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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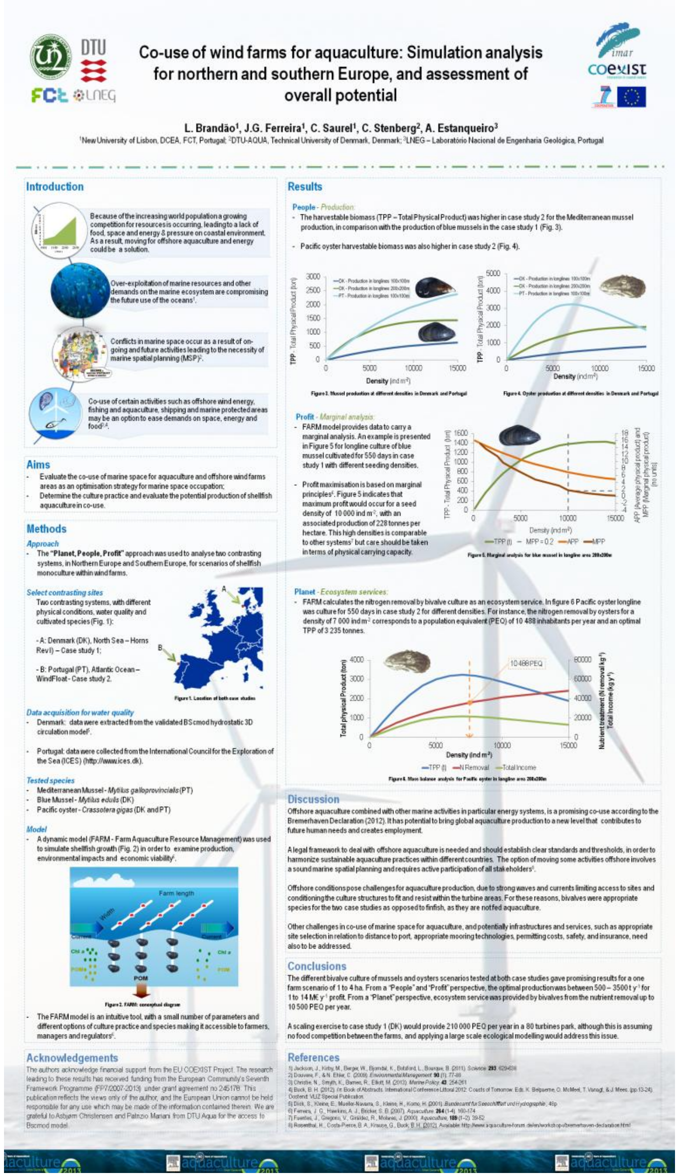
Presentation layout

- 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

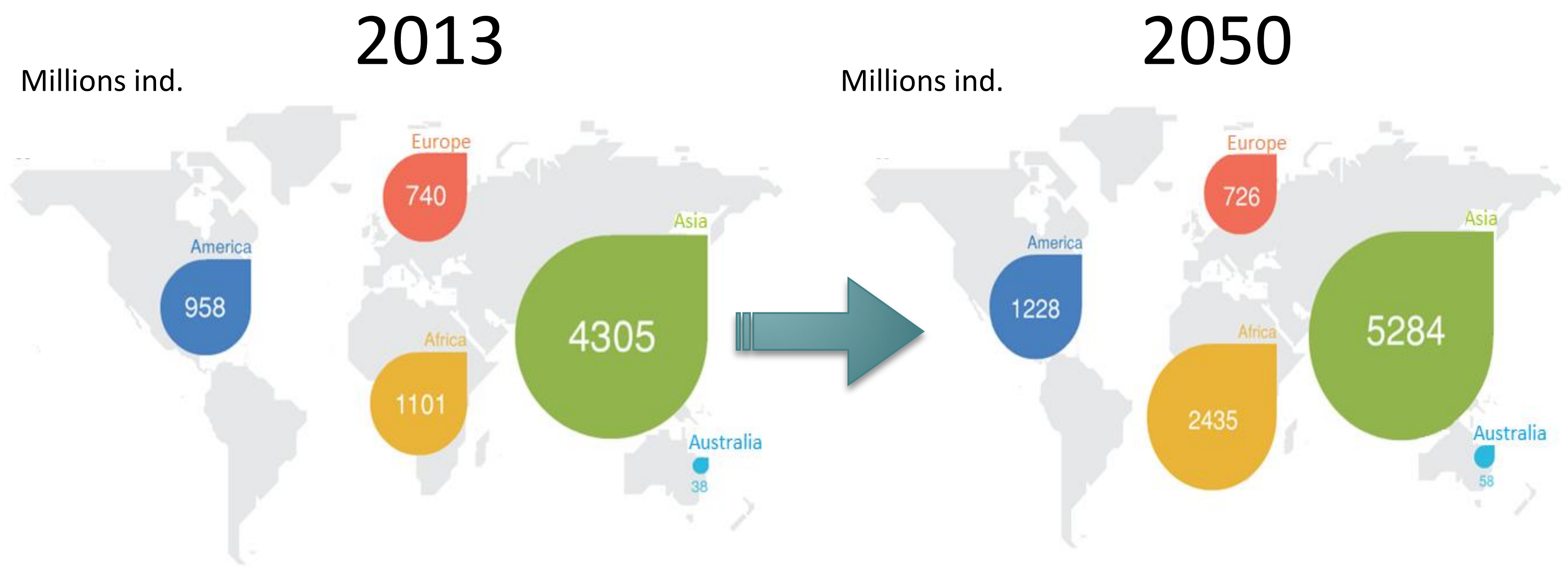
- **COEXIST** - Interaction in European coastal waters: A roadmap to sustainable integration of aquaculture and fisheries. FP7, Cooperation, Food, Agriculture and Fisheries, and Biotechnology
- Multidisciplinary project which aims at:
  - evaluate competing activities and interactions in coastal areas.
  - 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
  - Physical conditions; water quality; aquaculture, energy
- Knowledge transfer
  - Aquaculture modelling, energy
- Objective: Evaluate the co-use of marine space for aquaculture within offshore wind farms



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



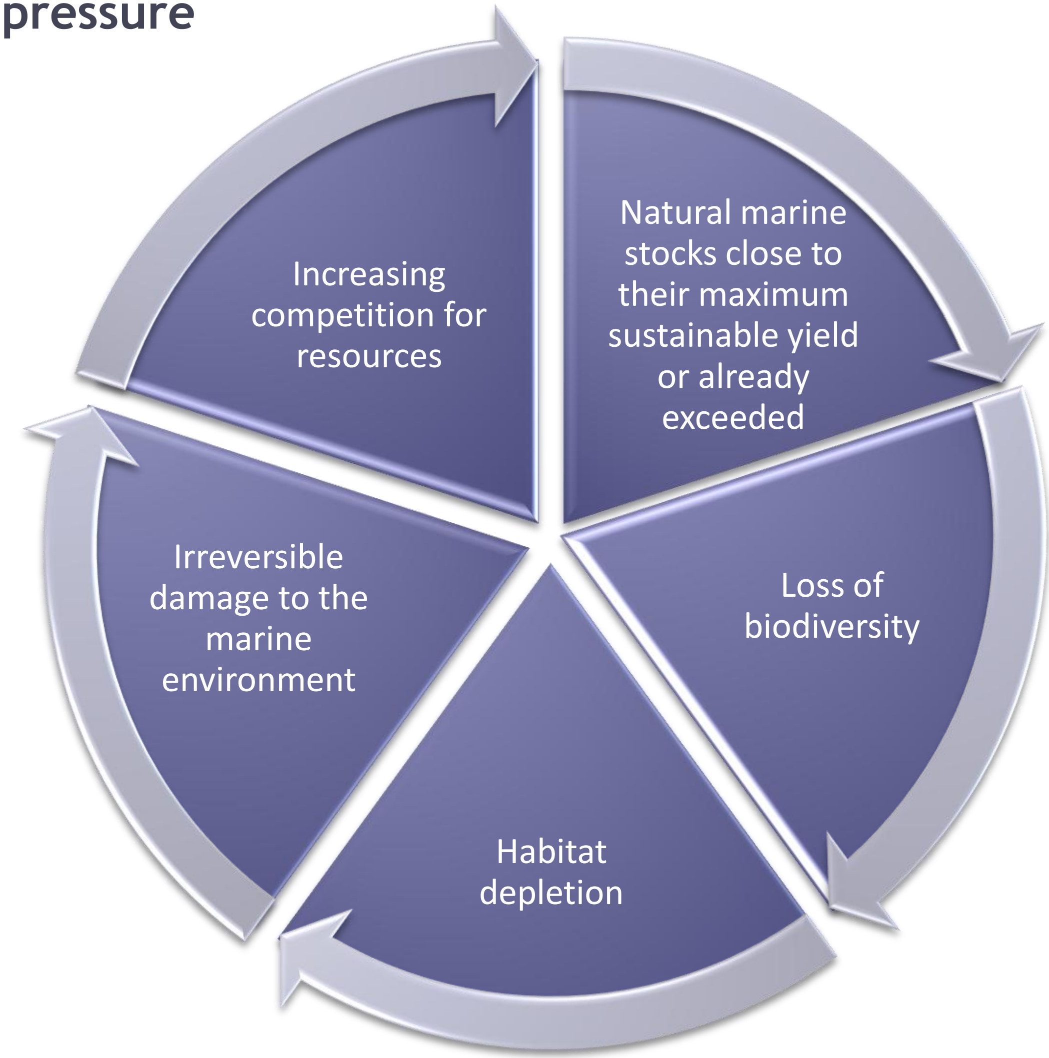
Coastal ecosystems are some of the most impacted and altered worldwide

"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

Source: Institut National Etudes Démographiques, 2013 ; Scheme adapted from Público, 2013

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

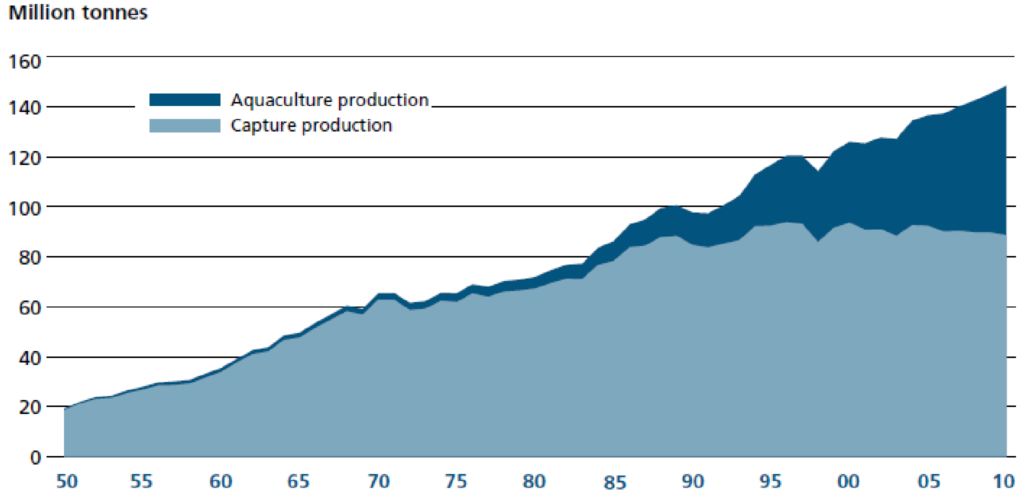
0–2 kg/year	10–20 kg/year	> 60 kg/year
2–5 kg/year	20–30 kg/year	
5–10 kg/year	30–60 kg/year	

