Climate Cycles and Population Dynamics of North Sea Herring

Joachim P. Gröger[1], Gordon H. Kruse[2], and Norbert Rohlf[1]

[1]Institute of Sea Fisheries, Federal Research Institute for Rural Areas, Forestry and Fisheries, Hamburg, Germany

[2]University of Alaska Fairbanks
School of Fisheries and Ocean Sciences, Juneau Center
Juneau, Alaska, USA

Slave to the rhythm: how large-scale climate cycles trigger herring (*Clupea harengus*) regeneration in the North Sea

Joachim P. Gröger, Gordon H. Kruse, and Norbert Rohlf

Gröger, J. P., Kruse, G. H., and Rohlf, N. 2010. Slave to the rhythm: how large-scale climate cycles trigger herring (*Clupea harengus*) regeneration in the North Sea. – ICES Journal of Marine Science, 67: 454–465.

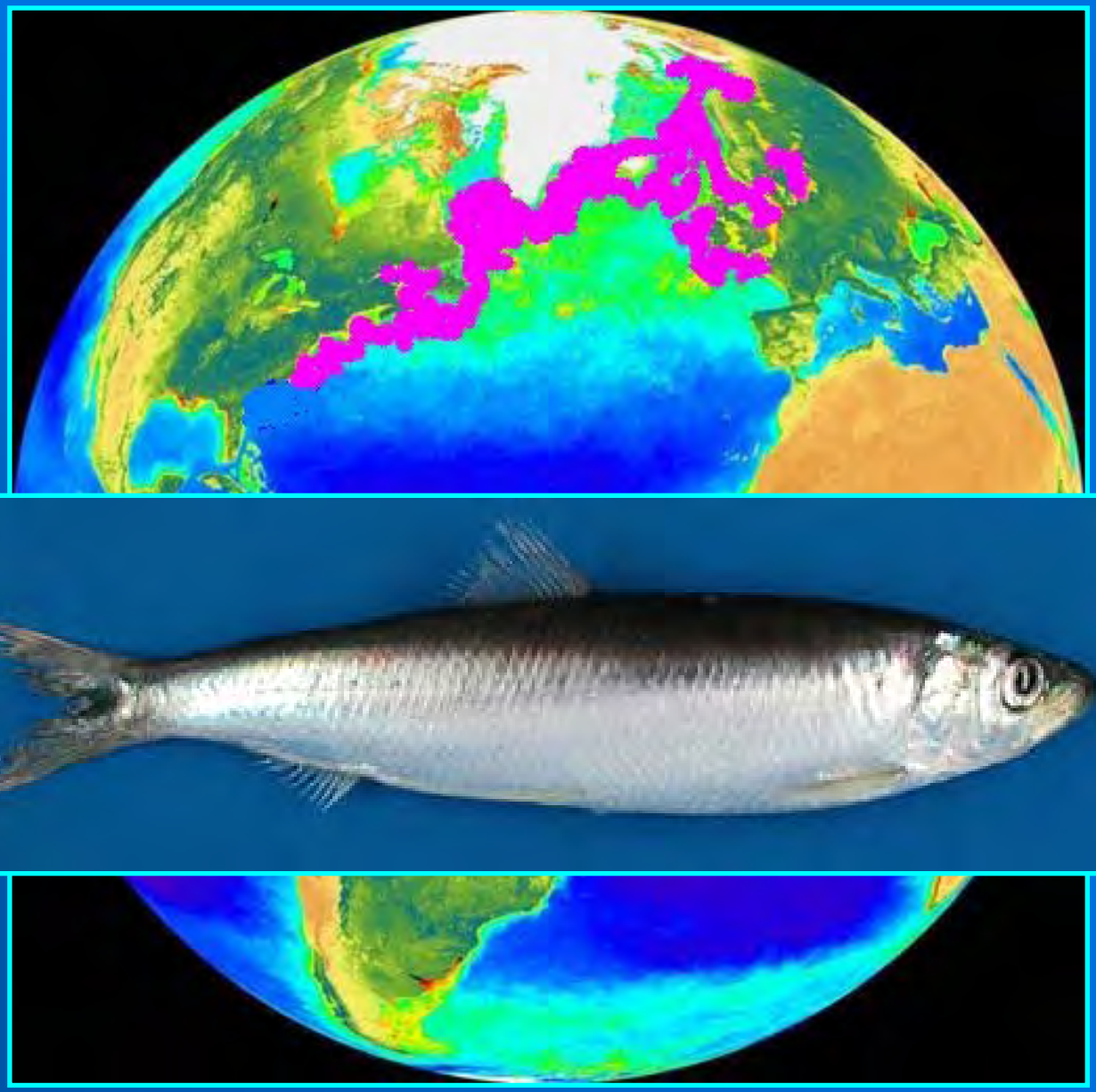
Understanding the causes of variability in the recruitment of marine fish stocks has been the "holy grail" of fisheries scientists for more than 100 years. Currently, debate is ongoing about the functionality and performance of traditional stock–recruitment functions used during stock assessments. Additionally, the European Commission requires European fishery scientists to apply the ecosystem approach to fisheries in part by integrating environmental knowledge into stock assessments and forecasts. Motivated to understand better the recent years of reproductive failures of commercially valuable North Sea herring, we studied large-scale climate changes in the North Atlantic Ocean and their potential effects on stock regeneration. Applying traffic light plots and time-series (TS) analyses, it was possible not only to explain the most recent reproductive failures, but also to reconstruct the full TS of recruitment from climate cycles, indexed by the North Atlantic Oscillation and the Atlantic Multidecadal Oscillation. A prognostic model was developed to provide predictions of herring stock changes several years in advance, allowing recruitment forecasts to be incorporated easily into risk assessments and management strategy evaluations, to promote a sustainable herring fishery in the North Sea. Insights gained from the analysis permit reinterpretation of the sharp decline in the North Sea herring stocks in the 1970s.

Keywords: AMO, Atlantic herring, climate cycles, cross-correlations, NAO, North Sea, recruitment, time-series analysis.

Received 4 September 2008; accepted 16 October 2009; advance access publication 29 November 2009.

J. P. Gröger and N. Rohlf: Institute of Sea Fisheries, Federal Research Institute for Rural Areas, Forestry and Fisheries, D-22767 Hamburg, Germany. G. H. Kruse: School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 17101 Point Lena Loop Road, Juneau, AK 99801, USA. Correspondence to J. P. Gröger: tel: +49 40 38905 266; fax: +49 40 38905 263; e-mail: joachim.groeger@t-online.de.

Glvwulexwlrq#ri#Dwodqwlf#Khuulqj



Qruwk#Vhd

- :83/333#mp5
- <93#[#8;3#mp
- Ghswk=
  - <8#p#Dyh1,
  - :33#p#Pd{,
- Whps=#904:#F
- Vdoqlw|=#6706 8

