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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

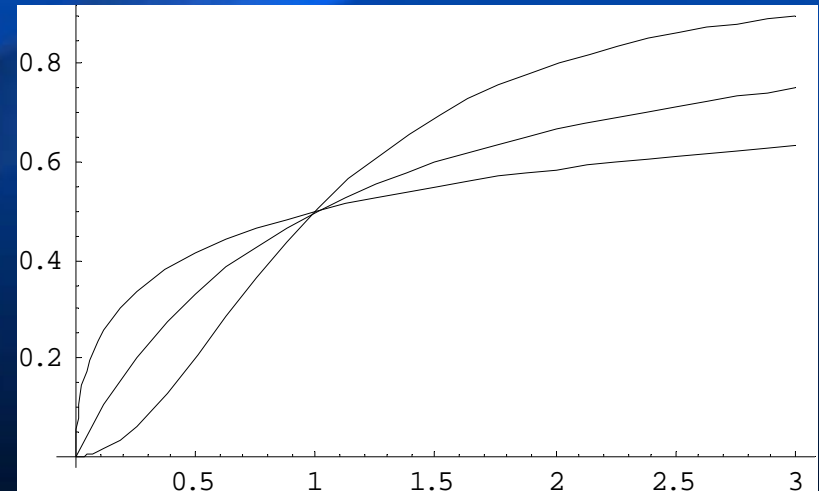
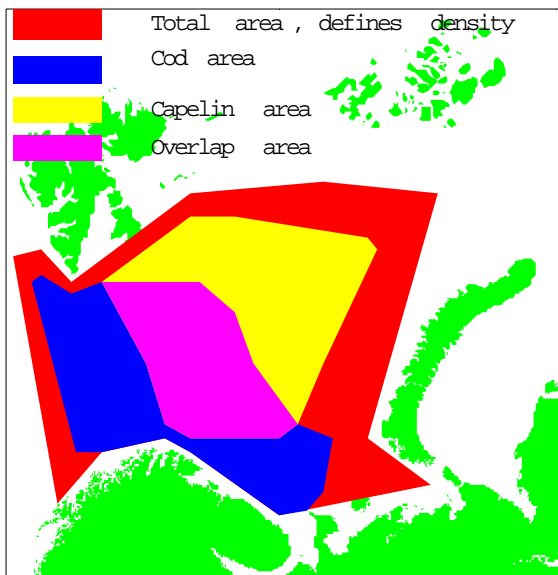
SeaStar
prognostic

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 obs par obs_{cap} par_{cap} obs_{cons} par_{cons} par

Capelin: 4 year old 1973-1980

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

Calculation of consumption

Оценка потребления

- 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

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

Weight at age of cod

Вес трески

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

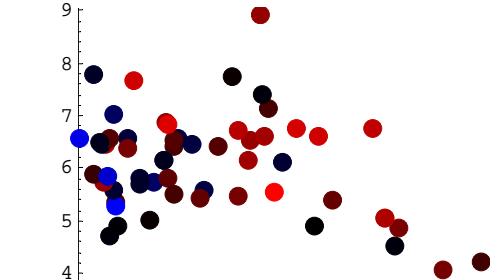
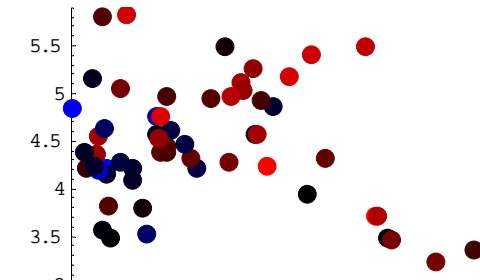
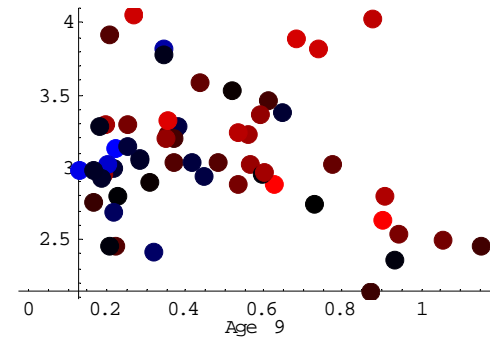
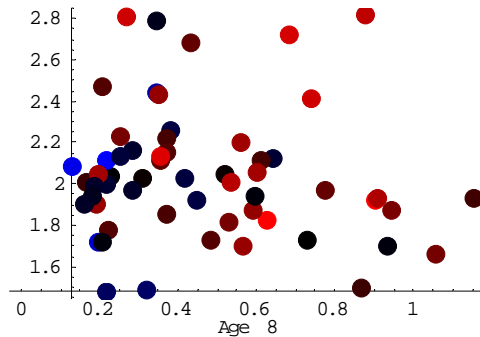
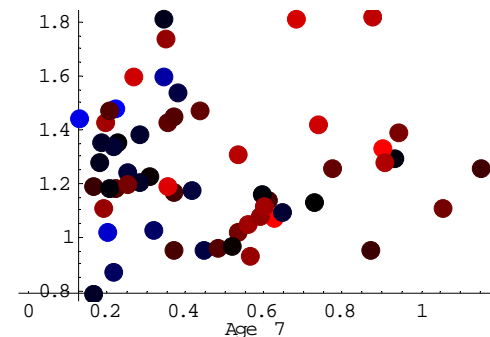
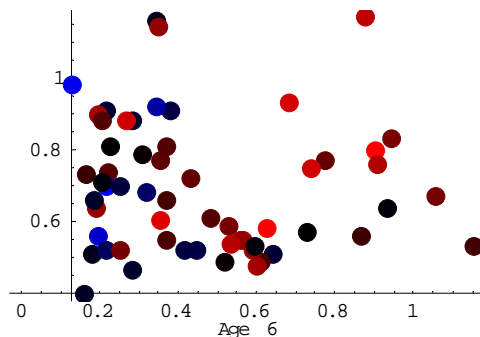
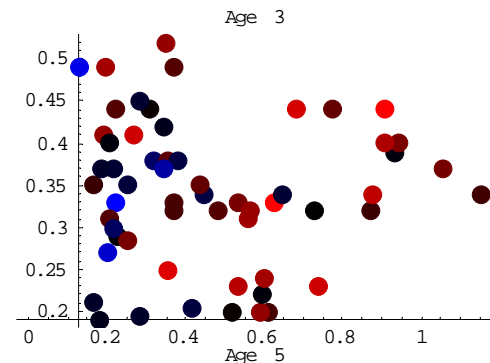
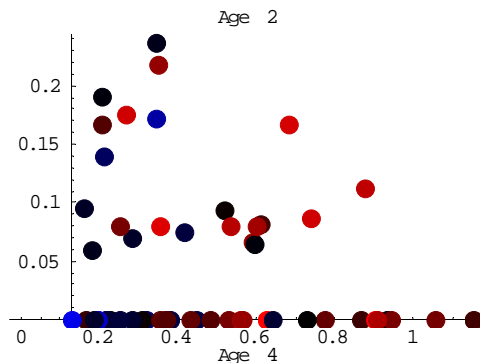
Модел:

