Crucial factors affecting reproductive investment of marine fishes in a changing climate

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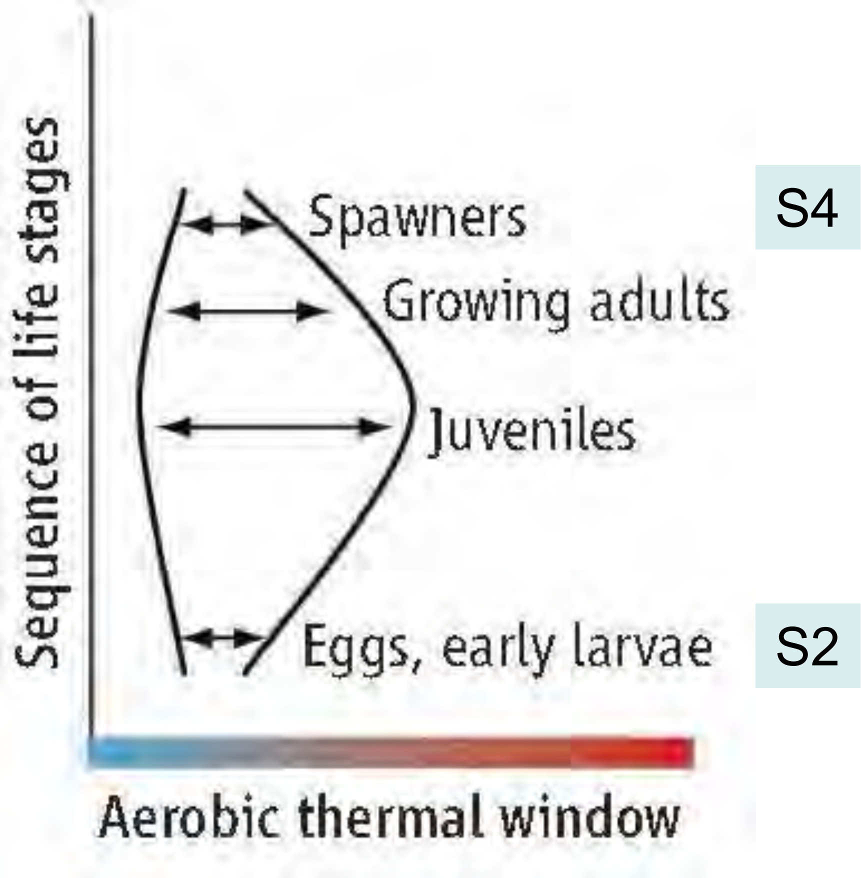
2016 PICES Annual Meeting
S4 Climate Variability, Climate Change and
the Reproductive Ecology of Marine Populations

focus on aerobic scope

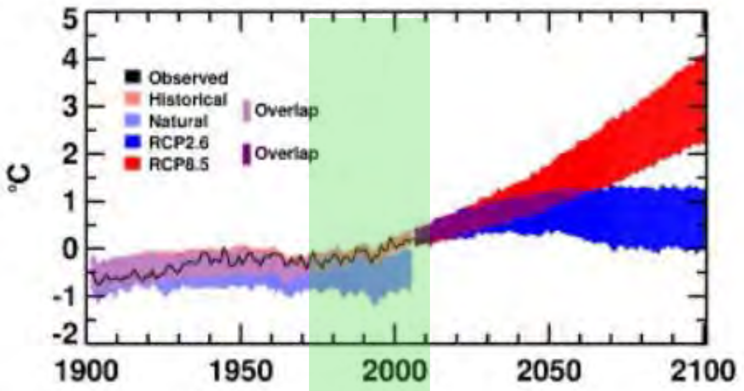
cf. also Philip Munday’s talk on Monday addressing acclimation and genetic adaptation



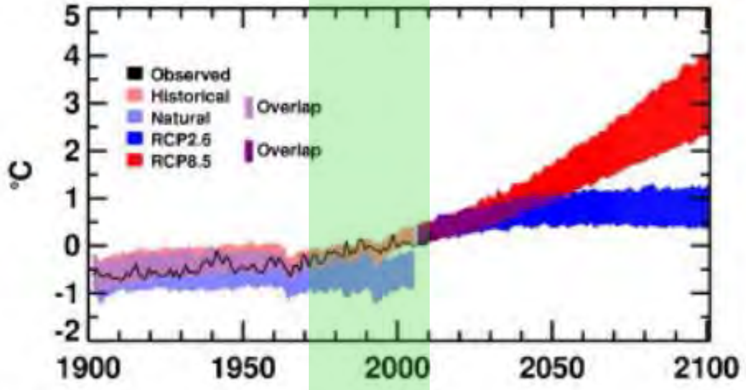
Pörtner & Farrell. 2008

Temperature anomaly from1970 to 2010

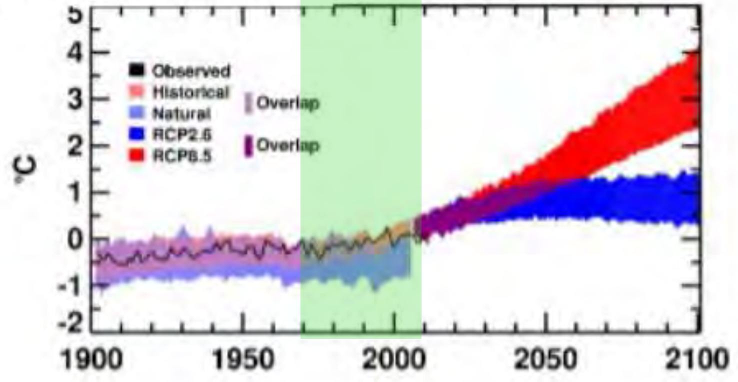
(e) Atlantic Ocean

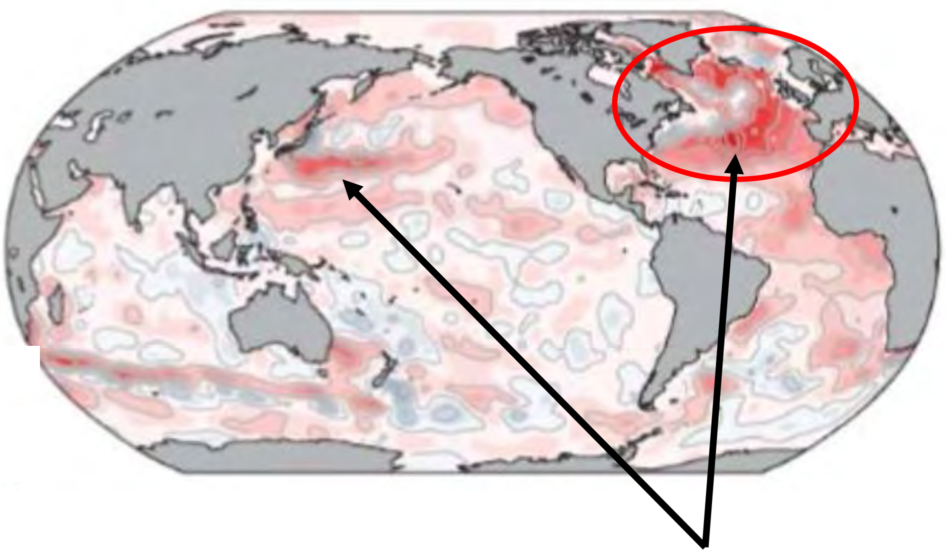


(f) Indian Ocean



(g) Pacific Ocean





case study possibilities!

12 AUG. 2016

Unusual warm ocean conditions off California, West Coast bringing specie:

By **PAUL ROGERS** | progers@bayareanewsgroup.co
PUBLISHED: November 2, 2014 at 9:00 am | UPDATED: August 12, 2016 at 4:56 ar

Hawaiian ono swimming off the California coast? Giant sunfish in Alaska? A sea turtle usu at home off the Galapagos Islands floating near San Francisc

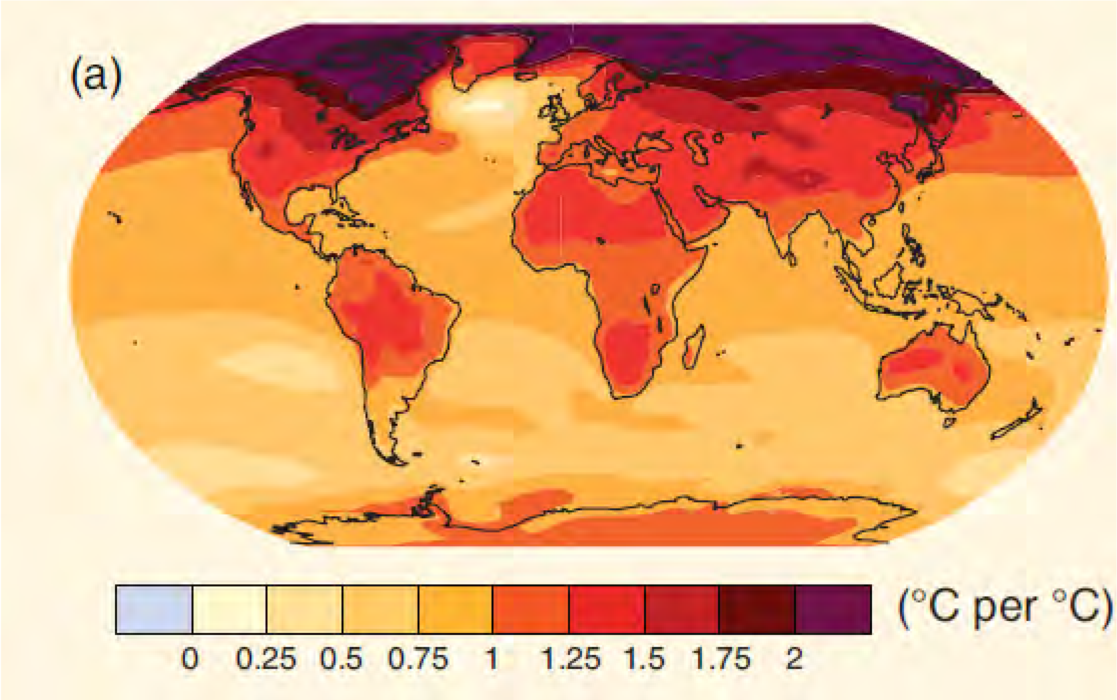
Rare changes in wind patterns this fall have caused the Pacific Ocean off California and West Coast to warm to historic levels, drawing in a bizarre menagerie of warm-water spe The mysterious phenomena are surprising fishermen and giving marine biologists an aq Christmas in Novembe

