



## Sigurd Tjelmeland

Long-term optimal exploitation of  
cod and capelin in the Barents Sea  
using the Bifrost model

Долгосрочный оптимальный эксплуатация треска и мойва с  
модел Bifrost

Norwegian-Russian symposium, Murmansk,  
August 2005

# Bifrost – Long time of development

Долгосрочный развитие

- 1980s – CAPELIN, optimal exploitation of capelin, single-species - Мойва
- 1990s – MULTISPEC, cod preying on pre-spawning capelin -Треска - мойва
- 2000s – BIFROST, capelin-cod model with influence from herring - треска – мойва - селд

At any time connected to practical management in  
the Barents Sea

Всегда управление

# Present tool

Настоящий инструмент

SeaStar  
historic

Bifrost

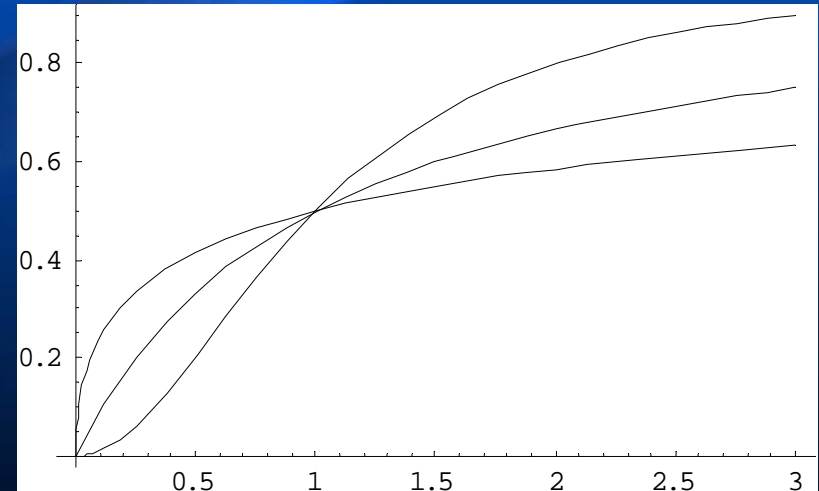
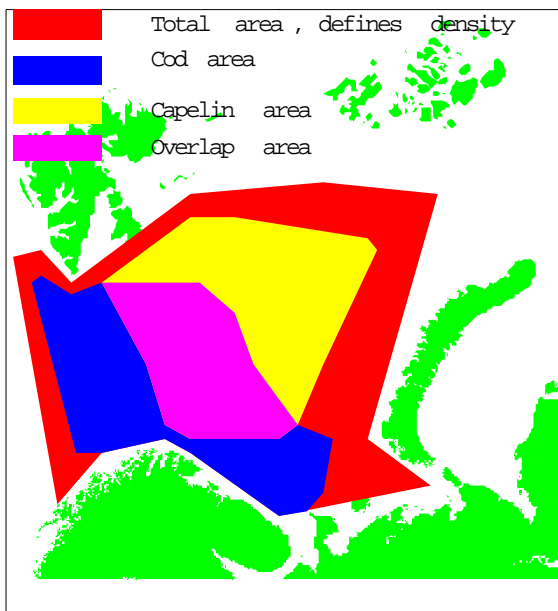
SeaStar  
prognostic

Herring  
historic  
replicates

# Predation by cod

- Key variables
  - partOfCodOverlappingCapelin
  - partOfCapelinOverlappedByCod
  - capelinFood
  - codFood
  - otherFood

$$\frac{\text{abundance}^k}{\text{constant}^k + \text{abundance}^k}$$



# Estimation of parameters

## Оценка параметров

- Estimation in two stages
  - Each historic run is a 10-stage iteration for calculation of residual mortality of capelin and recruits (0 years) of cod
  - Simultaneous maximum likelihood estimation of all other parameters

L  $d_{0s}$   $r$   $I_{cap}$   $d_{0s_{cap}}$   $r$   $I_{cons}$   $d_{0s_{cons}}$   $r$

Capelin: 4 year old 1973-1980

Consumption: From 1984, by quarter, cod, capelin, other

# Calculation of consumption

## Оценка потребление

- Consumption per cod – Exogeneous, replicate file
  - Laboratory evacuation rates
  - Station temperatures
  - Stomach content data
  - Bifrost swept area estimate of cod on Multspec areas
    - February and August
    - Age
    - Maturation
- Consumption by cod – During Bifrost estimation
  - AFWG assessment
    - Alternative: SeaStar, which gives uncertainty

# One year simulation

$$\mathbf{B}_{i+1} = T^9 S T^3 \mathcal{R} \mathcal{A} T^3 \mathcal{M}_{\text{cap}} \mathbf{B}_i = \mathcal{Y} \mathbf{B}_i$$

# Weight at age of cod

Вес трески

Model: linear function of capelin consumption, for biomass > 0.6 million tonnes also function of biomass

