Urchin harvesting and kelp regrowth in northern Norway under ocean acidification and warming

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AMAP Arctic Monitoring and Assessment Programme

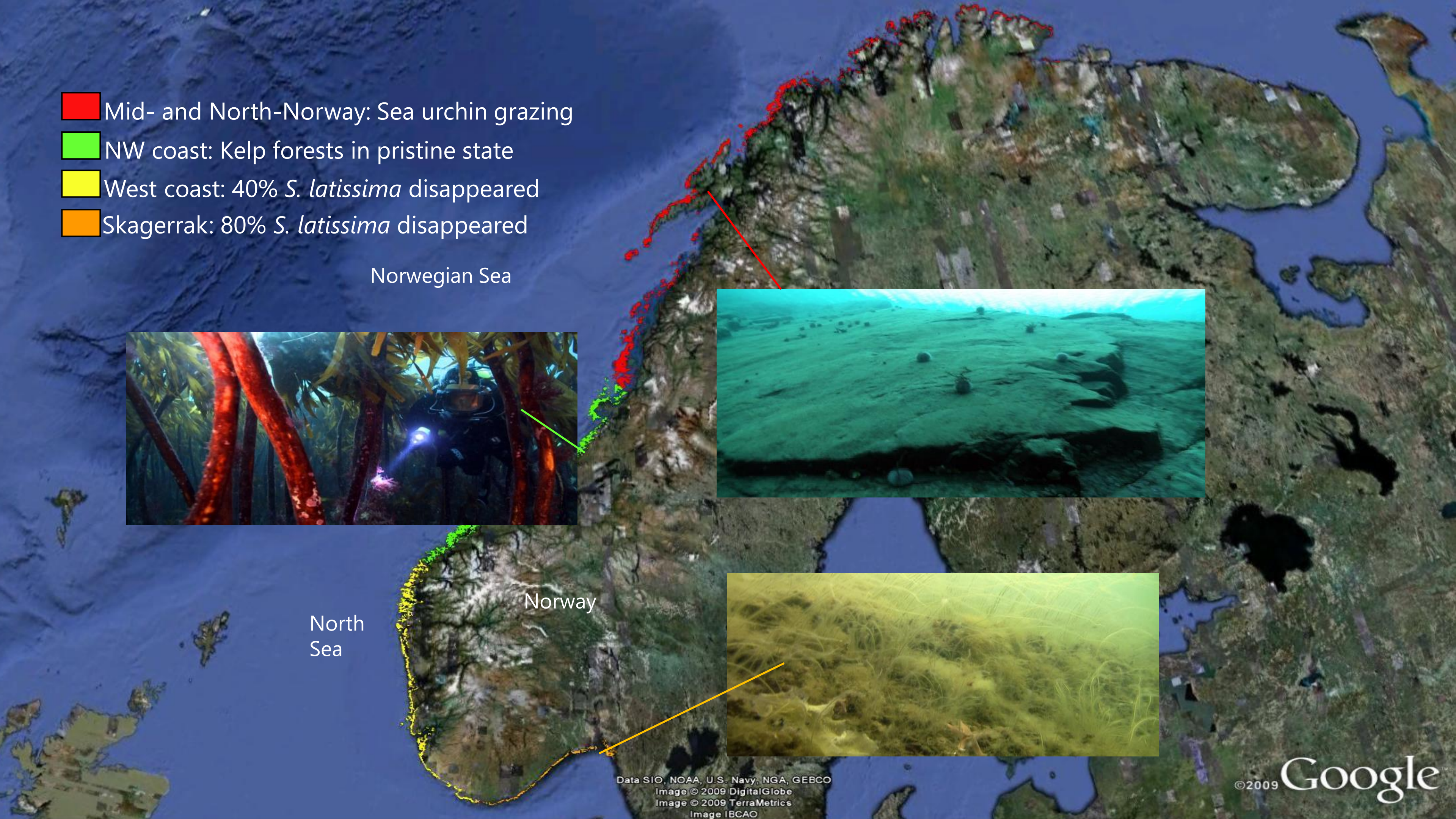
The Research Council of Norway

NIVA Norwegian Institute for Water Research

Background

Photos: Hartvig Christie

- The northern Norwegian coast is characterized by urchin "barrens" where green sea urchins have overgrazed the kelp.
- But in recent decades, kelp forests have been making a come-back, advancing northward from lower latitudes.


