# Seaweed cultivation: opportunities & barriers

***Adrian.Macleod@sams.ac.uk***
***The Scottish Association for Marine Science***
***Wales Seaweed Business Conference***
***26th February 2019***

MACROFUELS

SAMS

# Start with Why

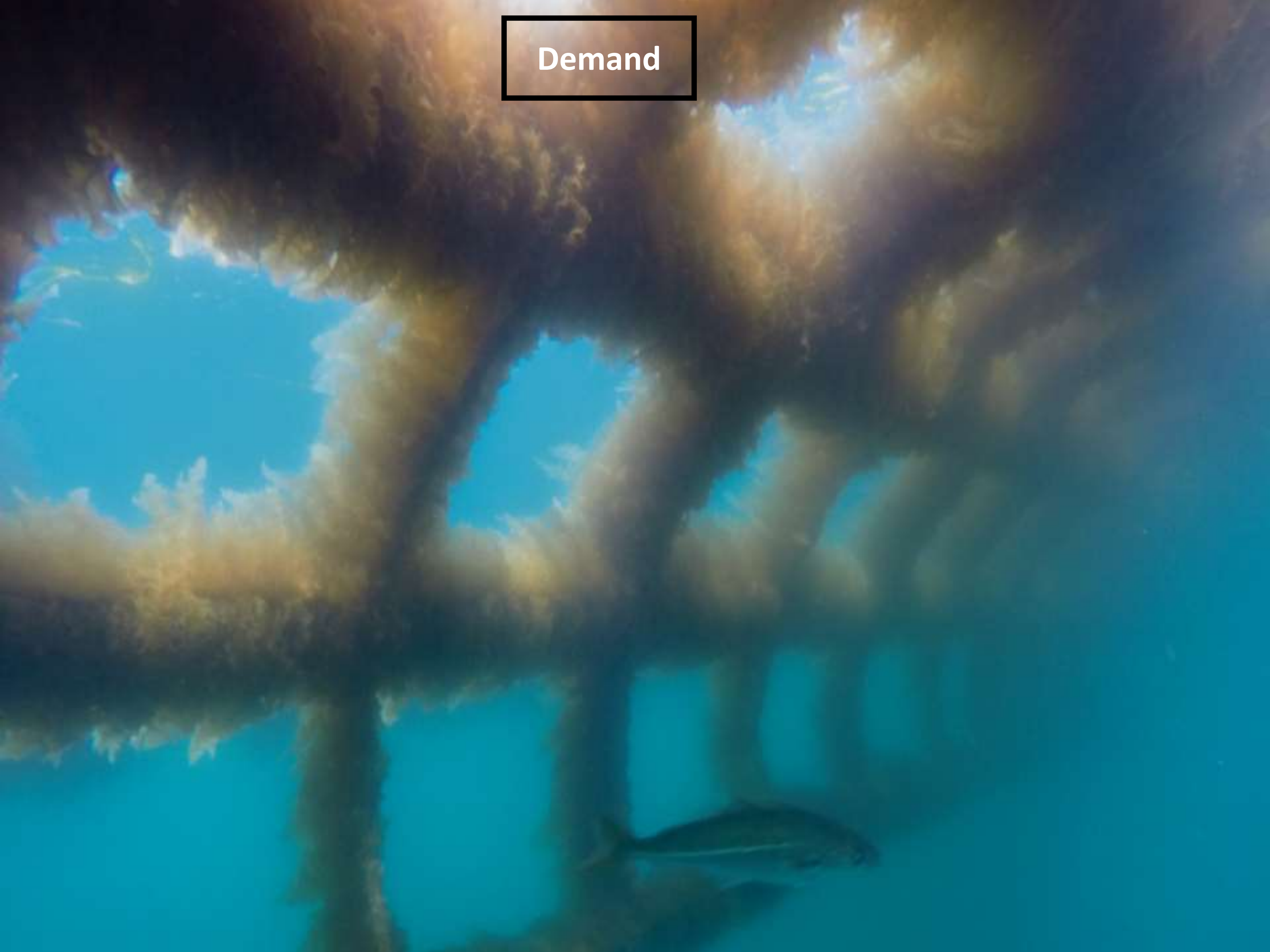
- Seaweeds are a sustainable source of biomass that grow fast, require no fresh water or pesticides and pose no conflict with terrestrial food supplies.

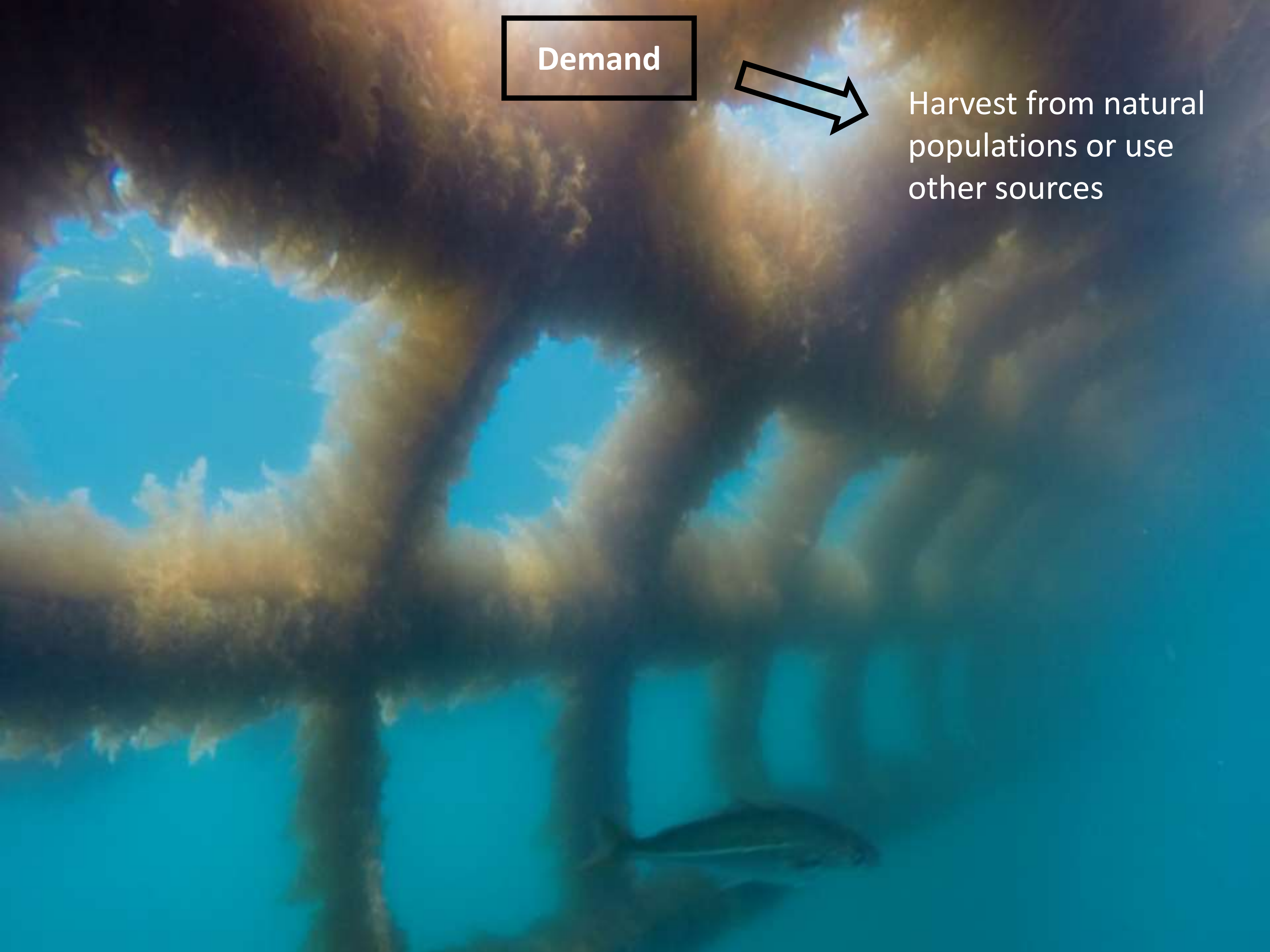
- Most of our food energy comes from agriculture on land. Seaweeds are increasingly a source for human food and health products, as well as wide ranging industrial applications (e.g. animal feed, biodegradable packaging and chemicals).

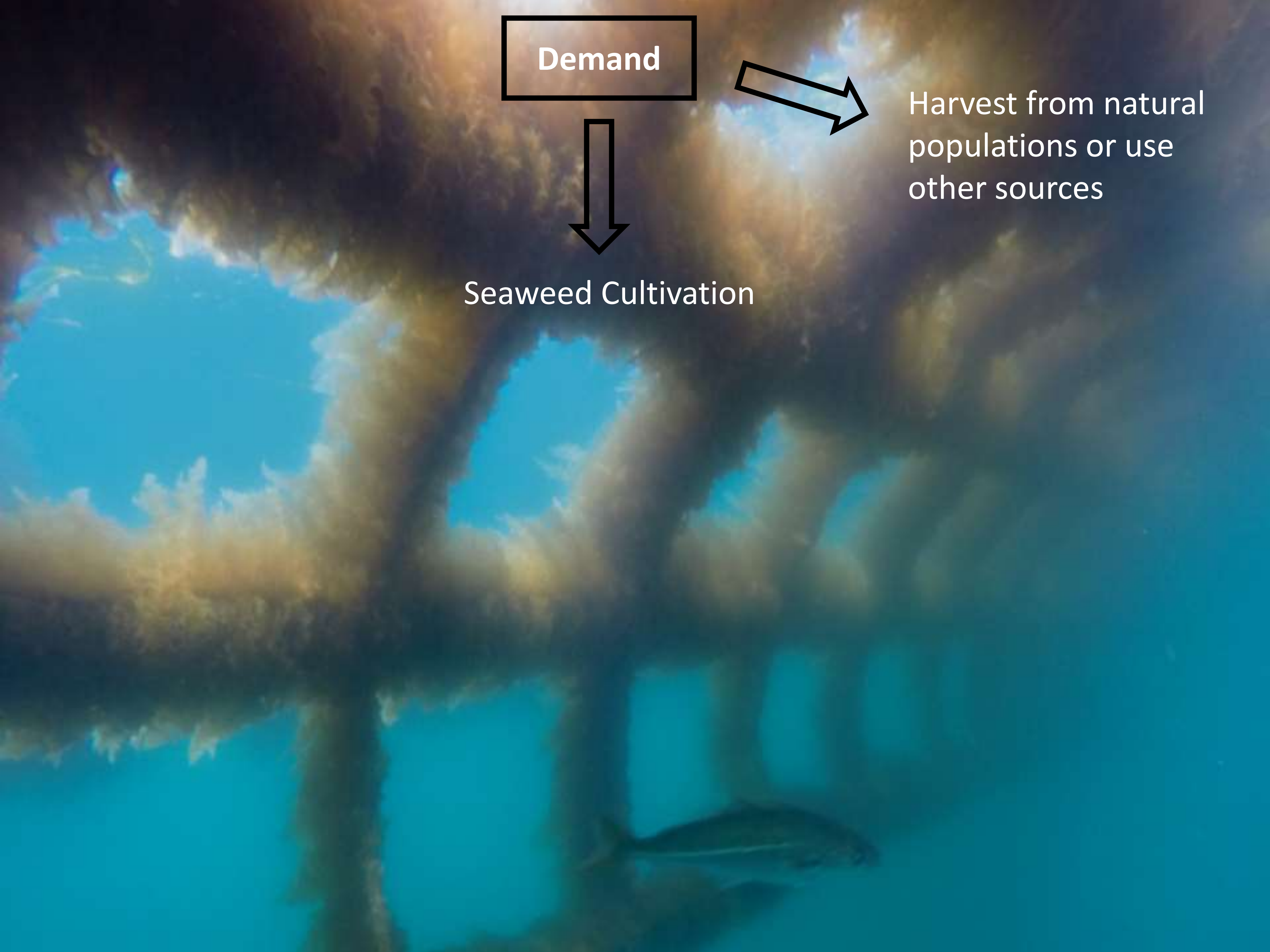
- Seaweeds cultivation has the potential to provide ecosystem services by filtering the water from excess inorganic nutrients, increasing habitat complexity and local productivity.

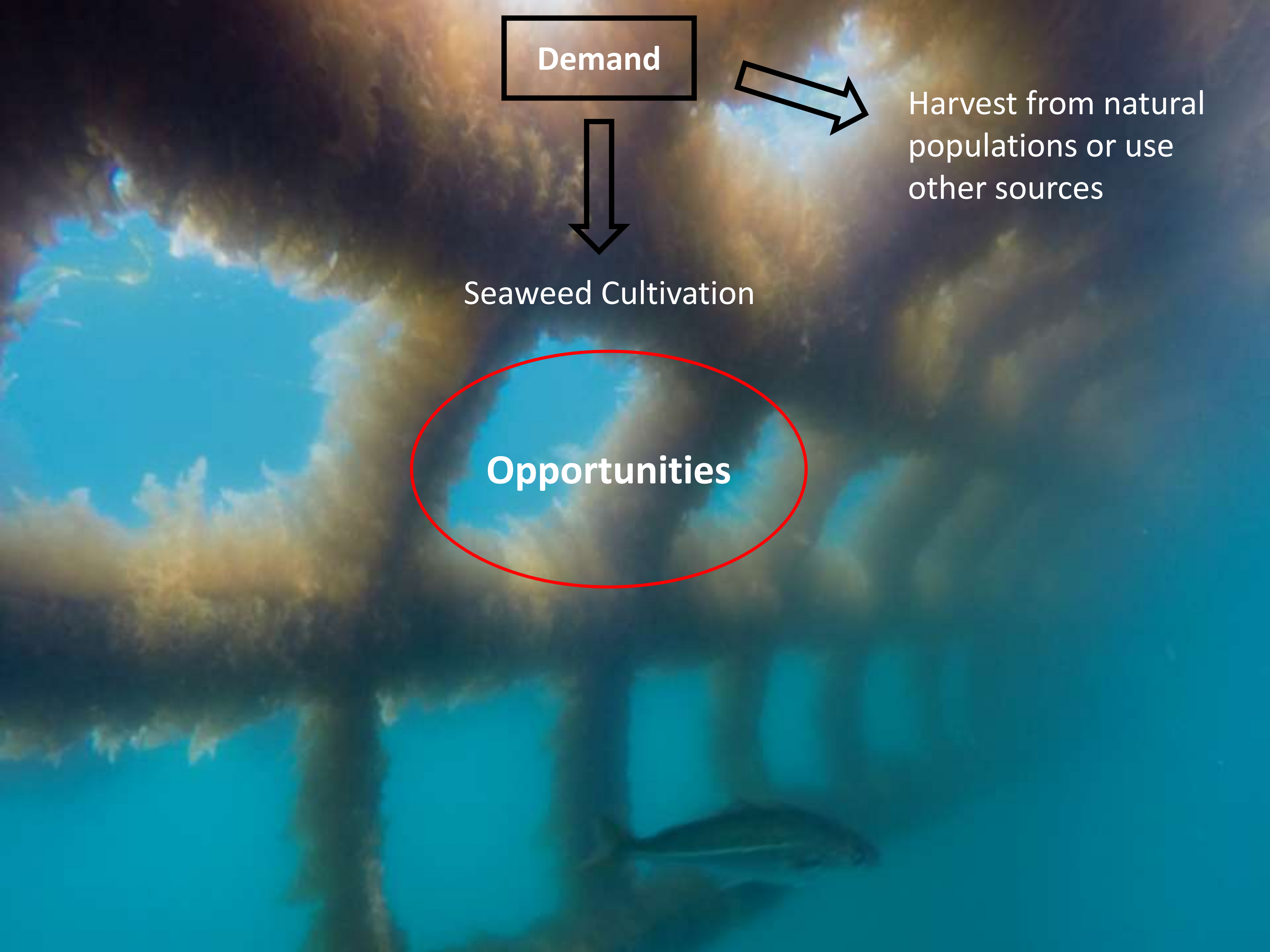
- Cultivation of seaweeds provide opportunities for established marine sectors through integrated aquaculture, inshore static fisheries, scallop ranching etc.