Fischbrötchen

Bückling

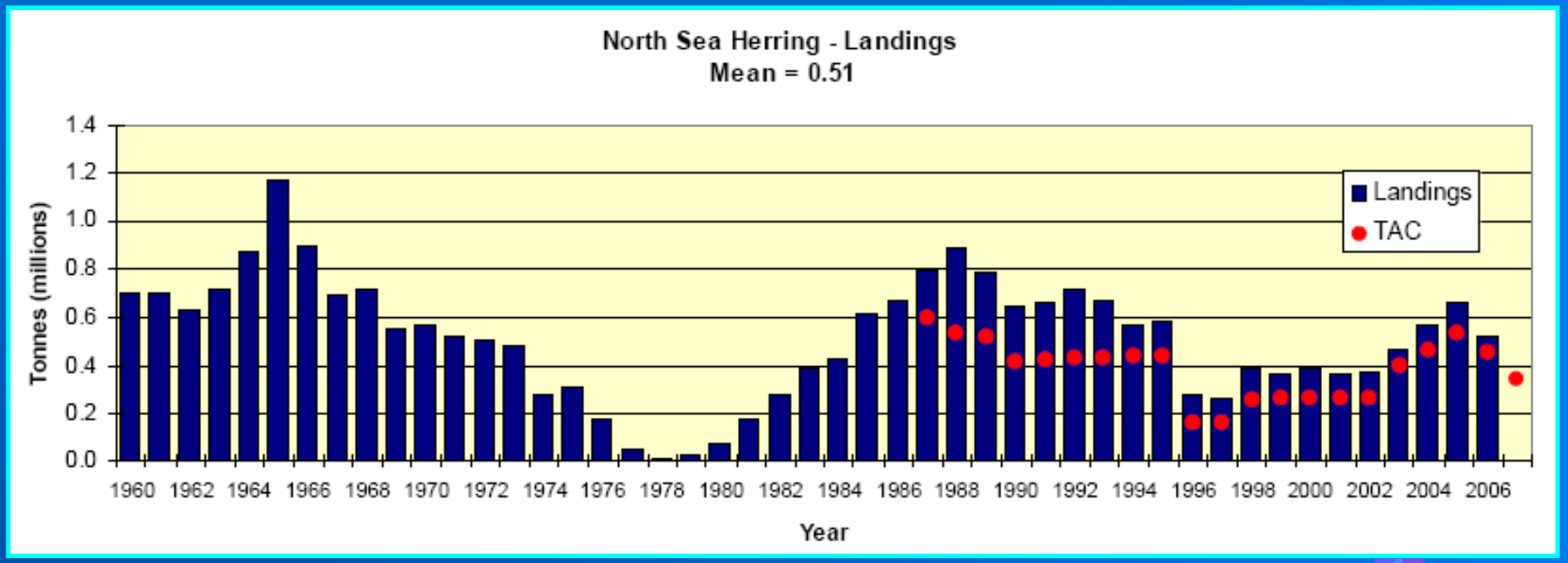
Red Herring Salad

Rollmops

Matjes herring

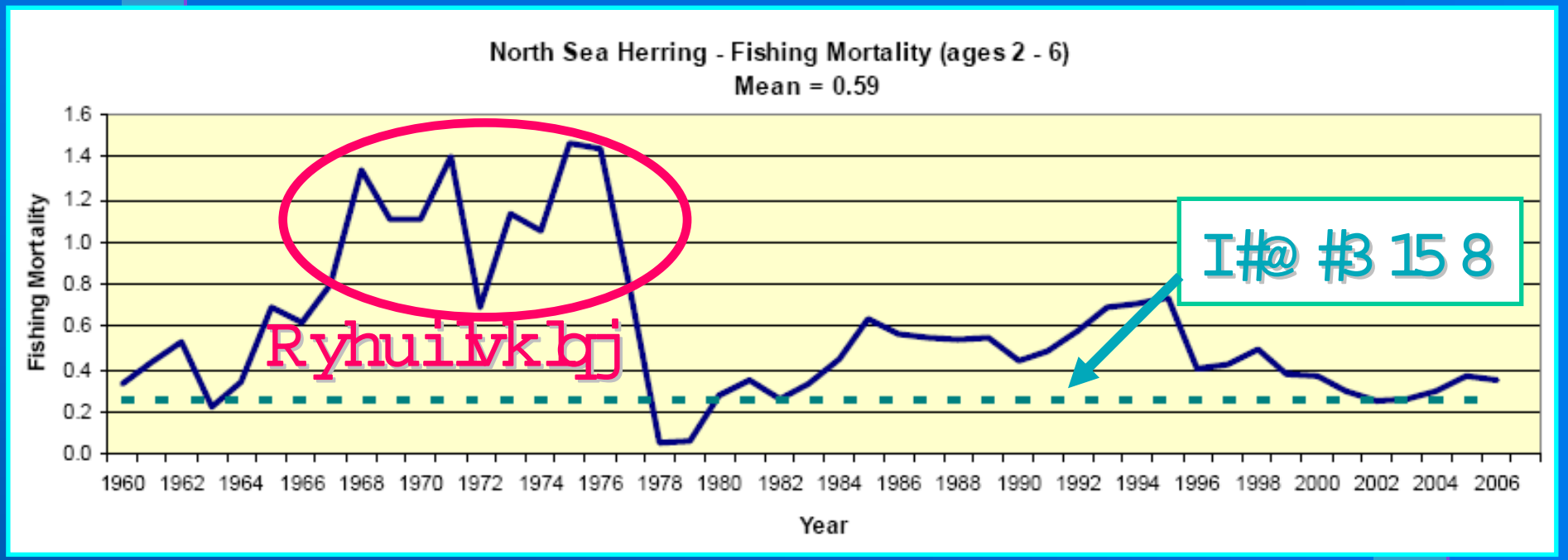
Brathering

Odqglqj v#Vlqfh#4 < 93



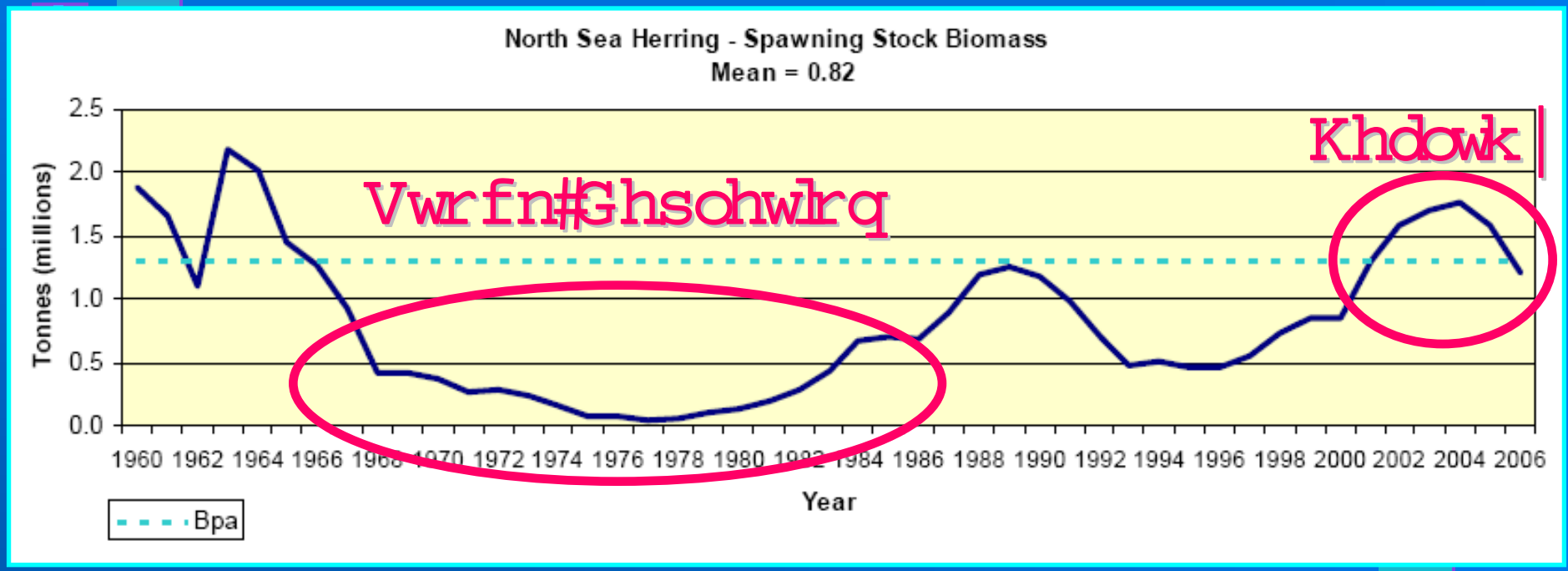
- Phdq#odqglqj v#ri#3184#pboolrq#wrqqhv

Ilvkbqj#Pruwdolw|#Vbqfh#4<93



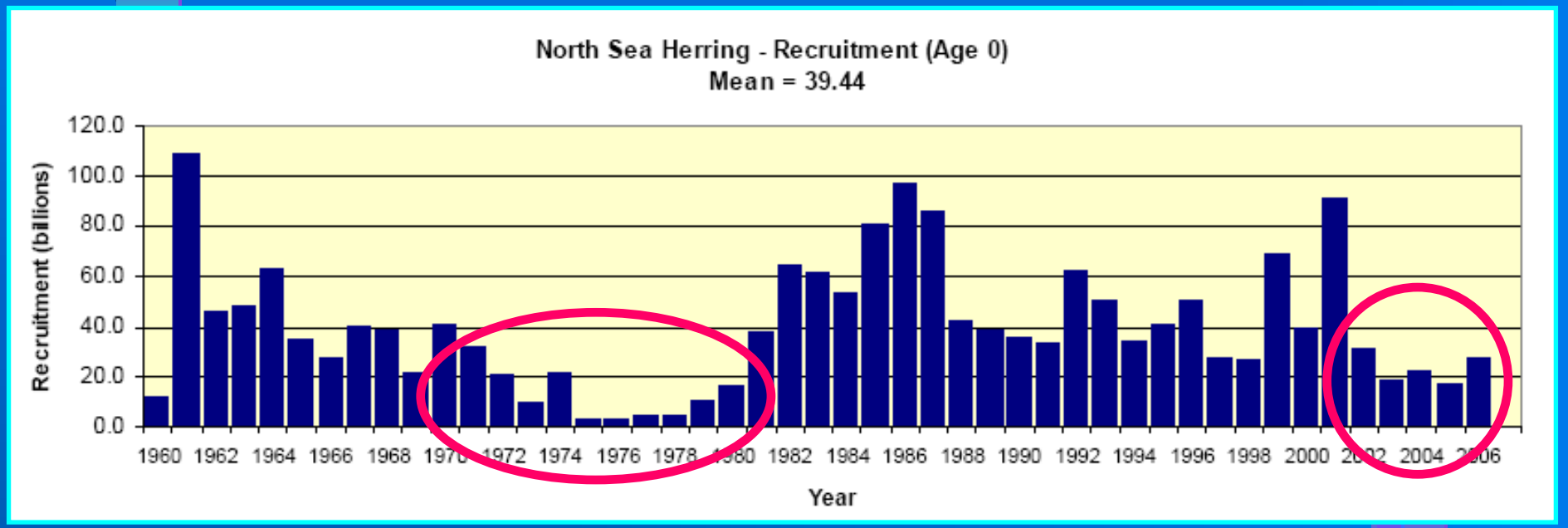
- Ilvkbqj#pruwdolw|#jhqhudoo|#h{fhhgv#uhfrppqghg#udwh#3158,
- khdy|#ryhuilvkbqj#q#4<93v04<:3v

Dwodqwlf#Khuulqj#*Foxshd#kduhqjxv,*



- Vsdzqlqj#vwrfn#elrpdvv#riwhq#ehorz#wkh#suhfdxwlrqdu|#elrpdvv#Esd,
- Qrwh#khdowk|#vwrfn#lq#533v

Dwodqwlf#Khuulqj#Fxshd#kduhqjxv,



- Qrwh#f|folfdo#uhfuxlwphqw#sdwwhuq
- srru#uhfuxlwphqw#lq#wkh#4<:3v#dqg#uhfhqw#|hduv

Remhfwlyhv=

- Hvwlpdwh#h{whqw#wr#zklfk#Qruwk#Vhd#khuulqj#uhfuxlwphqw#fdq#eh#uhfrqvwuxfwhg#iurp#folpdwh#bqglfhv
- Frqwulexwh#wr#dq#rqjrlqj#ghedwh#rq#wkh#ixqfwlrqdolw|#ri#vwrfn0uhfuxlw#ixqfwlrqv

Khuulqj#gdwd

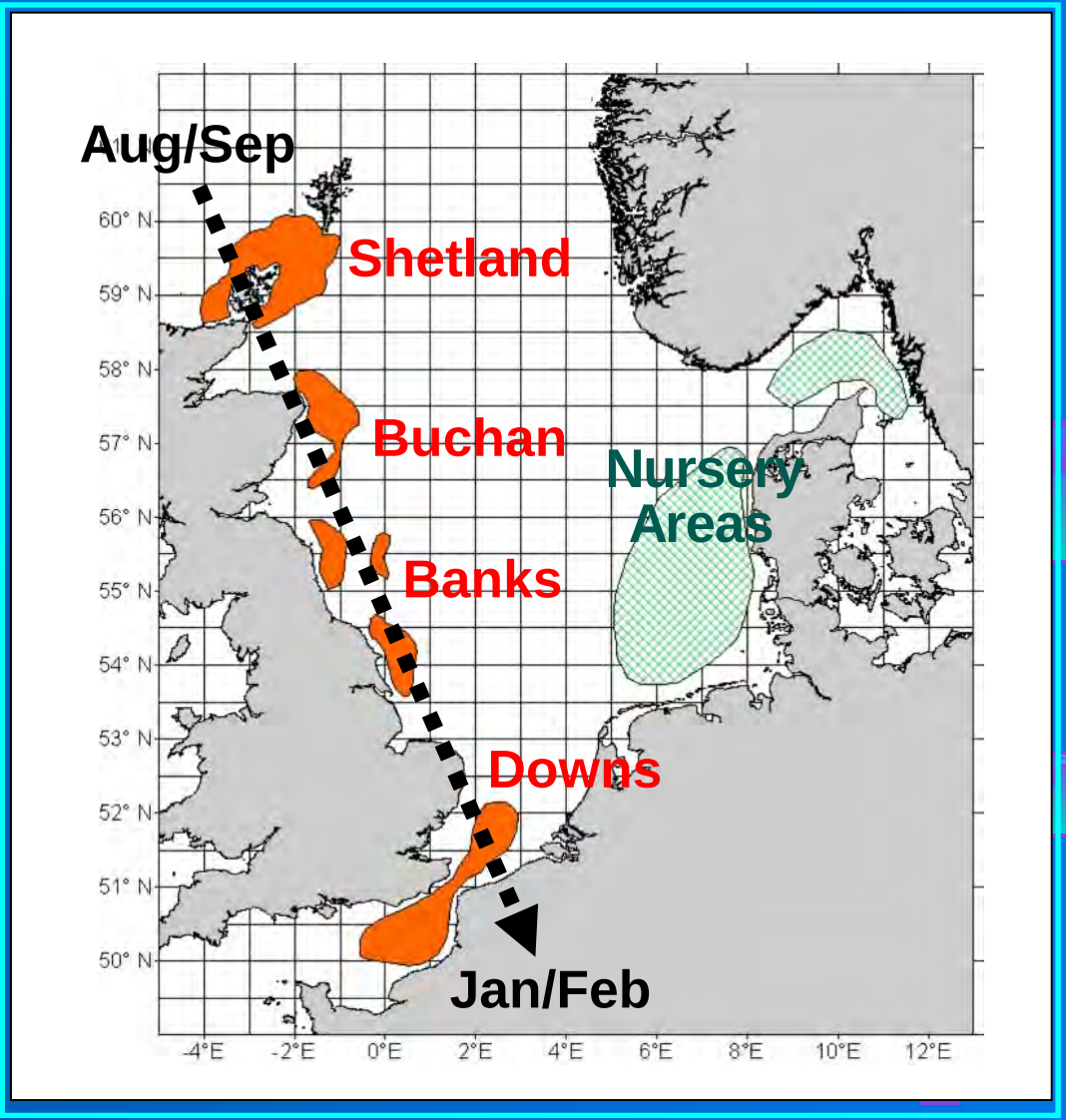
- Pxowlsolfdwlyh#bduydo#dexqgdqfh#bqgh{#+PODL, Ù bqgh{#ri#dexqgdqfh#ri#vpdoo#+? 43#pp,#bduydh#diwhu#vsdzqlqj#iurp#pxowlsoh#vxuyh|v
- Phwkrw#Evddfv0Nlgg#bqgh{#PIN, Ù bqgh{#ri#odwh0vwdjh#£ 63#pp,#bduydh#diwhu#ryhuzlqwhuslqj
- Uhfuxlwv#U, Ù dexqgdqfh#dw#dj h#4
- Vsdzqlqj#Vwrfn#Elrpdvv#VVE, Ù elrpdvv#ri#pdwxuh#ilvk#iurp#vwrfn#dvvhvvphqw