Temperatures off the California coast are currently 5 to 6 degrees Fahrenheit warmer t historic averages for this time of year — among the warmest autumn conditions of any tir the past 30 years.

"It's not bathtub temperature," said Nate Mantua, a research scientist with the Natio Marine Fisheries Service in Santa Cruz, "but it is swimmable on a sunny da

In mid-October, it was 65 degrees off the Farallon Islands and in Monterey Bay, and 69 deg

relative global temperature change



focus area
in this talk

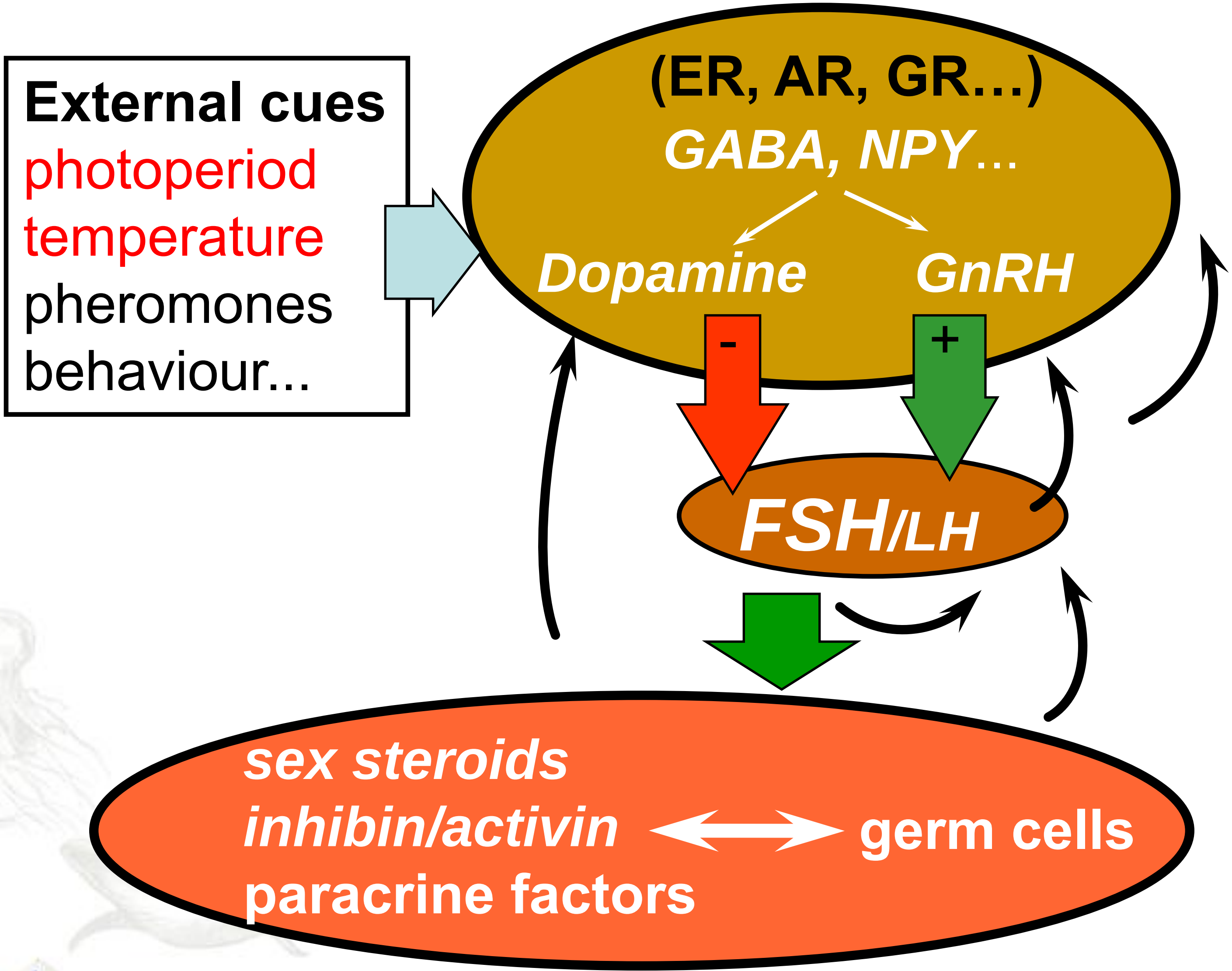
IPPC AR5 WG1 Fig FAQ 14.2-1

BUT: *Tropical species are considered to be especially sensitive to climate change because they live close to their thermal maximum and exhibit limited capacity for acclimation. Donelson et al. 2012.*

reproductive physiology

- most helpful insights but mainly directed towards aquaculture (e.g. egg quality, puberty, light manipulation)
- we (AFRB) need **“numbers”**; oocyte size, egg/embryo size, fecundity… to calculate spawning time, reproductive investment, total egg/embryo production (TEP; cf. SSB = scalar × TEP)…

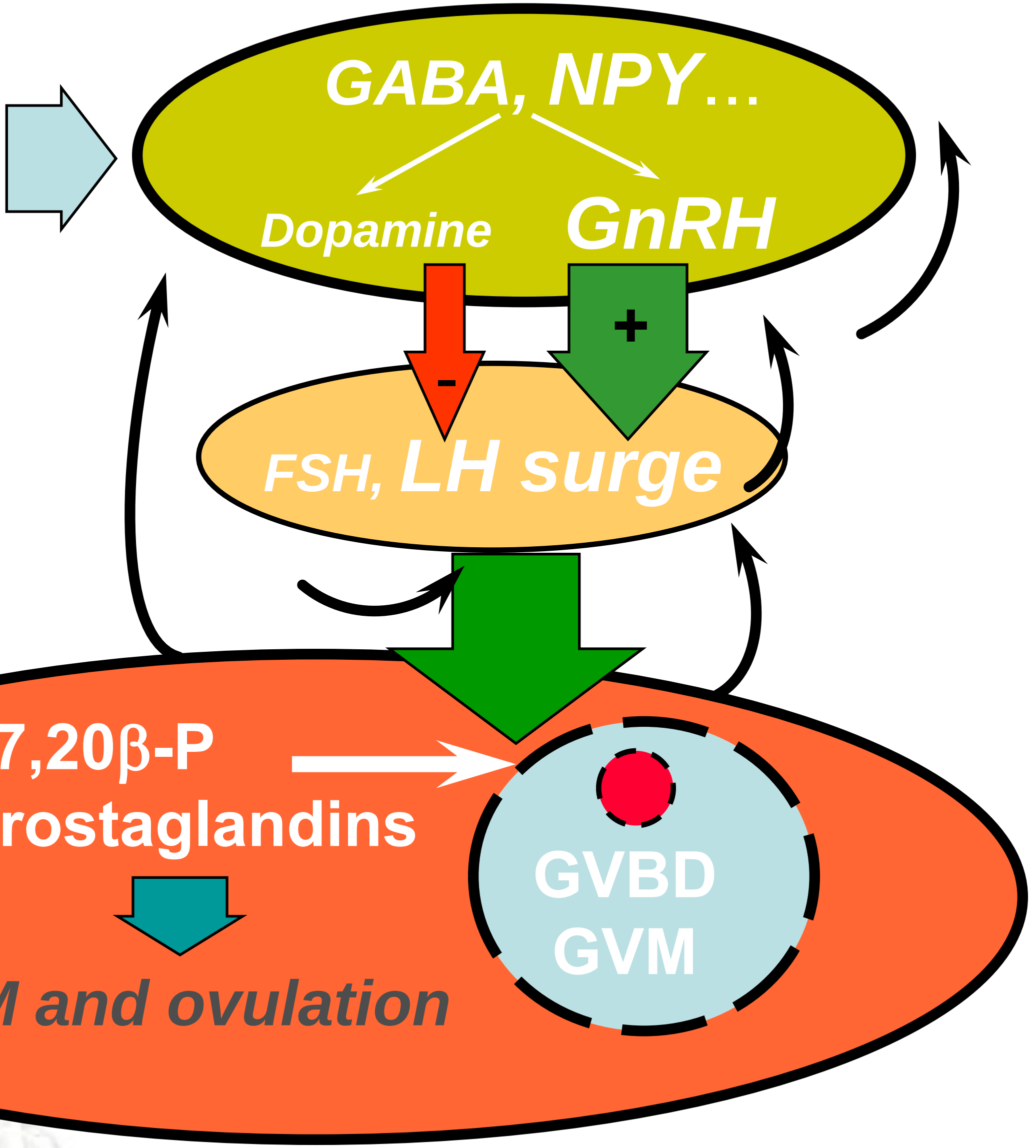
Brain-pituitary-gonad axis



©Geir Lasse Taranger, IMR 1999

Control of FOM and ovulation

photoperiod
temperature
pheromones
behaviour
substrate...