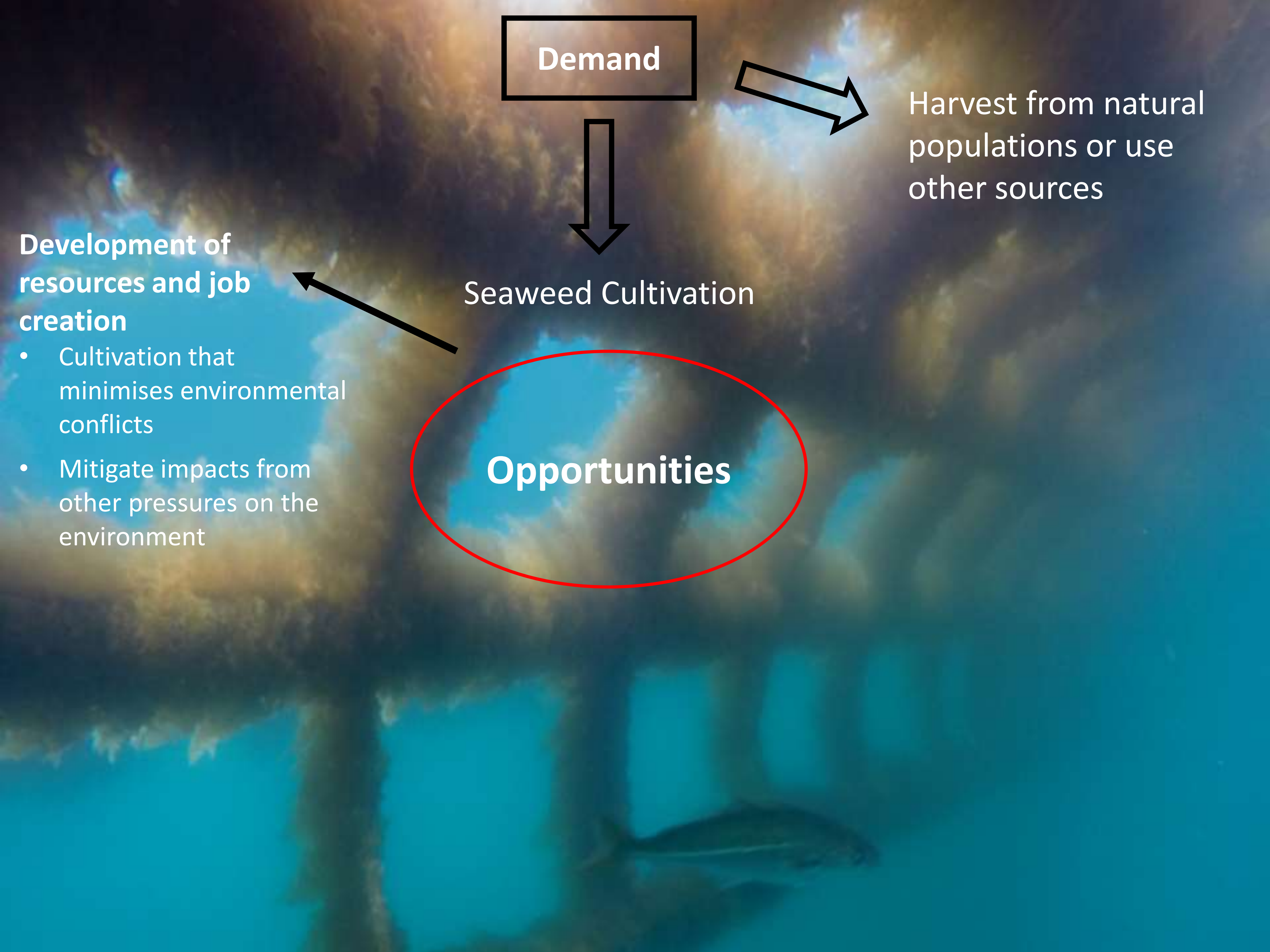
- Large-scale farming is proven in Asia (30 million tonnes annually), but has not yet been commercialised in the western world.


Demand


Demand
Harvest from natural populations or use other sources


Demand
Harvest from natural populations or use other sources
Seaweed Cultivation


Demand
Harvest from natural populations or use other sources
Seaweed Cultivation
Opportunities


Demand
Harvest from natural populations or use other sources
Seaweed Cultivation
Development of resources and job creation
• Cultivation that minimises environmental conflicts
• Mitigate impacts from other pressures on the environment
Opportunities

**Demand**

Harvest from natural populations or use other sources

Seaweed Cultivation

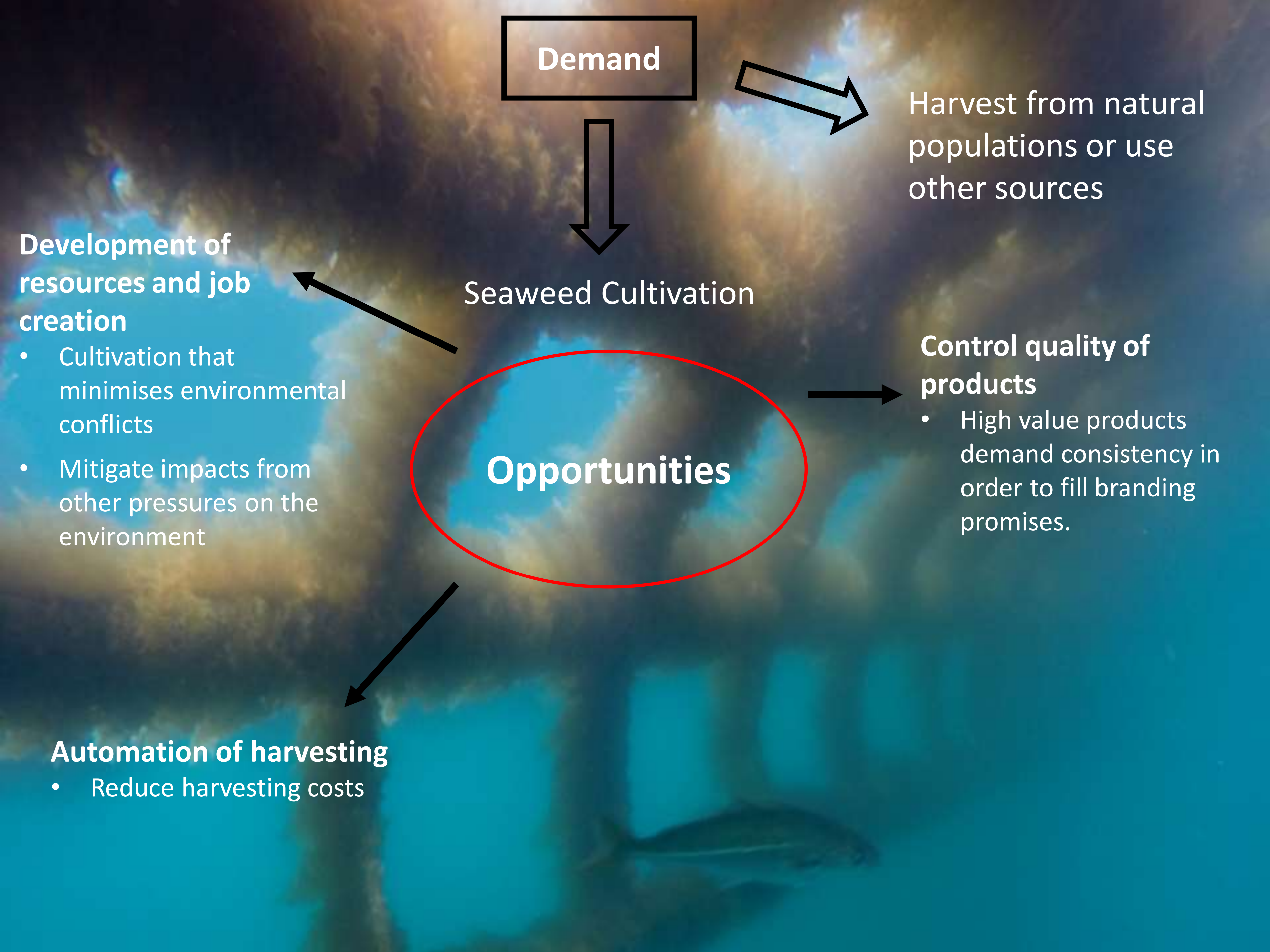
## Opportunities

**Development of resources and job creation**

- Cultivation that minimises environmental conflicts
- Mitigate impacts from other pressures on the environment

**Automation of harvesting**

- Reduce harvesting costs


Demand
Harvest from natural populations or use other sources
Seaweed Cultivation
Development of resources and job creation
• Cultivation that minimises environmental conflicts
• Mitigate impacts from other pressures on the environment
Opportunities
Control quality of products
• High value products demand consistency in order to fill branding promises.
Automation of harvesting
• Reduce harvesting costs

**Demand**

Harvest from natural populations or use other sources

Seaweed Cultivation

# Opportunities

**Development of resources and job creation**

- Cultivation that minimises environmental conflicts
- Mitigate impacts from other pressures on the environment

**Control quality of products**

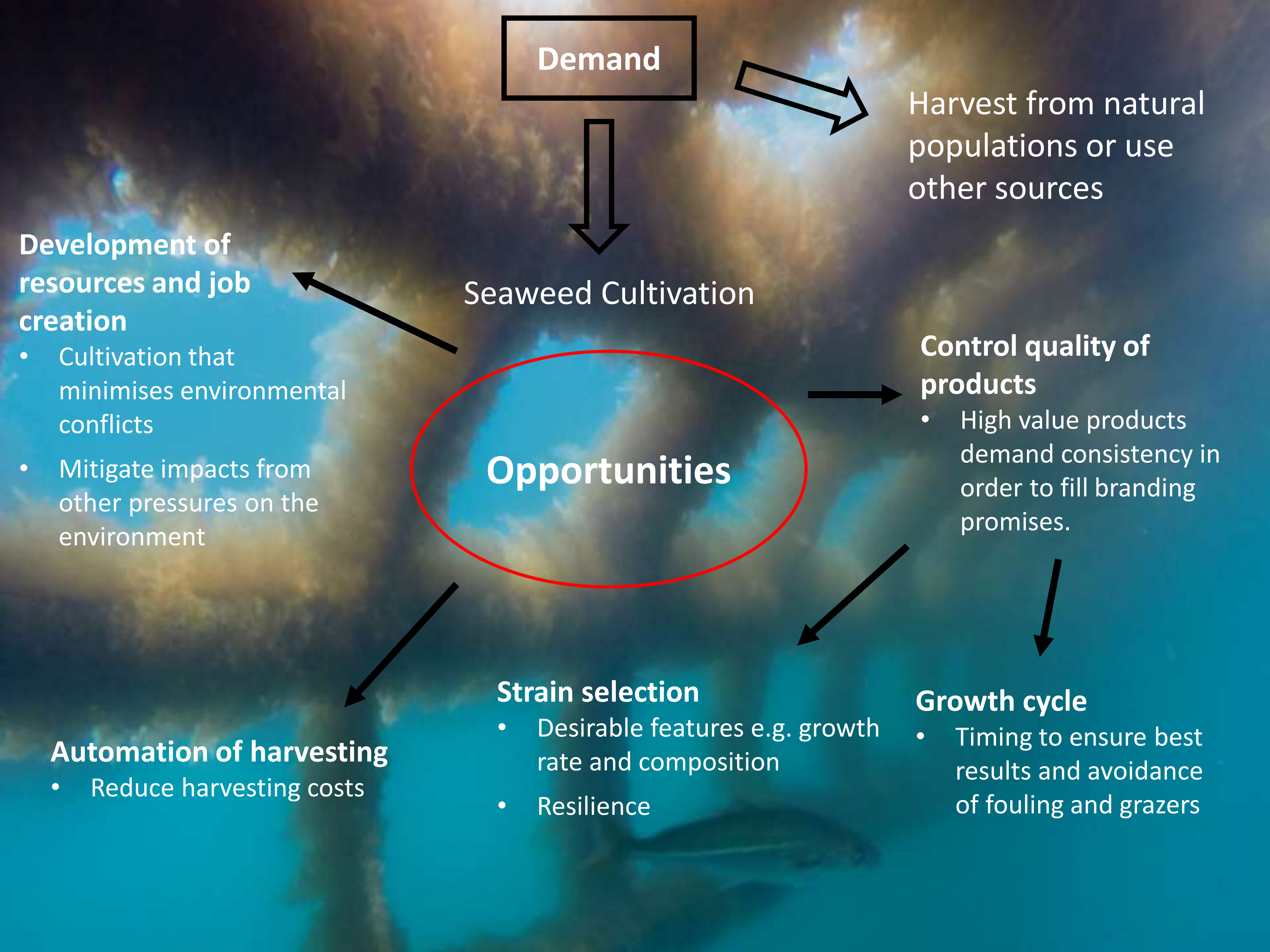
- High value products demand consistency in order to fill branding promises.