Qruwk#Vhd#Vwrfn#Vsdzqbj#Vlwhv

Dxwxpq# Vsdzqbj# Khuubj

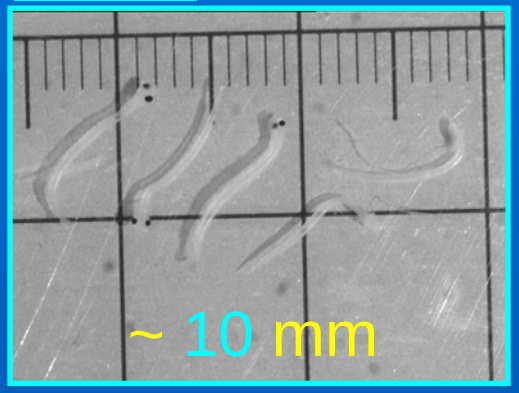
Irxu#Vwrfnv=

- Vkhwodqg
- Exfkdq
- Edqnv
- Grzqv

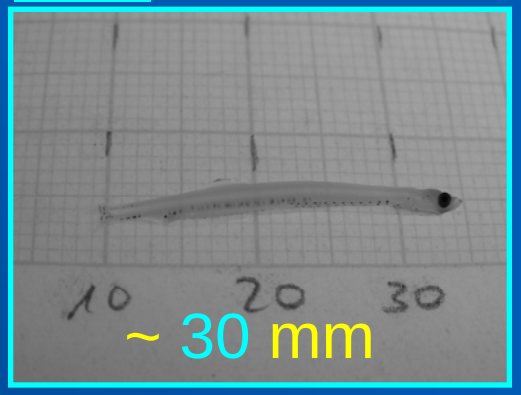


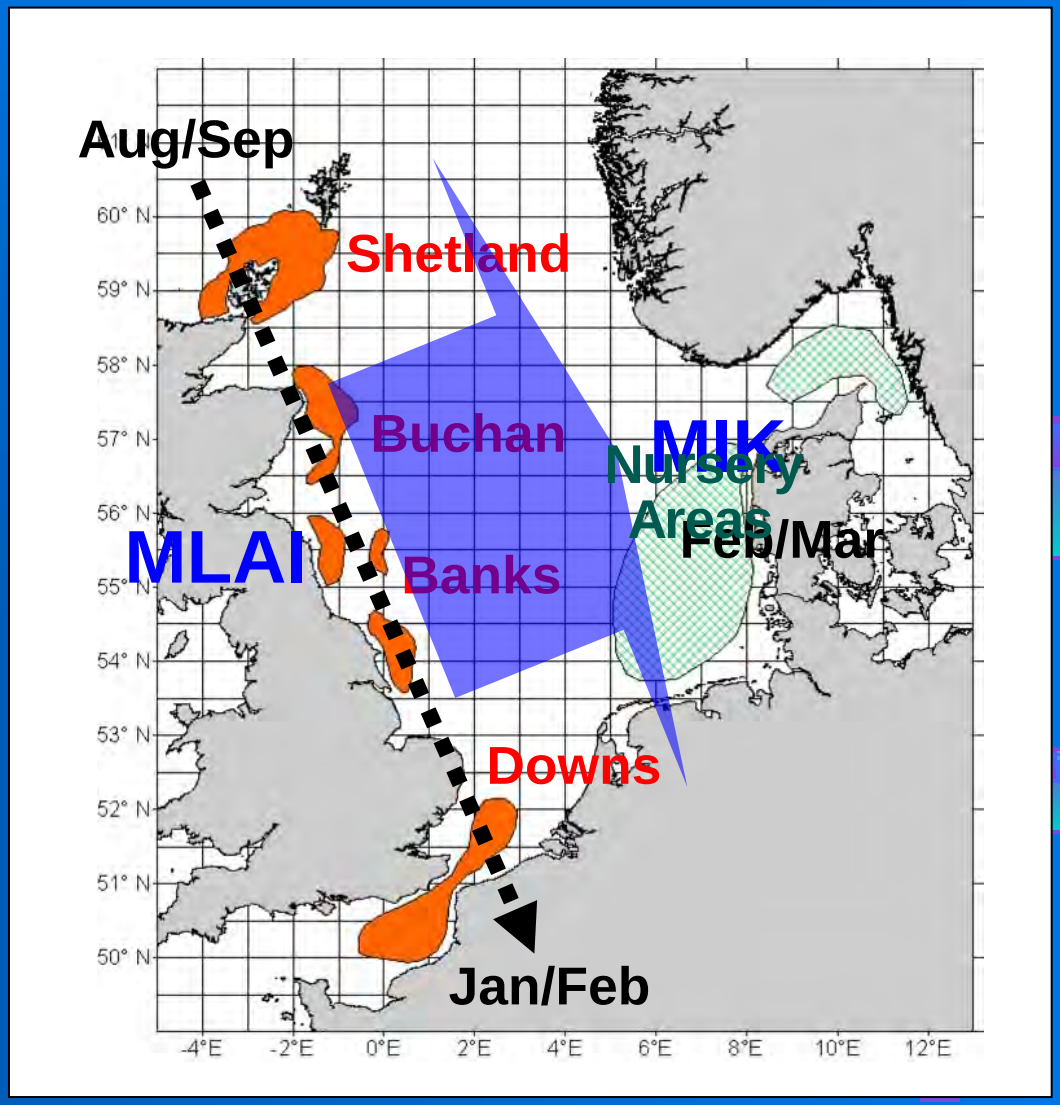
Vwrfn#Vsdzqbj#Vlwhv#)#Gdwhv

MLAI



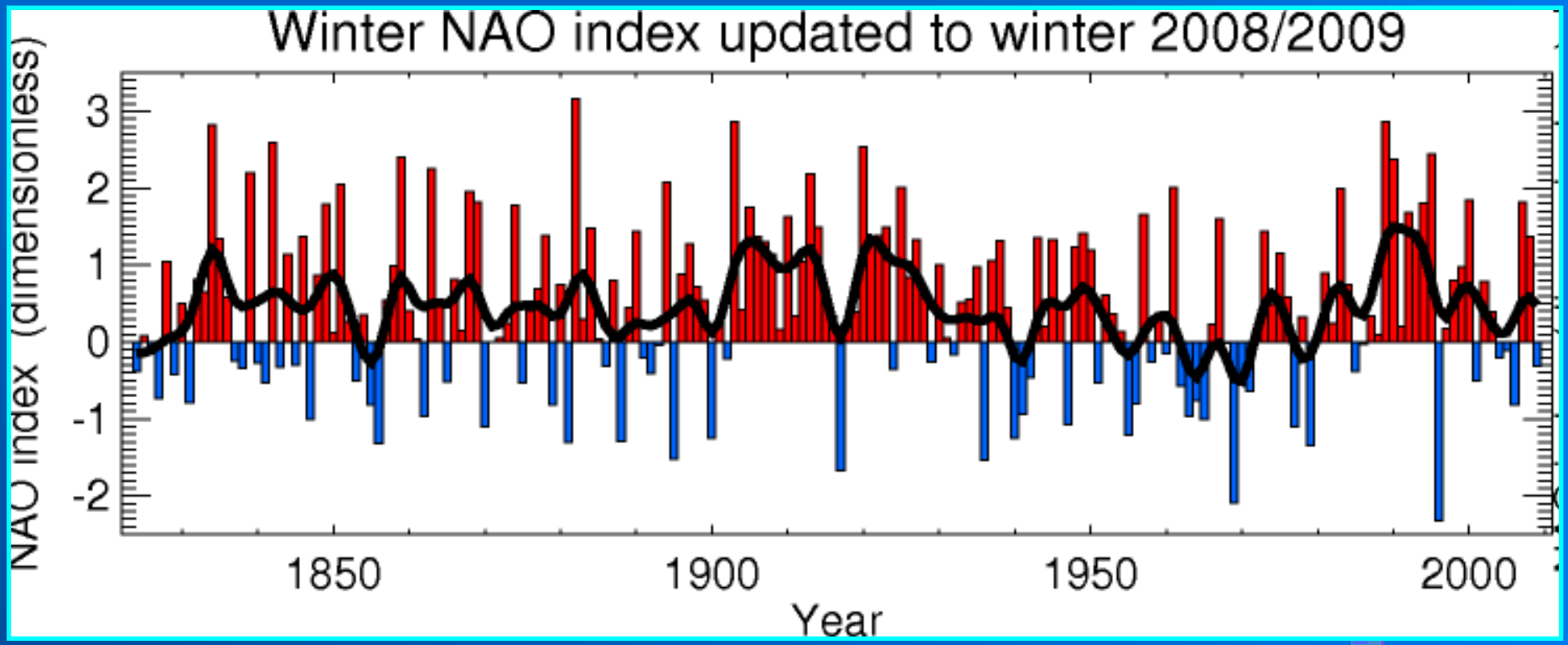
MIK



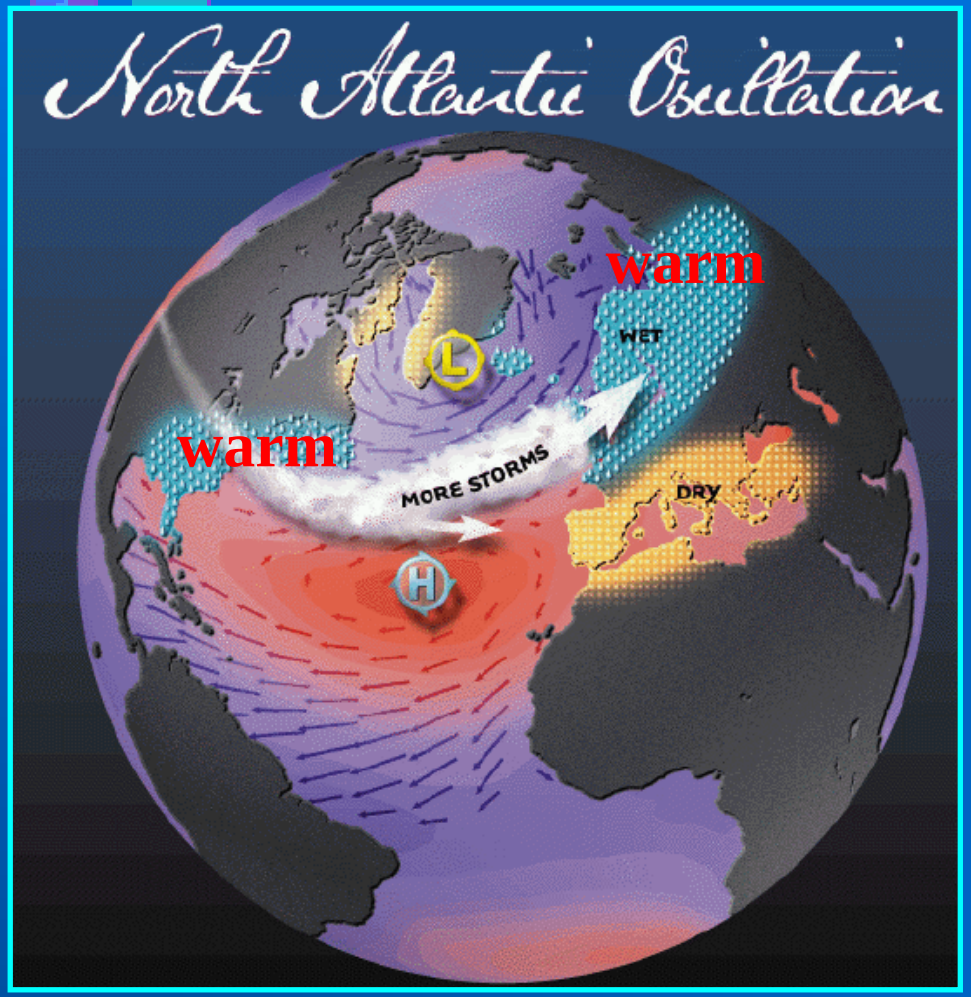


Foldwh#Lqglfhv

- Qruwk#Dwodqwlf#Rvfloodwlrq#QDR, Ù bqgh{#ri#vhd0ohyho#suhvvxuh#gliihuhqfh#ehwzhhq#Ifhodqglf#Orz#bqg#D}ruhv#Klj k

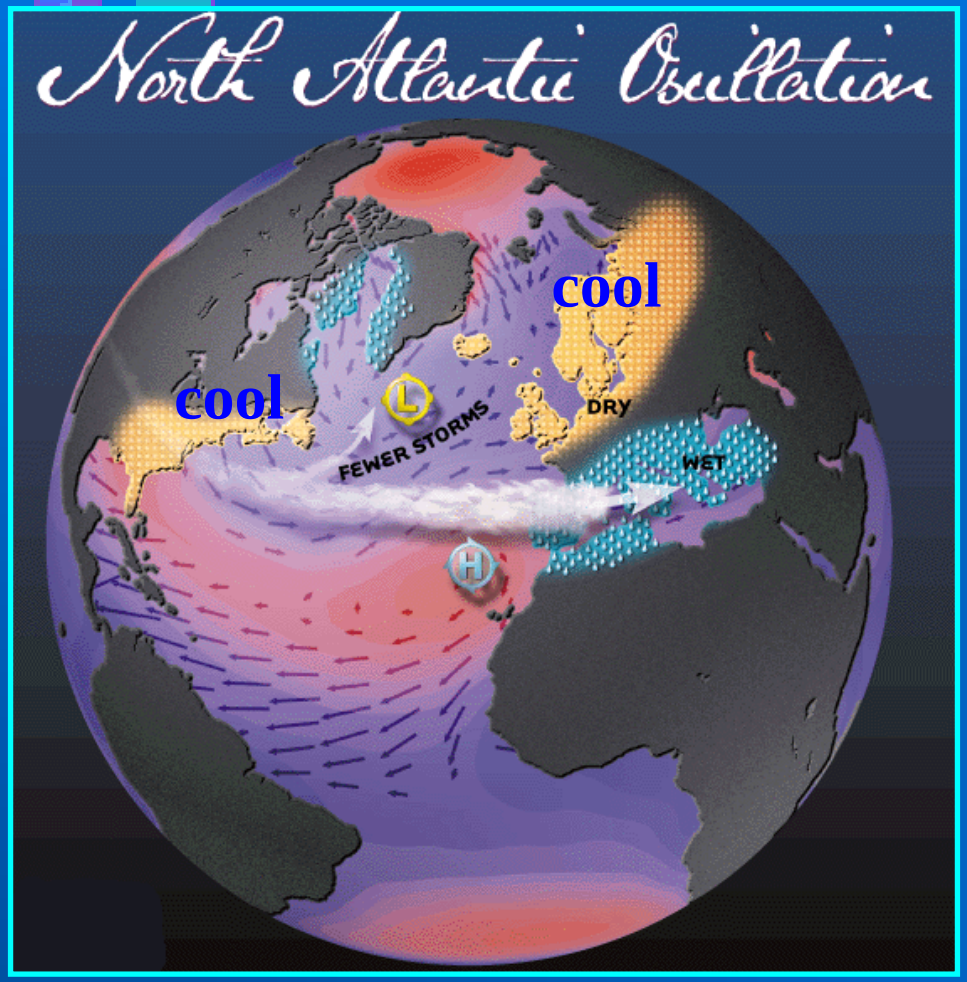


QDR#Srvlwlyh#Zdup,#Skdvh



- Vwurqjhu#wkdq#xvxdo# vxewurslfdo#kljk#dqg#d# ghhshu#wkdq#qrupdo# lfhodqglf#orz
- Pruh#dqg#vwurqjhu# zlqwhu#vwrupv#furvvlqj# wkh#Dwodqwlf#Rfhdq#rq#d# pruh#qruwkhuo|#wudfn1#
- Wklv#uhvxowv#lq#zdup# dqg#zhw#zlqwhuv#lq# Hxursh

