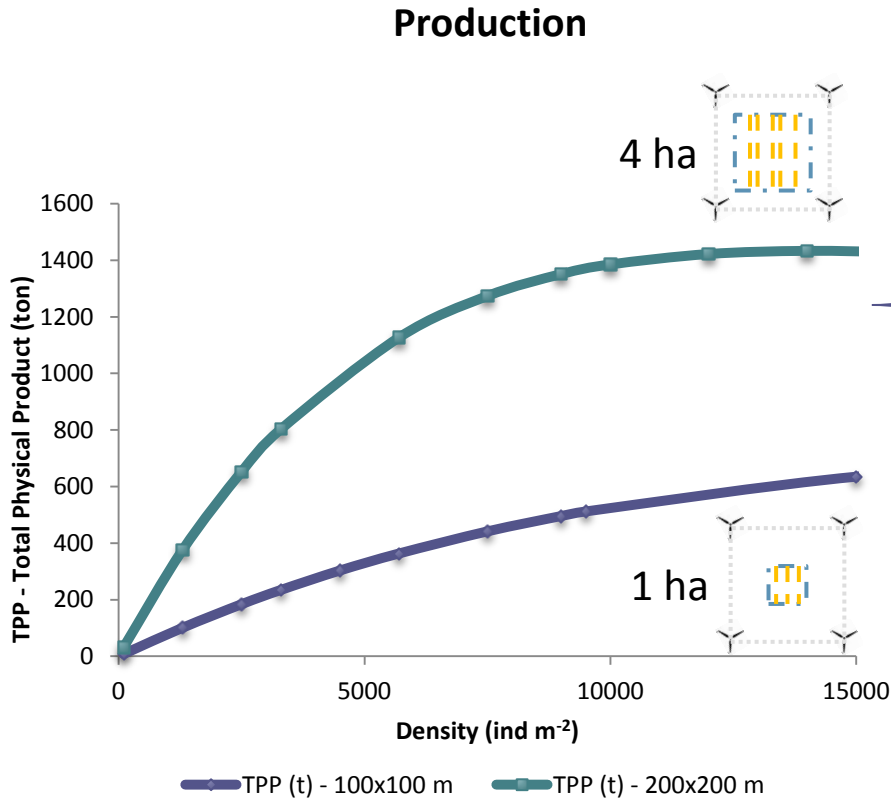


Results and Discussion

	Culture practice:	Drivers	Results
 Denmark:  blue mussel  Pacific oyster	<p>Case 1: 1 ha Case 2: 4 ha</p> 	<p>From model, only 1 scenario</p>	<p>Production</p> <p>Marginal analysis</p>
 Portugal:  Med. mussel  Pacific oyster	<p>1 ha</p> 	<p>Case 1: TPM = 2 mg l⁻¹ POM = 8 mg l⁻¹</p> <p>Case 2: TPM = 10 mg l⁻¹ POM = 16 mg l⁻¹</p>	<p>Mass balance</p>