-потребление

МОИВЫ

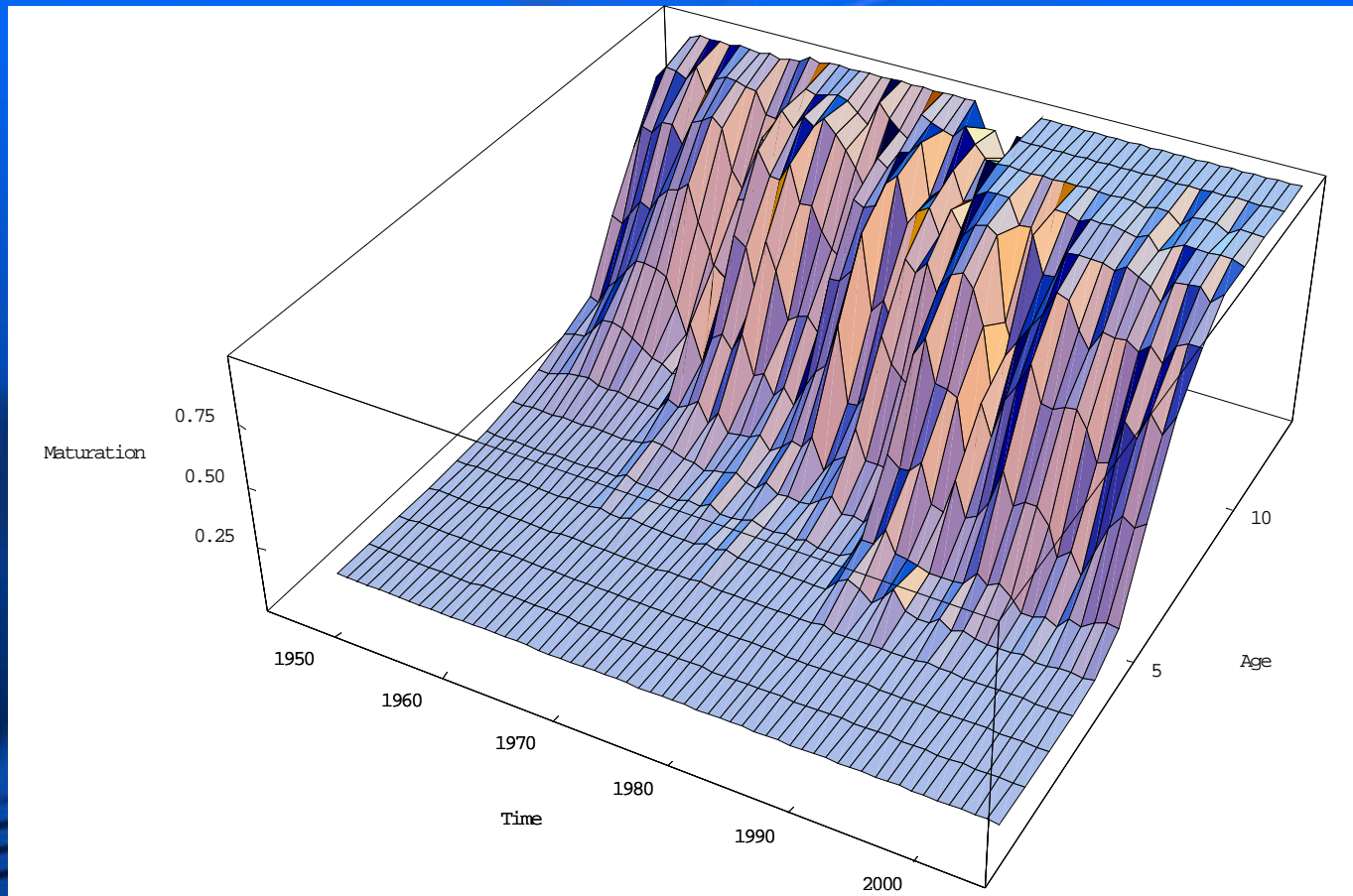
-биомасс трески

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

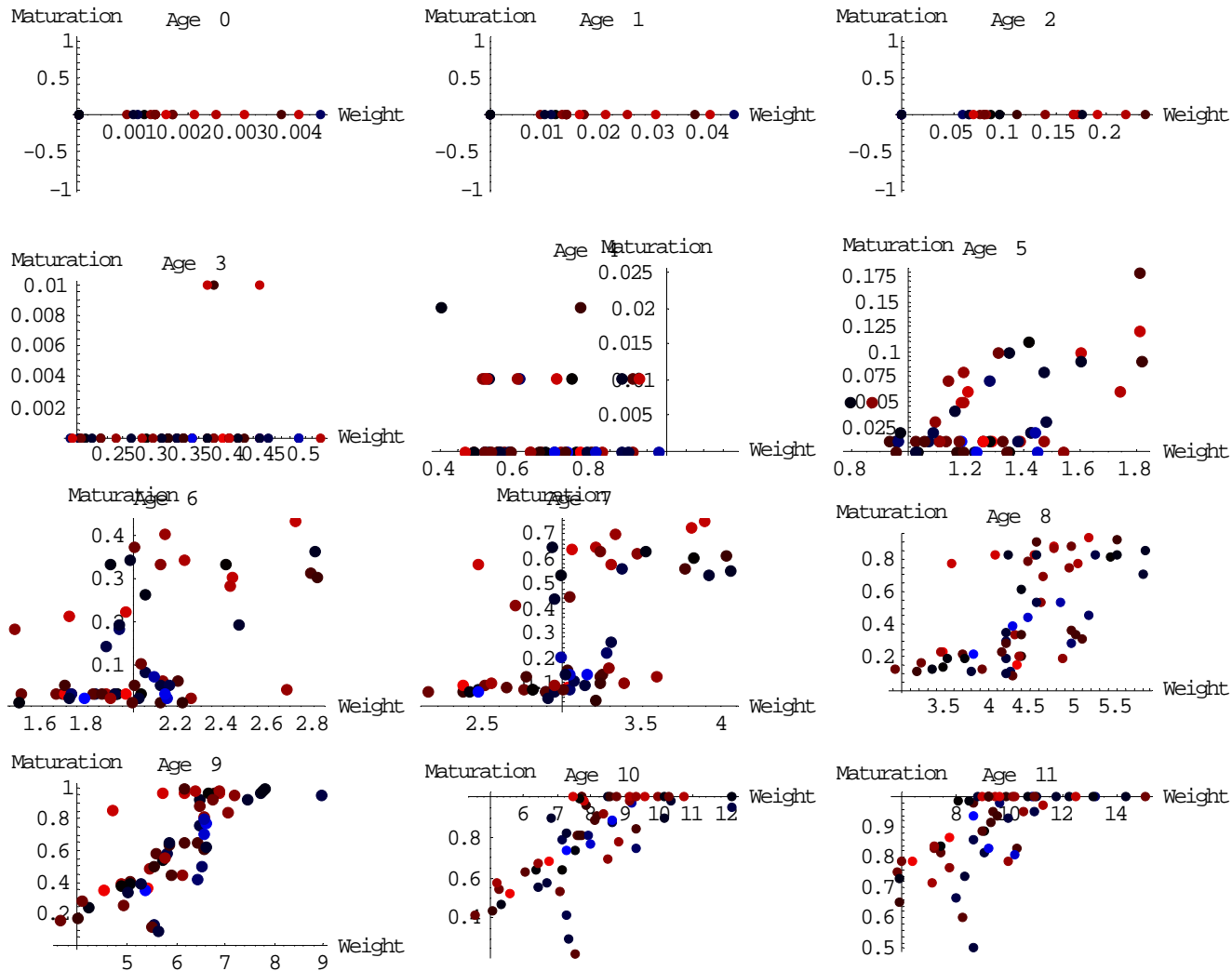


Proportion mature at age for cod

Нерест трески



Proportion mature at age for cod



Model: linear function of biomass, temperature and individual weight

