Functional Variability and Dynamics of Responses of Marine Forests to Global Change

MARFOR

BiodivERsA COFUND Call (2015-2016)

« Understanding and managing biodiversity dynamics to improve ecosystem functioning and delivery of ecosystem services in a global change context: the cases of soils and sediments, and land- river and sea-scapes »

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MARFOR - Functional Variability and Dynamics of Responses of Marine Forests to Global Change

Coordinator:
CCMAR, University of Algarve, Portugal

Funded partners:
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MBA - Marine Biological Assoc. UK, UK
National Univ. Ireland Galway, Ireland
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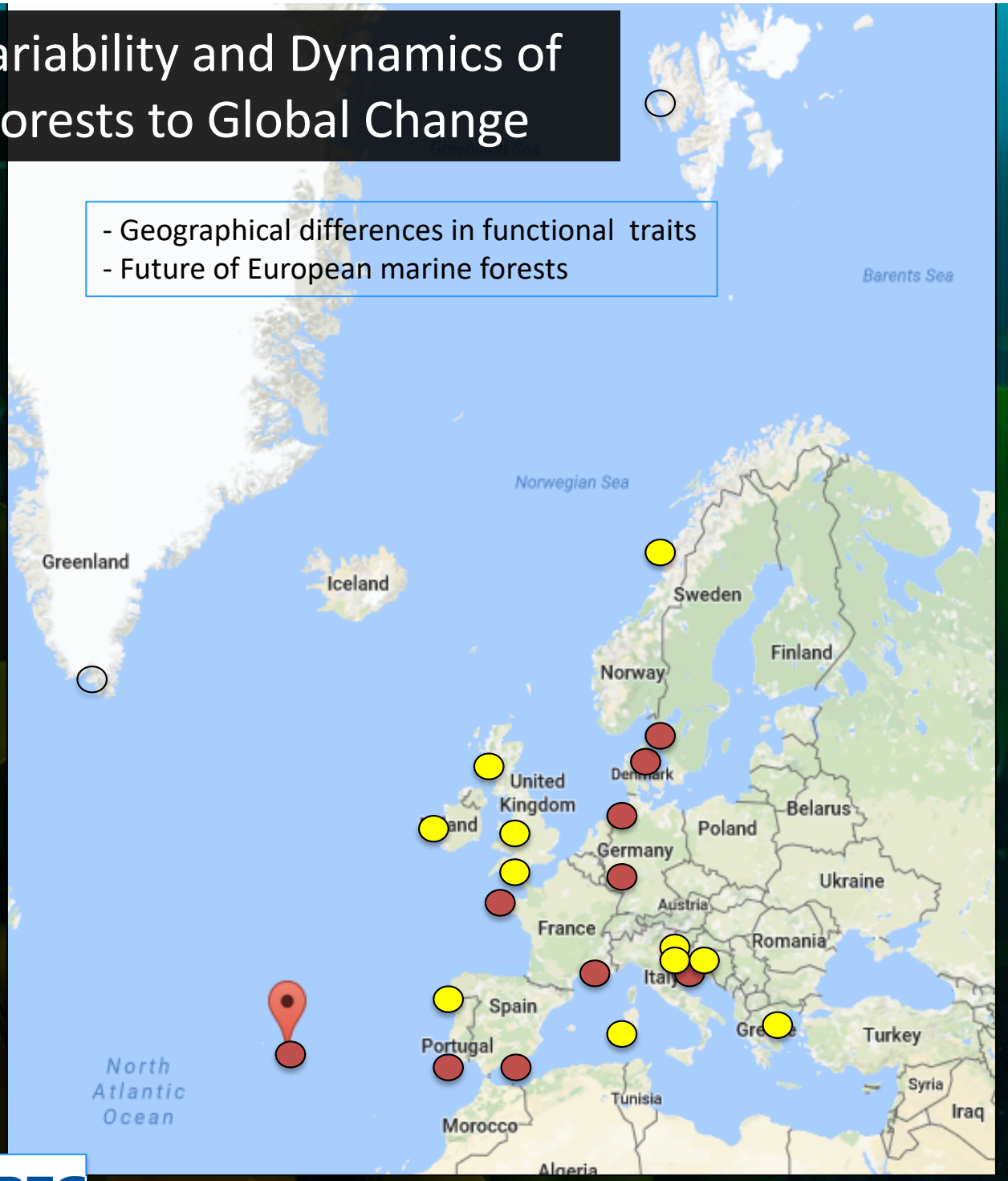
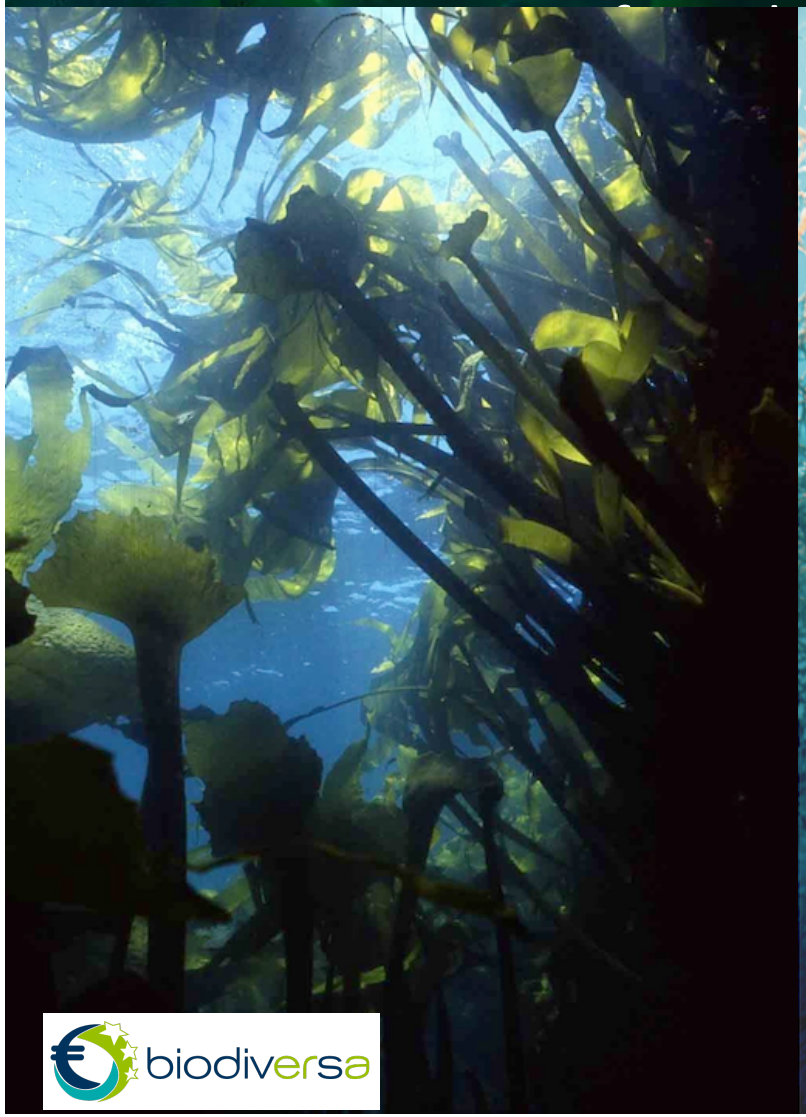
Univ. of Ghent, Belgium
European Commission-Joint Res. Centre (JRC)

- Geographical differences in functional traits
- Future of European marine forests



MARFOR models: large brown algae (marine forests)

kelp (*sensu lato*) (*Laminaria, Saccorhiza, et*



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PROJECT DESCRIPTION

MARFOR aimed to understand and apply:

Using as model: **large brown algae** (marine forests of major ecological and economic importance)

- **geographical variation** in traits that affect fitness from the genomic to the ecological and evolutionary responses

- predictions of consequences of this geographical trait variability for the **future** of European marine forest ecosystems

- implications for **practical applications** such as selection of breeders in aquaculture, selection of populations in ecosystem restoration, conservation and sustainability in management of natural exploited stocks

MARFOR
SCIENTIFIC OUTPUTS

main outputs and impact of MARFOR project

For marine forests of **large brown algae** of several distinct species:

- discovered the geographical separation of genetically distinct units of populations **geographical variation** in traits that affect fitness from the genomic to the ecological and evolutionary responses

- predictions of consequences of this geographical trait variability for the **future** of European marine forest ecosystems

- implications for **practical applications** such as selection of breeders in aquaculture, selection of populations in ecosystem restoration, conservation and sustainability in management of natural exploited stocks

MARFOR
SCIENTIFIC OUTPUTS

MARFOR WP 1 - Spatial variability of functional traits

discovered:

- differences between marginal and core populations in population size, diversity and differentiation, reproductive and other demographic traits.

- constraints for recruitment and survival to environmental stress across species, populations and life-cycle stages

- adaptive differences in marginal populations, with implications for aquaculture, restoration, management and climate change mitigation

- gene expression responses to thermal changes across species, populations and life cycle stages.

MARFOR
SCIENTIFIC OUTPUTS

monitoring and sampling of three sister kelp species of the genus *Laminaria* with different thermal affinities / distributions.

L. digitata

Cold water species

L. hyperborea

Temperate water species

L. ochroleuca

Warm water species

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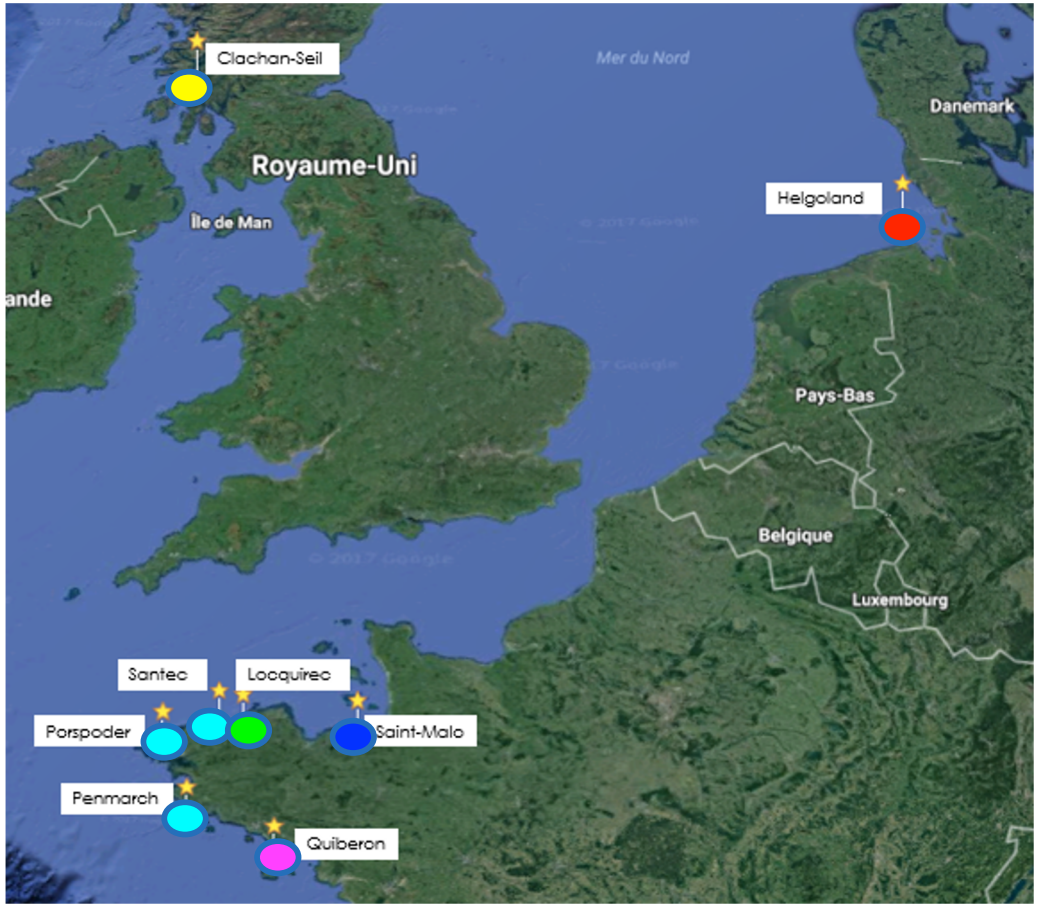
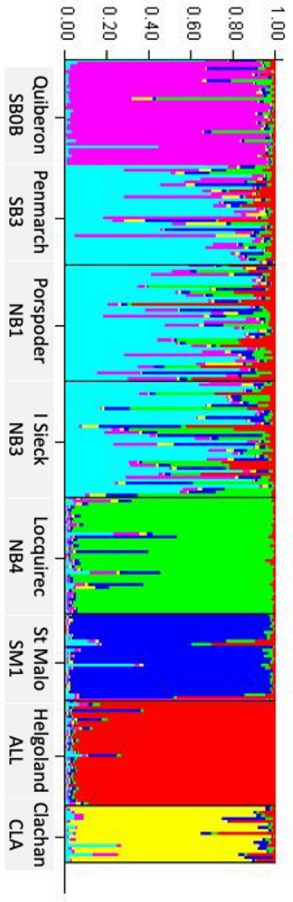
SCIENTIFIC OUTPUTS