Per capita supply (average 2007–2009)

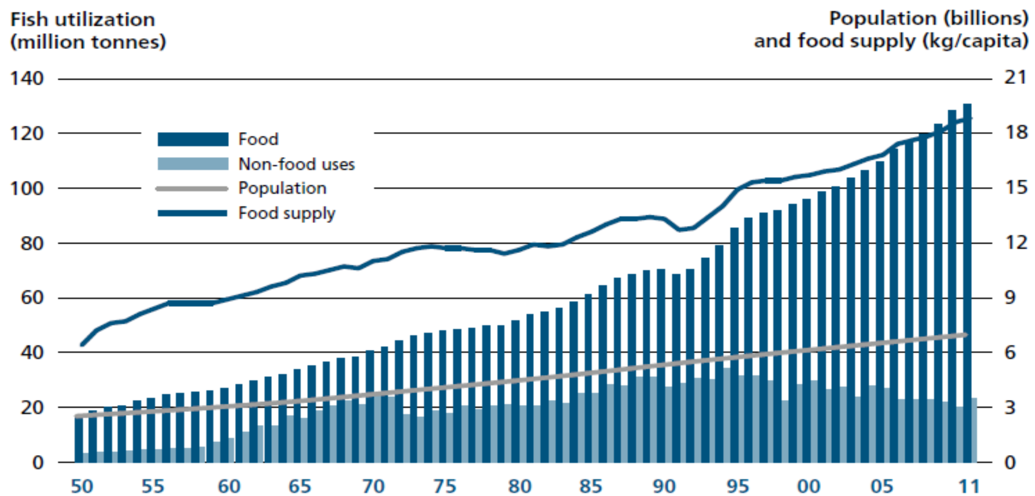
FAO, 2012

Problem definition

Aquaculture and Fisheries



World capture fisheries and aquaculture production



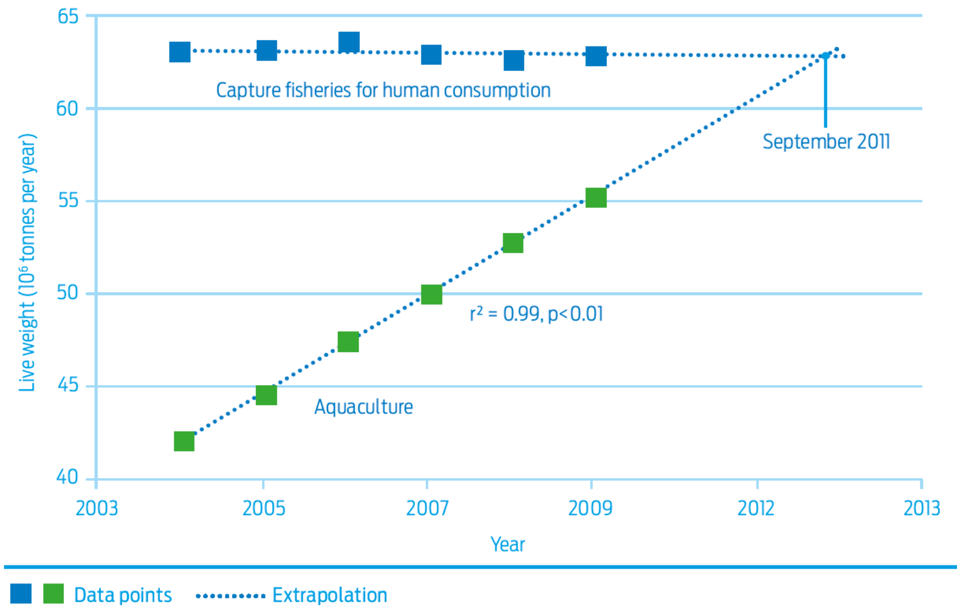
World fish utilization and supply

FAO, 2012

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.



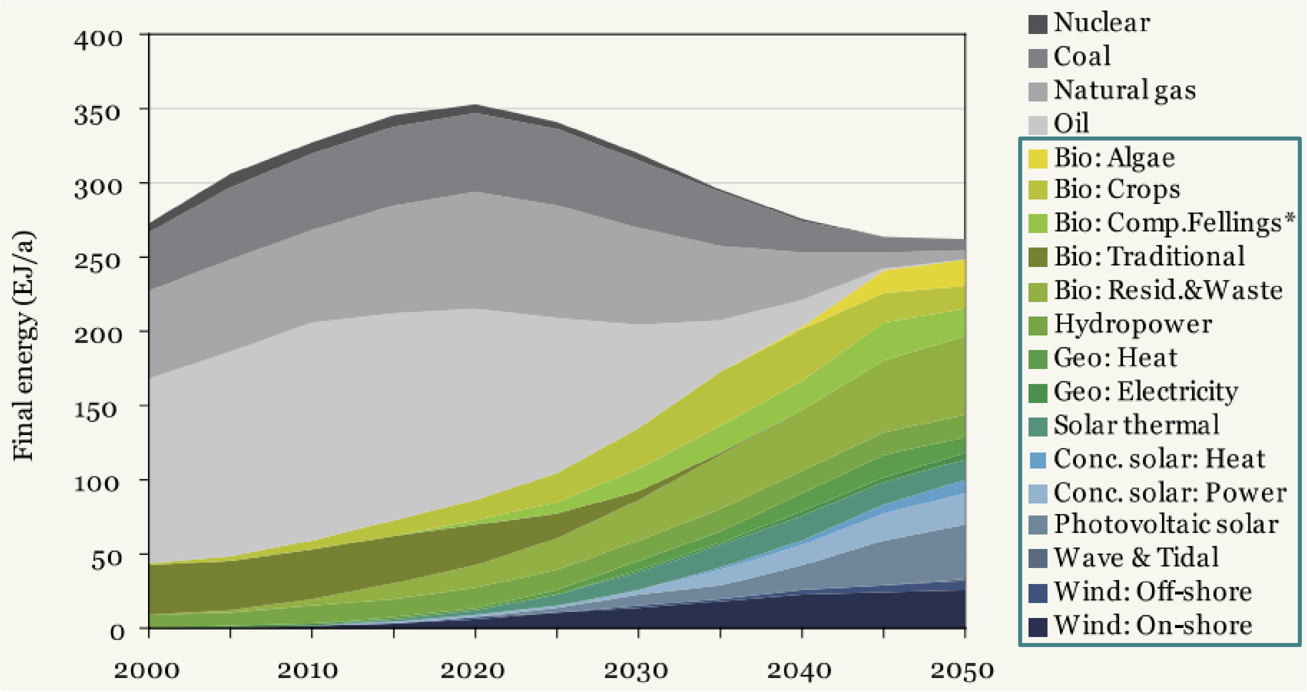
Projection of capture fisheries for human consumption and aquaculture

Ferreira *et al.* 2012

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

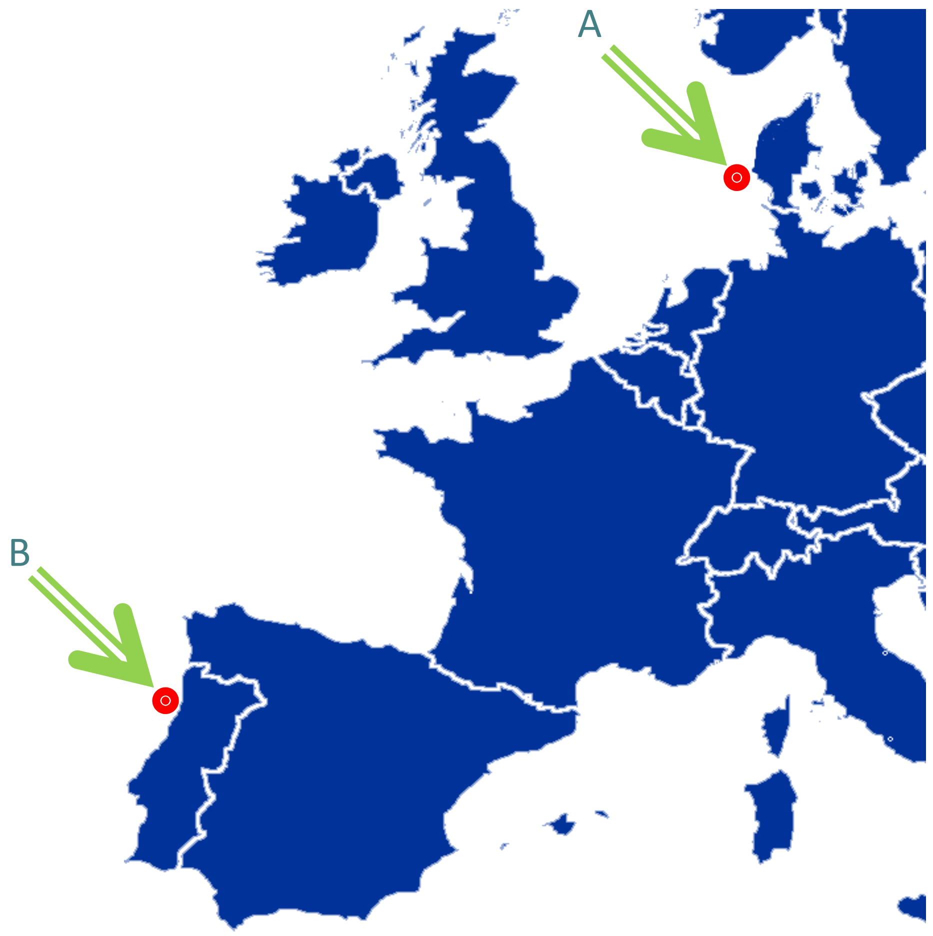
Source: WWF, 2011

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;