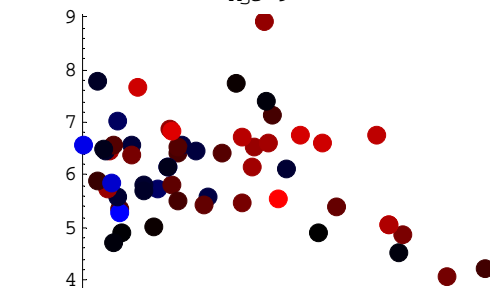
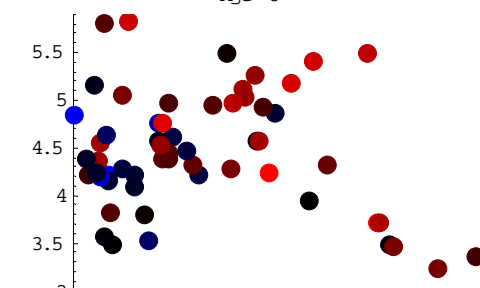
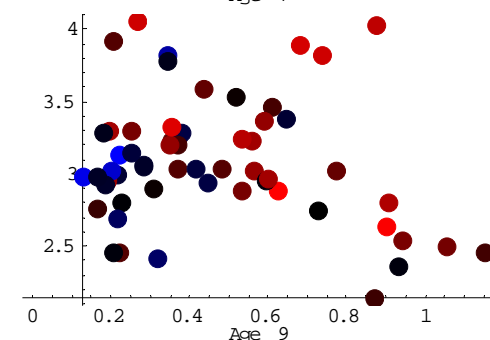
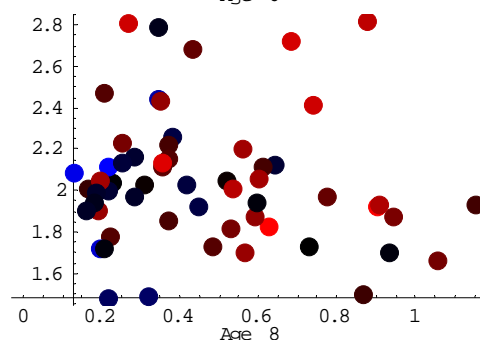
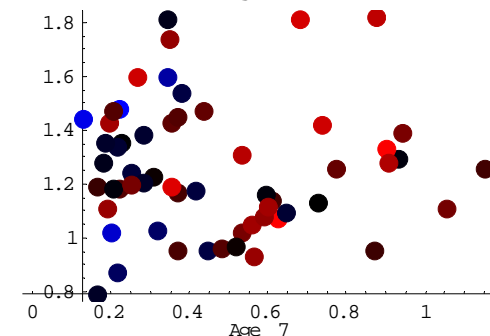
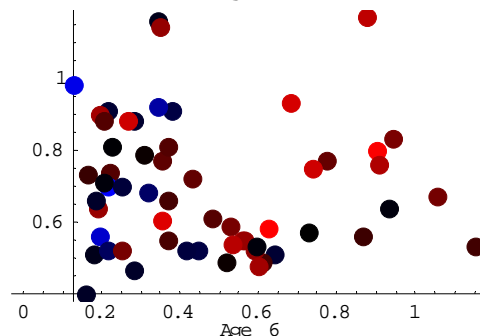
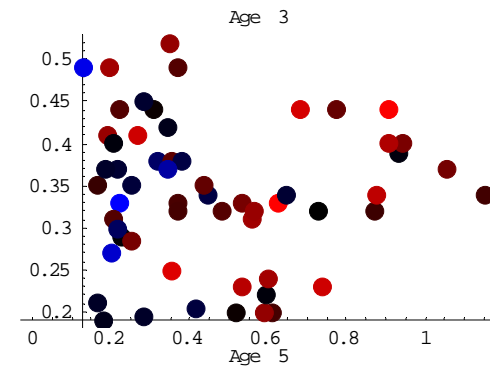
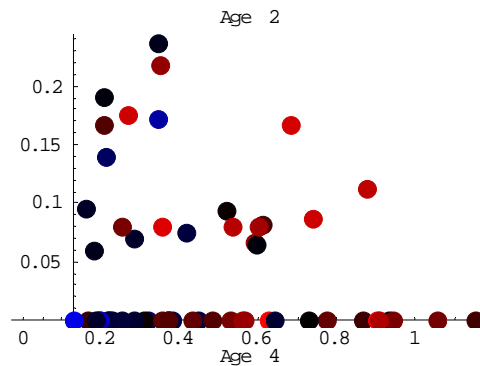
Модел:

-потребление

МОИВЫ

-биомасс трески

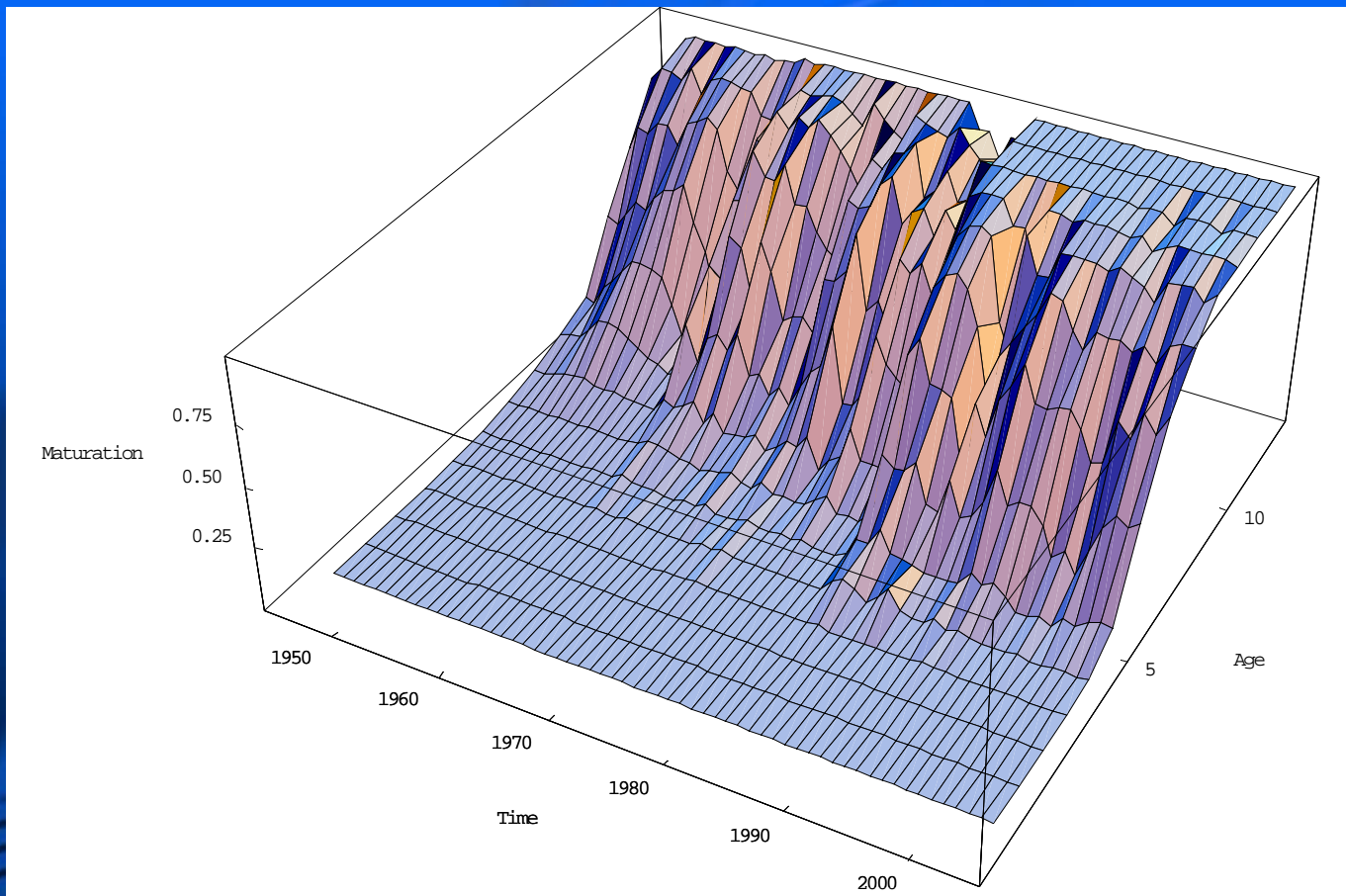
Weight at age vs cod SSB the year before  
Coloured according to temperature year before