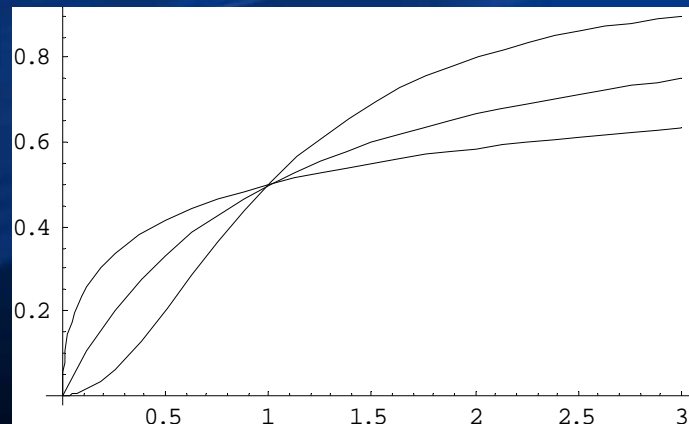
Recruitment cod - model

Пополнение трески

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

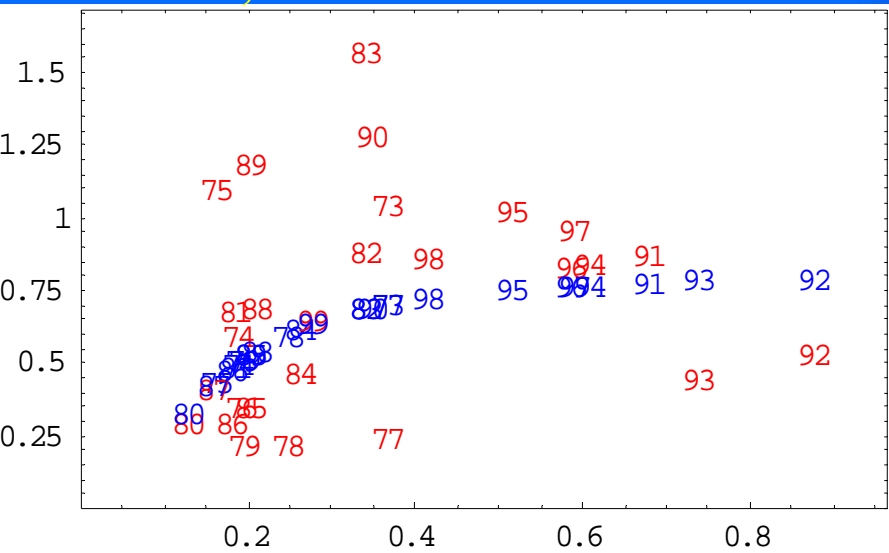
$$\text{SSB}^{\text{codExpRec}}$$
$$\text{codHalf}^{\text{codExpRec}} + \text{SSB}^{\text{codExpRec}}$$