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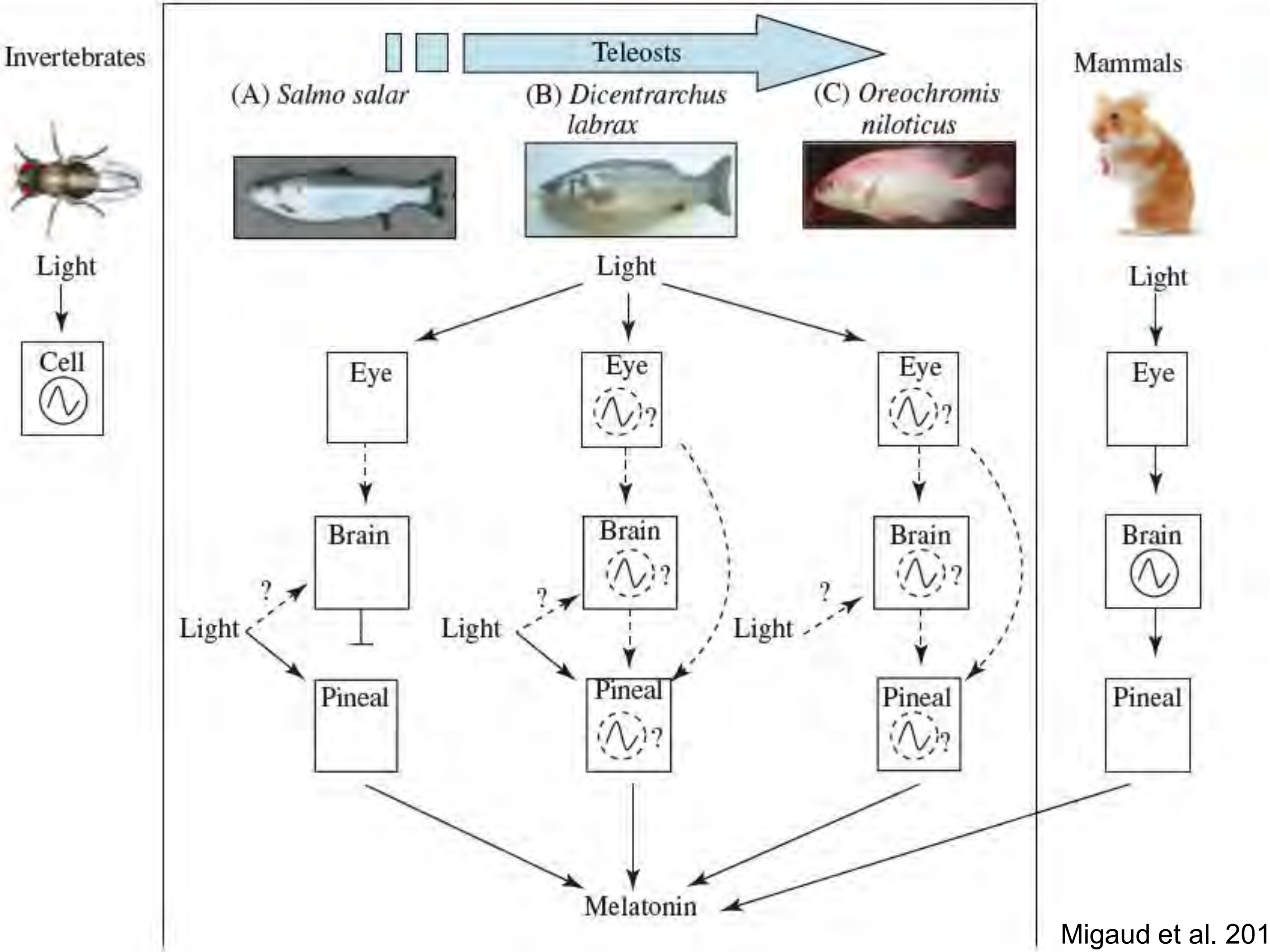
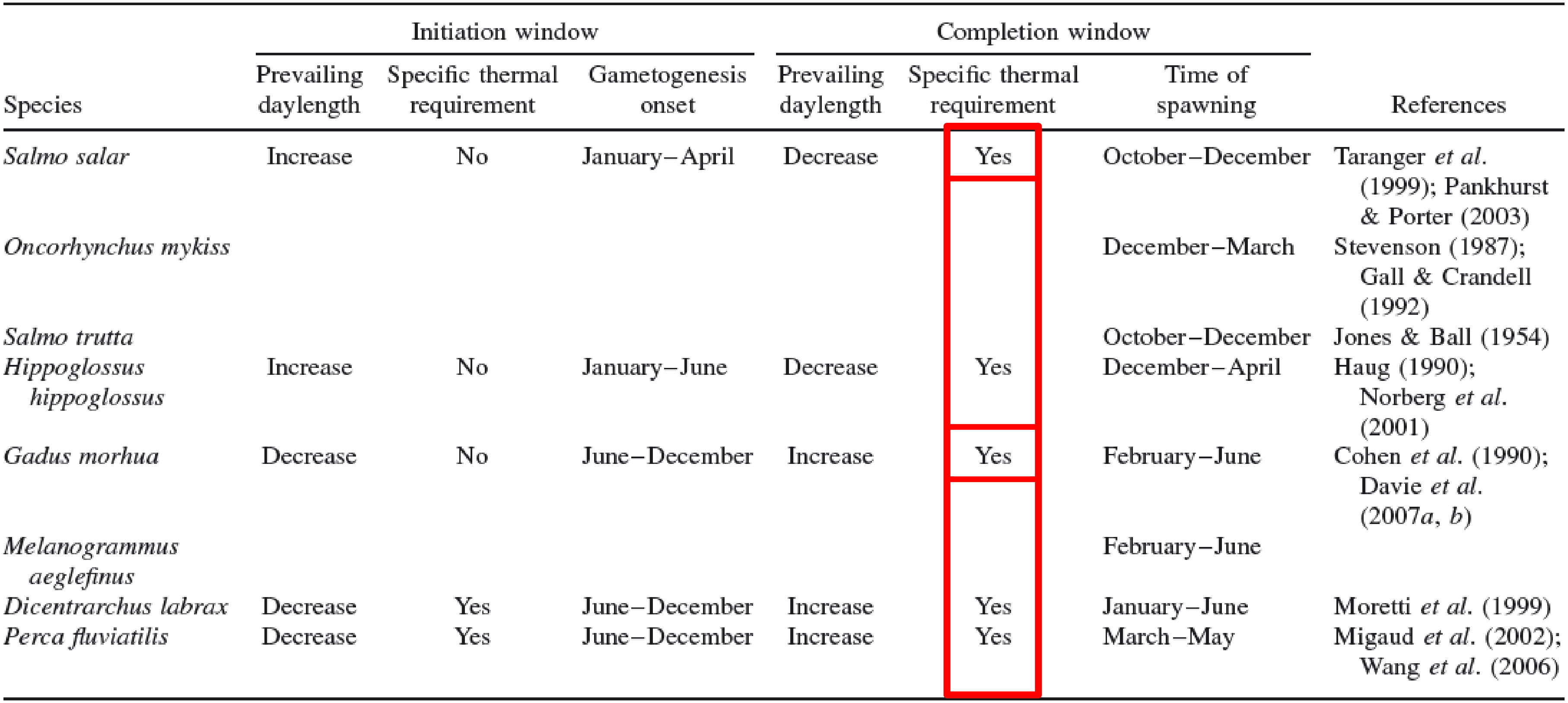
light; the production of melatonin



Migaud et al. 2010.