The reproductive success of *Laminaria digitata* differs between genetic groups and is lower at the southernmost range edge



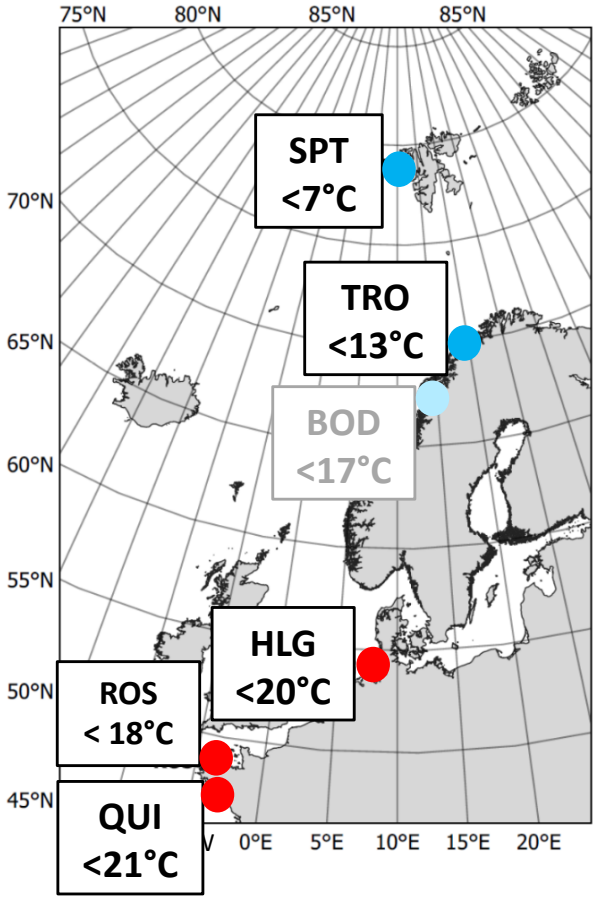
Southern limit of the range distribution

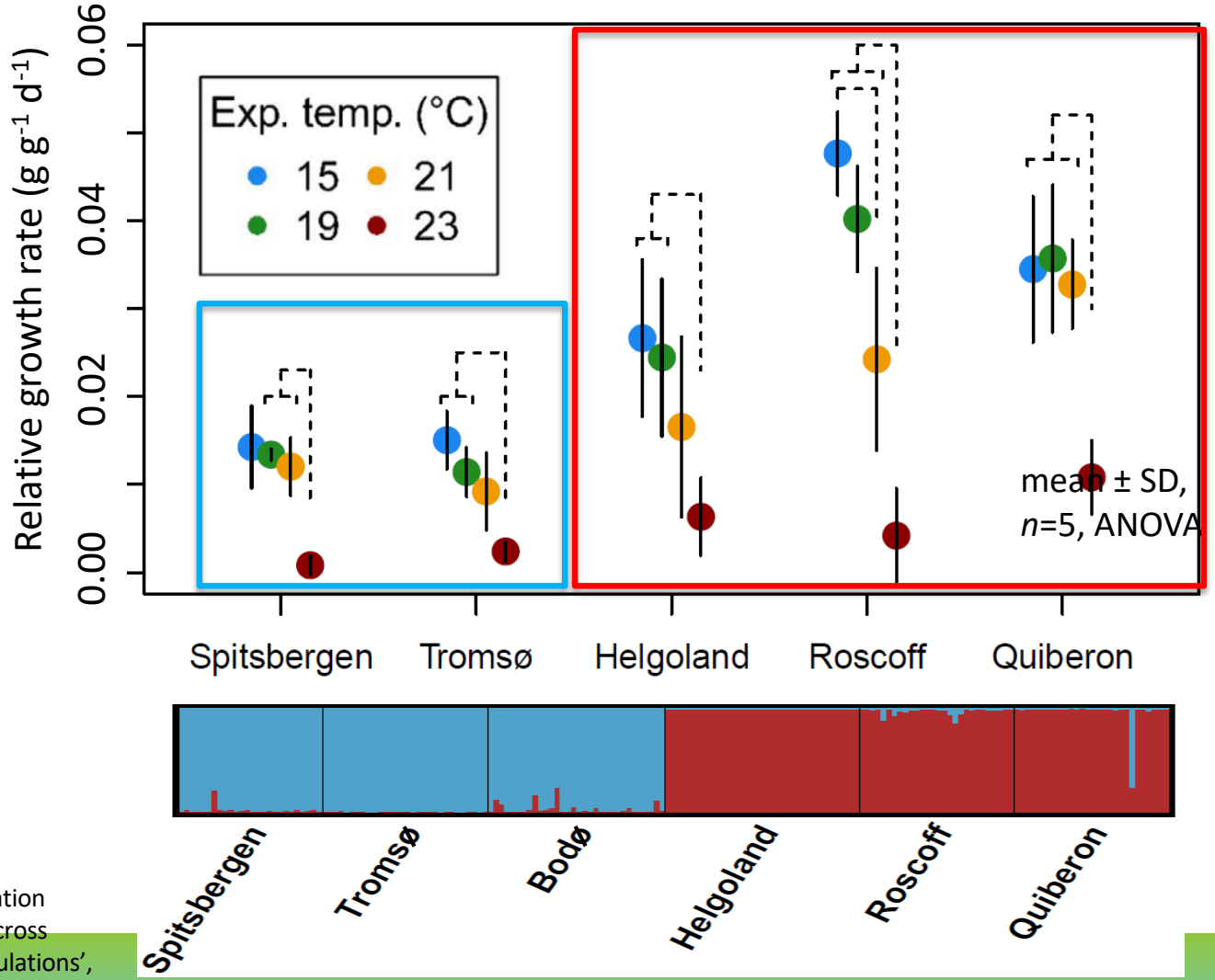


Region	Site	type of populations
South Brittany (SB0B)	Quiberon	marginal (warm)
South Brittany (SB3)	Penmarc'h	central (warm)
North West brittany (NB1)	Porspoder	central (cold)
North West Brittany (NB6)	Santec	central. (cold)
North East Brittany (NB4B)	Locquirec	marginal (warm)
North East Brittany (SM1)	Saint Malo	marginal (warm)
Germany (marginal ALL)	Helgoland	marginal (Warm/cold)
Scotland (centra: CLA)	Clachan-Sei	central. (cold)

MARFOR SCIENTIFIC OUTPUTS

Heat resilience of *Laminaria digitata differs between* populations but lethal limit is uniform

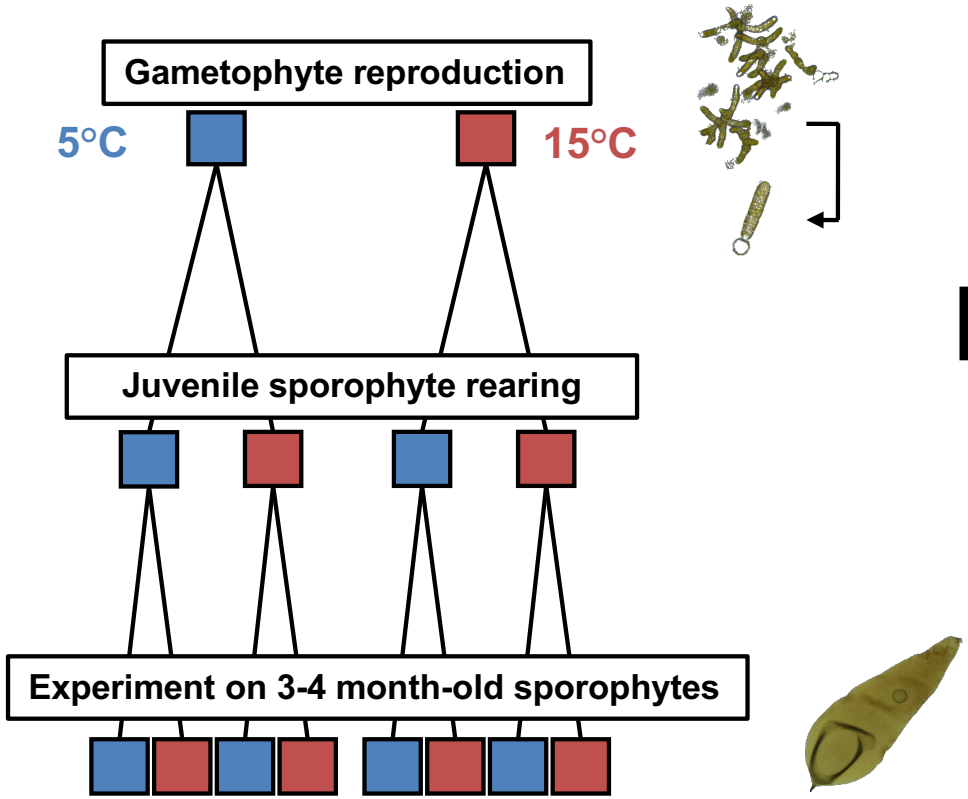




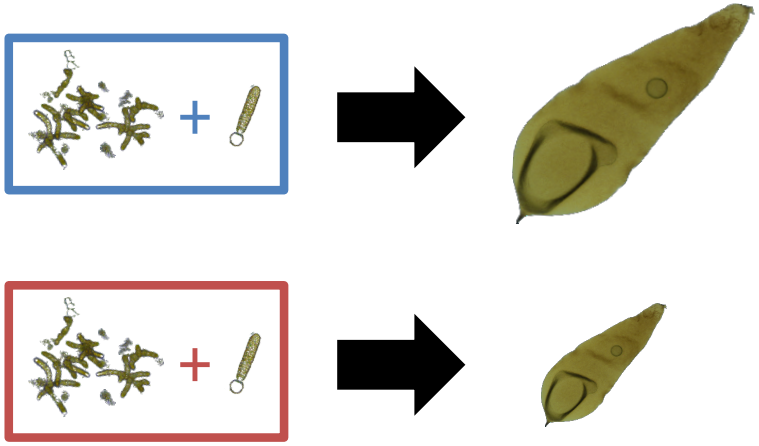
Liesner, D. *et al.* (2020) 'Heat stress responses and population genetics of the kelp *Laminaria digitata* (Phaeophyceae) across latitudes reveal differentiation among North Atlantic populations', *Ecology and Evolution*, 10(17), pp. 9144–9177. doi: 10.1002/ece3.6569.

MARFOR SCIENTIFIC OUTPUTS

Thermal Plasticity across life stages in *Laminaria digitata*



Cold reproduction benefits kelp growth



Underlines importance of cold seasons for kelp forests

Liesner, D. *et al.* (2020) 'Thermal Plasticity of the Kelp *Laminaria digitata* (Phaeophyceae) Across Life Cycle Stages Reveals the Importance of Cold Seasons for Marine Forests', *Frontiers in Marine Science*, 7: 456. doi: 10.3389/fmars.2020.00456.