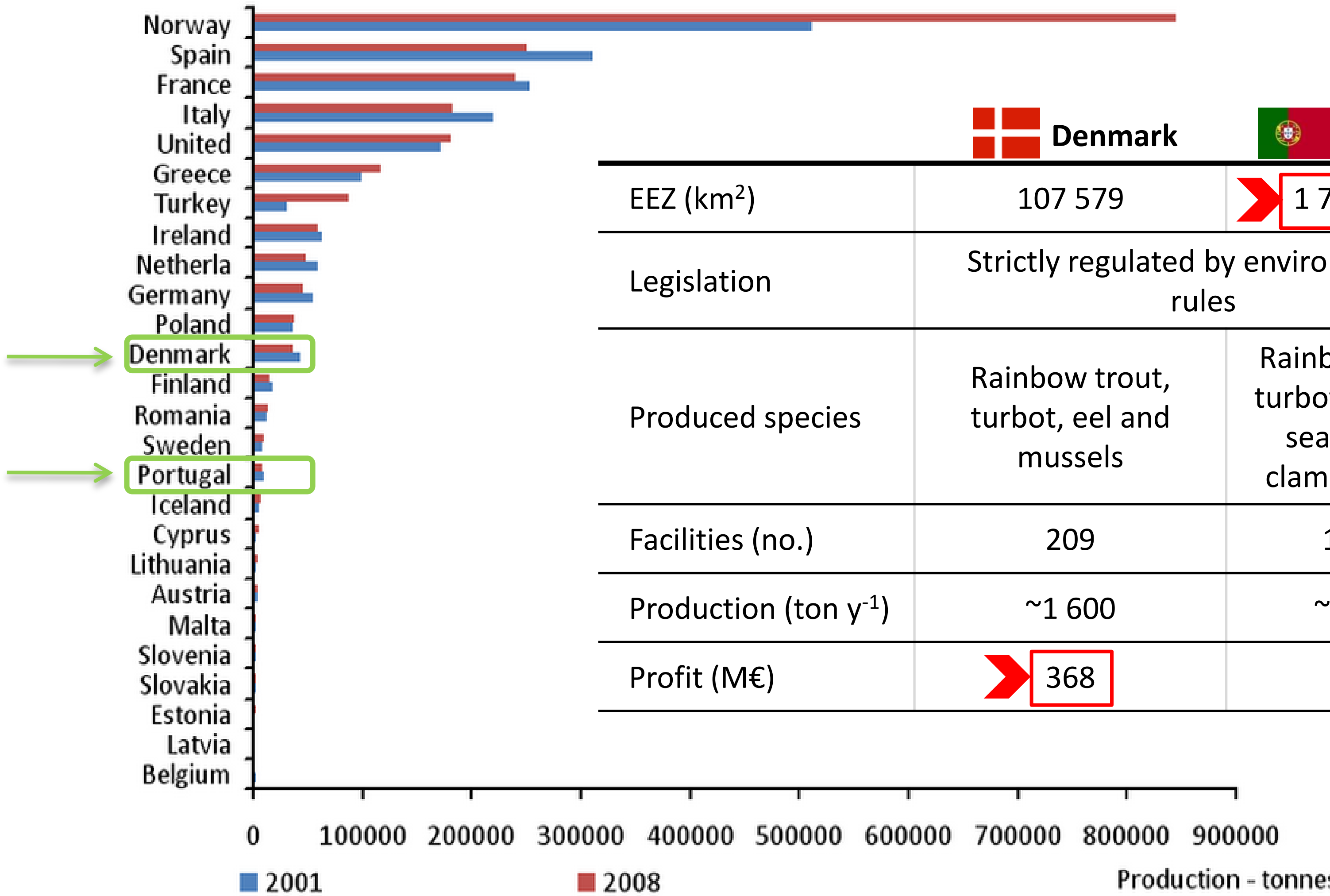
- Aquaculture: Apply a dynamic model to simulate shellfish growth, and examine production, environmental impacts, and economic viability and optimization;

- 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

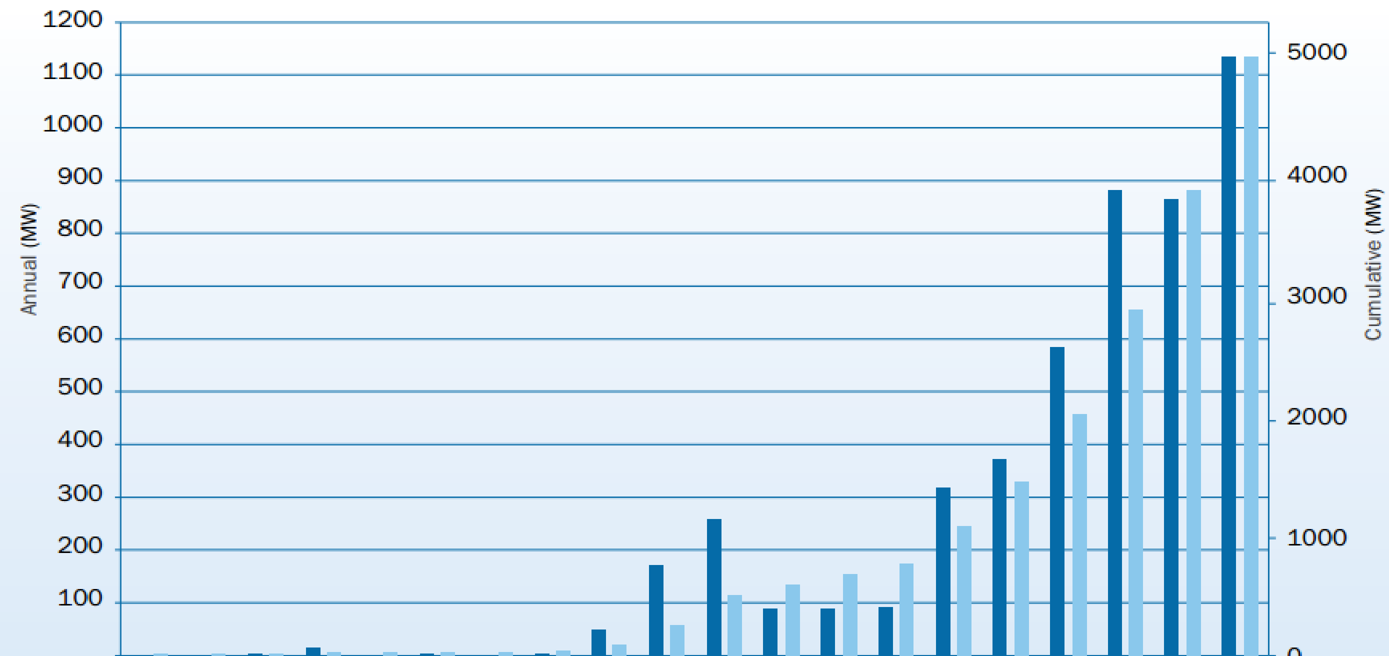


	Denmark	Portugal
EEZ (km²)	107 579	1 727 408
Legislation	Strictly regulated by environmental rules	
Produced species	Rainbow trout, turbot, eel and mussels	Rainbow trout, turbot, gilthead sea bream, clams, oysters
Facilities (no.)	209	1 570
Production (ton y^{-1})	~1 600	~6 000
Profit (M€)	368	37

Annual aquaculture production by country, 2001 and 2008

EPA, 2011 from FAO FISHSTAT Plus 2010

Energy from offshore wind farms



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Annual	0	2	5	17	0	3	0	4	51	170	276	90	90	93	318	373	577	883	874	1,166
Cumulative	5	7	12	29	29	32	32	36	86	256	532	622	712	804	1,123	1,496	2,073	2,956	3,829	4,995

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)

EWEA, 2013

Offshore wind farms: types

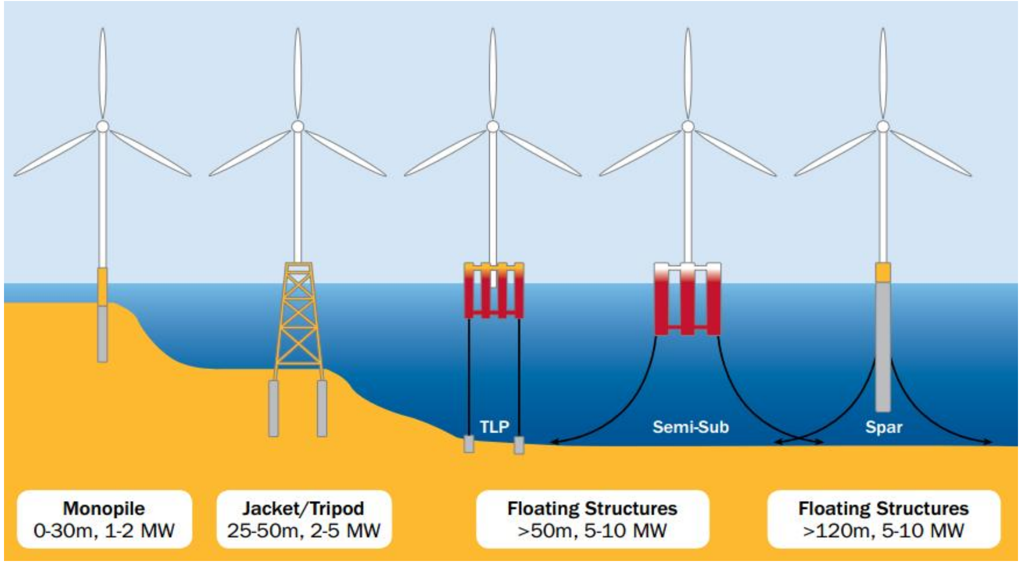
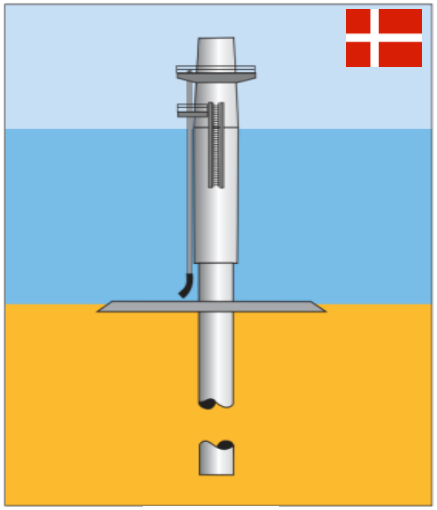
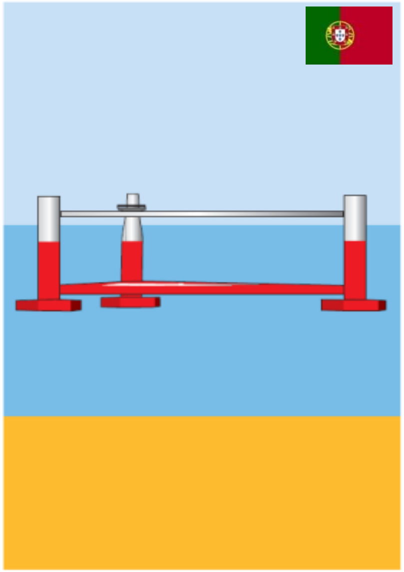


Figure 15 – Offshore wind foundations regarding the depth of water
Source: Arapogianni *et al.*, 2013



