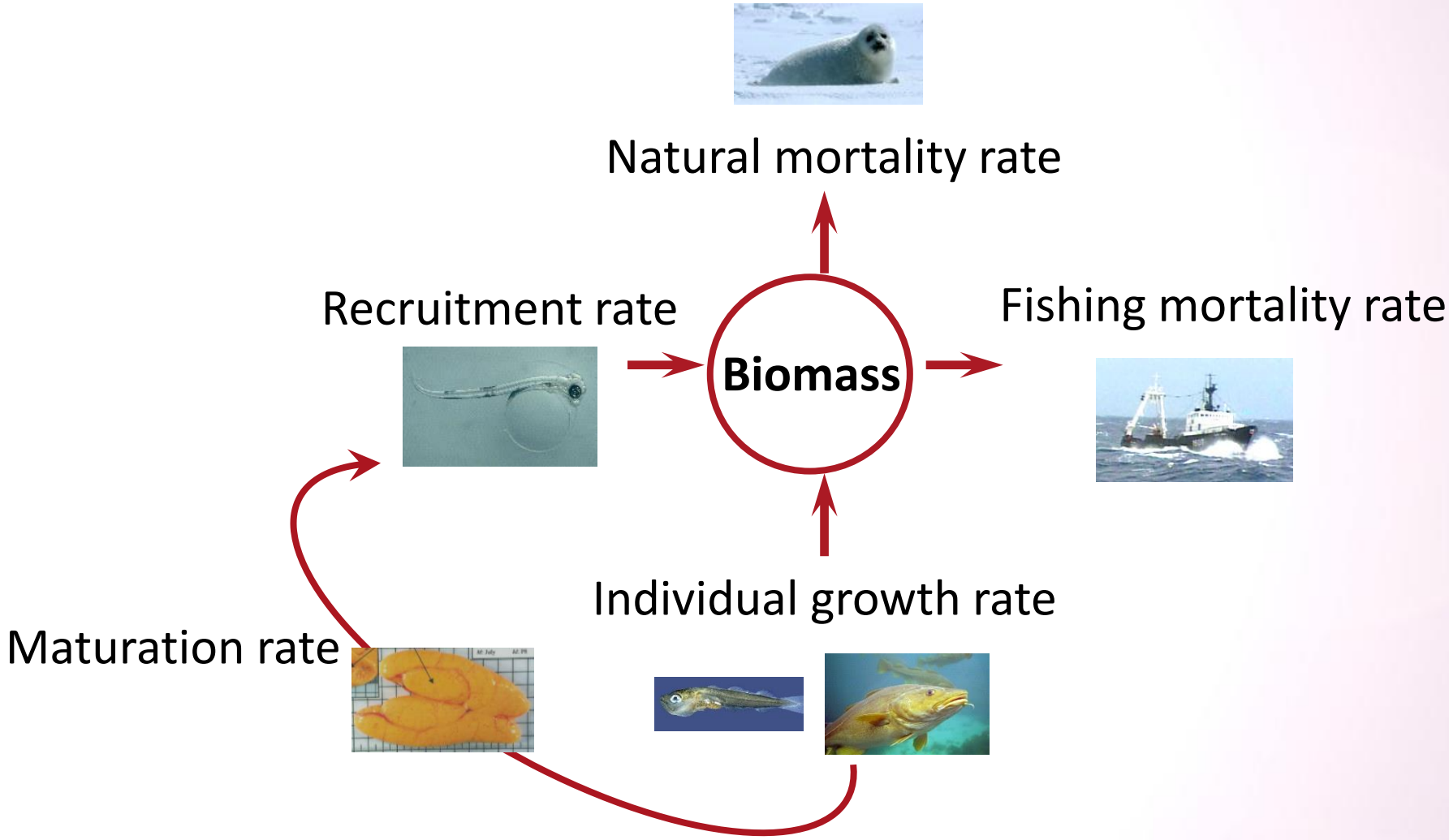
Climate impacts on productivity of NWW fish stocks and how fisheries management can adapt