seasonal environmental cues in temperate teleost species



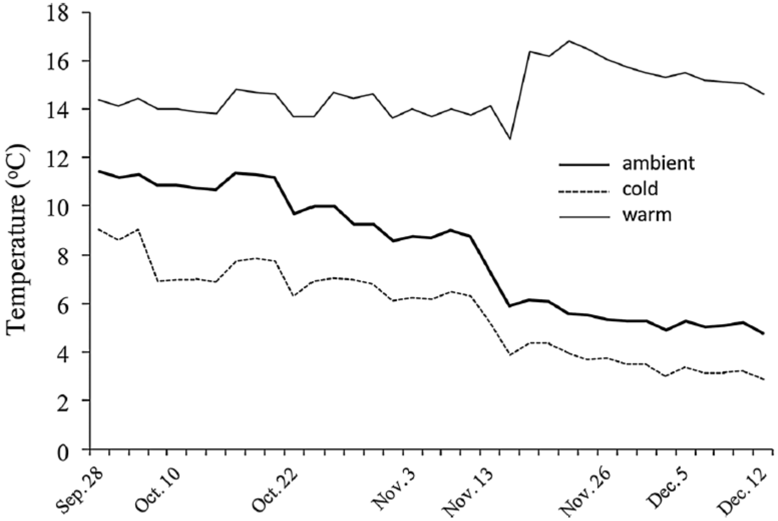
Species	Initiation window			Completion window			References
	Prevailing daylength	Specific thermal requirement	Gametogenesis onset	Prevailing daylength	Specific thermal requirement	Time of spawning	
Salmo salar	Increase	No	January–April	Decrease	Yes	October–December	Taranger *et al.* (1999); Pankhurst & Porter (2003)
Oncorhynchus mykiss						December–March	Stevenson (1987); Gall & Crandell (1992)
Salmo trutta						October–December	Jones & Ball (1954)
Hippoglossus hippoglossus	Increase	No	January–June	Decrease	Yes	December–April	Haug (1990); Norberg *et al.* (2001)
Gadus morhua	Decrease	No	June–December	Increase	Yes	February–June	Cohen *et al.* (1990); Davie *et al.* (2007*a*, *b*)
Melanogrammus aeglefinus						February–June	
Dicentrarchus labrax	Decrease	Yes	June–December	Increase	Yes	January–June	Moretti *et al.* (1999)
Perca fluviatilis	Decrease	Yes	June–December	Increase	Yes	March–May	Migaud *et al.* (2002); Wang *et al.* (2006)

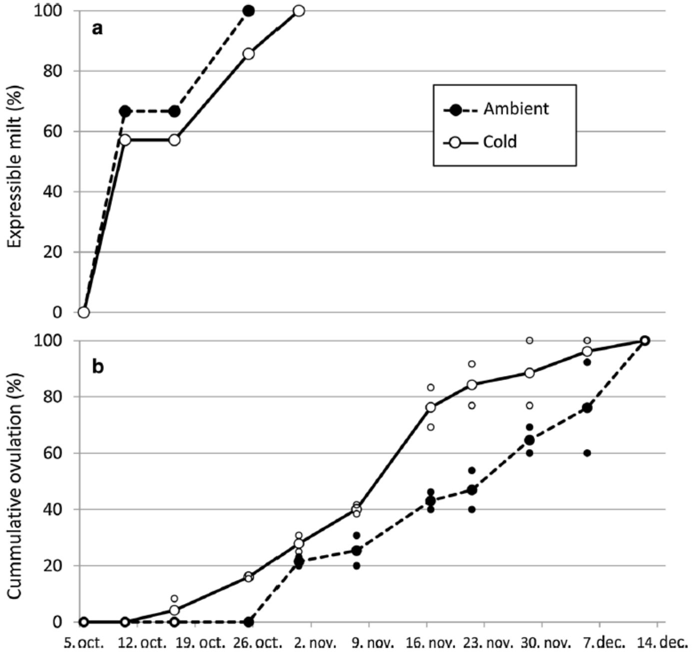
Migaud et al. 2010.

ovulation temperature is critical

Atlantic salmon

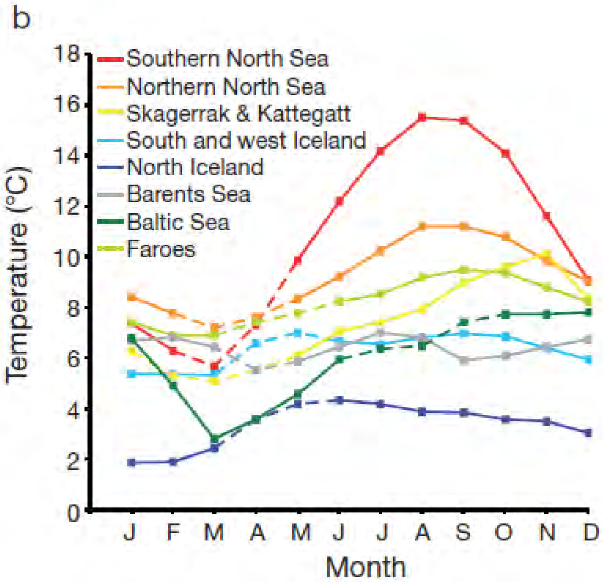
Vikingstad et al. 2016.

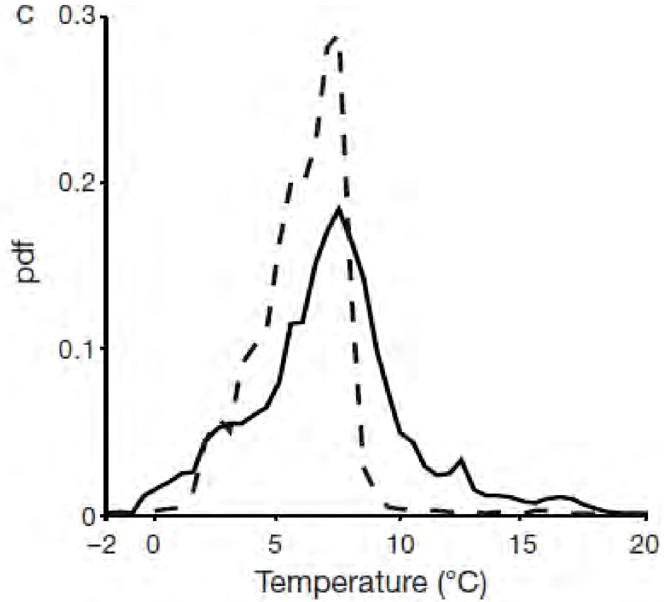




Atlantic cod

Righton et al. 2010.





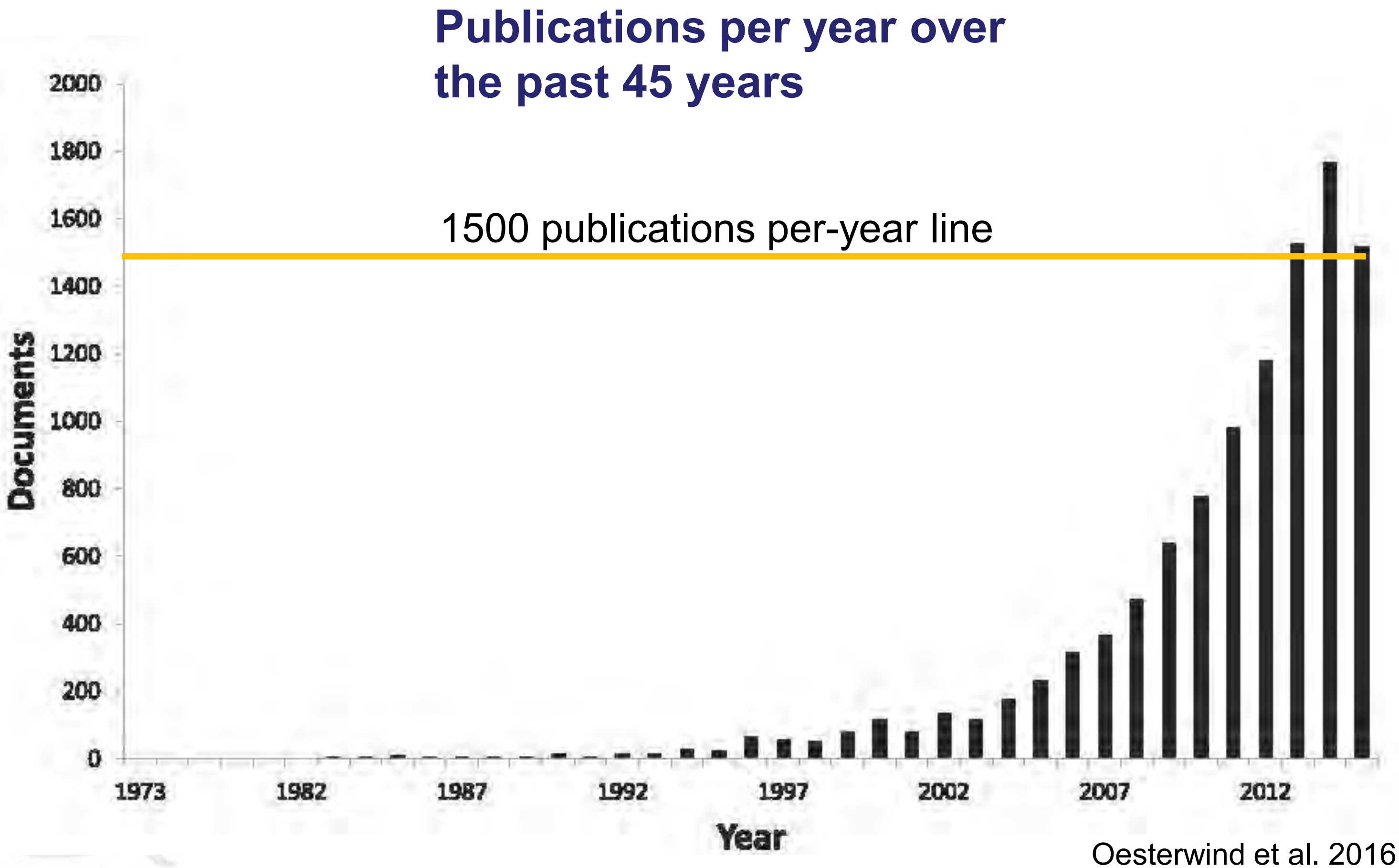
reproductive ecology and climate

a simple literature survey

- generally, little emphasis on *climate change*
- search output highly dependent upon chosen terms
- four results are shown