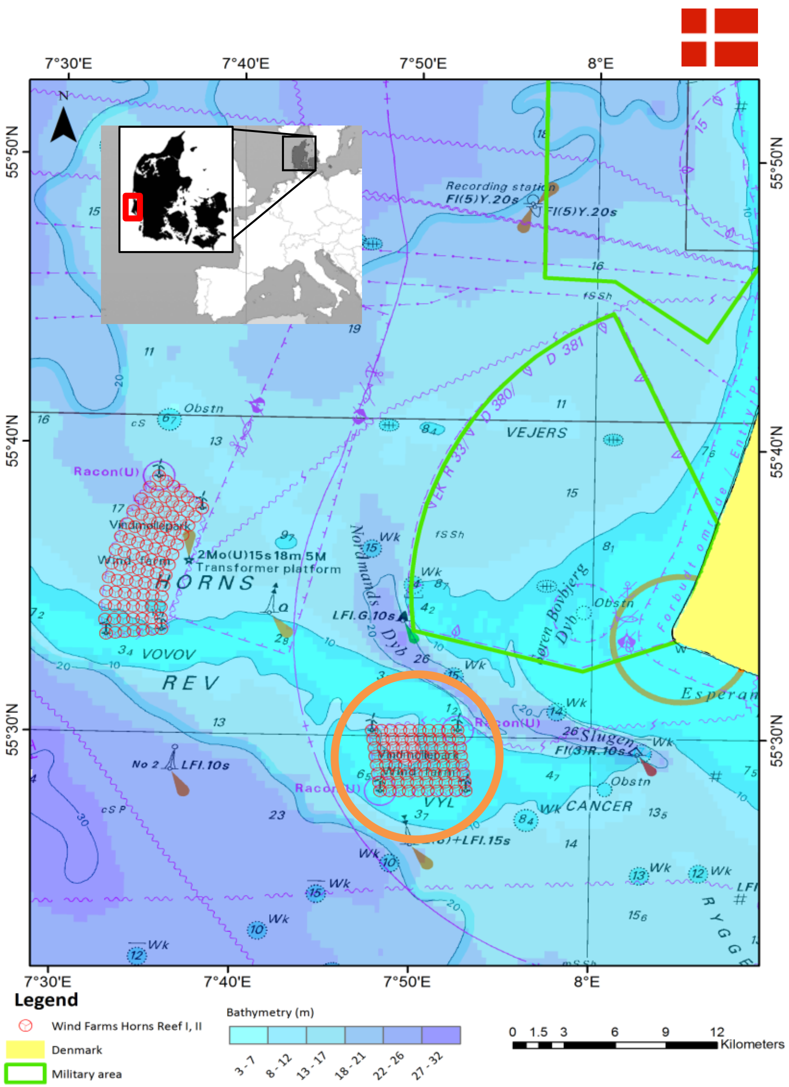
Monopile



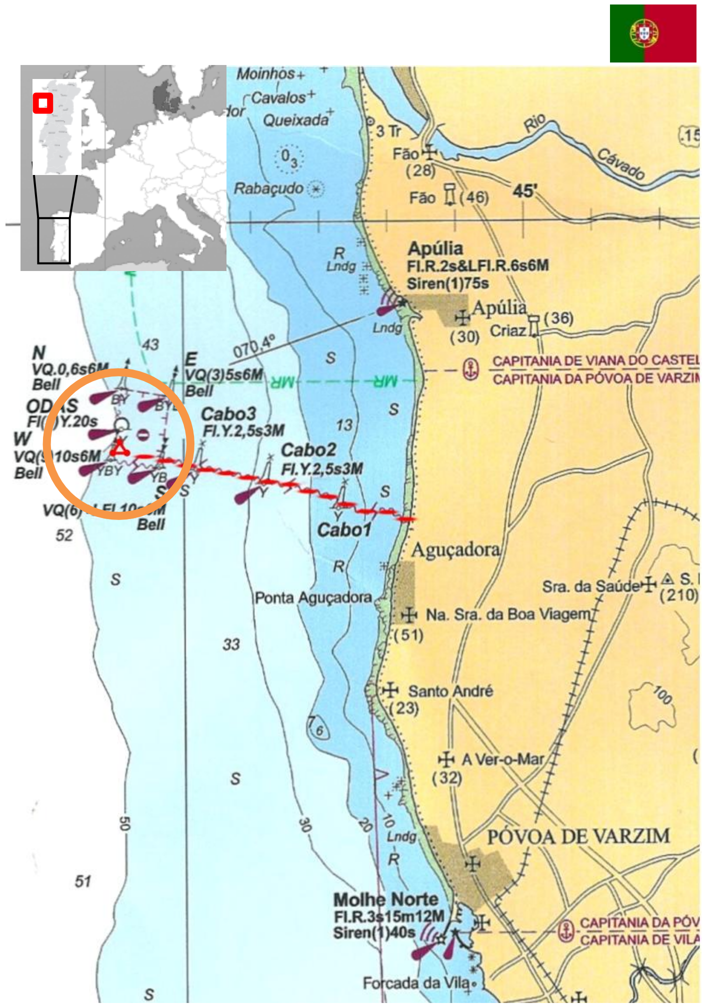
Jacket

Arapogianni *et al.*, 2013

Offshore wind farms in case studies



Horns Rev I – orange circle



WindFloat - orange circle

Methodology

Approach

People, Planet, Profit

for scenarios of shellfish monoculture within wind farms

Select contrasting sites

Denmark (DK), North Sea – Horns Rev I

Portugal (PT), Atlantic Ocean –WindFloat

Data acquisition for water quality

Data extracted from the validated BScmod hydrostatic 3D circulation model

Data collected from the International Council for the Exploration of the Sea (ICES)