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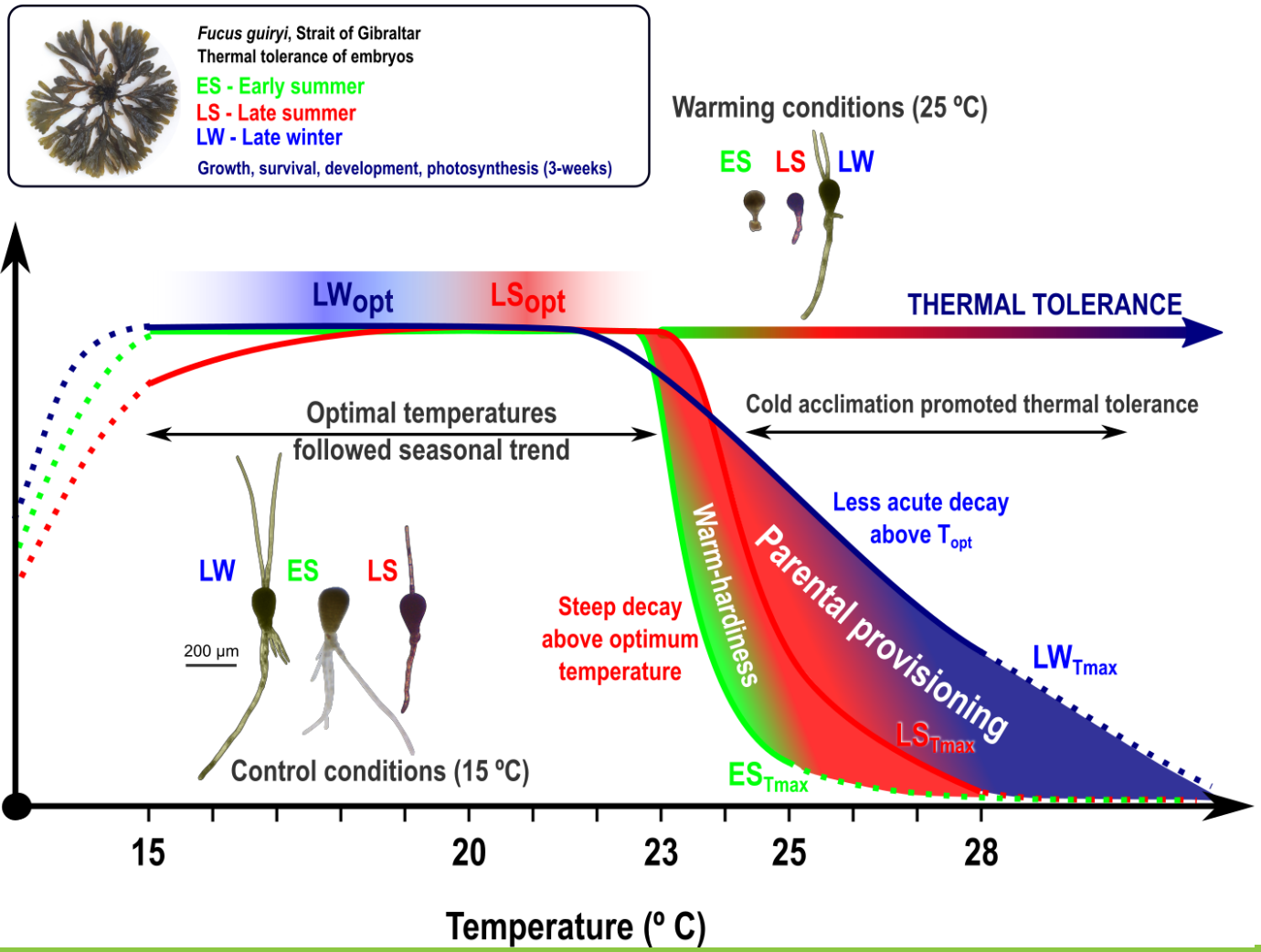
SCIENTIFIC OUTPUTS

Thermal resilience of microscopic stages of *Fucus guiryi* varies across seasons



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SCIENTIFIC OUTPUTS

High local variability in conservation status of populations of *Fucus guiryi* in the Strait of Gibraltar (South Spain)

Demography and reproductive ecology varies at mesoscale (close populations) due to microclimatic conditions

Extinct populations or with anecdotic thalli

Calaburras (Mijas, Málaga)

Extinct from 2012

Calamocarro* (Ceuta)

n=3 isolated individuals

Benítez (Ceuta)

Extinct

El Sarchal (Ceuta)

Extinct

Populations with low-intermediate density and cover

Guadalmesí (Cádiz)

San Amaro (Ceuta)

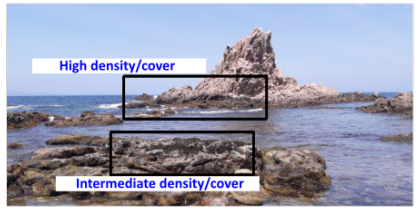
Piedras Gordas* (Ceuta)

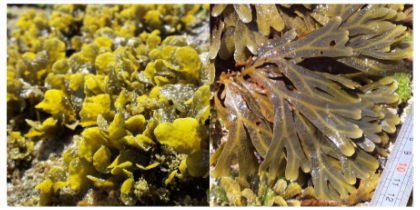
Desnarigado* (Ceuta)

Populations with intermediate-high density and cover

Tarifa (Cádiz)

Santa Catalina (Ceuta)





*** Populations with individuals < 3 cm and absence of reproductive population**

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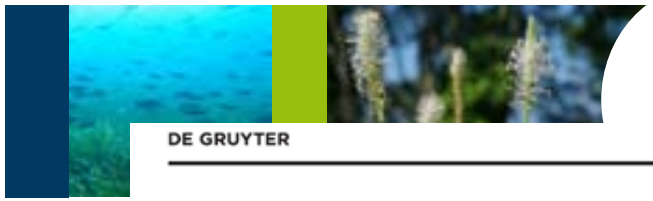
SCIENTIFIC OUTPUTS



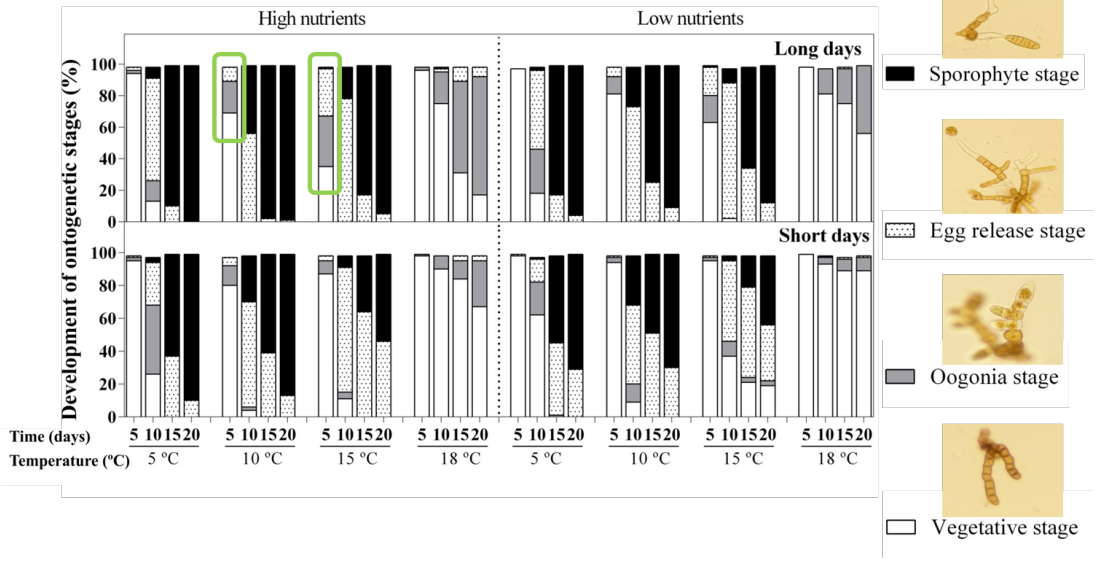
DE GRUYTER

Botanica Marina 2017; 60 (2): 109–12

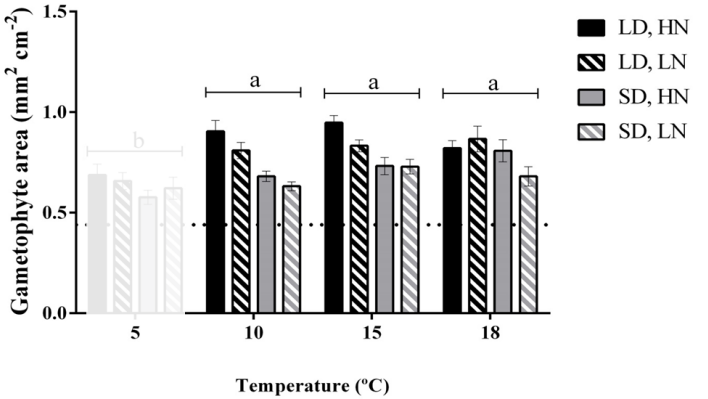
Neusa Martins*, Heidi Tanttu, Gareth A. Pearson, Ester A. Serrão and Inka Bartsch

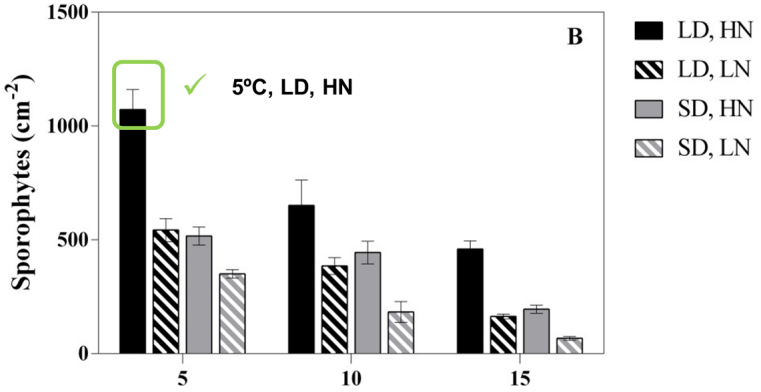
Interactions of daylength, temperature and nutrients affect thresholds for life stage transitions in the kelp *Laminaria digitata* (Phaeophyceae)

✓ 10-15 ºC, High nutrients, Long days



✓ 10-18ºC





Life cycle processes ≠ **Optimal Temperatures**

⇨ **Gametophyte growth** 10-18ºC | **Gametogenesis** 10-15ºC | **Recruitment** 5 ºC

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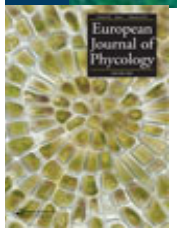
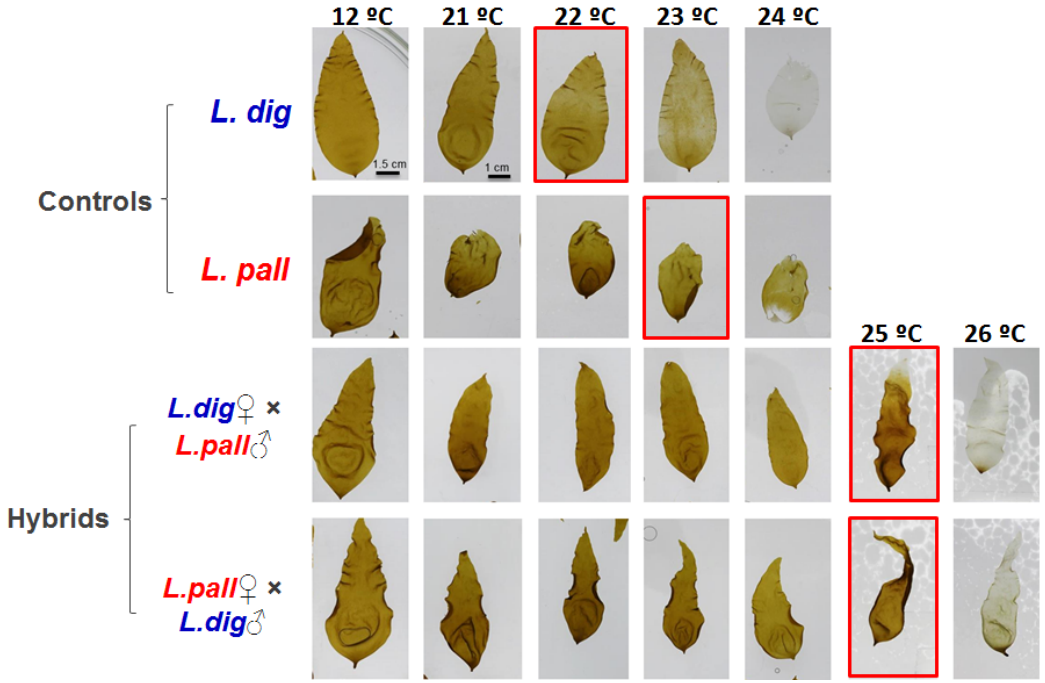
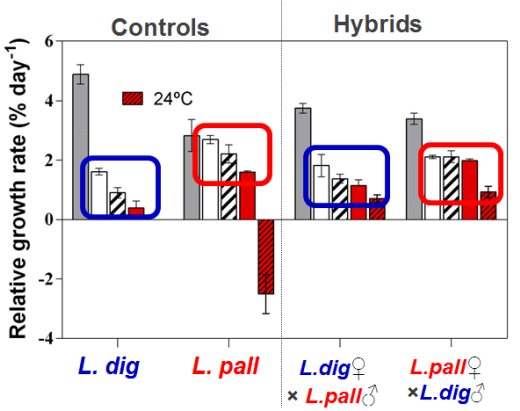