BACKGROUND INFO.

today increased focus on terms (keywords) like “driver + pressure + marine + ecosystem + assessment”



Publications per year over the past 45 years

1500 publications per-year line

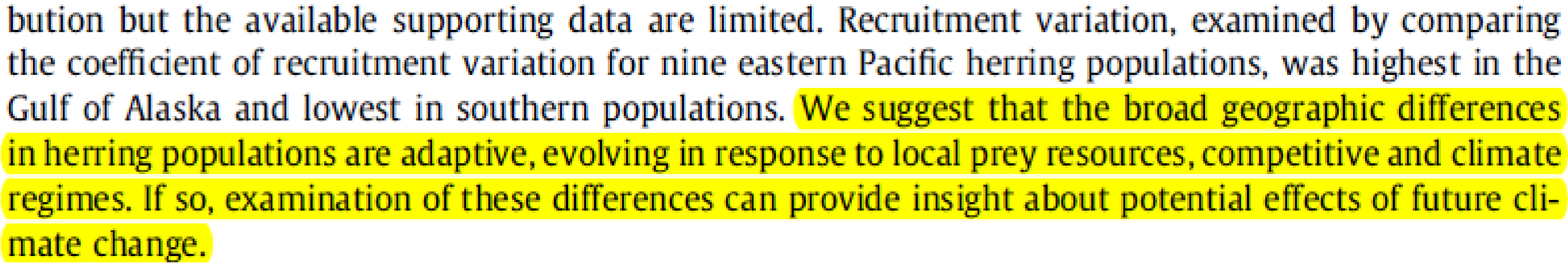
Oesterwind et al. 2016.

so what about our field of interest?

Date: 04 November 2016 (ISI WoS)

Key words	1946-2016	Last 5 years	Increase (%)
marine, fish, climate change	2501	1474	59
marine, fish, climate change, fecundity	23	16	70
marine, fish, climate change, maternal	6	6	100
marine, fish, climate change, viviparous	0	0	
marine, fish, climate change, egg	113	72	64

PS: fish + fecundity; several thousand papers between 1946 and 2016

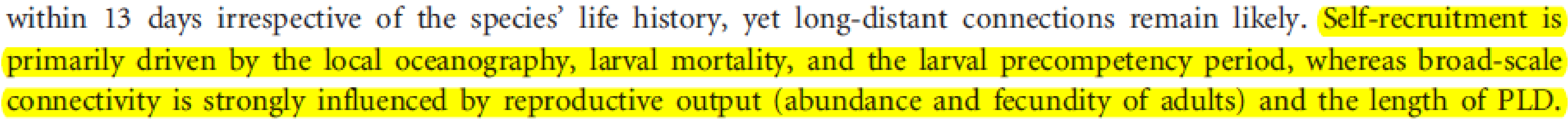


bution but the available supporting data are limited. Recruitment variation, examined by comparing the coefficient of recruitment variation for nine eastern Pacific herring populations, was highest in the Gulf of Alaska and lowest in southern populations. We suggest that the broad geographic differences in herring populations are adaptive, evolving in response to local prey resources, competitive and climate regimes. If so, examination of these differences can provide insight about potential effects of future climate change.

Hay et al. 2008

bution range (cod and plaice), but increased at the northern limit (cod). Although the underlying mechanisms remain uncertain, available evidence suggests climate-related changes in recruitment success to be the key process, stemming from either higher production or survival in the pelagic egg or larval stage, or owing to changes in the quality/quantity of nursery habitats.

Rijnsdorp et al. 2009

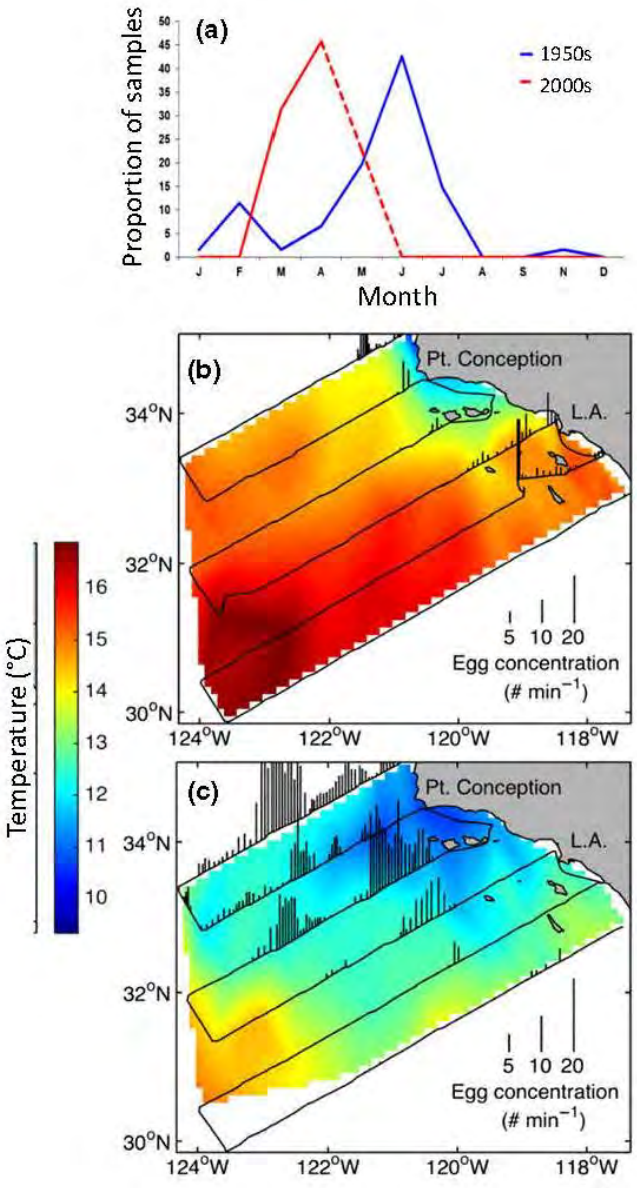


within 13 days irrespective of the species' life history, yet long-distant connections remain likely. Self-recruitment is primarily driven by the local oceanography, larval mortality, and the larval precompetency period, whereas broad-scale connectivity is strongly influenced by reproductive output (abundance and fecundity of adults) and the length of PLD.

Treml et al. 2012

Reproductive resilience: a paradigm shift in understanding spawner-recruit systems in exploited marine fish

Lowerre-Barbieri et al. 2016



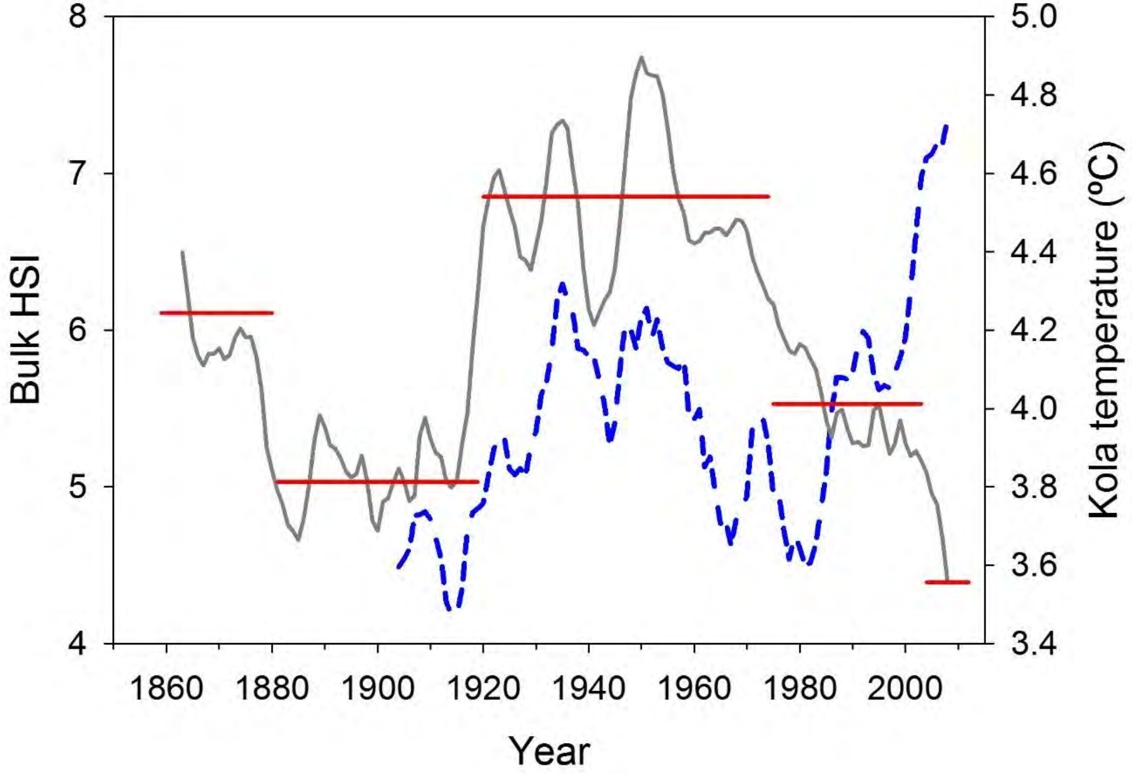
Asch 2013;
Asch & Checkley 2013

methods available to glance into the future

- life history theory/theoretical ecology: fundamental assumptions
- biophysical modelling: model parameterization
- extrapolations of time series: predictions vs projections
- experimental studies: representativeness, generation time
- studying “warm-water ecosystems”: photoperiod, trophodynamics

extrapolations of time series

Kola temperature and HSI:
recent trends in opposite directions



Kjesbu et al. 2014.