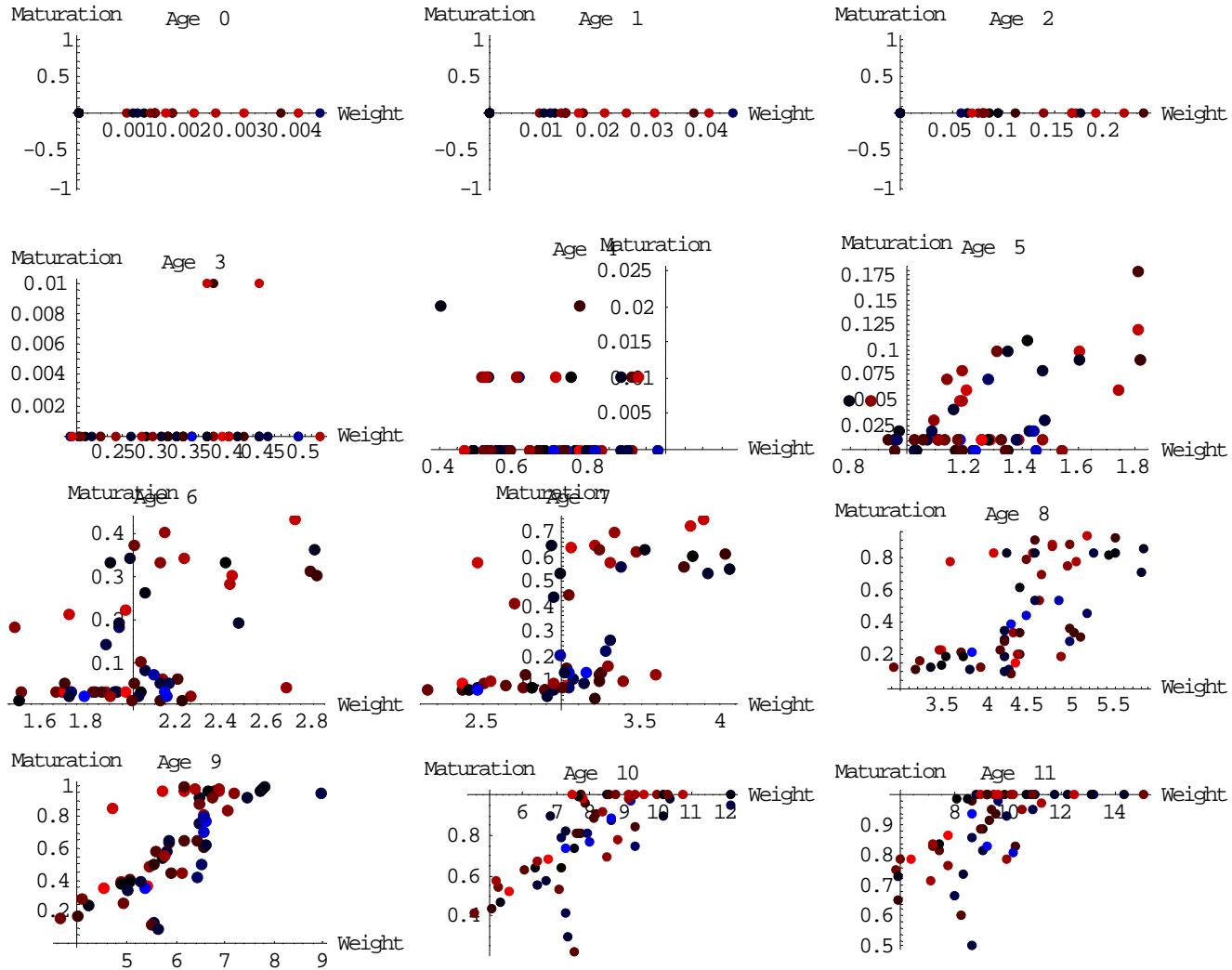


# Proportion mature at age for cod

Нерест трески



# Proportion mature at age for cod



Model: linear function of biomass, temperature and individual weight

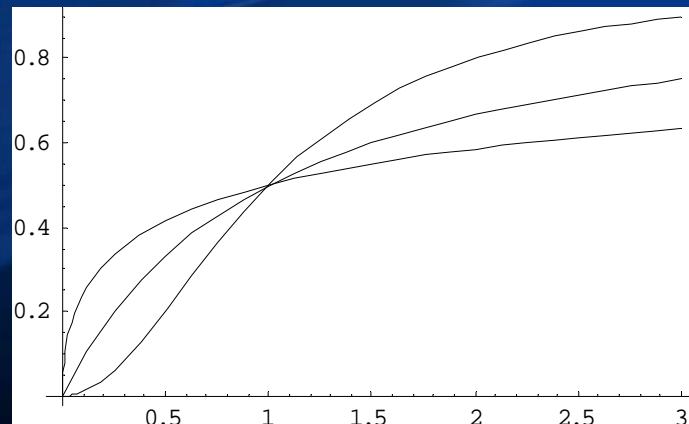
# Recruitment cod - model

Пополнение трески

$\text{codMaxRec} e^{\text{codTemp temp} + \text{meanWeightPar meanWeight} + \text{meanAgePar meanAge}}$

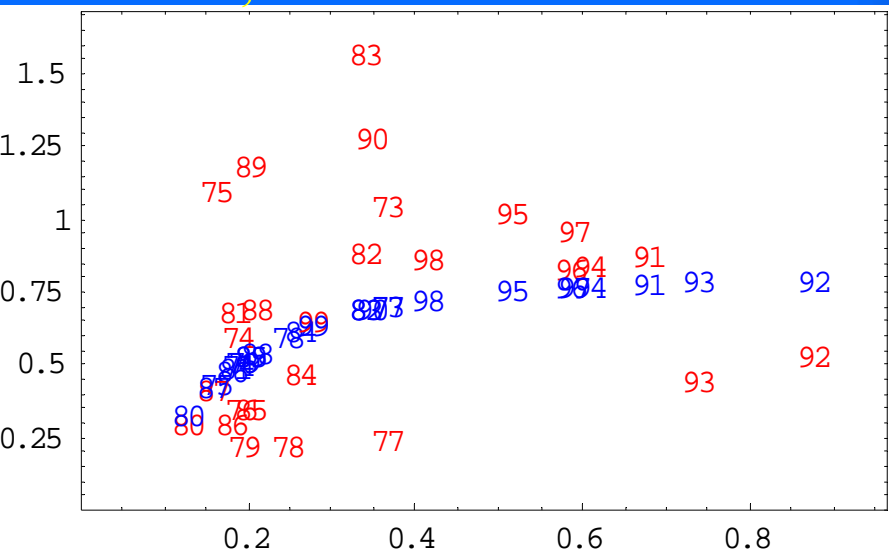
$$\text{SSB}^{\text{codExpRec}}$$
$$\text{codHalf}^{\text{codExpRec}} + \text{SSB}^{\text{codExpRec}}$$