Tested species

monoculture practice in longlines

Blue Mussel *Mytilus edulis*

Pacific oyster *Crassotera gigas*

Mediterranean Mussel *Mytilus galloprovincialis*

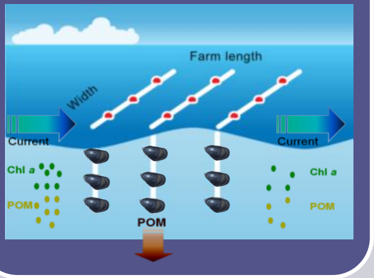
Pacific oyster *Crassotera gigas*

Model

FARM *Farm Aquaculture Resource Management*

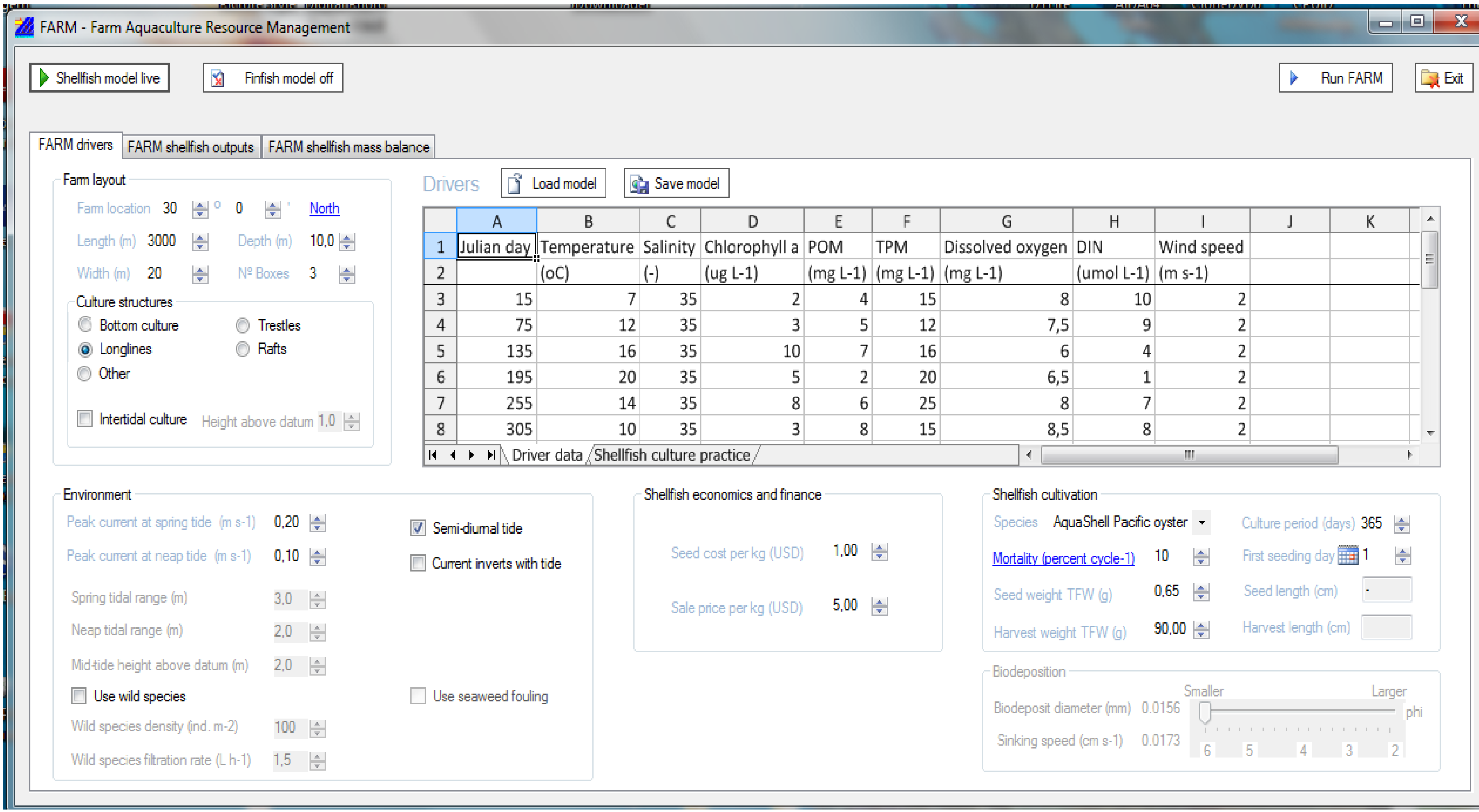
simulate shellfish growth

examine production environmental impacts economic viability



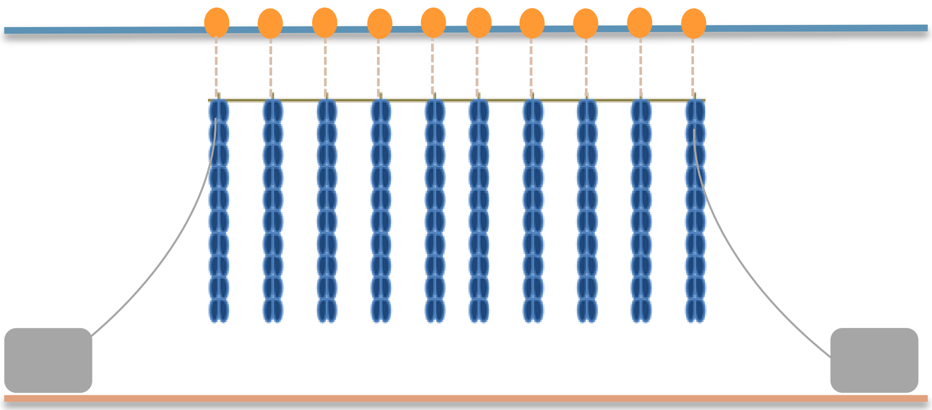
Methodology

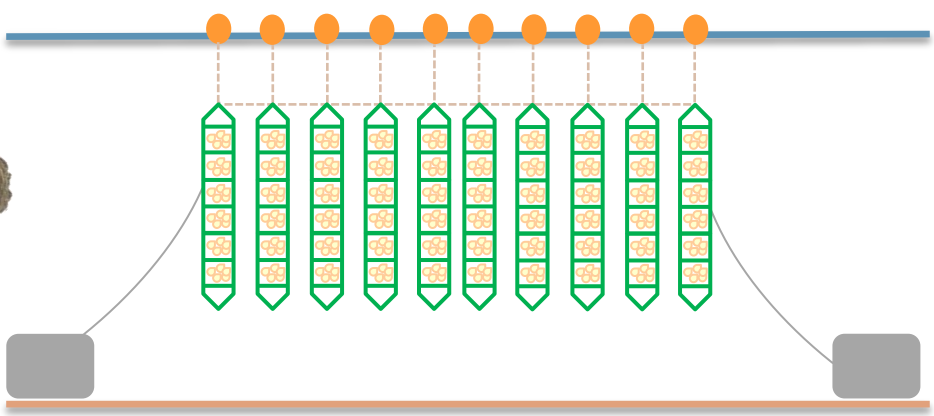
FARM data requirements



Methodology

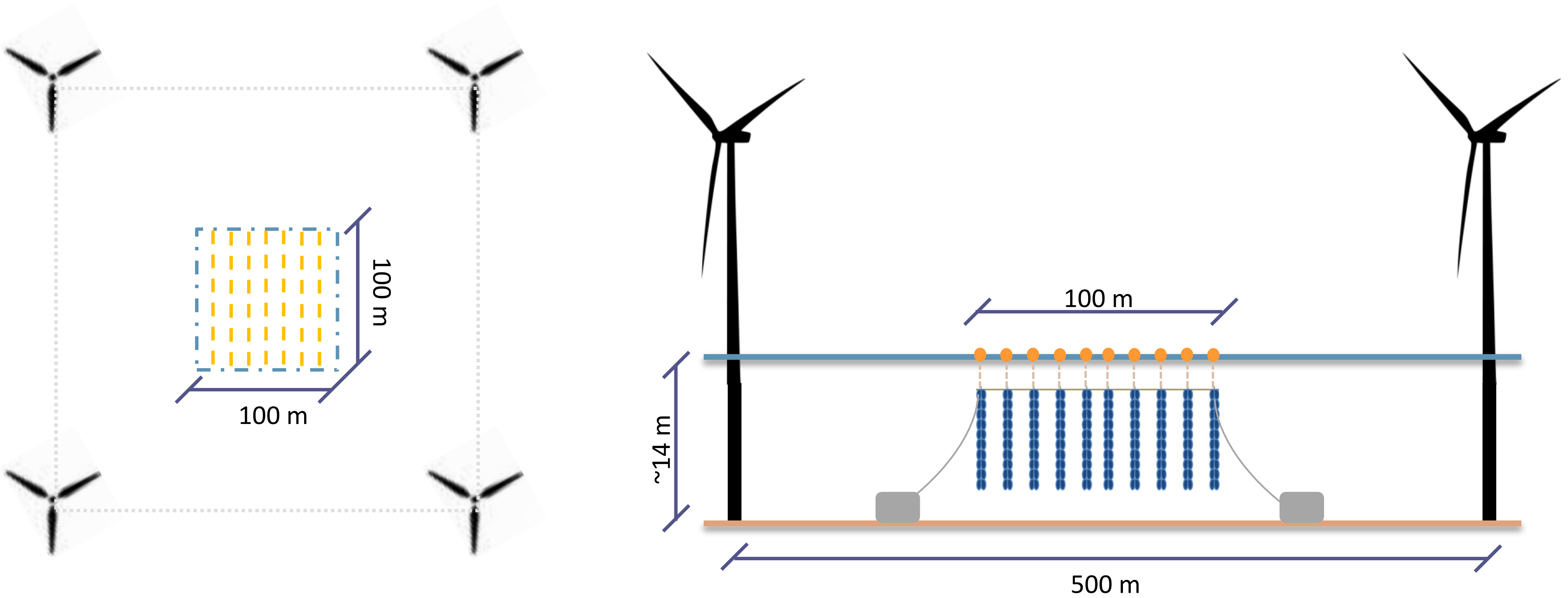
Culture practice





Methodology

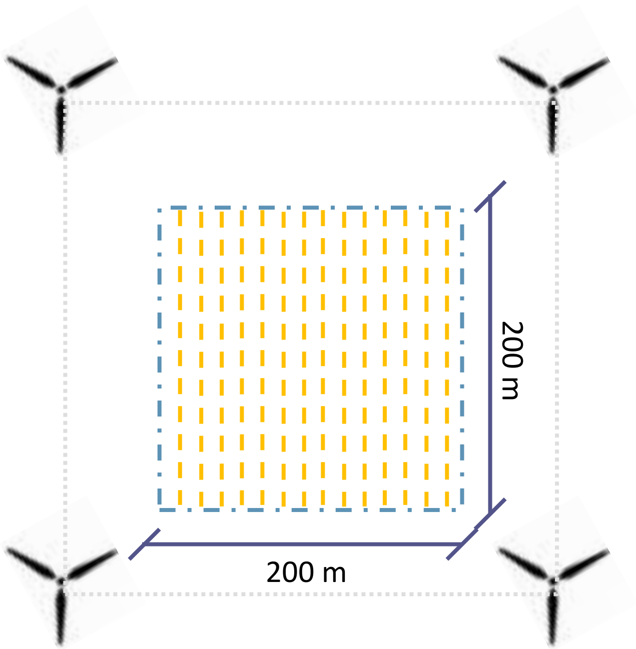
Adopted layout for a possible aquaculture structure within Horns Rev I

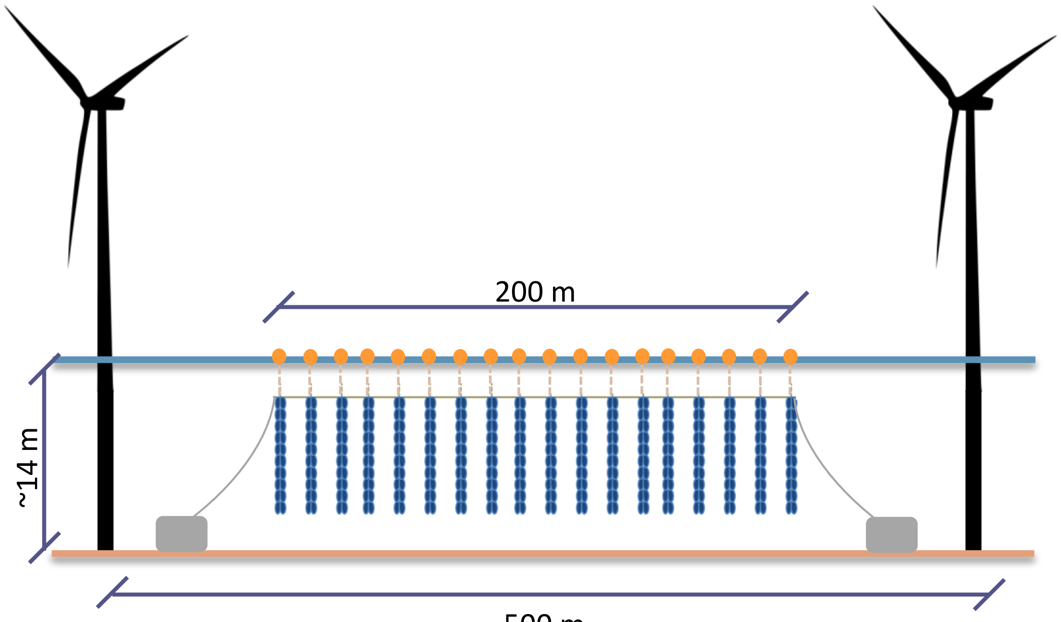


Aquaculture area: 1 ha

Methodology

Adopted layout for a possible aquaculture structure within Horns Rev I

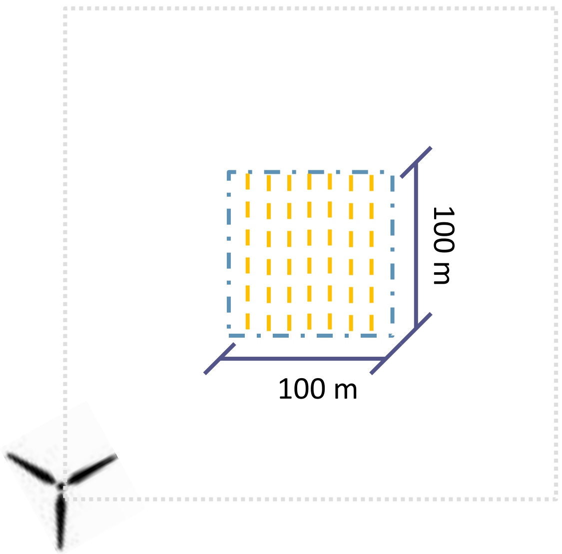


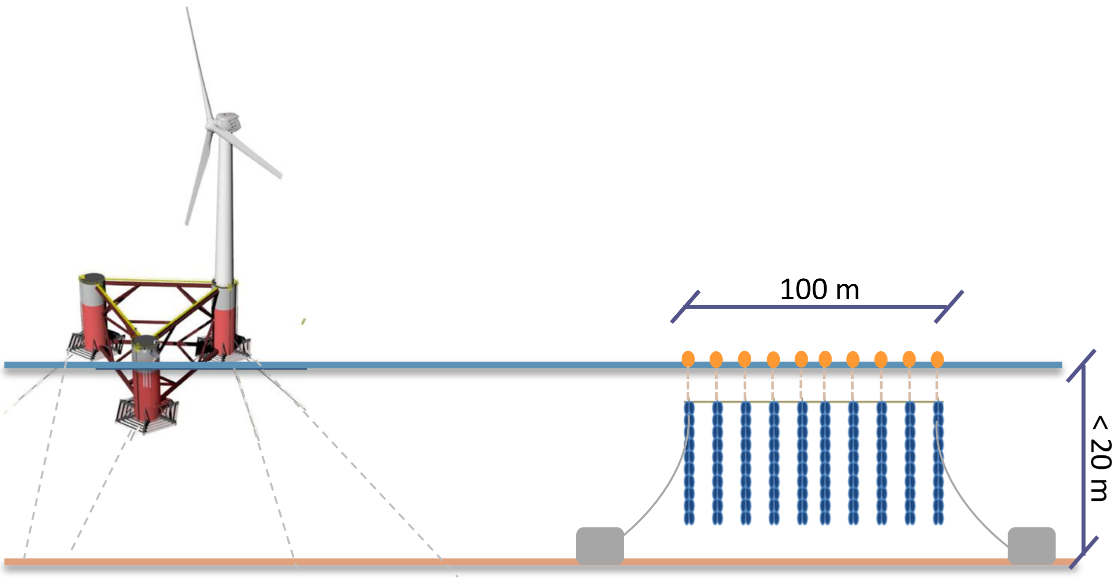


Aquaculture area: 4 ha

Methodology

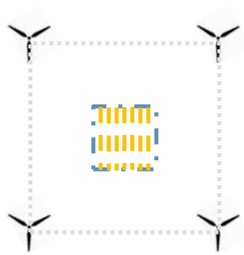
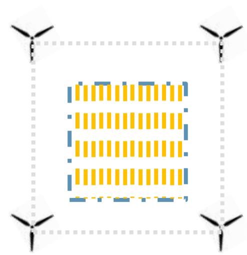
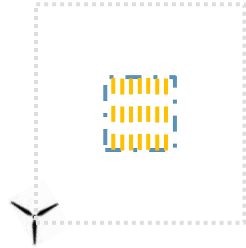
Adopted layout for a possible aquaculture structure close to WindFloat