temp: Mean of August-October

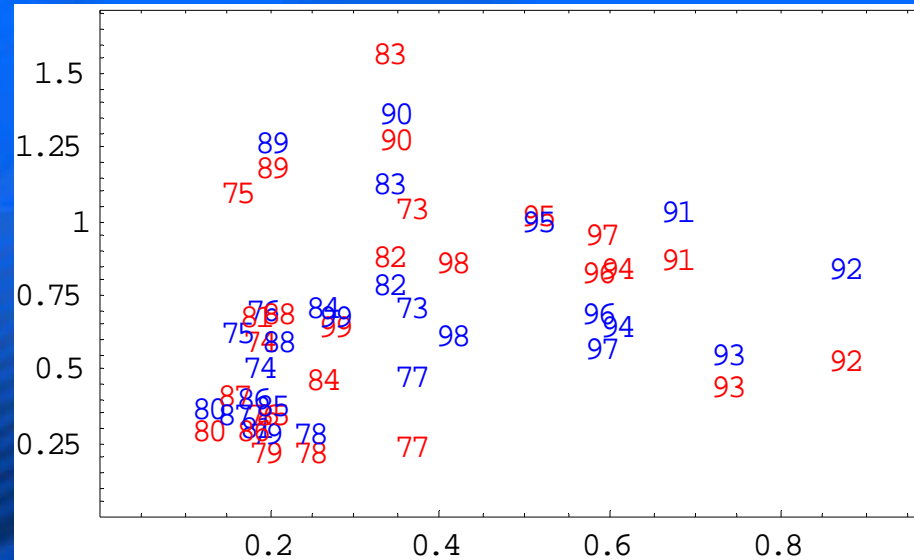


Recruitment cod - results

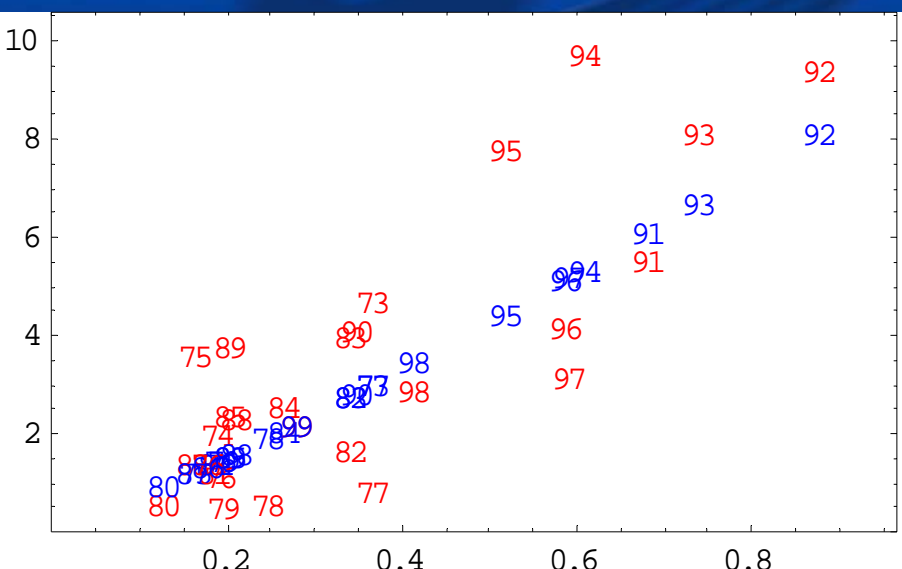
Basic, $R^2 = 0.17$



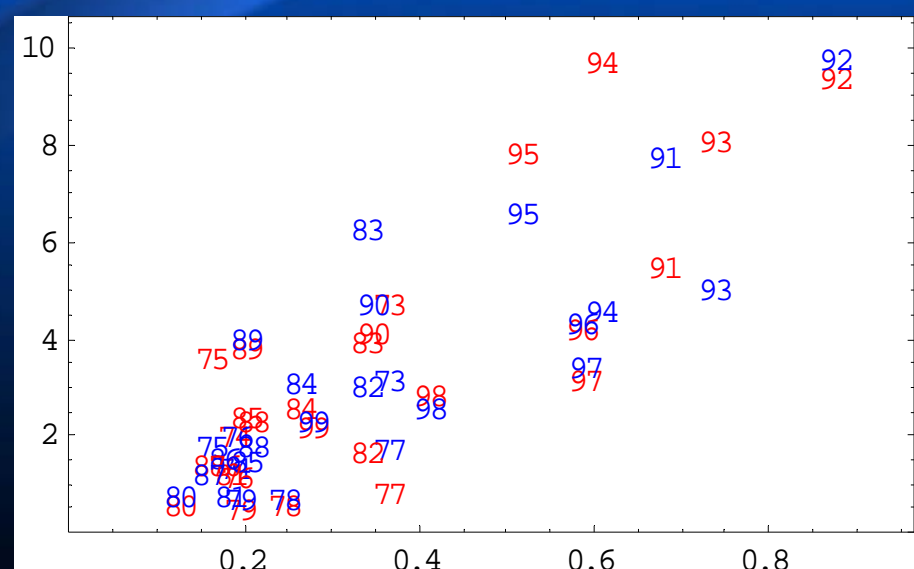
Env.++ $R^2 = 0.59$



Cannibalism, $R^2 = 0.50$



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



Recruitment capelin - model

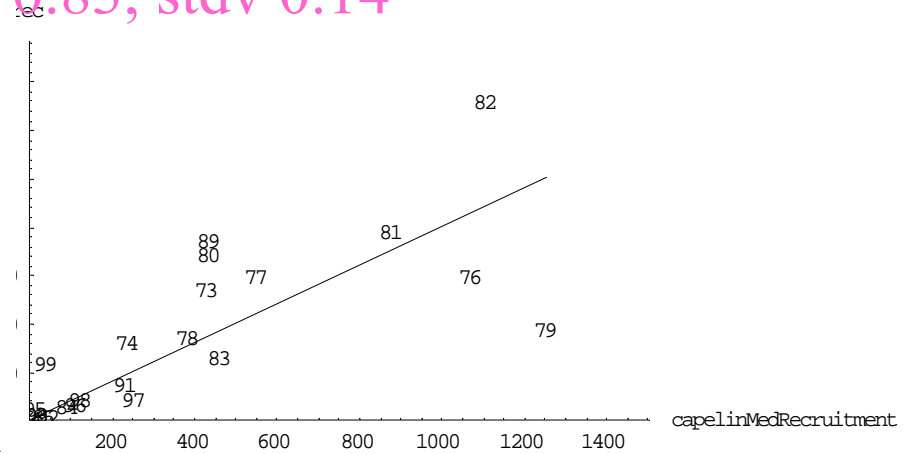
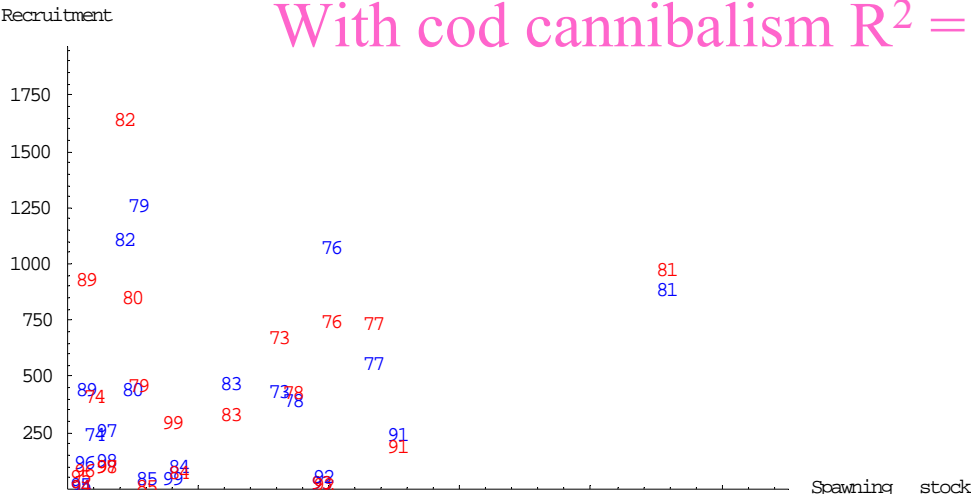
