DYNAMICS OF SHORT-LIVED SPECIES: the case of exploited stocks of Octopus and shrimps in Senegal

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PhD Thesis defense
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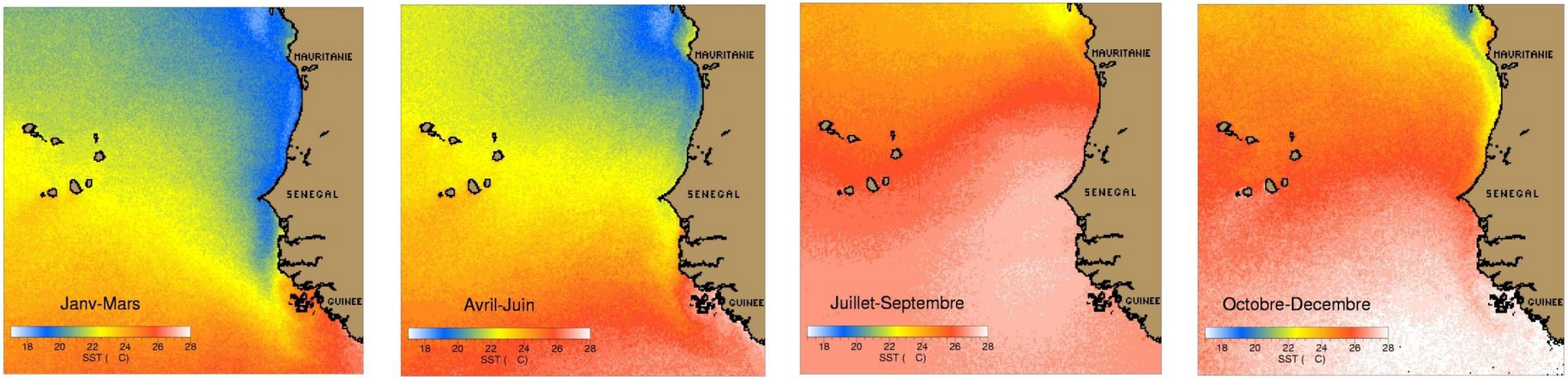
Contents

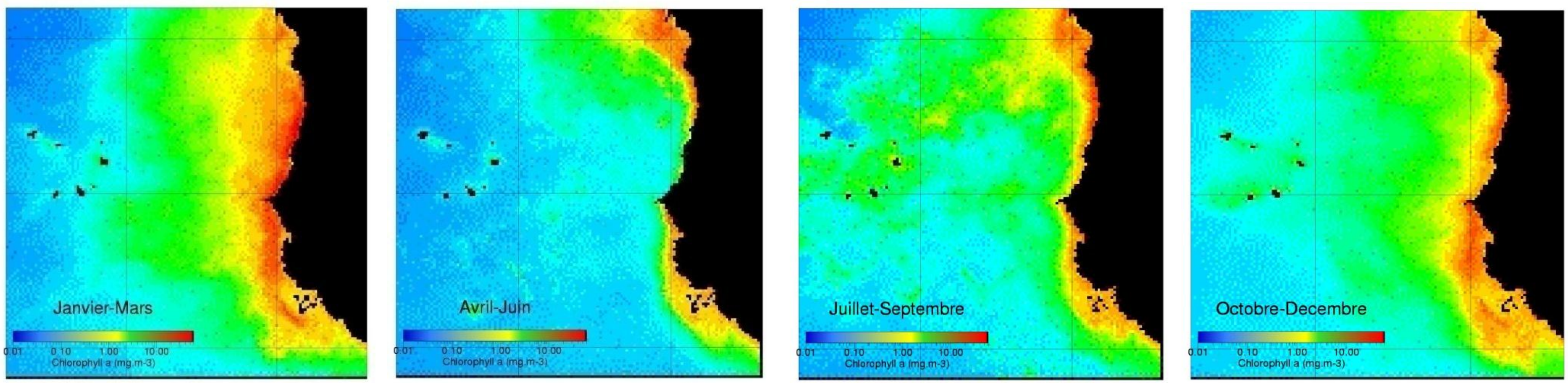
Fisheries in Senegal

- **Social and economical importance** (*National Fisheries department*)
  - Average annual catch = 400 000 tons
  - 30% of exportation
  - Gross National Product (GNP) 5%
  - 600 000 employers
  - contribute to the nutrition of populations

One of the world's most productive area



SST (METEOSAT satellite data)



Chlorophyll a (SeaWiFS satellite data)

- Favorable climatic conditions due to the presence of coastal upwelling (*Roy, 1989*)

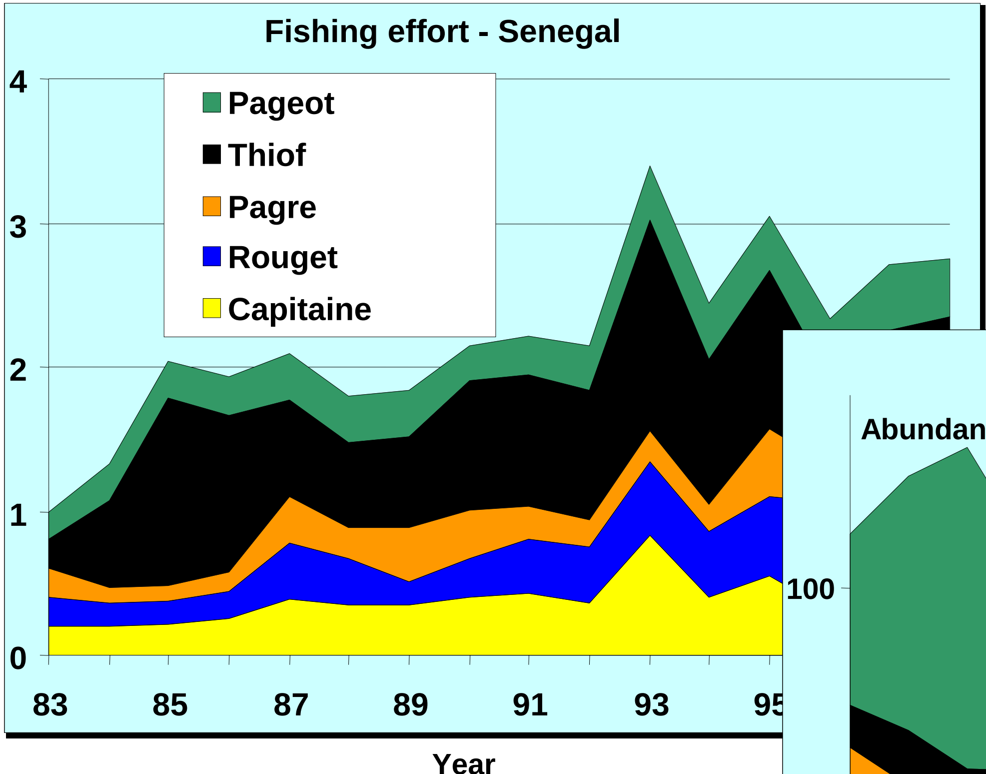
HIGH LEVEL OF ANTHROPIC PRESSURE

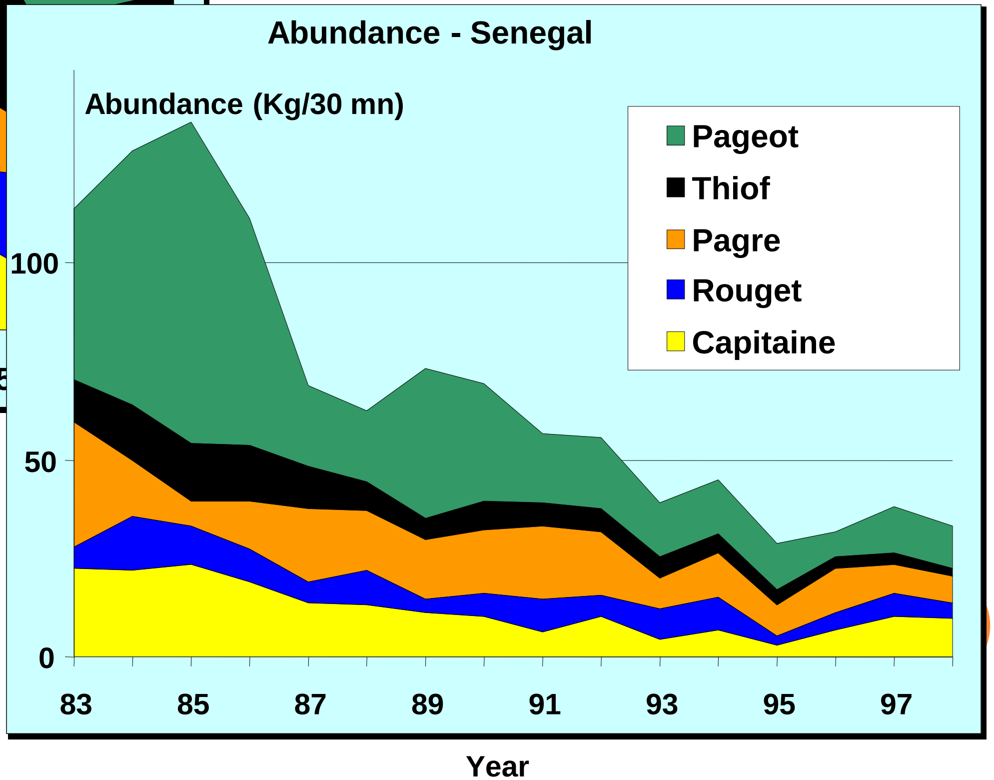
Fishing impact: development of demersal fisheries