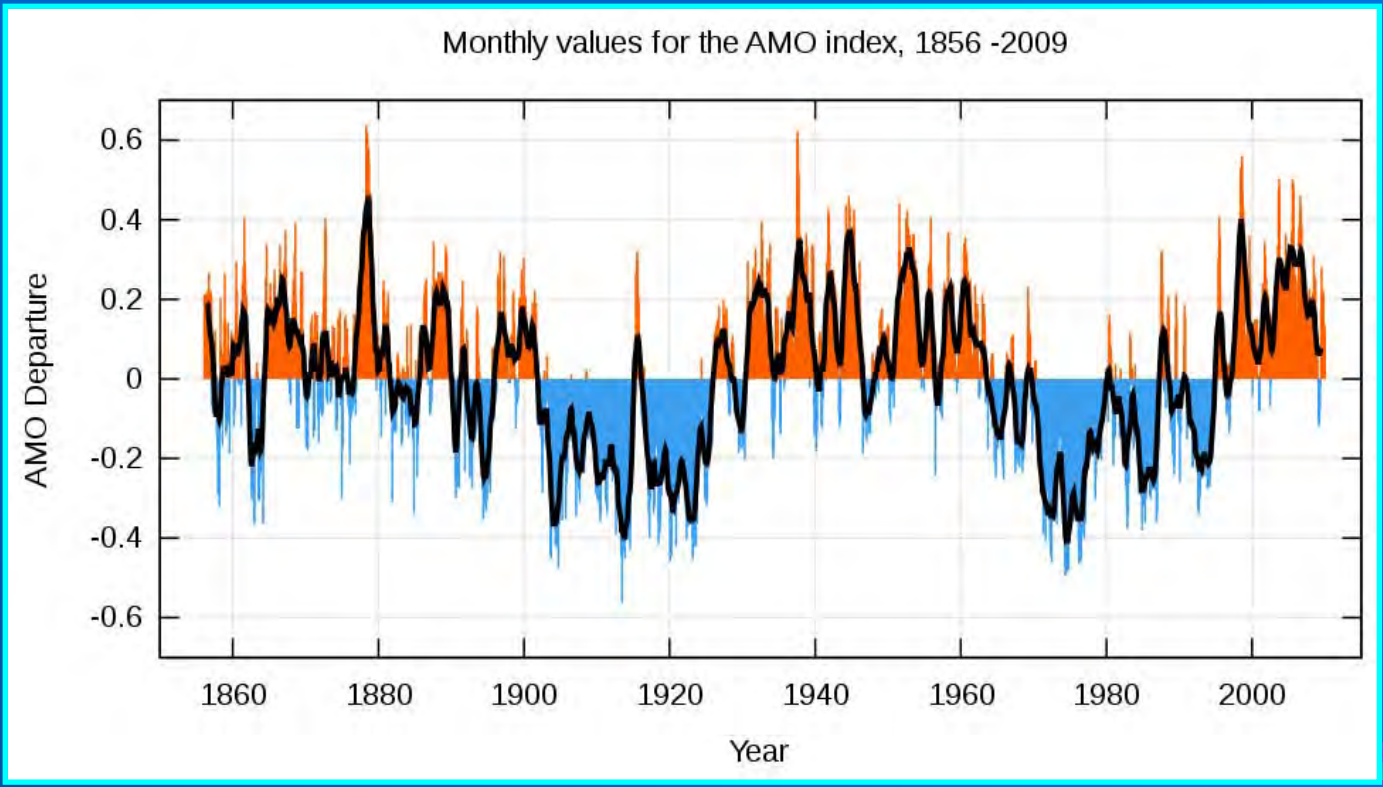
QDR#Qhjdwlyh#Frro,#Skdvh



- zhdn#vxewurslfdo#kljk#dqg#zhdn#fhodqglf#orz#
- uhgxfhg#suhvvxuh#judglqw#uhvxowv#lq#ihzhu#dqg#zhdnhu#zlqwhu#vwrupv#furvvlqj#rq#d#pruh#zhvwdnvw#sdwkzd|1#
- prlvw#du#iorzv#qwr#wkh#Phglwhuudqhdq/#ohdylqj#frog#du#lq#qruwkhuq#Hxursh#

Folpdwh#Lqglfhv

- Dwodqwlf#Pxowlghfdgdo#Rvfloodwlrq#DPR,
  Ù lqgh{#ri#orqj0whup#vhd#vxuidfh#
  whpshudwxuh#lq#wkh#Qruwk#Dwodqwlf



Vwrfn0Uhfuxlw#Dqdo|vhv

Ilwwhg#wkuhh#frqyhqwlrqdo#prghov=

- Ulfnhu
- Ehyhuwrq0Krow
- Vhjphqwhg#uhjuhvvlrq

Ilwwhg#h{whqghg#Ulfnhu#prgho=

$$\ln\left(\frac{R_t}{\mathrm{SSB}_{t-1}}\right) = \ln(b_1) + b_2\,\mathrm{SSB}_{t-1} + b_3\,\text{winter AMO}_{t-\text{lag1}} + b_4\,\text{winter NAO}_{t-\text{lag2}},$$

Wlph#Vhulhv#Dqdo|vhv

- Furvvfruuhodwlrq#dqdo|vlv Ù fruuhodwlrqv#dprqj#¹5#wlph#vhulhv#wr#h{dplqh#srwhqwldo#ghod|hg#hiihfwv
- Vshfwudo#dqdo|vlv Ù dqdo|vlv#ri#f|folfdo#ri#uhfuxlwphqw#dqg#h{whuqdo#idfwruv#wr#orrn#iru#fruuhvsrqglqj#wudmhfwrulhv
- dxwruhjuhvvlyh#qwhjudwhg#prvlqj#dyhudjh#DUIMA,#prgho Ù lqfoxghv#idfwruv#dqg#sdwwhuqv#qhqwlilhg#qwr#d#uhfuxlwphqw#iruhfdvwlqj#prgho

8#Vwhsv#wr#Prgho#Ghqwlilfdwlrq

4 1Vwdeolvh#dqg#suh0zklwhq#wkh#wlph#vhulhv

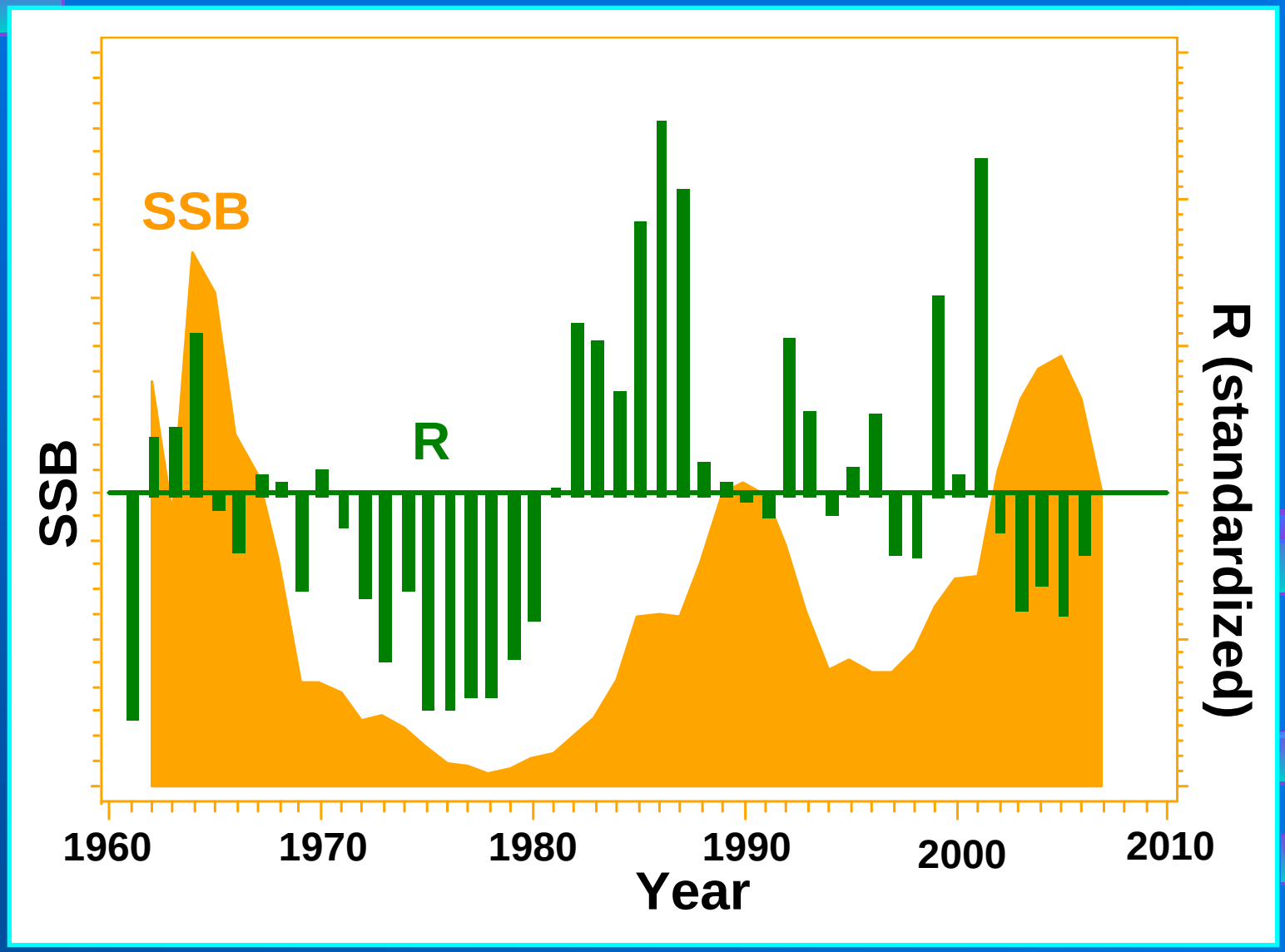
5 1Surfhvv#ghqwlilfdwlrq#-fdxvdwlyh#idfwruv/#wlph#odjv,

