Stability versus shifts on temperate reefs in the Anthropocene

Marine Biological Association

Benthic Ecosystems & Environmental CHange BEECH

UK Research and Innovation

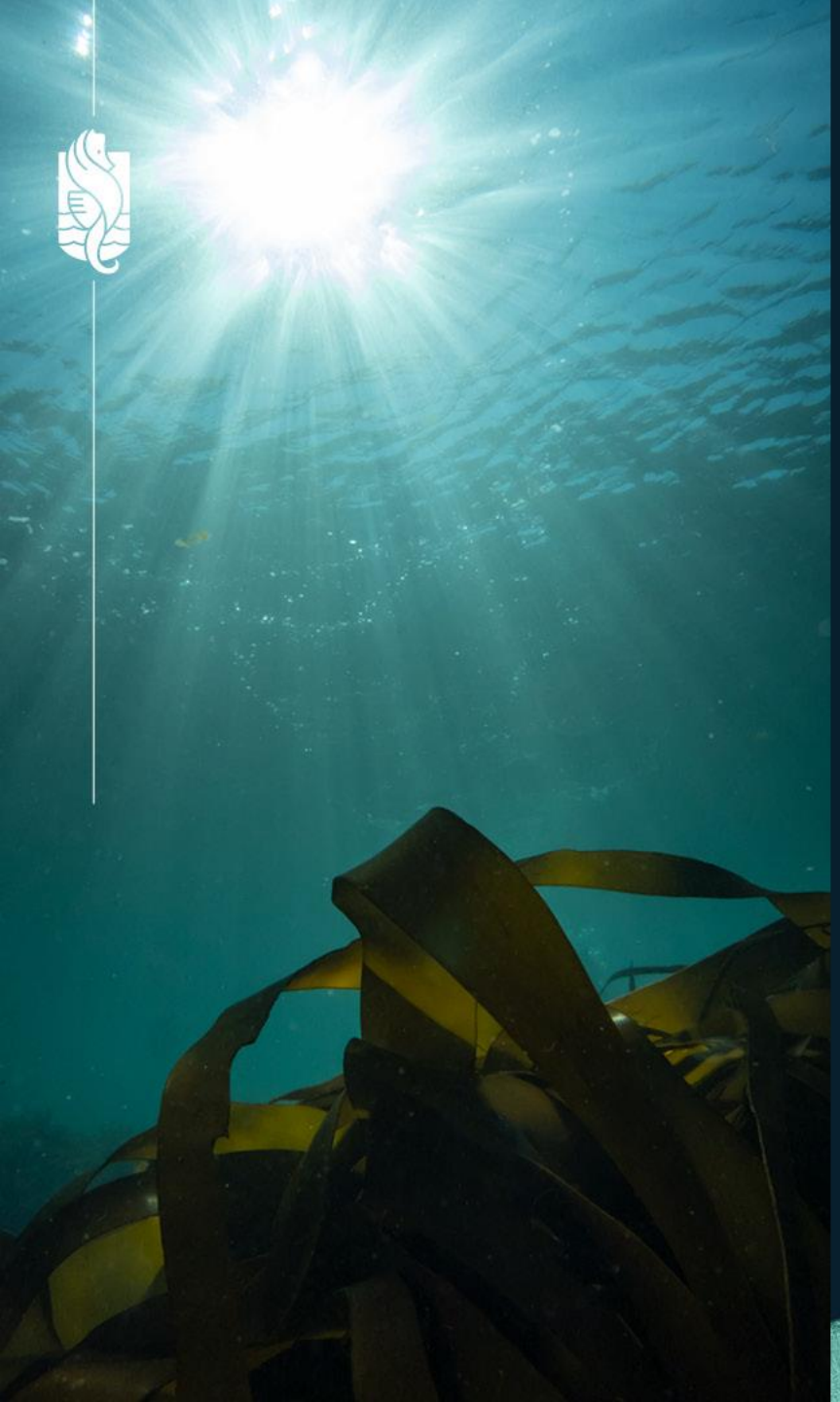
NERC SCIENCE OF THE ENVIRONMENT

Dan Smale

MBA Senior Research Fellow

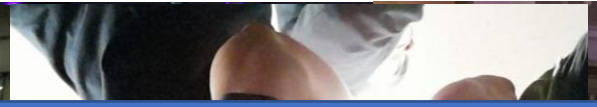
UKRI Future Leaders Fellow

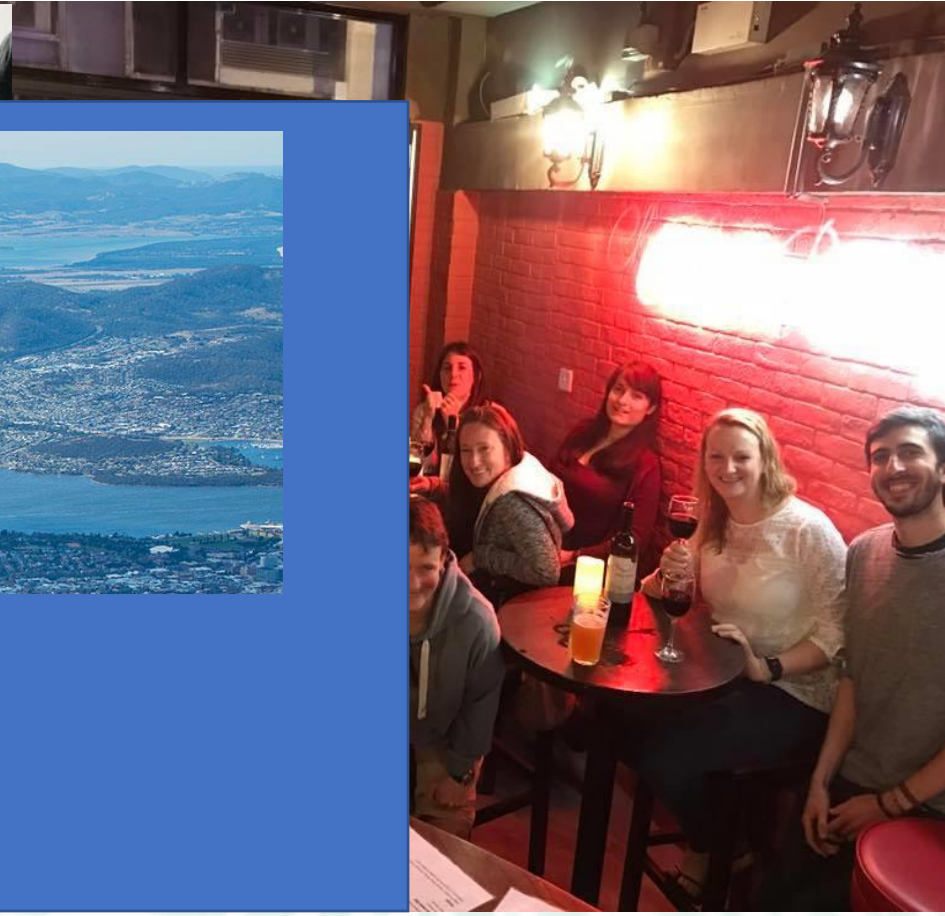
ITRS, Hobart, January 2023



Outline

- Kelp forests as dynamic ecosystems (?)
- Biogeographical context of our research
- Long term stability in a critical foundation species (?)
- Declines at the trailing range edge
- Proliferation at the leading range edge
- Novel communities and functions?
- Conclusions and wider context





???

Plymouth 2011

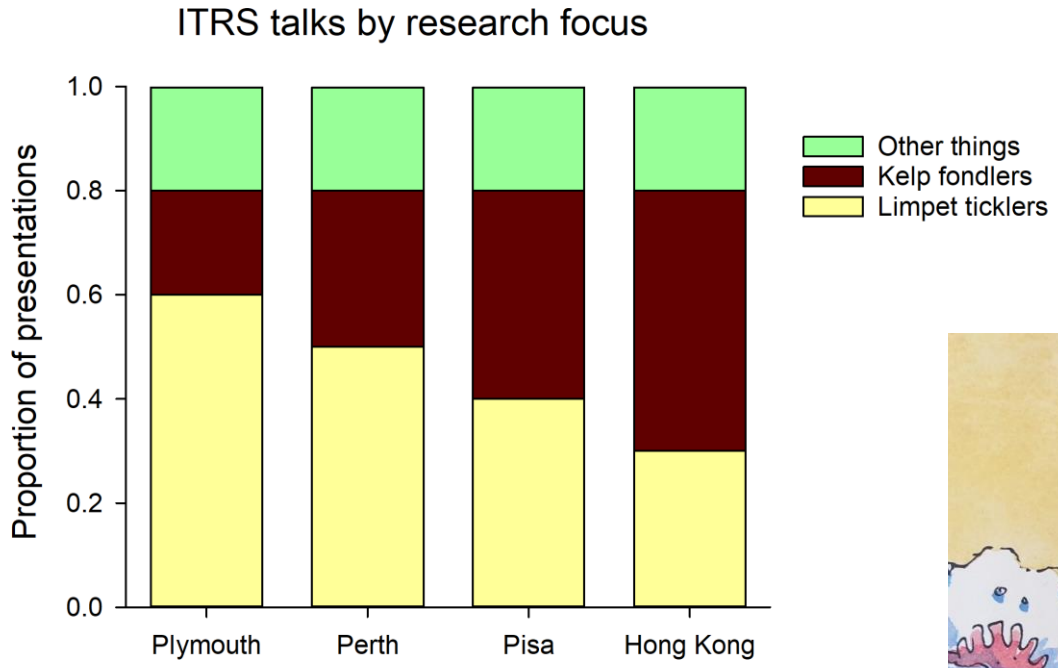
Perth 2014

Pisa 2016

Hong Kong 2019

Hobart 2023

Time series of ITRS research focus*



Sally and the Limpet by Simon James, 1991

* Not actual data

Kelp forest ecosystems historically seen as dynamic and highly variable through space and time…..

Ecological Monographs, 62(3), 1992, pp. 421–445
© 1992 by the Ecological Society of America

TEMPORAL AND SPATIAL PATTERNS OF DISTURBANCE AND RECOVERY IN A KELP FOREST COMMUNITY[1]

PAUL K. DAYTON, MIA J. TEGNER, PAUL E. PARNELL,[2] AND PETER B. EDWARDS
Scripps Institution of Oceanography, La Jolla, California 92093-0201 USA

Abstract. This paper addresses questions of community and patch stability as defined by the population biology of dominant plants in the context of different areas within a large kelp forest. We ask (1) "Do large-scale episodic events override biological mechanisms as major community structuring processes?", (2) "Are different local areas characterized by different processes?", and (3) "How persistent are the patches or biological structure over decadal and local spatial scales?" We evaluate these questions with regard to the

Vol. 123: 95–106, 1995 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published July 20

Recurrent destructive grazing of successionally immature kelp forests by green sea urchins in Vestfjorden, Northern Norway

Nils T. Hagen

Department of Fisheries and Natural Science, Bodø College, N-8002 Bodø, Norway

14

Kelp Forests
Dynamic Patterns, Processes, and Feedbacks

Robert S. Steneck and Craig R. Johnson

Vol. 189: 125–134, 1999 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published November 26

Changes in community structure in temperate marine reserves

Russell C. Babcock*, Shane Kelly, Nick T. Shears, Jarrod W. Walker, Trevor J. Willis

Leigh Marine Laboratory, University of Auckland, PO Box 349, Warkworth, New Zealand

Ecological Monographs, 65(1), 1995, pp. 75–100
© 1995 by the Ecological Society of America

SEA OTTERS AND KELP FORESTS IN ALASKA: GENERALITY AND VARIATION IN A COMMUNITY ECOLOGICAL PARADIGM[1]

JAMES A. ESTES
National Biological Survey, Institute of Marine Sciences, University of California, Santa Cruz, California 95064 USA

DAVID O. DUGGINS
Friday Harbor Laboratories, University of Washington, Friday Harbor, Washington 98250 USA

ICES Journal of Marine Science, 57: 579–589. 2000
doi:10.1006/jmsc.2000.0715, available online at http://www.idealibrary.com on IDEAL®

Ecosystem effects of fishing in kelp forest communities

M. J. Tegner, and P. K. Dayton

Tegner, M. J., and Dayton, P. K. 2000. Ecosystem effects of fishing in kelp forest communities. – ICES Journal of Marine Science, 57: 579–589.