C. Tara Marshall

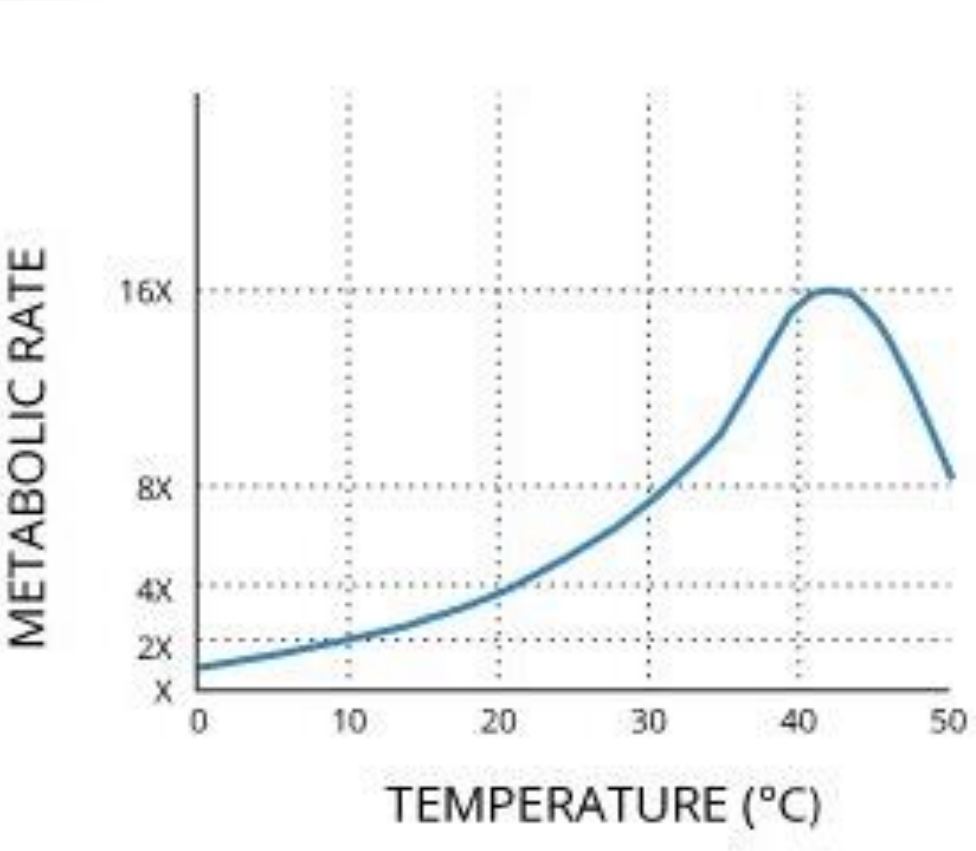
School of Biological Sciences

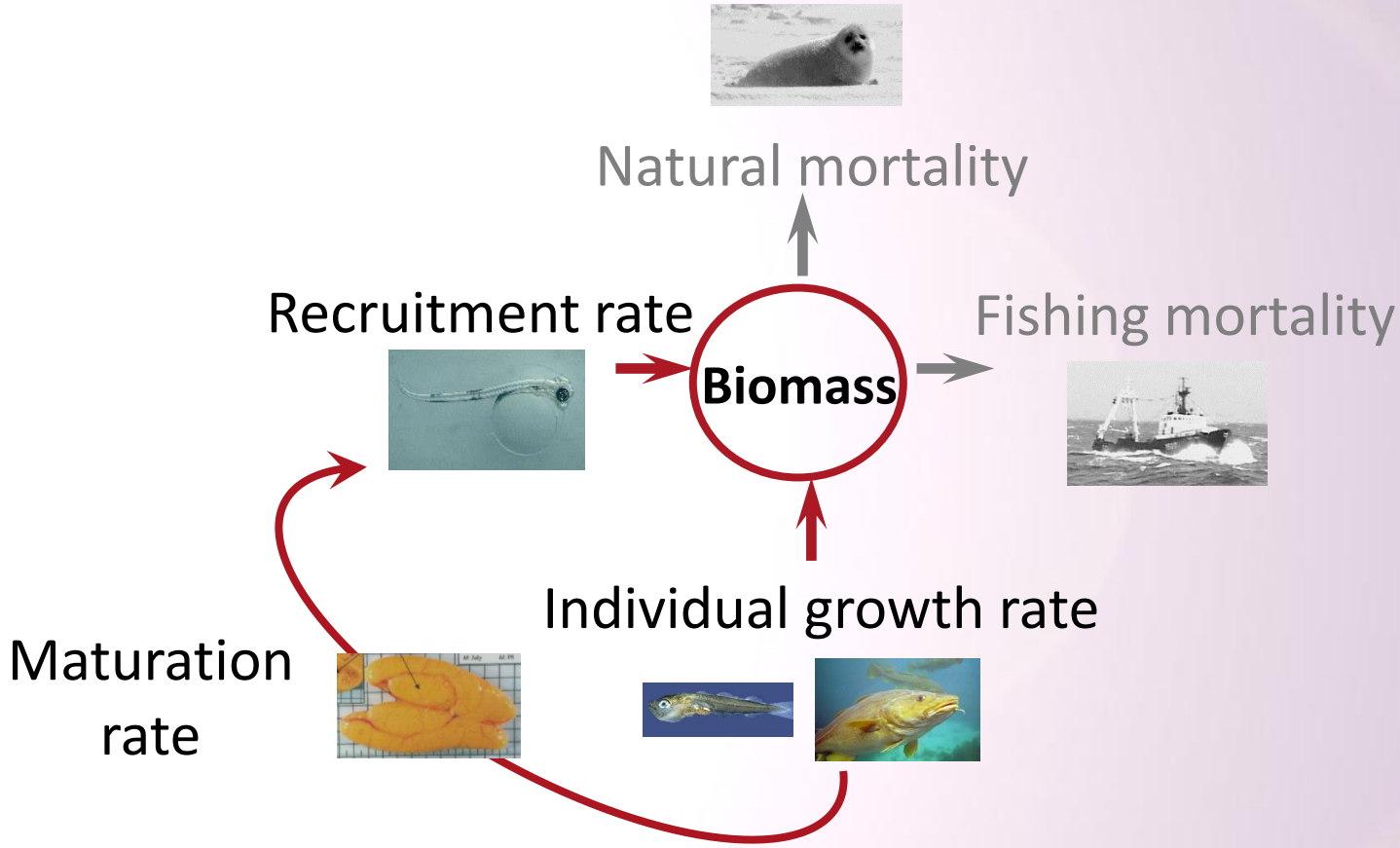
c.t.marshall@abdn.ac.uk

Productivity depends on five “vital rates”