6 1Hvwlpdwlrq#ri#prgho#sdudphwhuv

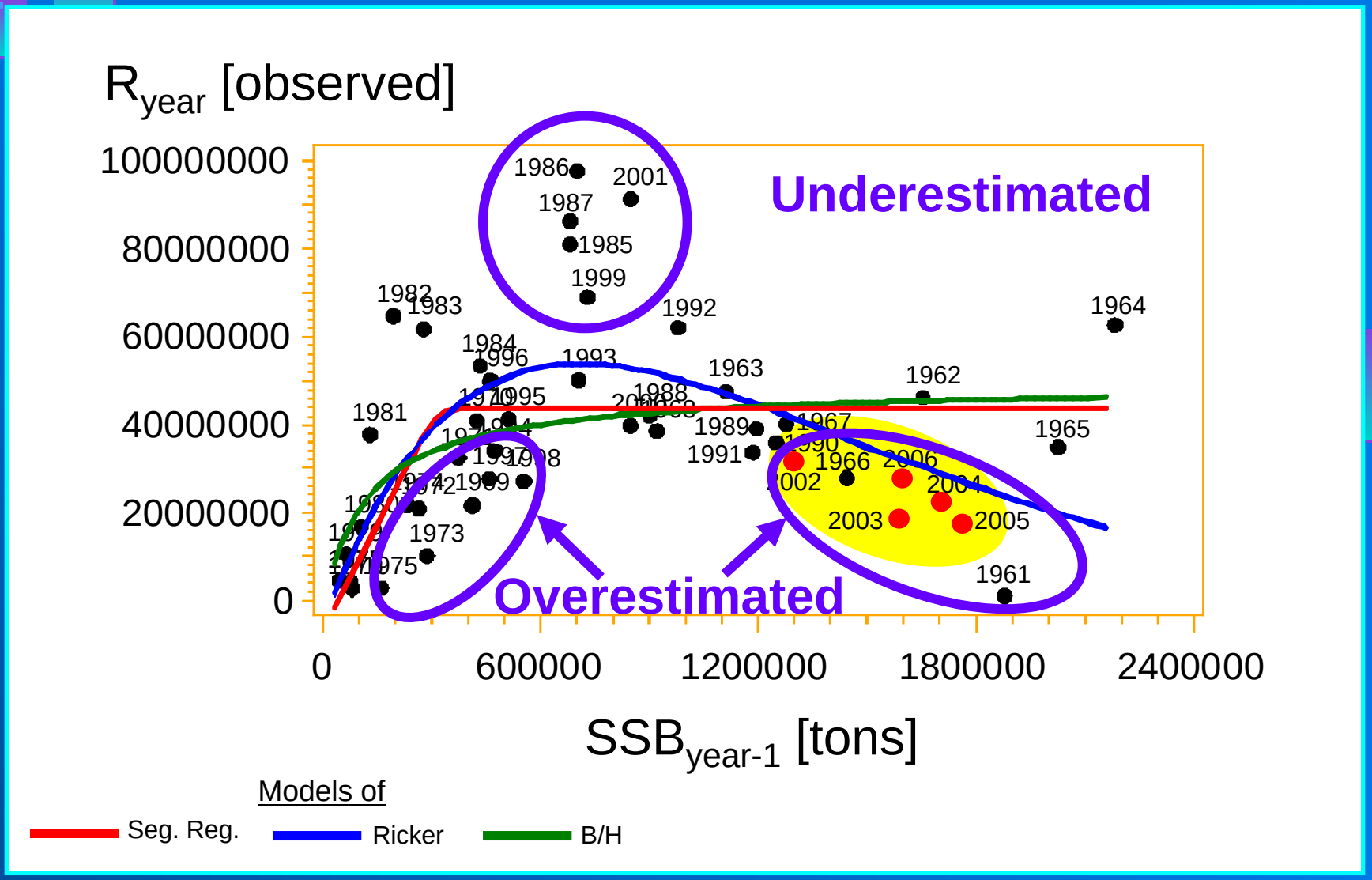
7 1Gbjqrvwlfv

8 1Iruhfdvwbqj

Wuhqgv#bq#VVE#) #U



Vwrfn0uhfuxlwphqw#uhodwlrqvkls



Vwrfn0uhfuxlwphqw#uhodwlrqvkls

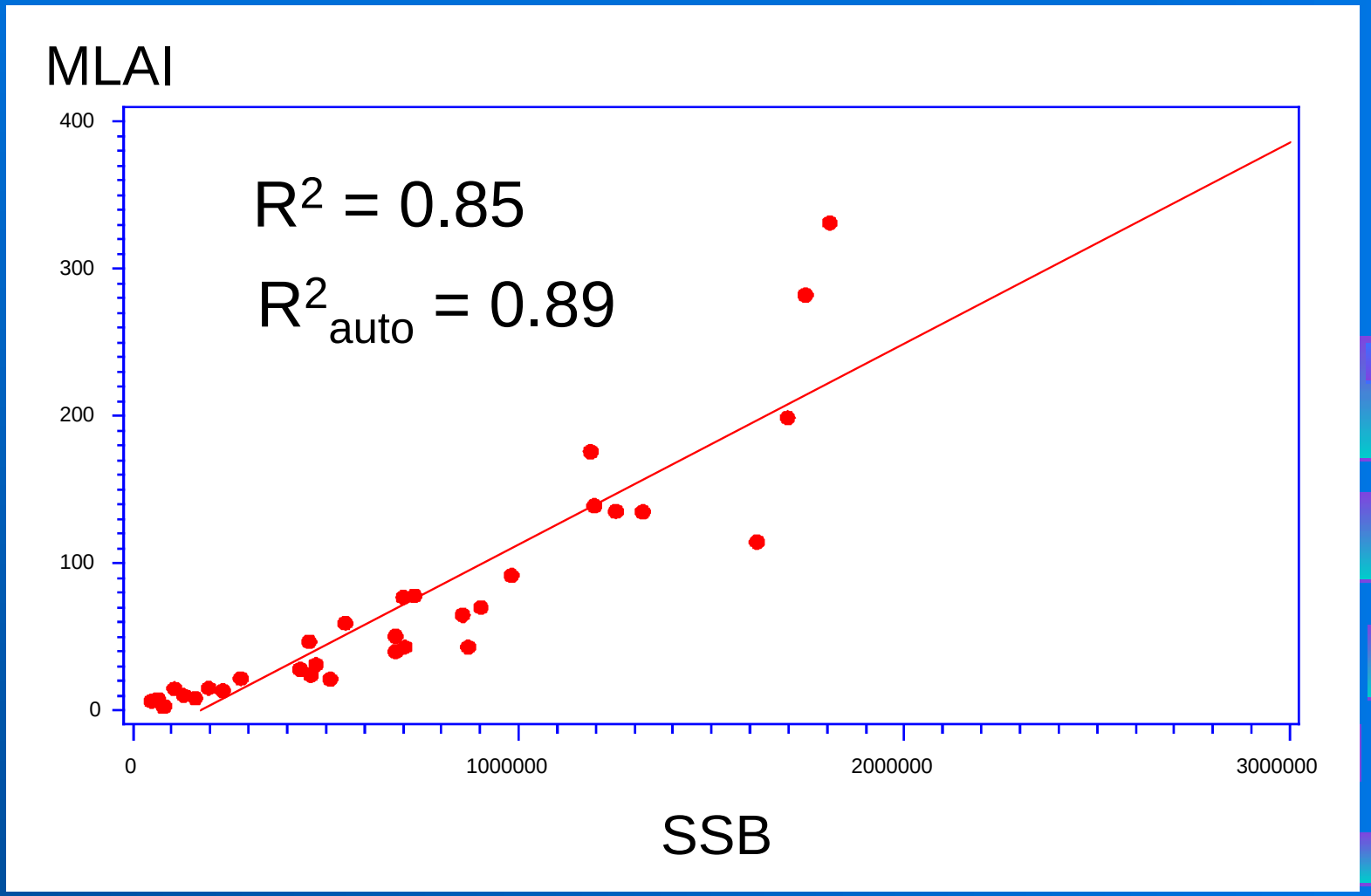
Table 1. Parameter estimates and quality-of-fit information from fits of stock–recruitment models.

	Model parameters		Model diagnostics	
Model	b_1	b_2	$r_{performance}$	**AICC**
Segmented regression	130.7	356 091	0.49	33.9384
Ricker	167.4	1.154E–6	0.51	33.9069
Beverton and Holt	0.002 85	54 137 400	0.47	33.9607

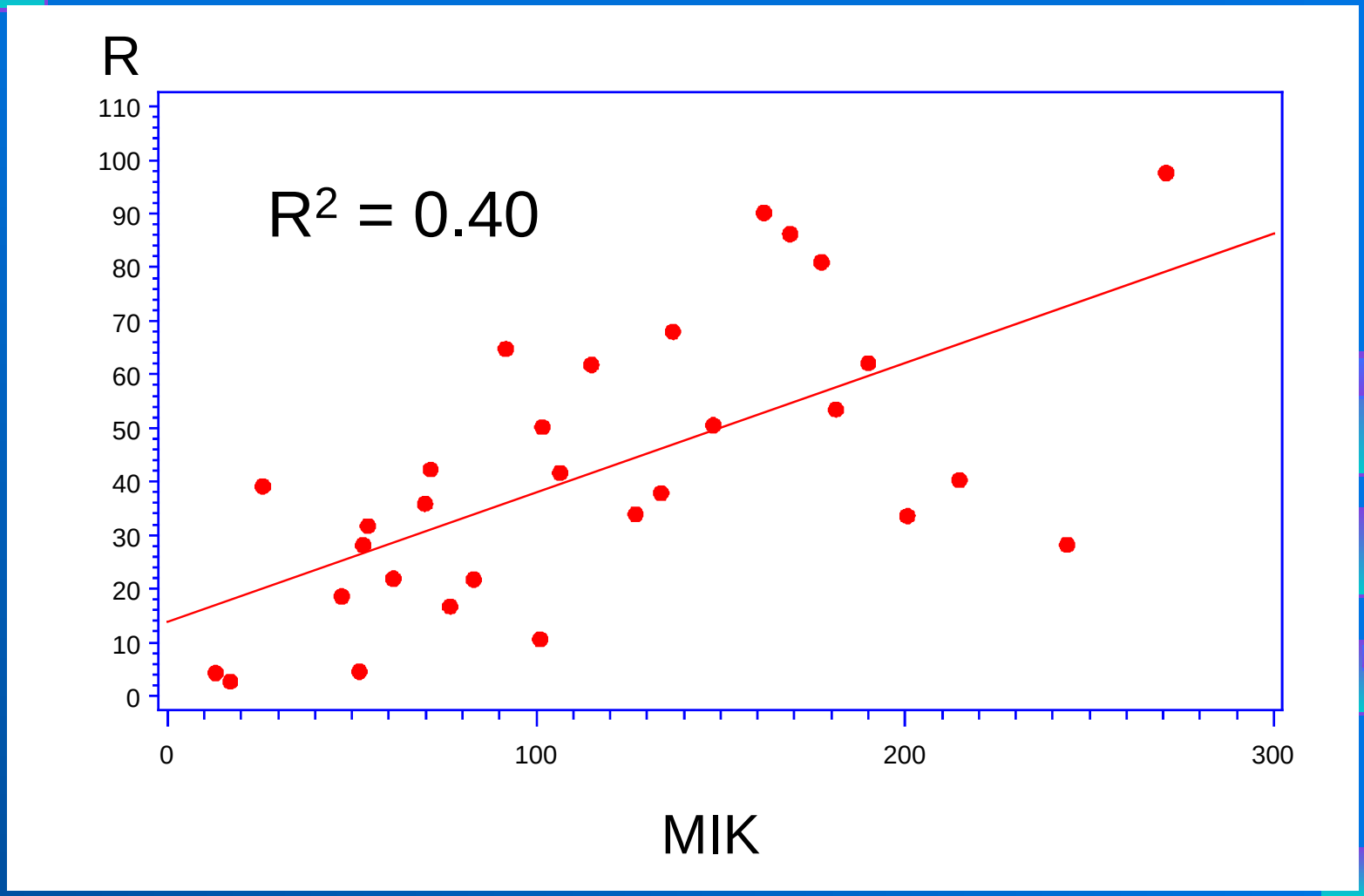
All three models and the single parameters associated with them were asymptotically significant at a 5% level.

- doo#prghov#duh#Vljqlilfdqw#=S? 3 13 8 ,#
- Hdfk#h{sodlqv#5 5 05 9 (#ri#ydulbeolw|