Gascuel et al. (2004) in Senegal

Barry et al. (2004) in Senegal

Sidibe et al. (2002) in Guinea

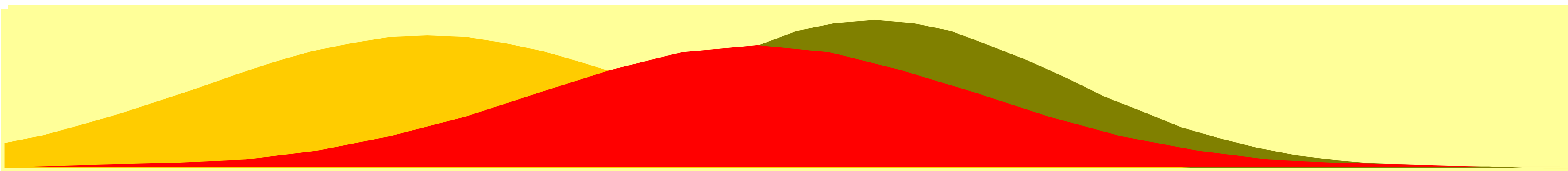




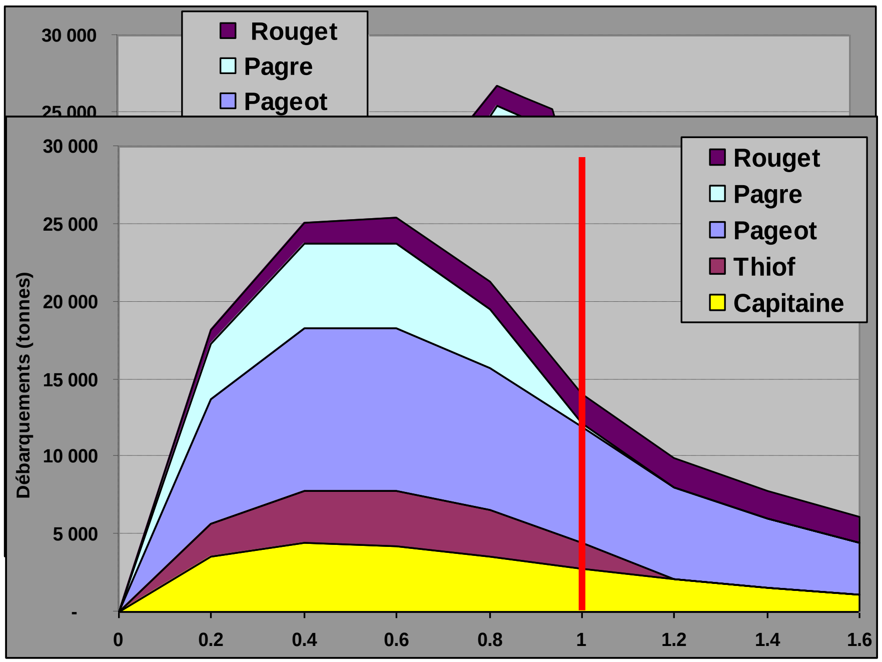
Decrease in abundance of demersal fish

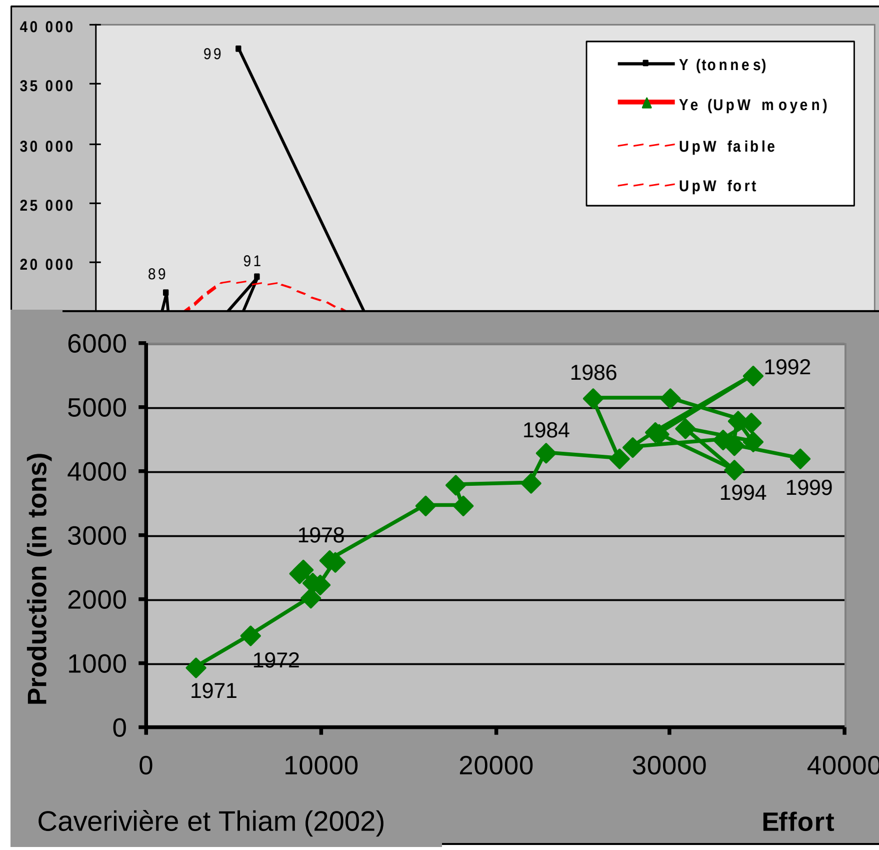
ECOLOGICAL SUCCESSION SCENARIO

FISH -> -> SHRIMPS - OCTOPUS



Example : Senegal





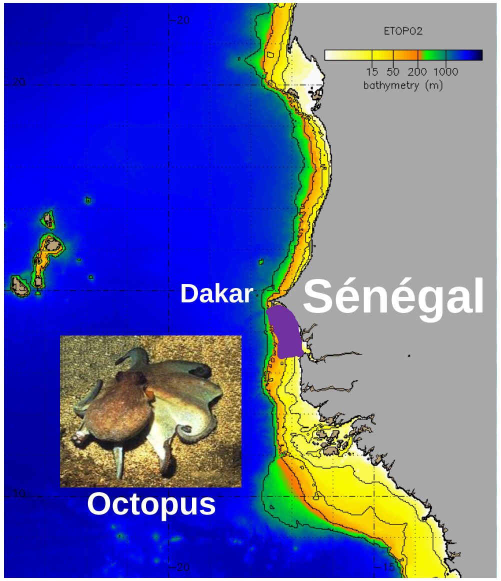
Catches equilibrium curves for the main exploited demersal fish

Some demersal stocks have been collapsed to the advantage of short-lived species.


DAK 931
OLEIL 20

CASE STUDY

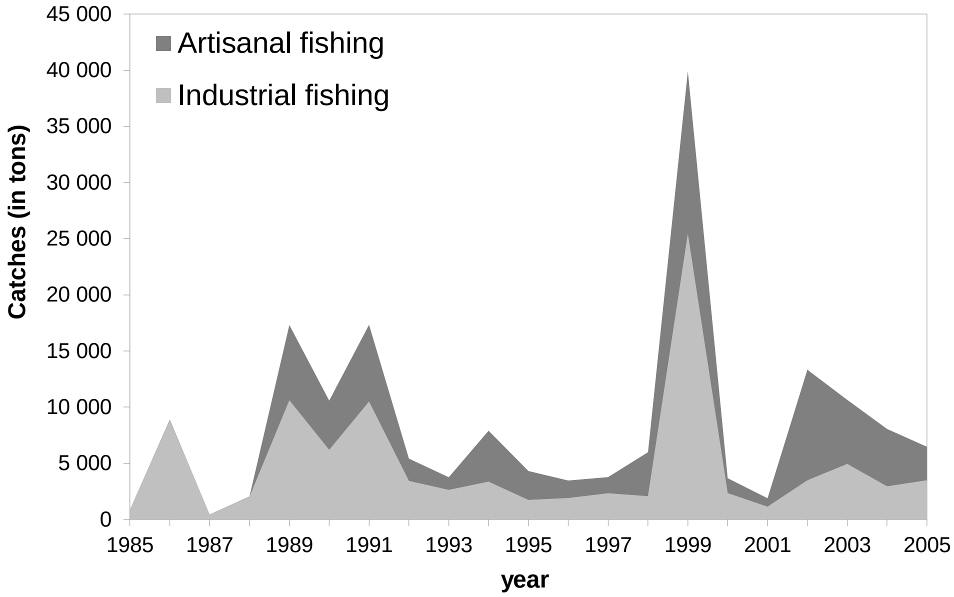
- **Octopus stock: south of Dakar (Petite Côte)**
  - **The stock is composed by a single annual cohort.**



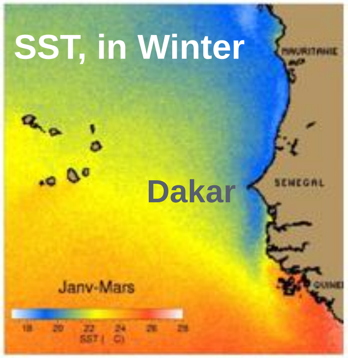
Special jigging hand line for fishing Octopus

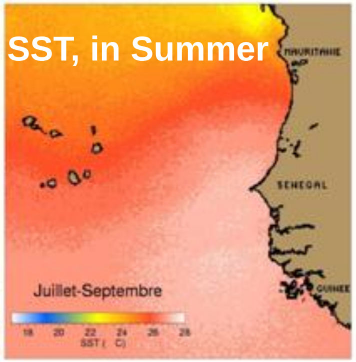
« Turluttes »

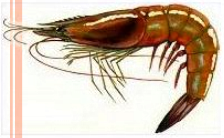
- **High variability of production from year-to-year**



- **Potential impact of seasonal upwelling**

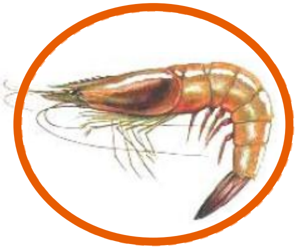






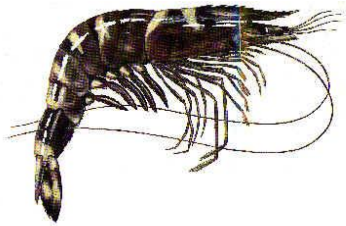
EXPLOITED SHRIMPS IN SENEGAL

• Coastal water shrimps (4)



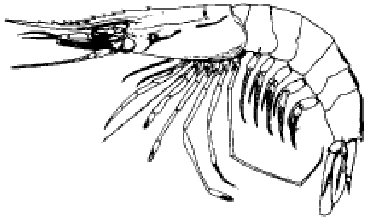
Farfantepenaeus notialis
White Shrimp
Length max: 230 mm TL (female)
170 mm TL (Male)
80% of the shrimp catch

Melicertus kerathurus
Tiger Shrimp
Length max: 180 mm TL (female)
135 mm TL (Male)



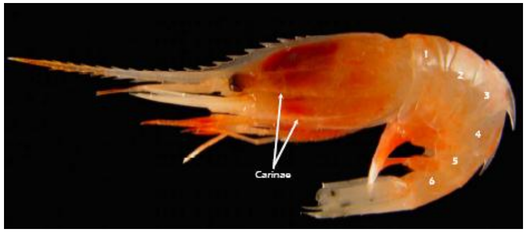
Penaeus monodon
Giant Tiger Shrimp or "Black Tiger''
310 mm TL, 250 g

Parapenaeopsis atlantica
Guinea Shrimp
Length max: 170 mm TL (female)
120 mm TL (Male)



• Shallow water shrimps (5)

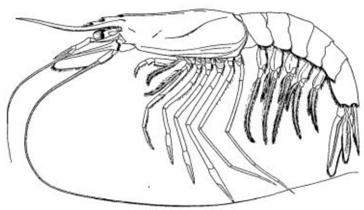
Parapenaeus longirostris
Cappa Shrimp or « Gambas »
Length max: 190 mm TL



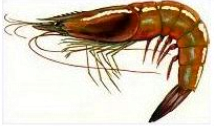
Heterocarpus ensifer

Plesionika martia

Plesiopenaeus edwarsianus
« Carabinero»

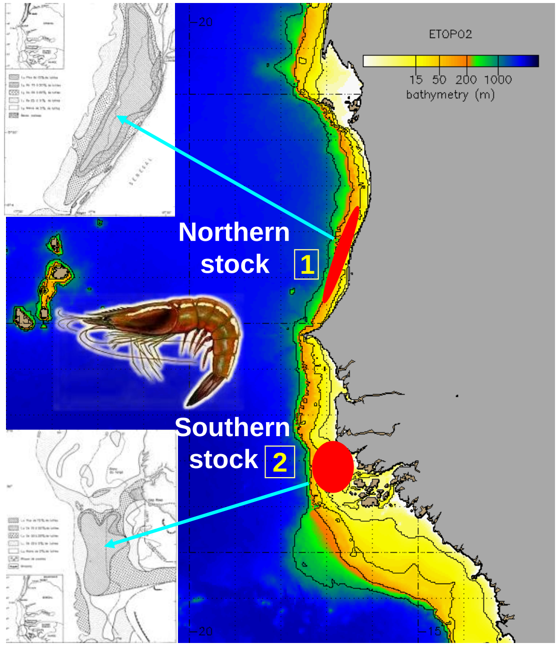


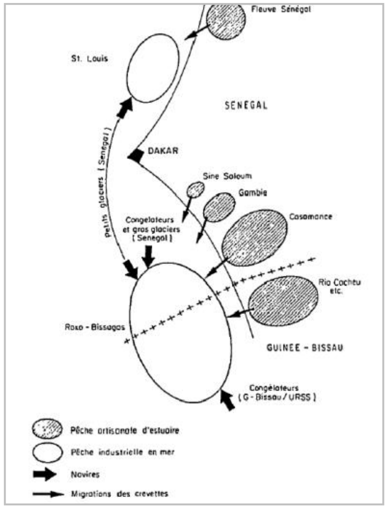
Aristeus varidens
« Alistado »