Kelp forests, highly diverse cold water communities organized around the primary productivity and physical structure provided by members of the Laminariales, support

Oecologia (Berlin) (1986) 68:186–198

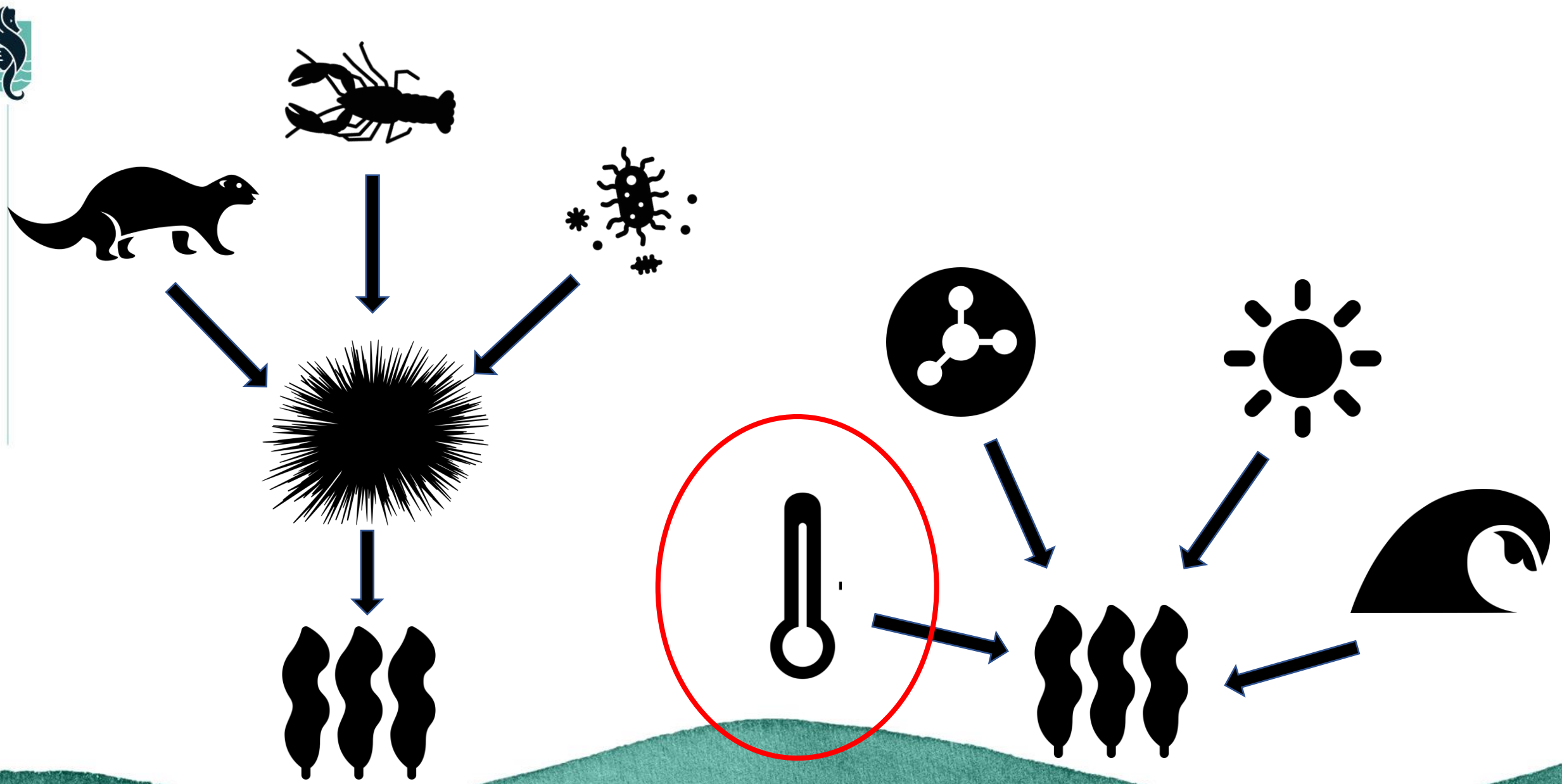
Oecologia
© Springer-Verlag 1986

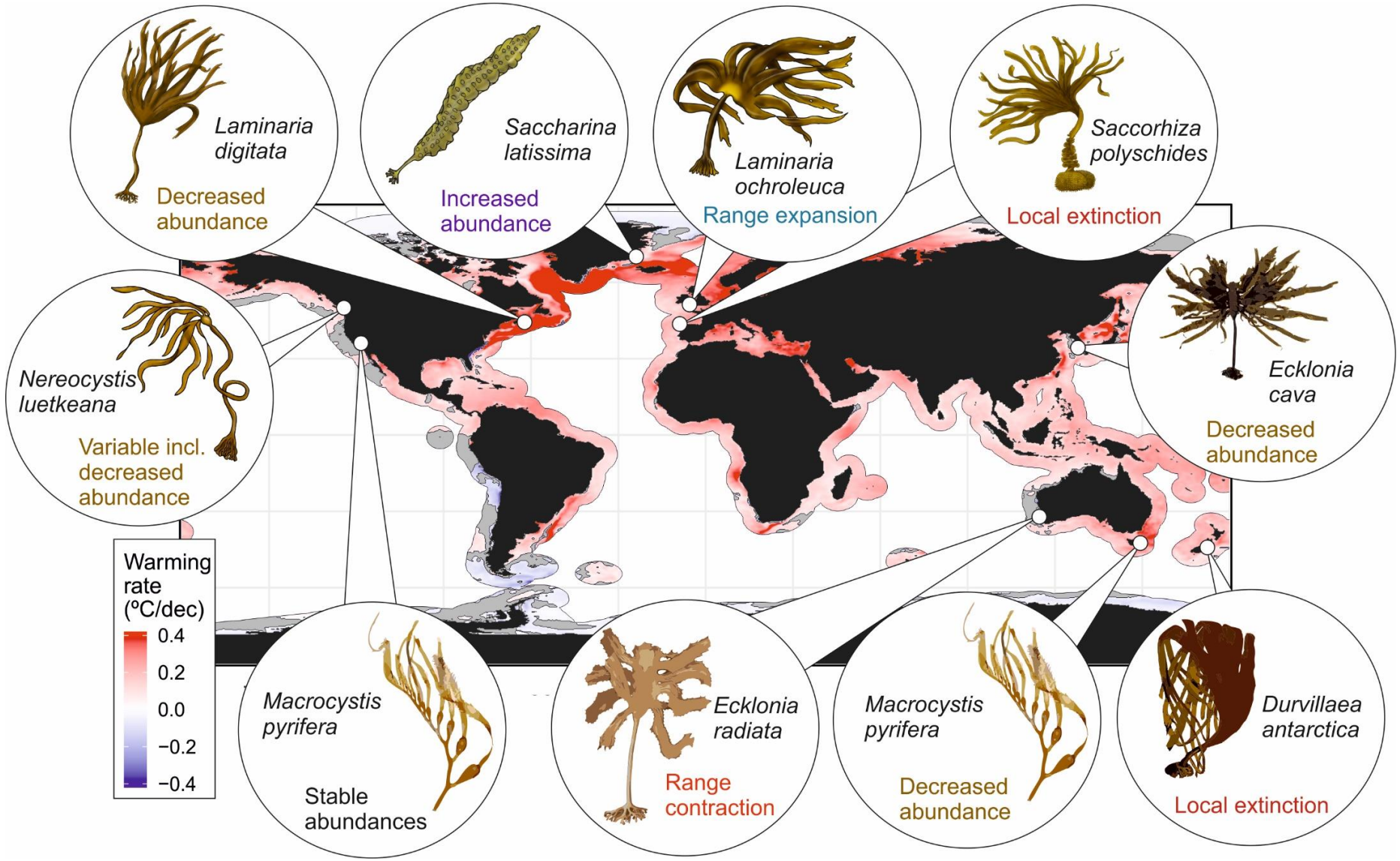
Increased macroalgal abundance following mass mortalities of sea urchins (*Strongylocentrotus droebachiensis*) along the Atlantic coast of Nova Scotia

Robert Scheibling
Biology Department, Dalhousie University, Halifax, Nova Scotia, Canada, B3H 4J1

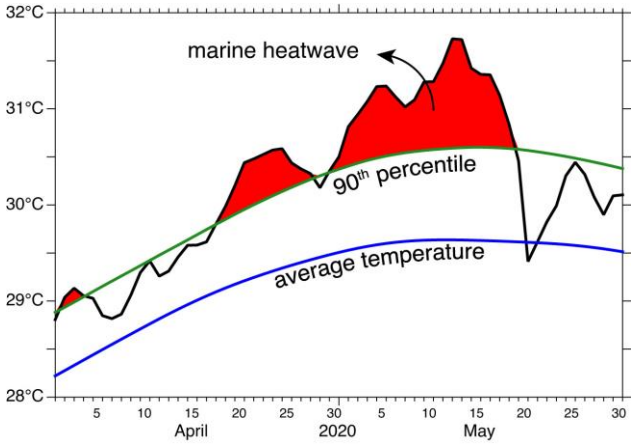
Summary. Recurrent outbreaks of disease between 1980 and 1983 caused catastrophic mortality of sea urchins (>260,000 t fresh weight) along 280 km (straight line dis-

and Palmisano 1974; Breen and Mann 1976b; Mann 1977; Estes et al. 1978; Simenstad et al. 1978; Duggins 1980). In many areas, destructive grazing of macrophytes by expand-





Smale 2020 New Phytologist

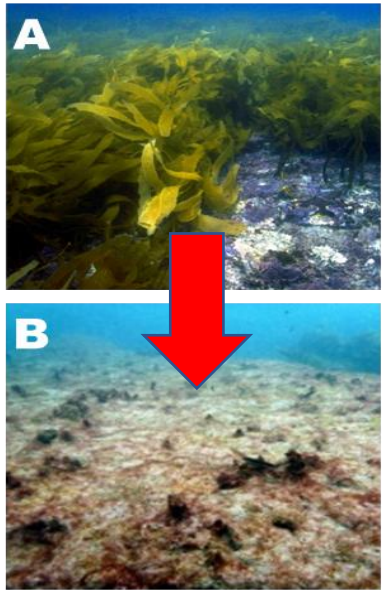


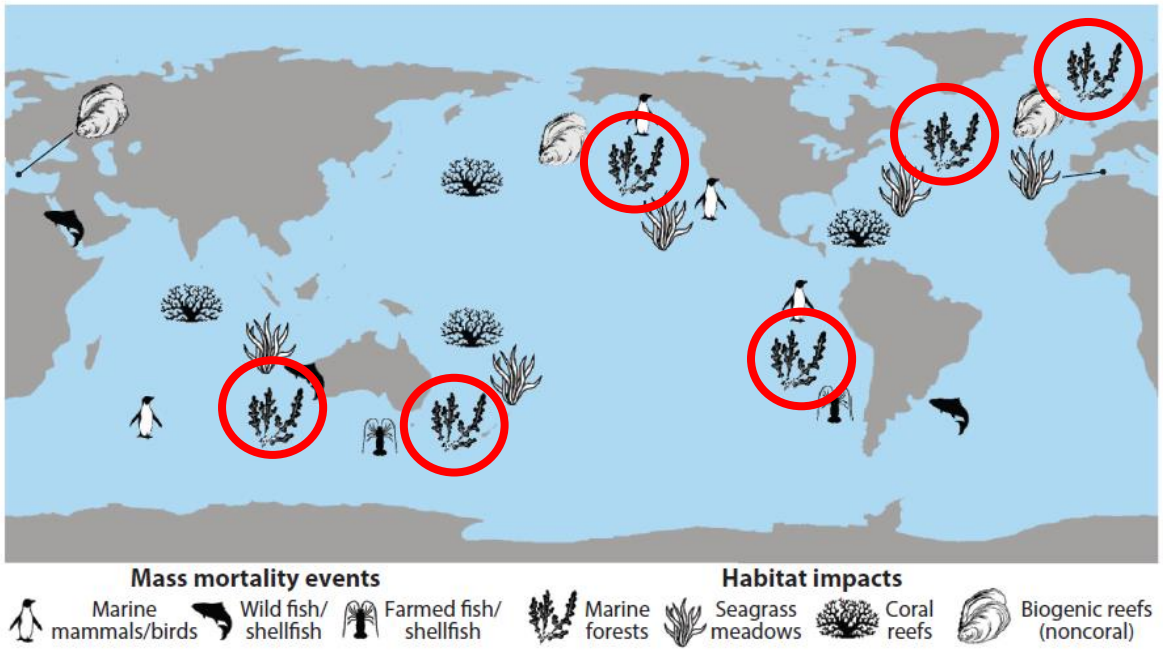
CLIMATE CHANGE

Climate-driven regime shift of a temperate marine ecosystem

Thomas Wernberg,[1*†] Scott Bennett,[1,2,3†] Russell C. Babcock,[1,4] Thibaut de Bettignies,[1,5] Katherine Cure,[1,6] Martial Depczynski,[6] Francois Dufois,[7] Jane Fromont,[8] Christopher J. Fulton,[9] Renae K. Hovey,[1] Euan S. Harvey,[2] Thomas H. Holmes,[1,10] Gary A. Kendrick,[1] Ben Radford,[6,11] Julia Santana-Garcon,[1,2,3] Benjamin J. Saunders,[2] Dan A. Smale,[1,11] Mads S. Thomsen,[1,12] Chenae A. Tuckett,[1] Fernando Tuya,[13] Mathew A. Vanderklift,[7] Shaun Wilson[1,10]