temp: Mean of August-October

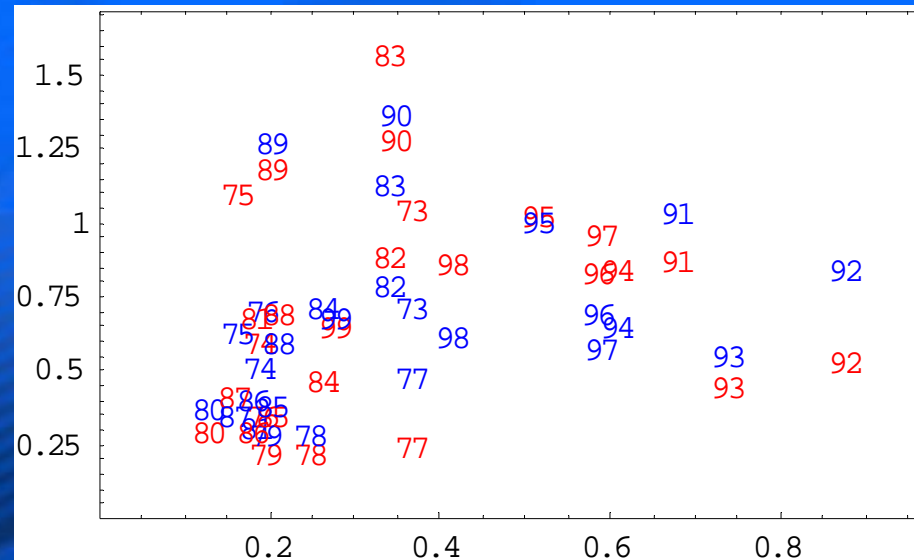


# Recruitment cod - results

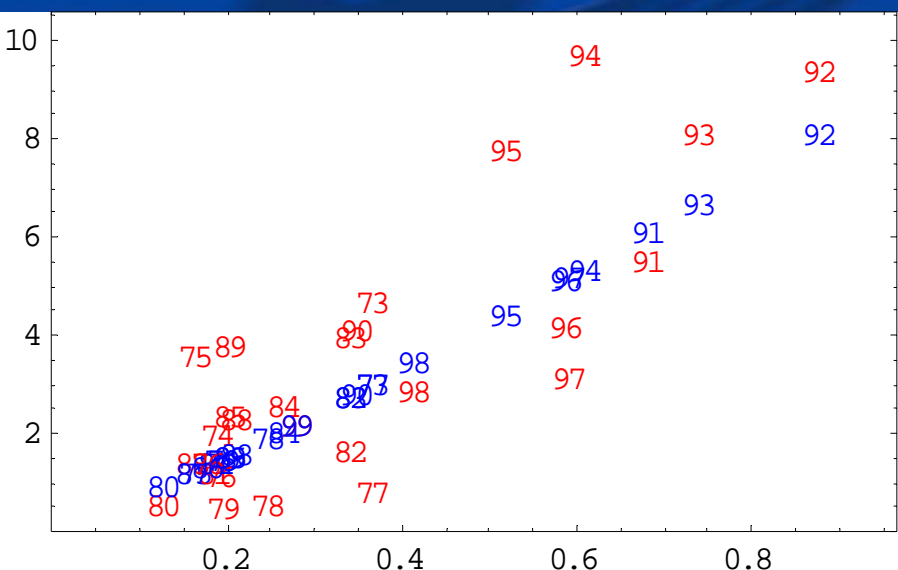
Basic,  $R^2 = 0.17$



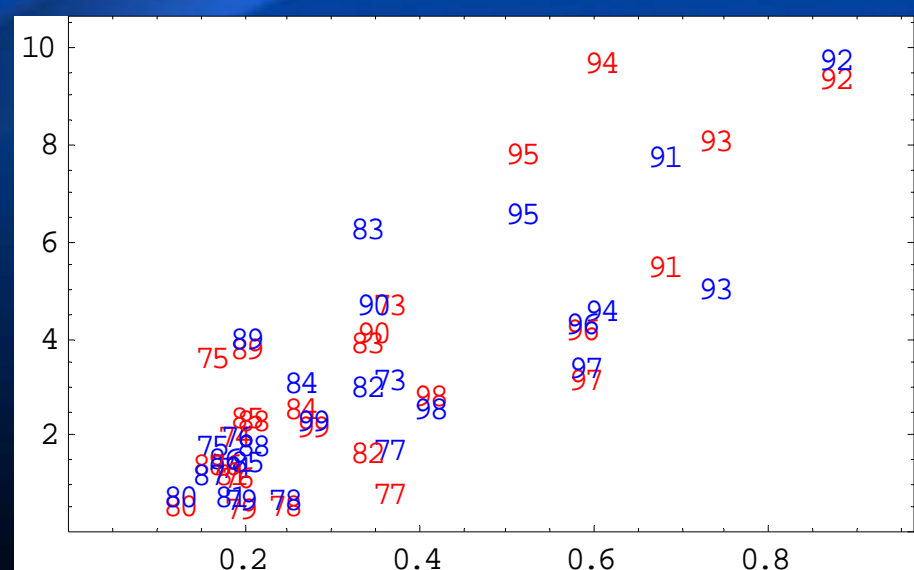
Env.++  $R^2 = 0.59$



Cannibalism,  $R^2 = 0.50$



Env.++ and cannibalism,  $R^2 = 0.78$



# Recruitment capelin - model

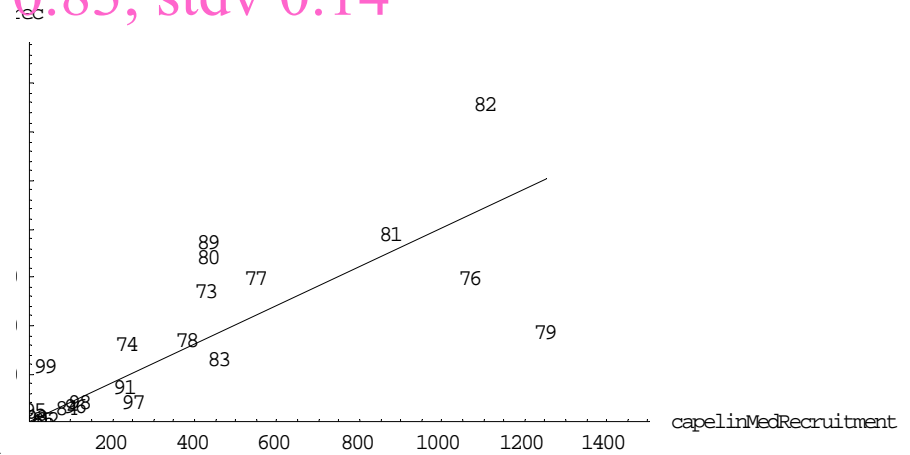
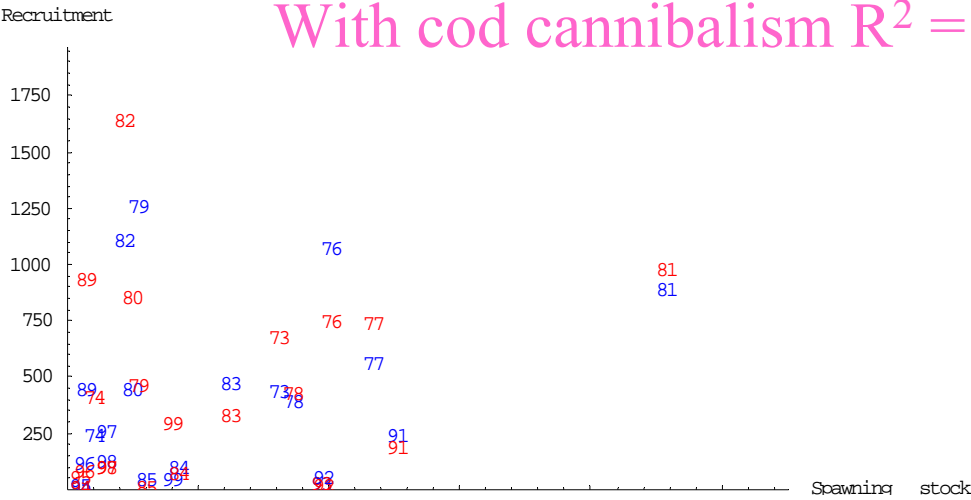
$$\text{capMax} \tilde{a}^{\text{capTemp}} \frac{\text{tempdiff}}{\text{capHalf} + \text{capPred} + \text{SSB}}$$