Mid- and North-Norway: Sea urchin grazing
NW coast: Kelp forests in pristine state
West coast: 40% *S. latissima* disappeared
Skagerrak: 80% *S. latissima* disappeared
Norwegian Sea
Norway
North Sea
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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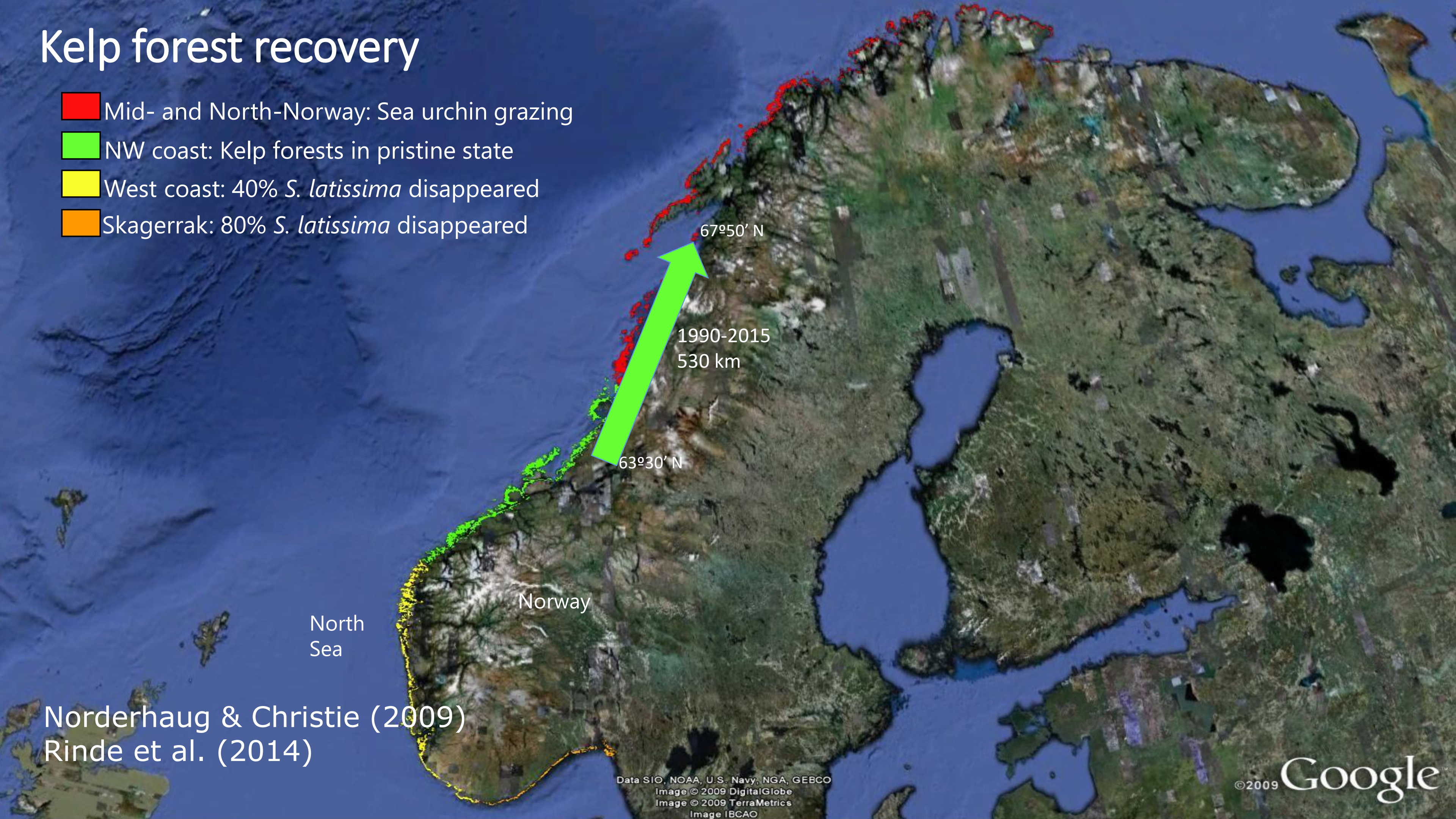
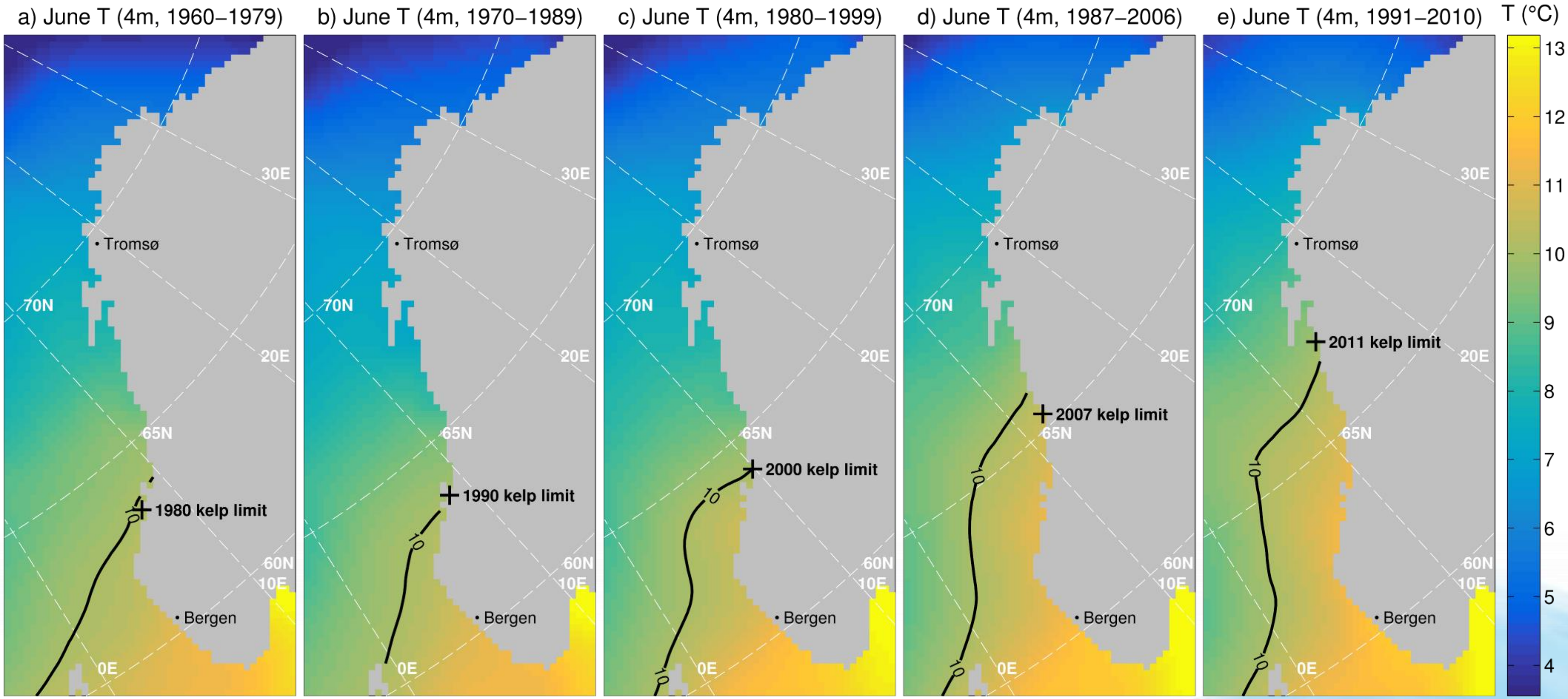
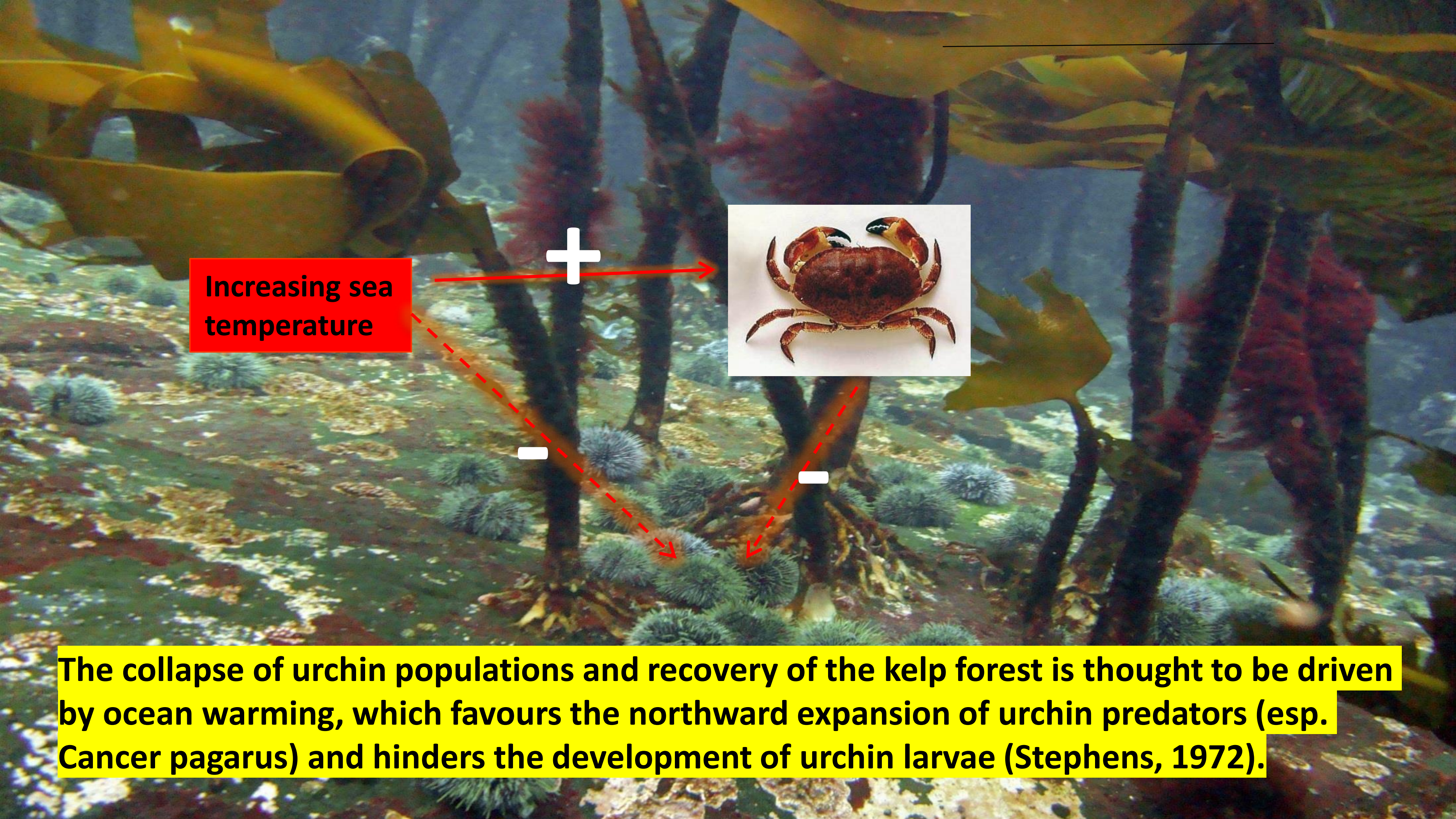
Kelp forest recovery