$$\text{capMax} \Gamma^{\text{capTemp tempdiff}} \frac{\text{SSB}}{\text{capHalf} + \text{capPred} + \text{SSB}}$$

$$\text{capPred} = \text{capHerProp} \text{errring} + \text{capHerOffset} \text{pHerExp} + \text{capCodProp zeroCod} + \text{capCapProp capelin}$$

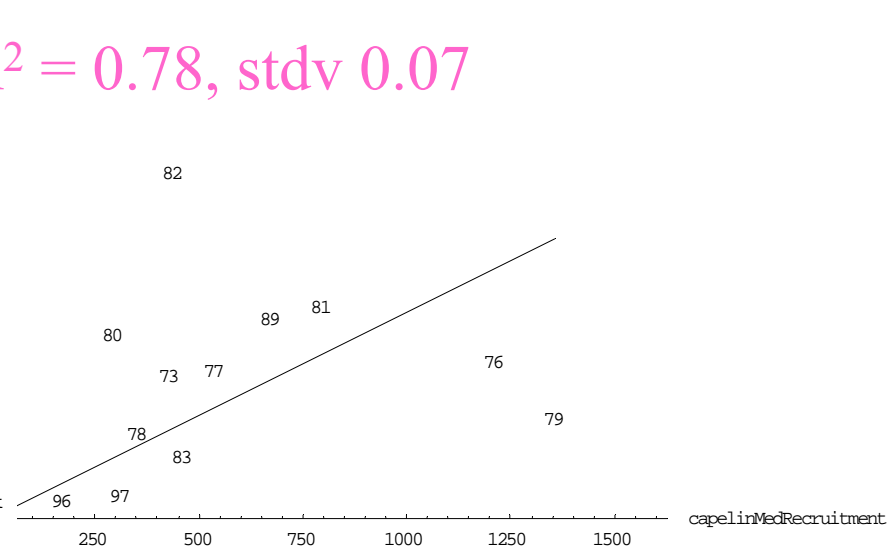
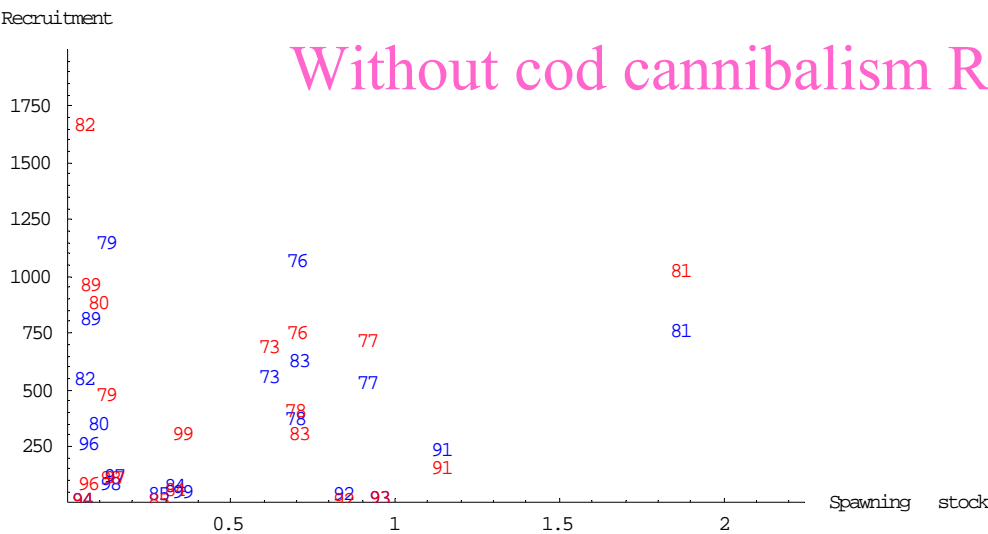
tempdiff: Difference between mean temperature during August-December and mean temperature during January-April