Fish are ectotherms ⇒ vital rates will be temperature dependent

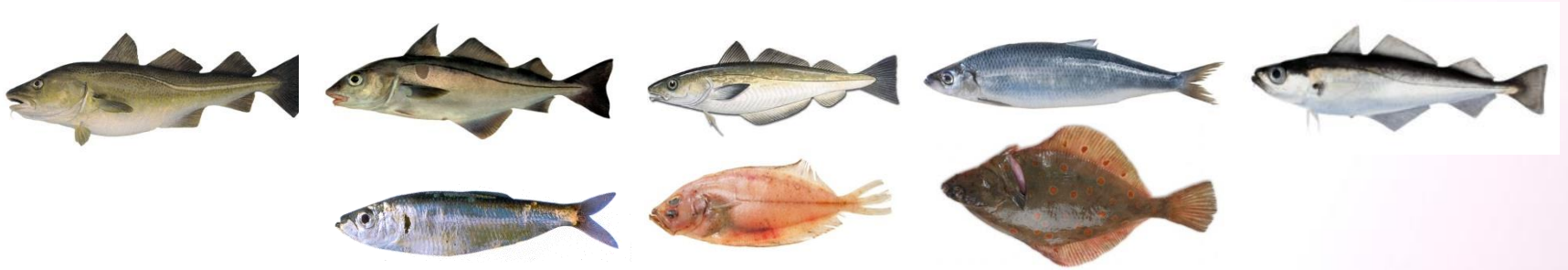




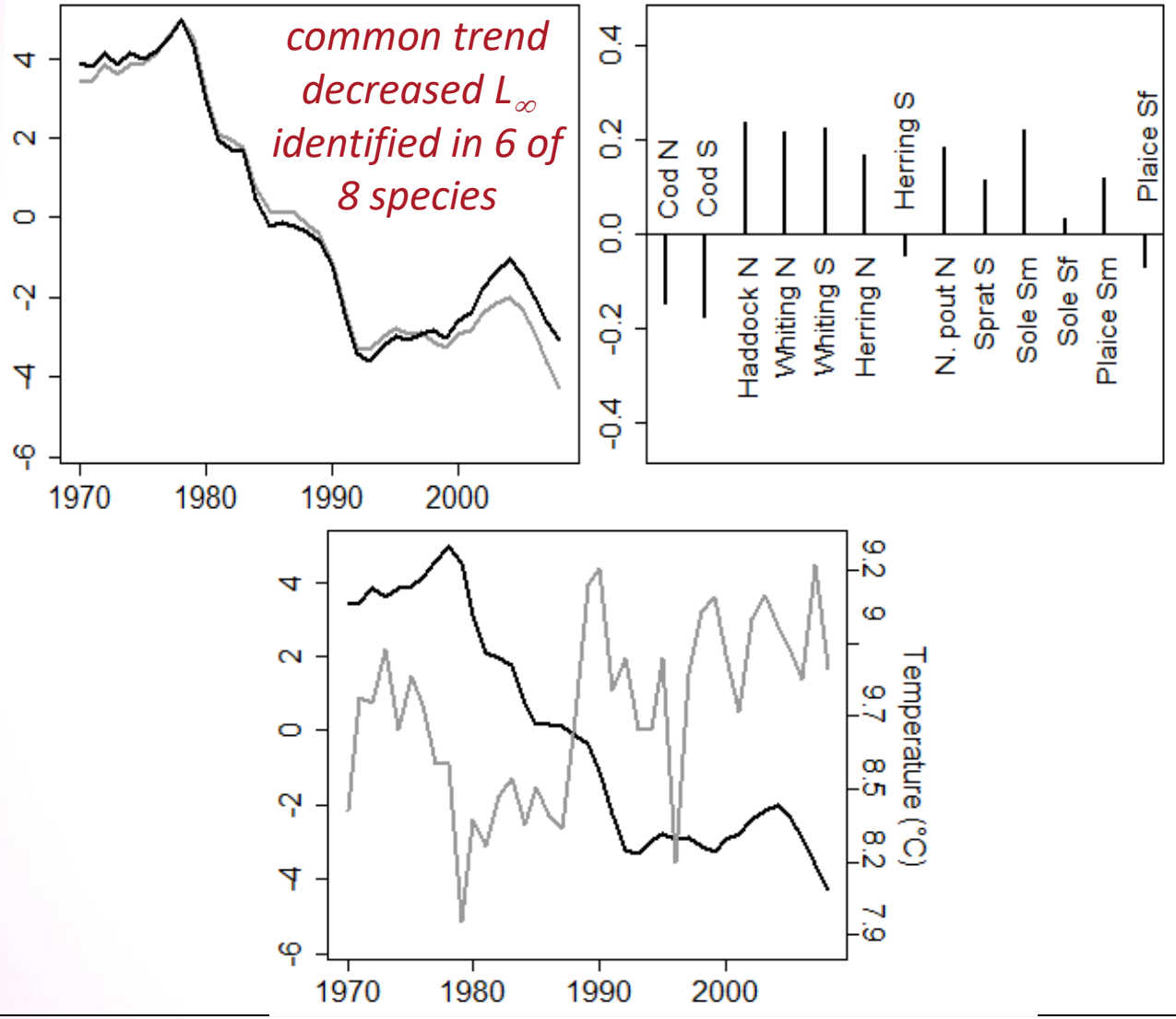
Individual growth rates are temperature-dependent

- age/length data for eight commercial species in North Sea were obtained from DATRAS (http://datras.ices.dk) and from Dutch market sampling and surveys (for flatfish species)
- VBGF fit on a cohort-by-cohort basis over 1970 to 2006

Baudron et al. (2014)



Individual growth rates are temperature-dependent



Correlations between common trend in L_∞ and different formulations of temperature

Time period	Correlation	p-value	$\alpha(1 + k - i)^{-1}$
0 to 2 years	-0.54	0.00064	0.010*
0 to 1 years	-0.49	0.00182	0.013*
2 years	-0.49	0.00200	0.017*
1 year	-0.45	0.00510	0.025*
0 years	-0.43	0.00640	0.050*