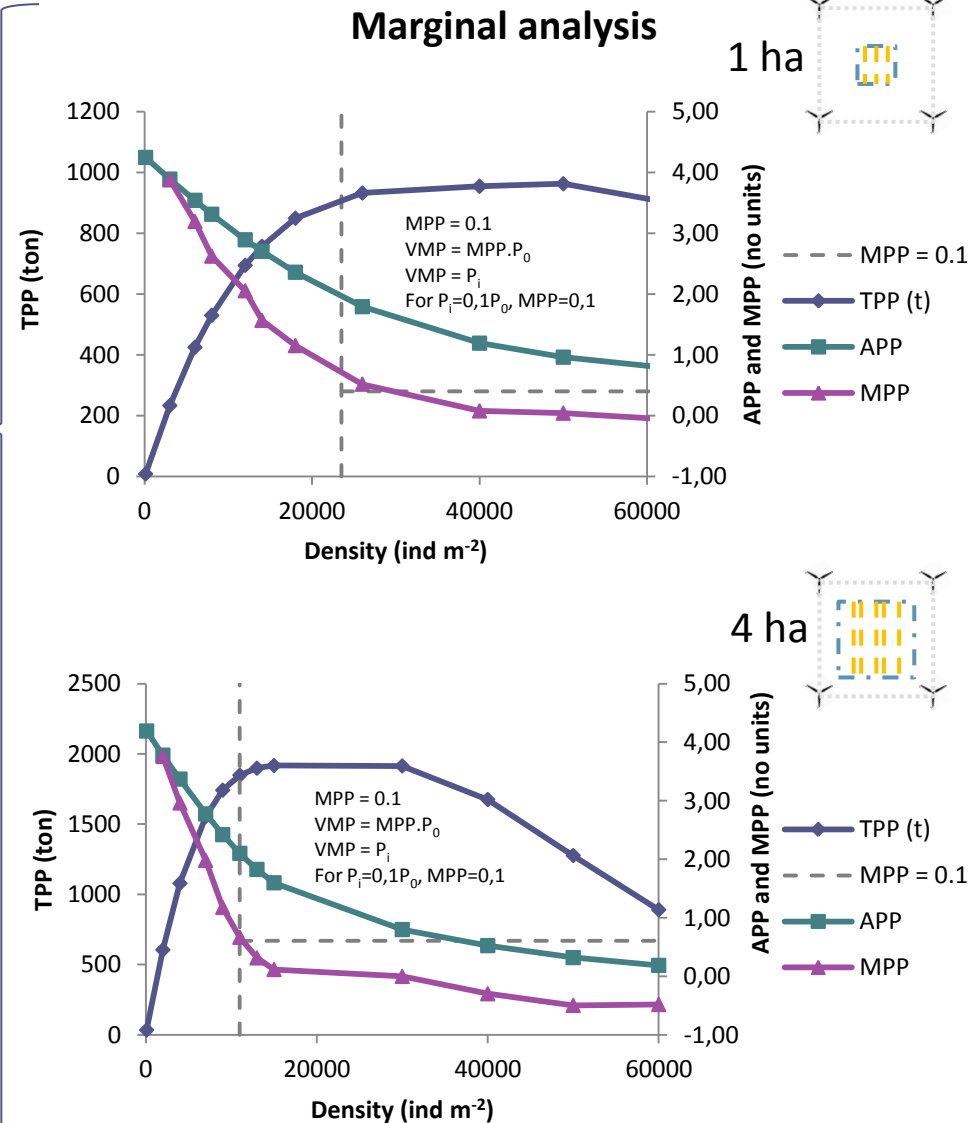
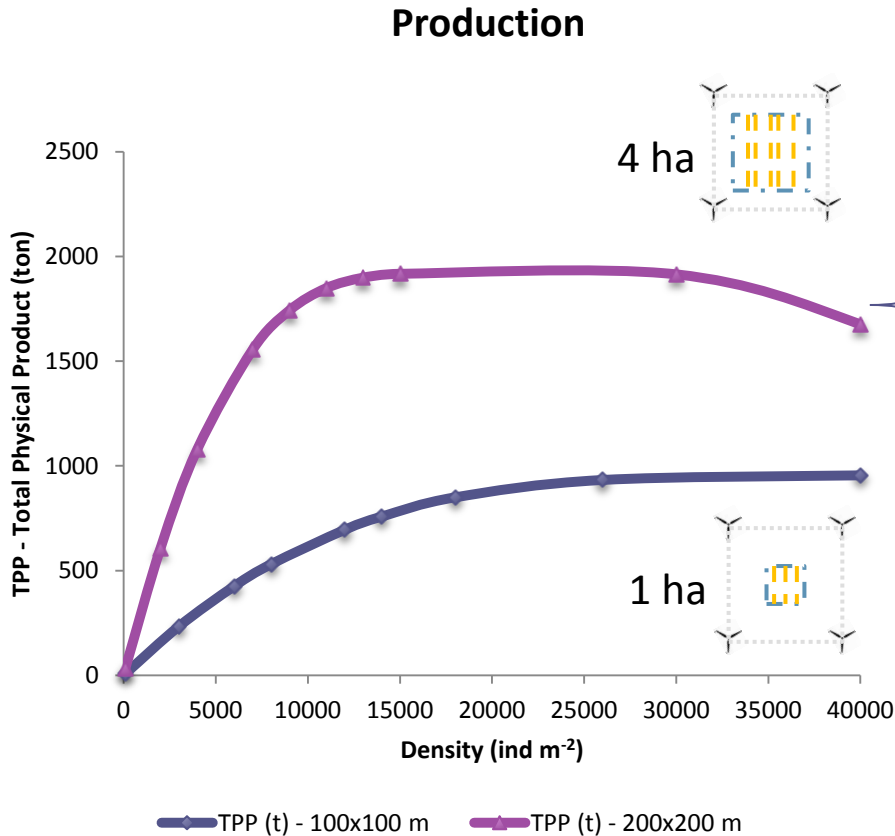