Wernberg et al. 2016 Science

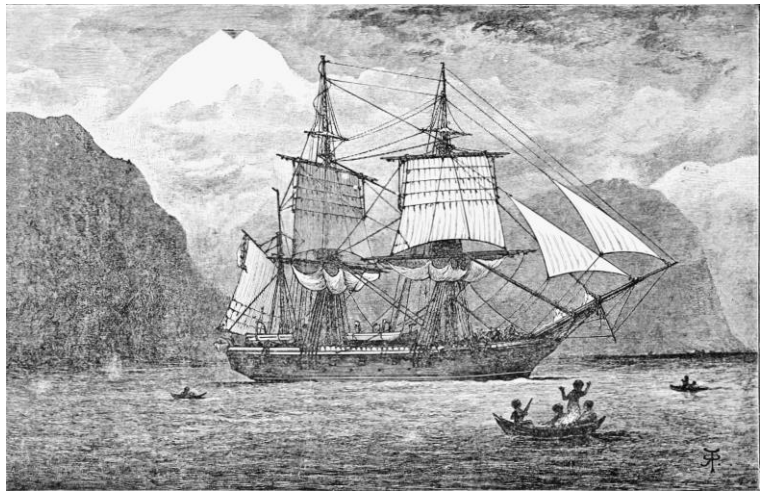




Smith et al. 2023
Ann Rev Mar Sci

MHW impacts of kelp forest ecosystems = Weds PM concurrent session 8, Alissa Bass and Katie Smith

Stability?



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DOI: 10.1111/jbi.14221

RESEARCH ARTICLE

Journal of Biogeography WILEY

One of the least disturbed marine coastal ecosystems on Earth: Spatial and temporal persistence of Darwin's sub-Antarctic giant kelp forests

Alejandra Mora-Soto[1] | Austin Capsey[2] | Alan M. Friedlander[3,4] | Mauricio Palacios[5,6,7,8] | Paul E. Brewin[9,10] | Neil Golding[9] | Paul Dayton[11] | Brigitta Van Tussenbroek[12] | Américo Montiel[13] | Whitney Goodell[3,14] | Catalina Velasco-Charpentier[15,16] | Tom Hart[17] | Erasmo C. Macaya[7,18] | Alejandro Pérez-Matus[19,20] | Marc Macias-Fauria[1]

Mora-Soto et al 2021 J Biogeogr

PNAS

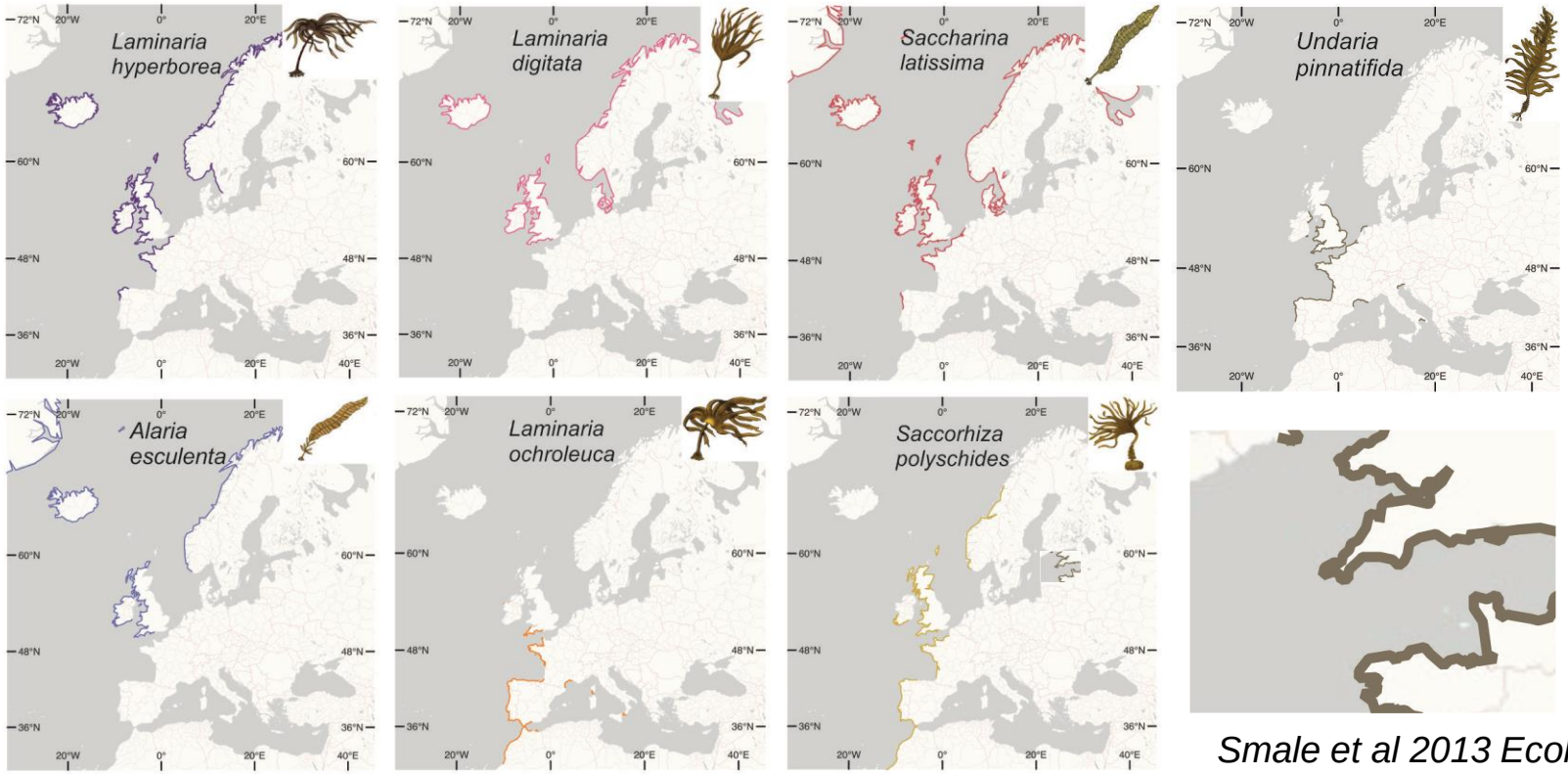
Global patterns of kelp forest change over the past half-century

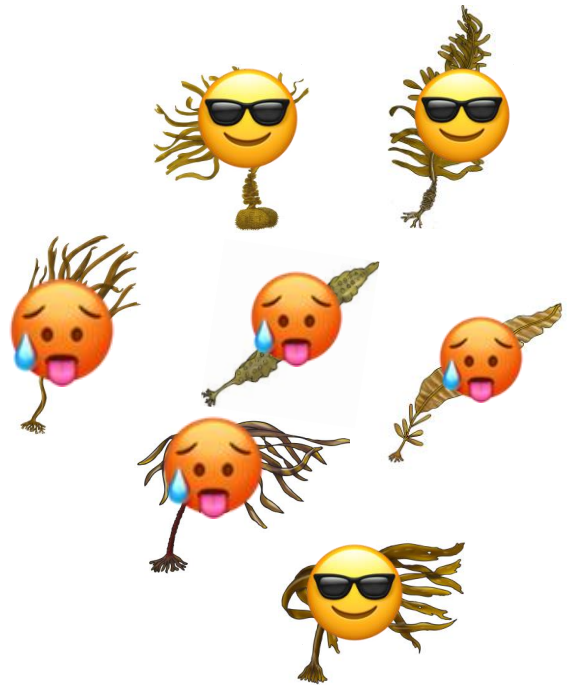
Kira A. Krumhansl[a,1], Daniel K. Okamoto[a], Andrew Rassweiler[b], Mark Novak[c], John J. Bolton[d], Kyle C. Cavanaugh[e], Sean D. Connell[f], Craig R. Johnson[g], Brenda Konar[h], Scott D. Ling[g], Fiorenza Micheli[i], Kjell M. Norderhaug[j], Alejandro Pérez-Matus[k], Isabel Sousa-Pinto[l,m], Daniel C. Reed[n], Anne K. Salomon[a], Nick T. Shears[o], Thomas Wernberg[p,q], Robert J. Anderson[d,r], Nevell S. Barrett[g], Alejandro H. Buschmann[s,t], Mark H. Carr[u], Jennifer E. Caselle[n], Sandrine Derrien-Courtel[v], Graham J. Edgar[g], Matt Edwards[w], James A. Estes[u], Claire Goodwin[x], Michael C. Kenner[u], David J. Kushner[y], Frithjof E. Moy[z], Julia Nunn[x], Robert S. Steneck[aa], Julio Vásquez[bb], Jane Watson[cc], Jon D. Witman[dd], and Jarrett E. K. Byrnes[ee]

Krumhansl et al 2016 PNAS

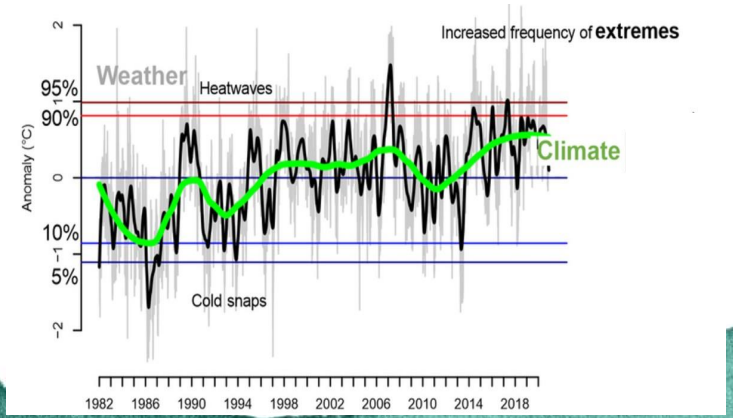
- Global analysis showed that kelp forests were stable or increased in 62% of ecoregions examined.
- Kelp forests faced with rapid environmental change and multiple stressors
- Temporal trends (i.e. stability vs shifts) will depend on ecological/evolutionary context

Biogeographical context – ecologist's playground

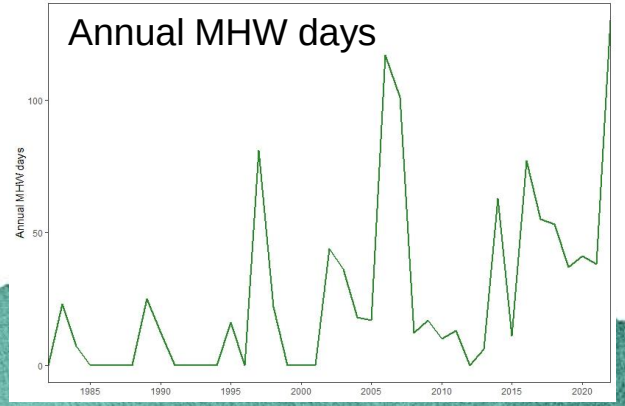




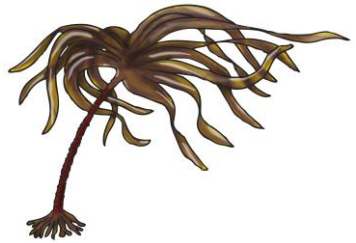
Smale et al 2013 Ecol Evol



Hawkins et al 2022 Glob Change Biol



Laminaria hyperborea – a tale of long-term stability?