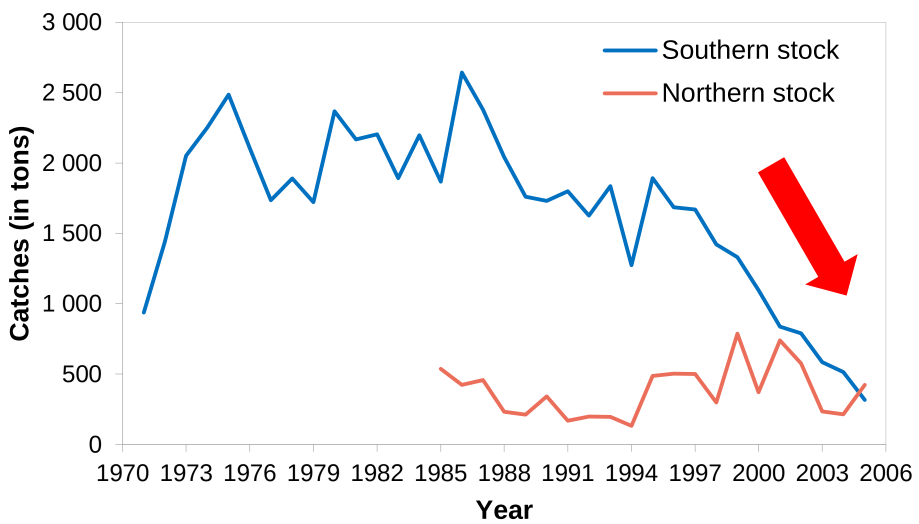
CASE STUDY

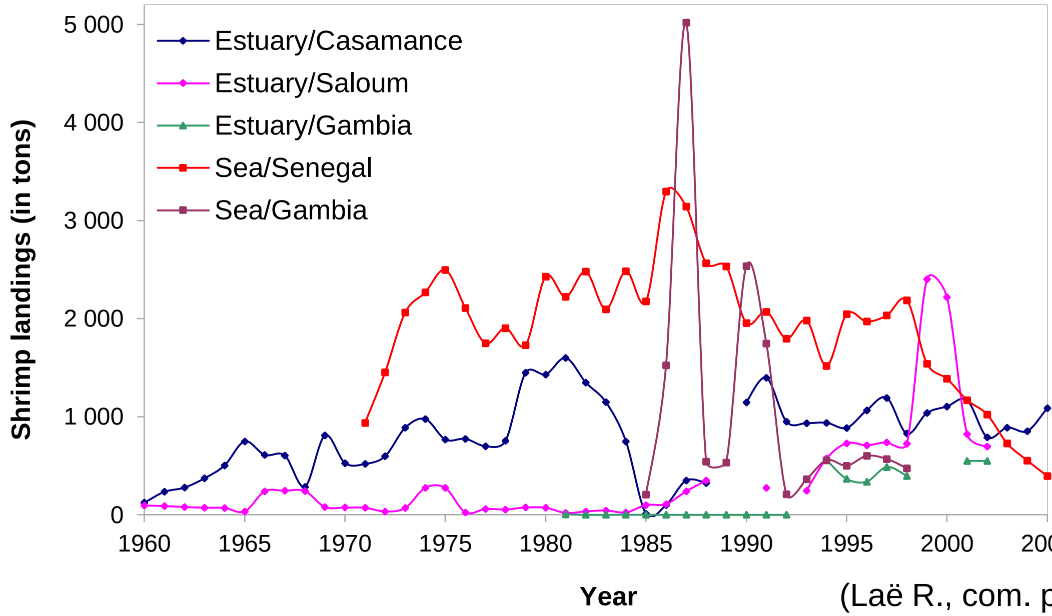
- **Two shrimp stocks in Senegal**



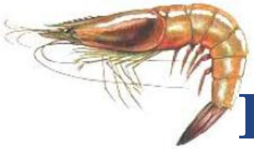


- **Trends of shrimp catches**

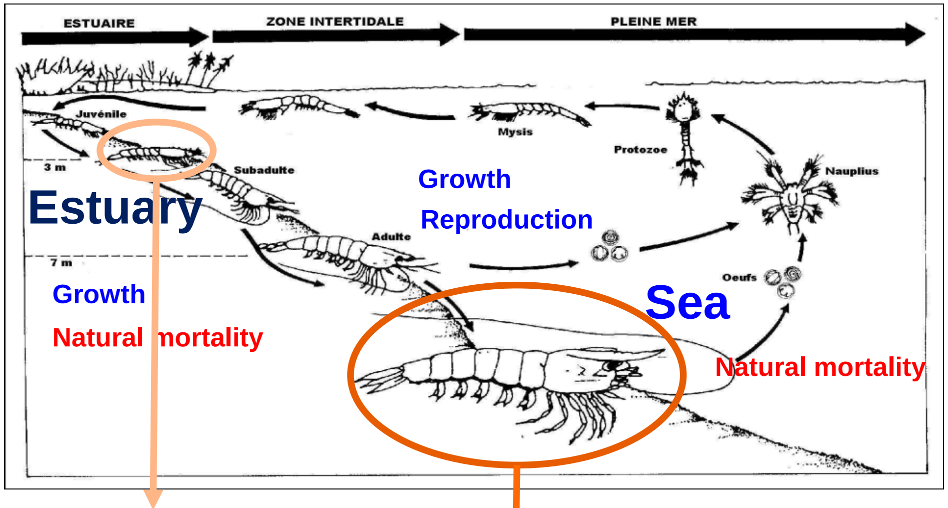




(Laë R., com. pers.)

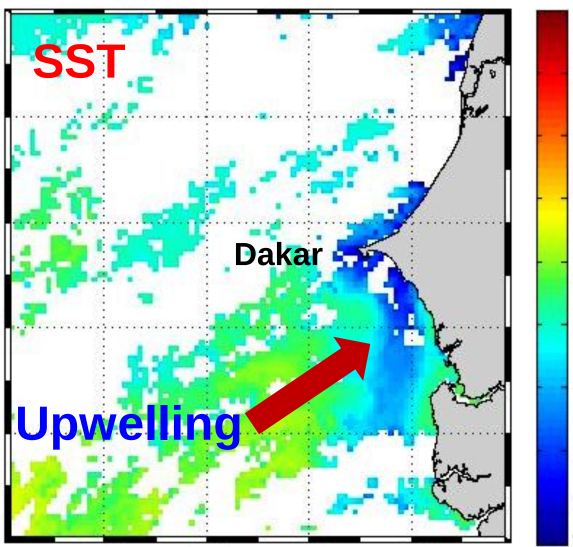


RECRUITMENT PATTERNS OF WHITE SHRIMP



- **Spawning and living areas**
  - Shrimp lives in the sea
  - Juveniles grow in estuaries (3-4 months)
  - Reproduction in the sea
  - Industrial fishing of adults in the sea
  - Artisanal fishing of juveniles in the estuary

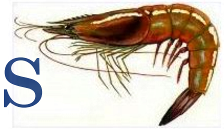
- **Potential impact of seasonal upwelling**



SST images produced from METEOSAT satellite data : 5 km, 15 days

- **Fishery collapse related to recruitment failure**
  - ✓ Causes
    - bad growth
    - recruitment overexploitation
    - environment forcing on recruitment
    - parental stock biomass

MODELS FOR SHORT-LIVED SPECIES



<u>Characteristics of short-lived species</u>

- Biology: short life cycle, rapid growth, post spawning mortality (Octopus) and high rates of natural mortality associated with the early stages of life (*Lhomme, 1981*; *Garcia et Le Reste, 1986; Jouffre et al., 2002*).
- Extremely dependant on variability of environment
- Stocks present rapid and unstable dynamics
  - their potential production varies widely from year-to-year (Caverivière et al., 2002; Thiaw et al., 2009).
  - marked variability in catches for most fisheries of short-lived species (Wang et al., 2003).

➔ Specific modeling strategy for population dynamics and stocks assessment

Principle Objective

To understand the population dynamics of octopus and shrimps in order to improve the scientific bases of specific fisheries management plan.

Outline

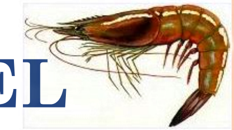
Three scientific questions:

Three parts:

What is the variability of the recruitment and biomass of short-lived species stocks?	Monthly cohort analysis Linear model
What is the part of the variability of octopus abundance linked to the environment (upwelling)?	Seasonal decomposition analysis Correlations between recruitment and environmental factors
In this variability context, what is the diagnosis on the stocks status?	Yield per recruit and Spawning potential ratio diagnoses Surplus production models

CONTENTS

MONTHLY COHORT ANALYSIS MODEL



Monthly catches
(CRODT, 1985-2005)

Catch per category
(Sampling 1996-2005)

Mean weight at age
(Jouffre et al., 2002)

Abundance index
(GLM CPUE 1996-2005)

Catch-at-age

Terminal fishing mortalities ($F_{i, T}$, $F_{I-1, t}$)

Cohort analysis model

Natural mortality

Recruitment R

Abundance N

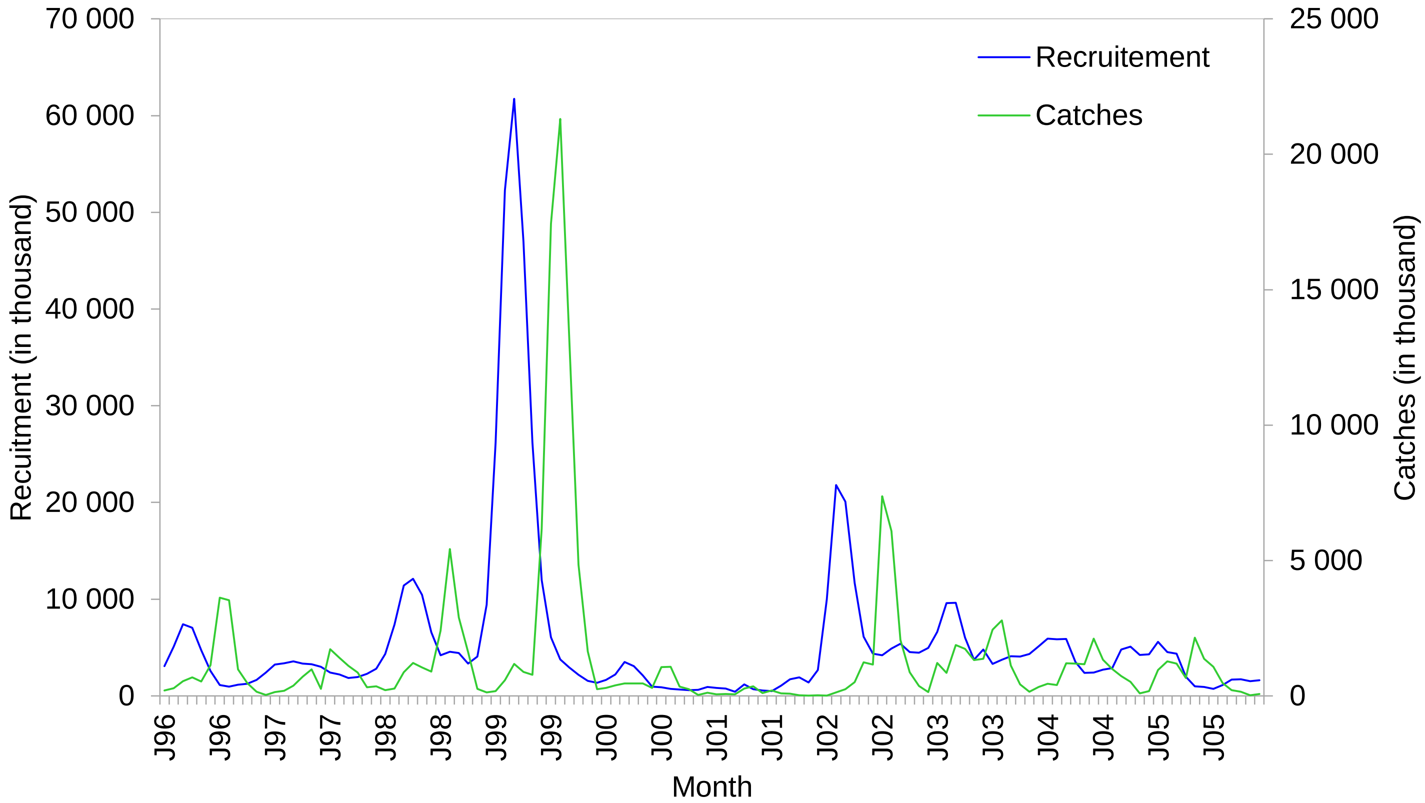
Fishing mort. F

Pre-processing | **Input variables** | **Cohort analysis model** | **Outputs**

Sensibility of the model to the parameters $F_{i, T}$ and $F_{I-1, t}$ was tested.