Recruitment capelin - results

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



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



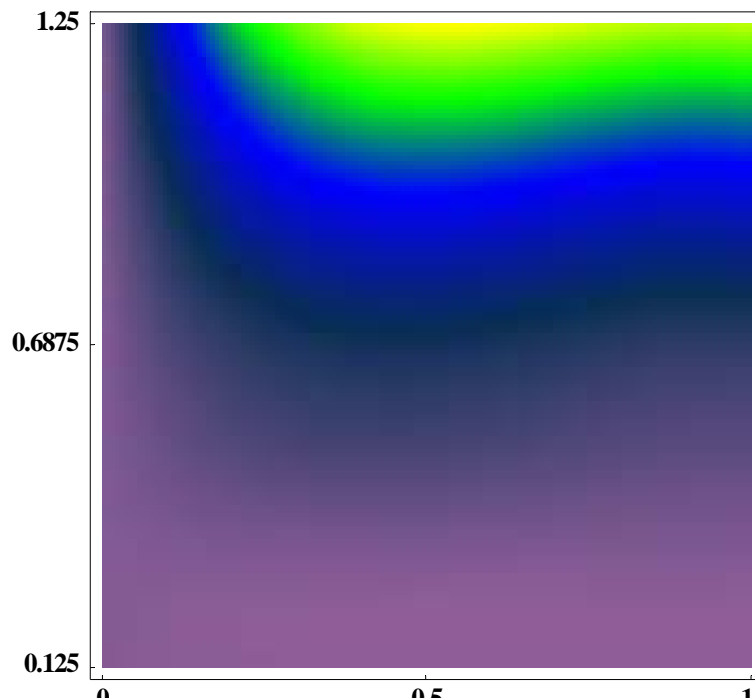
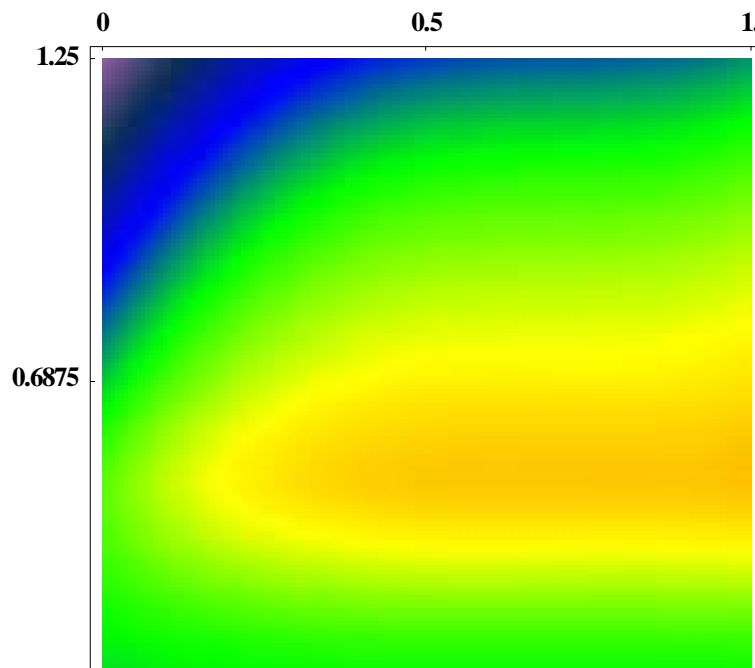
Evaluating HCRs

- 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

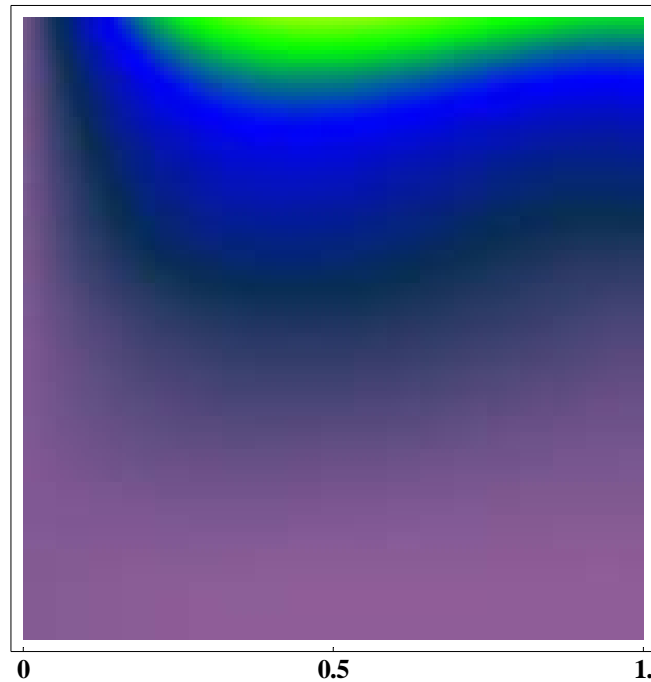
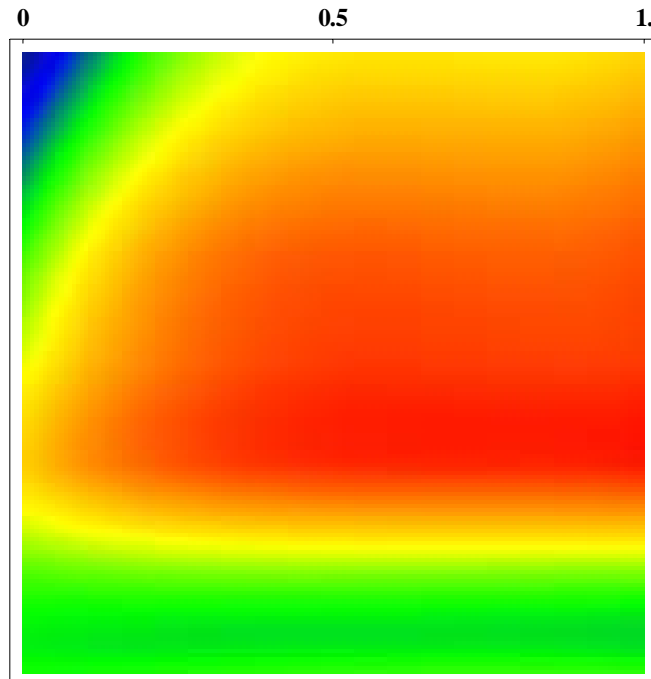