- Foundation species and assemblage dominant on wave-exposed subtidal reefs across NE Atlantic
- Highly productive, supports high levels of biodiversity, underpins vital fisheries habitat
- Predicted areal extent in UK and Ireland is ~3000 km^2 and across Europe is ~18,000 km^2
- Around 5.7 Tg C released annually, greater per unit area release rate than seagrass and temperate trees

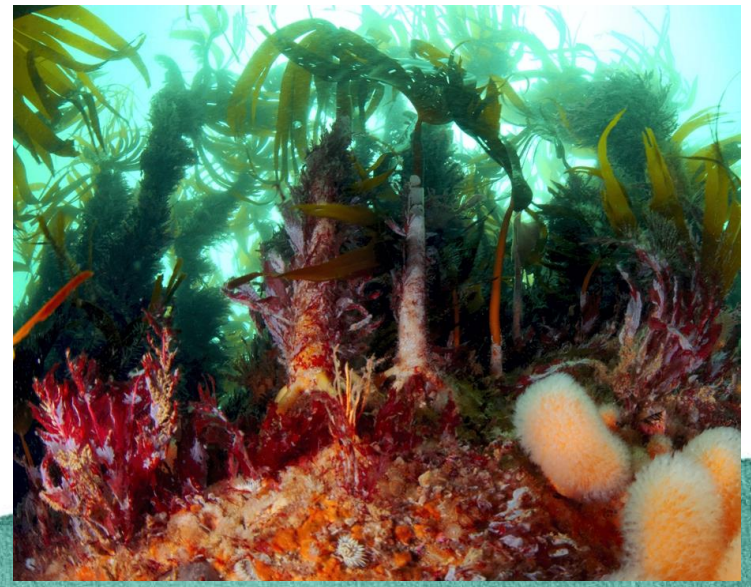
Pessarrodona et al 2018 Global Change Biology

- Very little information on *Laminaria* forests in the UK

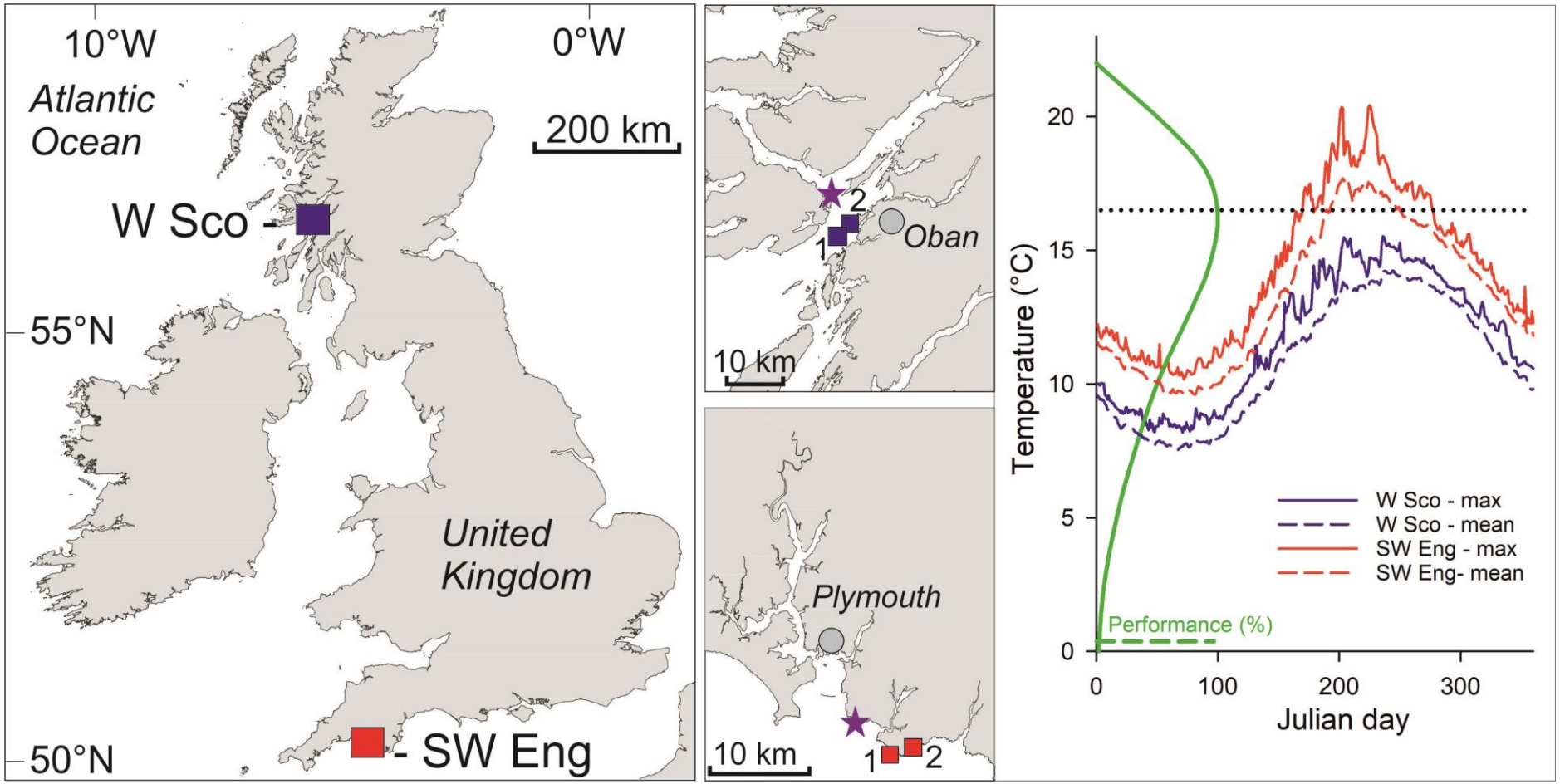
- Large-scale (~9° latitude, ~3°C mean temp) field effort commenced in 2014

- Shown that kelp forest structure, productivity, detritus production shifts with temperature/latitude, with more C held and released in colder regions

- Shown that UK kelp forests support high levels of biodiversity (>500 macro-taxa), including many socioeconomically important species, and that communities are highly variable across multiple spatial scales



e.g. Smale et al 2023 JMBA, King et al 2021 MEPS, Smith et al 2021 L&O, Smale et al 2021 L&O, Smale et al 2020 Sci Reps, Smale et al 2020 Biodivers Conserv, Bue et al Divers Dist, Pessarrodona et al. 2018 Glob Change Biol, Teagle et al 2018 PLOS One, Smale & Moore 2017 JEMBE, Smale et al 2016 MEPS

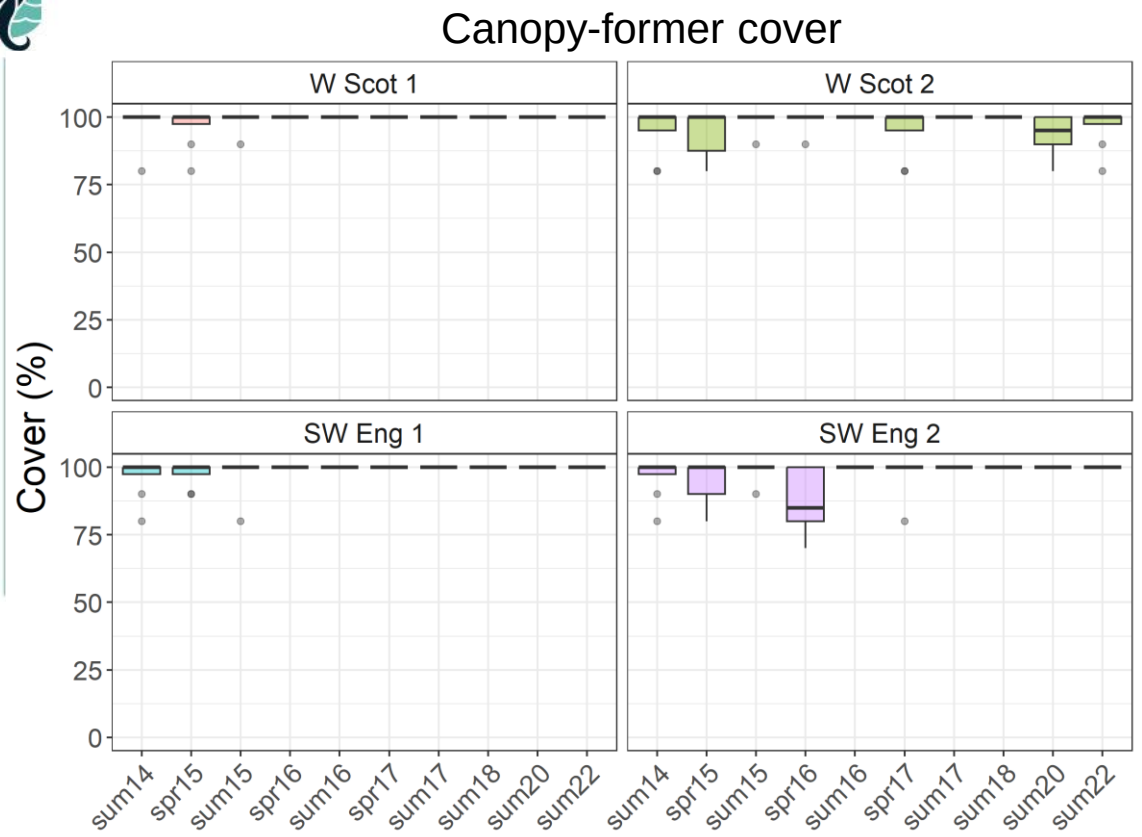


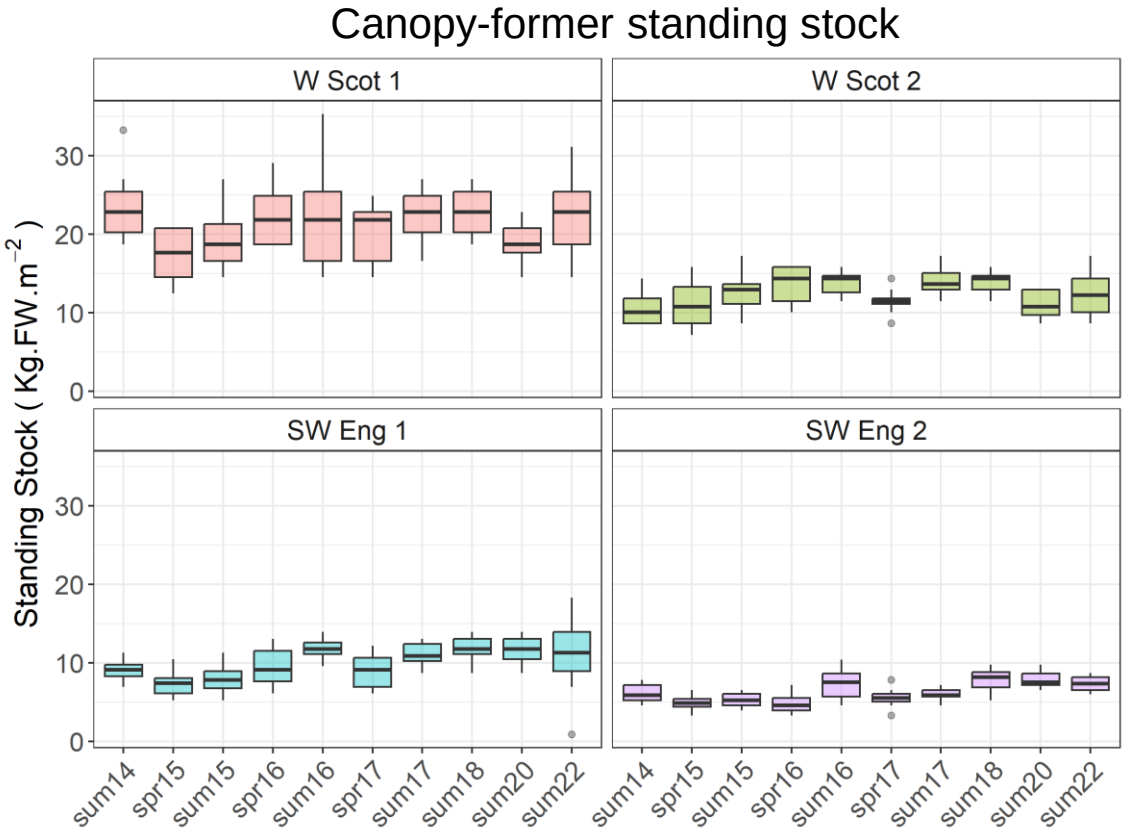
Very low densities of sea urchins (*Echinus* = 0.01 m^2, no other urchins)

Mostly well-mixed, nutrient rich, clear sea water

Goldilocks zone?