European Journal of Phycology

ISSN: 0967-0262 (Print) 1469-4433 (Online) Journal homepage: https://www.tandfonline.com/loi/tejp20

Hybrid vigour for thermal tolerance in hybrids between the allopatric kelps *Laminaria digitata* and *L. pallida* (Laminariales, Phaeophyceae) with contrasting thermal affinities

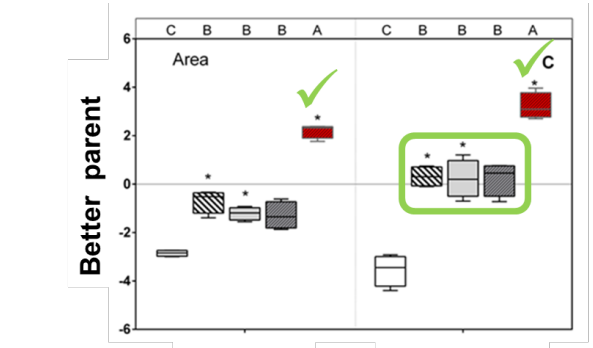




Transmission of thermal tolerance may be sex-dependent

♀

Heterosis



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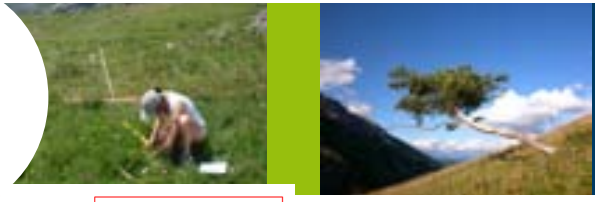


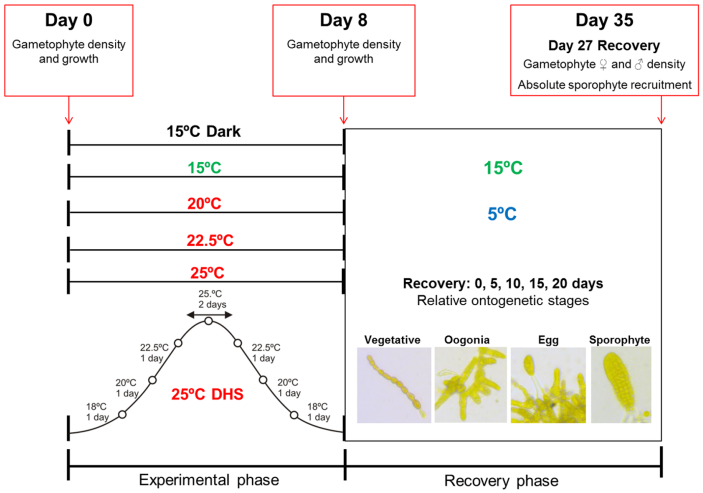
RESEARCH ARTICLE

Thermal traits for reproduction and recruitment differ between Arctic and Atlantic kelp *Laminaria digitata*

Neusa Martins[1,2]*, Gareth A. Pearson[1], Julien Bernard[1], Ester A. Serrão[1], Inka Bartsch[2]

1 Centre of Marine Sciences (CCMAR), University of Algarve, Faro, Portugal, 2 Alfred-Wegener-Institute, Helmholtz Center for Polar and Marine Research, Bremerhaven, Germany

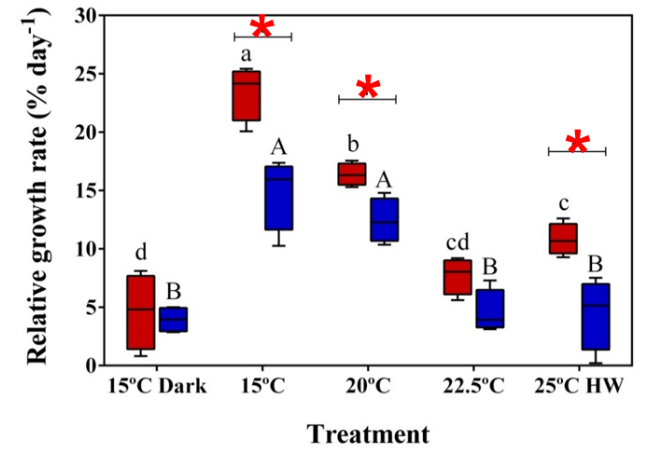
* nemartins@ualg.pt

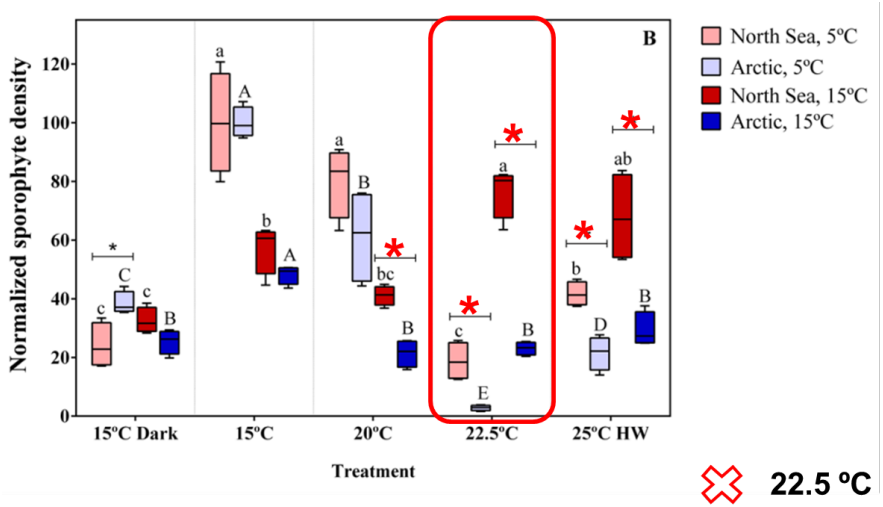


Population-specific responses:

✗ Arctic

✓ North Sea





✗ 22.5 ºC

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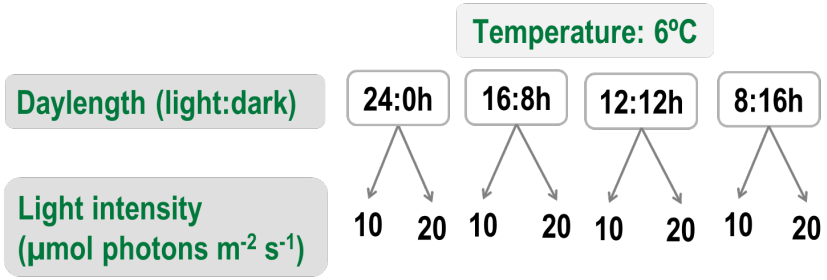
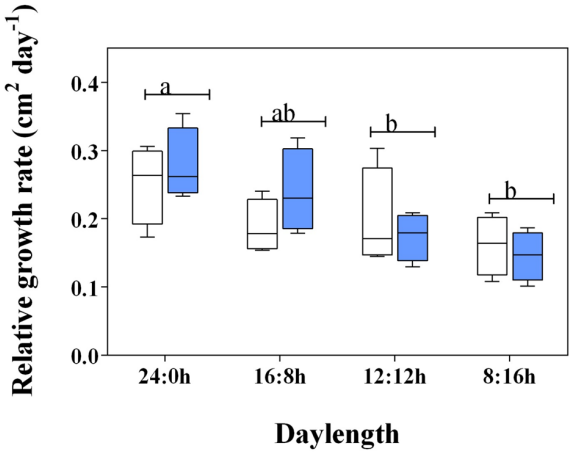
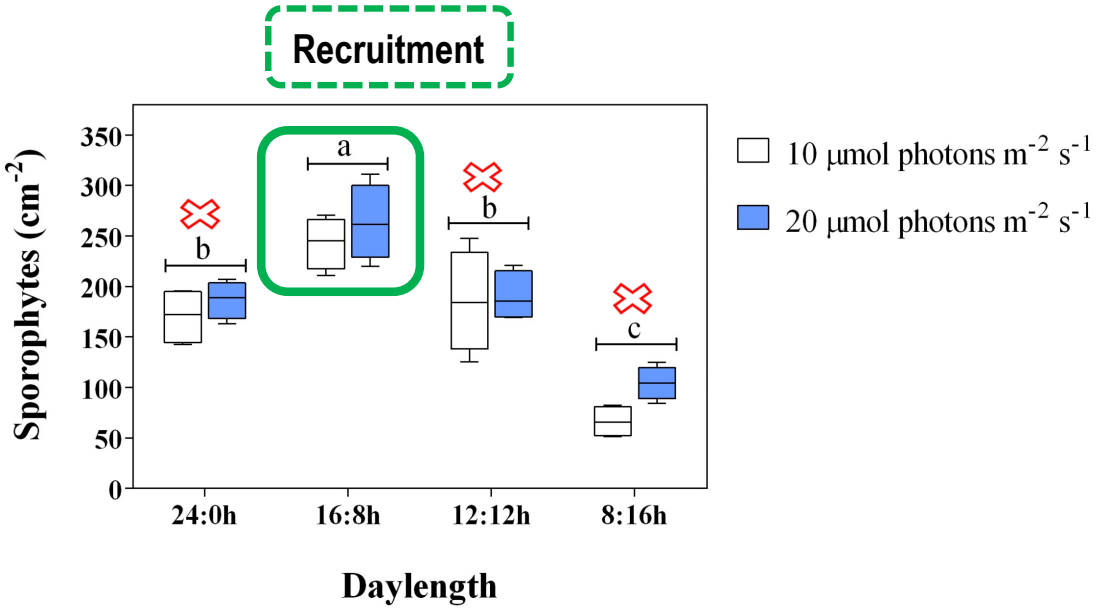
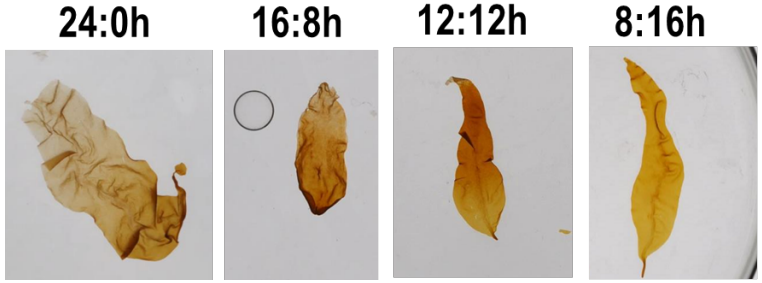
SCIENTIFIC OUTPUTS

Continuous light disrupts recruitment success in the Arctic kelp *Alaria esculenta*









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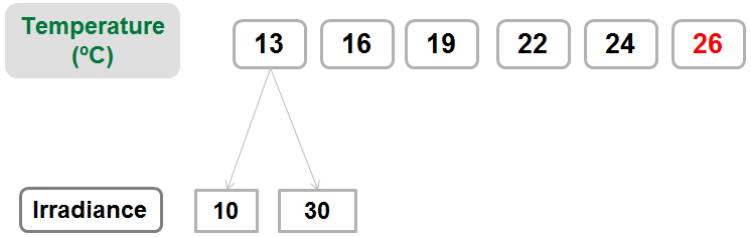
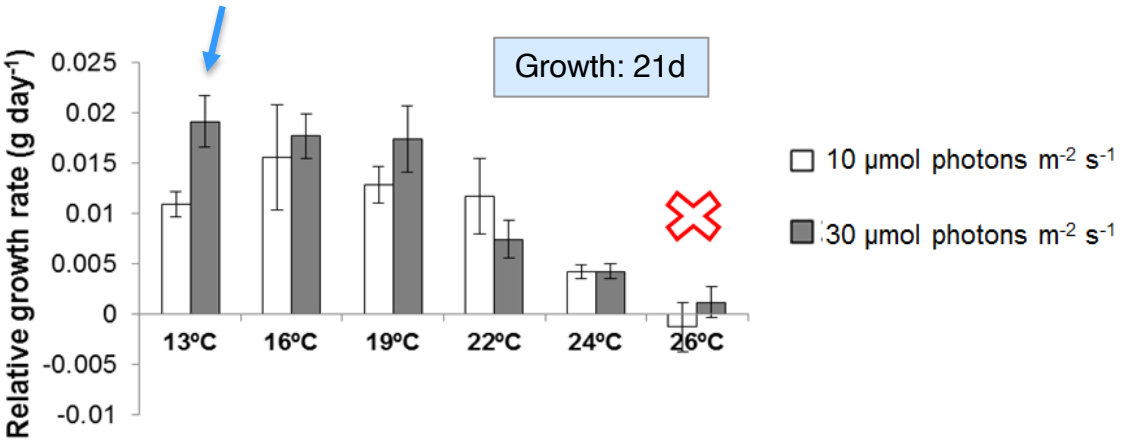
Laminaria rodriguezii: thermal physiology of meristematic discs