Denmark: blue mussel





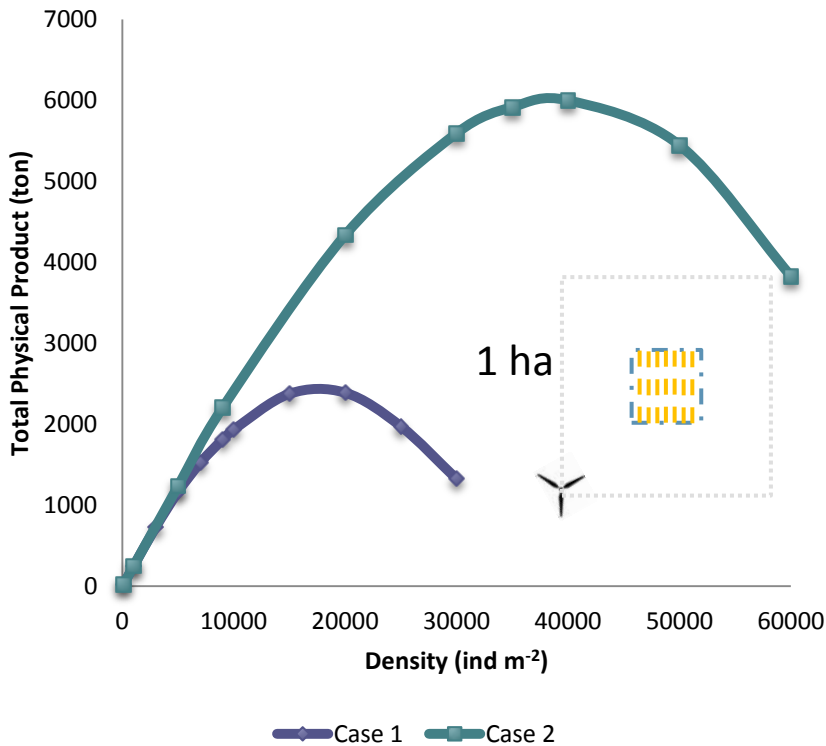
Denmark: Pacific oyster





Portugal: Mediterranean mussel

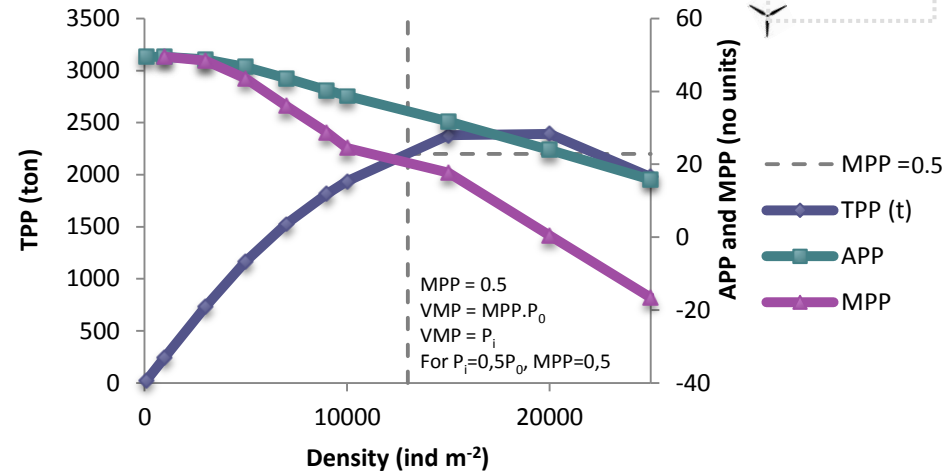