2.1. POPULATION DYNAMICS OF OCTOPUS

- **Octopus recruitment**



1. Monthly recruitment
2. Fishing mortalities F
3. Stock abundance

- **Yield per recruit for each monthly cohort**
- **Spawning potential ratio for each monthly cohort**

DECOMPOSITION OF THE VARIABILITY

Recruitment, spawning potential ratio and yield per recruit were used as input data to show the interannual and seasonal variability of the dynamics of octopus stock using Linear Model (LM).

1. Monthly recruitment
2. Spawning potential ratio, for each cohort
3. Yield per recruit, for each cohort

→ Linear Model →

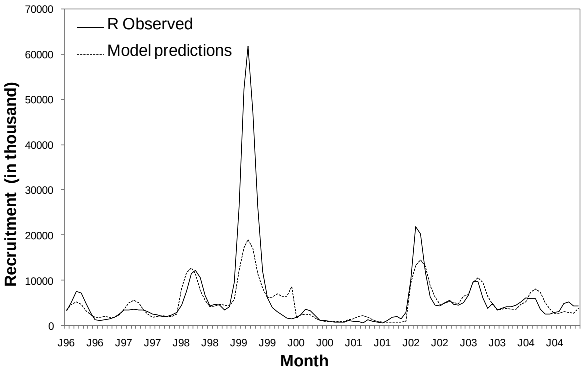
Seasonal variability

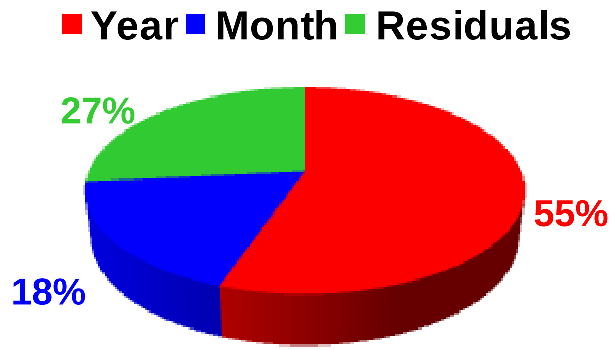
Interannual variability

Residuals

2.1. DYNAMICS OF OCTOPUS STOCK AND VARIABILITY

Recruitment

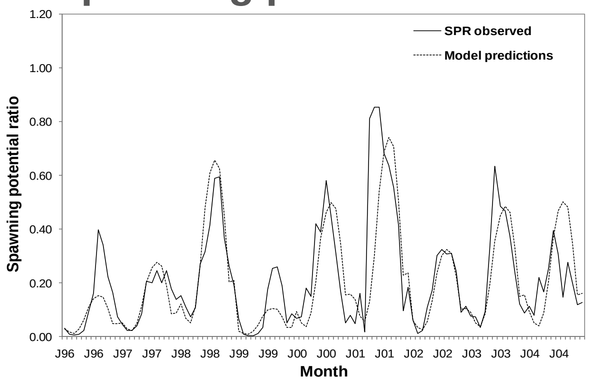


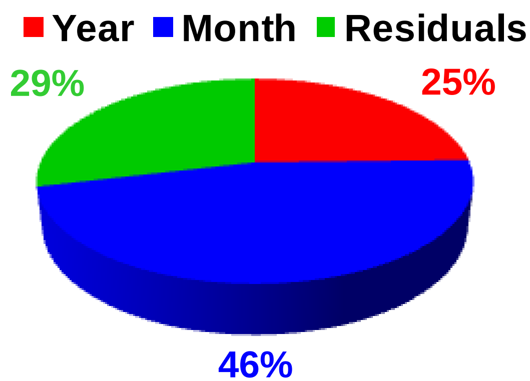


CV=157%

Interannual variability

Spawning potential ratio

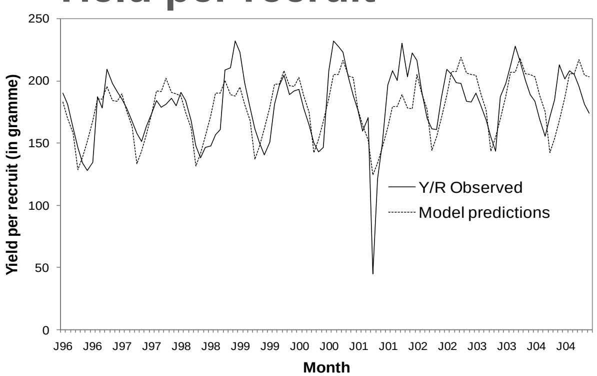


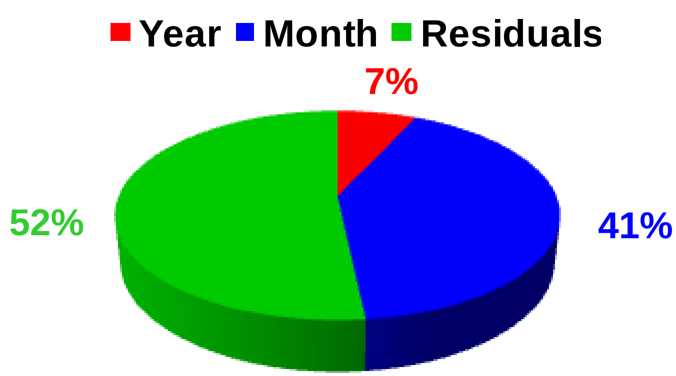


CV=90%

Seasonal variability

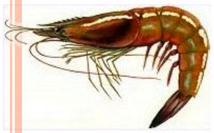
Yield per recruit





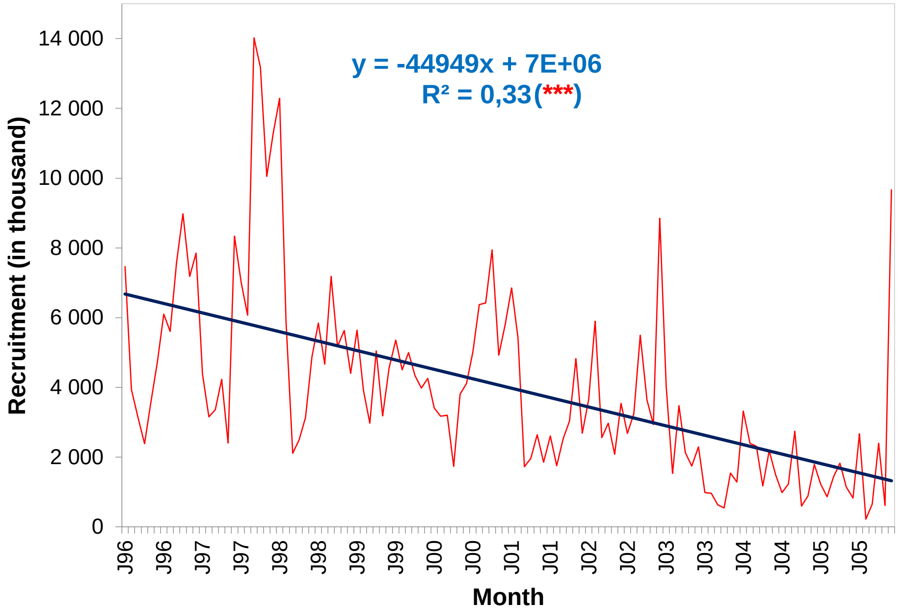
CV=16%

Seasonal variability and low variability with year



2.2. DYNAMICS OF SOUTHERN SHRIMP STOCKS

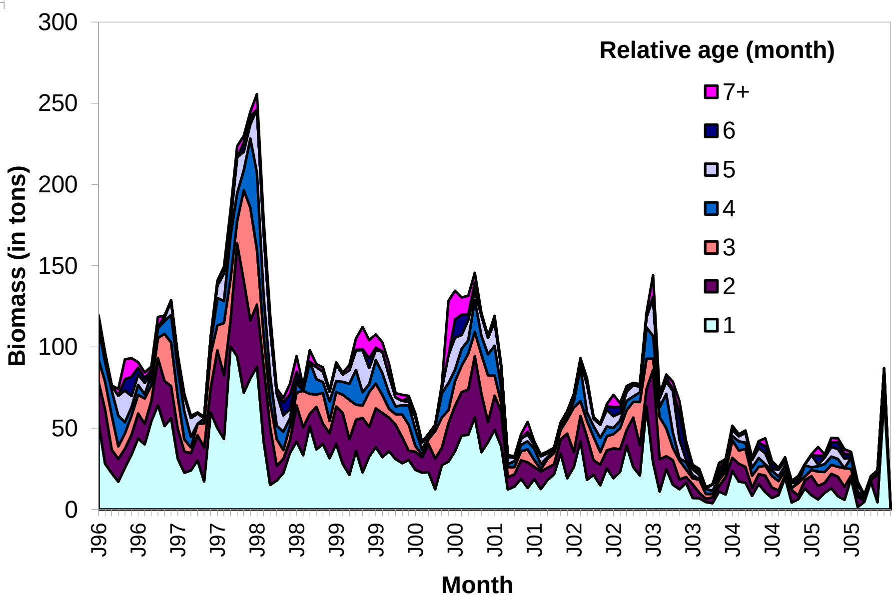
- **Estimation of the recruitment**



Trend of recruitment:

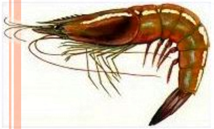
- **Seasonal variability** **(main peak at the end of the rainy season)**
- **Year-to-year variability**
- **Clear trend to decrease**

- **Estimation of biomass stock**



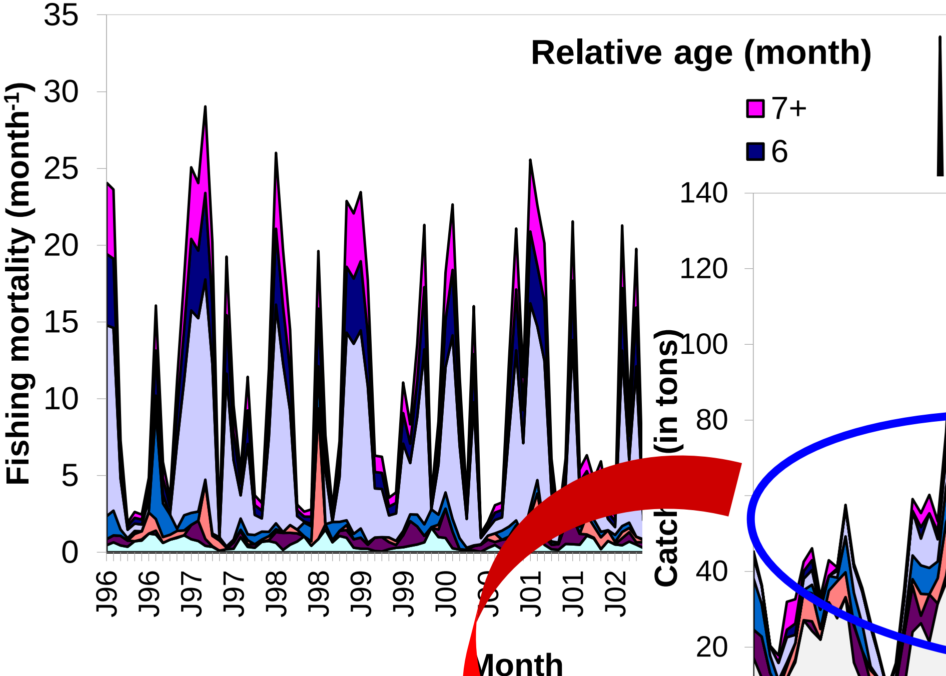
Trend of biomass:

- **Seasonal and year-to-year variability**
- **Decrease over the 1996-2005 period**
- **Decrease in shrimps length**