experimental studies

Atlantic mackerel (IMR Matre Research Station)

many tanks around but surprisingly few with environmental control

studying “warm-water ecosystems”

“Critical latitudes” 63-68 °N

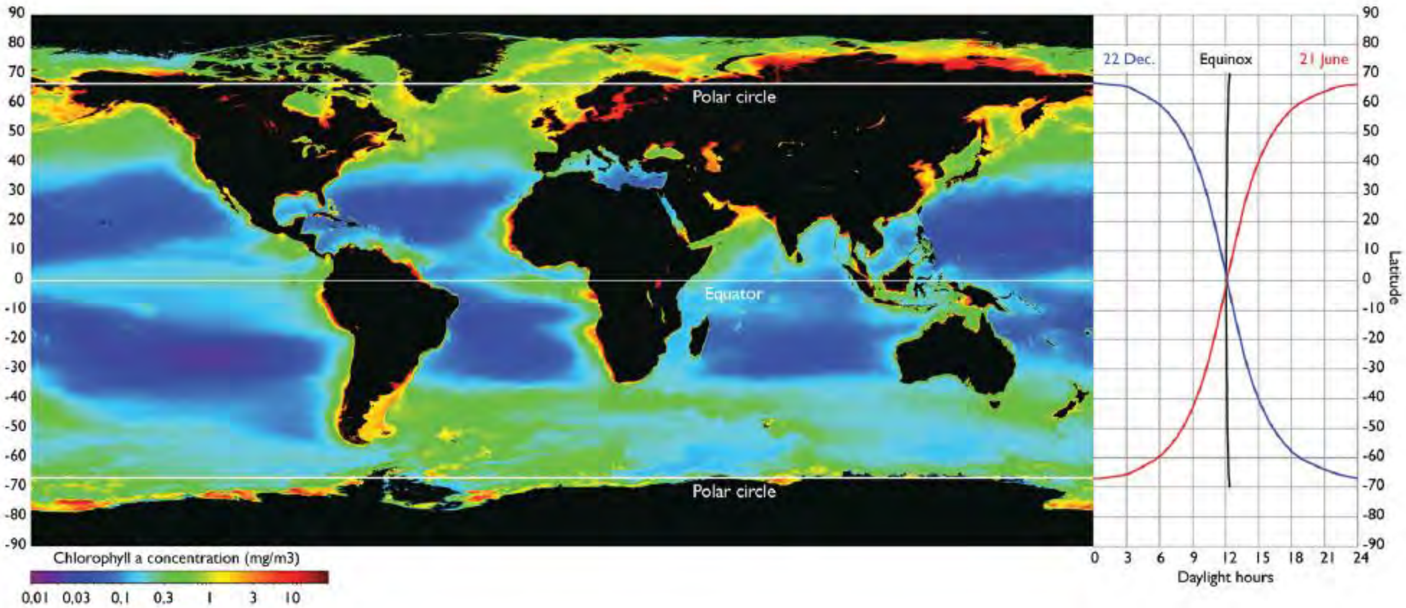


FIGURE 1 | The seasonal light cycle strongly structures the phytoplankton production at high latitudes, and this effect cascades to higher trophic levels. Right panel shows latitudinal variation in daylight length for the two solstices (about 21 June and 22 December) and for the two equinoxes (about 20 March and 22 September). The source of the global map of annual mean chlorophyll concentration is from SeaWIFS satellite sensor averaged over the interval 4 September 1997–30 November 2010 (**left panel**). http://oceancolor.gsfc.nasa.gov/cgi/l3/S19972472010334.L3m_CU_CHL_chlor_a_9km.png?sub=img.

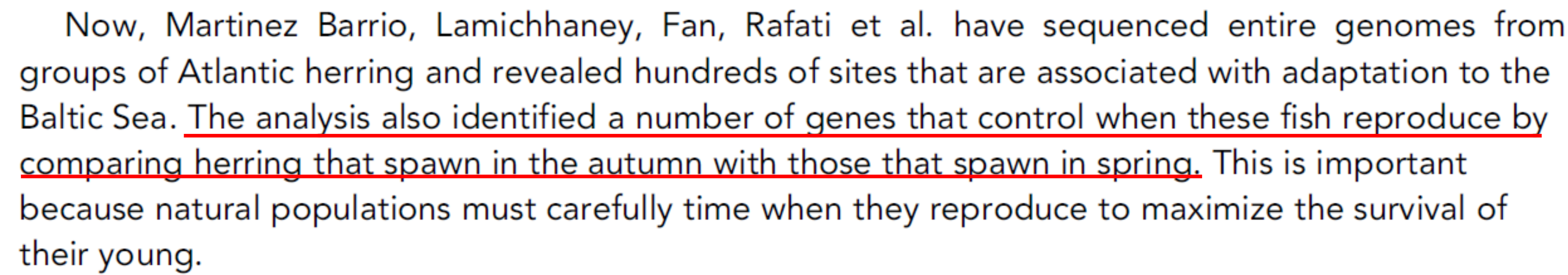
Sundby et al. 2016

reproductive ecology and climate change
some additional reflections

- spawning time: a strong genetic component OK
- the same also likely applies to egg/embryo size
- fecundity highly dynamic OK
- better conceptual models are needed OK

spawning time: a strong genetic component

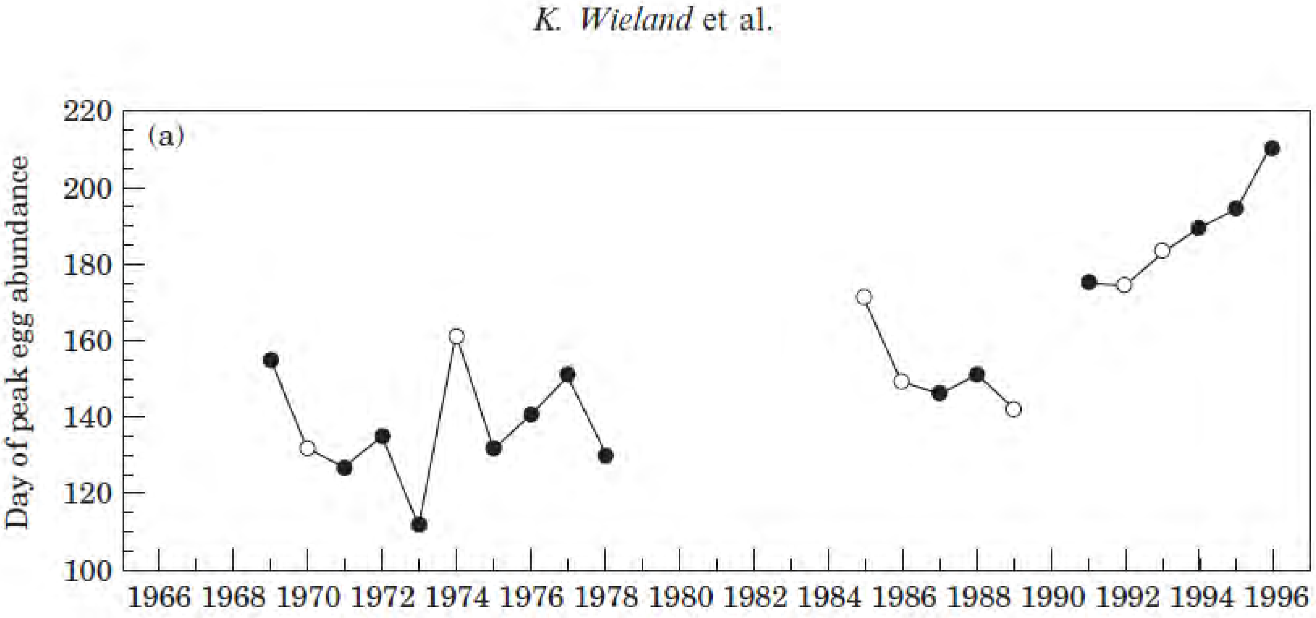
but modulated by light ("trigger") and temperature ("regulator")



Now, Martinez Barrio, Lamichhaney, Fan, Rafati et al. have sequenced entire genomes from groups of Atlantic herring and revealed hundreds of sites that are associated with adaptation to the Baltic Sea. The analysis also identified a number of genes that control when these fish reproduce by comparing herring that spawn in the autumn with those that spawn in spring. This is important because natural populations must carefully time when they reproduce to maximize the survival of their young.