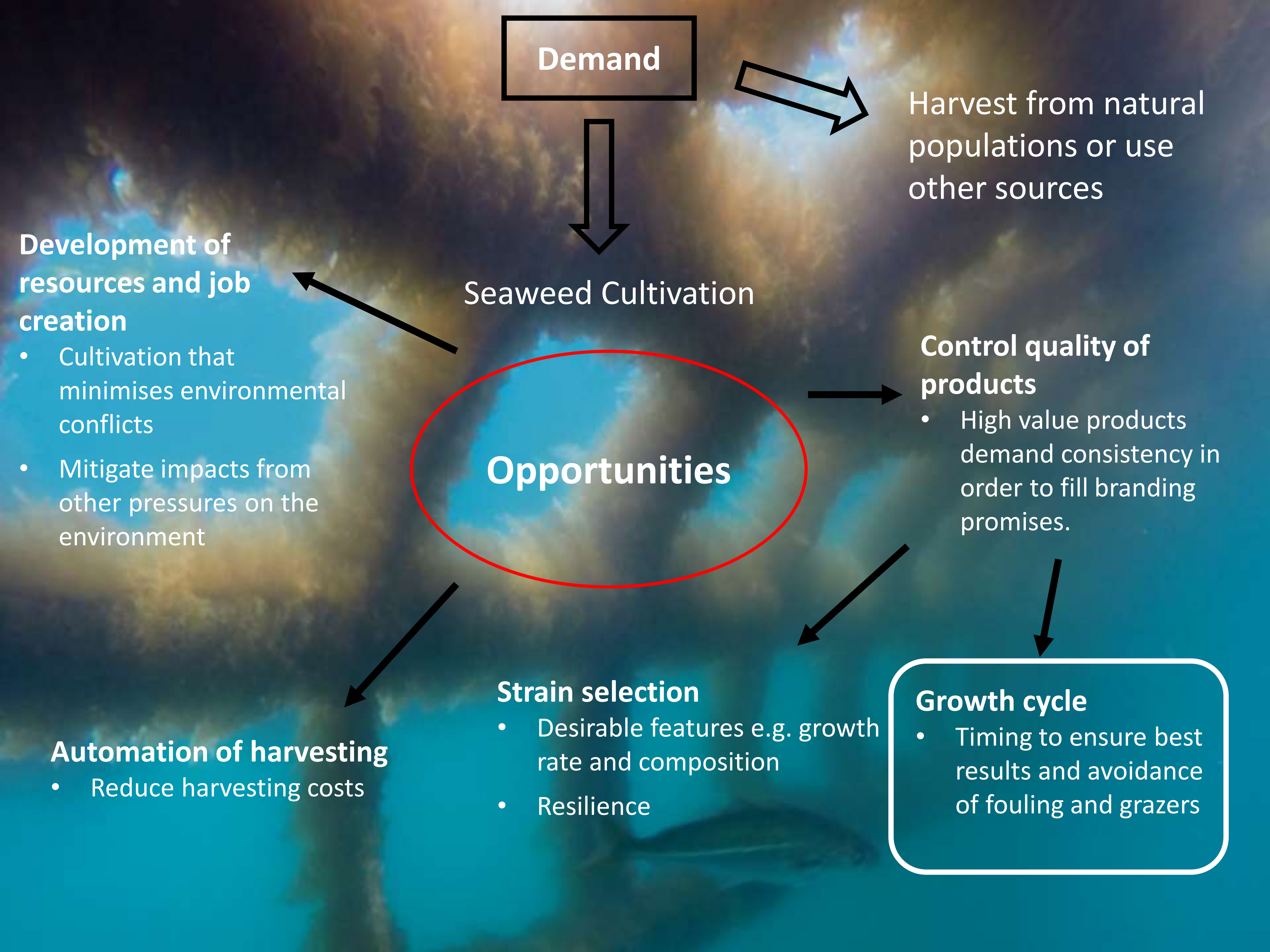
**Automation of harvesting**

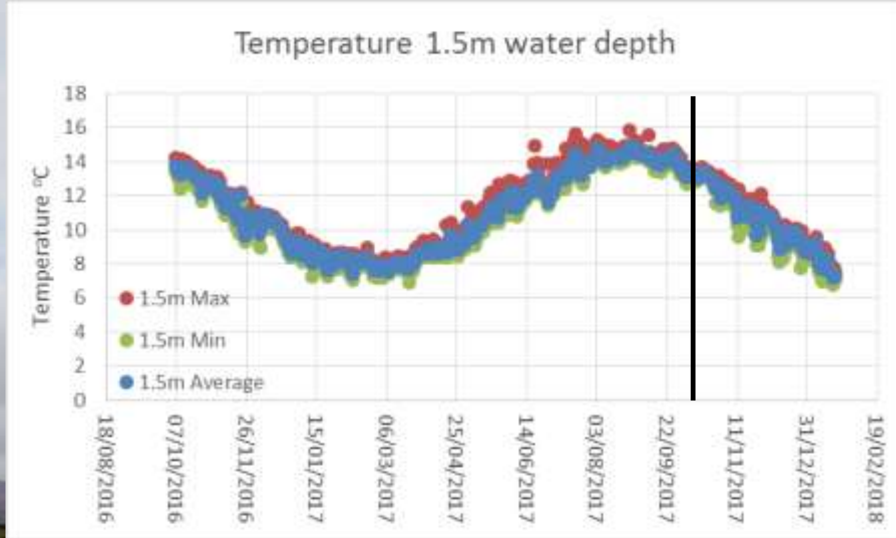
- Reduce harvesting costs

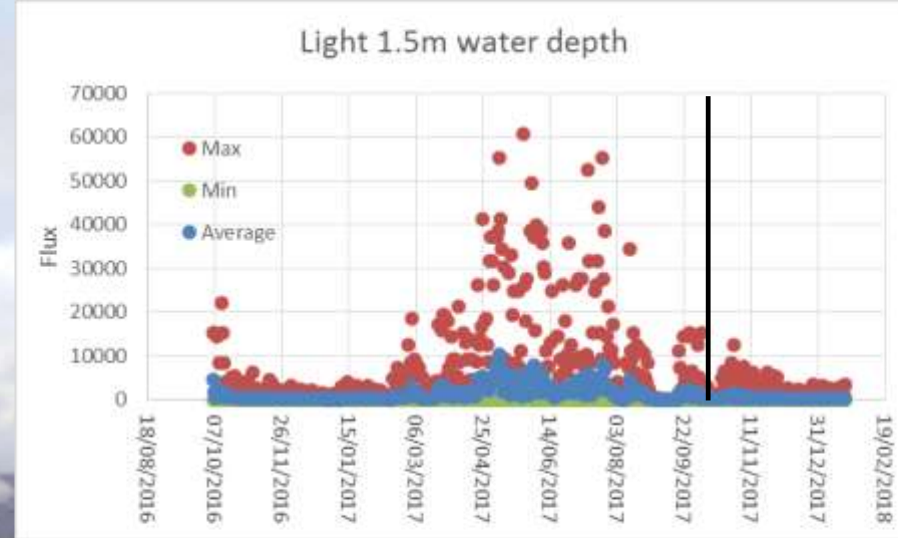
**Strain selection**

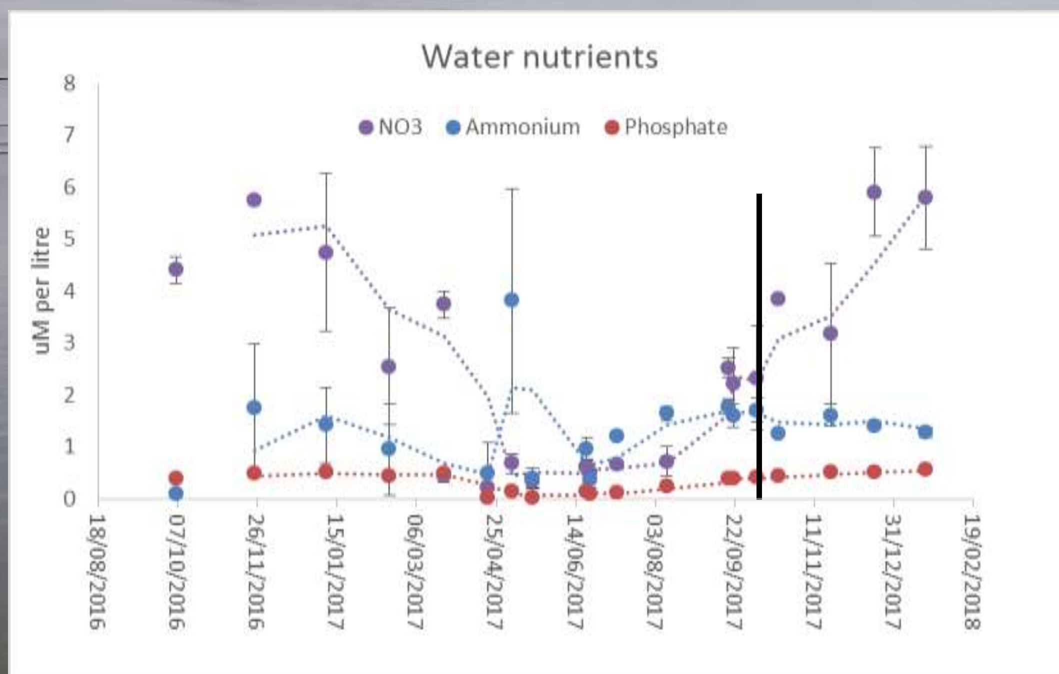
- Desirable features e.g. growth rate and composition
- Resilience


Demand
Harvest from natural populations or use other sources
Seaweed Cultivation
Development of resources and job creation
• Cultivation that minimises environmental conflicts
• Mitigate impacts from other pressures on the environment
Opportunities
Control quality of products
• High value products demand consistency in order to fill branding promises.
Automation of harvesting
• Reduce harvesting costs
Strain selection
• Desirable features e.g. growth rate and composition
• Resilience
Growth cycle
• Timing to ensure best results and avoidance of fouling and grazers

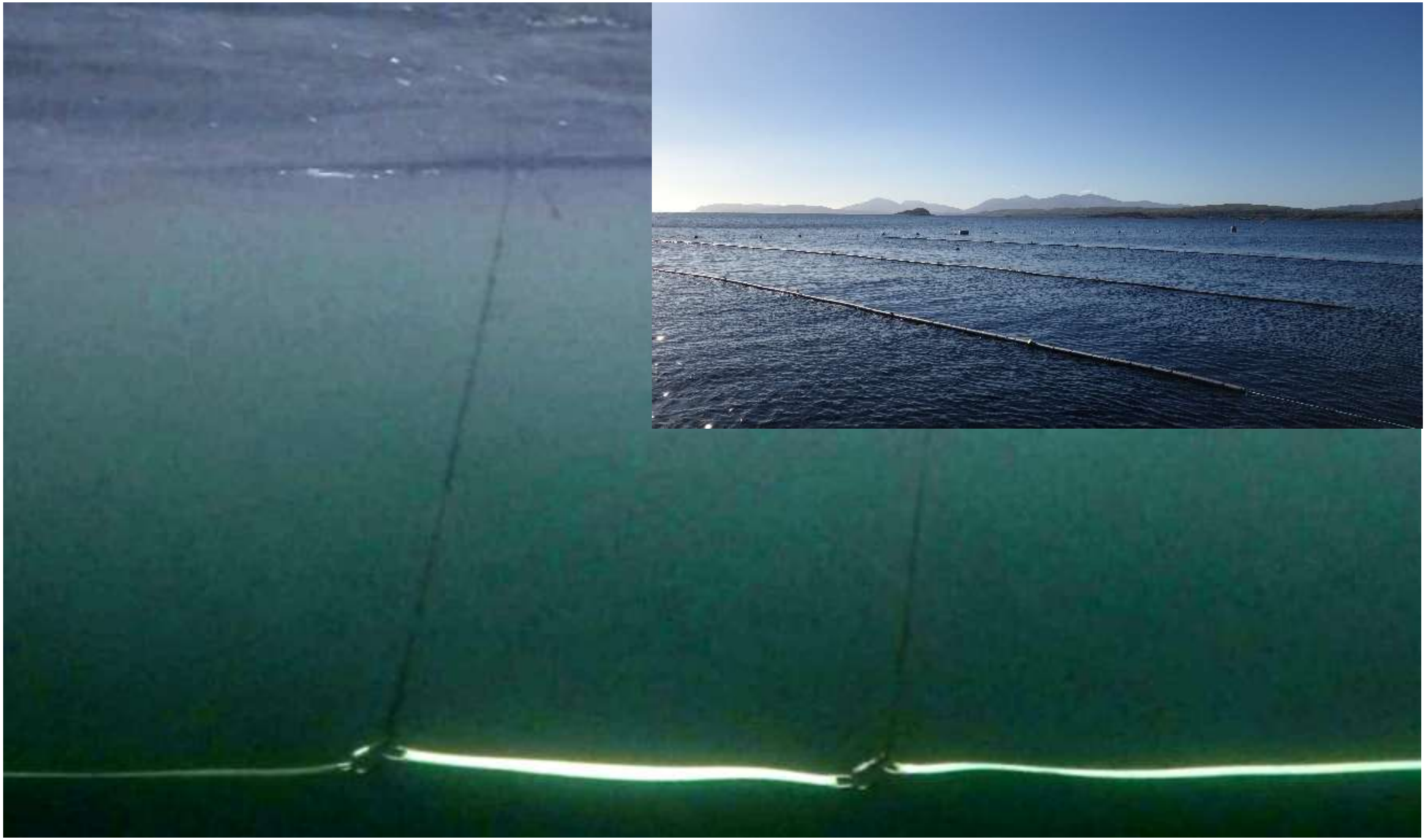

Demand
Harvest from natural populations or use other sources
Seaweed Cultivation
Development of resources and job creation
• Cultivation that minimises environmental conflicts
• Mitigate impacts from other pressures on the environment
Opportunities
Control quality of products
• High value products demand consistency in order to fill branding promises.
Automation of harvesting
• Reduce harvesting costs
Strain selection
• Desirable features e.g. growth rate and composition
• Resilience
Growth cycle
• Timing to ensure best results and avoidance of fouling and grazers


Temperature 1.5m water depth
Temperature °C
1.5m Max
1.5m Min
1.5m Average
0
2
4
6
8
10
12
14
16
18
18/08/2016
07/10/2016
26/11/2016
15/01/2017
06/03/2017
25/04/2017
14/06/2017
03/08/2017
22/09/2017
11/11/2017
31/12/2017
19/02/2018


Light 1.5m water depth
Flux
Max
Min
Average
0
10000
20000
30000
40000
50000
60000
70000
18/08/2016
07/10/2016
26/11/2016
15/01/2017
06/03/2017
25/04/2017
14/06/2017
03/08/2017
22/09/2017
11/11/2017
31/12/2017
19/02/2018

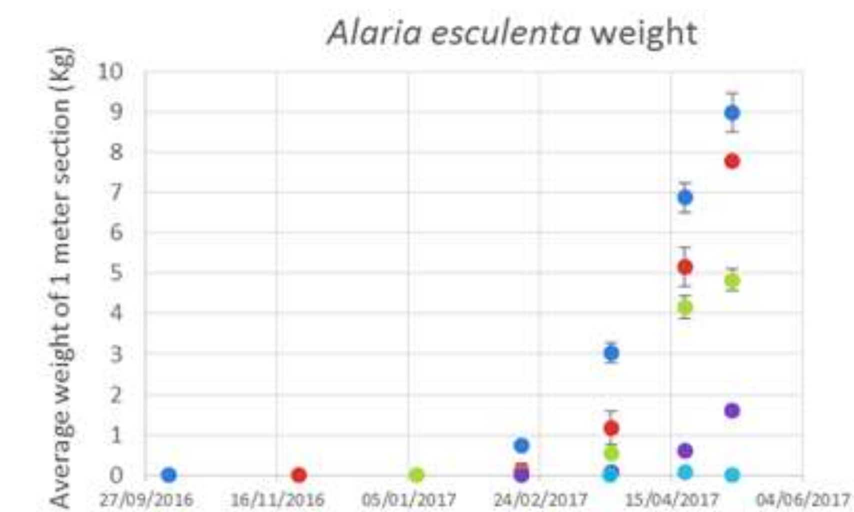

Water nutrients
uM per litre
NO3
Ammonium
Phosphate
0
1
2
3
4
5
6
7
8
18/08/2016
07/10/2016
26/11/2016
15/01/2017
06/03/2017
25/04/2017
14/06/2017
03/08/2017
22/09/2017
11/11/2017
31/12/2017
19/02/2018

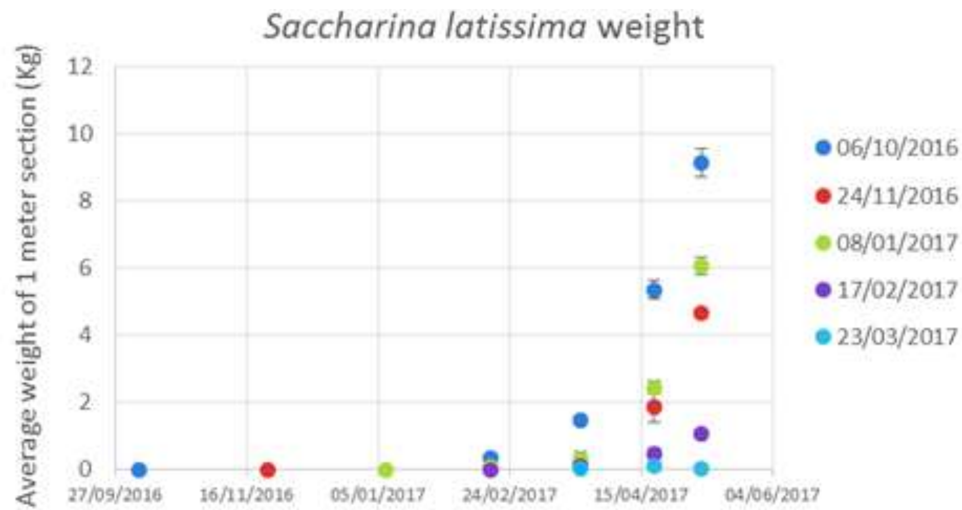
# Optimising growing conditions



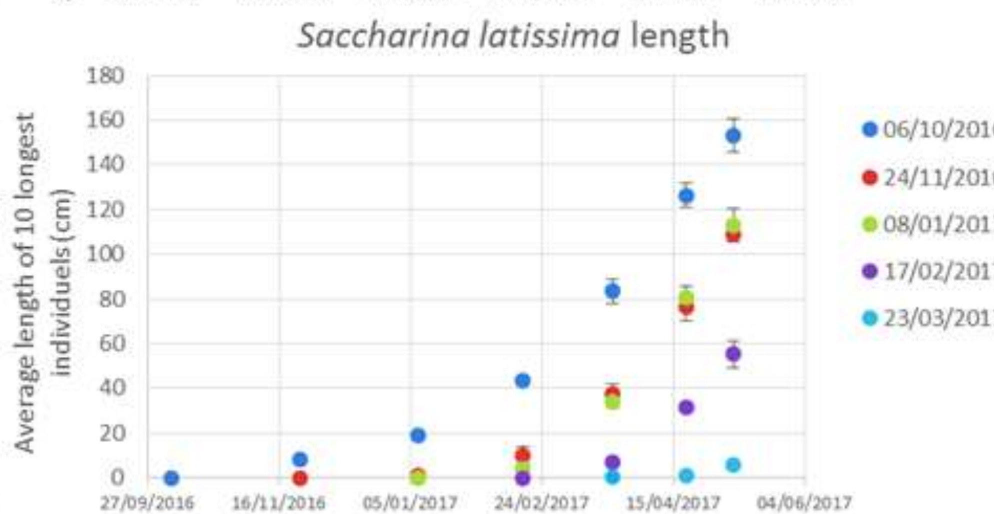
**Seeding time and coppicing experimental lines with 1 m test section.**