Laminaria hyperborea populations exhibit low levels of inter-annual variability

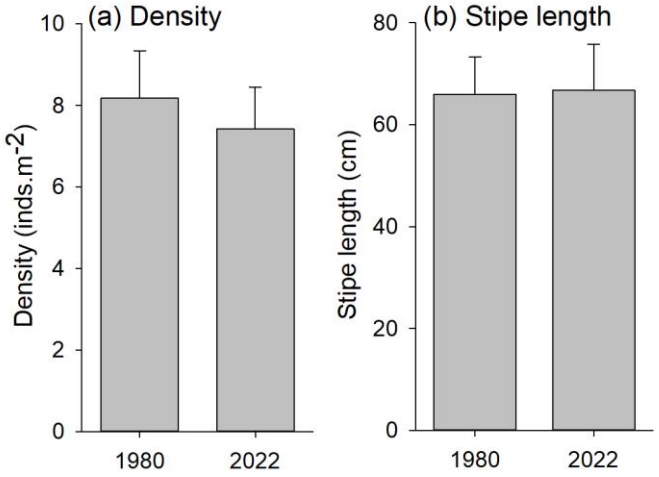




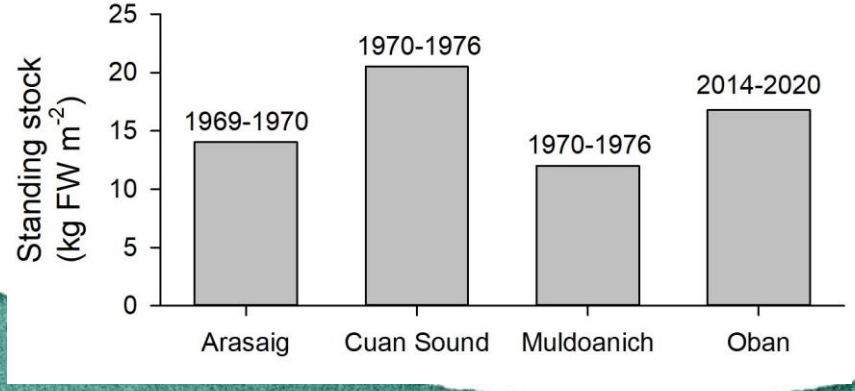
Sampling event (10 between summer 2014 and 2022)

Decadal scale variability?

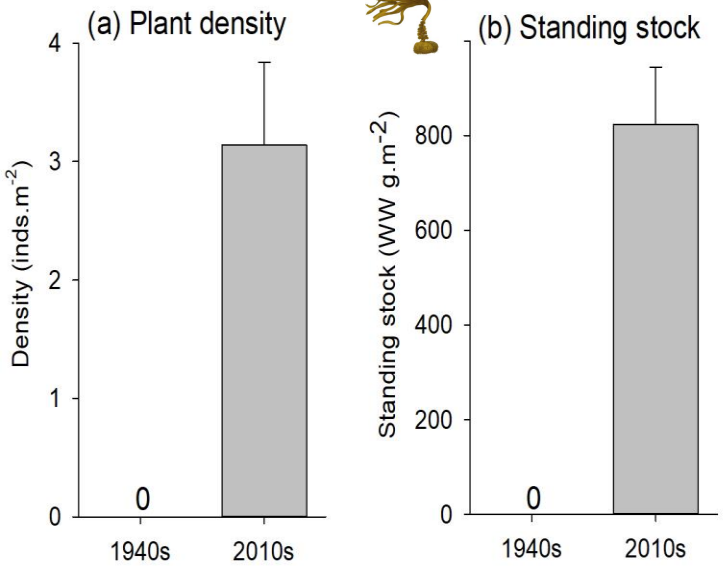
- Reef below Duart Castle, Isle of Mull
- First surveyed autumn 1980, resurveyed autumn 2022
- 60 quadrats over four depths



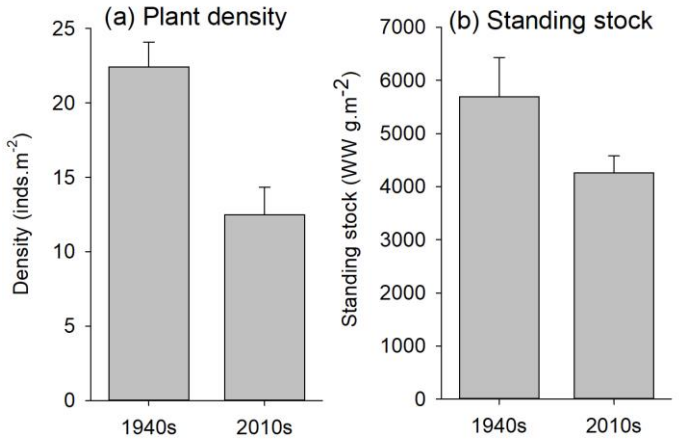
- Comparison of contemporary standing stock with historical values reveals little change



- Church Reef, Wembury, SW England
- Surveyed by Mary Parke et al,12 times between 1942-1944
- Resurveyed >70 years later, 7 times between 2016-2018



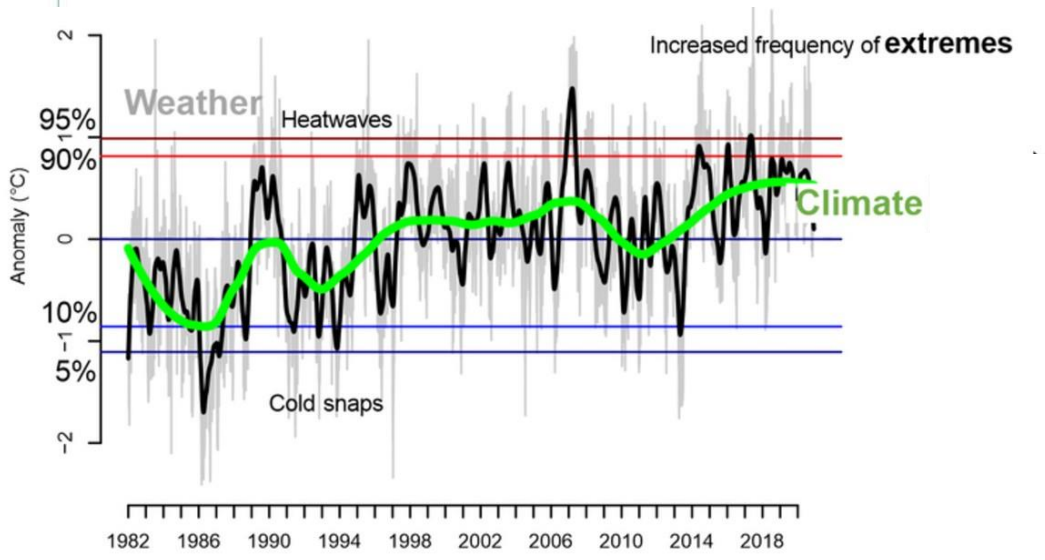
- Declines in density and standing stock observed



- Goldilocks zone off Scotland has facilitated persistence of subtidal *Laminaria hyperborea* populations for decades (centuries?) with little evidence of change

- Recent warming trends in southwest England and (perhaps) increased disturbance events may be eroding long-term persistence of *Laminaria hyperborea*
- Ecosystem-level implications due to importance of *Laminaria hyperborea*
- However, limited evidence base due to lack of long-term monitoring

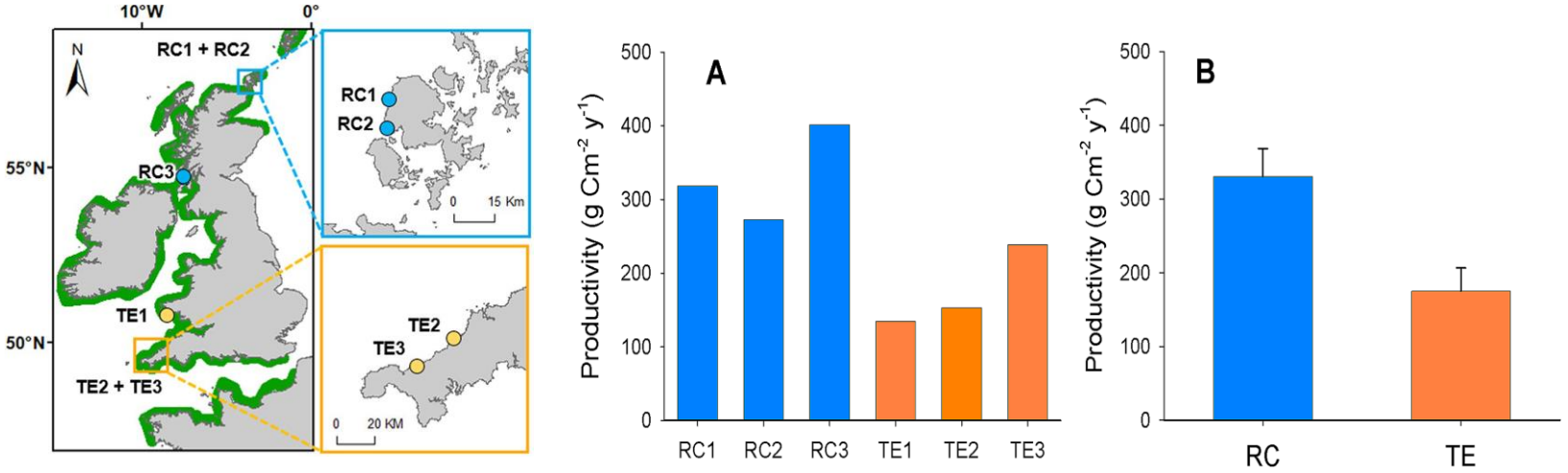
More on resurveys of historical kelp sites? = Nora Salland, concurrent session 9, Weds PM



Hawkins et al Glob Change Biol 2022

Community impacts of loss of foundation species

- *Laminaria digitata* dominates lower intertidal on wave exposed coastlines – vital habitat former
- Trailing range edge populations in SW England/NW France exhibit lower growth, plant biomass & performance than range centre populations