$$\text{capPred} = \text{capHerProp} \frac{\text{herring}}{\text{herring} + \text{capHerOffset}} \frac{\text{capHerExp}}{\text{capHerExp} + \text{capCodProp}} \text{zeroCod} + \text{capCapProp} \text{capelin}$$

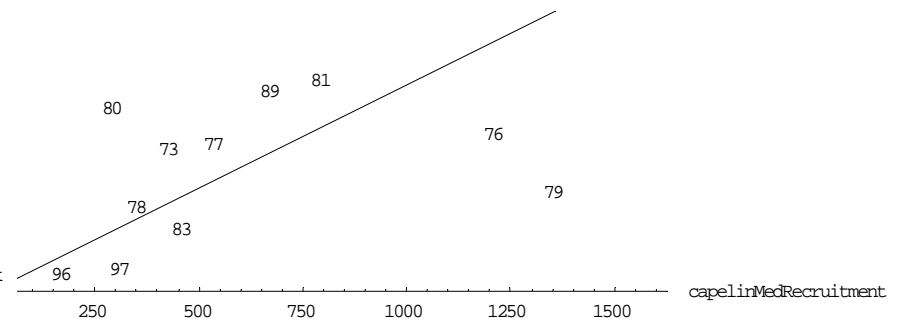
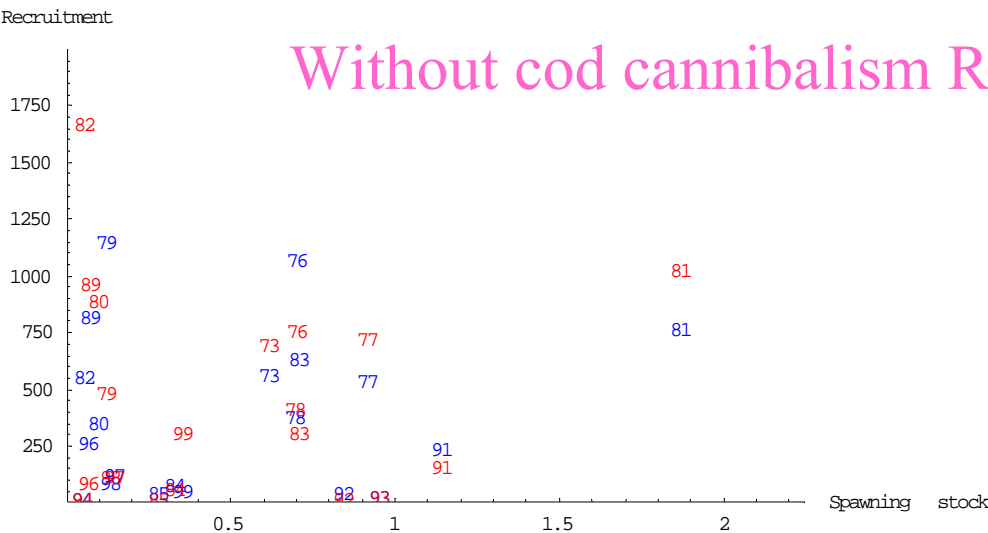
tempdiff: Difference between mean temperature during August-December and mean temperature during January-April