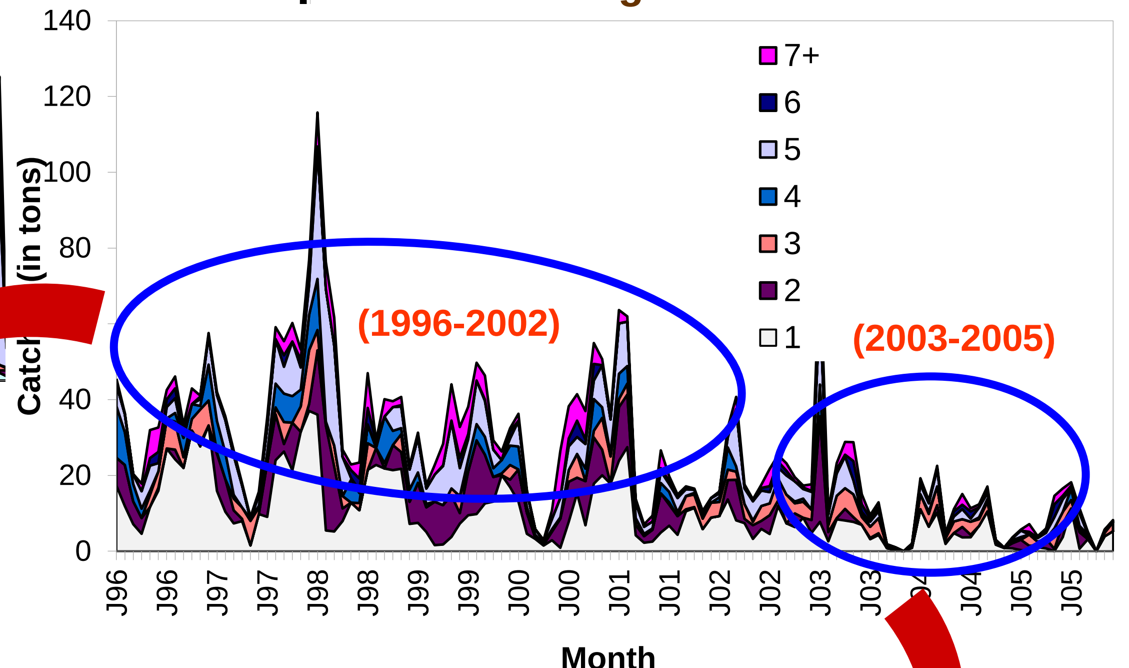


DYNAMICS OF SHRIMPS FISHERIES

- Estimation of fishing mortality



- Catch-at-age



SUMMARY OF STOCKS DYNAMICS

- **High variability of recruitment and biomass from year-to-year**
  - **Recruitment and biomass highly change between years and seasons. For Octopus stock, there is no trend. For the southern shrimp stock, results indicate also a high variability with a clear decrease over the period.**

- **Markedly interannual and seasonal exploitation pattern**
  - **Fishing mortality changes from year-to-year according to the yearly recruitment and abundance.**

- **What relationship between environment and recruitment variability?**
  - **Even in this context of high seasonal and year-to-year variability of octopus recruitment, what is the part of this variability linked to the environment?**

Contents

3. ENVIRONMENTAL EFFECTS ANALYSIS

Biological data

- **Monthly recruitment of Octopus** estimated by the cohort analysis (1996-2005)

Environmental data

- **Monthly coastal upwelling index** (CUI, $m^3/s/m$) from NOAA website (1985-2005)
- **Monthly sea surface temperature** (SST, °C) from AVHRR satellite data (1985-2005)

Seasonal decomposition of Time Series (Census II Method, Makridakis et al., 1983)

$$R_t = p_t + s_t + u_t$$

Pt: smoothed mean: **Trend component**

st : Mean by month: **seasonal component**

Ut : Residuals: **short-term disturbance**

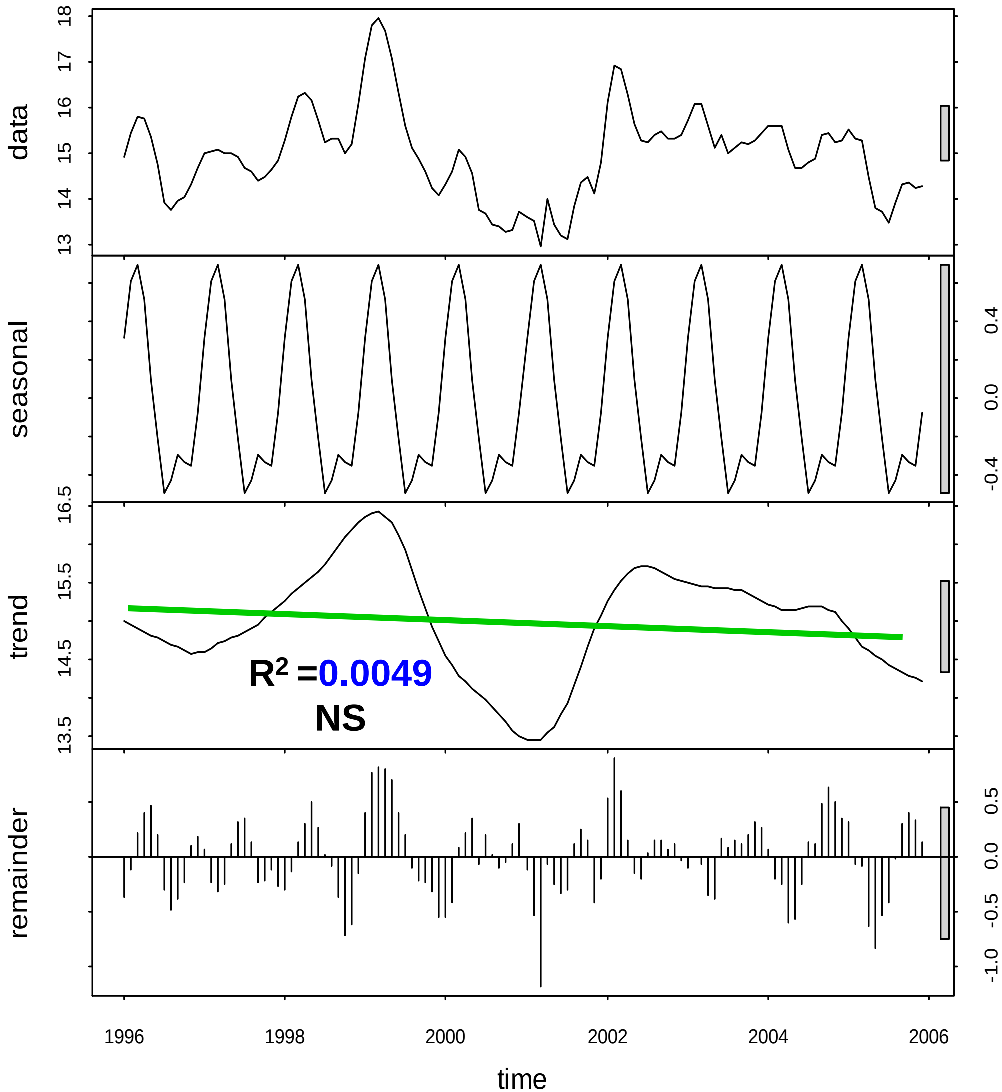
Application to

1. Monthly recruitment
2. Sea surface temperature
3. Coastal upwelling index

→ **Values without seasonal effect**

SEASONAL DECOMPOSITION OF RECRUITMENT

Octopus recruitment



Input variable: recruitment from VPA

Seasonal component:

- **Main recruitment : March**
- **Secondary: September**

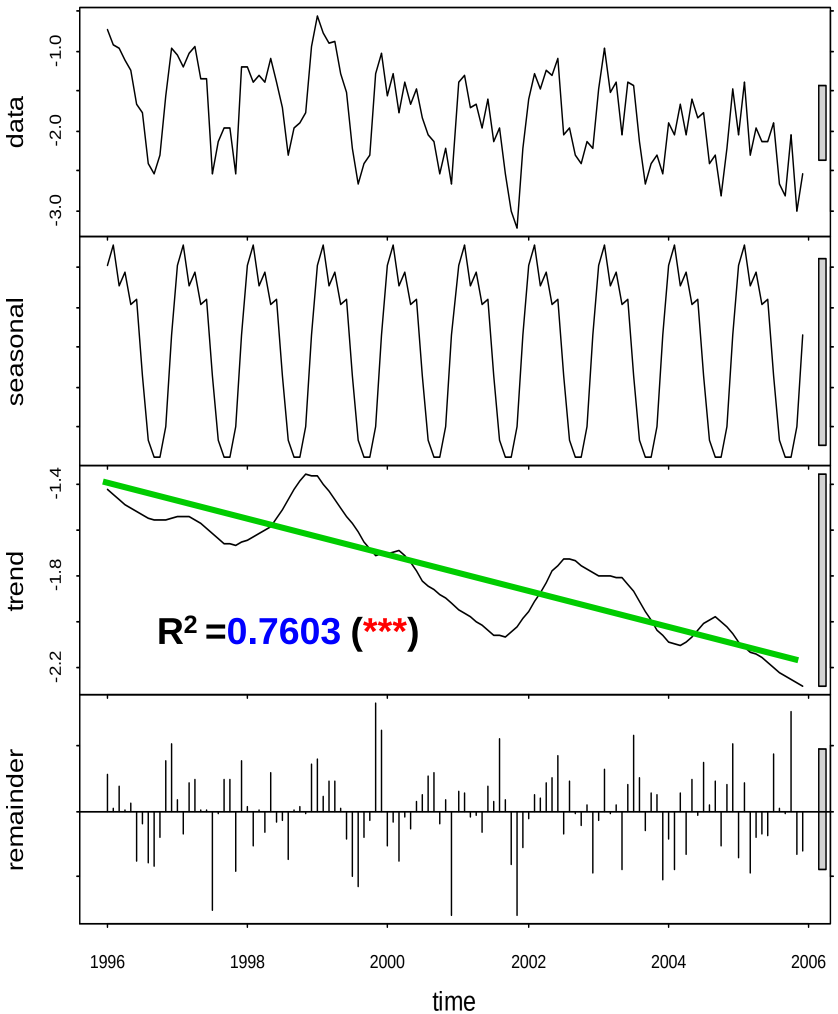
Trend:

- **Maximum: 1999 and 2002**
- **Minimum: 2001**

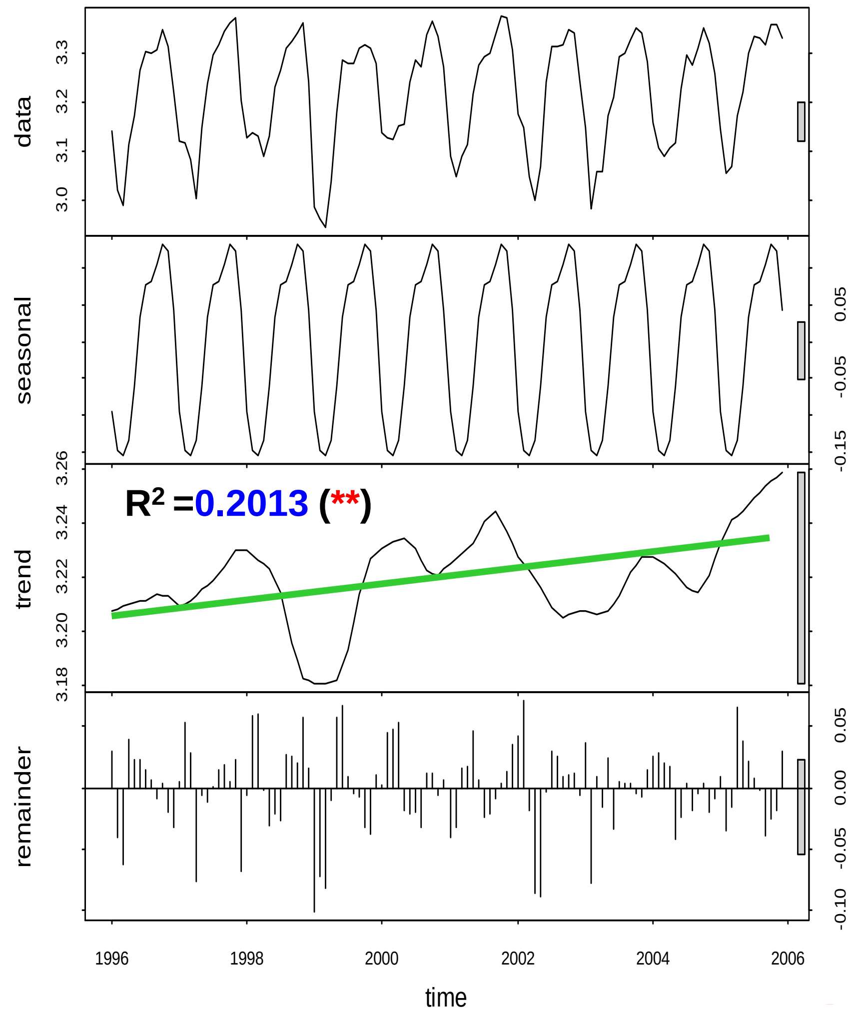
Residuals

SEASONAL DECOMPOSITION OF ENVIRONMENT

Coastal upwelling index

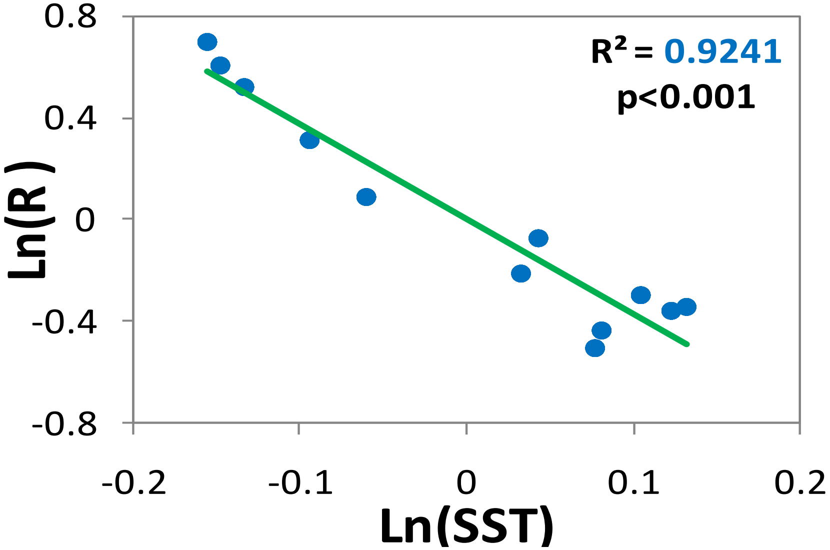


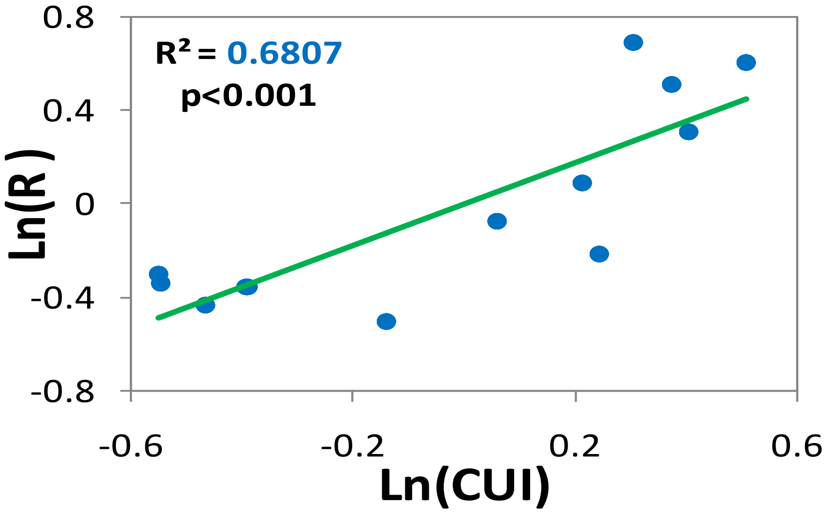
Sea surface temperature



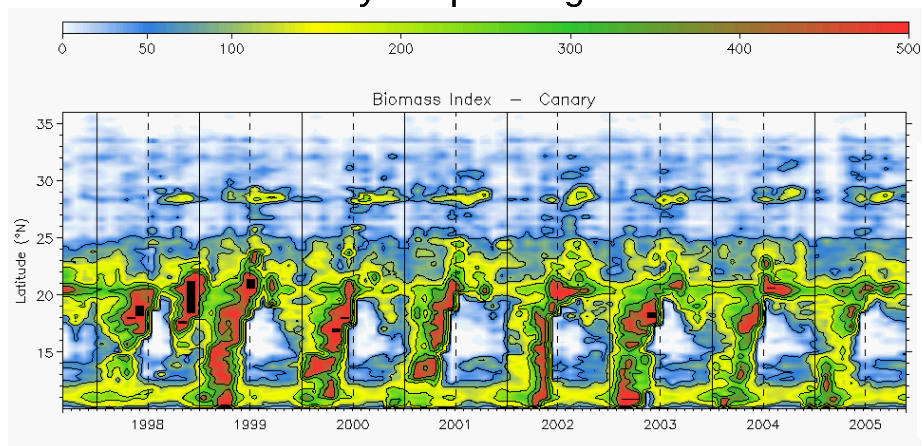
SEASONALITY OF RECRUITMENT AND UPWELLING

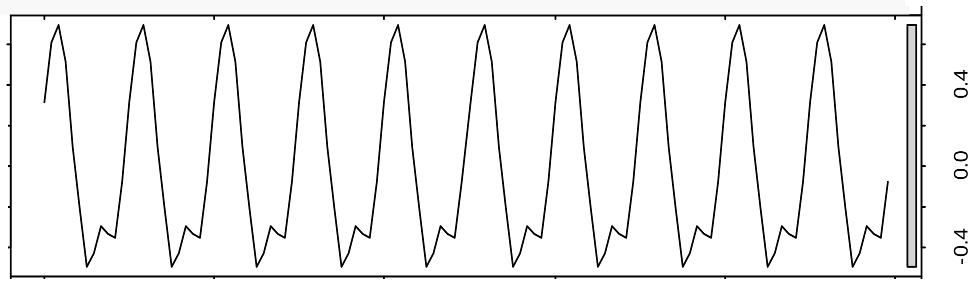
Seasonal component





Seasonal variability of upwelling



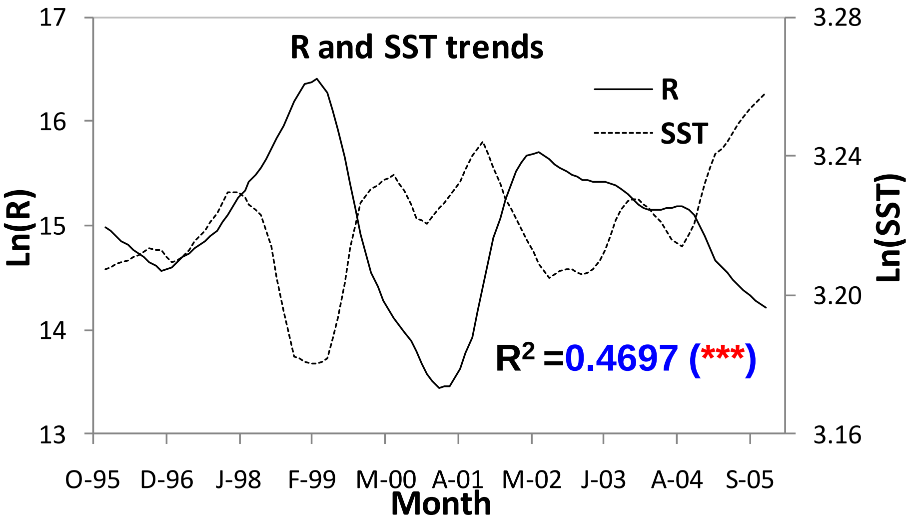


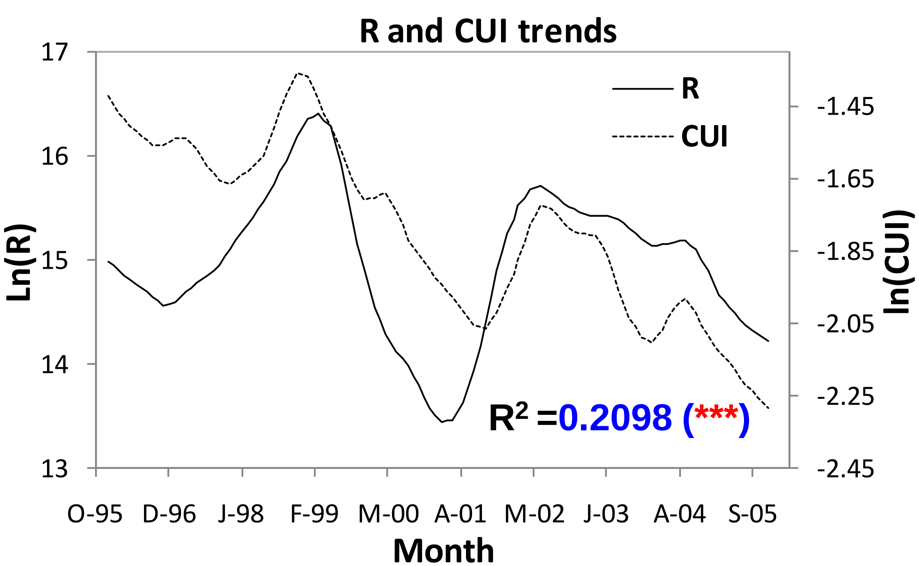
Seasonal variability of octopus recruitment

High seasonality of recruitment and upwelling

ENVIRONMENTAL EFFECTS ON RECRUITMENT

Trend





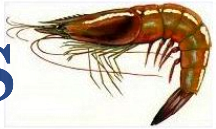
Year-to-year variability of recruitment due to upwelling intensity.

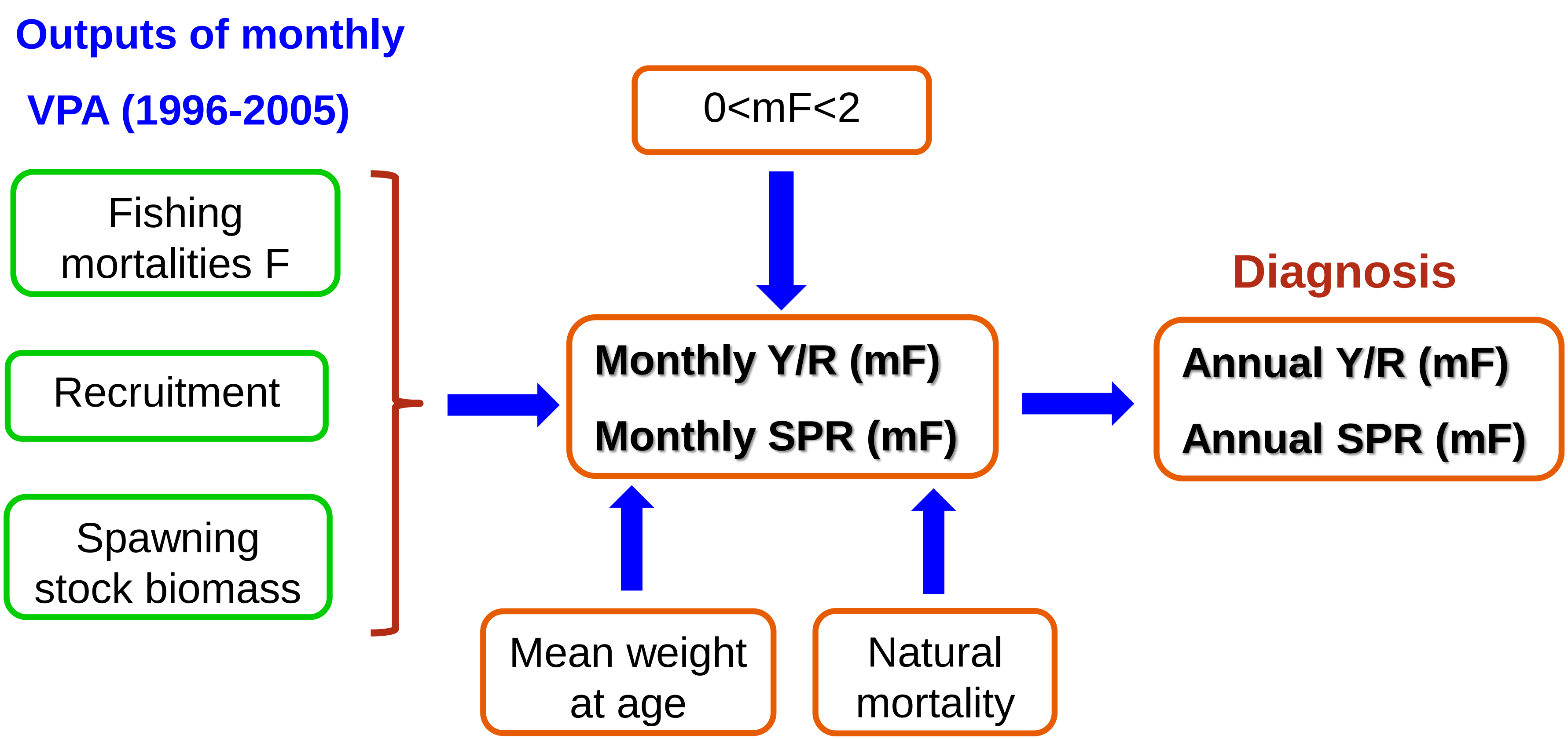
3. ENVIRONMENTAL EFFECTS ON STOCKS RECRUITMENT

- Interannual variability of recruitment due to environment
  - Two peaks of recruitment each year. The success of the yearly recruitment is significantly related to the upwelling intensity.
- What evolution of the stock on the long term?
  - The upwelling intensity significantly decreased over the 1996-2005 period: what will be the long term effects on the Senegalese octopus stock?
- Relationship between shrimp abundance and environment
  - Shrimp abundance was assessed depending on recruitment and environmental variability in the estuary (Laë, com. pers.)
- Even in this environmental variability, what status of Octopus and shrimp stocks?
  - Even in this high environmental variability, what is the fishing impact on the abundance of Octopus and shrimp stocks?