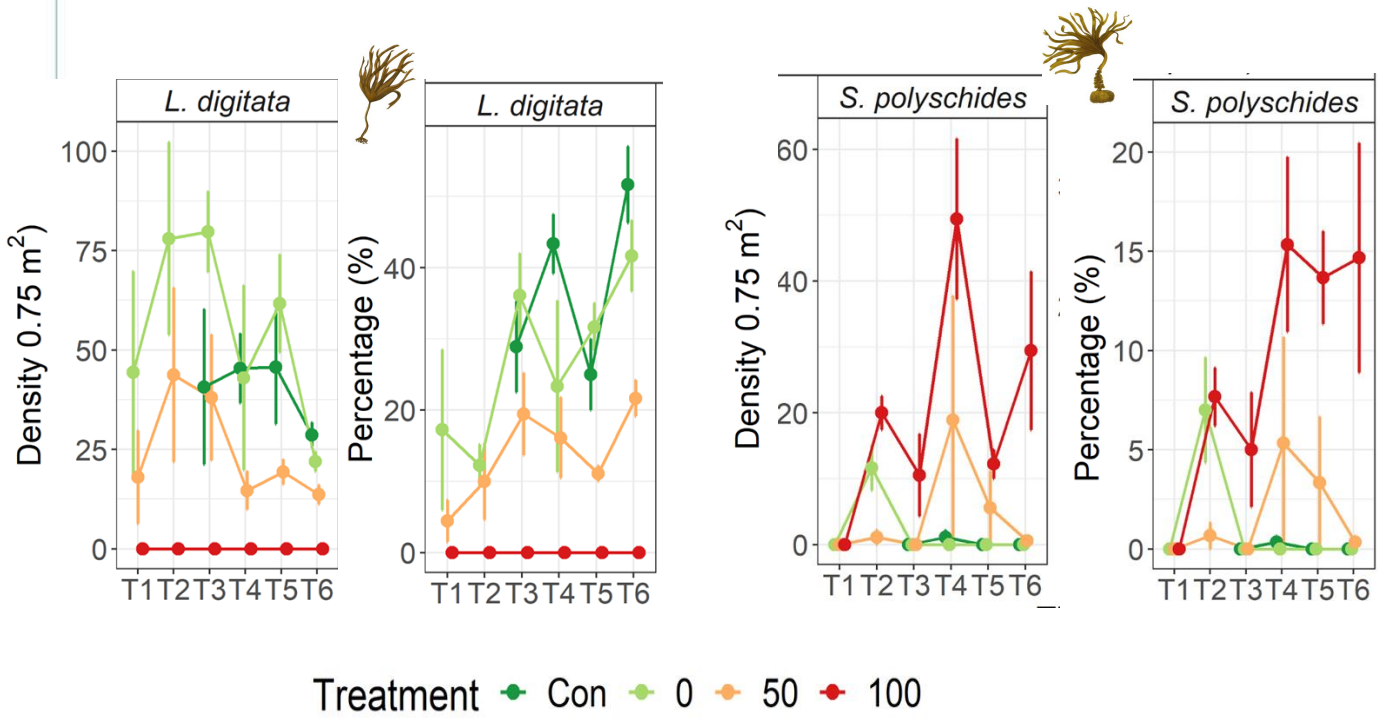


King et al 2020 Mar Biol

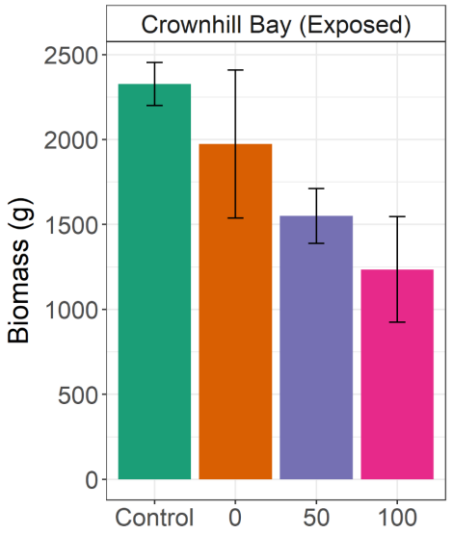
- *Laminaria digitata* is declining at range edge in France (Raybaud et al. 2013) and (probably) SW England (unpublished data)

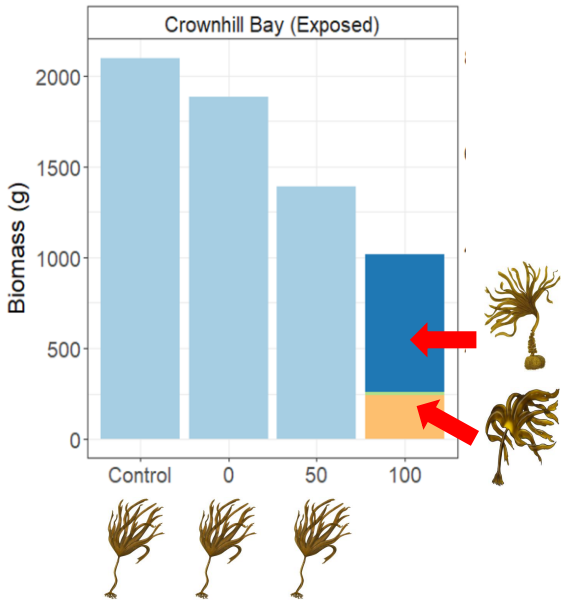
So what? How do range contractions alter ecological structure and functioning?

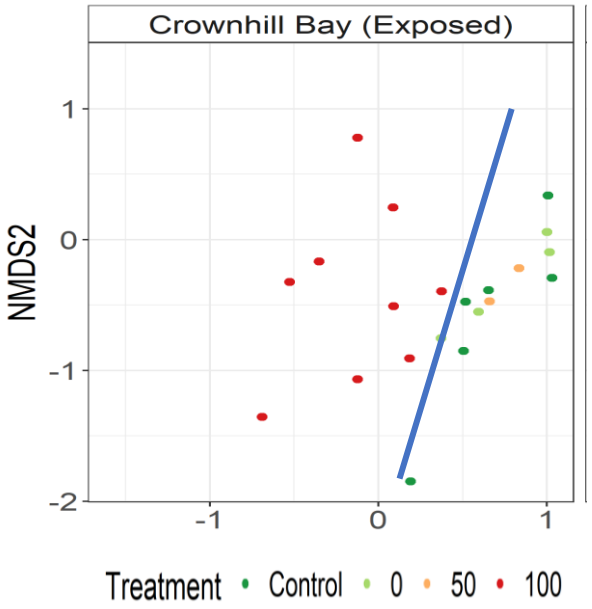
- Multi-year manipulative experiment in the low intertidal (*Laminaria digitata* zone)
- Pulse disturbance followed by press removal to simulate contraction at the range edge
- All canopy removed from 9 large plots (~4 m diameter) then 3 assigned to each of (i) 100 % removal of *Laminaria digitata* recruits (ii) 50 % removal and (iii) 0 % removal. Plus 3 undisturbed controls.
- Maintained for ~3 years at 2 sites (data shown here from one site)



Teagle et al (in prep)







- Loss of long-lived perennial foundation species leads to shift in dominance by short-lived annual
- Subsequent changes in biomass dynamics (standing stock and productivity patterns)
- Shifts in community structure and functioning
- Climate-driven range contractions have wide-ranging consequences (even with some level of redundancy)

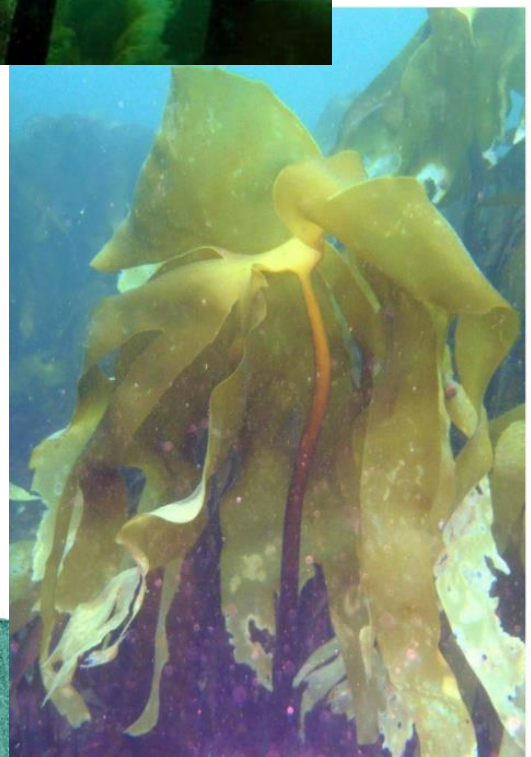
Teagle et al (in prep)

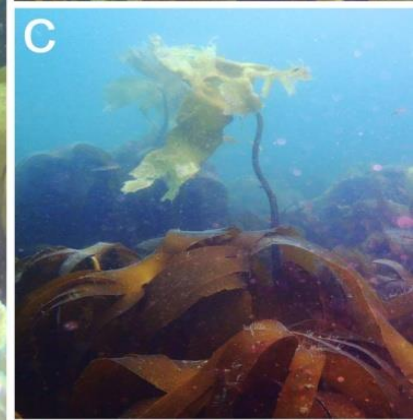
Laminaria ochroleuca – rapid proliferation?

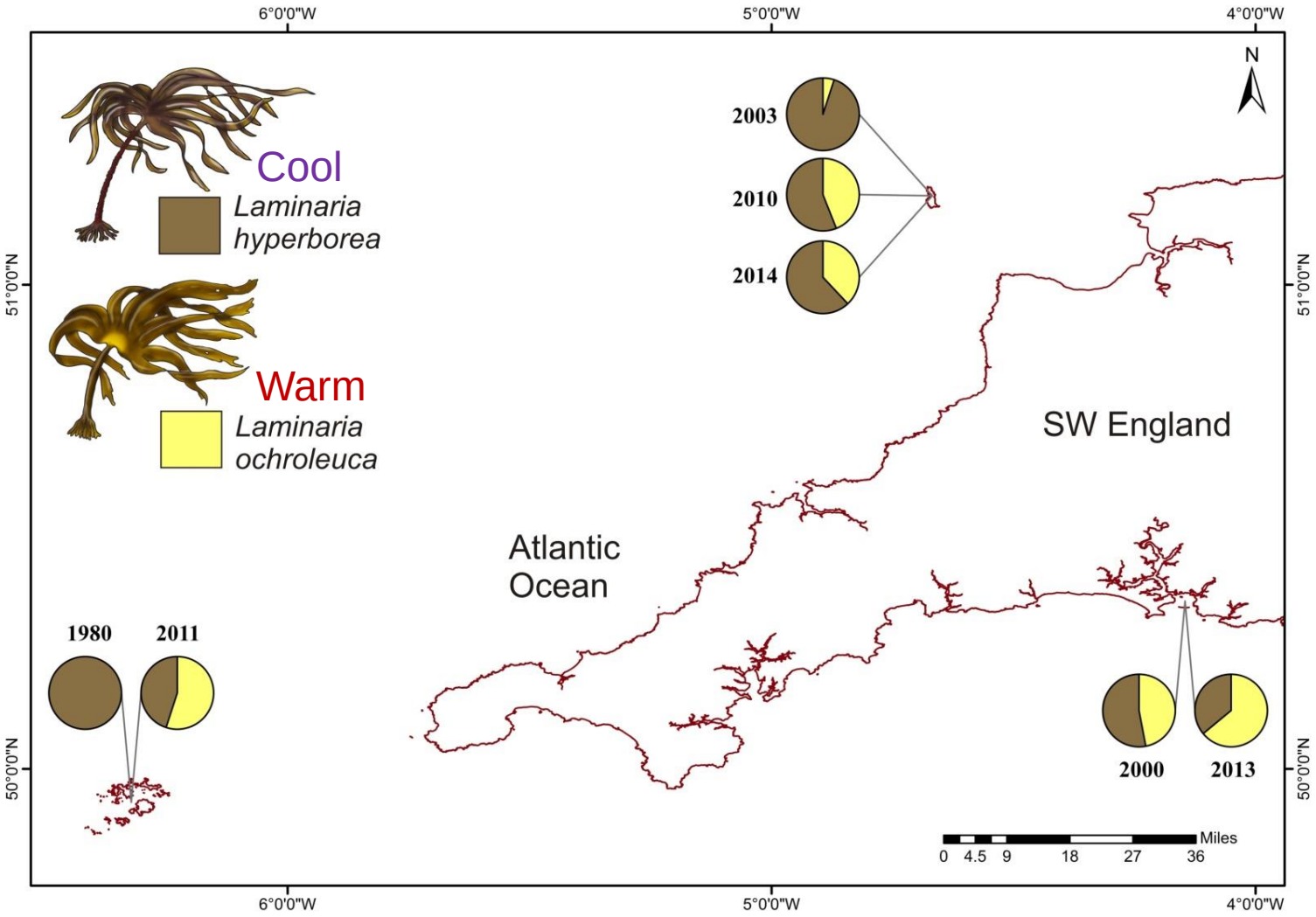
Laminaria ochroleuca is a ‘warm water kelp’, distributed from Morocco/Mediterranean to southwest UK and Ireland - first recorded in UK in 1948 by Mary Parke (MBA).