Barrio et al. 2016

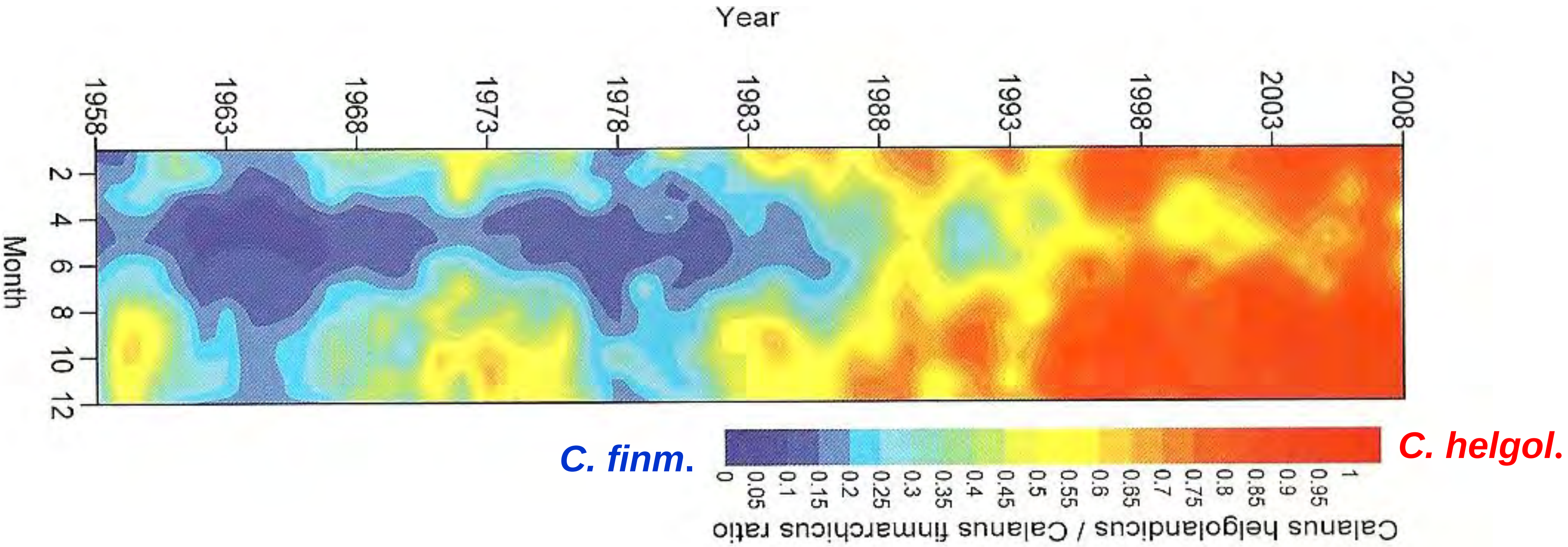
switching from spring spawner to autumn spawner e.g. the Baltic cod (55-56 °N)



Wieland et al. 2000. ICES JMS

Regime shift in the North Sea

Calanus finmarchicus vs. ***Calanus helgolandicus*** from the cold 1960s and 1970s to present warm period. Abundance of ***C.f.*** and ***C.h.*** peaks in spring and autumn, respectively.

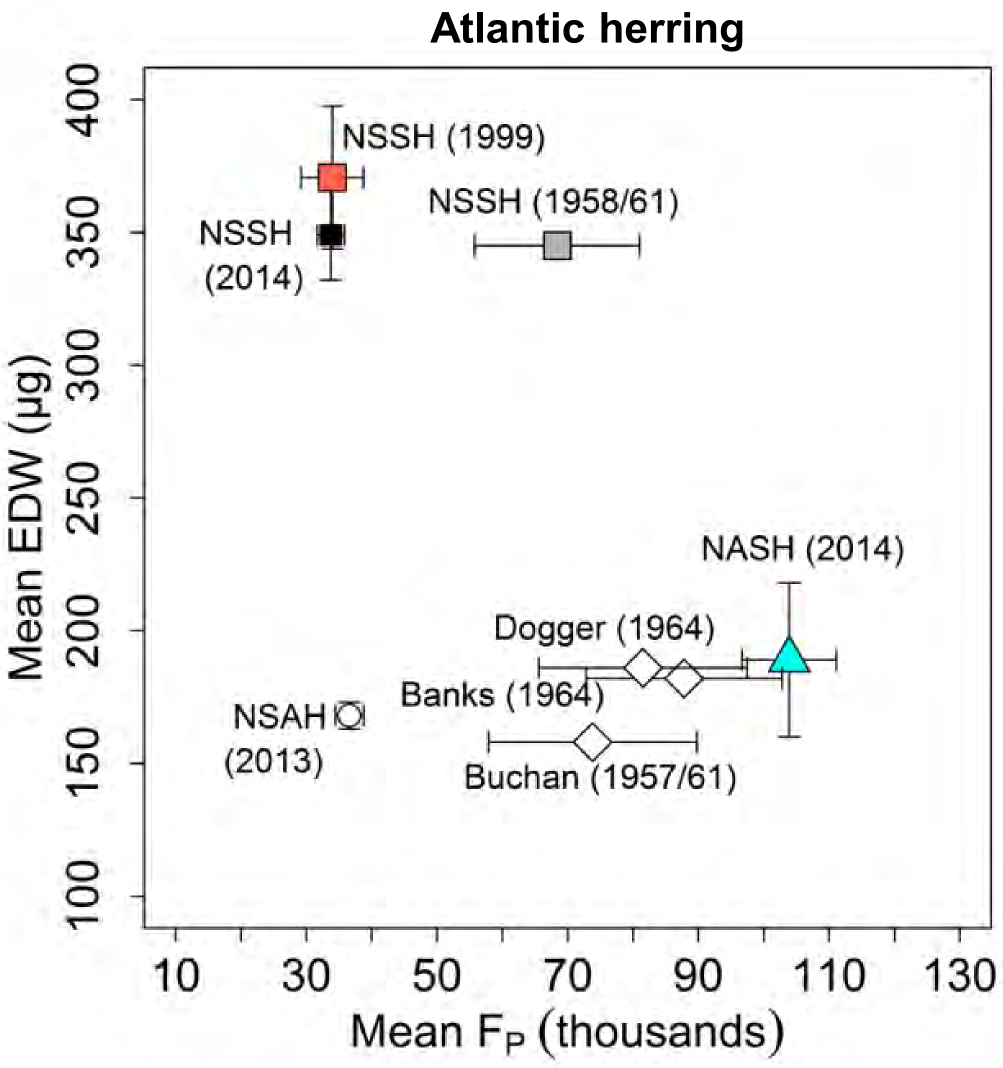


SAHFOS. 2010

Phenology: Richardson. 2008. ICES JMS

the same also likely applies to egg/embryo size

egg dry weight (historic change 1-10%) vs. fecundity (historic change 50-58%)

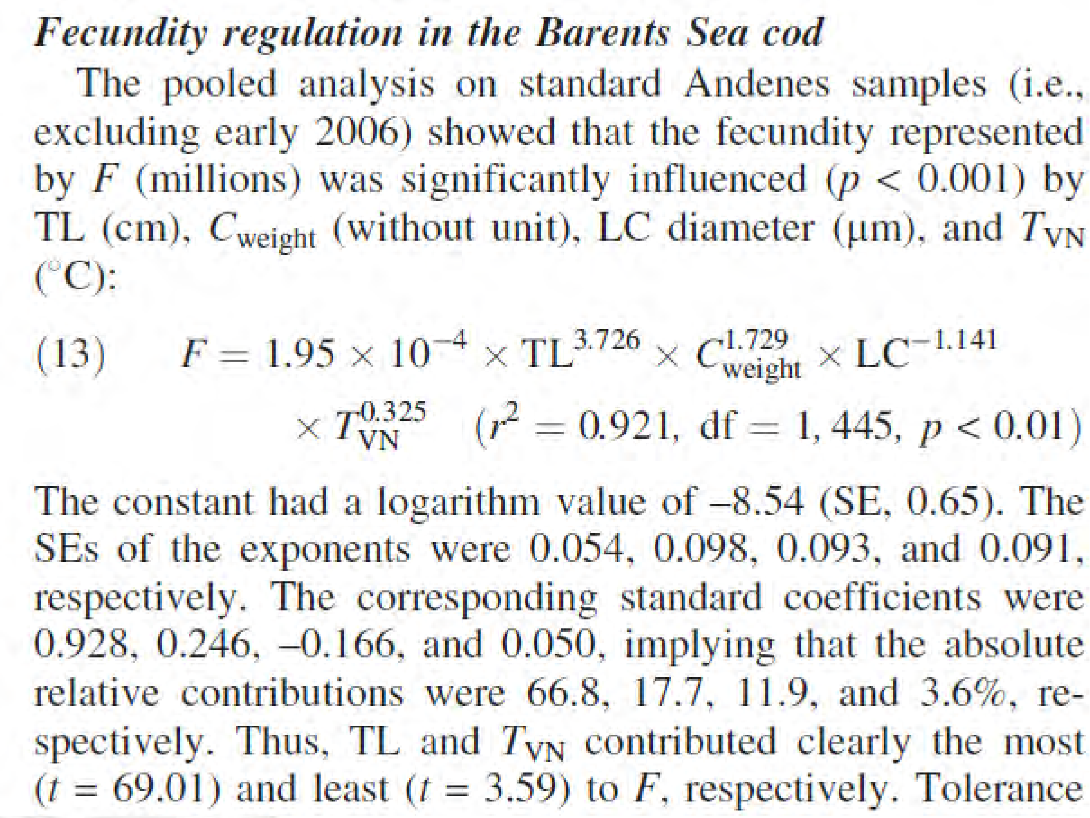


dos Santos Schmidt et al. (in review)

fecundity highly dynamic

Oogonial proliferation should increase under climate change: fecundity ↑

Atresia should increase under climate change: fecundity ↓



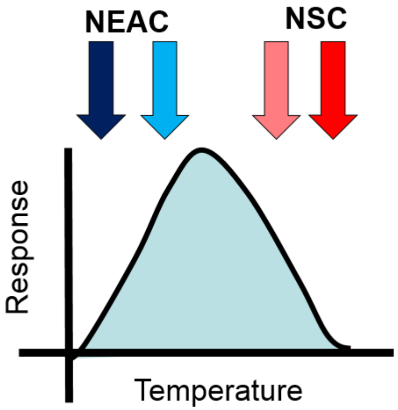
Fecundity regulation in the Barents Sea cod