# Time of out-planting



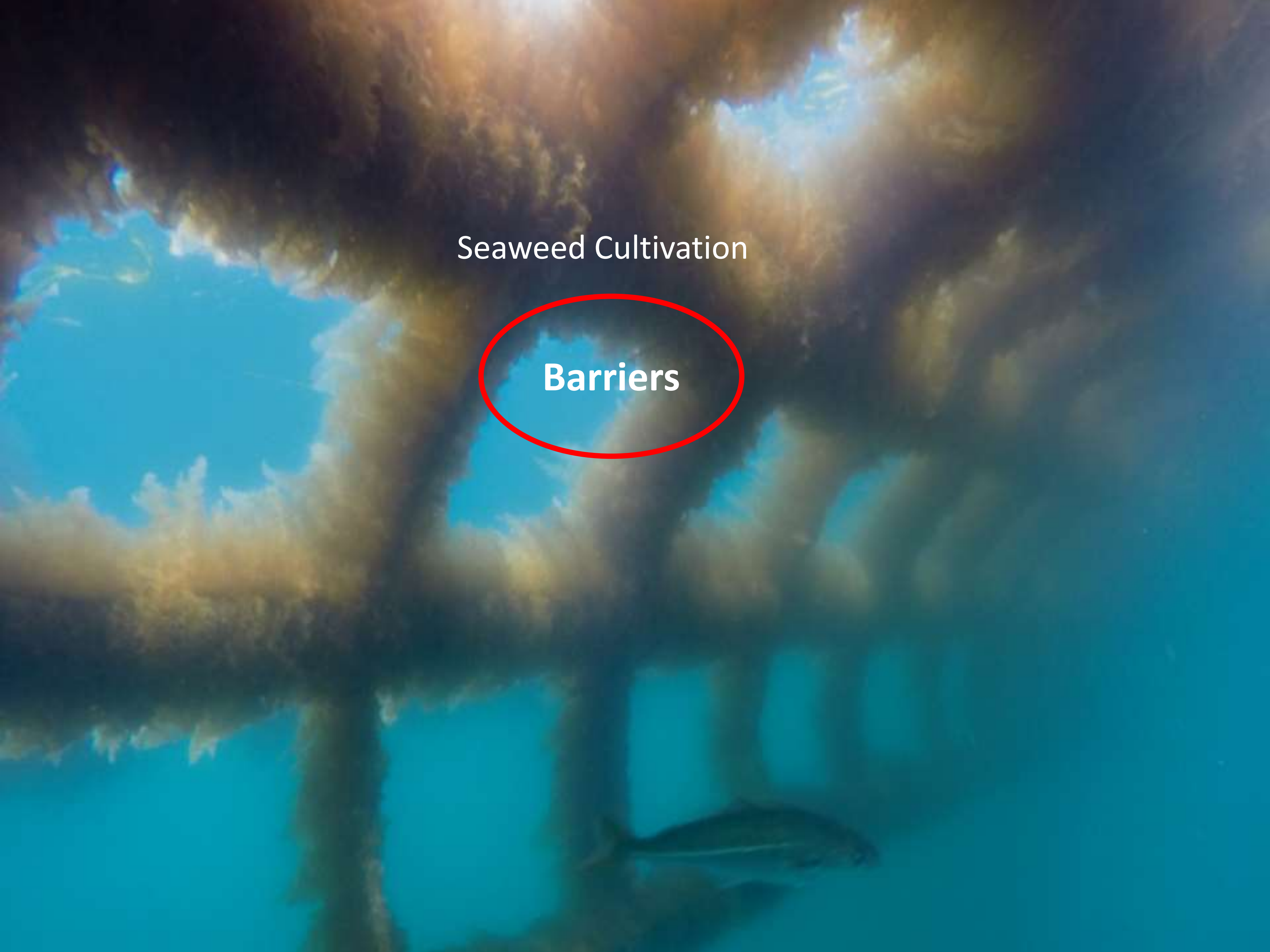



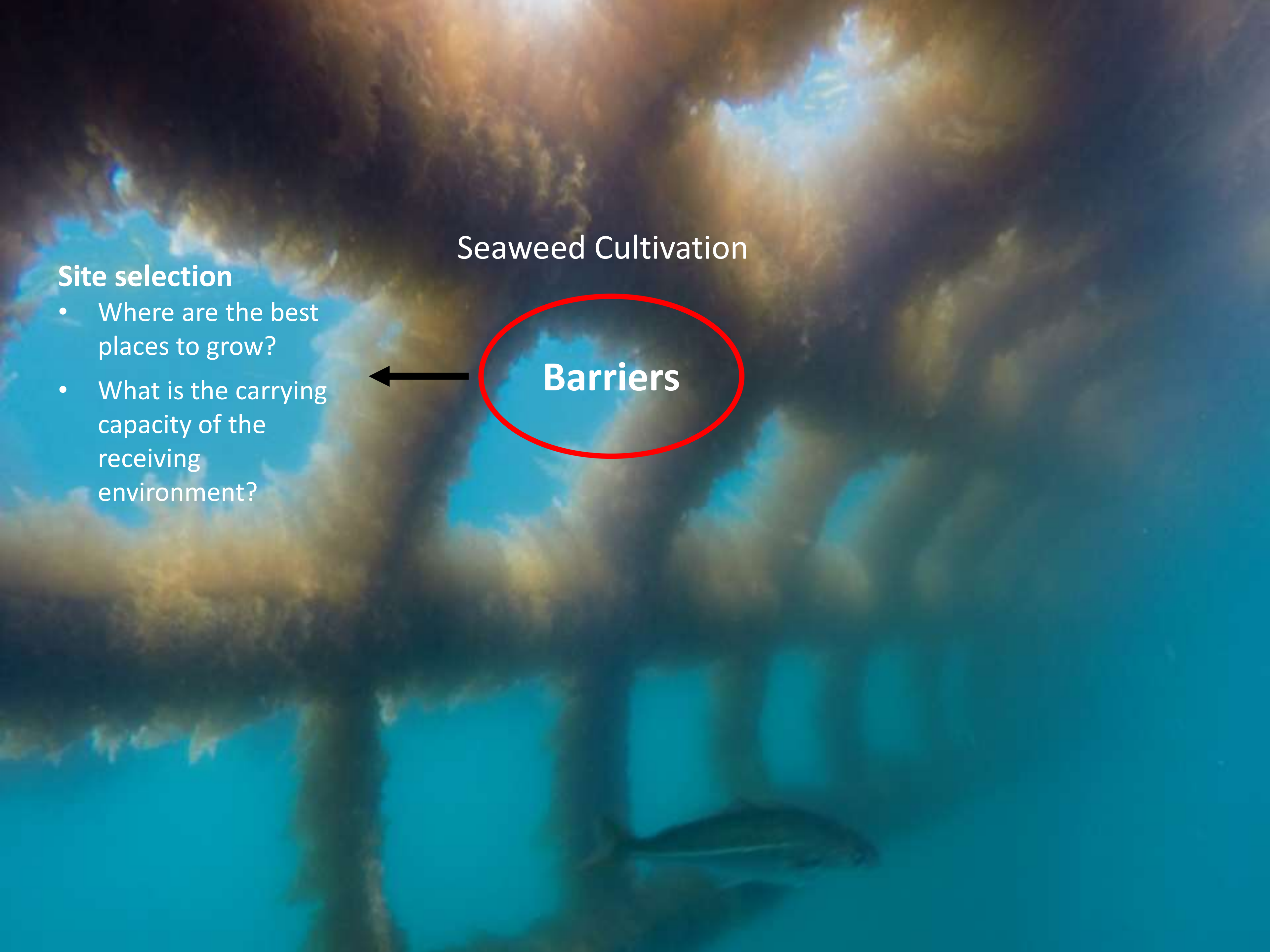


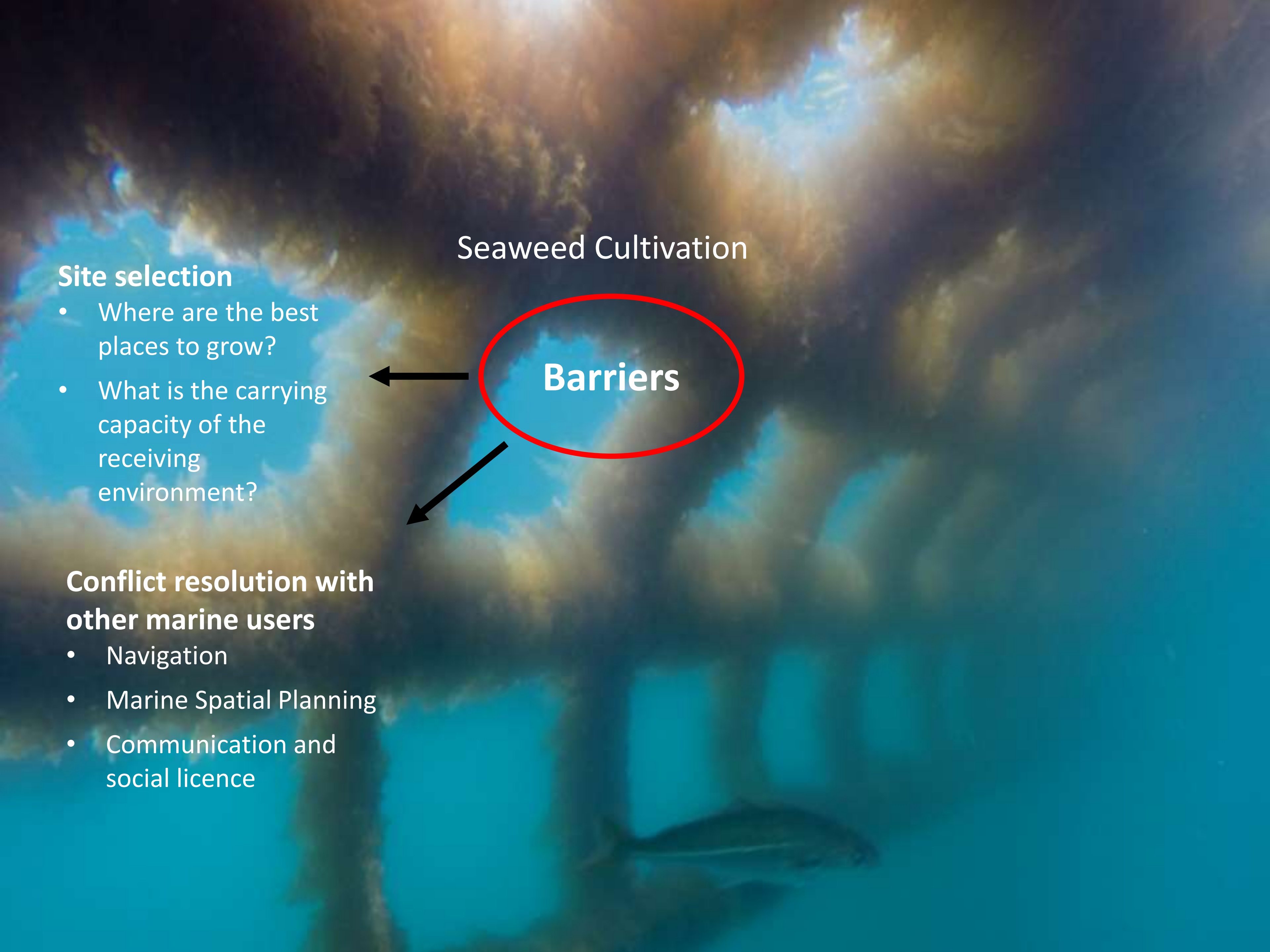



STORMFORCE


Seaweed Cultivation


Seaweed Cultivation
Barriers


Seaweed Cultivation
Site selection
Where are the best places to grow?
What is the carrying capacity of the receiving environment?
Barriers



Seaweed Cultivation

**Barriers**

**Site selection**

- Where are the best places to grow?
- What is the carrying capacity of the receiving environment?

**Conflict resolution with other marine users**

- Navigation
- Marine Spatial Planning
- Communication and social licence

Seaweed Cultivation

**Barriers**

**Site selection**

- Where are the best places to grow?
- What is the carrying capacity of the receiving environment?

**Conflict resolution with other marine users**

- Navigation
- Marine Spatial Planning
- Communication and social licence

**Management of foreseeable problems**

- Disease?
- Other pests?

## Seaweed Cultivation

# Barriers

**Site selection**

- Where are the best places to grow?
- What is the carrying capacity of the receiving environment?

**Infrastructure costs and maintenance**

- Design of mooring and surface cultivations systems e.g. optimal stocking density
- Licencing

**Conflict resolution with other marine users**

- Navigation
- Marine Spatial Planning
- Communication and social licence

**Management of foreseeable problems**

- Disease?
- Other pests?

# Seaweed Cultivation

## Barriers

**Site selection**

- Where are the best places to grow?
- What is the carrying capacity of the receiving environment?

**Infrastructure costs and maintenance**

- Design of mooring and surface cultivations systems e.g. optimal stocking density
- Licencing

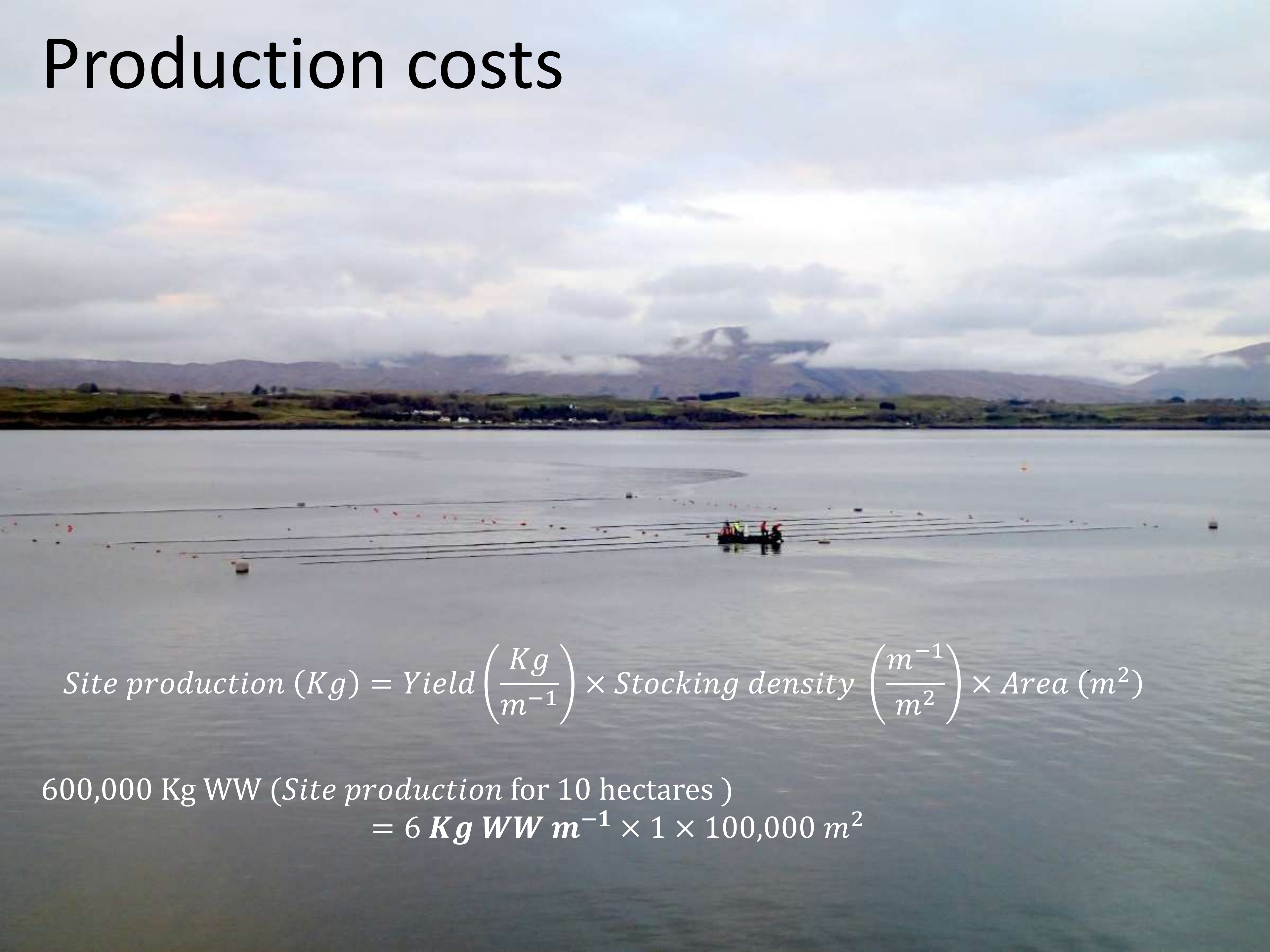
**Conflict resolution with other marine users**

- Navigation
- Marine Spatial Planning
- Communication and social licence

**Management of foreseeable problems**

- Disease?
- Other pests?

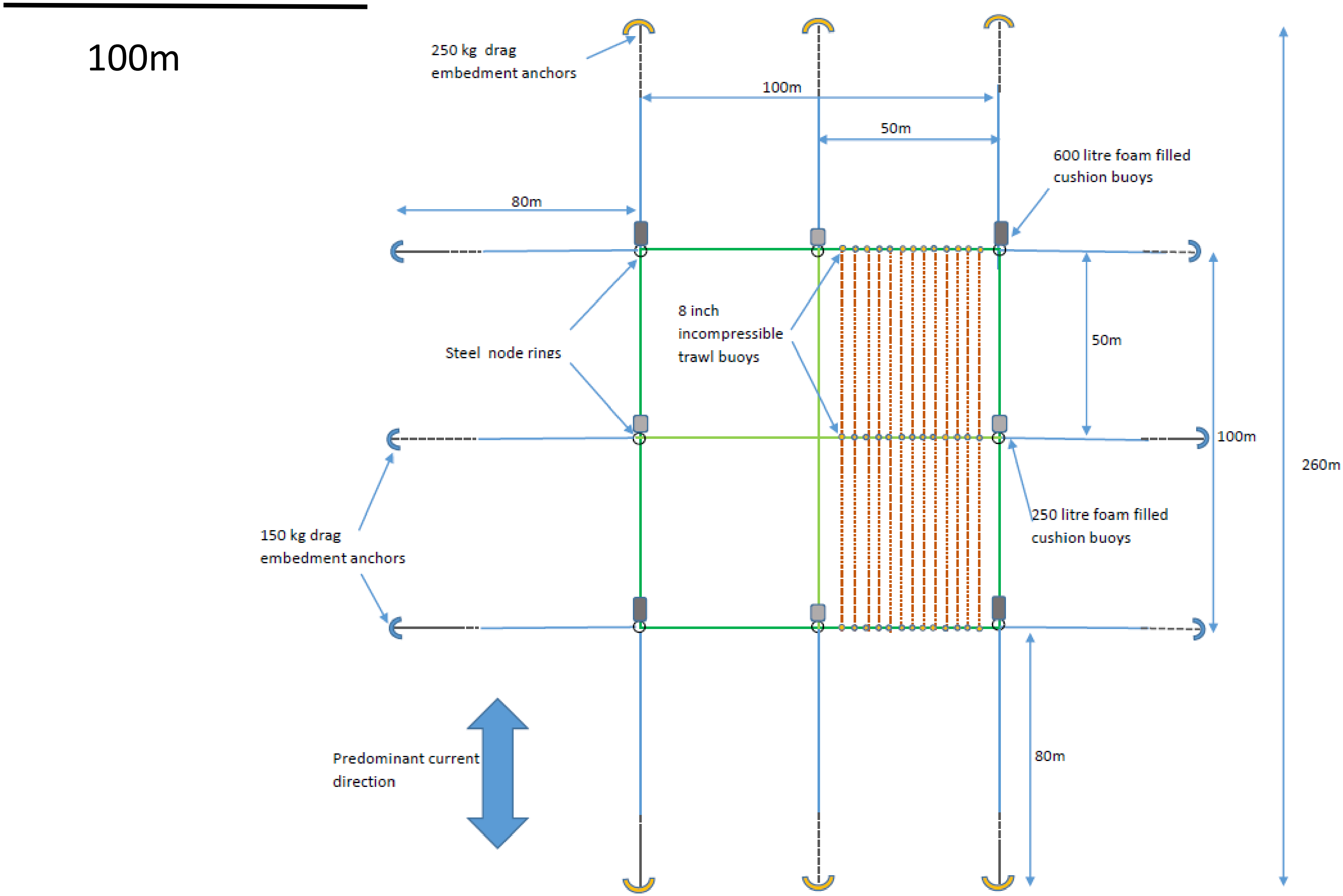
# Production costs



$$Site\ production\ (Kg) = Yield\left(\frac{Kg}{m^{-1}}\right) \times Stocking\ density\ \left(\frac{m^{-1}}{m^2}\right) \times Area\ (m^2)$$