Production



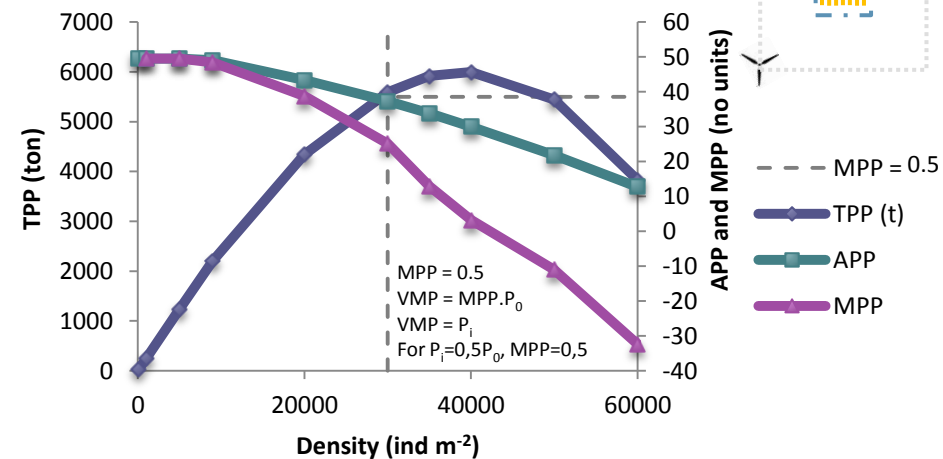
Case 1: TPM = 2 mg l⁻¹ - POM = 8 mg l⁻¹

Case 2: TPM = 10 mg l⁻¹ - POM = 16 mg l⁻¹