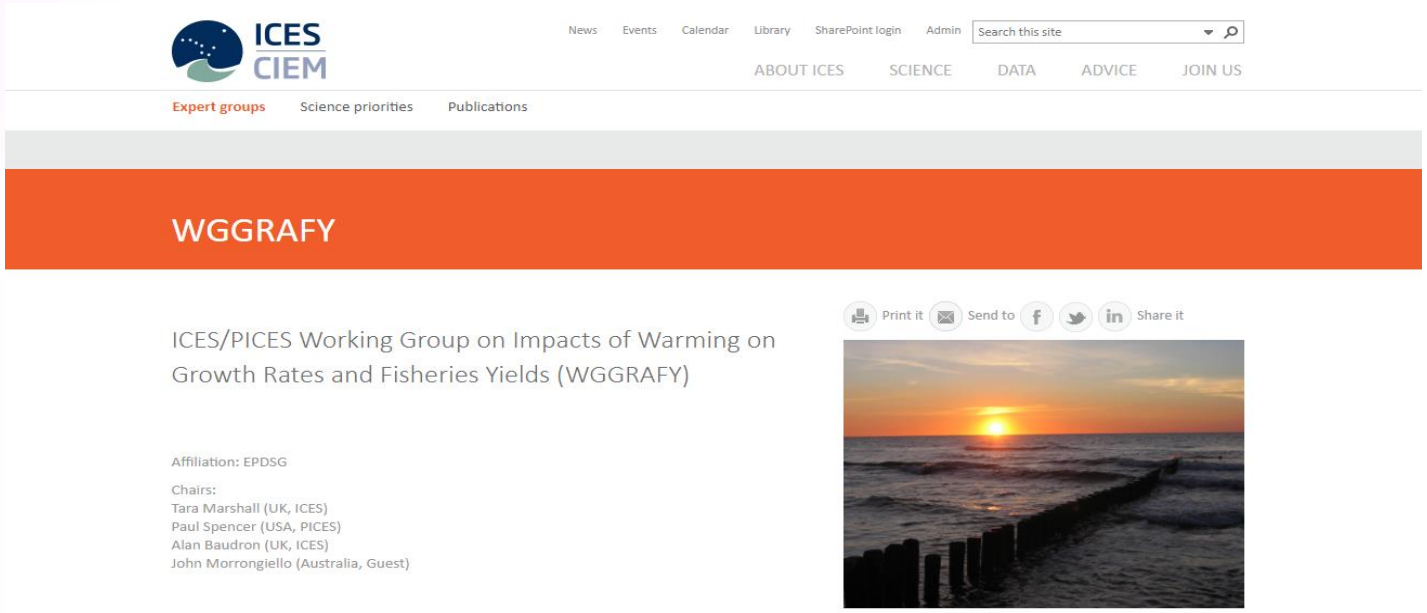
Baudron et al. 2014

Yield-per-recuit is temperature dependent

Species	Sub-stock	Decrease in L_∞	Decrease in YPR
Haddock	North	**29%**	38.7%
Whiting	North	13%	**3.1%**
Whiting	South	**29%**	**48.1%**
Herring	North	10%	12.3%
Norway pout	North	19%	22.2%
Sprat	South	16%	4.0%
Plaice	Male South	12%	46.2%
Sole	Male South	13%	17.8%
Sole	Female South	**1%**	15.9%
AVERAGE		**16%**	**23%**

Baudron et al. 2014

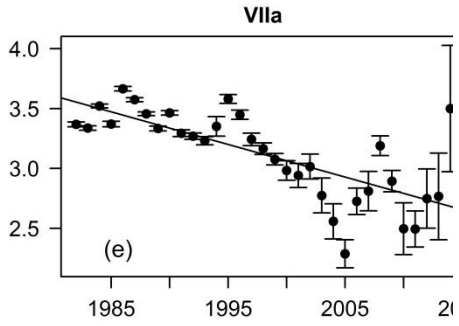
What are the implications of smaller-sized adults for yields?

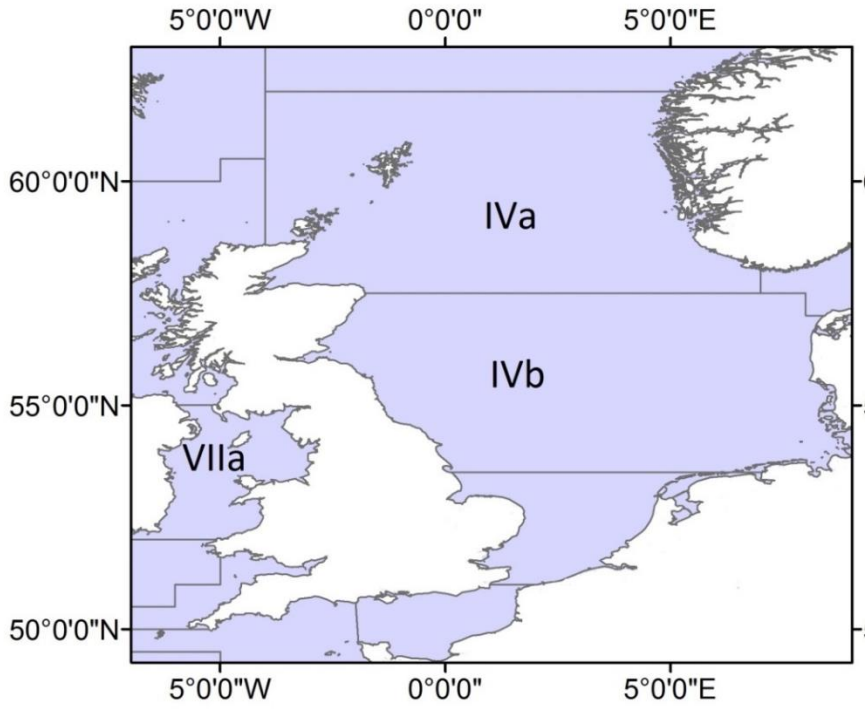


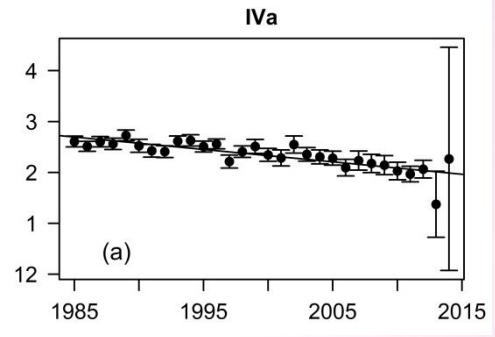
https://www.ices.dk/community/groups/Pages/WGGRAFY.aspx

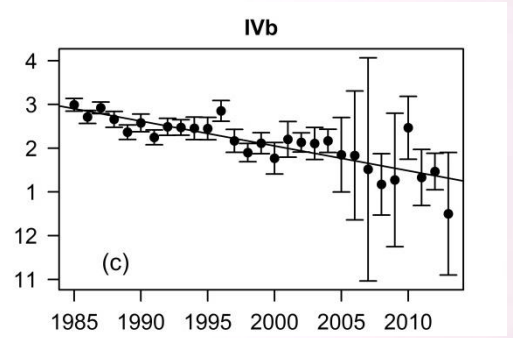
1. Develop models to incorporate temperature-dependency of growth.
2. Analyse long-term growth patterns across multiple large marine ecosystems.
3. ***Assess the impacts of warming on past YPR and forecast trends in future yields under plausible warming scenarios.***
4. Identify options for expanding access to global length-at-age data.