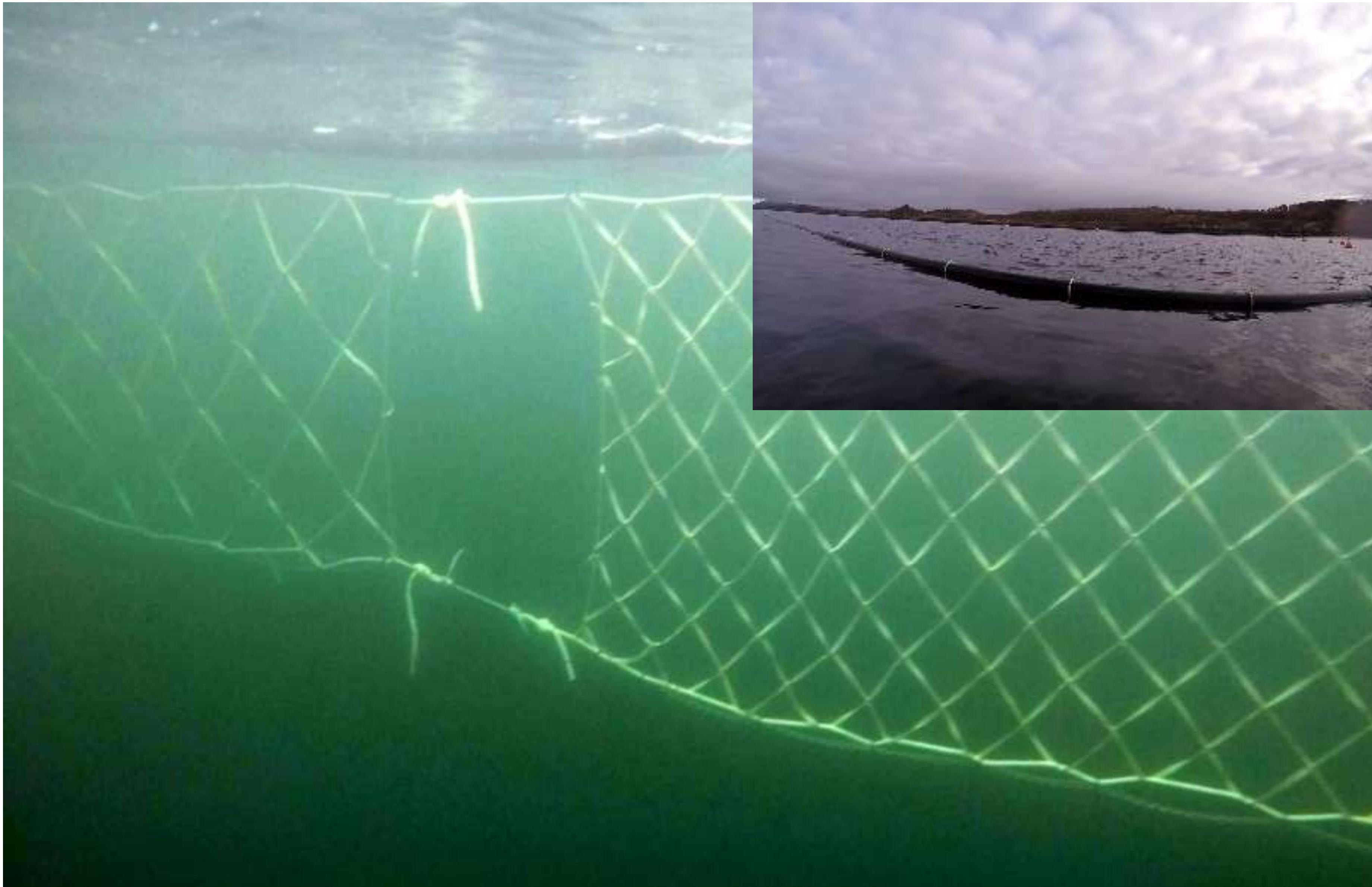
600,000 Kg WW (*Site production* for 10 hectares )

$$= 6\ \boldsymbol{Kg\ WW\ m^{-1}} \times 1 \times 100{,}000\ m^2$$

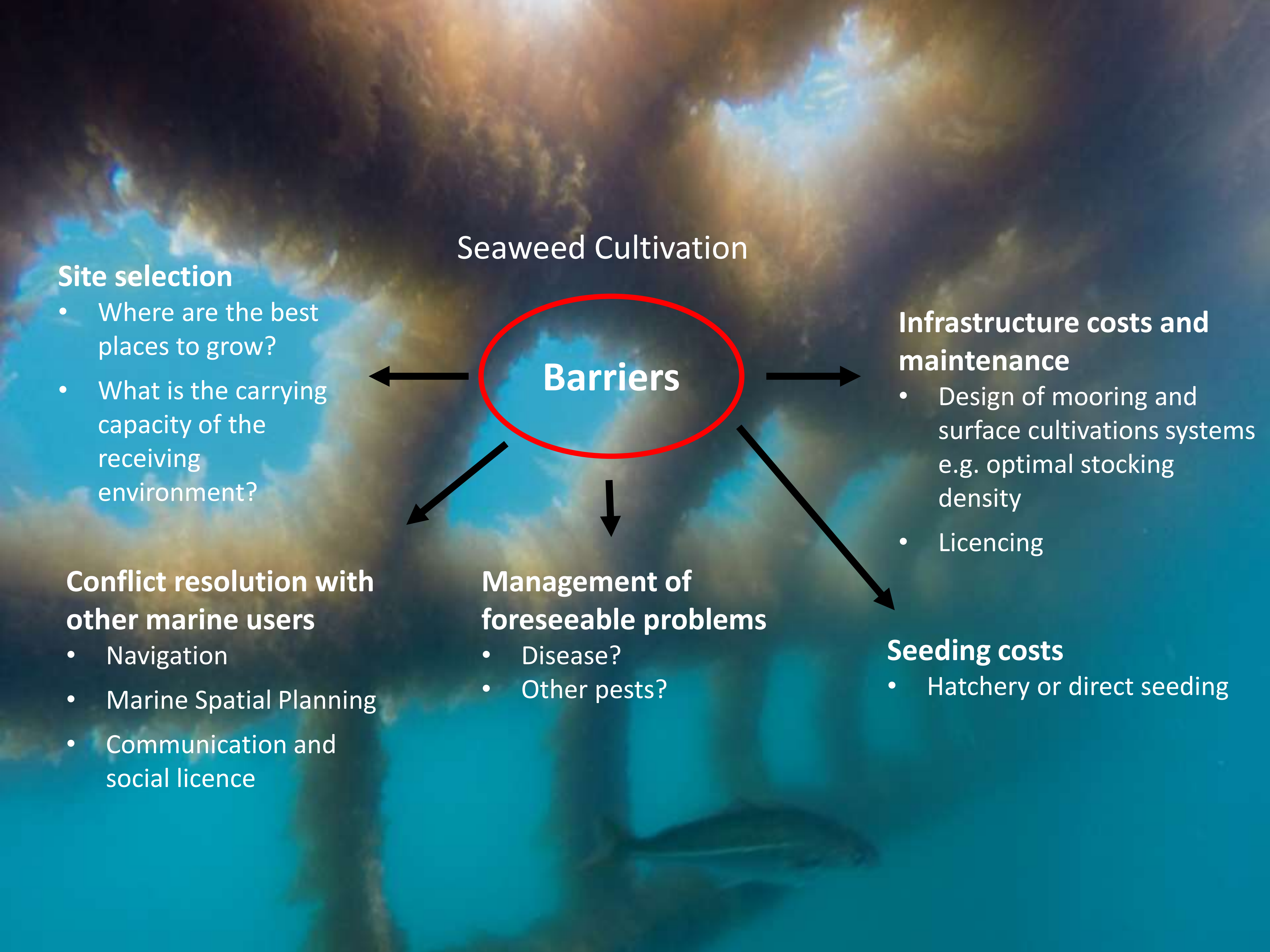



100x100m grid with the capacity for 2.4 kilometre of line. We would like to expand our site by deploying a second larger grid whilst increasing stocking densities and developing surface cultivation systems

# Surface cultivation systems



# Automation


Seaweed Cultivation
Barriers
Site selection
• Where are the best places to grow?
• What is the carrying capacity of the receiving environment?
Infrastructure costs and maintenance
• Design of mooring and surface cultivations systems e.g. optimal stocking density
• Licencing
Conflict resolution with other marine users
• Navigation
• Marine Spatial Planning
• Communication and social licence
Management of foreseeable problems
• Disease?
• Other pests?
Seeding costs
• Hatchery or direct seeding

## Seaweed Cultivation

# Barriers

**Site selection**

- Where are the best places to grow?
- What is the carrying capacity of the receiving environment?

**Infrastructure costs and maintenance**

- Design of mooring and surface cultivations systems e.g. optimal stocking density
- Licencing

**Conflict resolution with other marine users**

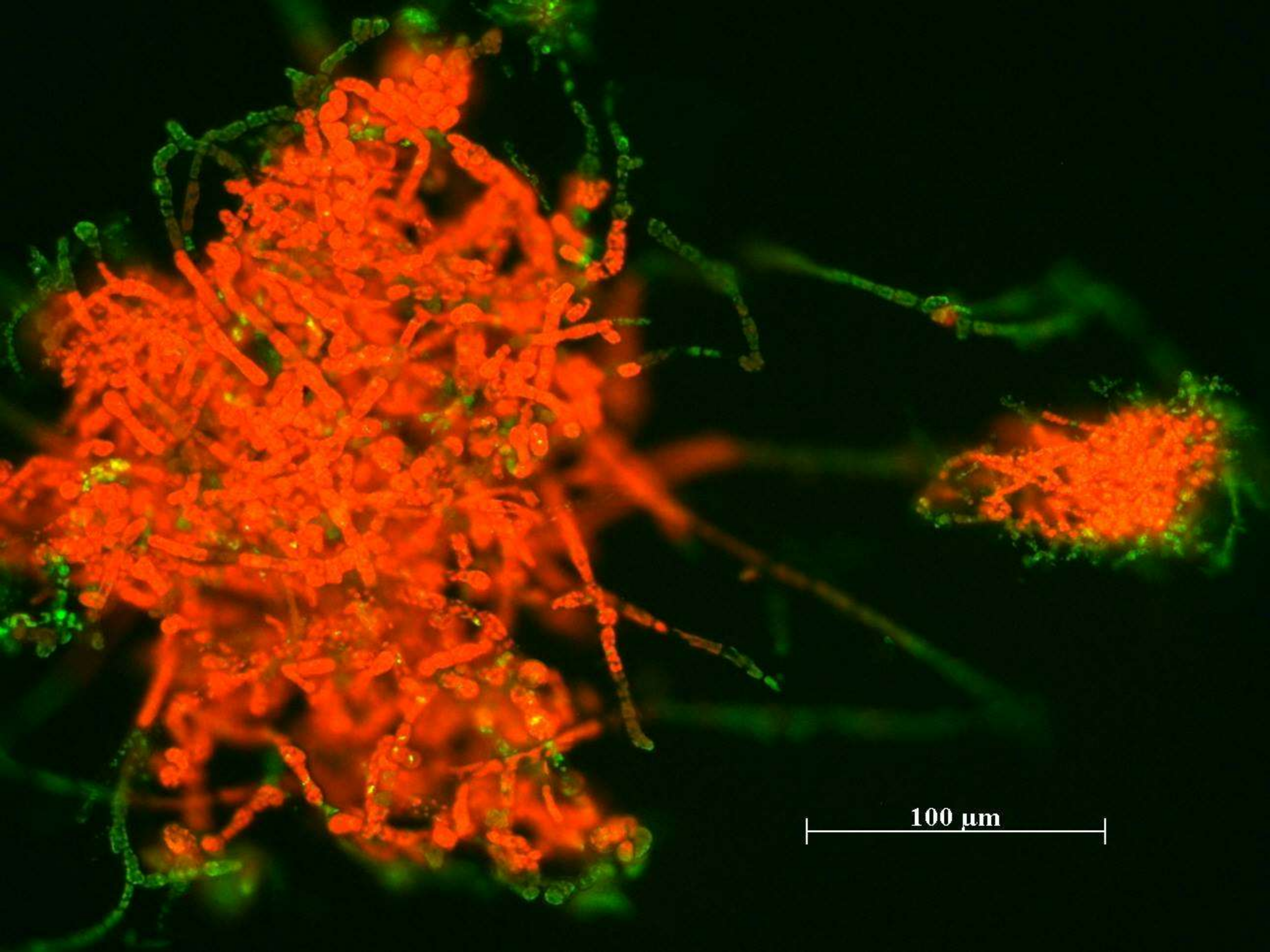
- Navigation
- Marine Spatial Planning
- Communication and social licence

**Management of foreseeable problems**

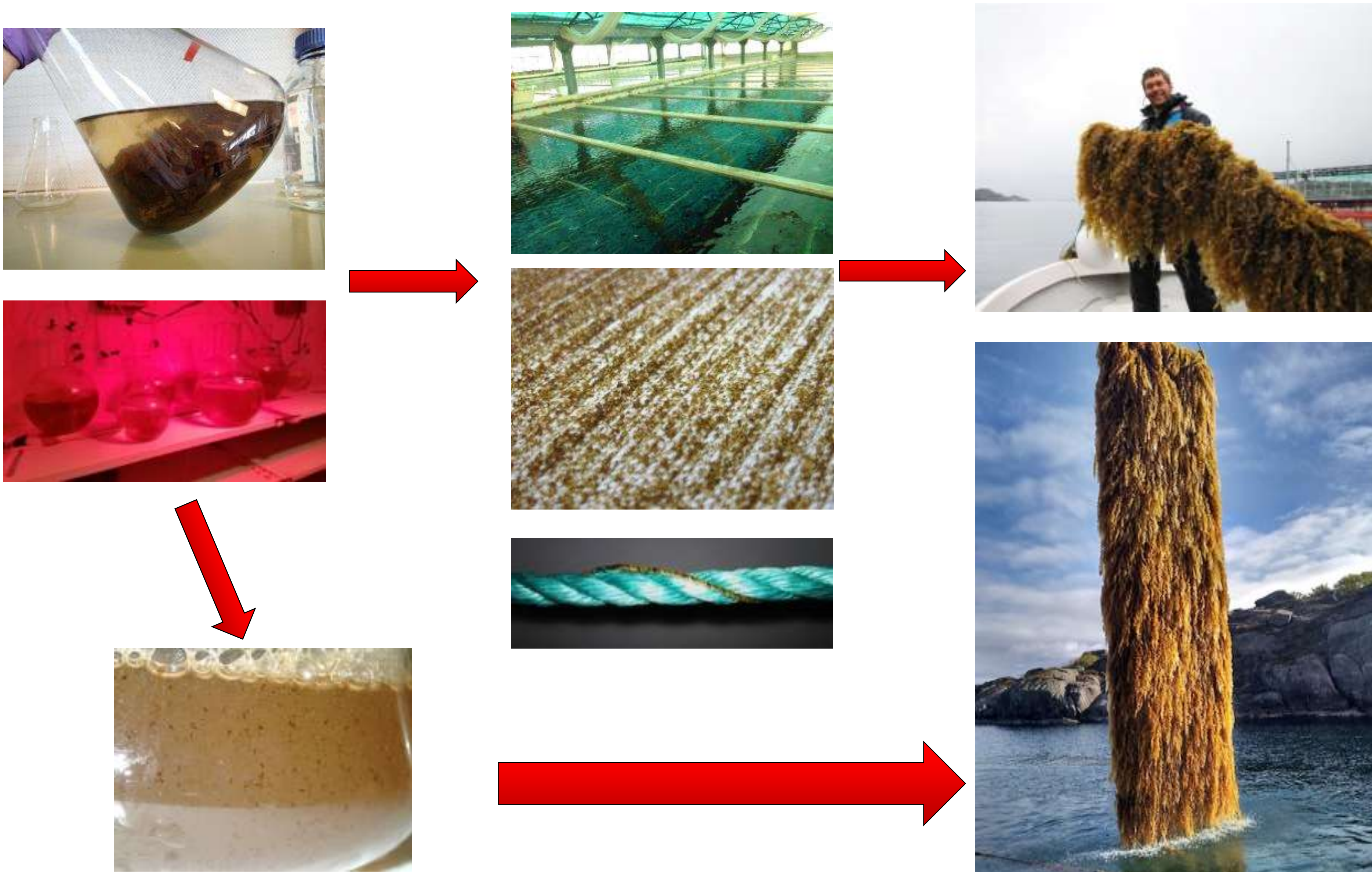
- Disease?
- Other pests?