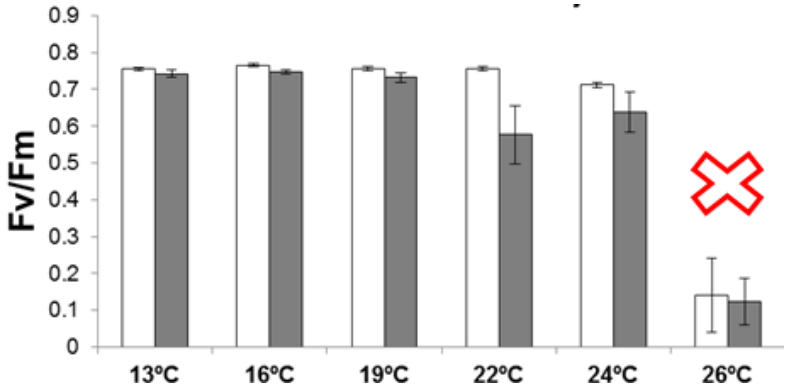
26ºC - Lethal temperature

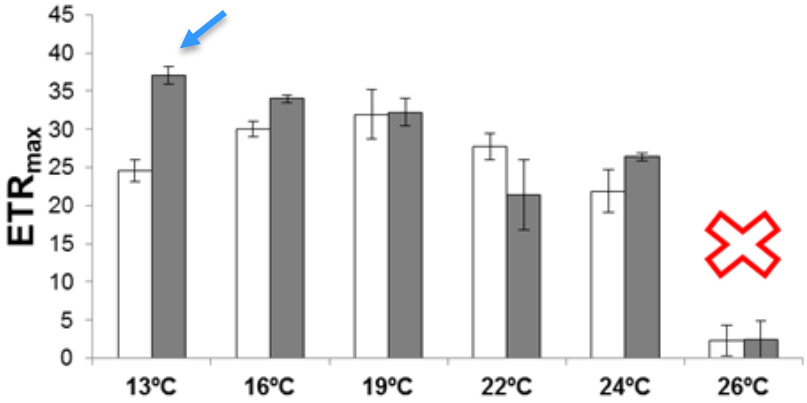
24ºC - Upper survival temp

13ºC - Higher irradiance is beneficial









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SCIENTIFIC OUTPUTS

MARFOR WP 2 - Modelling spatial distributions, range shifts, connectivity, trajectories

discovered:

- which populations/areas host the greatest genetic variation identified critical populations for conservation

- estimated the realized connectivity (gene flow) between different genetic clusters / habitats, and key sites for connectivity

- modeled the realized and fundamental niche of different species and genetic entities of NE Atlantic marine forests

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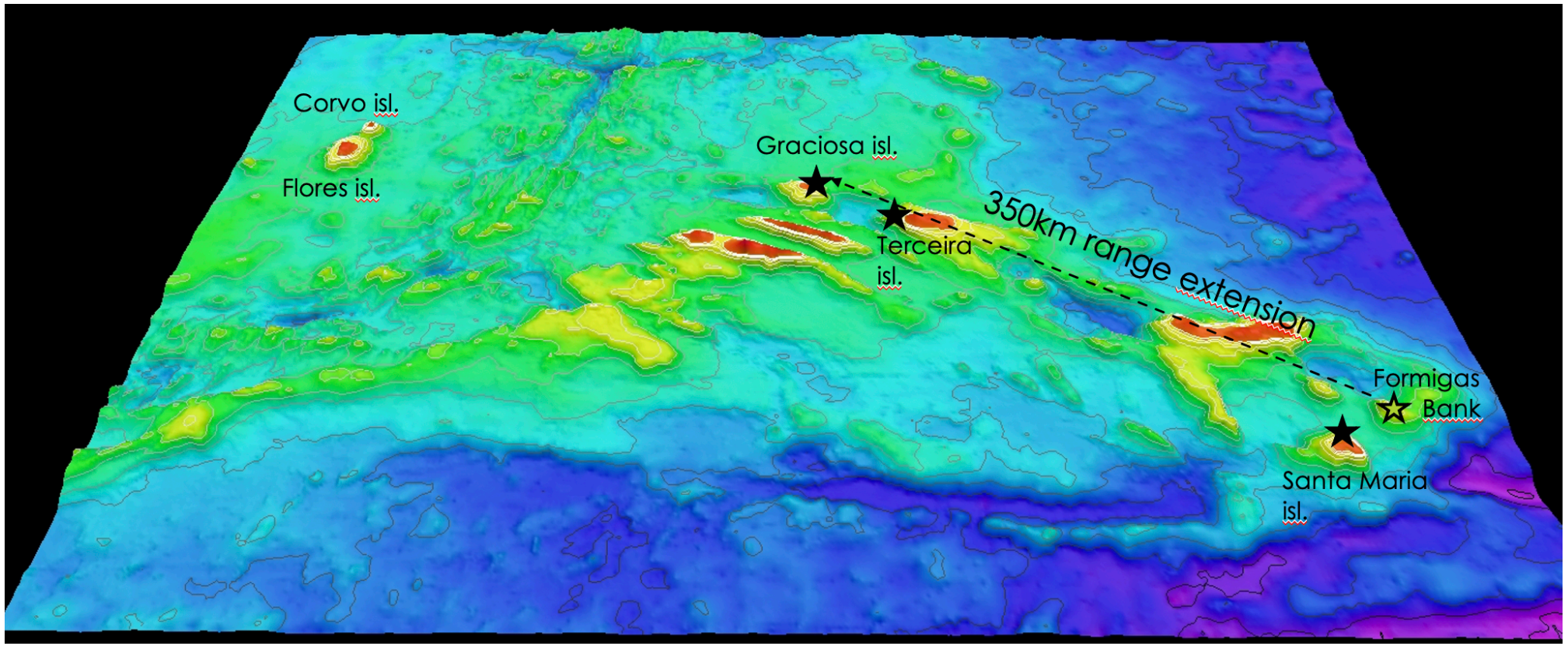
Discovery:
Novel populations of kelp *Laminaria ochroleuca* discovered in the Azores islands.
They are isolated, very distinct and very rich in unique endemic genetic diversity



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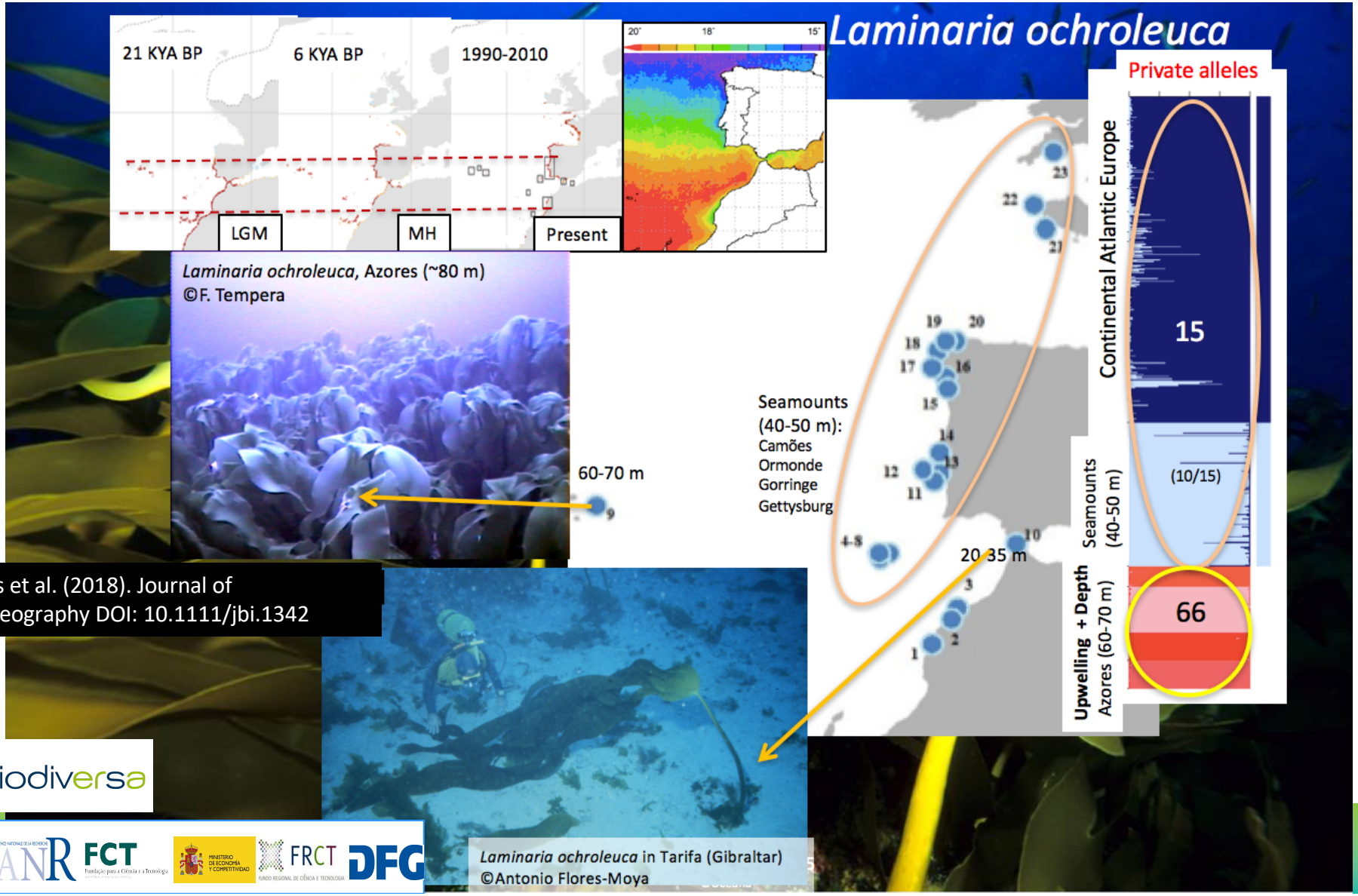
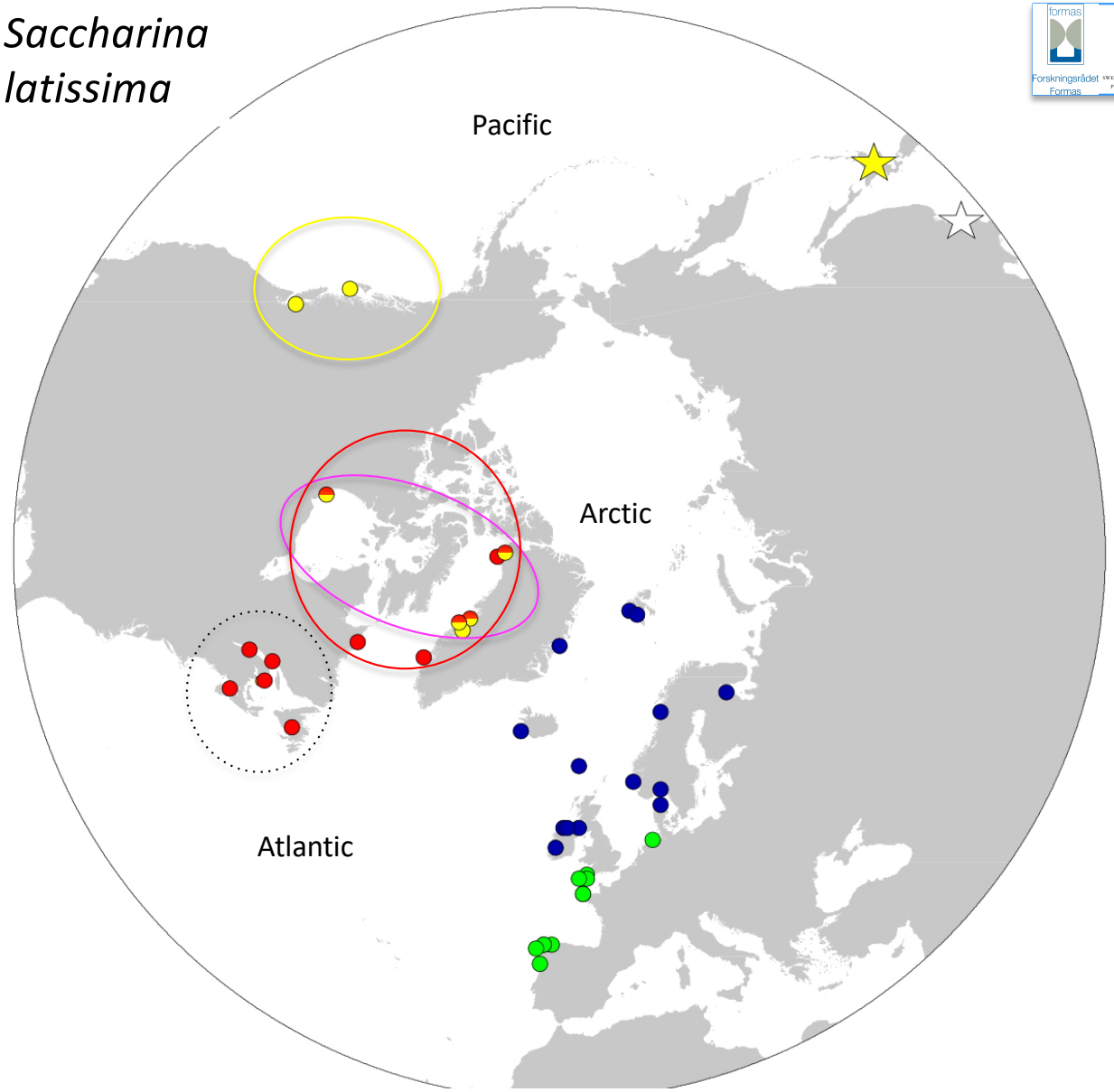
Climate driven range shifts shaped unique genetically rich marginal populations in *L. ochroleuca:*