Marginal analysis



C1

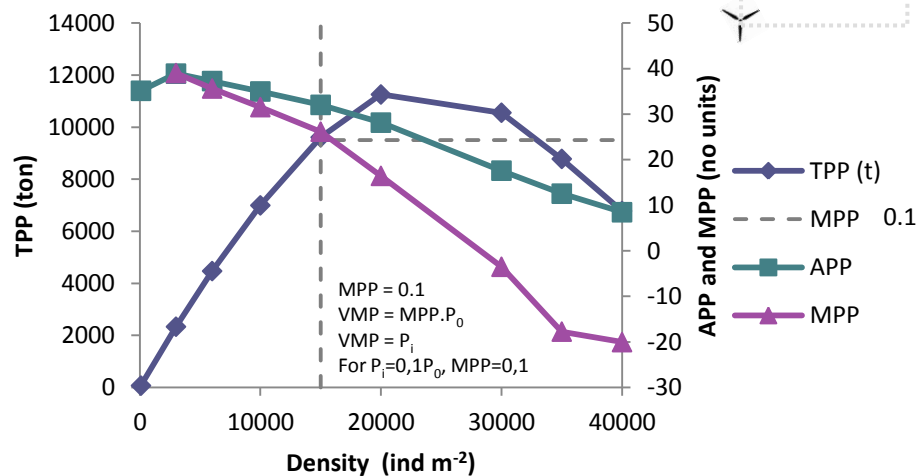
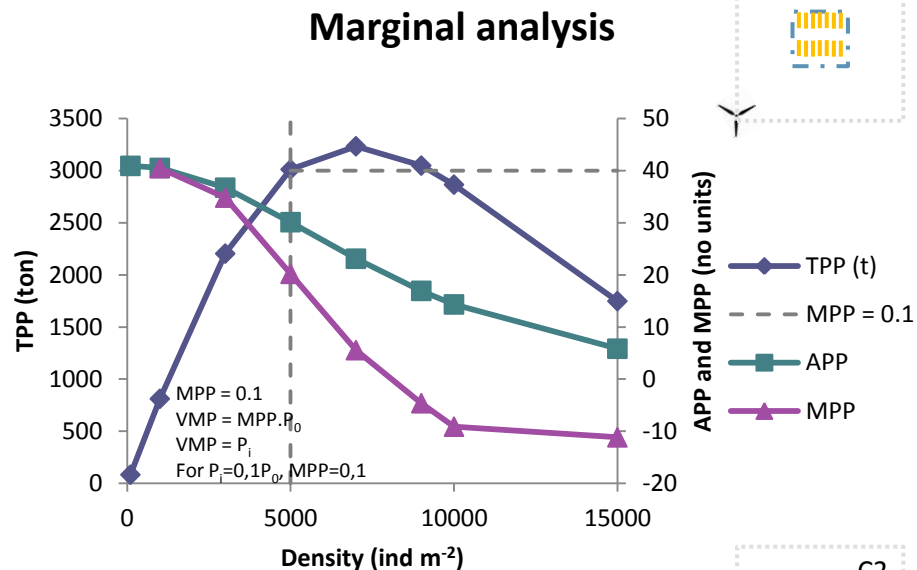
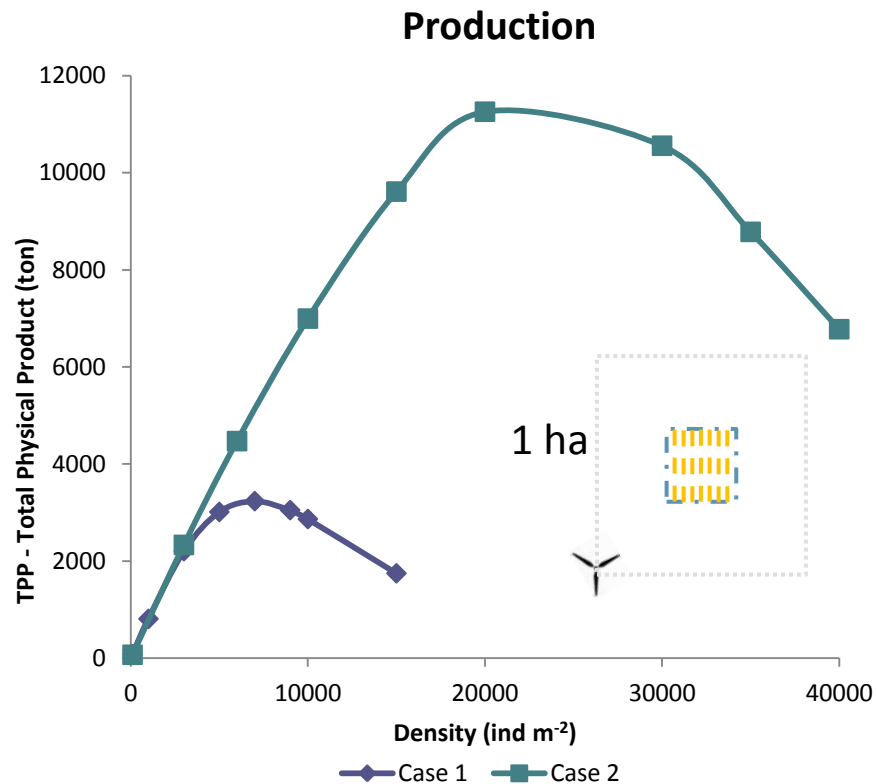