**Seeding costs**

- Hatchery or direct seeding


100 µm

**Seedstock** | **Hatchery** | **Grow-out**



# Is there an economic business case for seaweed farming?

- **There are opportunities to improve techniques and reduce production costs. Many of these are being trailed at the SAMS seaweed farms (e.g. automated seeding techniques).**

- **Cost of production estimate are variable (£1,383 – £16,000 per tonne DW)**

- **There is a perception that seaweed farming could provide biomass for a wide variety of seaweed applications including animal feed and alginates. However current cultivation techniques would be unlikely to provide sufficient revenue to be economically viable (Van den Burg et al 2016).**

- **Development of alternative economic models and further innovations are necessary to diversify the applications within economic reach. SAMS is undertaking a feasibility study for Argyll and Butte council and the results of this work will be published at the end of the year.**

**£126 per dry tonne of seaweed for production of animal feed (required in large quantities)**

**£752 per dry tonne seaweed for hydrocolloid production (required in large quantities)**


**£14,000 – £120,000 per dry tonne for High value food products (required in small quantities)**

Values taken from Van den Burg et al 2016


FINGAL


STORMFORCE

**REVIEW ARTICLE** Provisionally accepted We'll notify you at publication.

Front. Mar. Sci. | doi: 10.3389/fmars.2019.00107

# The environmental risks associated with the development of seaweed farming in Europe - prioritizing key knowledge gaps

Iona Campbell[1], Adrian Macleod[1*], Christian Sahlmann[2], Luiza Neves[3], Jon Funderud[3], Margareth Overland[2], Adam Hughes[1] and Michele Stanley[1]

[1]Scottish Association For Marine Science, United Kingdom

[2]Norwegian University of Life Sciences, Norway

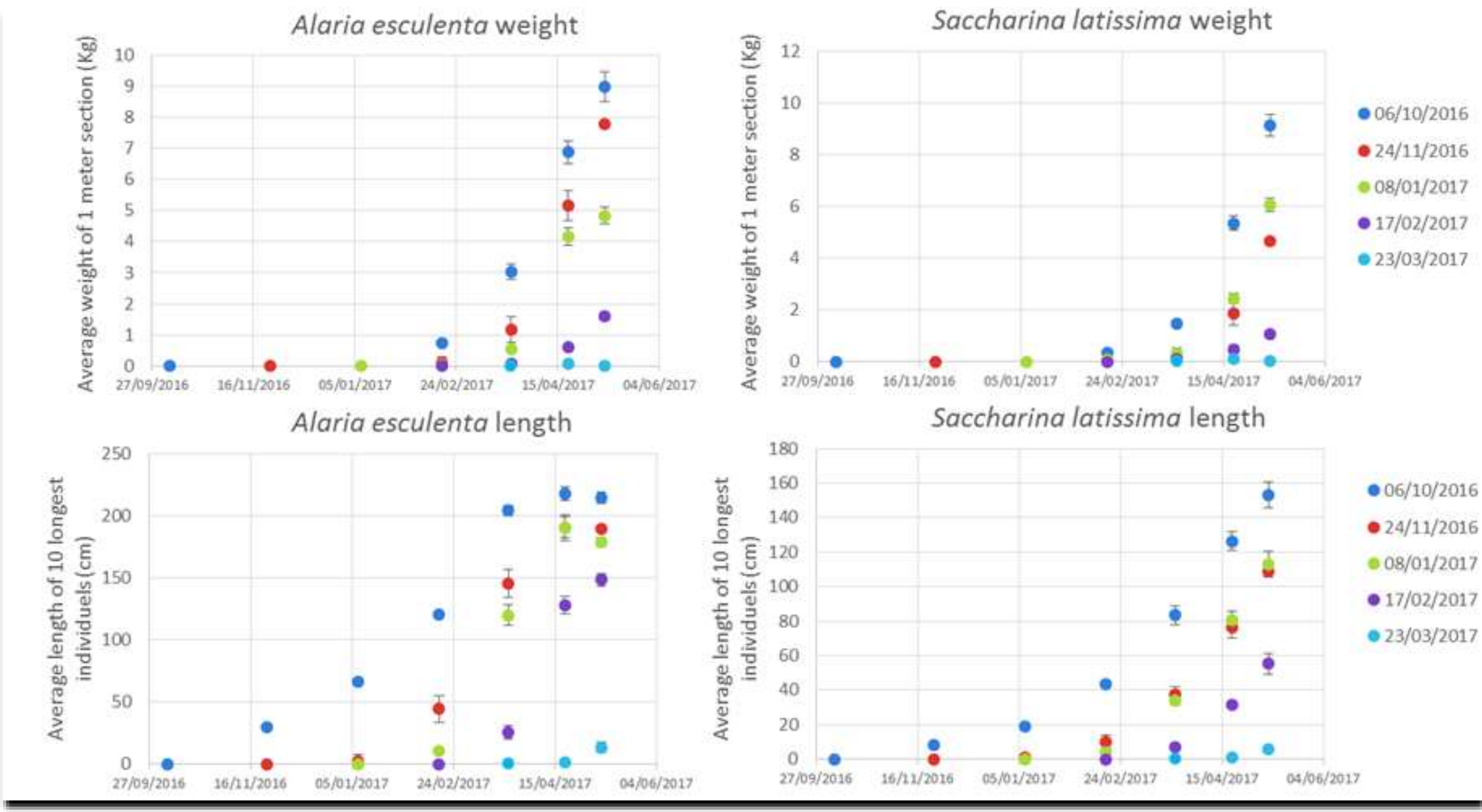
[3]Seaweed Energy Solutions (Norway), Norway

Cultivation of kelp has been well established throughout Asia, and there is now growing interest in the cultivation of macroalgae in Europe to meet future resource needs. If this industry is to become established throughout Europe, then balancing the associated environmental risks with potential benefits will be necessary to ensure the carrying capacity of the receiving environments are not exceeded and conservation objects are not undermined. This is a systematic review of the ecosystem changes likely to be associated with a developing seaweed aquaculture industry. Monitoring recommendations are made by risk ranking environmental changes, highlighting the current knowledge gaps and providing research priorities to address them. Environmental changes of greatest concern were identified to include: facilitation of disease, alteration of population genetics and wider alterations to the local physiochemical environment. Current high levels of uncertainty surrounding the true extent of some environmental changes mean conservative risk rankings are given. Recommended monitoring options are discussed that aim to address uncertainty and facilitate informed decision-making. Whilst current small-scale cultivation projects are considered 'low risk', an expansion of the industry that includes 'large-scale' cultivation will necessitate a more complete understanding of the scale dependent changes in order to balance environmental risks with the benefits that seaweed cultivation projects can offer.

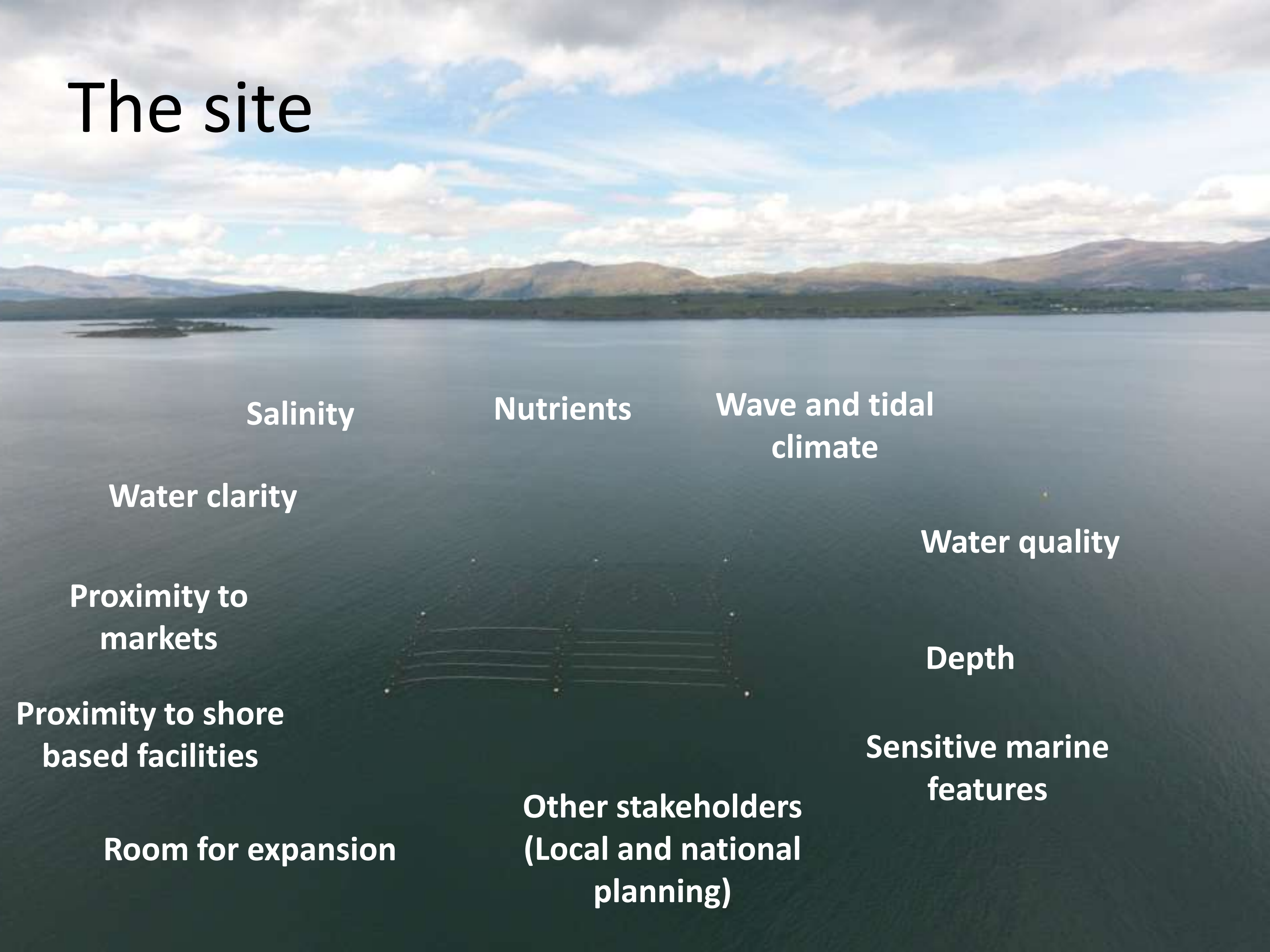
**Marine Scotland**: Marine Scotland has a vision for Scottish seas to deliver sustainable economic growth through "clean, healthy, safe, productive, biologically diverse marine coastal environments, managed to meet the long-term needs of nature and people".

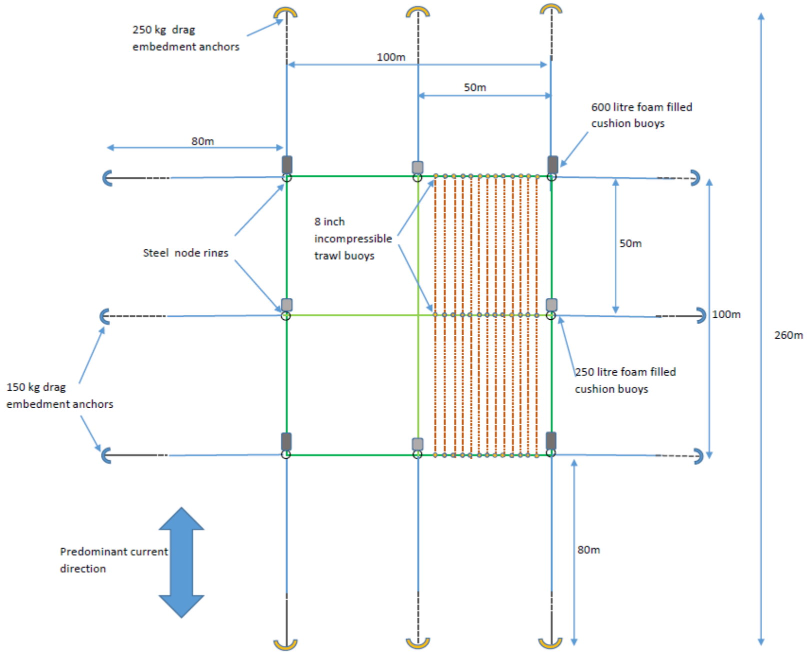
**A Seaweed farming business**: To think differently about managing marine resources for the benefit of nature and people, to create clean, healthy, food, feeds, nutraceuticals, pharmaceuticals, and other products

# Time of out-planting initial results



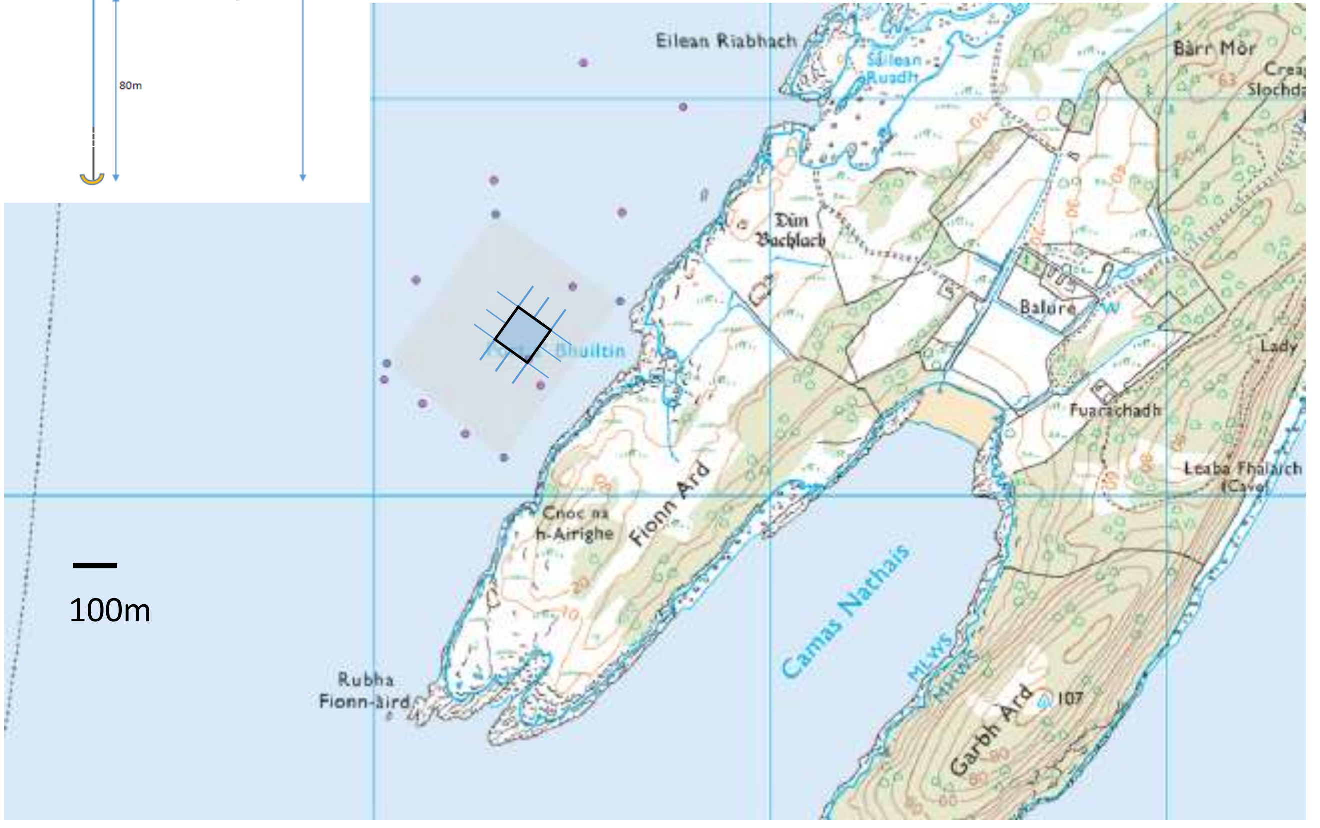
# The site


Salinity
Nutrients
Wave and tidal climate
Water clarity
Water quality
Proximity to markets
Depth
Proximity to shore based facilities
Sensitive marine features
Room for expansion
Other stakeholders (Local and national planning)