Anecdotal evidence suggests rapid increase in abundance along southwest coastline of UK

Is *Laminaria ochroleuca* proliferating at the poleward range edge and if so, so what?







Teagle & Smale 2018 Diversity and Distributions

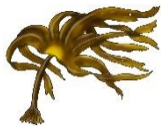
How will this affect associated biodiversity?

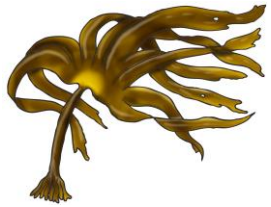
Sessile stipe assemblages

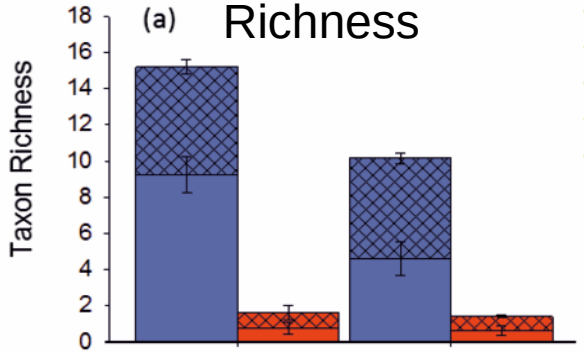
Teagle & Smale 2018 Diversity and Distributions

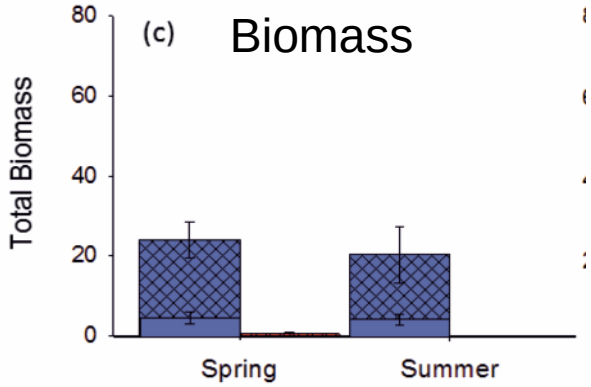
Cool

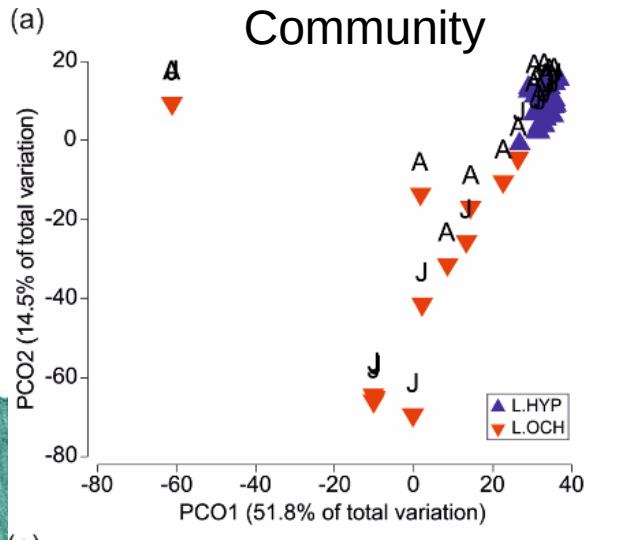
Warm



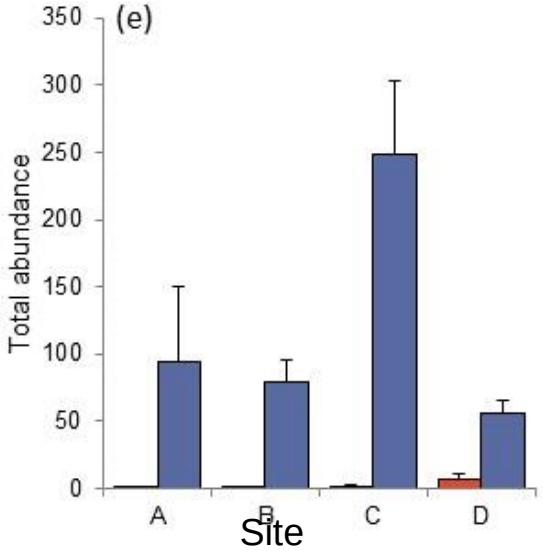


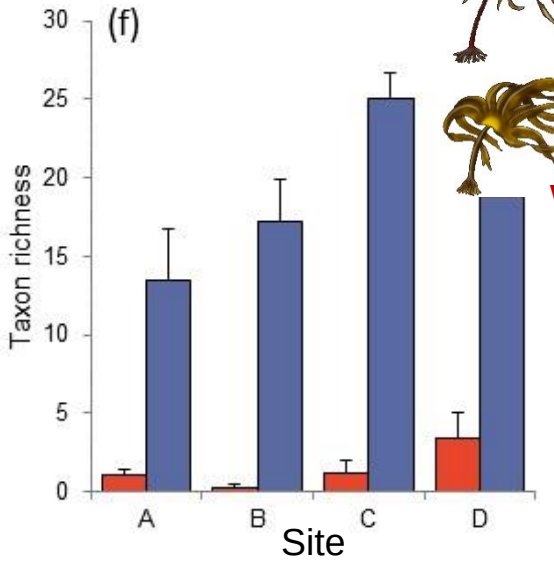


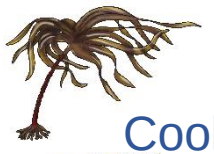




Mobile stipe assemblages

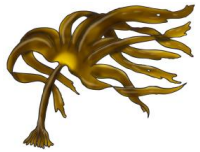






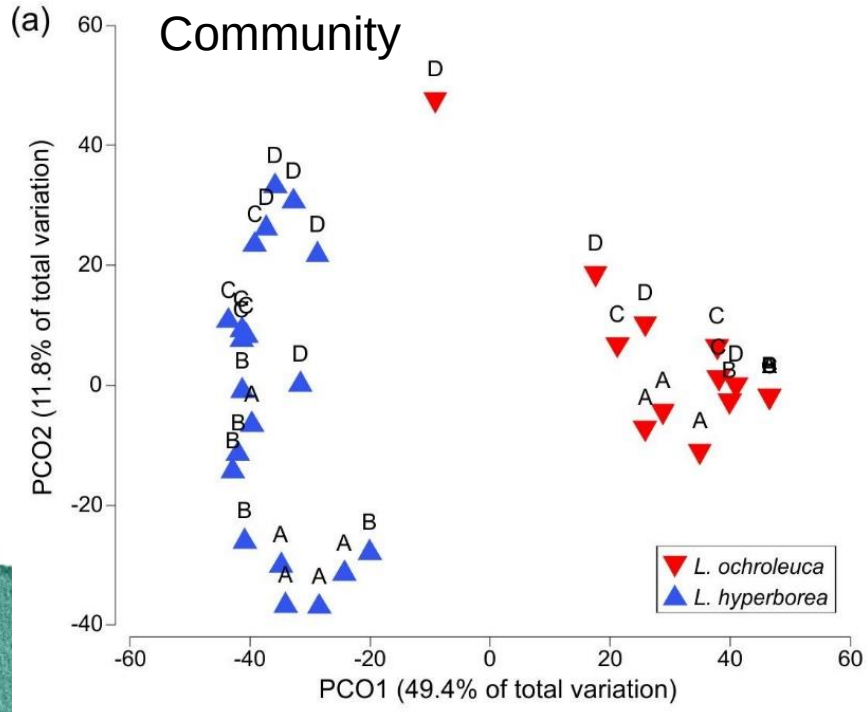
Cool

Warm



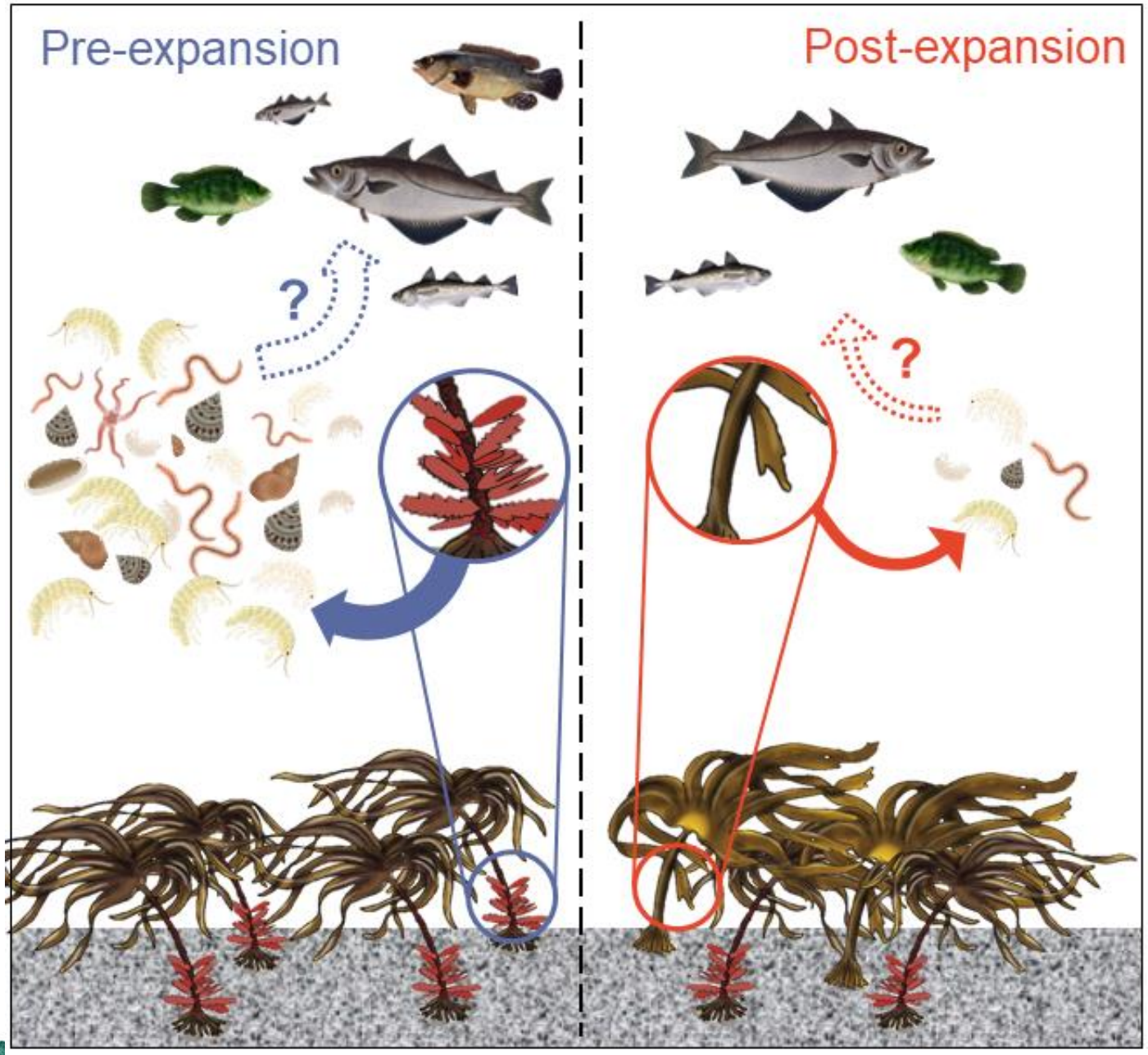
Fifty times (!!!) fewer mobile invertebrates supported by warm water kelp

Very different stipe-associated communities



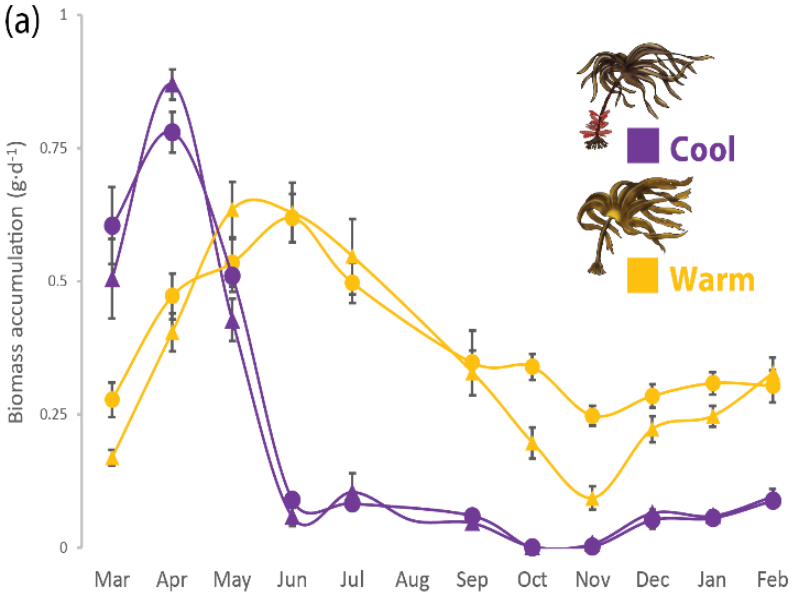
Smale et al 2022 J Ecol

Implications for food webs?