Spawning times of cod are temperature-dependent







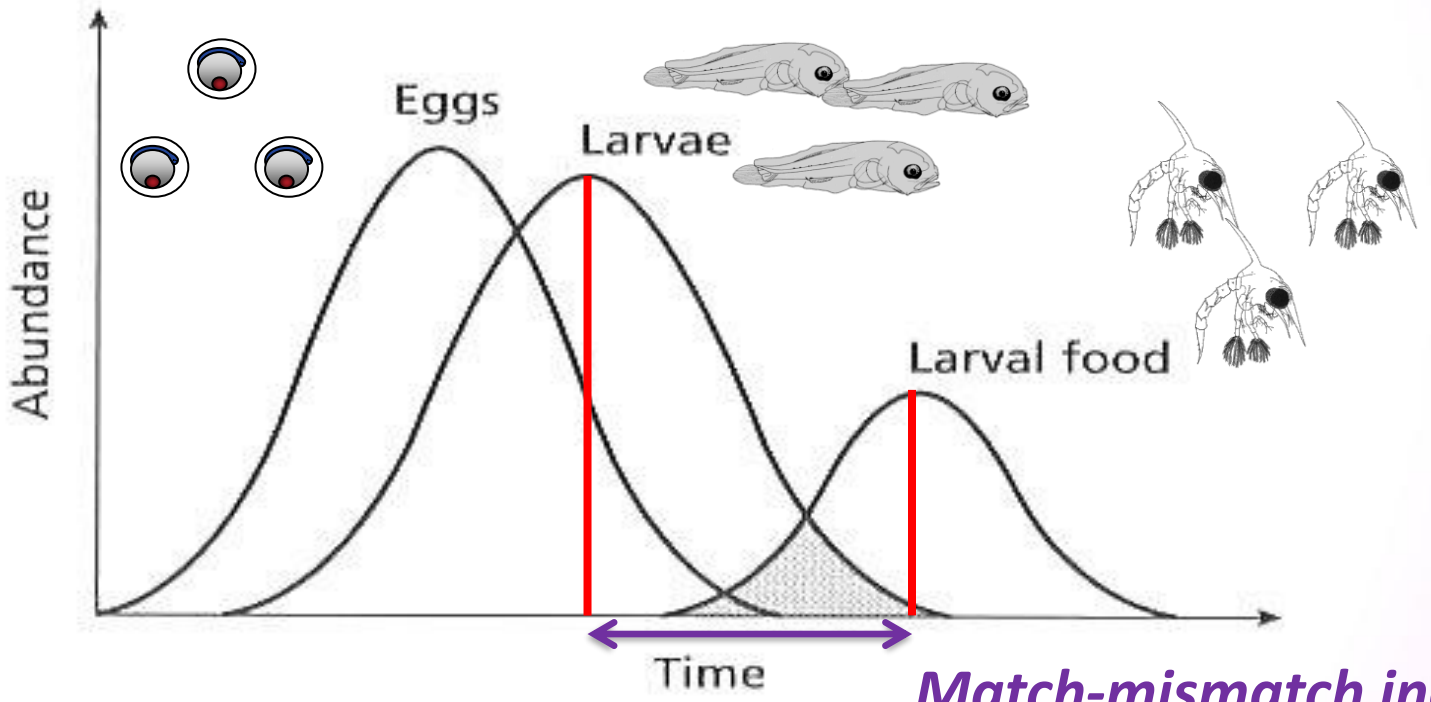


Cod have shifted to earlier spawning times:

- **1** week per decade in the northern North Sea
- **2.3** weeks per decade in the central North Sea
- **0.7 weeks per decade in the Irish Sea**

McQueen and Marshall 2017

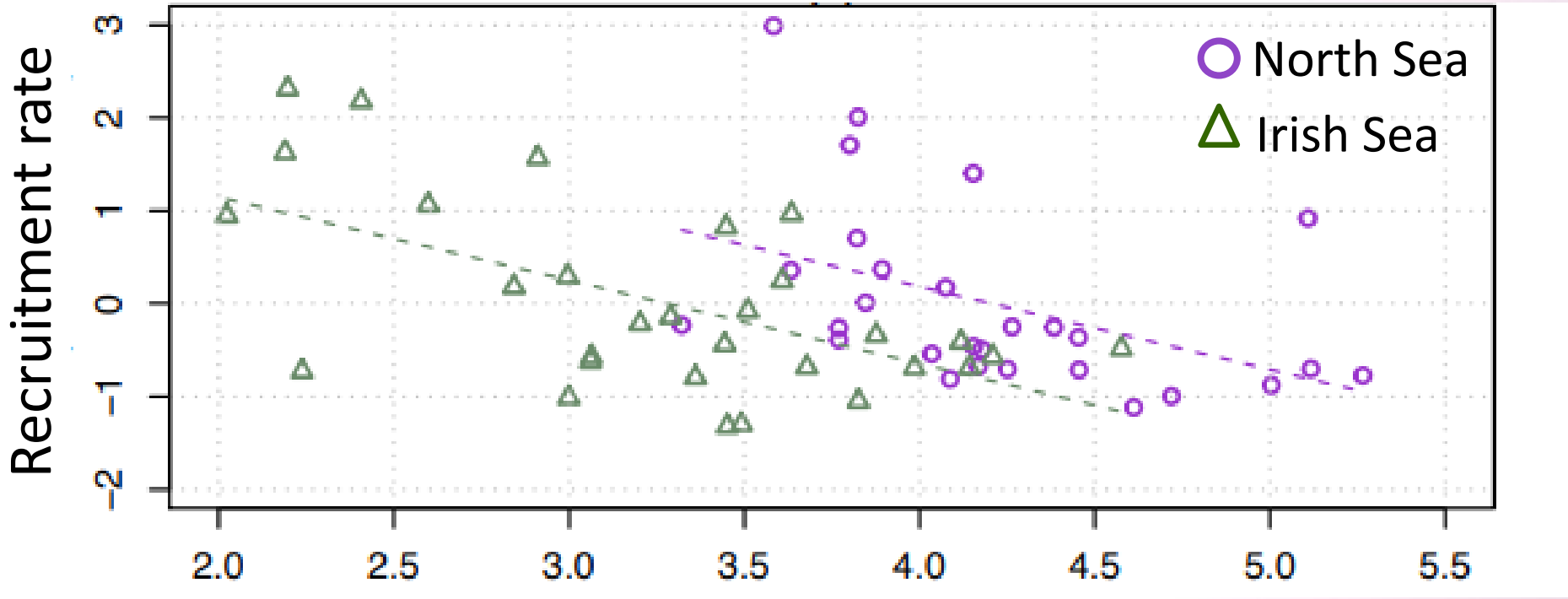
Earlier spawning increases the temporal mismatch with larval prey