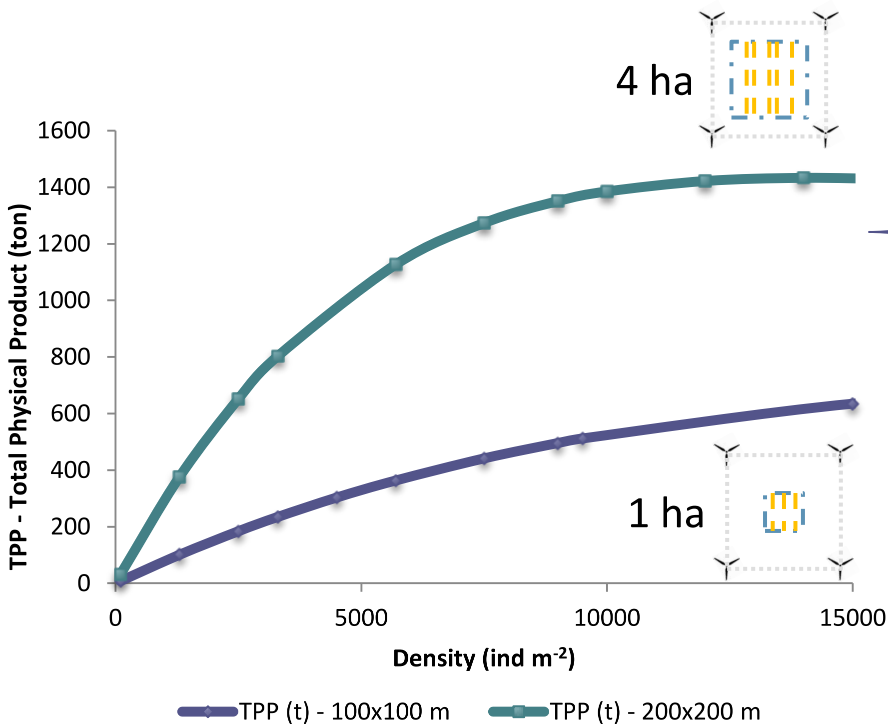
Aquaculture area: 1 ha

Results and Discussion

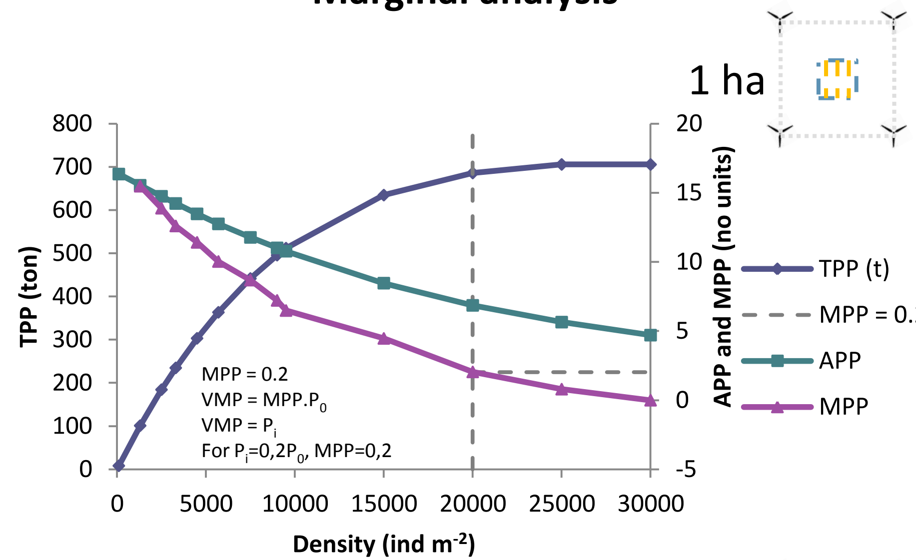
	Culture practice:	Drivers	Results
Denmark:  **blue mussel**  **Pacific oyster**	Case 1: 1 ha  Case 2: 4 ha 	From model, only 1 scenario	Production Marginal analysis Mass balance
Portugal:  **Med. mussel**  **Pacific oyster**	1 ha 	Case 1: TPM = 2 mg l^{-1} POM = 8 mg l^{-1} Case 2: TPM = 10 mg l^{-1} POM = 16 mg l^{-1}	