Norderhaug & Christie (2009)
Rinde et al. (2014)



- Kelp regrowth over the last 35 years has roughly followed the 10 °C isotherm (June, 4m, average over 20 preceding years)



The collapse of urchin populations and recovery of the kelp forest is thought to be driven by ocean warming, which favours the northward expansion of urchin predators (esp. Cancer pagarus) and hinders the development of urchin larvae (Stephens, 1972).

Harvesting of green sea urchins in Norway

- High demand on global market and global shortage of supply suggest a potentially profitable industry.

- Urchin harvesting could bring dual benefits by assisting the recovery of kelp forest, as well as bringing revenue from urchin sales.

→ Q1: How should urchin harvesting in northern Norway be managed (restricted) to optimize the sustainable yield or urchins?

→ Q2: How might yields and optimal restrictions be affected by near-term ocean warming and acidification?

Kelp-Urchin dynamical model

Parameter values from:
1) literature experimental results
2) field data (+statistical models)
3) expert opinion

Uncertainties by Monte Carlo simulation

Warming

Acidification

Kelp growth
Logistic: growth rate, carrying capacity

Urchin recruitment
Stochastic variation between years

Urchin growth
Track (mean,sd) size in each age class

Sporeling settlement

Saccharina latissima
Bulk biomass

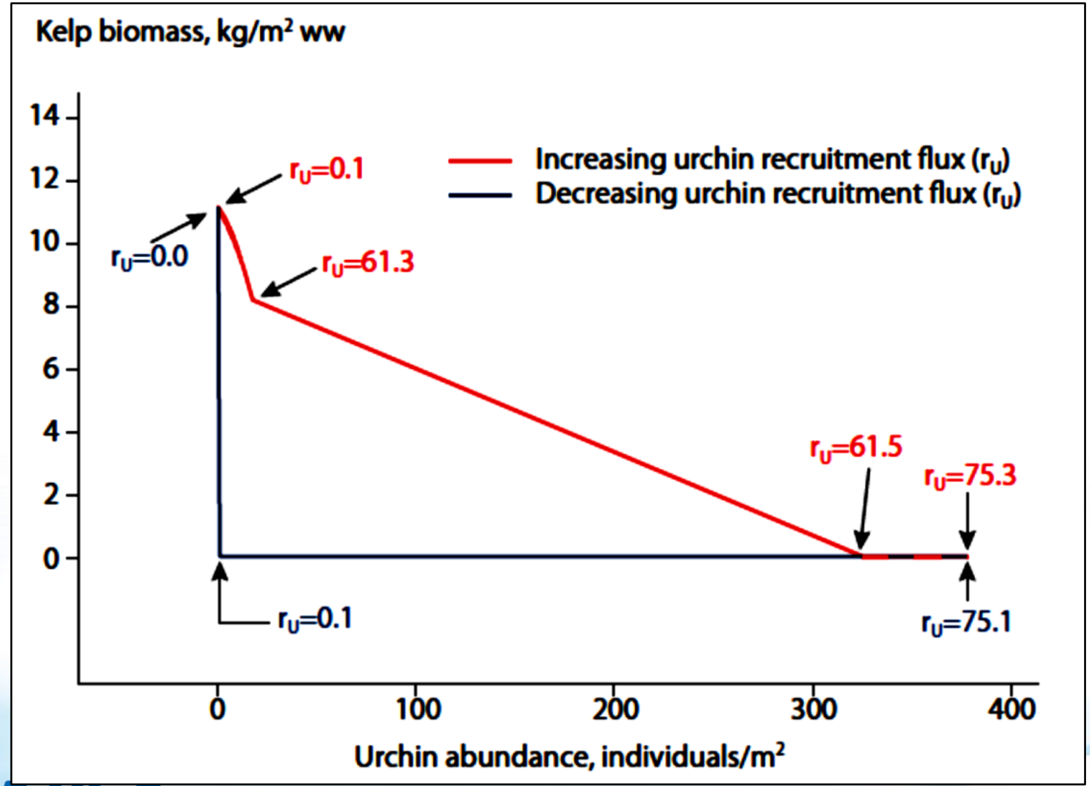
Grazing: urchin size-dependent

Strongylocentrotus droebachiensis
Age/size-structured population

Urchin mortality
Increases with kelp cover (more predators)

Urchin harvest
Exhaustive for all sizes
> minimum catch size

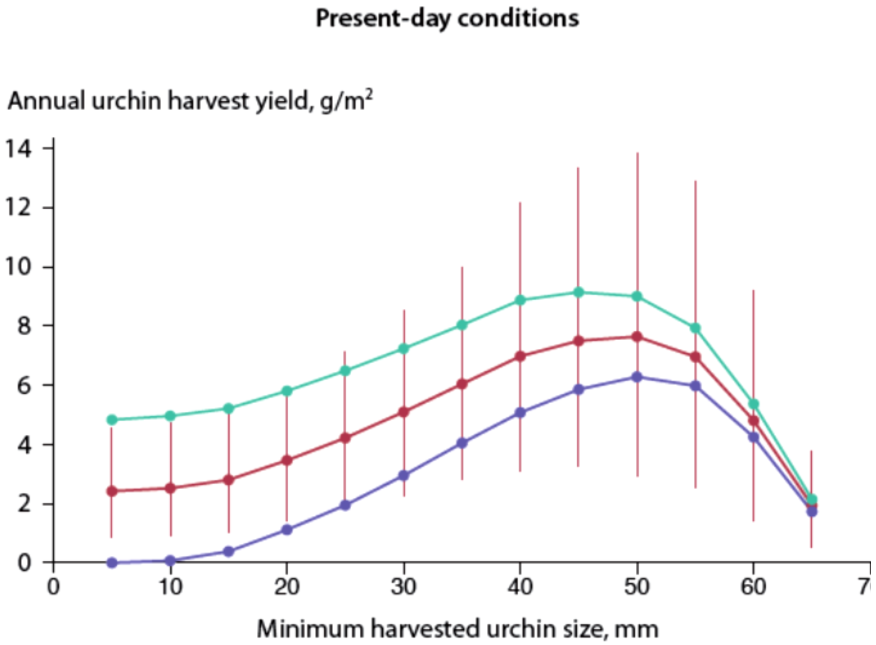
Model behaviour: alternative stable states