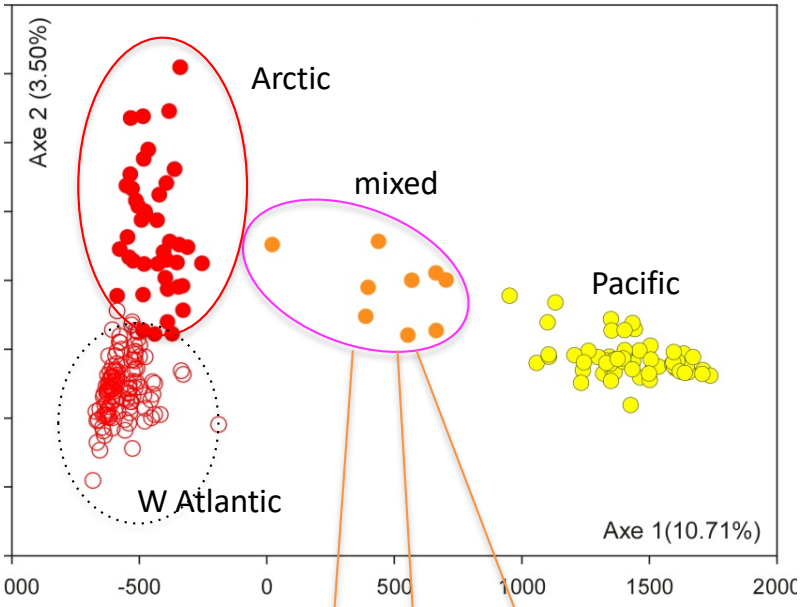
Assis et al. (2018). Journal of Biogeography DOI: 10.1111/jbi.1342

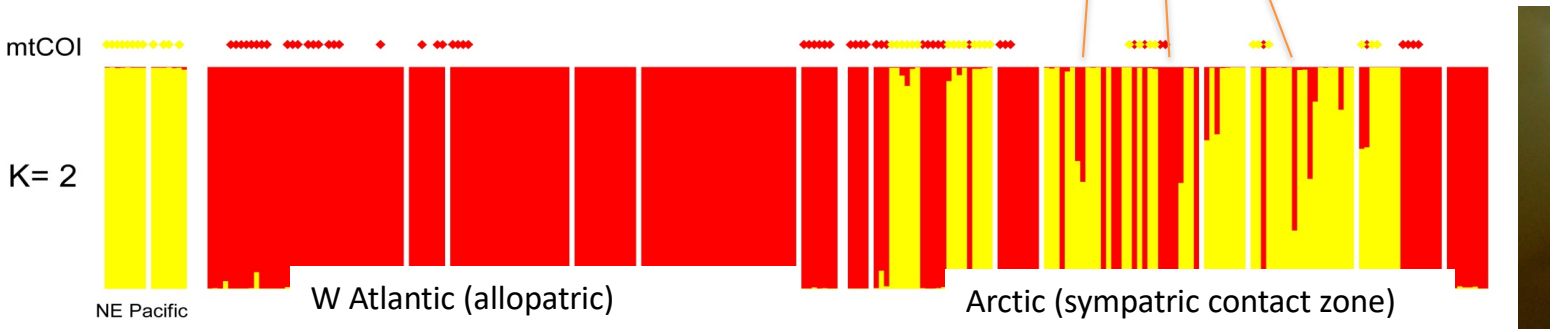
Saccharina latissima

Saccharina latissima



Neiva J et al.(2018)
Scientific Reports 8:1112

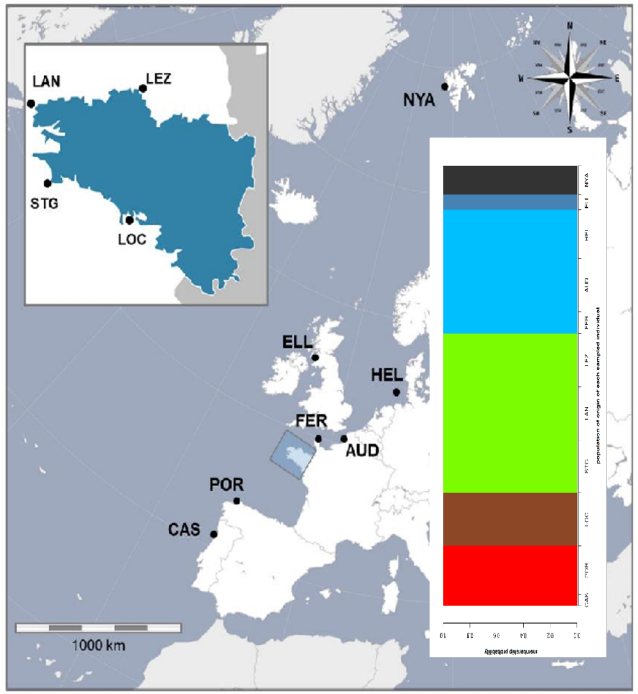


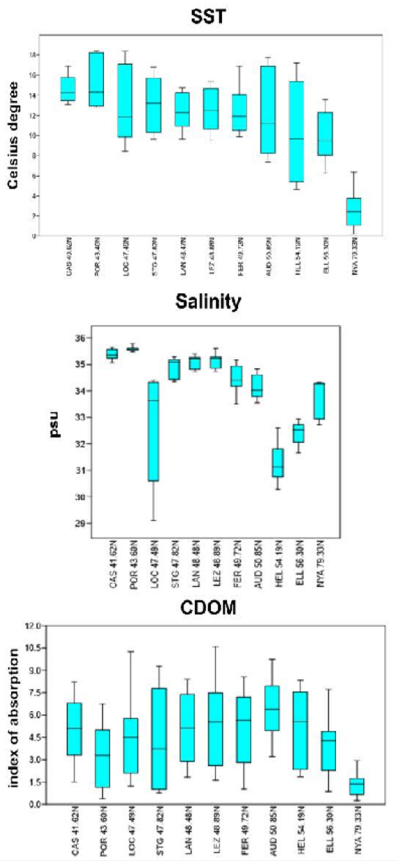


Seascape Genomics of the Sugar Kelp *Saccharina latissima*

(from Guzinski et al., 2020, Genes)

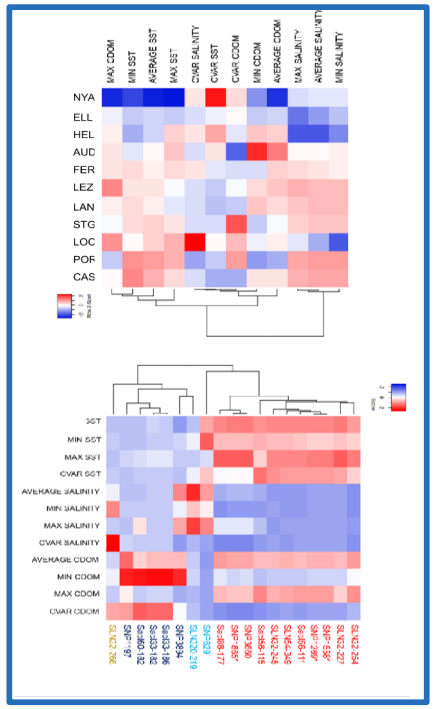
Six distinct genetic clusters were delimited using more than 4000SNPs along the atlantic coast (11 locations showing different ecological characteristics)





Heat-map graphs with co-association dendrograms for S. latissima. Pairwise Spearman's ρ correlations between 12 environmental parameters plotted according to their geographical variation. Variation in the coefficient of determination (R2) resulting from the correlations between 19 markers (seven SNPs and 12 microsatellite alleles) and 12 environmental parameters.

This knowledge will be helpful for the conservation management of the eastern Atlantic populations of *S. latissima* as it will allow specific geographic areas containing putatively locally adapted strains to be defined more accurately which is vital for sustainable management of these wild resources for kelp aquaculture.



The genome-wide outlier scan approach identified several outlier loci that might be involved in differential adaptive responses to the local environmental along the European Atlantic coast.

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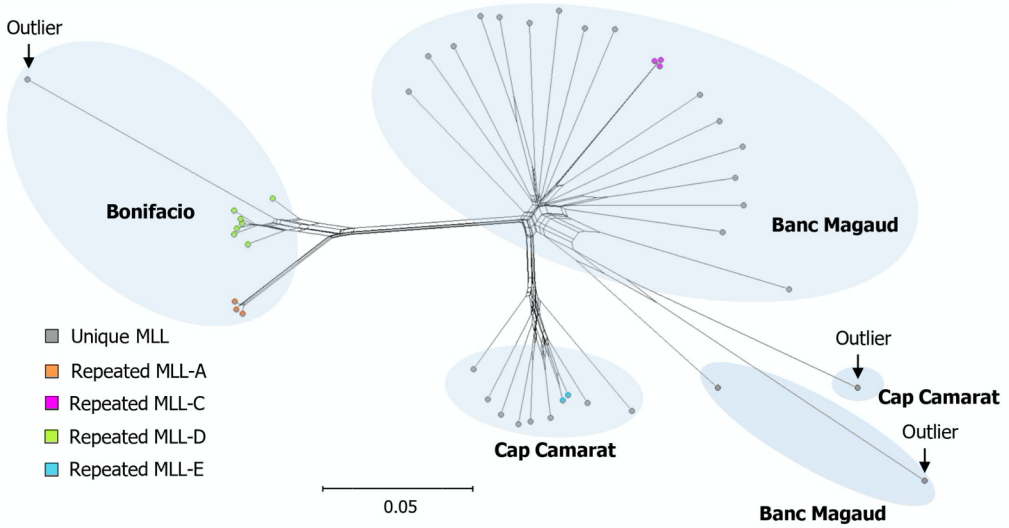
SCIENTIFIC OUTPUTS

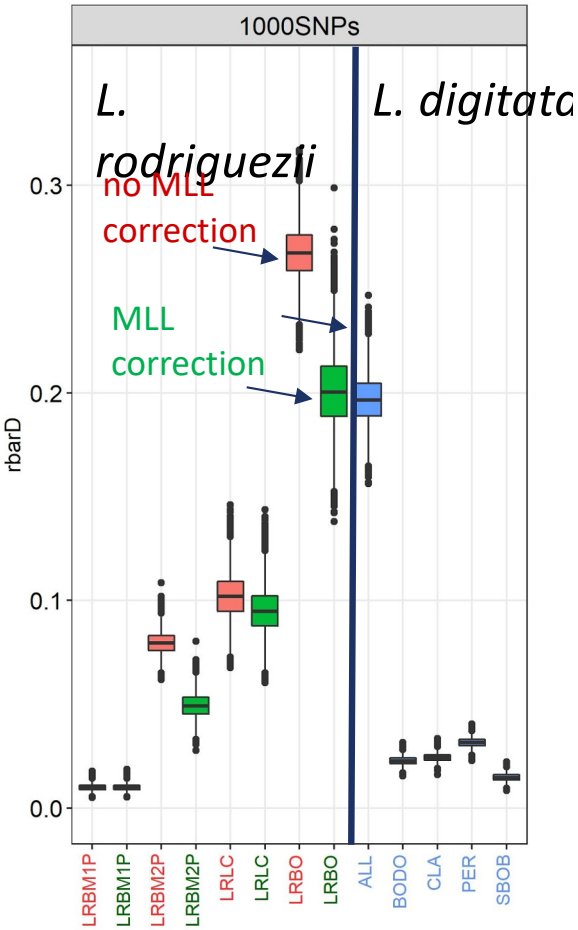
Reynes Lauric, et al. "Genomic signatures of clonality in the deep water kelp *Laminaria rodriguezii*." *Authorea Preprints* (2020)