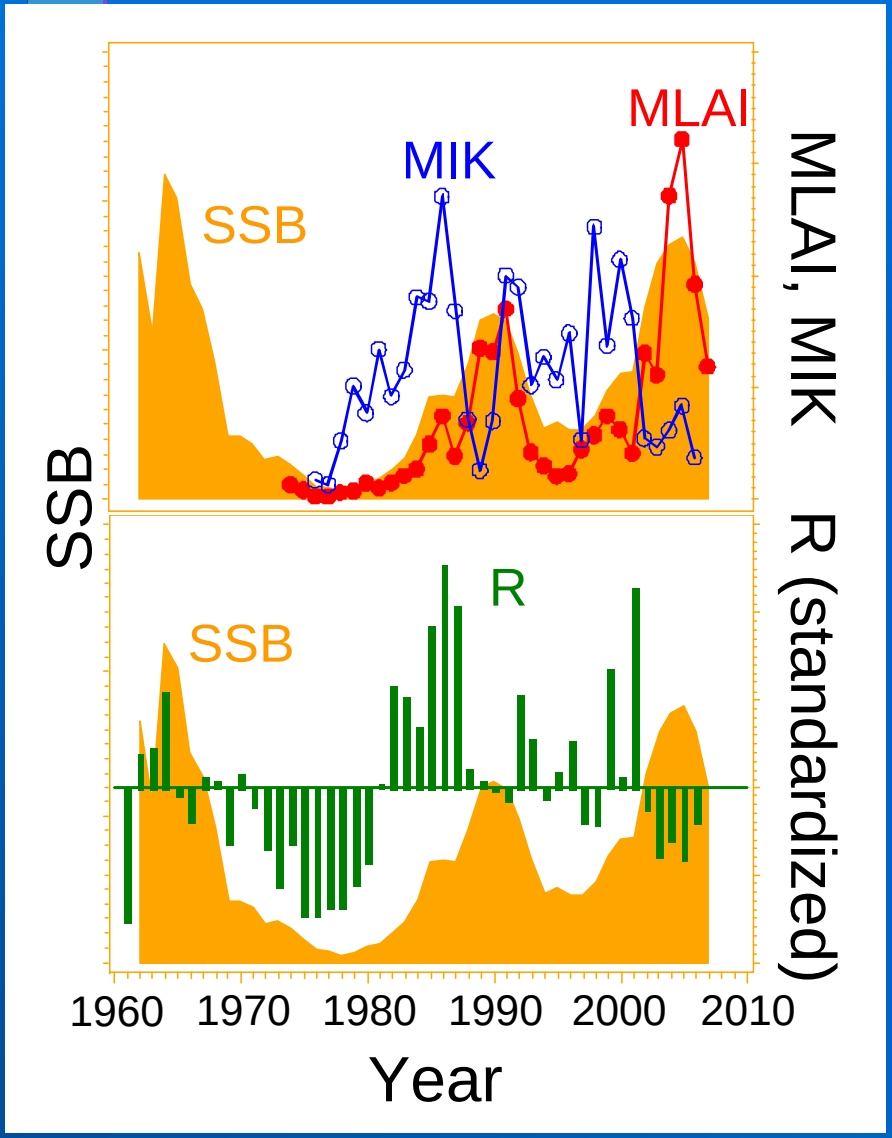
PODI#@ #VVE#Lqgh{



PIN# #Uhfuxlwphqw#Lqgh{



Wuhqgv#q#qglfhv



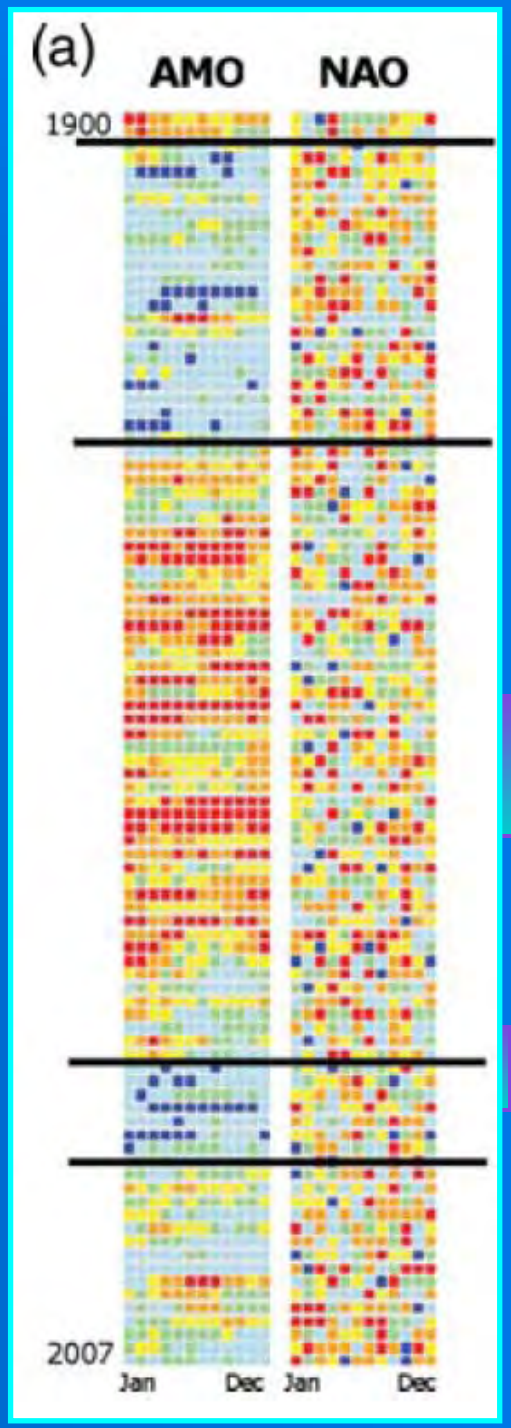
Traffic Light Plot (quintiles)

Year	R	MIK	MLAI	SSB
1976	20	20	20	20
1977	20	20	20	20
1978	20	20	20	20
1979	20	40	20	20
1980	20	40	20	20
1981	40	60	20	20
1982	80	40	20	20
1983	80	60	40	20
1984	80	80	40	40
1985	100	80	40	60
1986	100	100	60	60
1987	100	80	40	60
1988	60	40	60	60
1989	60	20	80	80
1990	40	40	80	80
1991	40	100	100	80
1992	80	100	60	80
1993	60	40	40	60
1994	40	60	40	40
1995	60	60	20	40
1996	60	80	40	40
1997	40	20	40	40
1998	40	100	40	40
1999	100	60	60	60
2000	60	100	40	60
2001	100	80	40	60
2002	40	20	80	100
2003	20	20	80	100
2004	20	20	100	100
2005	20	40	100	100
2006	40	20	100	100

Wuhqgv#lq#DPR#) #QDR

Qrupdol}hg#iru#hdfk#prqwk#ryhu#43:#|hduv=

- DPR#bqglfdwhv#wzr#frrolqj#shulrgv=#4<3604<58#) #4<9804<:<
- QDR#ydoxhv#duh#poruh#hyhqo|#glvwulexwhg#

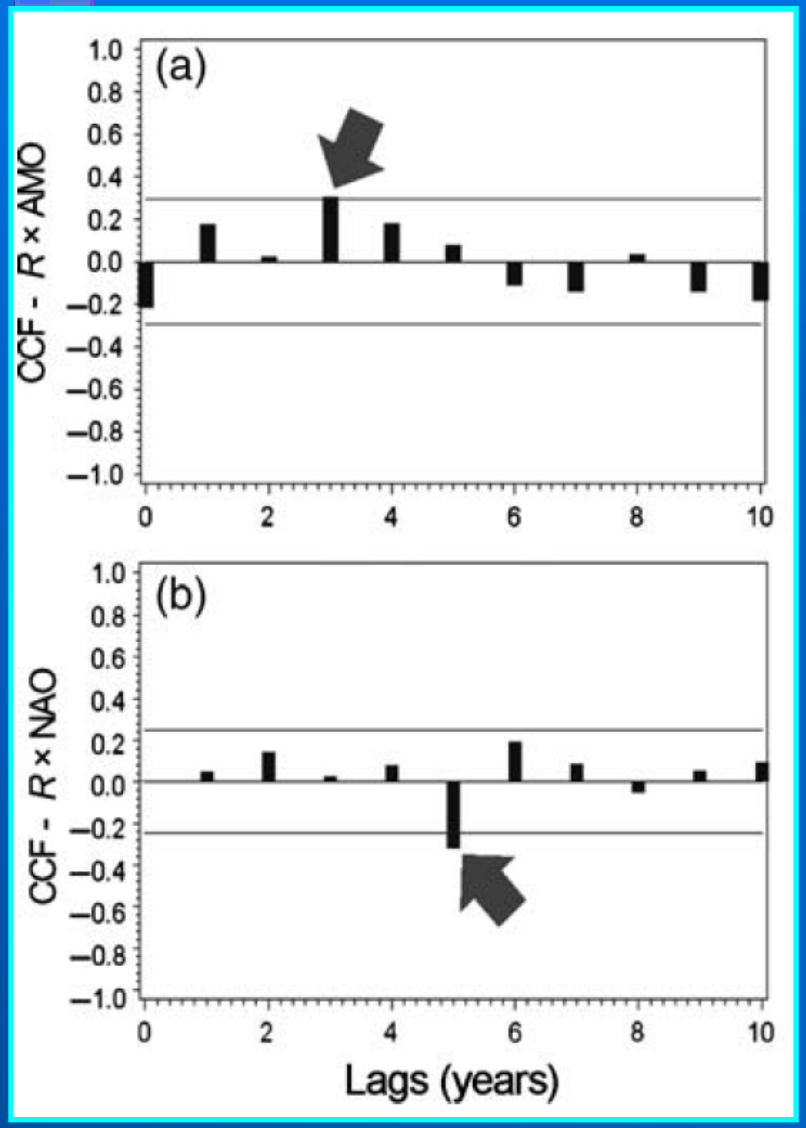


Wuhqgv#q#DPR#) #QDR

Qrupdol}hg#iru#hdfk#|hdu#dfurvv#prqwkv=

- Iq#odvw#4 ; 04 < #|hduv/#QDR#v#orzhu#q#Dxj0Qry#dqg#klj khu#q#Ghf0Ihe#

FFIv#Ehwzhhq#U#dqg#DPR#ru#QDR



Diwhu#suh0zklwhqhg#vwdwlrqdu|#wlph#vhulhv=

$CCF = Corr(R_t, NAO_{t-l})$

$CCF = Corr(R_t, AMO_{t-l})$

zkhuh=

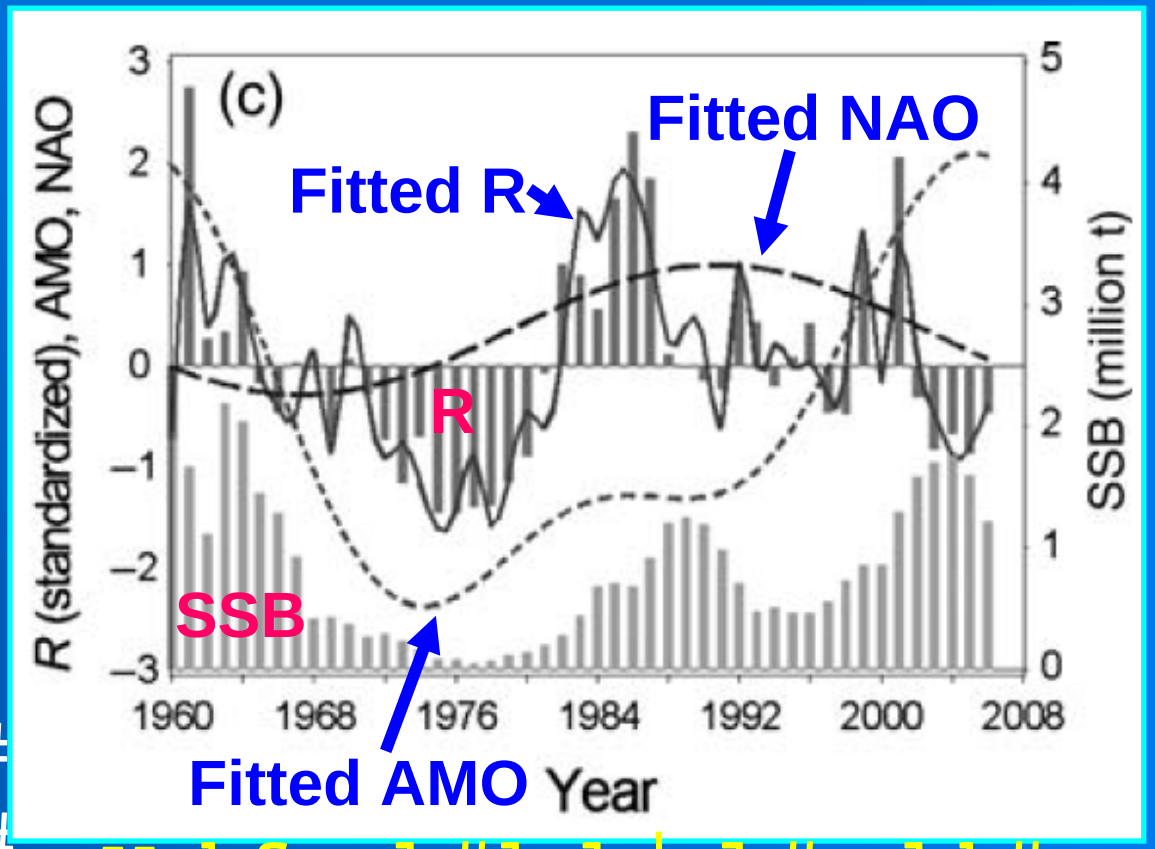
lag window: $0 \le l \le 10$

Vljqlilfdqw#hiihfwv=

- DPR#Ù 6 #|uv
- QDR#Ù 8 #|uv

Vshfwudo#Dqdo|vlv=#Ilwwhg#U

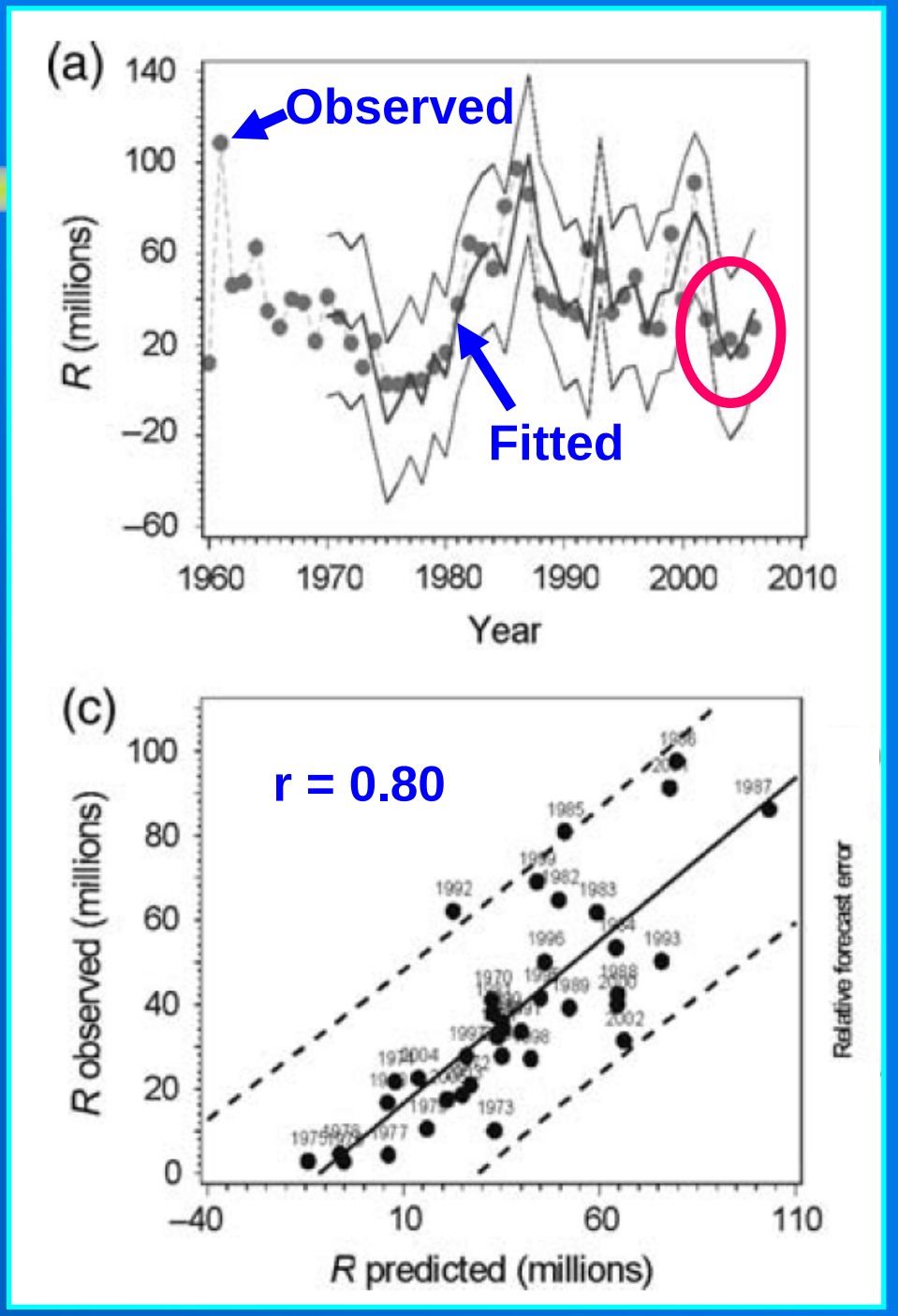
- Ilwwhg#zlqwhu#DPR#uhvhpeohv#U#ryhu#4<930 4<;4
- Ilwwhg#QDR#kdv#dq#qiohfwlrq#q#4<;5
- Ilwwhg#U#pdwfkhv#revhuyhg#U#zhoo#