- Suppose we start with an urchin barren (bottom right) and reduce the urchin abundance by reducing the recruitment flux r_U (blue line).

- The kelp forest does not recover until the urchins have been almost entirely eliminated. *But once it has,* the urchin recruitment has to be raised to a high level to trigger the reverse regime shift back to urchin barren (red line).

Urchin harvesting simulations



ΔT = 0.8 °C
ΔpCO_2 = 100 µatm (ΔpH ~ -0.1)

- In the present day simulations, sustainable yield over 20 years (red) is optimized by a size limit of 50 mm (cf. 50, 51 mm limits implemented in the Nova Scotia, Maine green sea urchin fisheries)
- In the 2030-2050 simulations, the urchin population biomass and harvest yield are reduced **roughly sevenfold**.

Why is the urchin biomass/harvest so sensitive?

Primary reason: Temperature sensitivity of the urchin recruitment, as inferred from field data (Fagerli et al., 2013).
This alone → fivefold decrease in harvest.

Caveats:

- Based on only two temperatures (Hammerfest vs. Vega).
- Includes ecological effects (crabs, disease) which might not correlate with decadal warming in the north.

Secondary reason: pCO_2/pH sensitivity of urchin recruitment, in turn dominated by sensitivity of juvenile survival (Dupont et al., 2013)

Caveat:

- Based on interpolation between only two, widely-spaced experimental pCO_2 levels…

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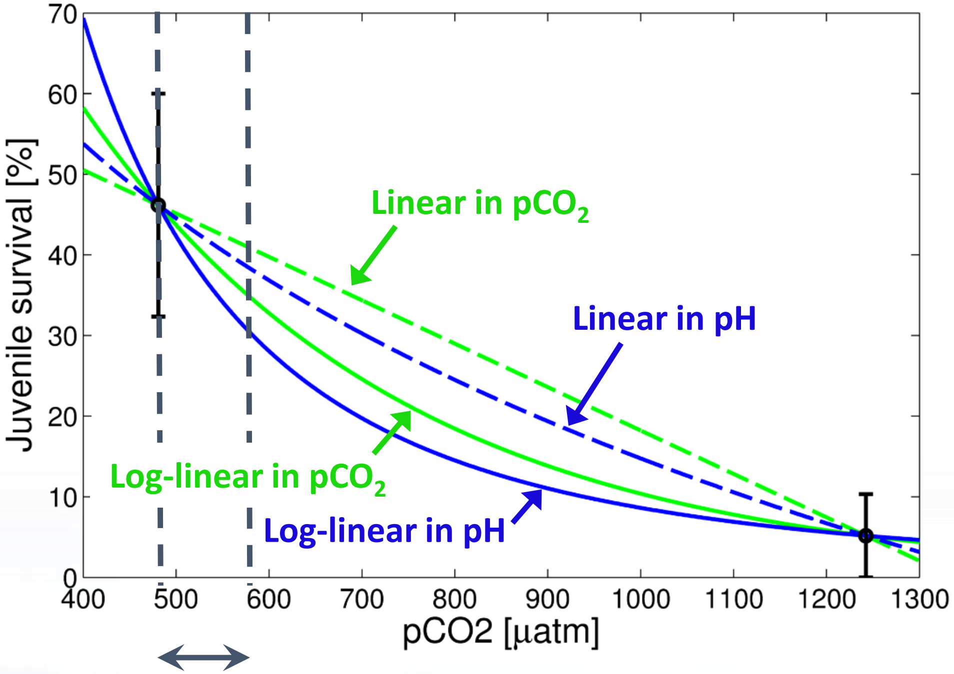
A question of interpolation