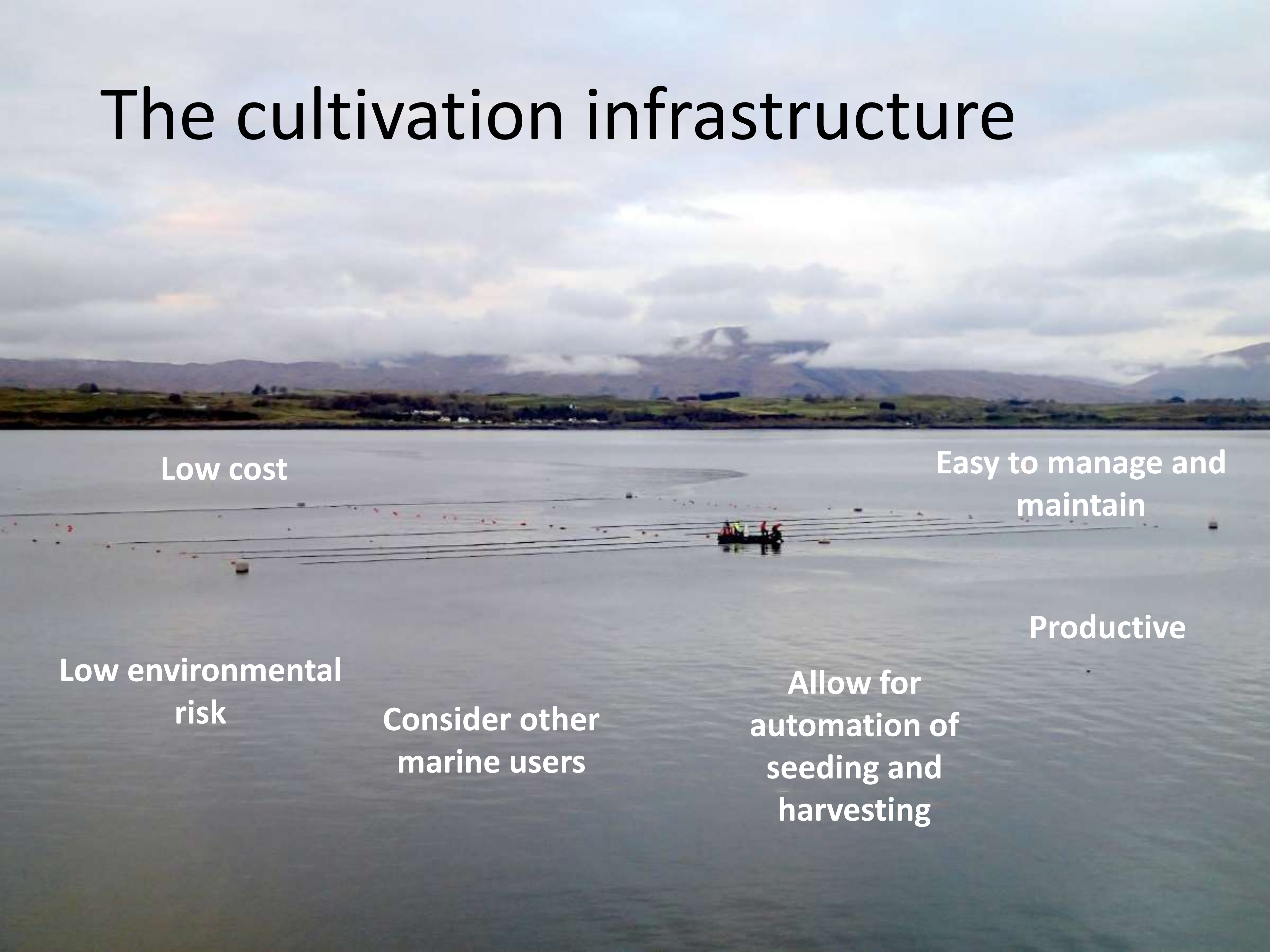



**Port a Bhuiltin (2014)**

Currently a single 100 x 100m grid deployed

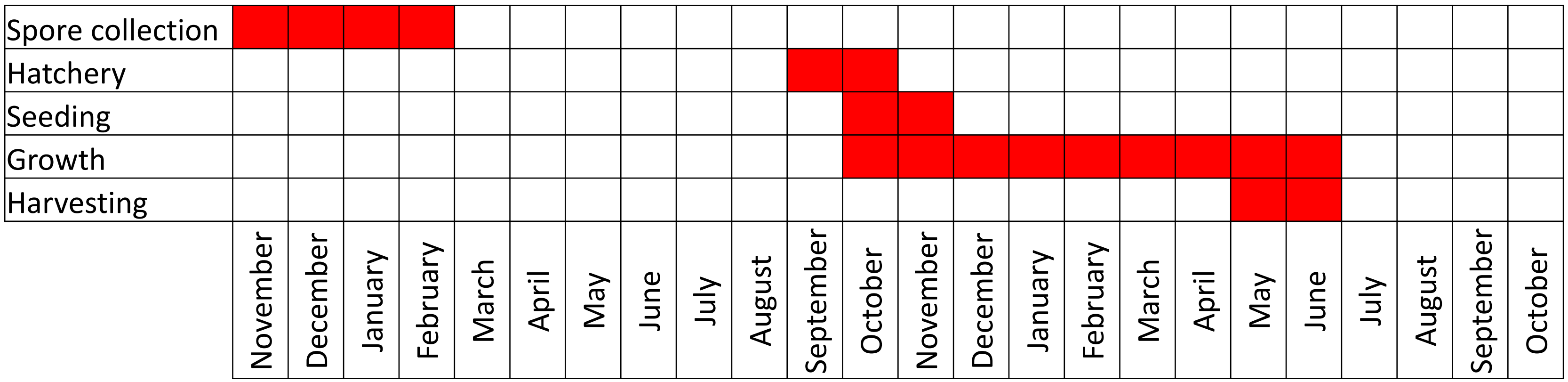


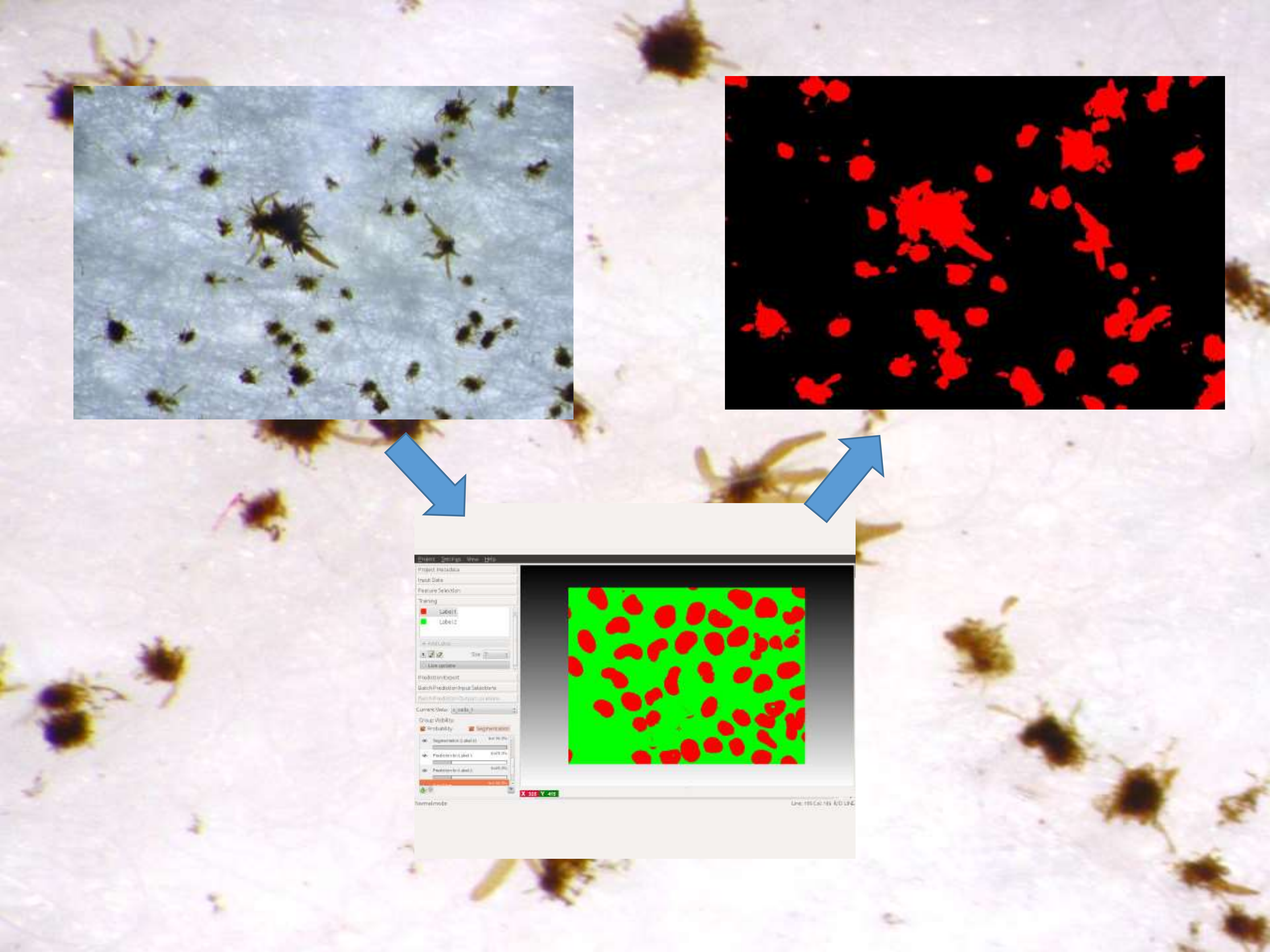
# The cultivation infrastructure



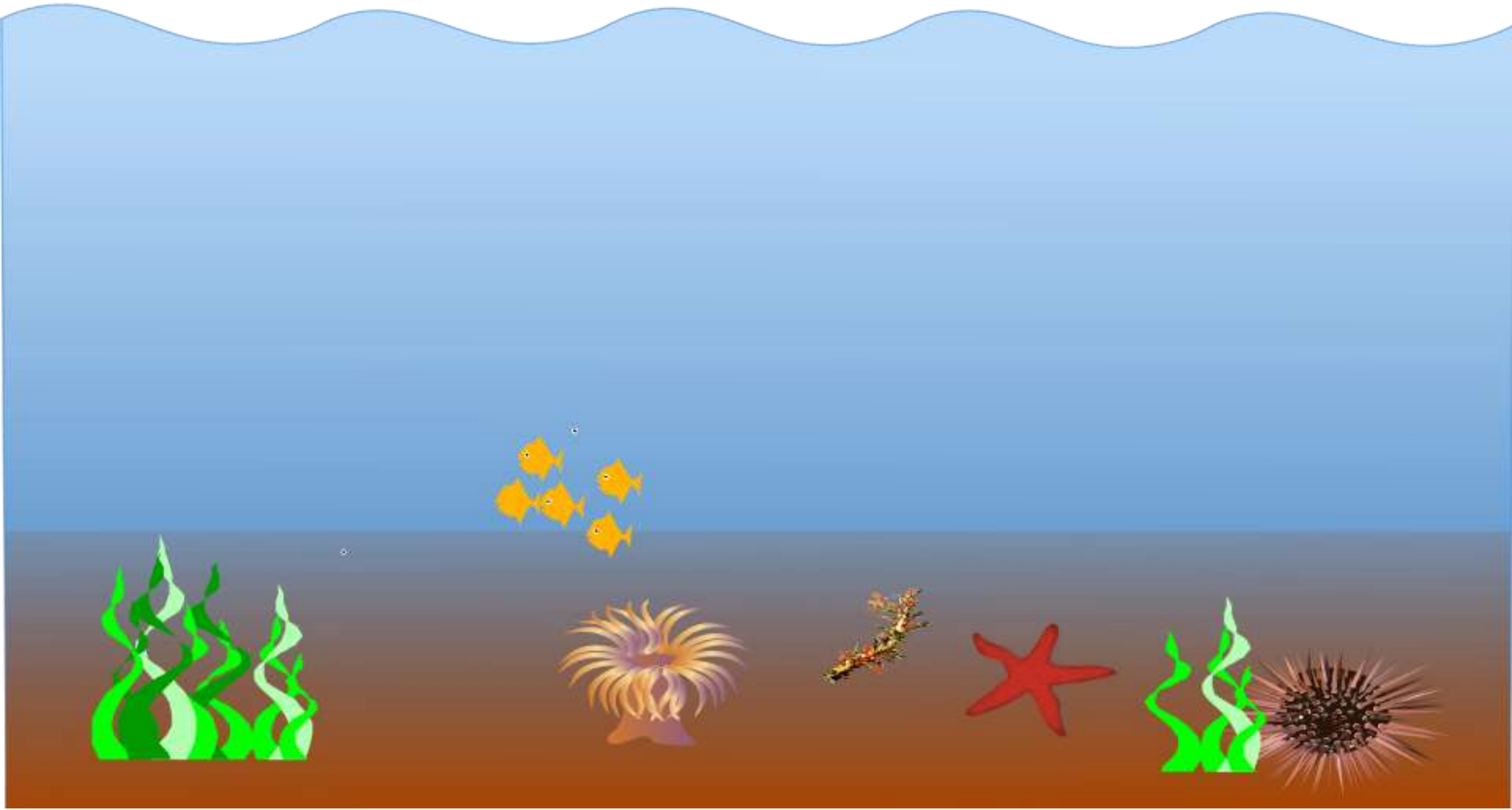
# Cultivation Season

**Deploy: Autumn - Winter**
**Harvest: Spring - Summer**

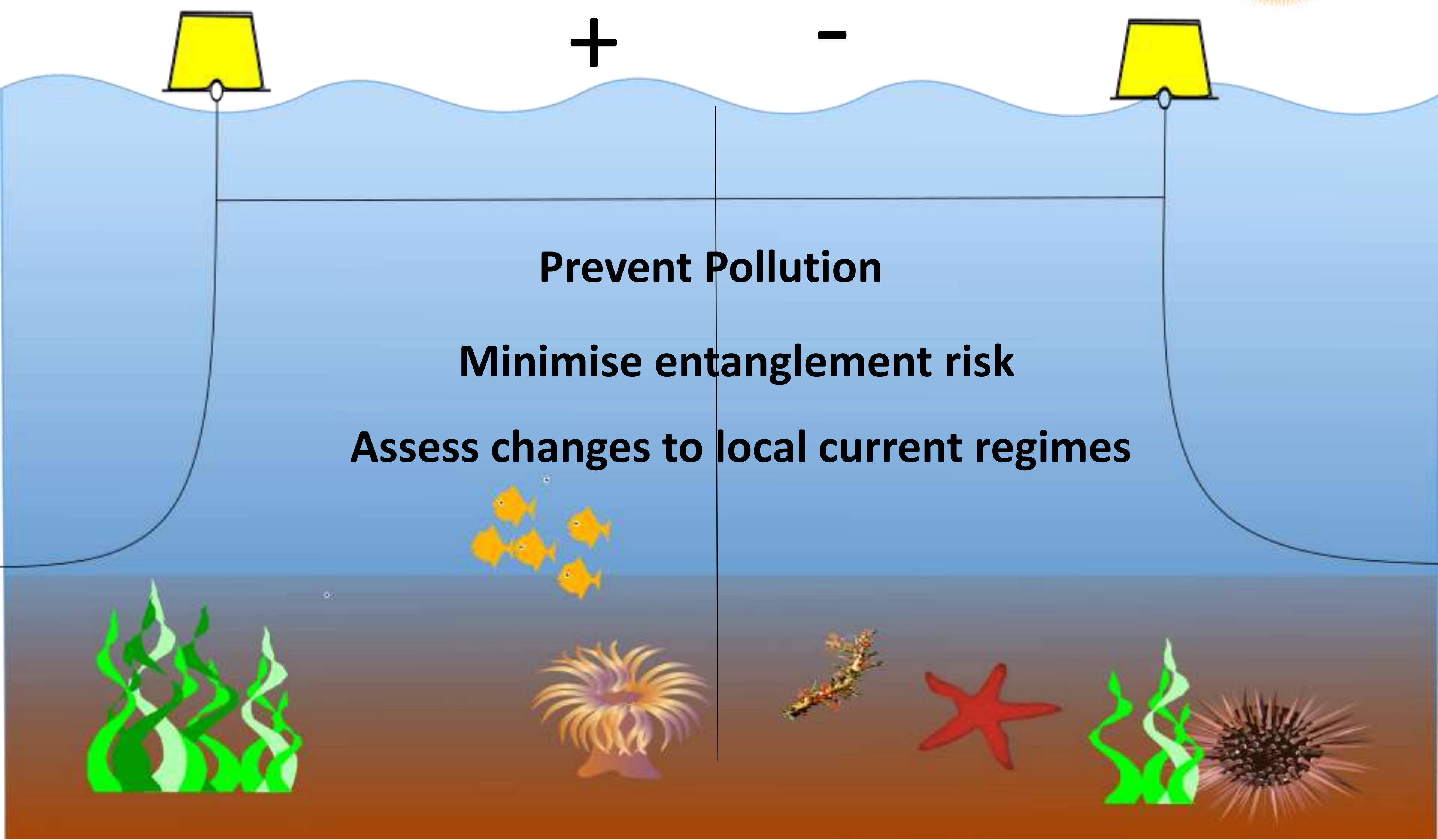




Input Data
Training
Label 1
Label 2
Batch Prediction Input Selections

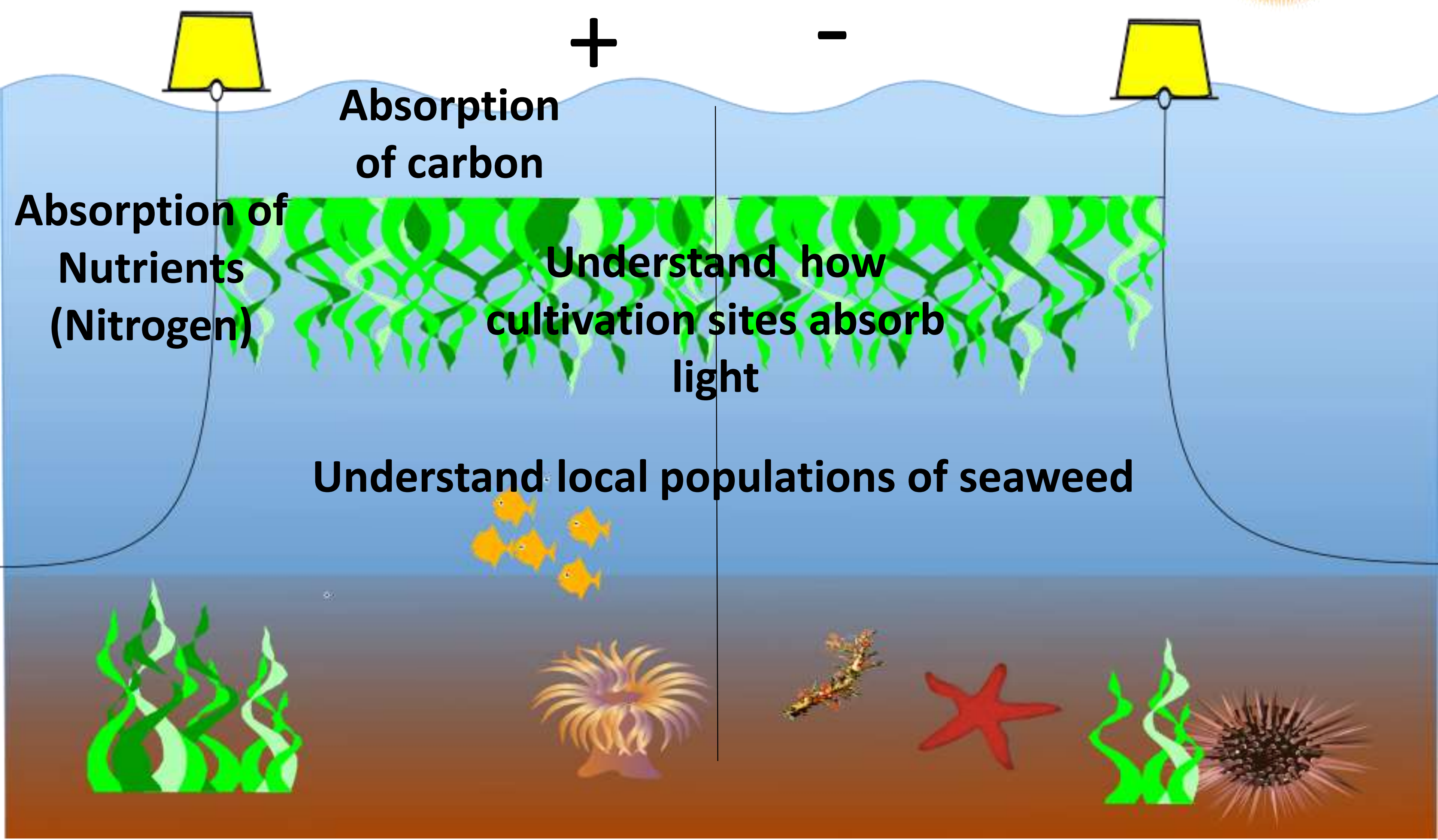
# What are the possible environmental interactions?



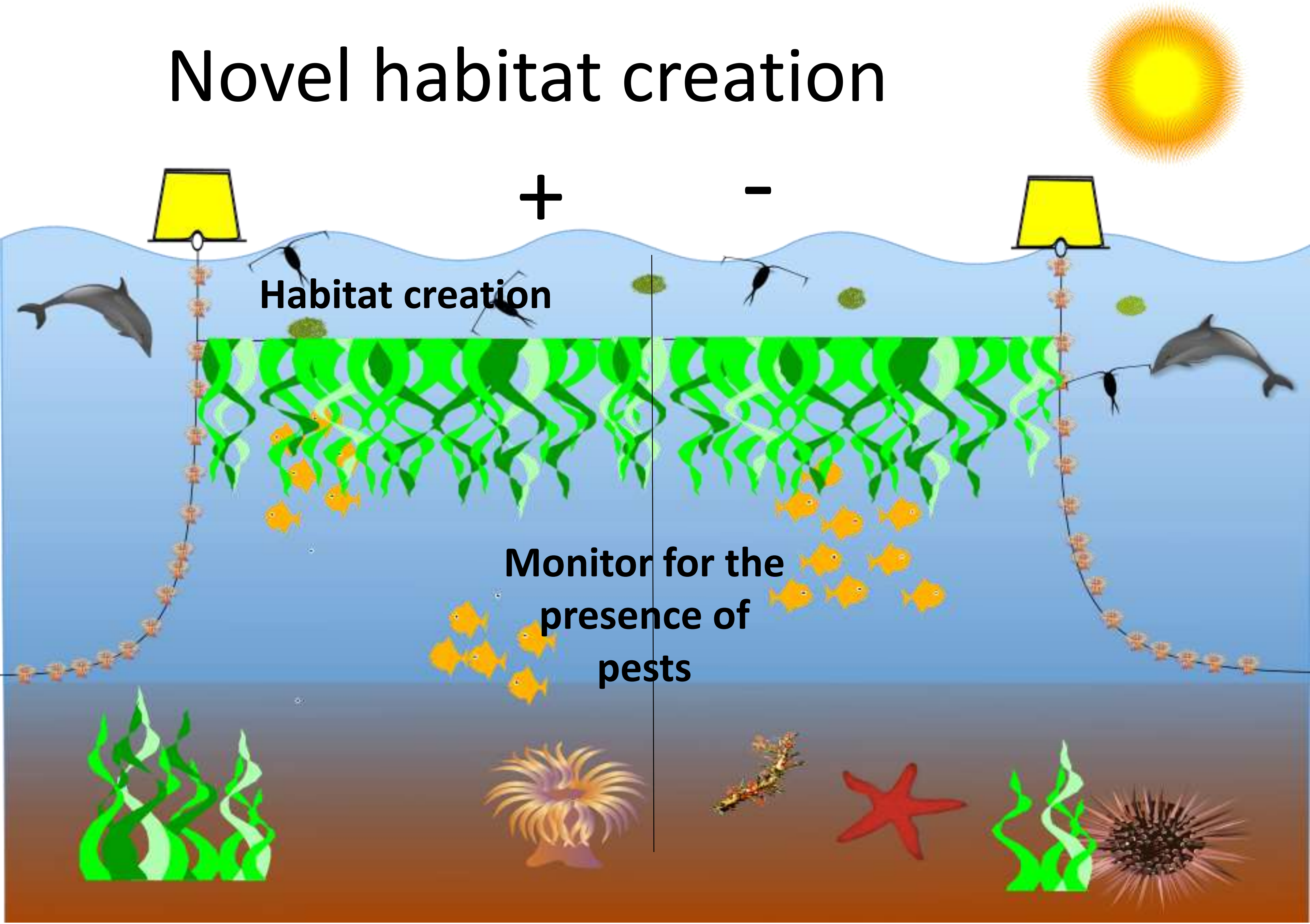
# Deployment of growing structures



# Cultivation requirements



# Novel habitat creation

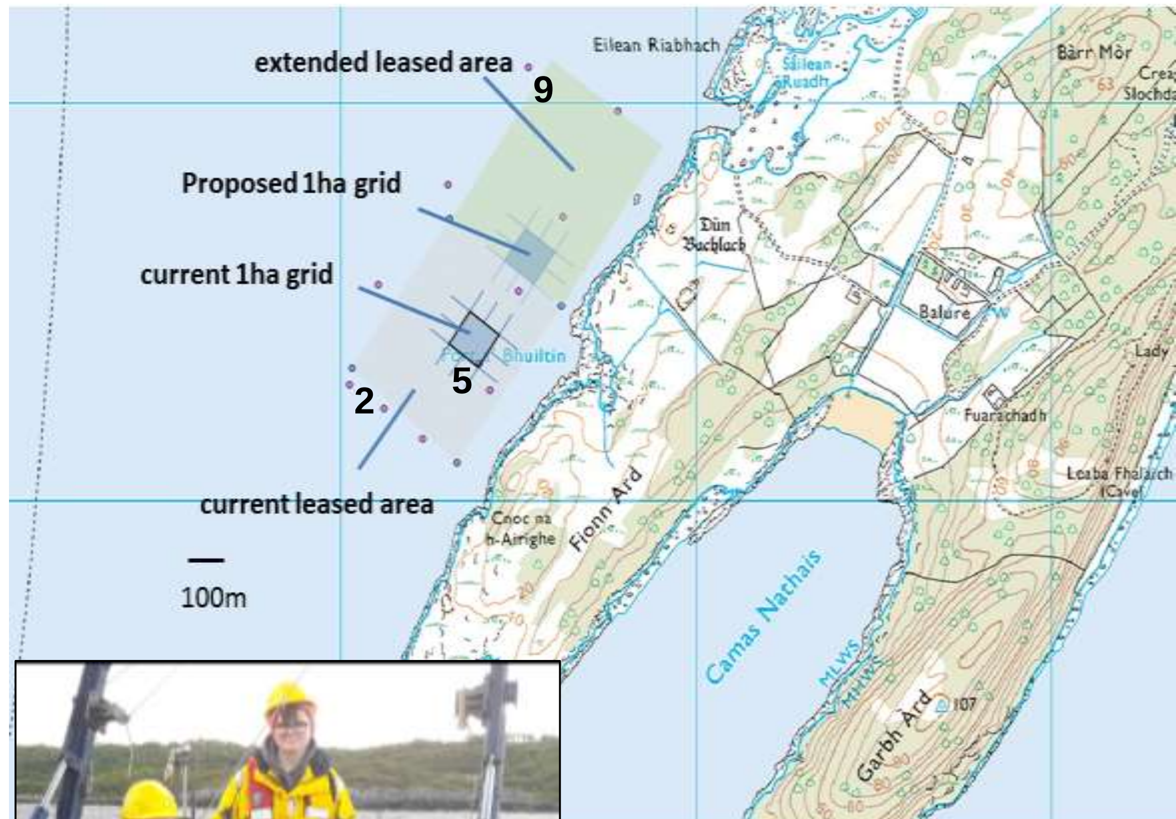


# Environmental research at the SAMS seaweed cultivation site

- SAMS has undertaken a full baseline survey of the cultivation site
- Sampled 3 times annually before & after harvest
- Sediment and water samples collected

Water: Nutrients, oxygen, organic carbon, temperature and salinity and chlorophyll

Sediment: particle size analysis, chlorophyll, organic carbon, species presence and abundance.




Scottish Government
Riaghaltas na h-Alba
gov.scot

# Seaweed Cultivation Policy Statement

http://www.gov.scot/Publications/2017/03/1340

# Scale

**Small-medium (0-50 x 200m lines)**

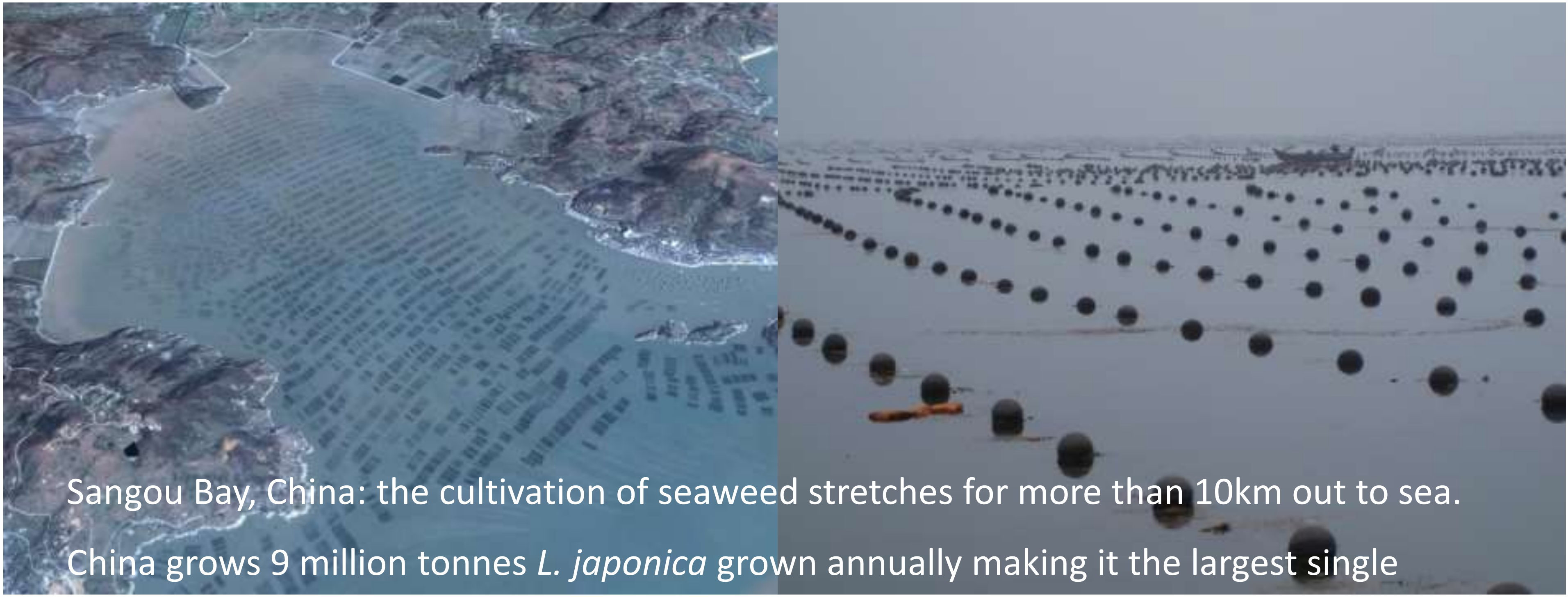
The Scottish Strategic Environmental Report indicated that there is likely to be limited environmental interactions from smaller sites, but potential negative environmental interactions from larger sites of 30-100 200m lines. Such farms will be required to demonstrate mitigation measures, particularly in relation to sensitive areas. (Policies: 1-6)

SAMS's 1 hectare farm (25 x 100m line)

# Scale

**Large (>50 x 200m lines)**

This scale refers to larger sites that may utilize different equipment to that used in shellfish production.



Sangou Bay, China: the cultivation of seaweed stretches for more than 10km out to sea.

China grows 9 million tonnes *L. japonica* grown annually making it the largest single