CONTENTS

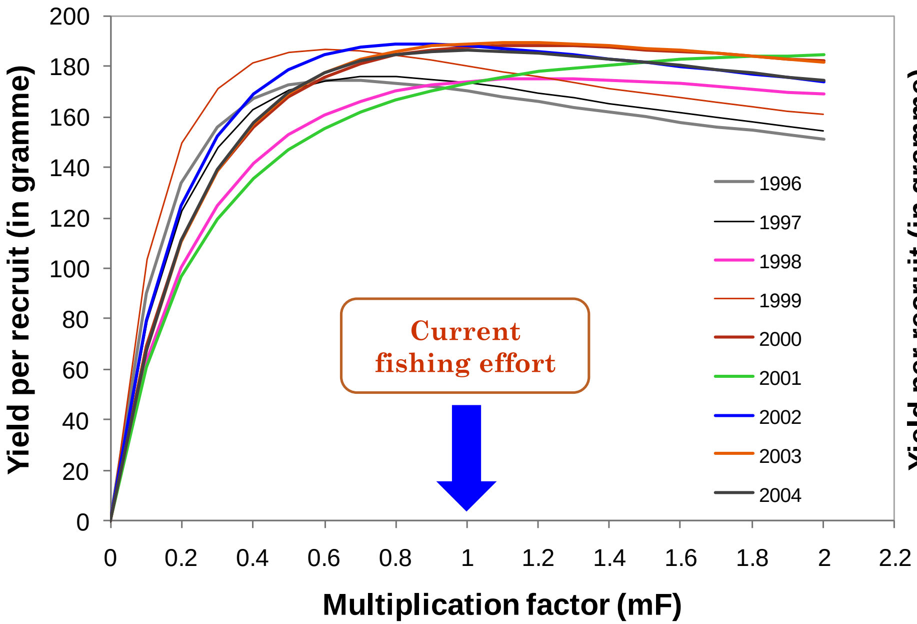
4.1. USING Y/R AND SPR TOOLS

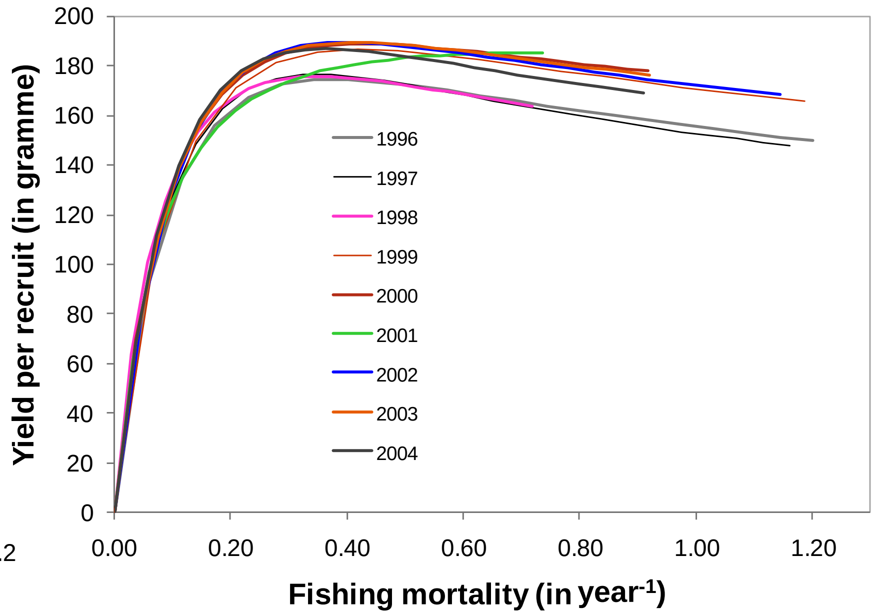




Thompson and Bell model (1934)

RESULTS FOR THE OCTOPUS STOCK

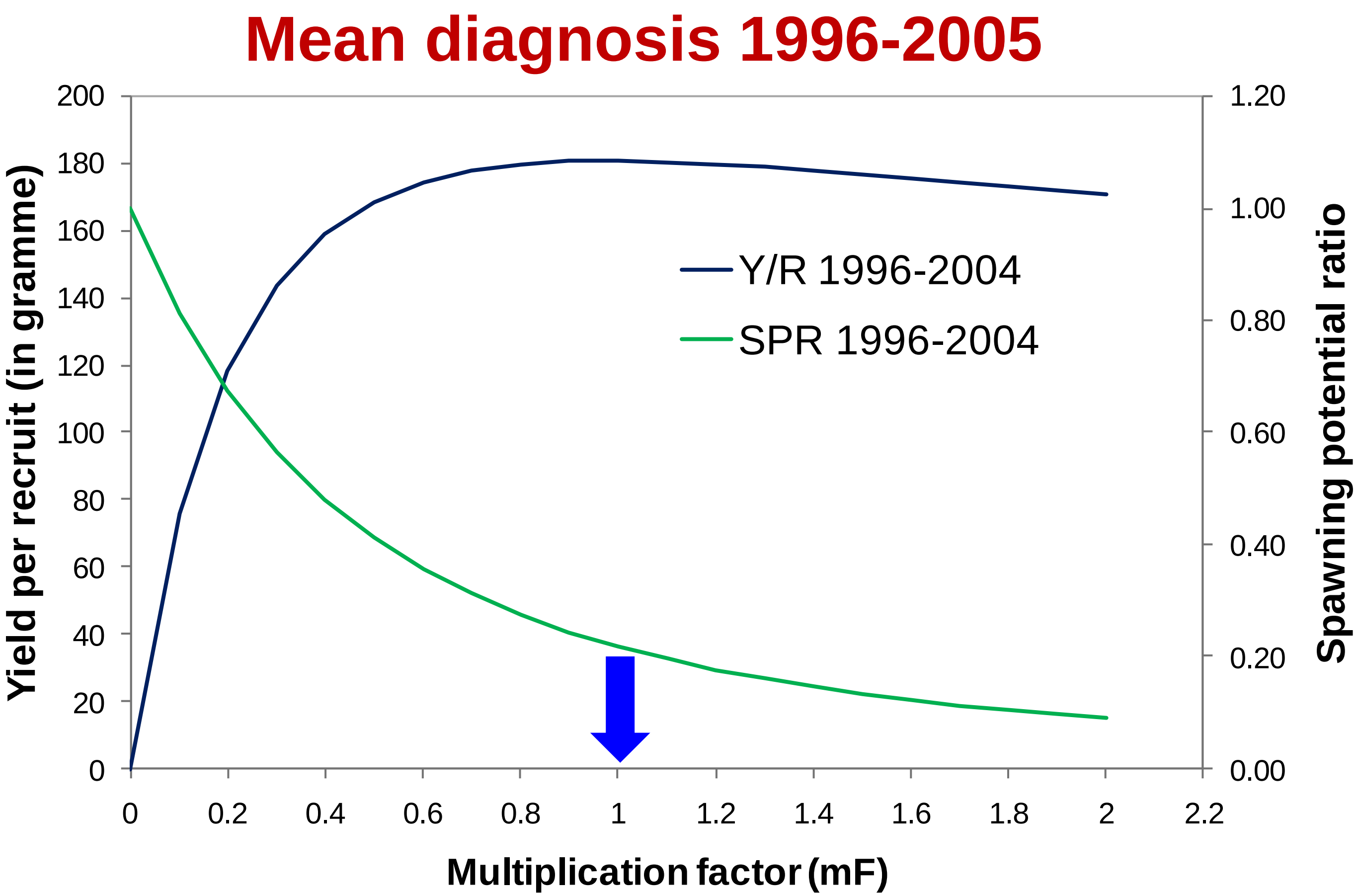




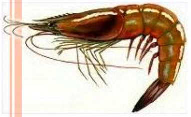
In Senegal, all of the cohorts are **close to full exploitation.**

However, recruitment overfishing might occur if adults are overexploited before spawning.

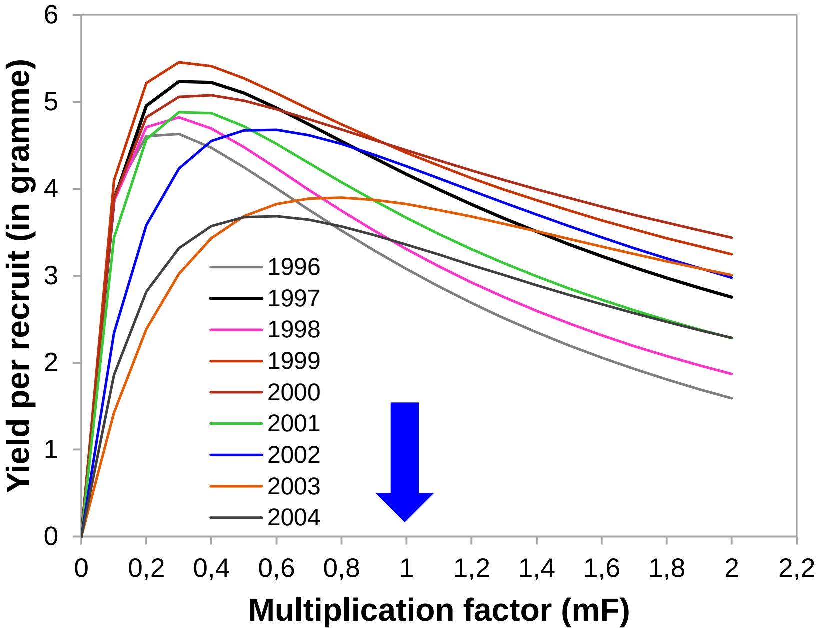
FISHING EFFECTS AND EXPLOITATION PATTERN



Actual spawning potential ratio was 25% compared to the unexploited stock.