Yield of cod

5% increase of
temperature

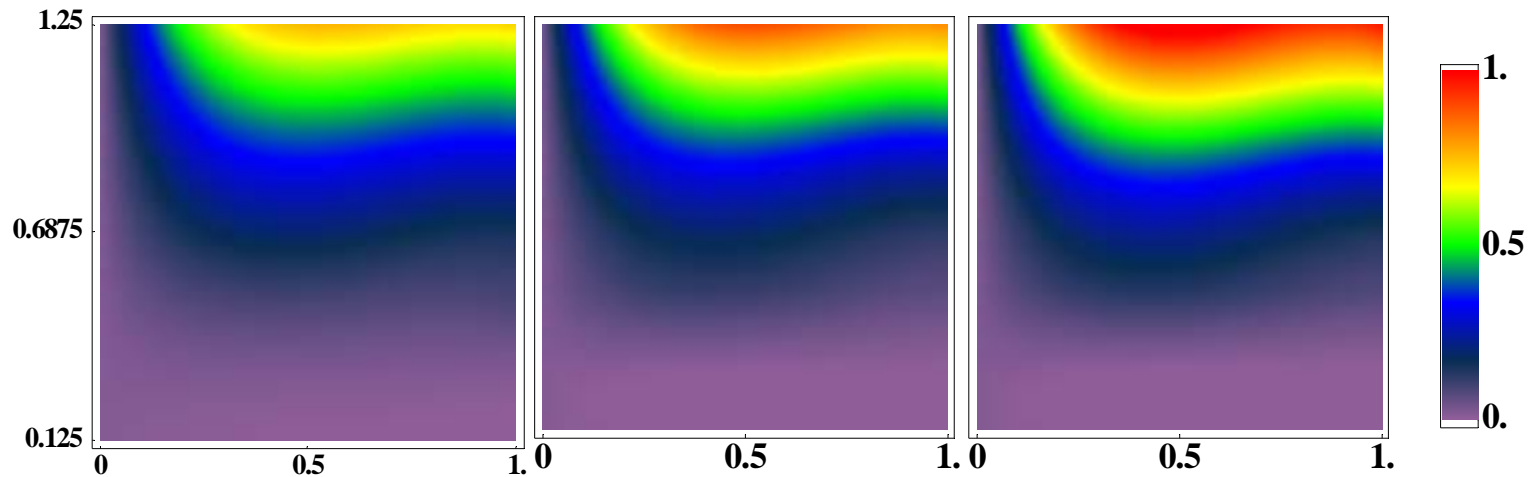
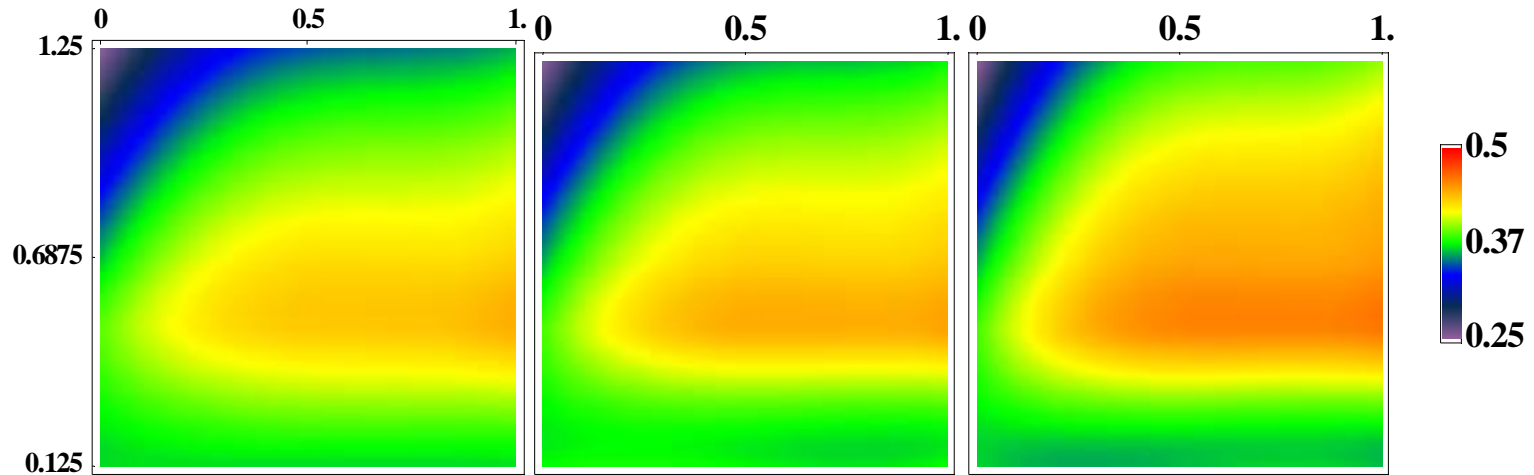
$$F_{\text{herring}} = 0.125$$