# Scottish seaweed policy statement

**Policy 1 - In principle, the Scottish government is supportive of small-medium farm seaweed cultivation, subject to regulatory consideration; the General Policies set out in Chapter 4 of Scotland's' National Marine Plan; and any other relevant policies within that Plan. Applications for such seaweed farms should demonstrate that mitigation measures have been considered to prevent adverse environmental impacts, and set out how these will be delivered**.

**Policy 2 – Only species native to the area where seaweed cultivation will take place should be cultivated, to minimise the risk from non-native species.**

**Policy 3 – Where seaweed is grown for human consumption, cultivators should site farms away from sewage outfalls and other potential sources of pollution.**

**Policy 4 – Equipment used in seaweed cultivation should be fit for purpose to withstand damage from adverse weather conditions.**

**Policy 5 - Other marine users and activities should be considered in the siting of farms.**

**Policy 6 – Small-medium size farming is unlikely to be spatially limited, and may be located anywhere in Scotland, subject to agreement and appropriate local conditions.**

**Policy 7 – The Scottish Government is supportive of IMTA.**

# Review of impact pathways

| Change | Mitigation options | Monitoring options |
|---|---|---|
| Pollution | Good farm design and management | Reporting |
| Entanglement risk | Good sites selection. Siting projects away from sensitive areas. Farm design | Reporting |
| **Alteration of hydrodynamic regimes** | **Good site selection. Modelling at a strategic level.** | **Monitoring of local hydrodynamics** |
| **Absorption of nutrients (Nitrogen)** | **Good sites selection. Siting projects in enriched areas (e.g. IMTA). Modelling at a strategic level.** | **Ecosystem monitoring** |
| Shading effects | Good site selection. Siting projects away from sensitive areas | Ecosystem monitoring |
| **Genetic depression** | **Provision of seed sourced in a way that maintains the genetic diversity of wild populations and crops.** | **Monitoring of wild population genetic diversity** |
| Release of DIM, DOM, POM | Good site selection through ecosystem modelling | Ecosystem monitoring |
| Absorption of Carbon | - | Ecosystem monitoring |
| Habitat creation | Good site selection | Ecosystem monitoring |
| Habitat for invasive species | Biosecurity measures | Monitoring for invasive non-native species |
| **Habitat for disease** | **Biosecurity measures** | **Monitoring for disease** |