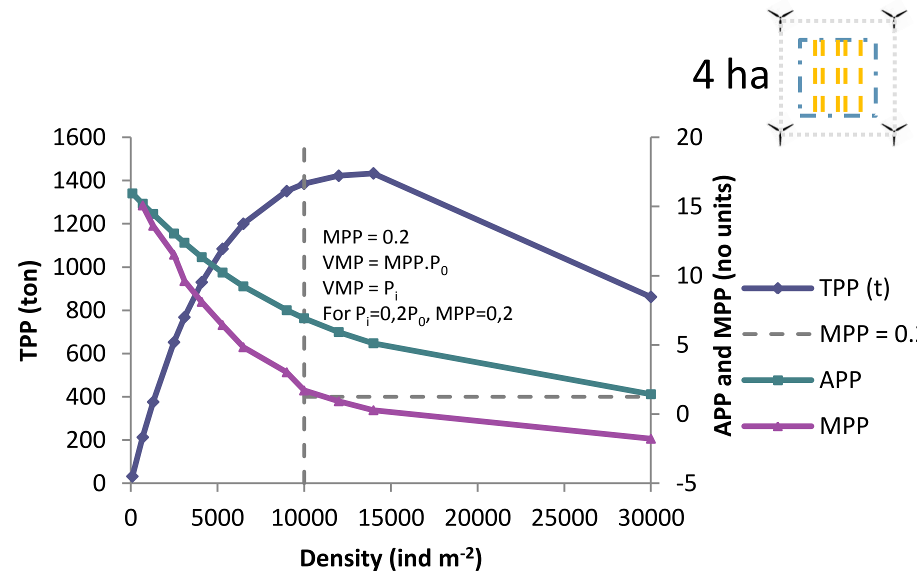
Denmark: blue mussel

Production

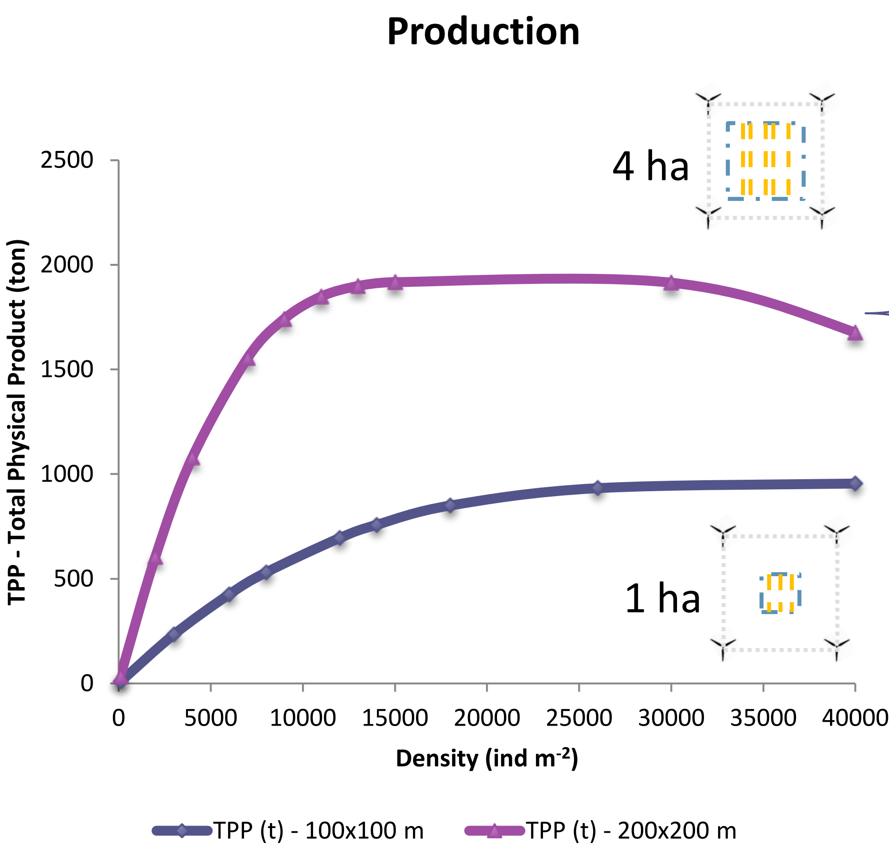


Marginal analysis

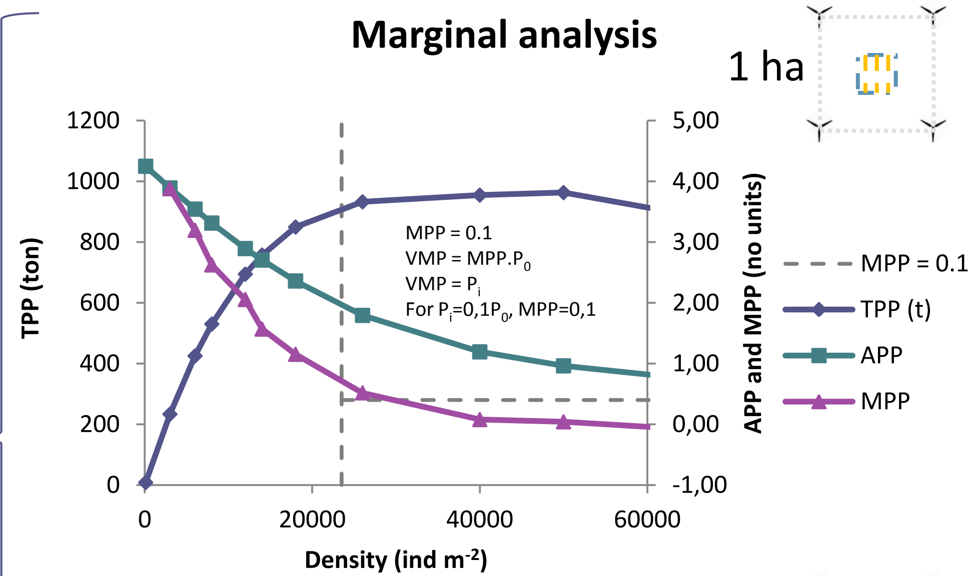


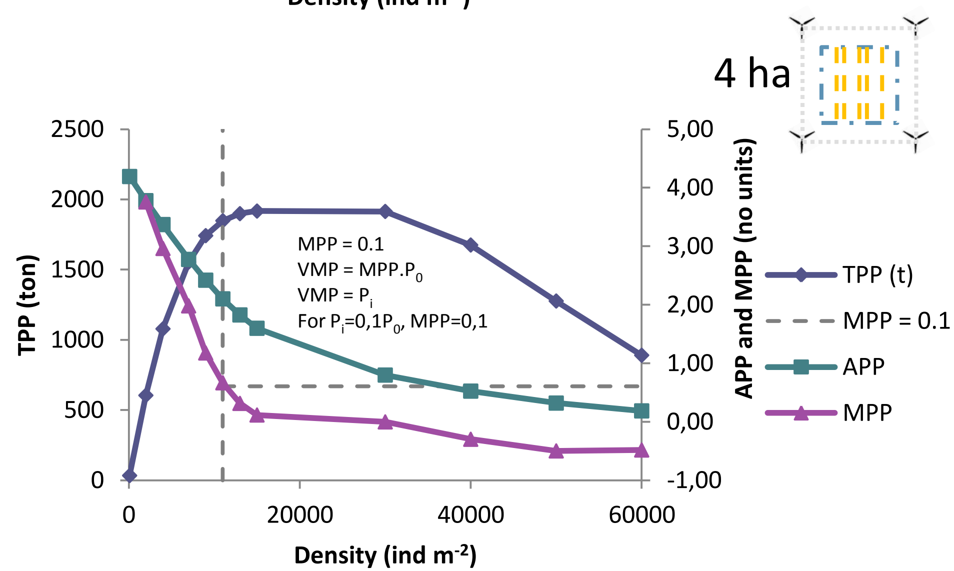


Denmark: Pacific oyster



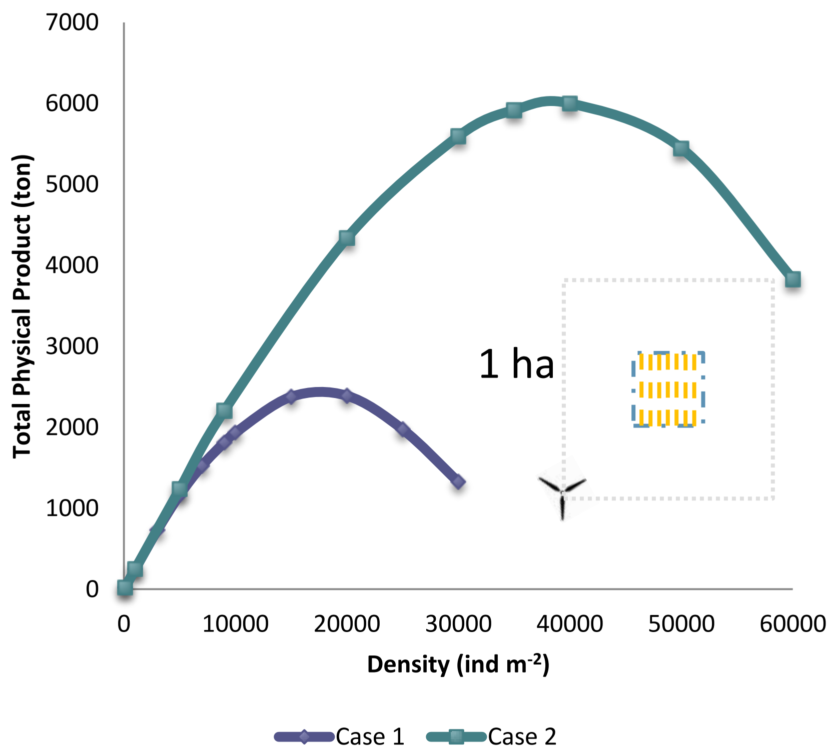
Marginal analysis



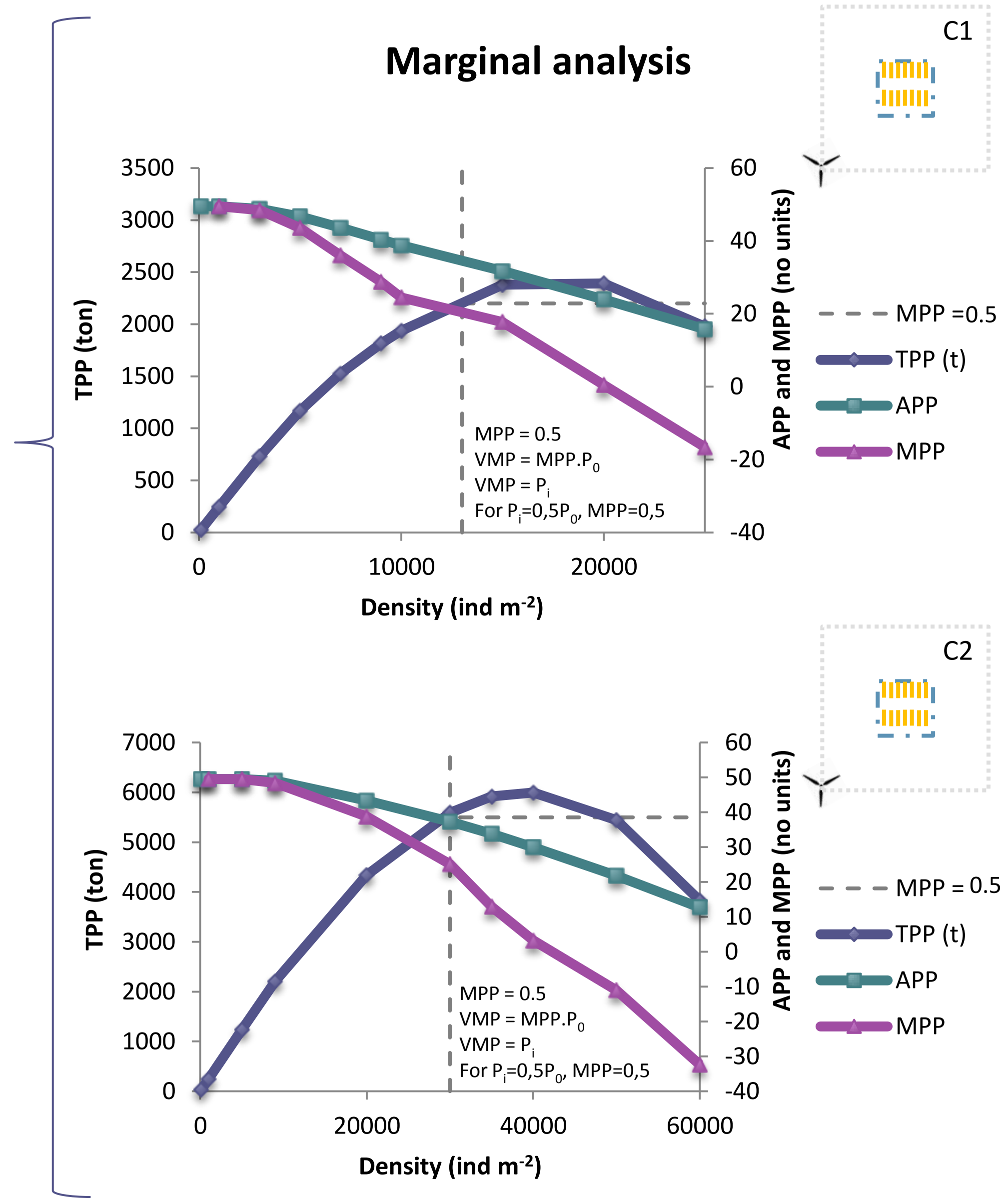


Portugal: Mediterranean mussel

Production



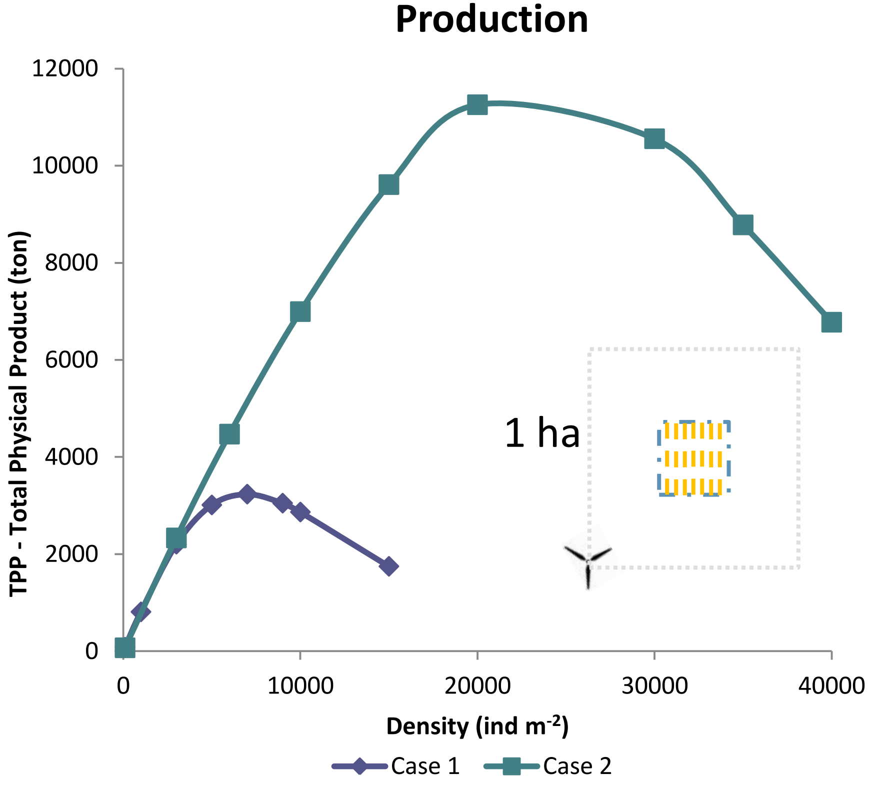
Marginal analysis



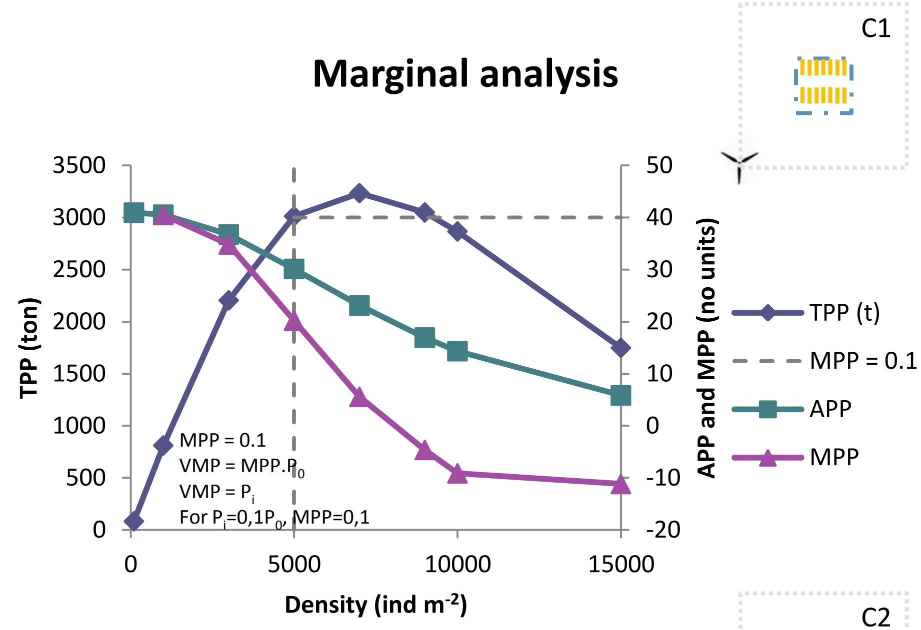
Case 1: TPM = 2 mg l^{-1} - POM = 8 mg l^{-1}

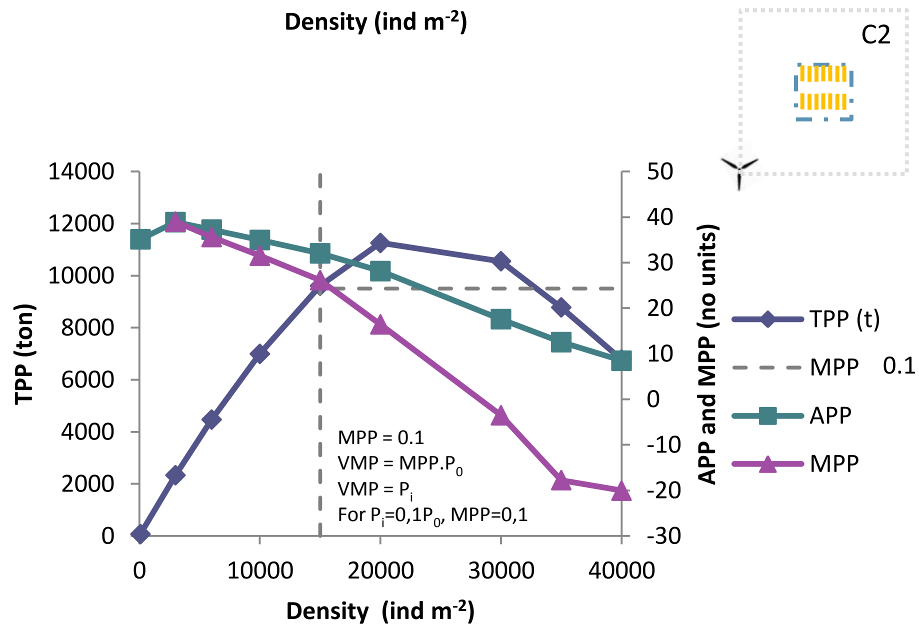
Case 2: TPM = 10 mg l^{-1} - POM = 16 mg l^{-1}