Match-mismatch index

Recruitment rates of cod are temperature-dependent

As mismatch increases due to earlier spawning → recruitment rates of Irish Sea cod have decreased



Marshall et al. in prep.

Temperature-dependency of vital rates in stock assessment

Spawning phenology → Recruitment rate

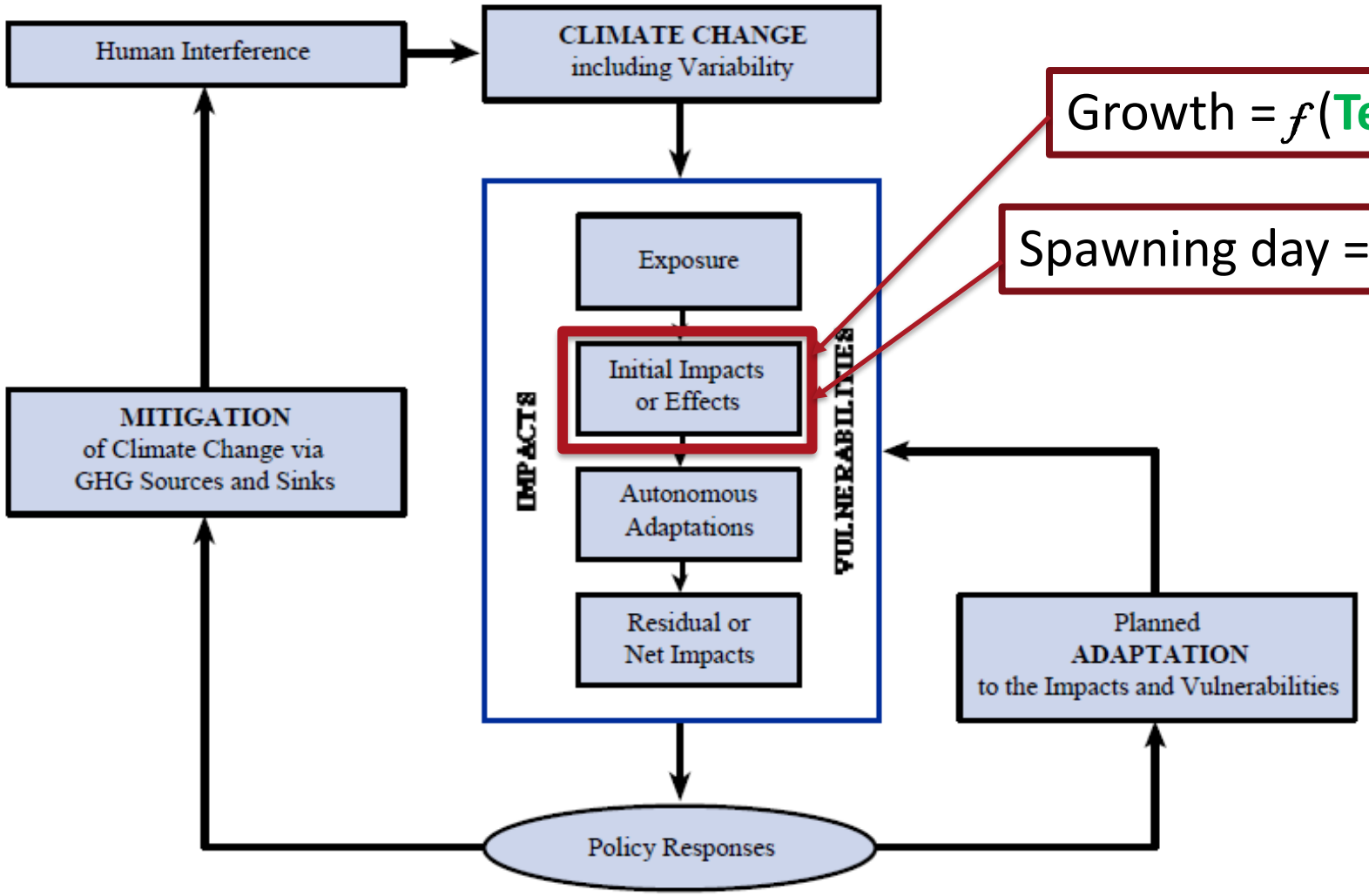
Age	Numbers	Individual Weight	Proportion Mature	Natural Mortality	Fishing Mortality
0	1488346	0.031	0	1.024	0.004
1	2108931	0.145	0	1.188	0.040
2	78915	0.417	0	0.581	0.412
3	60264	0.561	1	0.357	0.453
4	8929	0.752	1	0.340	0.355
5	16608	0.698	1	0.337	0.503
6	78677	0.631	1	0.252	0.367
7	6862	0.685	1	0.219	0.166

Growth rate → Maturation rate

current B_{MSY} and F_{MSY} are based on historical levels of productivity and will need to be adjusted for expected future levels

How can fisheries management adapt to CC? (*Three ideas*)