Vshfwudo#dqdo|vlv#zdyh#ghfrpsrvlwlrq,#xvlqj#frvlqh0vlqh#prghov

DUIPD[

- Edvhg#rq#FFIv#60
  - |hdu0odj#DPR/#80
  - |hdu0odj#2DR,#bqg#VD
- Vwurqj#Ilw#ehwzhhq#suhglfwhg#bqg#revhuyhg#U#+S? ? 3138,
- Uhfhqw#ghfolqh#bq#U#lv#ilwwhg#



Frpsdulvrqv#Dfurvv#Doo#Prghov

(i) B/H model: $r_{\text{perfomance}} = 0.47$, AICC = 33.9607;

(ii) Ricker model: $r_{\text{perfomance}} = 0.51$, AICC = 33.9069;

(iii) Segmented regression model: $r_{\text{perfomance}} = 0.49$, AICC = 33.9384;

(iv) ARIMAX [Equation (4)]: $r_{\text{perfomance}} = 0.80$, AICC = 33.4960;

(v) Extended Ricker model [Equation (1)]: $r_{\text{perfomance}} = 0.74$, AICC = 33.7532.

- H{whqghg#Ulfnhu#prgho#shuiruphg#ehwwhu#wkdq#rwkhu#6#VW#prghov1#
- DUIPD[#prgho#shuiruphg#ehvw#lqglfdwlqj#vwurqjhu#uroh#ri#folpdwh#wkdq#VVE#rq#U1

Glvfxvvlrq=#VOU#Uhodwlrqvkls

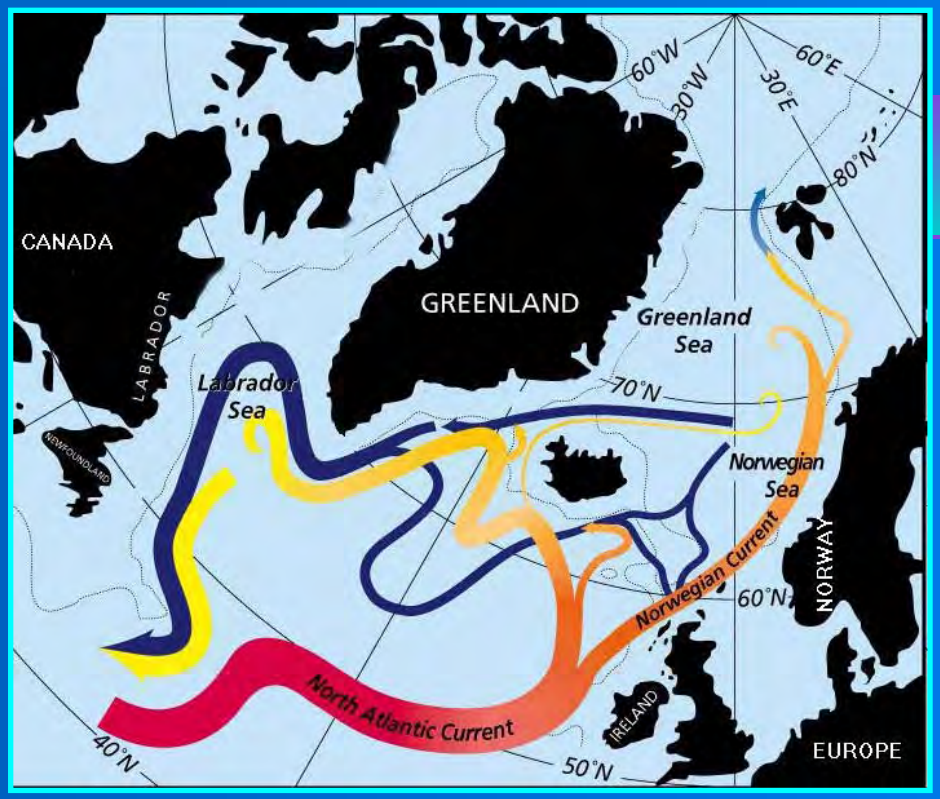
- Ryhuilvkbqj#sod|hg#d#uroh#q#srru#uhfuxlwphqw#q#4<93v#)#4<:3v
- Vrph#frqiolfwbqj#hylghqfh#ri#ghshqghqfh#ri#U#rq#VVE
- Fdqqledolvp#pd|#sduwo|#h{sodq#srru#uhfuxlwphqw#q#uhfhqw#|hduv#h1j1/#vxpphu#dfrxvwlf#vxuyh|/#533:,

Glvfxvvlrq=#Folpdwh#Iruflqj

- Dexqgdqfh#ri#hjjv#dqg#vpdoo#oduydh#ghwhuplqhg#e|#VVE
- Dexqgdqfh#ri#odujh#oduydh#dqg#uhfuxlwphqw#ghwhuplqhg#e|#zlqwhu#hqylurqphqwdo#frqglwlrqv#
- uhfuxlwphqw#f|foh#ilwwhg#zhoo#e|#DPR#=#dj#6#|u,#dqg#QDR#=#dj#8#|u,
- Wlph#djv#pd|#eh#gxh#wr#djv#lq#dwprvskhulf#Orfhdq#frxsolqj dqg#wurskli#lqwhudfwlrqv

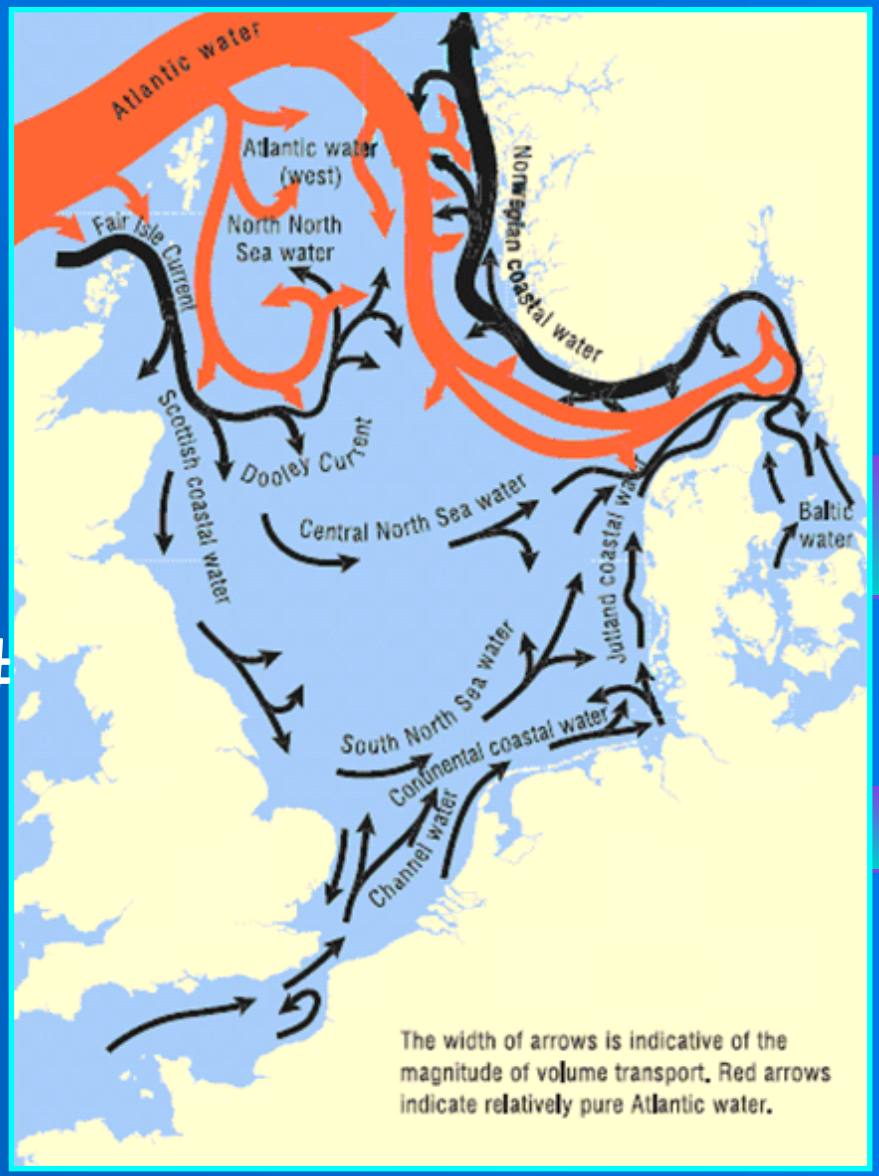
Glvfxvvlrq=#Srwhqwldo#Phfkdqlvpv

- Ghfd|#vfdoh#ri#wkh#Qruwk#Dwodqwlf# Fxuuhqw#lq#uhvsrqvh#wr#fkdqjhv#lq# zhvwhuo|#zlqg#vwuhvv#lv#6#|hduv# +Slqjuhh#5338,



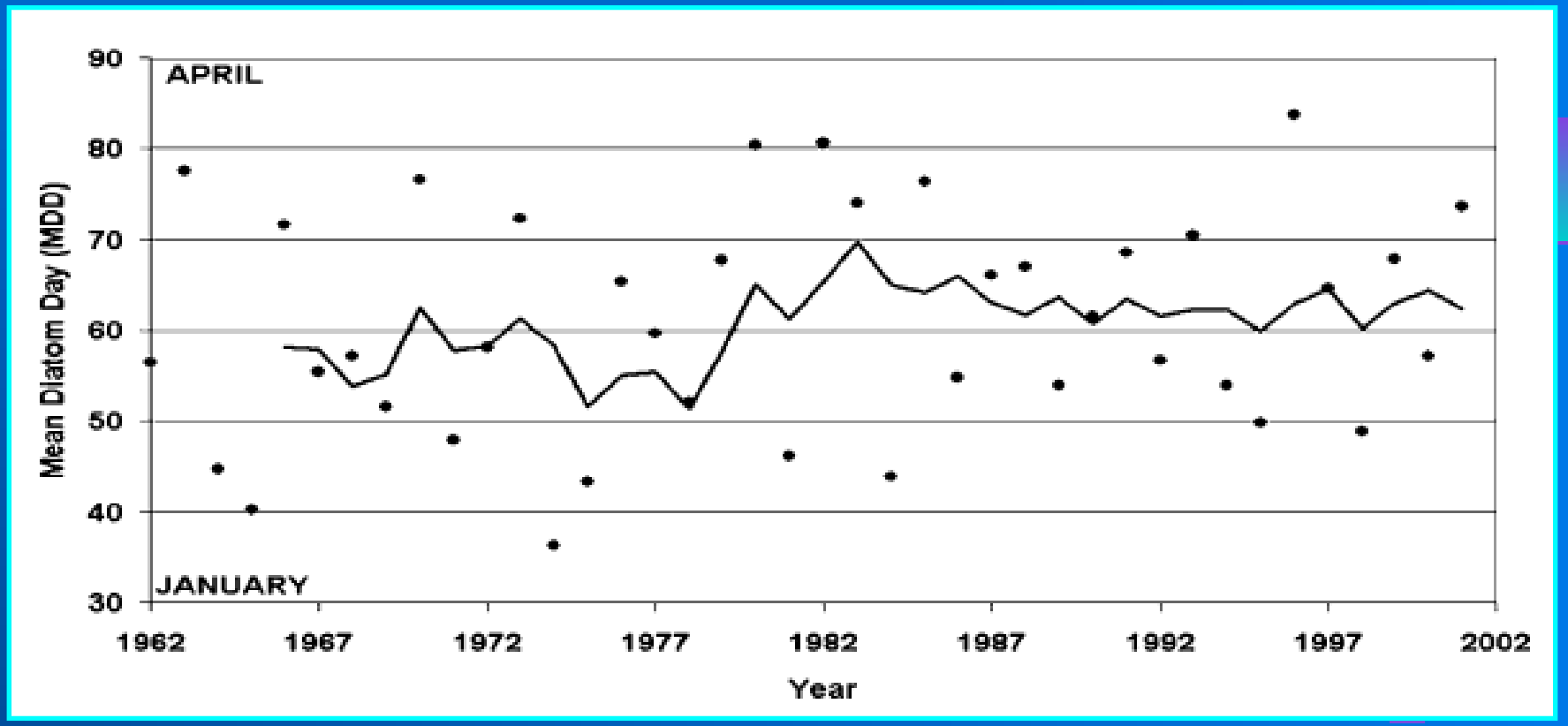
Qruwk#Vhd#Rfhdq#Fxuuhqwv

- QZ#hqwu|#ri#Dwodqwlf#zdwhu
- Vrph#zdup#zdwhu#iorz#wkurxjk#Hqjolvk#Fkdqqho
- Zdwhu#h{lwv#dorqj#Qruzhjbq#frdvw
- Orz#vdolqlw|#frdvwdo#zdwhu