The genomic diversity of *Laminaria rodriguezii* is shaped by partial clonality and genetic drift

The Mediterranean species *L. rodriguezii*



Network relationships among *L. rodriguezii* samples on the basis of RAD-sequencing data



Analysis of linkage disequilibrium

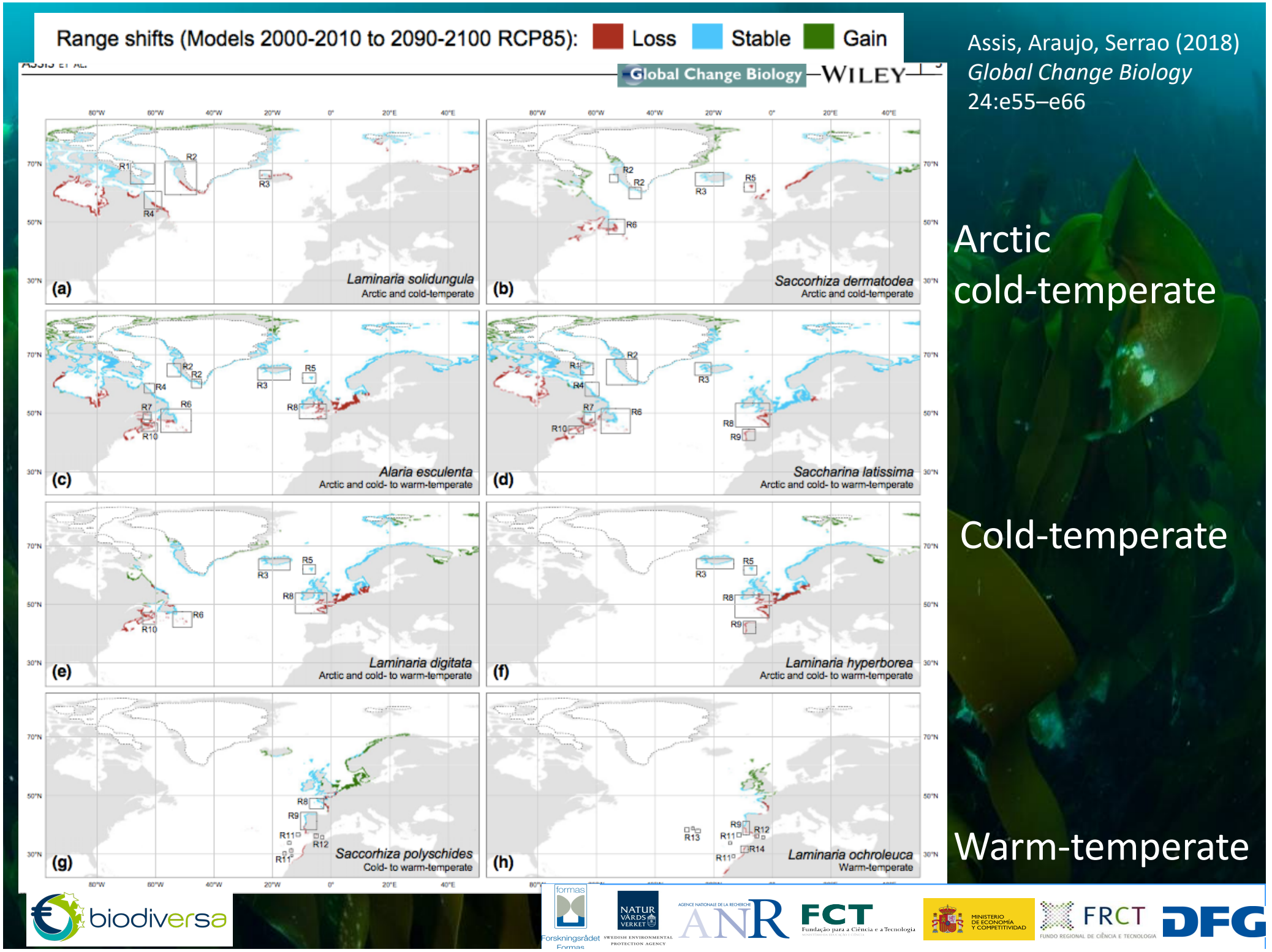
SOCIETAL / POLICY OUTPUTS

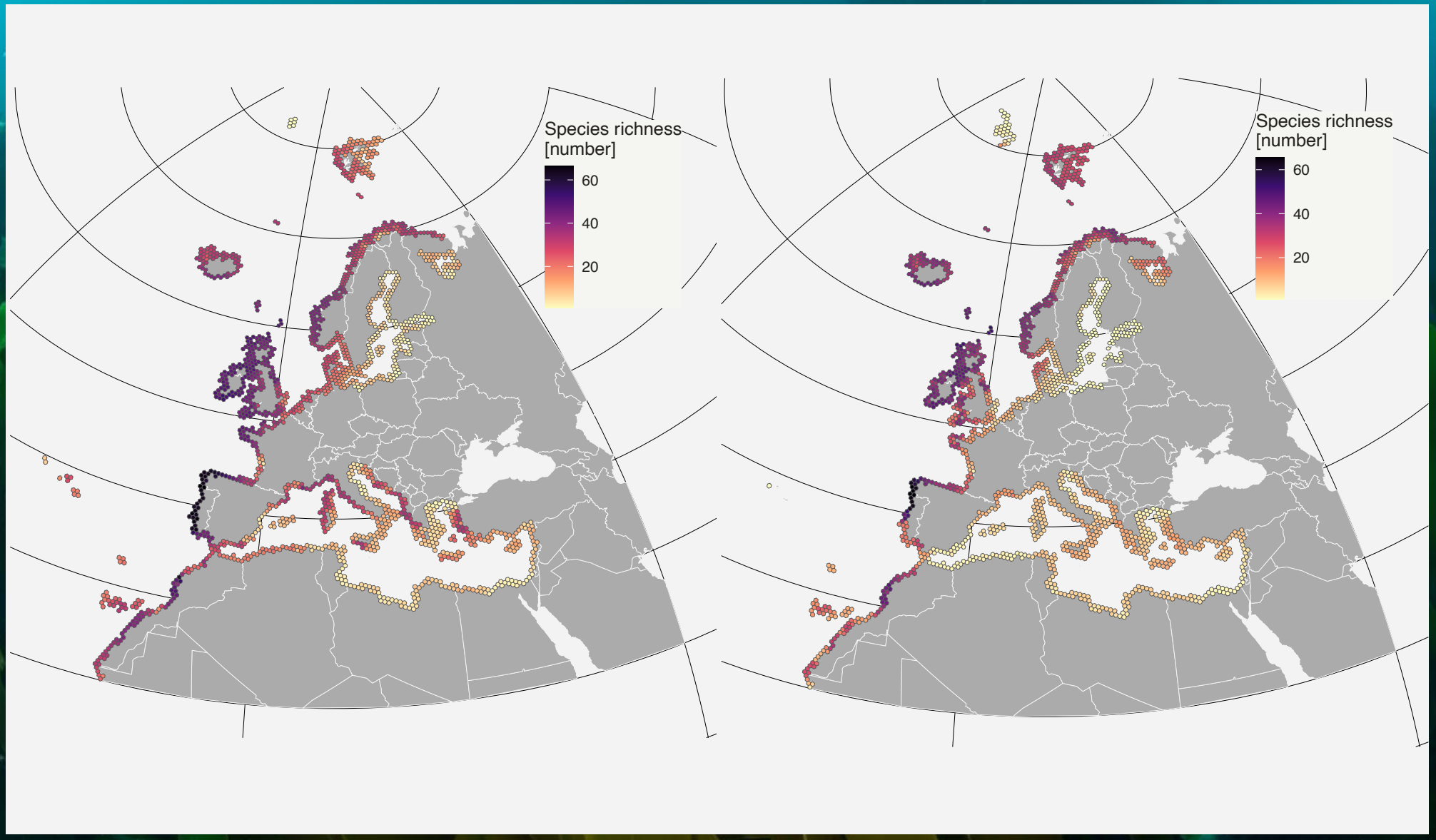
MARFOR WP 3. - Implications and Applications

discovered:

- predicted the consequences of future environmental changes for distinct units of functional traits/genetic diversity of marine forests.

- used genetic, demographic and ecological niche data collected in MARFOR for practical demonstrations of applications in conservation policy and in habitat restoration.


Range shifts (Models 2000-2010 to 2090-2100 RCP85): Loss Stable Gain
Global Change Biology —WILEY—
Laminaria solidungula
Arctic and cold-temperate
Saccorhiza dermatodea
Arctic and cold-temperate
Alaria esculenta
Arctic and cold- to warm-temperate
Saccharina latissima
Arctic and cold- to warm-temperate
Laminaria digitata
Arctic and cold- to warm-temperate
Laminaria hyperborea
Arctic and cold- to warm-temperate
Saccorhiza polyschides
Cold- to warm-temperate
Laminaria ochroleuca
Warm-temperate
Assis, Araujo, Serrao (2018)
Global Change Biology
24:e55–e66
Arctic
cold-temperate
Cold-temperate
Warm-temperate



Future potential distribution of the European diversity (species richness) of large brown algae inferred with species distribution modelling under the (left) RCP26 and (right) RCP85 future climate scenarios.

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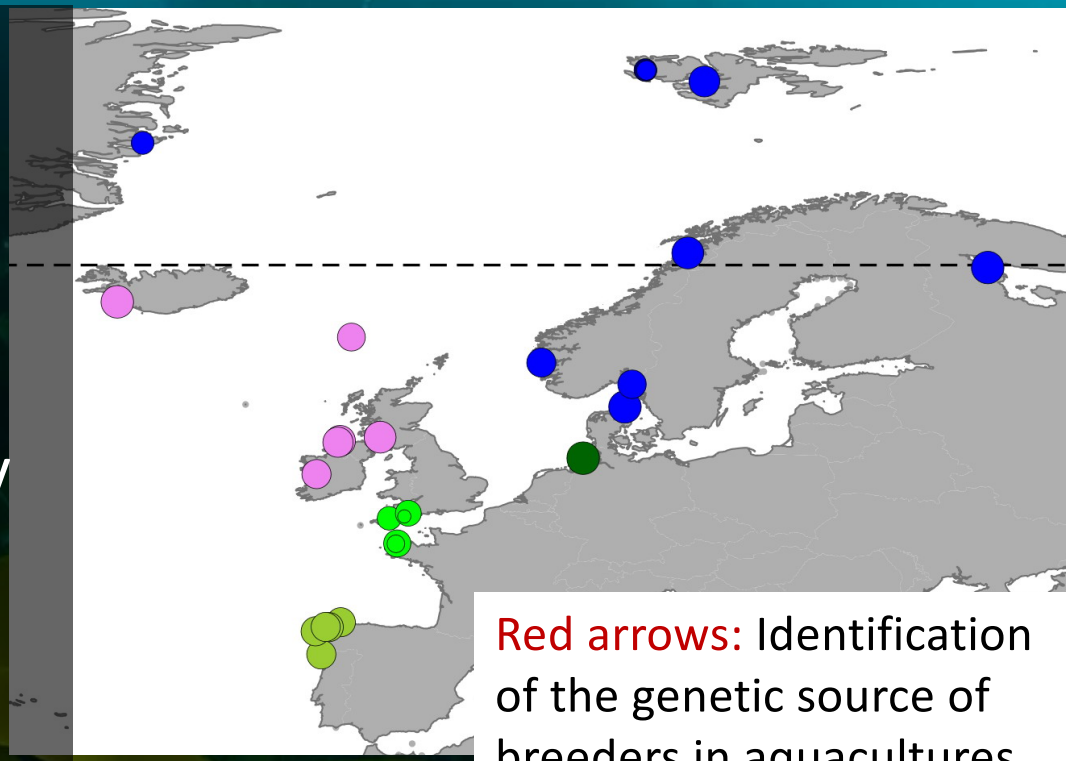
Example application to AQUACULTURE BREEDING (by MARFOR-Portugal):