# Recruitment capelin - results

With cod cannibalism  $R^2 = 0.83$ , stdv 0.14



Without cod cannibalism  $R^2 = 0.78$ , stdv 0.07



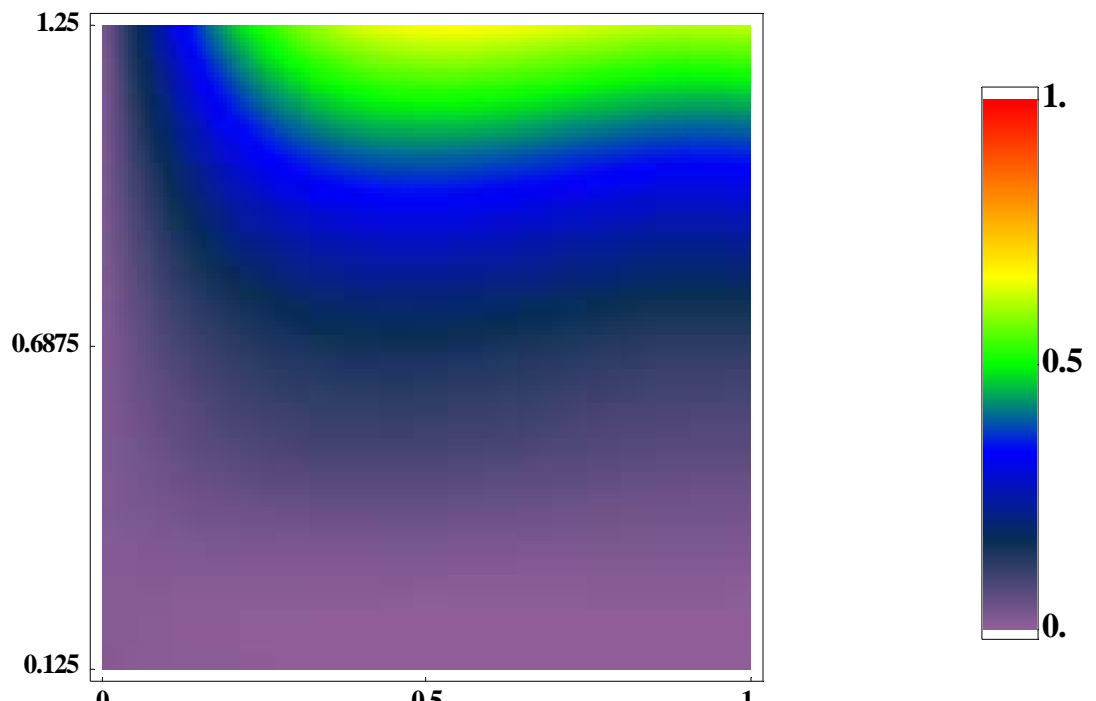
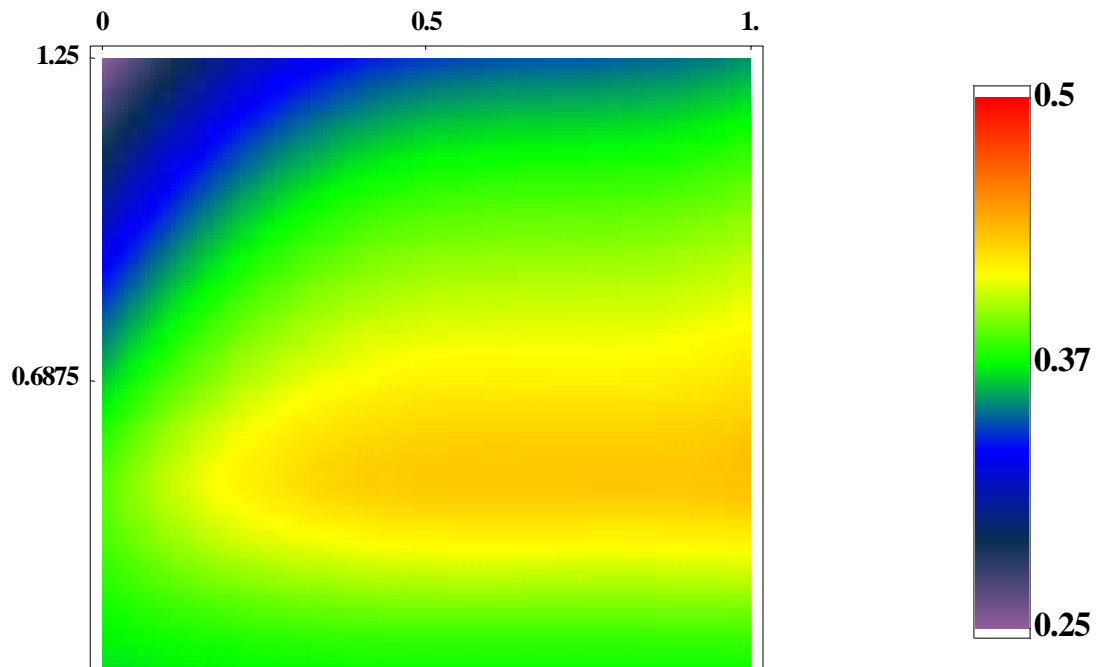
# Evaluating HCRs

- HCR – 3-species management rule
- In simple models, HCR can be evaluated analytically
- In complex models with uncertainty we must instead do long-term simulations
- 150 years, first 50 discarded
- Modelled components
  - Recruitment all species
  - Weight and maturation cod
- Components drawn from historic data
  - Residual mortality of capelin
  - Weight and maturation at age of capelin
- Constant components
  - M of adult cod and of herring
  - Other food

Yield of cod

$$F_{\text{herring}} = 0.125$$

Yield of capelin



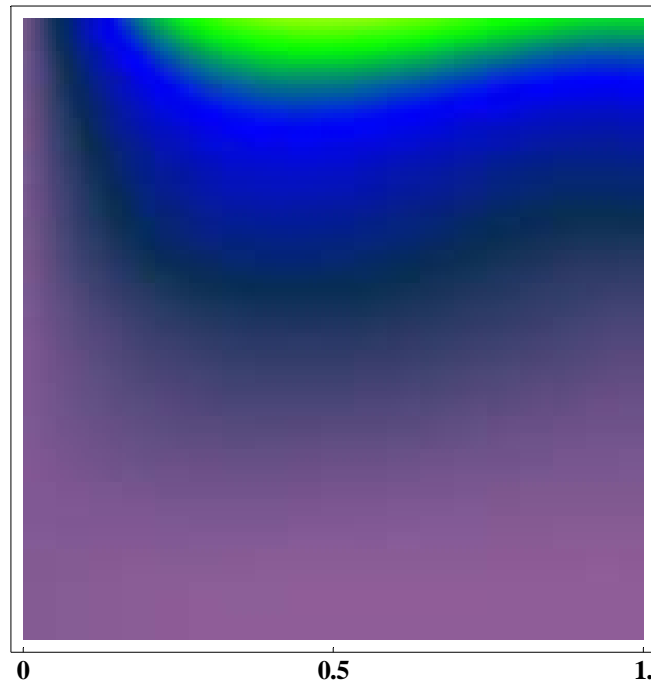
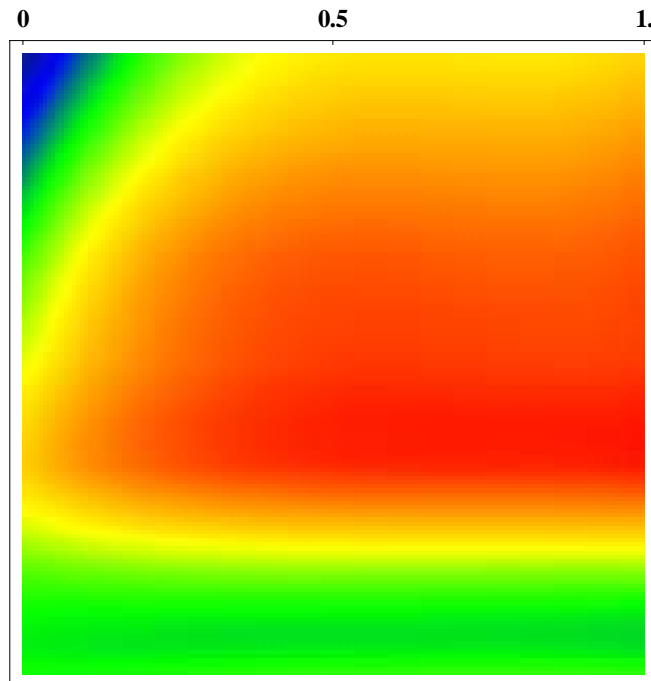