3. Climate-smart food production



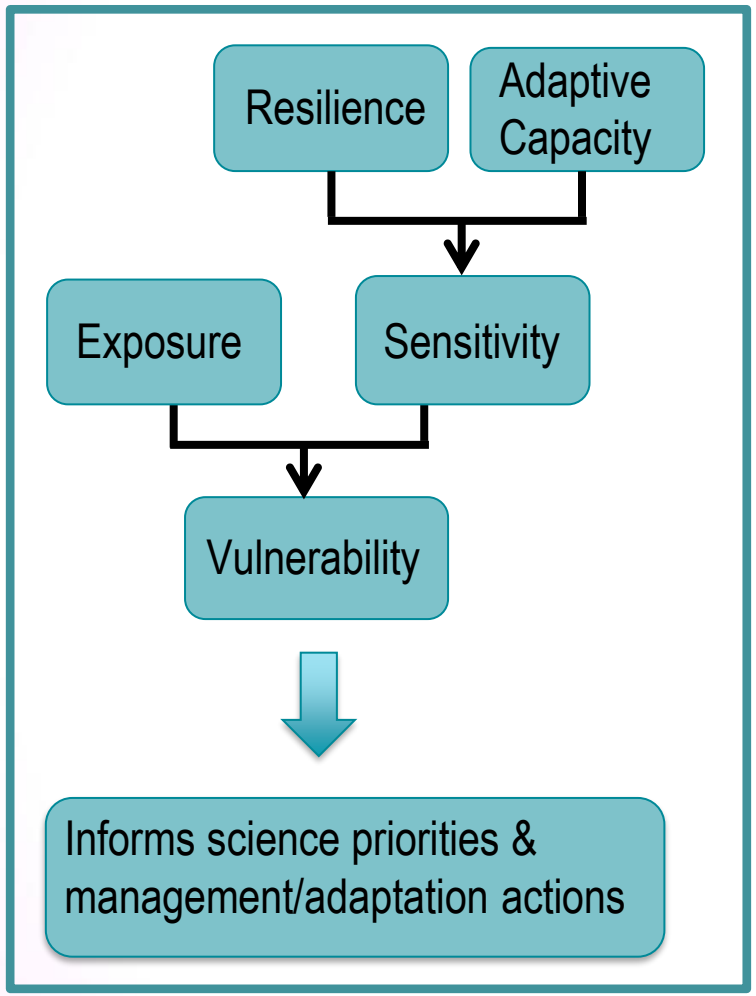
Growth = f(**Temperature**)

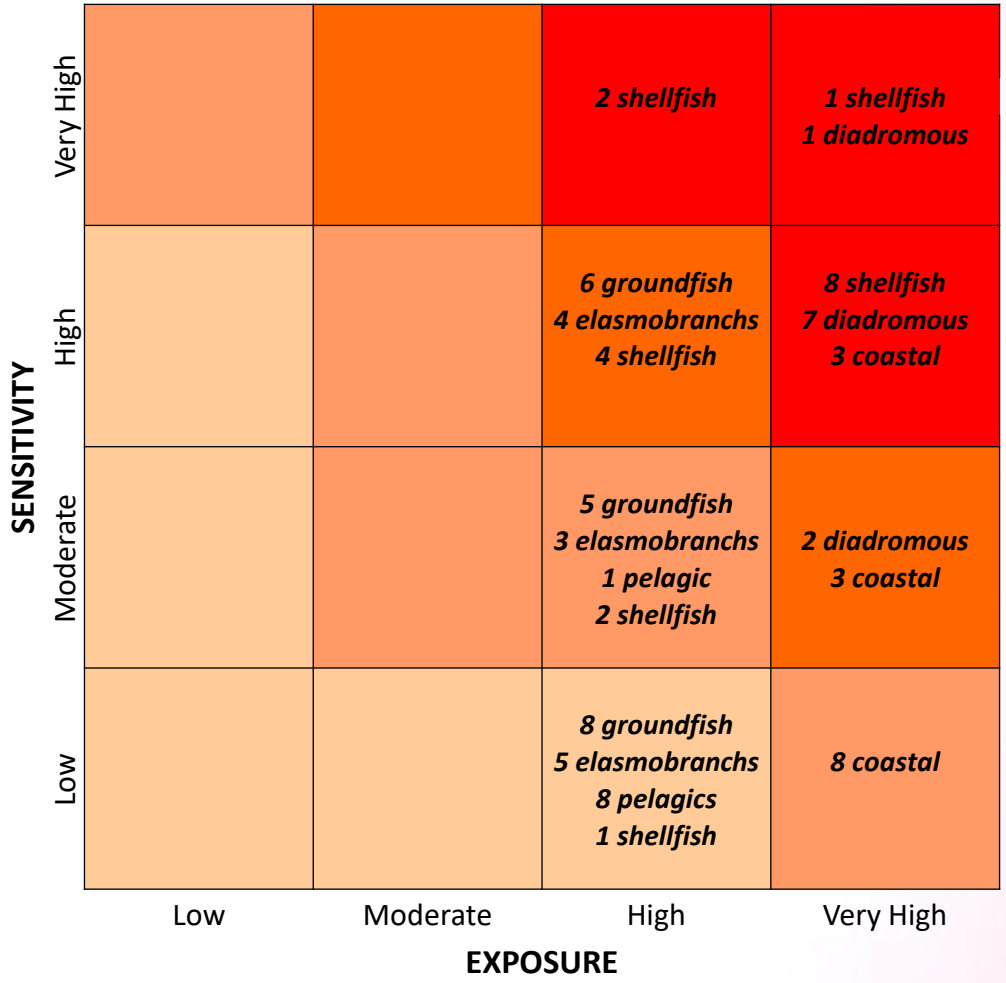
Spawning day = f(**Temperature**)

1. Vulnerability assessments

2. Responsive harvest control rules

Adaptation planning requires knowing species vulnerability





Vulnerability analysis of fish and invertebrates in the Northeast US ecosystem

Reference points need to be adapted to future productivity

the most vulnerable stocks need to have responsive HCRs

ICES Journal of Marine Science

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2019), 76(6), 1424–1435. doi:10.1093/icesjms/fsz038

Original Article

Responsive harvest control rules provide inherent resilience to adverse effects of climate change and scientific uncertainty