The pooled analysis on standard Andenes samples (i.e., excluding early 2006) showed that the fecundity represented by F (millions) was significantly influenced ($p < 0.001$) by TL (cm), C_{weight} (without unit), LC diameter (µm), and T_{VN} (°C):

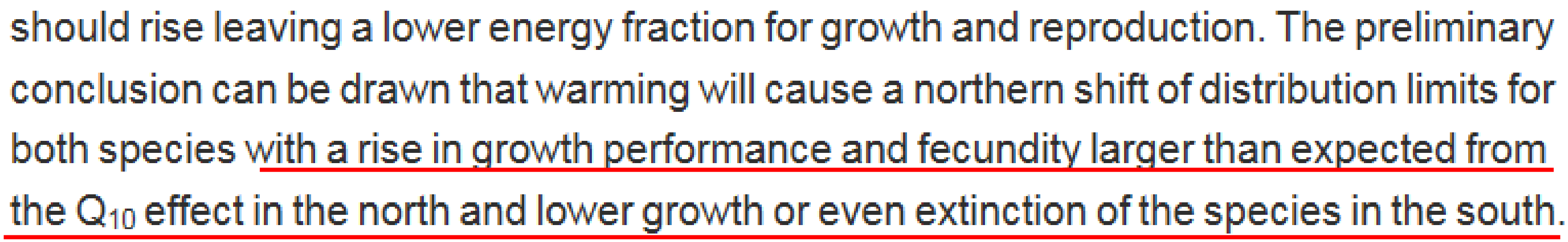
$$(13) \qquad F = 1.95 \times 10^{-4} \times \mathrm{TL}^{3.726} \times C_{\mathrm{weight}}^{1.729} \times \mathrm{LC}^{-1.141} \times T_{\mathrm{VN}}^{0.325} \quad (r^2 = 0.921,\ \mathrm{df} = 1,445,\ p < 0.01)$$

The constant had a logarithm value of –8.54 (SE, 0.65). The SEs of the exponents were 0.054, 0.098, 0.093, and 0.091, respectively. The corresponding standard coefficients were 0.928, 0.246, –0.166, and 0.050, implying that the absolute relative contributions were 66.8, 17.7, 11.9, and 3.6%, respectively. Thus, TL and T_{VN} contributed clearly the most ($t = 69.01$) and least ($t = 3.59$) to F, respectively. Tolerance

Kjesbu et al. 2010



based on physiological elaborations…

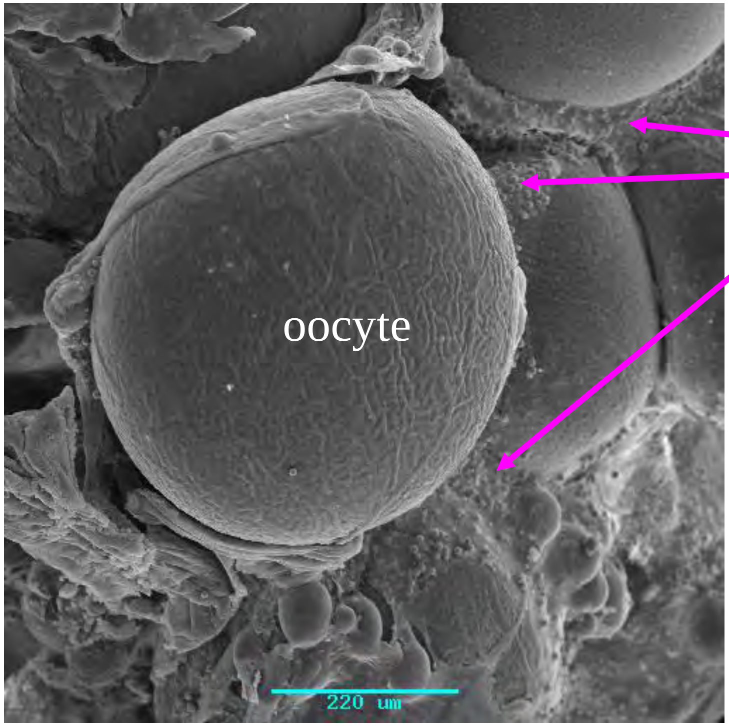


should rise leaving a lower energy fraction for growth and reproduction. The preliminary conclusion can be drawn that warming will cause a northern shift of distribution limits for both species with a rise in growth performance and fecundity larger than expected from the Q_{10} effect in the north and lower growth or even extinction of the species in the south.

Pörtner et al. 2001

How to enumerate the tiniest cells?

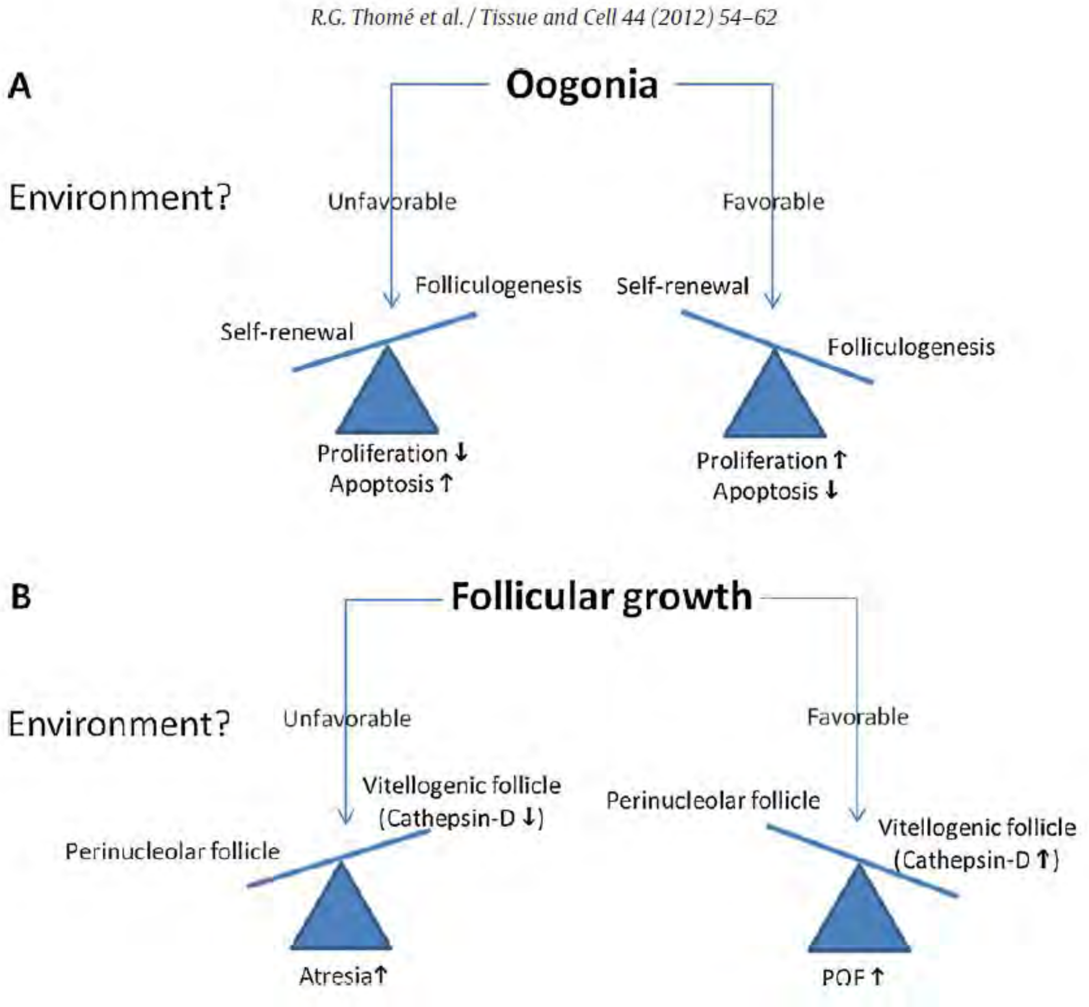
methods do exist today, e.g. packing density theory



Oogonial nests

Micrograph: Harald Kryvi, Univ. of Bergen

better conceptual models are needed



"numbers" and "lag effects" are missing
"Environment" should be expanded to include climate change

conclusions

- our work should be placed in an interdisciplinary context
- a suite of “tools” need to be combined
- adults are equally sensitive as the larvae
- the role of photoperiod is too little emphasized
- spawning time and likely egg/embryo size strongly genetically controlled
- ovulation dynamics known to be critical
- fecundity shows high plasticity but future development unclear
- better conceptual models should be developed
- much more will be known in a few years