Glvfxvvlrq=#Srwhqwldo#Phfkdqlvpv

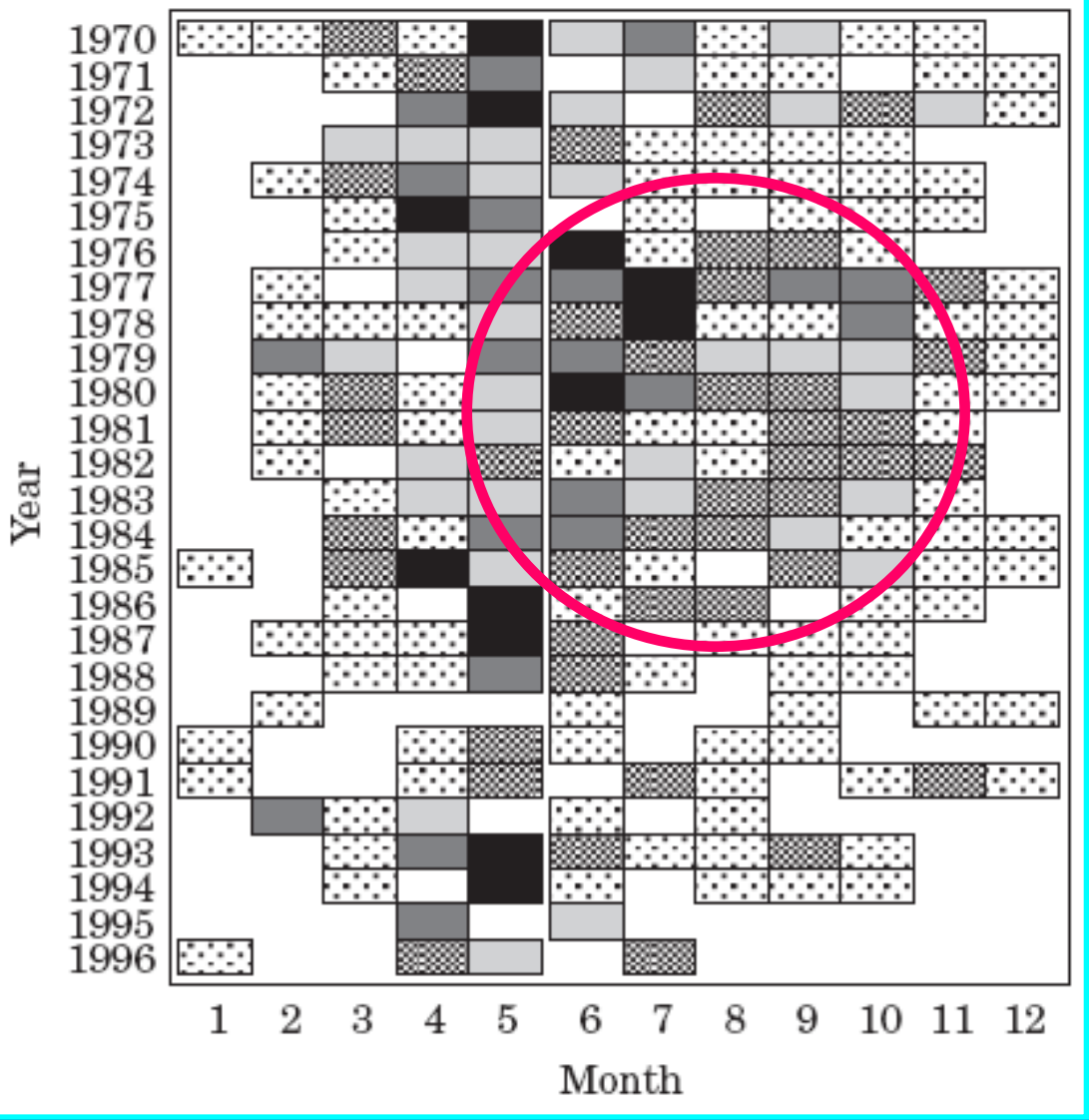
- ghod|#ri#vsubj#eorrp#uhodwhg#wr#zduphu#VVW#Zbwvkluh#)#Pdqo|#5337,



Glvfxvvlrq=#Srwhqwldo#Phfkdqlvpv

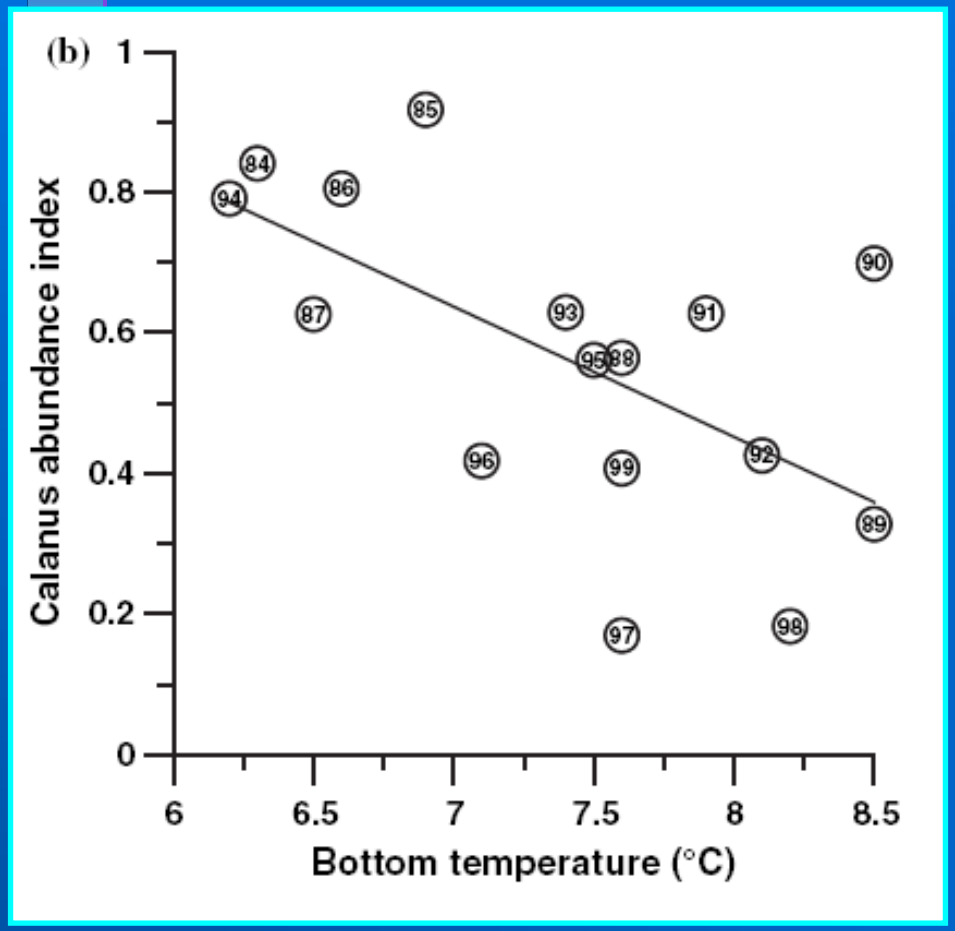
- *Svhxgrfdodqxv#plqlwxv* dqg#*Fdodqxv# ilqpdufklfxv* frpsulvh#pruh#wkdq#wzr# wklugv#ri#wkh#khuulqj#glhw

Glvfxvvlrq=#Srwhqwldo#Phfkdqlvpv



- Ghod|hg# khuulqj# pljudwlrq#iurp# hdvw#q#hduo|# 4<;3v
- Ydulhelw|#q# Wplqj#ri#*F1# ilqpdufklixv*q# QH#Qruwk#Vhd# +Fruwhq#5333,

Glvfxvvlrq=#Srwhqwldo#Phfkdqlvpv



Nash & Dickey-Colas (2005)

- dexqgdqfh#ri#*Fdodqxv#ilqpdufklfxv*lq#QH#Qruwk#Vhd#qhjdwlyho|#dvvrfldwhg#zlwk#erwwrp#whpshudwxuh

Glvfxvvlrq=#Srwhqwldo#Phfkdqlvpv

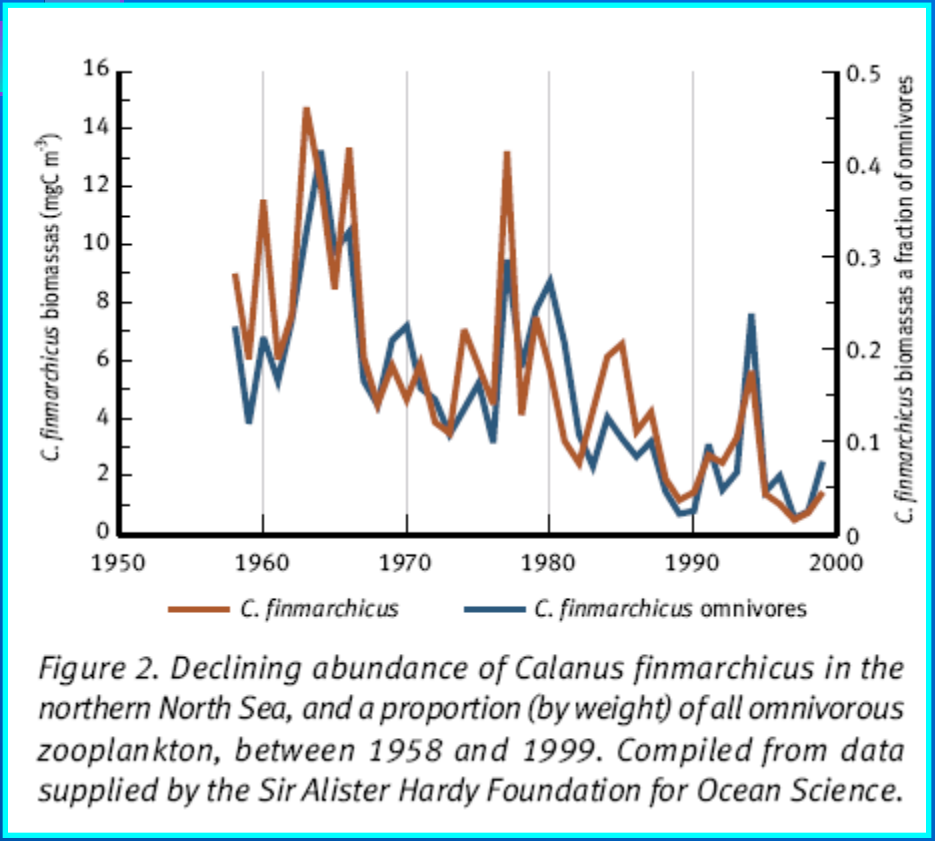


Figure 2. Declining abundance of Calanus finmarchicus in the northern North Sea, and a proportion (by weight) of all omnivorous zooplankton, between 1958 and 1999. Compiled from data supplied by the Sir Alister Hardy Foundation for Ocean Science.

Heath et al. (1999)

- dexqgdqfh#ri#*Fdodqxv#ilqpdufklfxv*#dvvrfldwhg#zlwk#QDR
- ghshqgv#rq#vxsso|#ri#ryhuzlqwhulqj#*F1#ilqpdufklfxv*#yv#Qruzhjldq#Vhd#Ghhs#Zdwhu

Frqfoxvlrqv

- Folpdwh#odujho|#uhjxodwhv#khuulqj#srsxodwlrqv#lq#wkh#Qruwk#Vhd
- Folpdwh0gulyhq#phfkdqlvpv#lqyroyh#erwwrp0xs#wurskf#hiihfw
- Dowkrxjk#wkh#ehvw#prgho#grhv#qrw#lqfrusrudwh#VVE/#ryhuilvklqj#pxvw#eh#dyrlghg
- Uhfuxlwphqw#iruhfdvw#6#|hduv#lq#dgydqfh#surylgh#ydoxh#lqirupdwlrq#wr#pdqdjhphqw#ri#wklv#psruwdqw#ilvkhu|