Yield of capelin

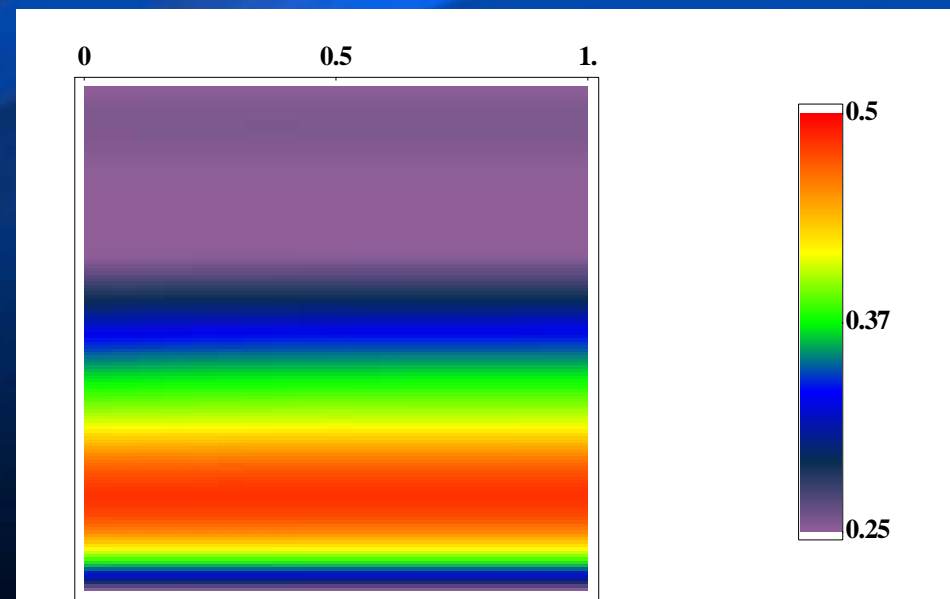
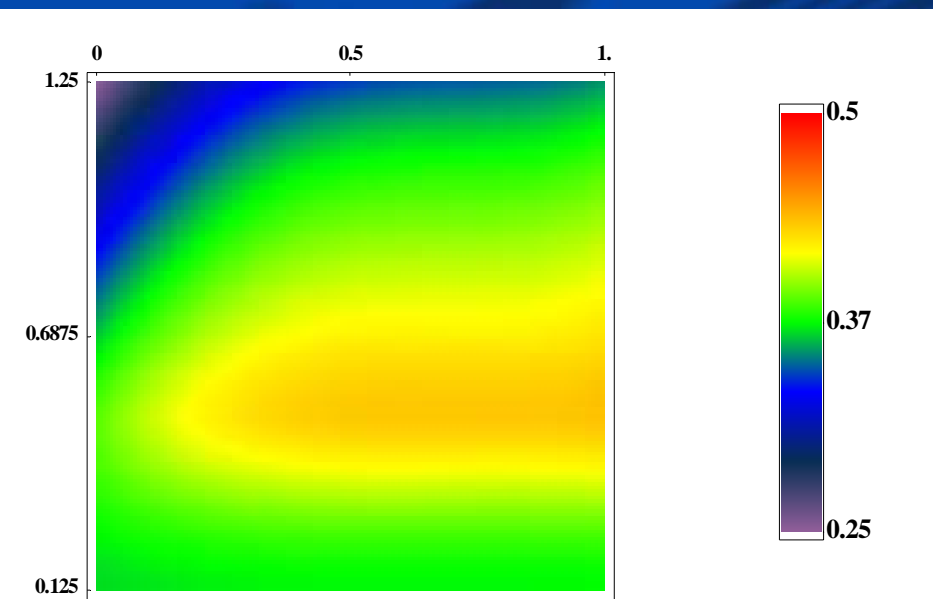
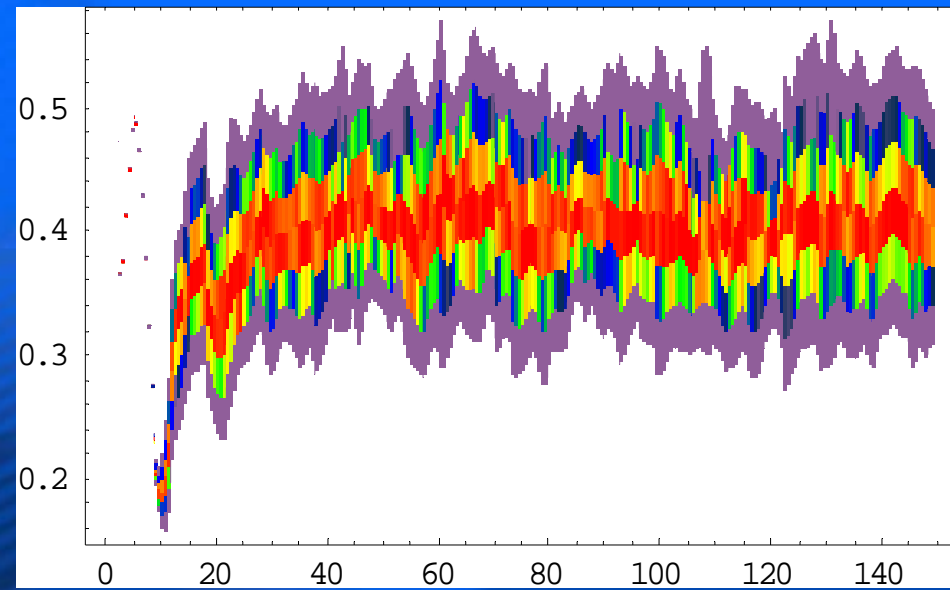
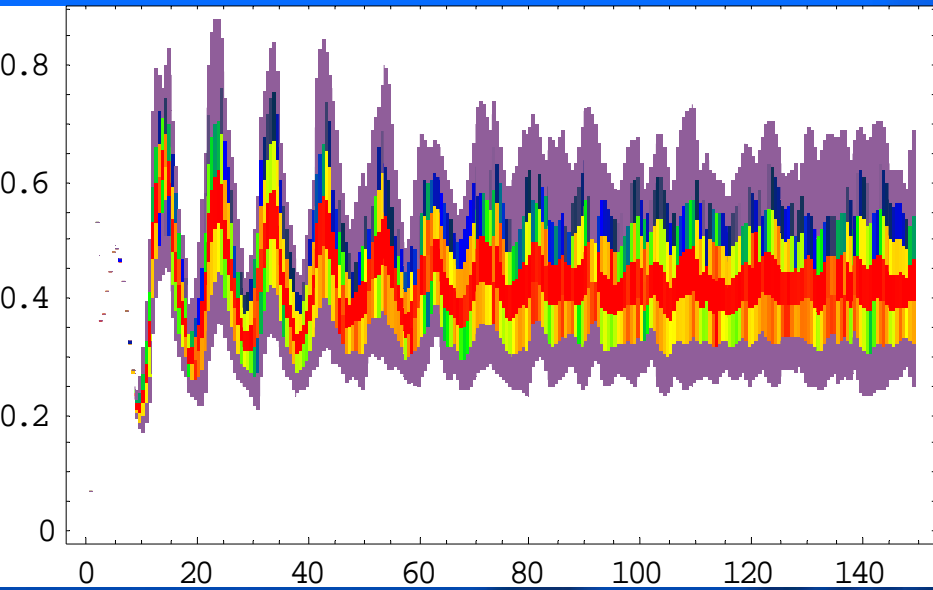


Fherring = 0.125 Fherring = 0.20 Fherring = 0.30

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**