Portugal: Pacific oyster

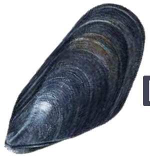


Marginal analysis





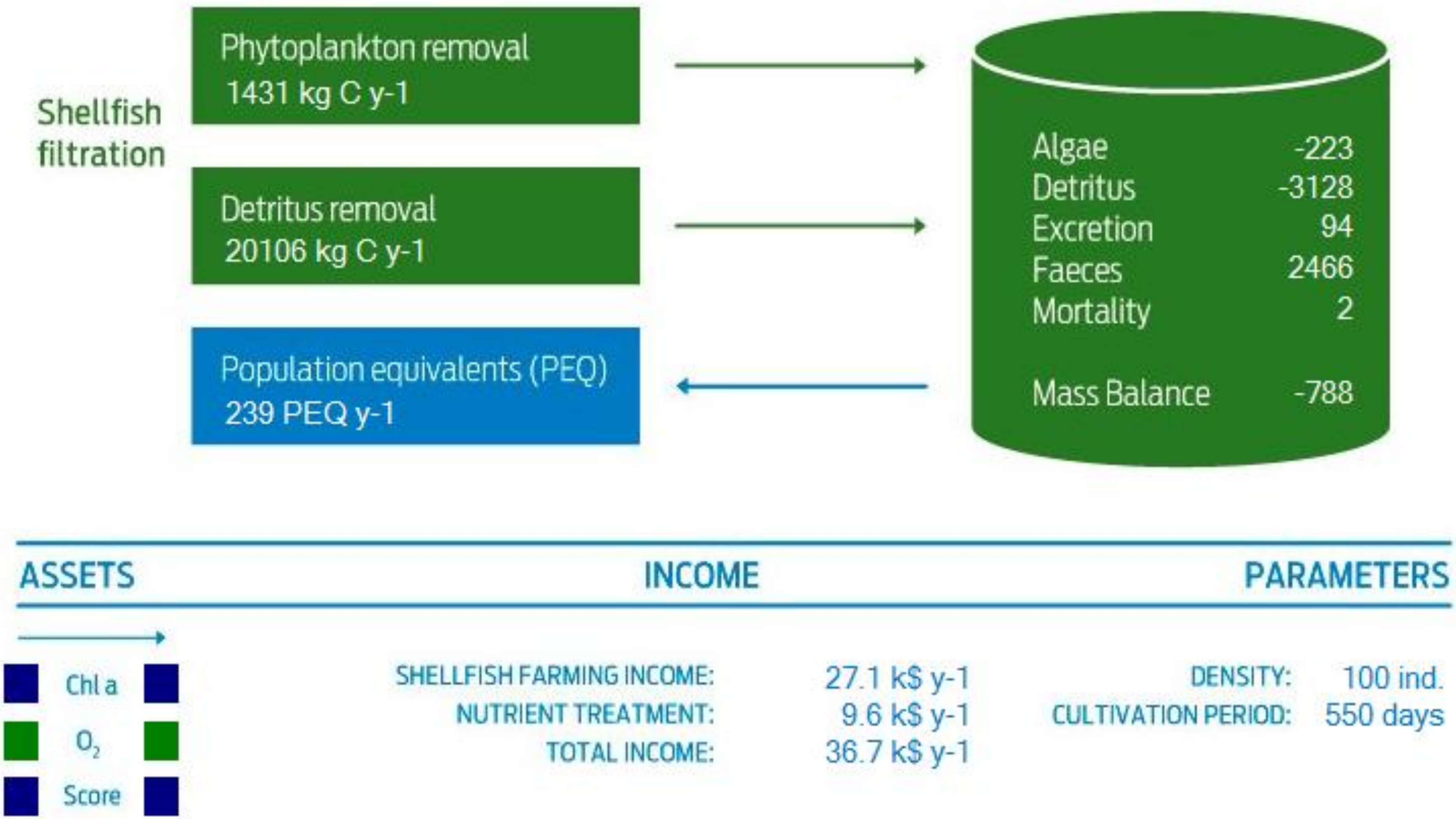
Mass balance



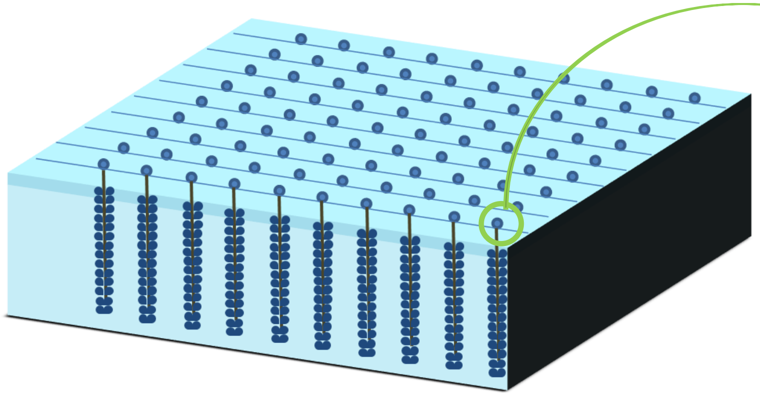
Denmark: blue mussel

1 ha

N removal (kg y^{-1})



Results and Discussion



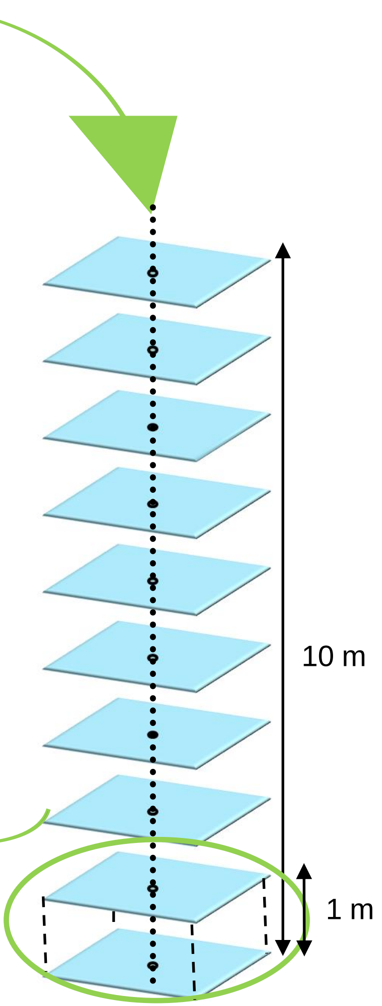
Seeds density for blue mussel culture: *10 000 ind. m⁻²*

→ In 1ha: 10 x 10^7 ind. => 100 longlines

→ 1 longline: 10 x 10^5 ind.

→ 1 rope (10 m): 2 x 10^4 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

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Thank you!

Obrigada pela vossa atenção!