Yield of cod

5% increase of  
temperature

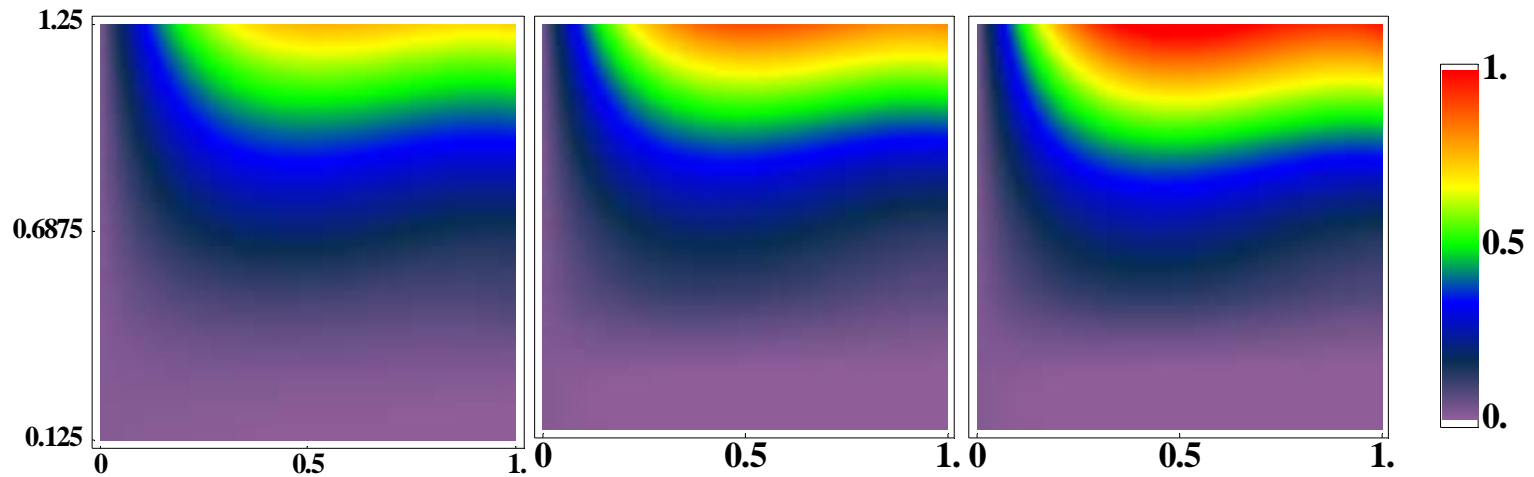
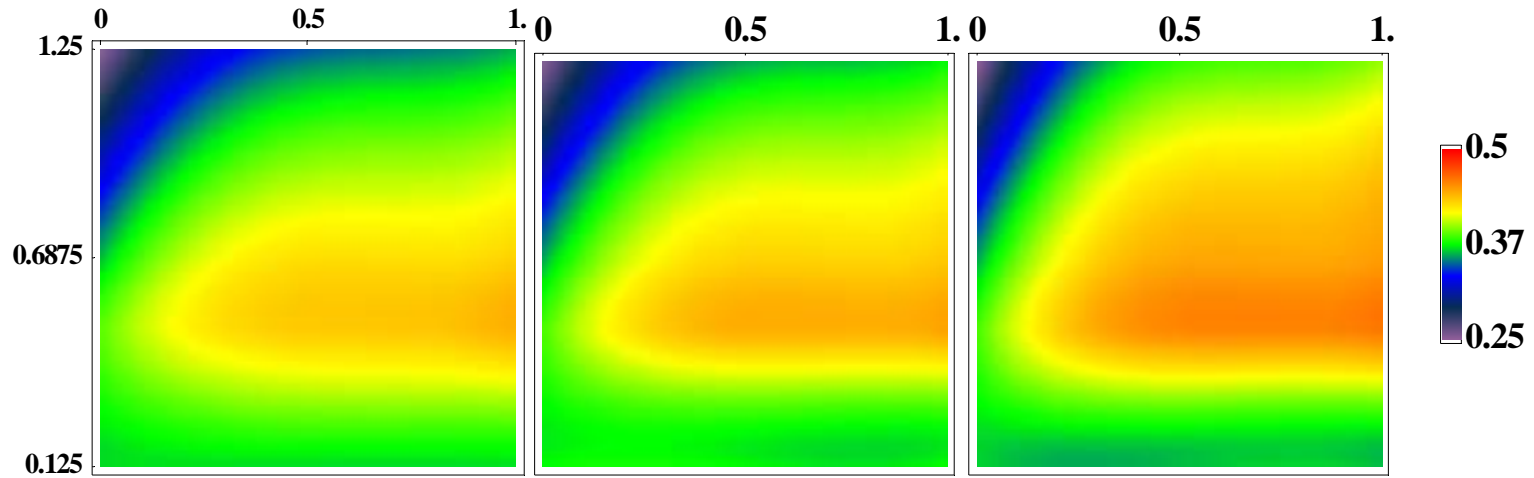
$$F_{\text{herring}} = 0.125$$