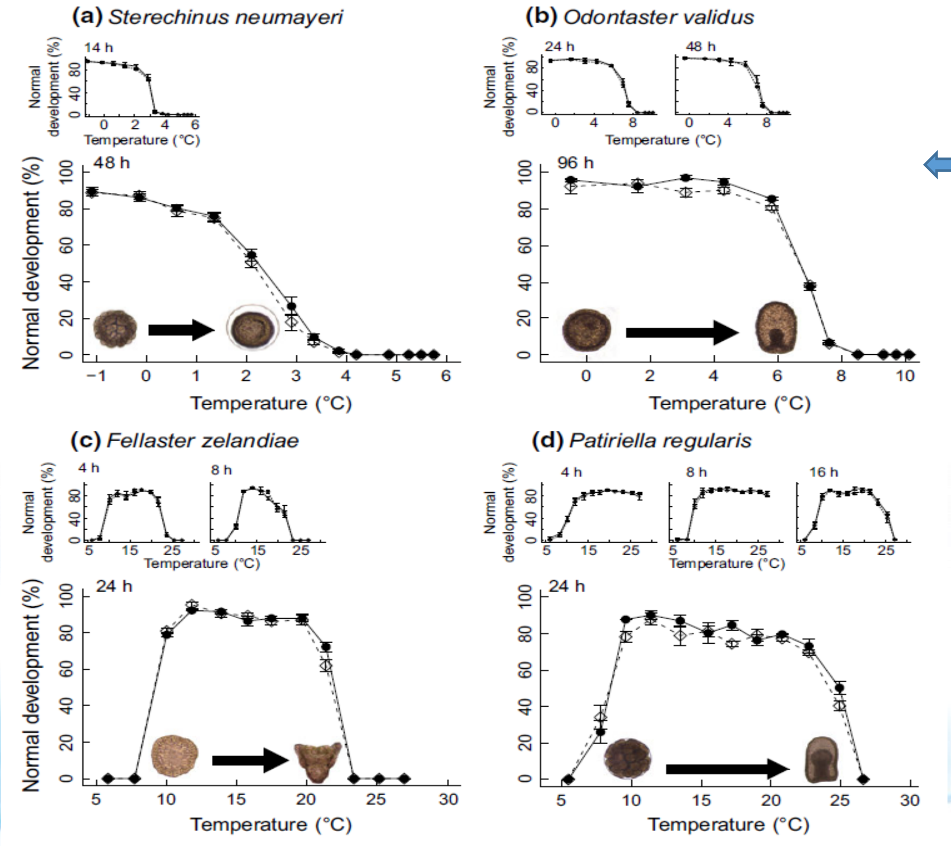


ΔpCO_2 (2030-2050, A1B)

- The interpolated change in survival at ΔpCO_2 = 100 µatm depends strongly on the choice of interpolating function.
- There is no *a priori* basis to favour one function over the others, and the 2-level ANOVA experimental design prevents us from distinguishing the functions on an empirical basis.

An unquantifiable uncertainty

More experiments needed!



- Thermal windows for normal embryo development in other echinoderms (Karelitz et al., 2017) suggest that a strong sensitivity of of green sea urchin larvae over ~1 °C is not implausible.

- Stephens (1972) suggested a threshold for normal development of 10 °C for green sea urchin larvae, but to our knowledge an experimental response curve has never been mapped.

Summary

- Harvesting of green sea urchins in northern Norway could bring profits from urchin sales and also assist the regrowth of kelp forest (thus improving biodiversity, habitat for larval fish, carbon storage, etc.).
- A minimum catch size of 50 mm seems to be a good starting for management to ensure sustainable exploitation.
- Under ocean acidification and warming, urchin biomass and harvest yield may decrease by a factor of seven over the next 30 years (A1B scenario, log-linear sensitivities). This is mainly driven by warming, and may demand adaptation of the industry to protect the larval/juvenile stages (e.g. aquaculture, sea-ranching).
- These results must be treated as provisional due to uncertainties regarding the impacts of warming and acidification on urchin larval/juvenile stages. More field data and experiments (regression rather than ANOVA design) are needed.