C2





Portugal: Pacific oyster



Mass balance



Denmark: blue mussel



Shellfish
filtration

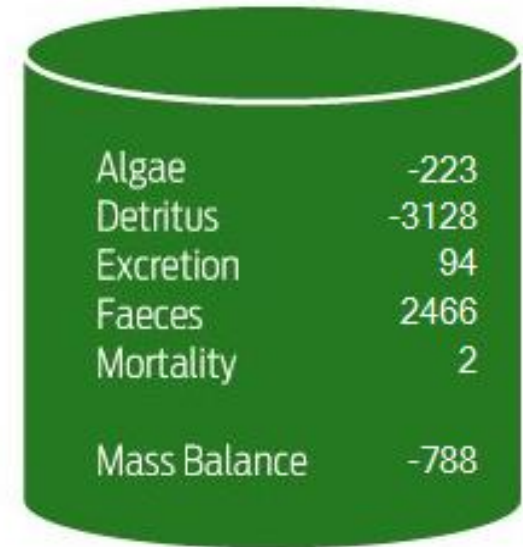
Phytoplankton removal
1431 kg C y⁻¹

Detritus removal
20106 kg C y⁻¹

Population equivalents (PEQ)
239 PEQ y⁻¹

N removal (kg y⁻¹)

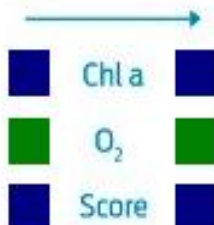
1 ha



ASSETS

INCOME

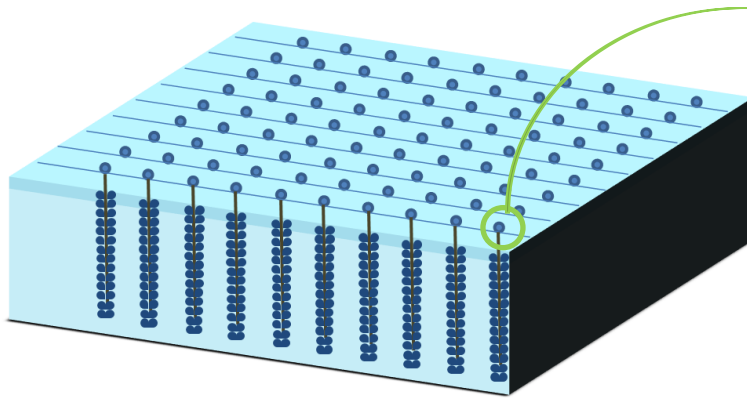
PARAMETERS



SHELLFISH FARMING INCOME: 27.1 k\$ y⁻¹
 NUTRIENT TREATMENT: 9.6 k\$ y⁻¹
 TOTAL INCOME: 36.7 k\$ y⁻¹

DENSITY: 100 ind.
 CULTIVATION PERIOD: 550 days

Results and Discussion



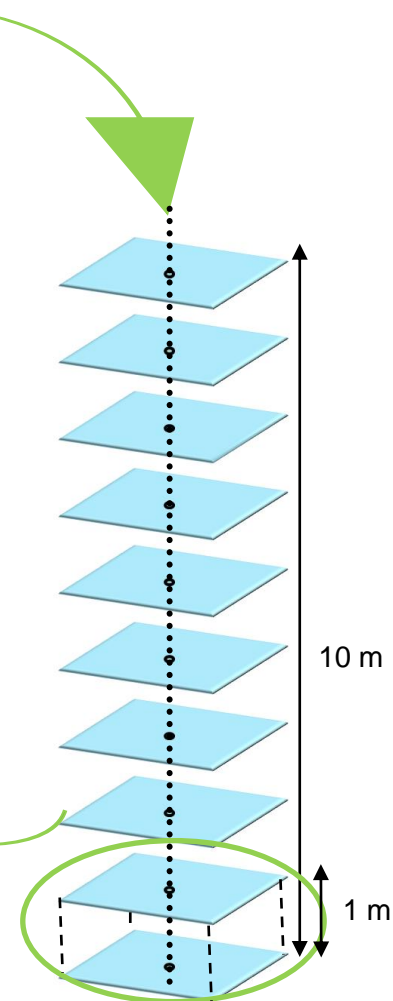
Seeds density for blue mussel culture: $10\,000\text{ ind. m}^{-2}$

→ In 1ha: $10 \times 10^7\text{ ind.}$ => 100 longlines

→ 1 longline: $10 \times 10^5\text{ ind.}$

→ 1 rope (10 m): $2 \times 10^4\text{ ind.}$

→ **1 m of rope: 2 000 ind.**



Seeds density description

Results and Discussion

- The harvestable biomass (TPP – Total Physical Product) was higher for the Mediterranean mussel production, in comparison with the production of blue mussels;
- Pacific oyster harvestable biomass was also higher in WindFloat location
- Profit maximisation is based on marginal principles:
 - For a seed density of 10 000 ind m⁻², with an associated production of 228 tonnes per hectare the maximum profit would occur.
- Used high densities are comparable to other systems but care should be taken in terms of physical carrying capacity
- FARM calculates the nitrogen removal by bivalve culture as an ecosystem service:
 - Nitrogen removal by oysters for a density of 7 000 ind m⁻² corresponds to a population equivalent (PEQ) of 10 488 inhabitants per year and an optimal TPP of 3 235 tonnes.

Conclusions I

- New developments of activities in the coastal area and offshore generates competition for space:
 - increase emergency in the development and application of MSP.
- Offshore aquaculture combined with other marine activities in particular energy systems, is a promising co-use;
- Aquaculture is currently under the spotlight as a possible solution to feed the growing world population in protein.