J. P. Kritzer[1]*, C. Costello[2], T. Mangin[2], and S. L. Smith[1]

[1]*Environmental Defense Fund, 18 Tremont Street, Boston, MA 02108, USA*
[2]*Bren School of Environmental Science and Management, University of California, 2400 Bren Hall, Santa Barbara, CA 93106, USA*

**Corresponding author: tel: + 1 617 406 1817; fax: + 1 (0) 617 723 2999; e-mail: jkritzer@edf.org.*

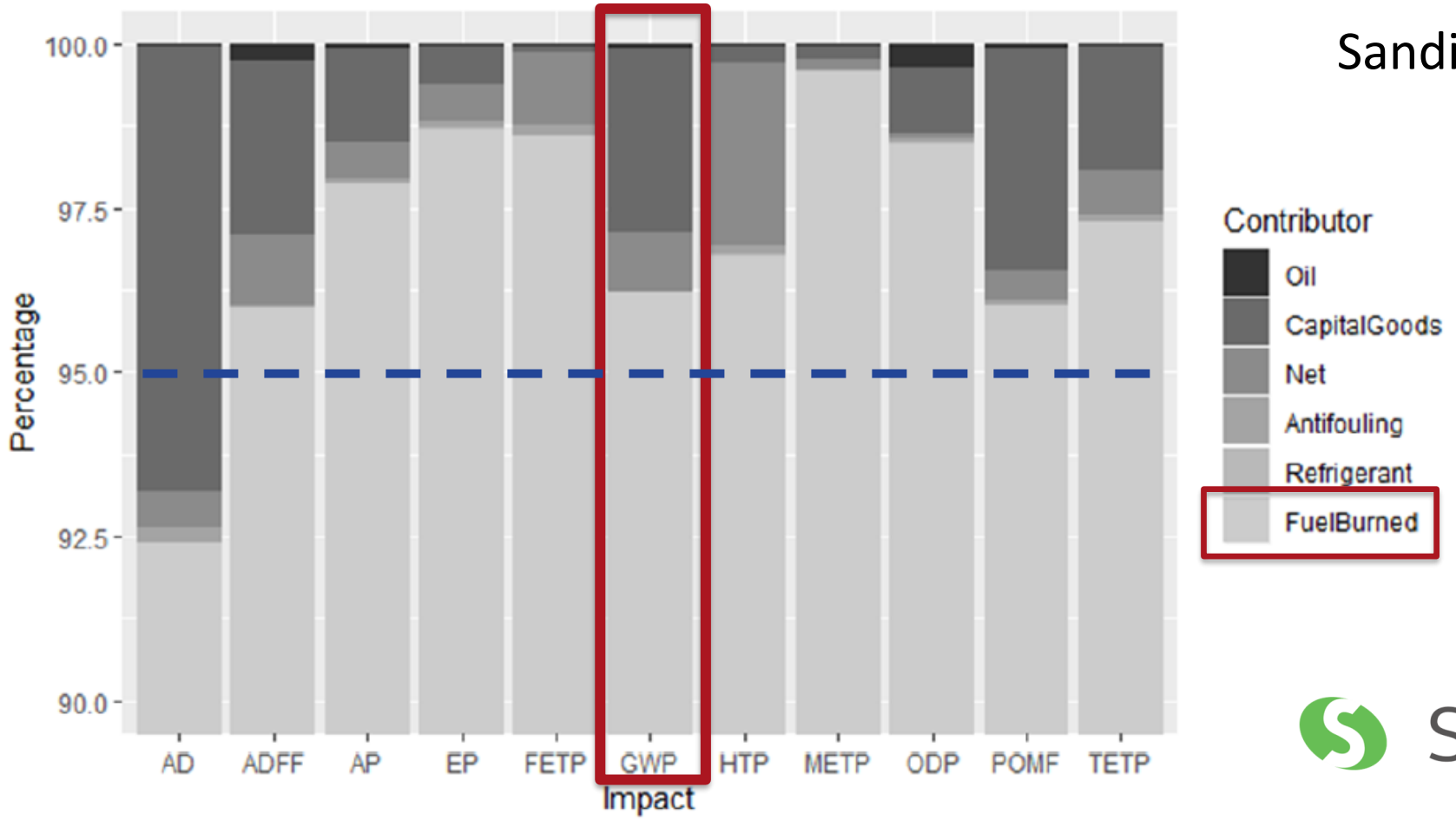
Seafood CF from comparable Life Cycle Assessment studies

Seafood type	Place	Fishing method	Carbon Footprint (kg CO2eq kg^{-1})	Source
Small pelagics	Scotland	Pelagic trawl	0.452	Sandison et al *in press*
Atlantic Mackerel	Galicia	Pelagic trawl	0.880	Iribarren et al. (2011)
Atlantic Mackerel	Galicia	Purse seine	0.610	Iribarren et al. (2011)
Atlantic Mackerel	Basque Country	Purse seine	> 0.200	Ramos et al. (2011)
Horse Mackerel	Galicia	Purse seine	0.797	Vázquez-Rowe et al. (2010)
Horse Mackerel	Galicia	Bottom trawl	2.28	Vázquez-Rowe et al. (2010)
Farmed Salmon	UK	Farmed	3.27	Pelletier et al. (2009)
Cod	Norway	Mixed	1.60	Winther et al. (2009)
Haddock	Norway	Mixed	1.75	Winther et al. (2009)
Shrimp	Senegal	Trawl	ca. 29	Ziegler et al. (2011)

Fuel burned accounts for >95% of GHG emissions

LCA component analysis for the Scottish pelagic fleet 2015-2017 showing the impact categories

Sandison et al *in press*



SimaPro

Summary

- temperature dependency of growth rates and spawning times have the potential for decreasing productivity as waters warm
- in response management should consider:
  - trait-based vulnerability assessments
  - responsive HCRs for the most vulnerable species
- sustainably produced fish are a climate smart protein source
  - industry and science can work together to estimate how smart
  - improving fuel efficiency will have the greatest impact on CF