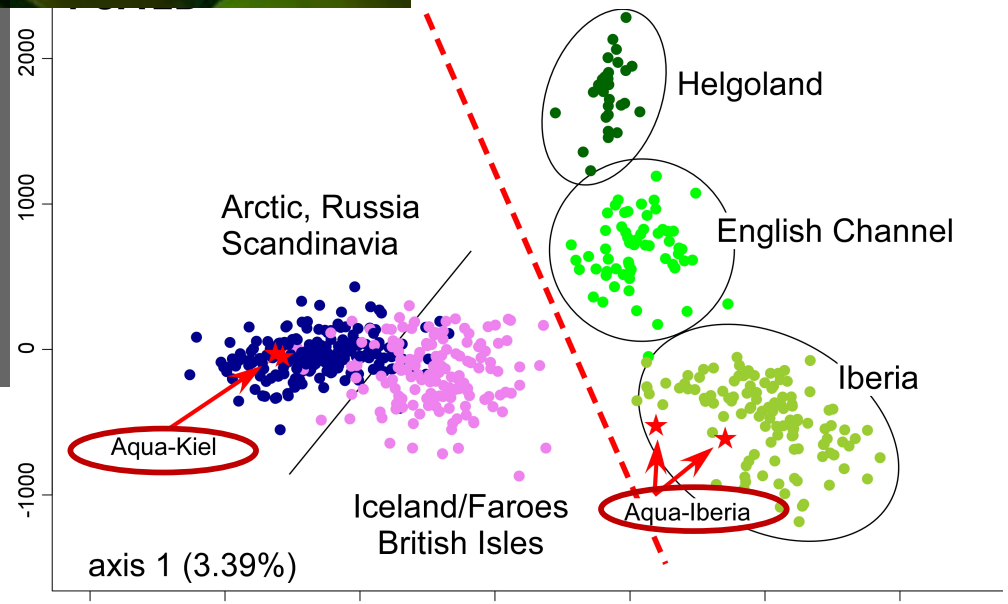
1) populations of commercial species genetically distinguished by MARFOR results

2) breeder samples provided by aquaculture companies were genetically assigned to the groups of natural populations, verifying the source of genetic material

(also collaborations undergoing with Seaweed Energy Solutions, Norway)



Red arrows: Identification of the genetic source of breeders in aquacultures



contacts and cooperation with AQUACULTURE companies (by MARFOR-Denmark)

MARFOR contact and co-operation with aquaculture companies:

- Hjarnø Havbrug (Commercial IMTA - trout, blue mussel, sugar kelp)
- PURE Algae (start-up company – Ulva cultivation on land)
- Bisserup Havbrug – Organic trout producer – feedig Fucus to trouts
- 13 maritime gardens cultivating seaweed and blue mussels for food
- Ocean Rainforest – Faroe Islands – large producer of kelps
- Nordisk Tang – producer of seaweed food specialities
- Heine Max – producer of seaweed crisps
- Dansk Tang – producer of seaweed food specialities, delivery of fresh seaweed
- Seaweed Matters – sustainable harvest of Fucus
- Organic Seaweed – sustainable harvest of Fucus
- Hortimare – cultivation of seaweeds

Example of results of this application in HABITAT RESTORATION (by MARFOR-Portugal):

1) threatened populations of kelp species genetically distinguished by MARFOR results

2) kelp restoration initiatives planting kelp where it disappeared, are using MARFOR data for verifying the source of genetic material suitable for planting in the recovery area (genetically similar to the pre-existing population)

- 3 initiatives, in collaboration with Marine Park of Arrabida, Cascais townhall, and Seaforester-Portugal.



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Applications to seaweed management (by MARFOR-Denmark)

- Cultivation of native species – *Saccharina latissima*, *Ulva* sp and *Palmaria palmata*
- Sustainable harvest of *Ulva* sp from ”Green tide” areas
- Sustainable harvest of *Fucus vesiculosus*
- Genetic variance in Danish *Saccharina* ecotypes – effect on production yield and quality
- Environmental impact of large-scale kelp cultivation

- Close cooperatin with authorities:
- **Danish Coastal Authorities** – environmental impact – advisory on broad perspective for licencing areas for cultivation and harvest
- **Danish Environmental Agency** – advisory on seaweed cultivation and harvest as an engieered instrument for accelerationg reduction of eutrophication
- **Danish Maritime Authority** – inputs for Marine Spatial Planning
- **Ministry for environment and food** – knowledge on Danish macroalgae food/feed safety

www.marineforests.com

The initiative was expanded to marine forests worldwide, not just Europe
(later, due to volunteer interest, animal forests were also added, like gorgonians)

HOME

ORDS

Marine Forests : Important Habitats Worldwide

Macroalgae, plants and animals like corals and sponges create complex habitats that provide resources, shelter and nursery grounds for many marine organisms.

Macroalgae

Marine forests of seaweeds are mainly formed by large brown algae (not plants) such as kelp or fucoids, but also by red and green algae.

Seagrass meadows

Seagrasses are plants that evolved and adapted to live in the sea. They have roots, leafs and produce flowers and fruits.

Animal gardens

Marine animal forests are mostly formed by invertebrates that live attached to rock, such as coral reefs and gorgonian gardens.

Volunteers add photos (also collect old photos)
and records from herbarium specimens and literature

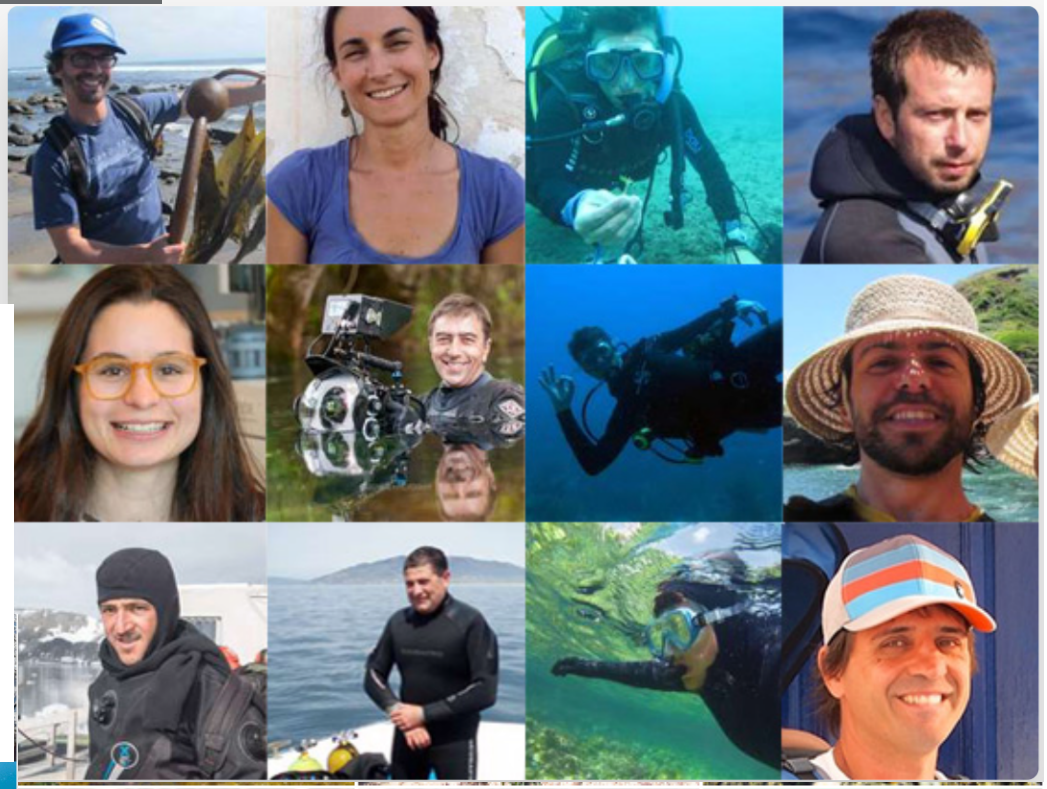
Experts validate (curate) the records

Scientific team and support

Project 'Marine Forests' is supported by scientists and volunteer citizens from all around the world.

>6700 volunteer records

Species identified: 682
Volunteers: >350
The data available is documented in :
Assis J., Fragkopoulou E., Frade D., Neiva J., Oliveira A., Abecasis D., Faugeron S., Serrão E.A. (2020). A fine-tuned global distribution dataset of marine forests. Scientific Data



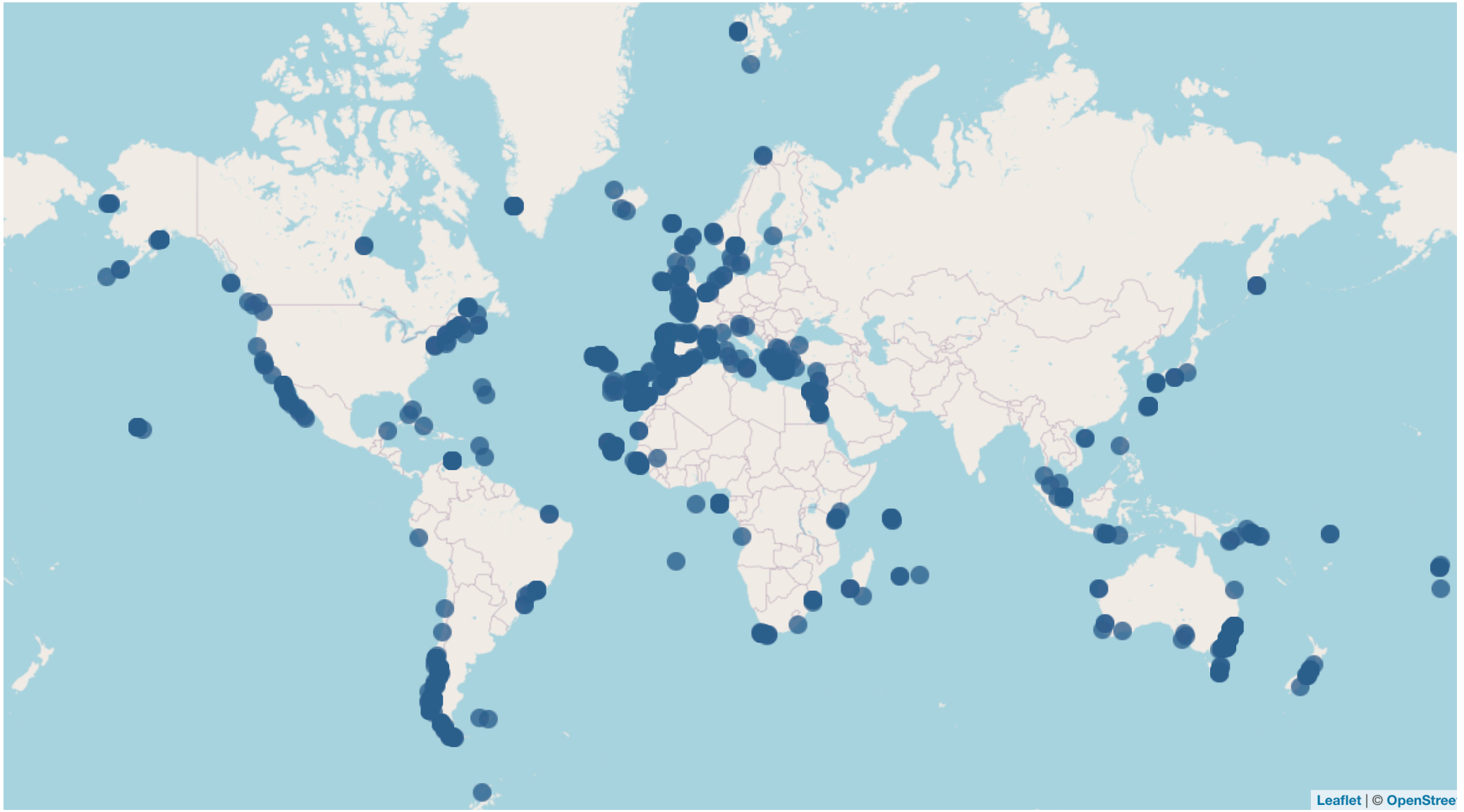
Data from citizens – mostly for European marine forests

Scientific Name | Region (locality, district, country) | Date : from | Date : to

Pictures | Literature | Herbarium | Curated | Sort by | Sorting | QUERY

6665 records (688 species) with pictures

DOWNLOAD | GALLERY VIEW | TABLE VIEW



IMAGES OF WORK

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