Conclusions II

- The different bivalve culture of mussels and oysters scenarios tested at both case studies gave promising results for a one farm scenario of 1 to 4 ha.
- From a “People” and “Profit” perspective, the optimal production was between 500 – 3500 t y⁻¹ for 1 to 14 M€ y⁻¹ profit. From a “Planet” perspective, ecosystem service was provided by bivalves from the nutrient removal up to 10 500 PEQ per year.
- A scaling exercise to case study 1 (DK) would provide 210 000 PEQ per year in a 80 turbines park, although this is assuming no food competition between the farms, and applying a large scale ecological modelling would address this issue.

Conclusions III and Further research

- Co-use of offshore wind farms and aquaculture integration has led to a growing interest in this field of research and the results of this work suggest that a pilot structure of co-use is needed in order to:
 - get measured data to validate the production results obtained with FARM model;
 - stakeholders opinions and availability to develop new co-use should be evaluated such as the demonstration of economic profitability.
- Other challenges in co-use of marine space for aquaculture, and potentially infrastructures and services, such as appropriate site selection in relation to distance to port, appropriate mooring technologies, permitting costs, safety, and insurance, need also to be addressed.

Acknowledgements

- Financial support from the EU COEXIST Project. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 245178.
- Claus Stenberg, Asbjørn Christensen and Patrizio Mariani from DTU Aqua for the access to Bscmod model.
- Dr.^a Ana Estanqueiro from LNEG for the access of information about offshore wind energy in Portugal.
- Dr. João Gomes Ferreira and Dr.^a Camille Saurel

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 245178. This publication reflects the views only of the author, and the European Union cannot be held responsible for any use which may be made of the information contained therein.

Thank you!



Obrigada pela vossa atenção!