Yield of capelin

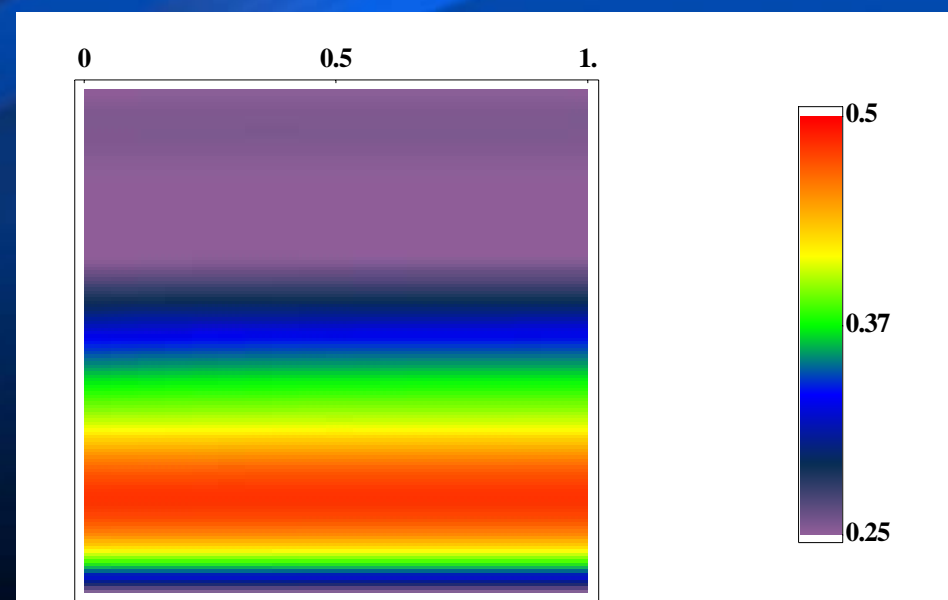
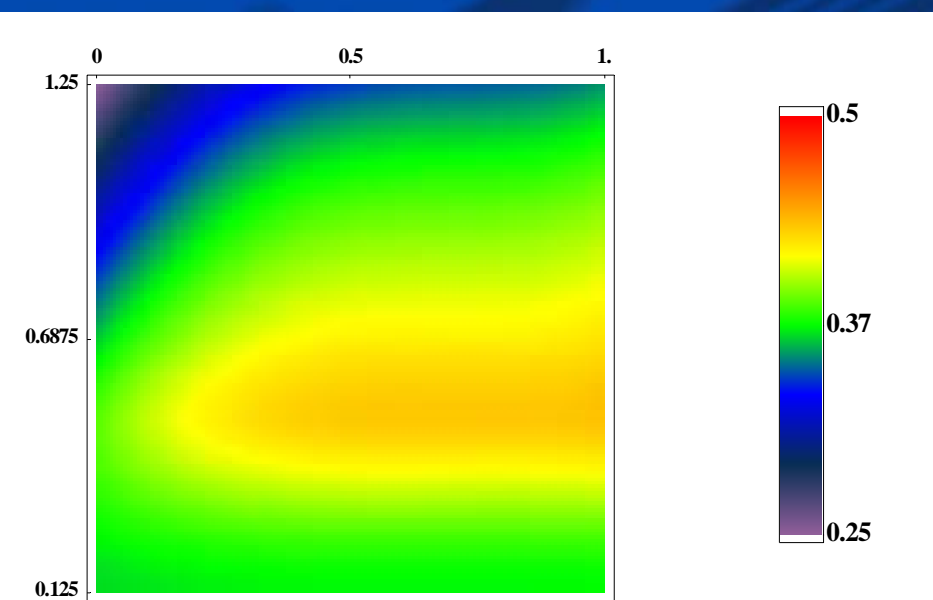
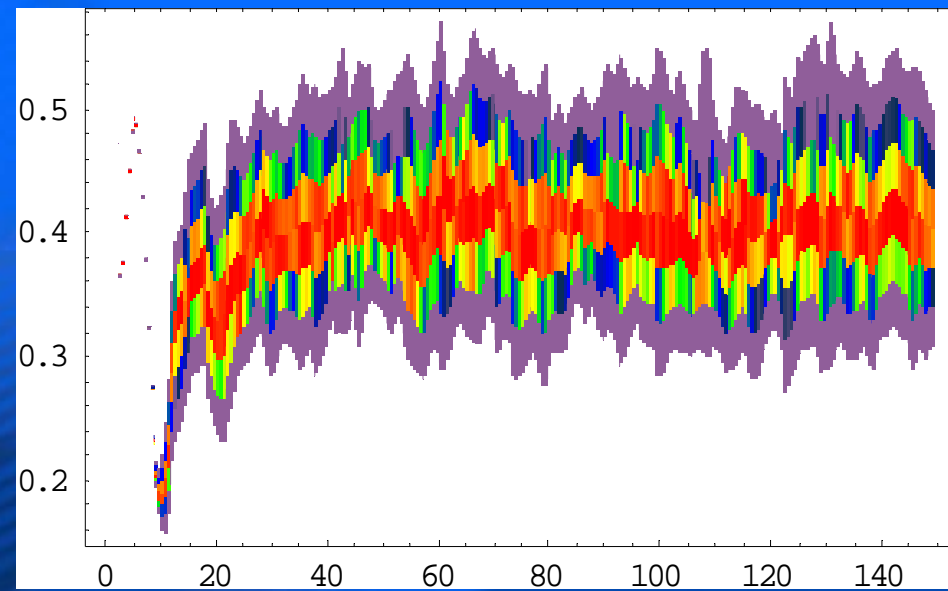
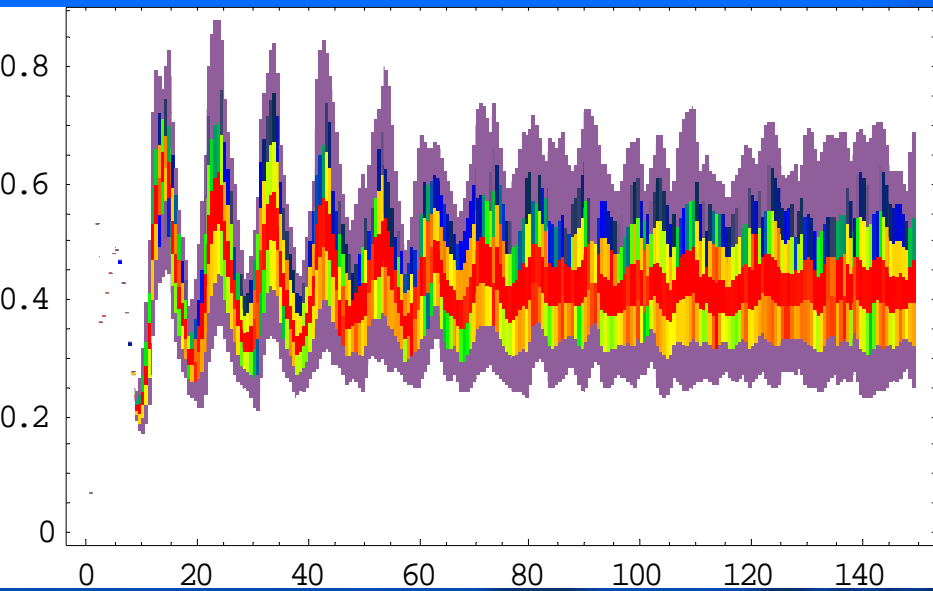


Fherring = 0.125    Fherring = 0.20    Fherring = 0.30

Yield herring = 0.81    Yield herring = 0.73    Yield herring = 0.46



# Effect of cannibalism



# Conclusions

- Strong cod-capelin interaction through cannibalism of cod
- Optimal F-value for cod is lower than present F-value, recruitment relation and cannibalism taken into account
- Strongly reduced yield of capelin when F for cod is reduced
- Increased yield of cod if future temperature is higher, optimal F-value remains the same

# Including predation by mammals – a fundamental problem

- The cod stock assessment is done using a constant  $M$
- The marine mammals generate a variable  $M$
- Compatibility only if marine mammals are included into the assessment
- A pilot project: Minke whales and herring (SeaStar)
- Hotspot: Harp seal, poor diet data

# Problem areas

- Exchange of data
  - Temperature by station
  - Qualitative stomach content data
- Data shortage
  - Harp seal diet data
  - Whale data – except minke whales
- Conceptual
  - Managing multispecies fishery, economic objectives

# Bifrost and request from Commission

- Commission: Evaluate long-time yield of cod, taking into account species interactions and influence from environment
- Bifrost can do this, but also other models
- Need to know processes better
- Response from IMR and PINRO: 10-year project
  - First 3 years – pragmatic
  - Last 7 years – multispecies models
- Other multispecies models as useful as Bifrost (STOCOBAR) – needs testing

# Let's get together and be all right (Marley)

- Effectiveness
- Trust
- Mutual acceptance



## **EKSEMPEL PÅ OVERSKRIFT**

**Eksempel på tekst**

- Bruk gjerne fonten Arial (fet)  
ved bruk av variant mørkeblå bunn**