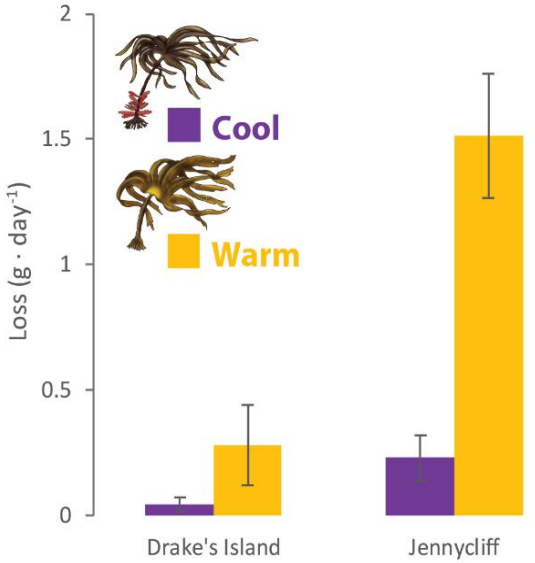
Smale et al 2022 J Ecol

Growth and consumption

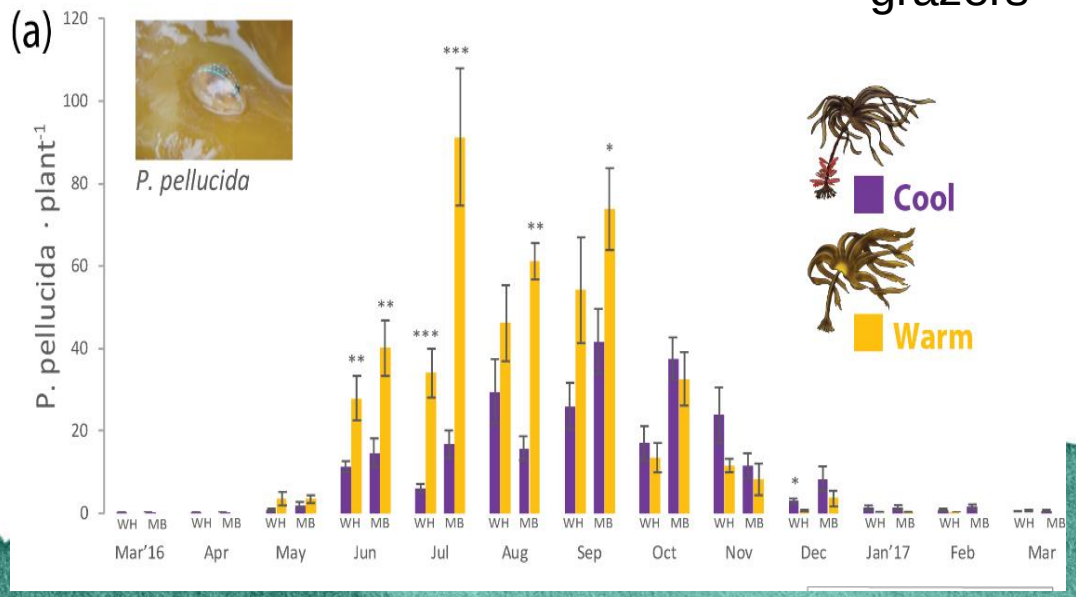


The warm water kelp exhibits different seasonal patterns of biomass accumulation and loss

The warm water kelp decomposes more quickly

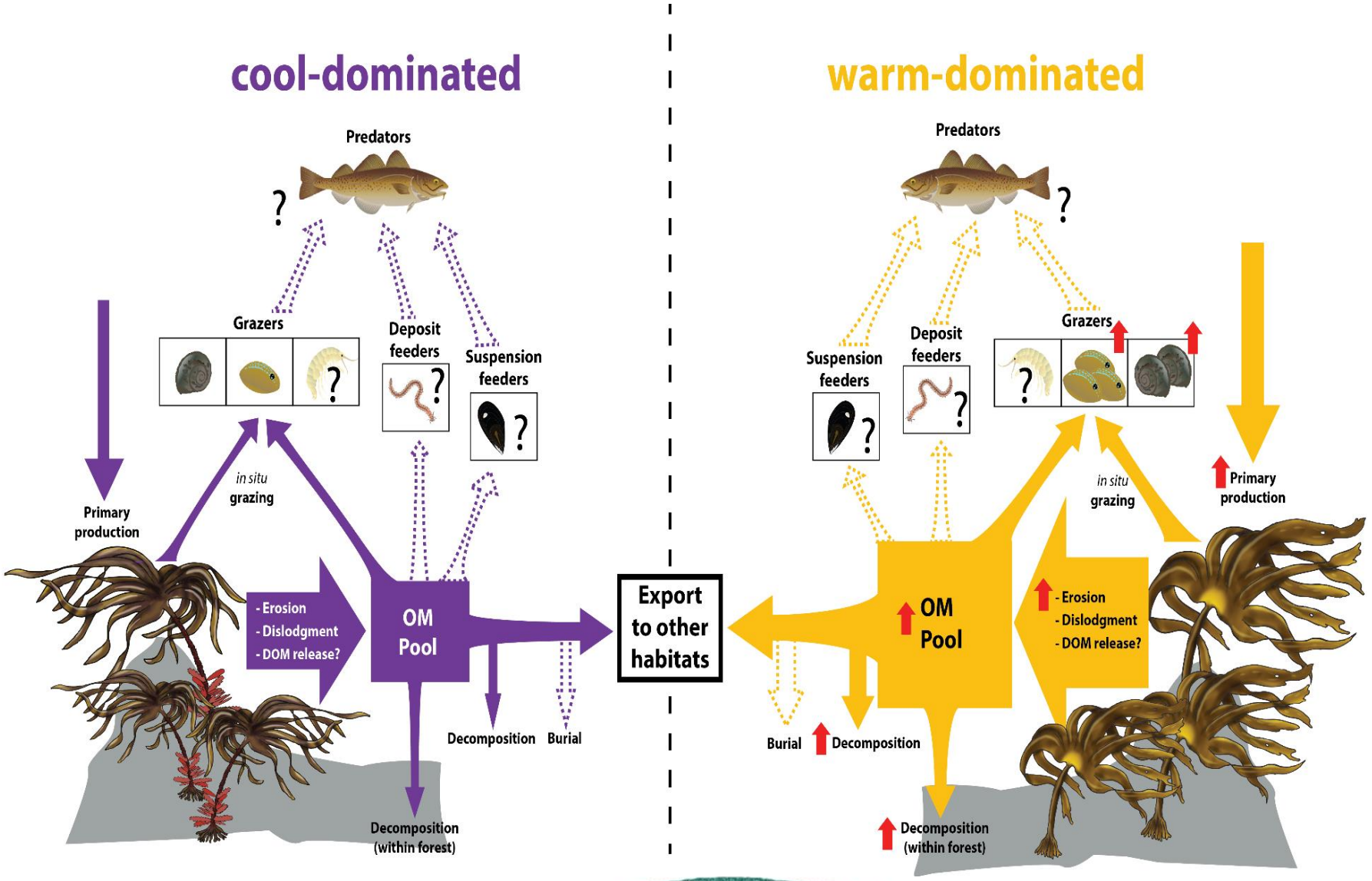


The warm water kelp is a preferred food source for grazers



Pessarrodona et al 2018 J Ecology

Implications for carbon cycling?



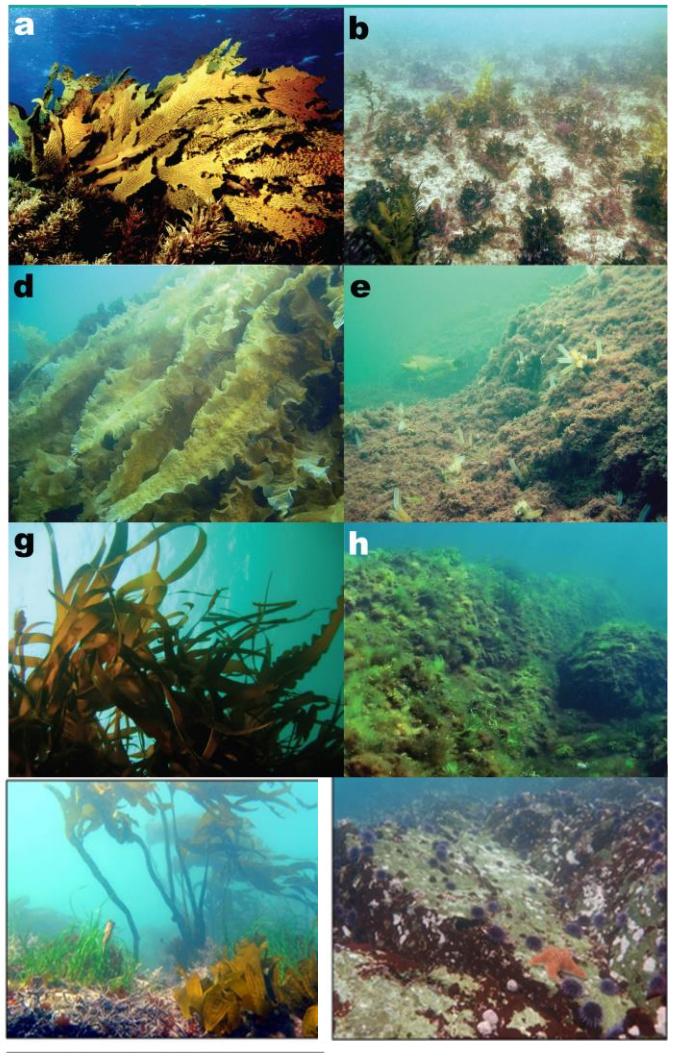
Pessarrodona et al 2018 J Ecology

Overall shifts in structure

- Kelp forests in SW England historically dominated by *Laminaria hyperborea* (subtidal) and *Laminaria digitata* (intertidal)
- Offer persistent stable habitat and support high local biodiversity
- Exhibit springtime peaks in growth and detritus production
- Biomass less readily consumed and turned over

- *Laminaria hyperborea* and *Laminaria digitata* often still dominate
- *But…. Laminaria ochroleuca* and *Saccorhiza polyschides* much more abundant and can be locally dominant
- Shift to less stable/persistent habitat
- Support lower local diversity
- Summertime peak in growth, autumn in detritus release
- Turned over more quickly (BC implications?)

Wider context



MHWs, grazing

Eutrophication, epiphytes

Invasive species, storms

MHWs, grazing

- Dramatic phase shifts reported for many kelp forests around the world
- More subtle shifts in kelp forest structure also occurring
- Less easy to detect (especially in the absence of proper monitoring) but can have wider consequences
- Even with some degree of redundancy changes in ecological structure and functioning can occur
- Novel communities and interactions
- Knock-on effects for Ecosystem Service provision?

Filbee-Dexter & Wernberg 2018 Bioscience

Rogers-Bennett & Catton 2019 Sci Reps

Thanks to….









…..BEECH group @MBA

… long-term collaborators/legends

… questions?...