RESULTS FOR THE SOUTHERN SHRIMP STOCK



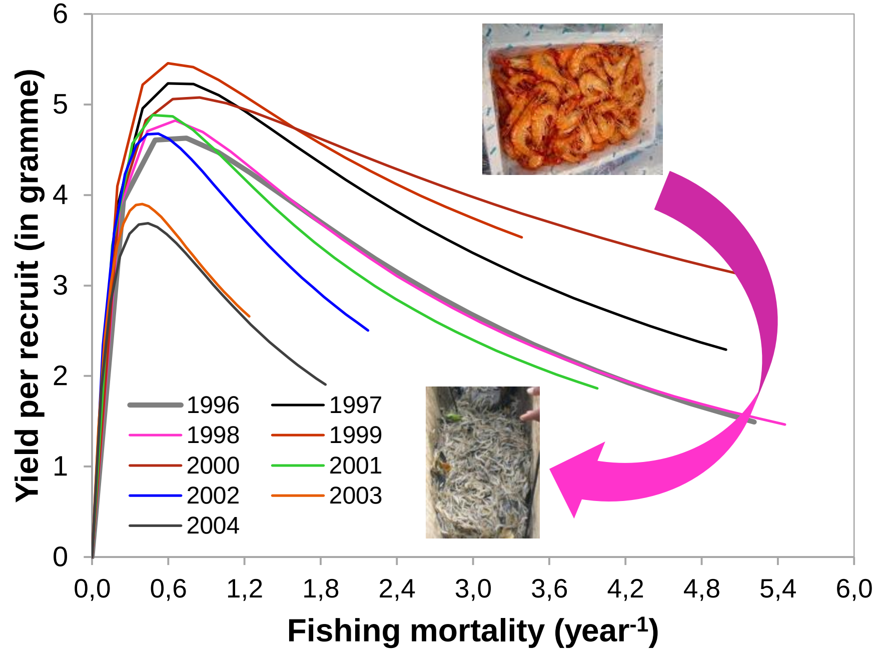
Diagnosis of stock status:

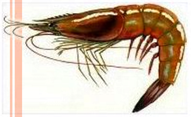
- **Curves are close similar (excepted the years 2002, 2003 and 2004)**
- **For each year, the stock is overfished**
- **Clear trend to decrease of Y/R**

Yield per recruit:

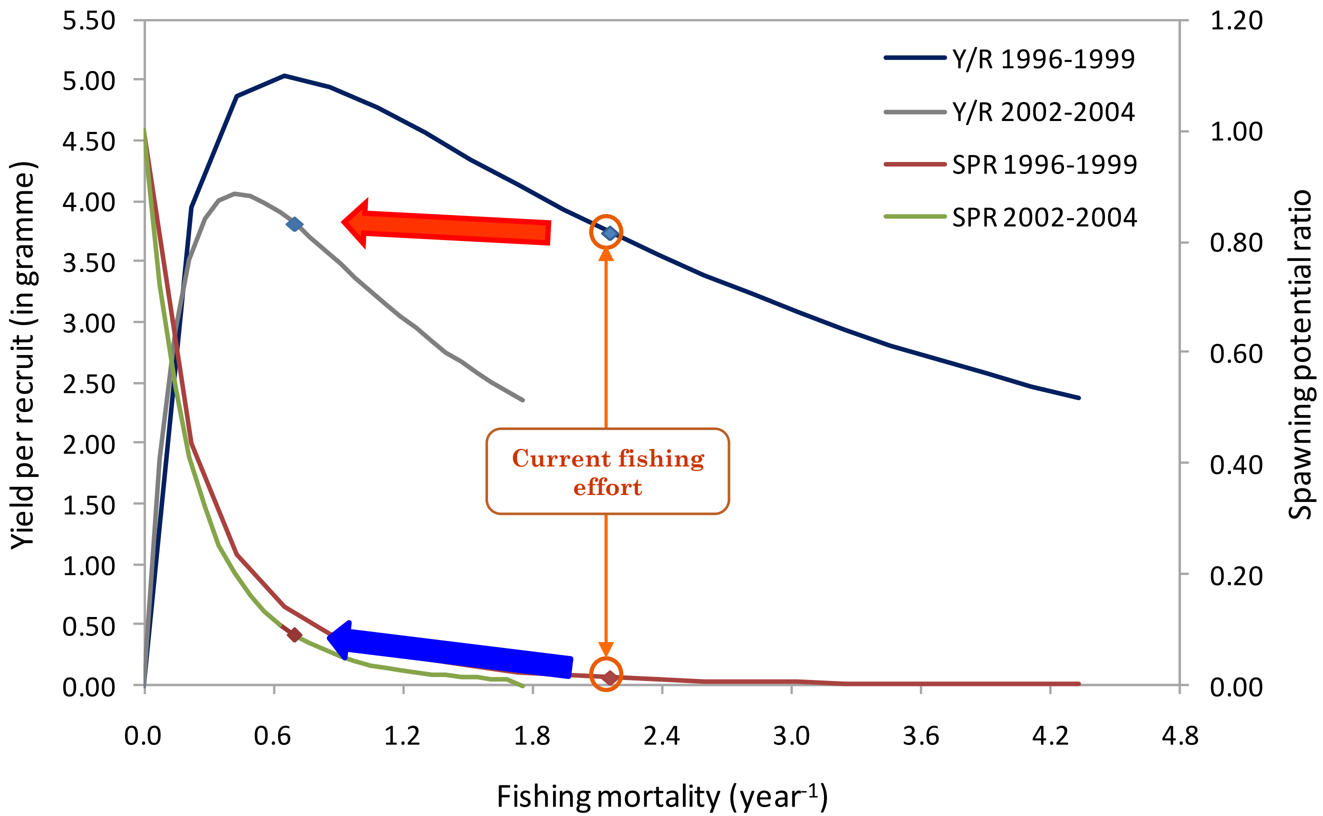
- **High year-to-year variability of Y/R**

  → **Different exploitation diagrams**
- **Decrease of length exploited shrimps**





FISHING EFFECTS ON SOUTHERN SHRIMP STOCK



Actual spawning potential ratio is lower than 10% compared to the unexploited stock.

CONTAINS

1. Context and case study

2. Dynamics of octopus and shrimps stocks (1996-2005)

3. Environmental effects on variability of Octopus abundance

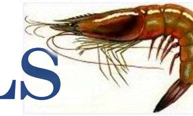
4. Diagnosis on stocks status in changing environment

    4.1. Using Y/R and SPR tools

    4.2. Surplus productions models

5. Conclusion

4.2. SURPLUS PRODUCTIONS MODELS



- **Fishing impact (Fox, 1970)**
- **Fishing and upwelling impacts (Freon, 1991)**

Total catches(Y_t)

Abundance AI_t GLM

Theorical fishing effort (E_t)

Upwelling V_t

Surplus production models (equilibrium)

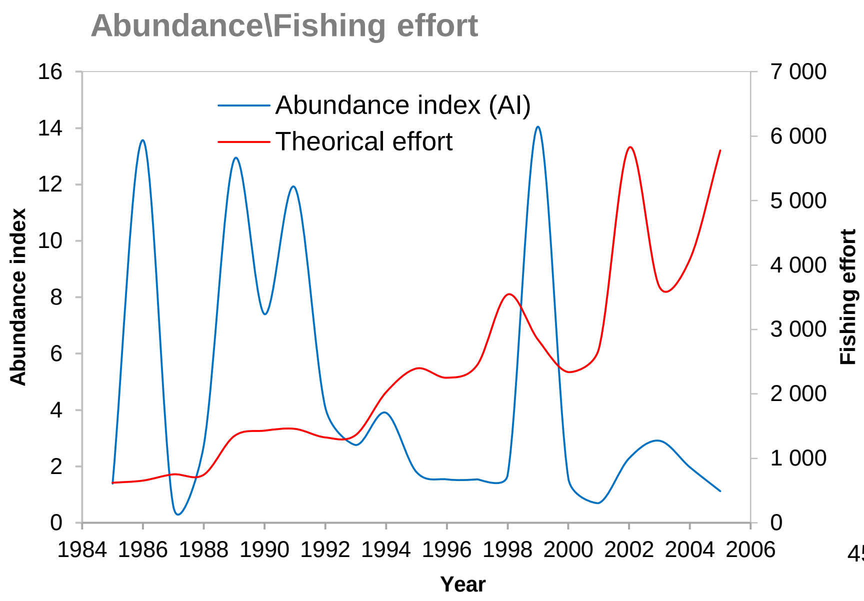
Fox model

Surplus production models (equilibrium) with environmental effect

Freon model

Model predictions:
- **Abundance (AI_t)**
- **Catches (Y_t)**

FISHING EFFECTS ON OCTOPUS STOCK

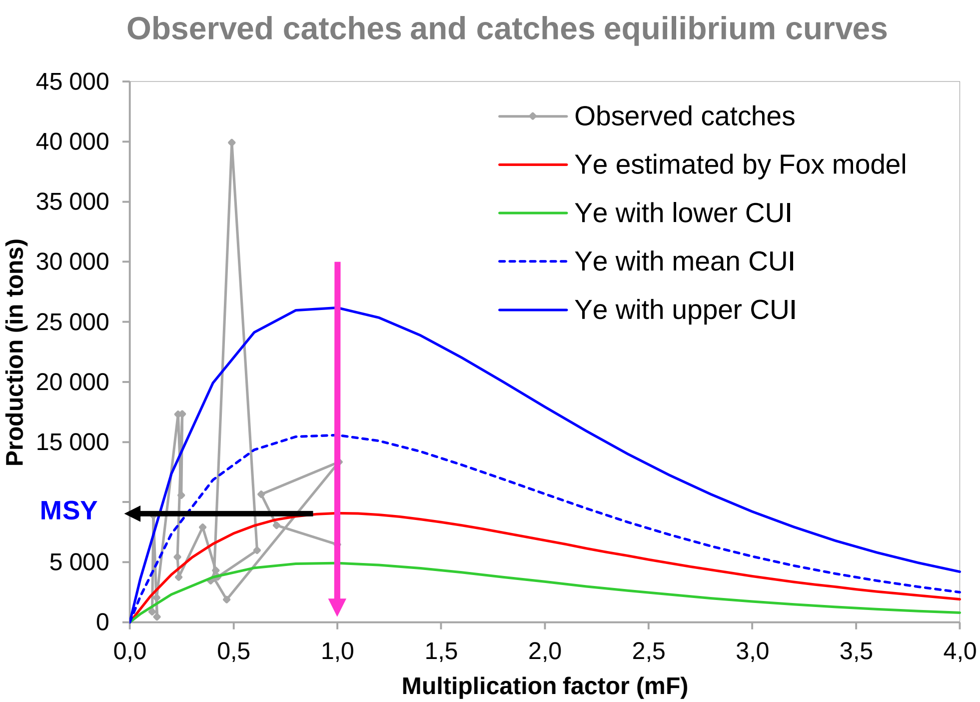


Abundance of Octopus stock:

- High year-to-year variability without trend
- Maximum: 1986, 1989, 1991 and 1999

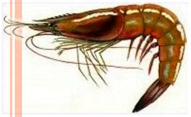
Fishing effort

- High increase

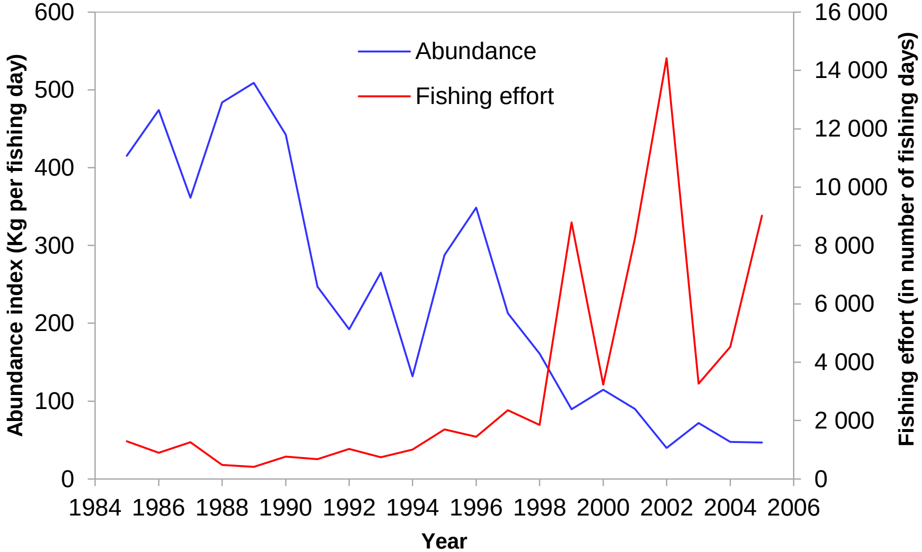


Diagnosis of Octopus stock

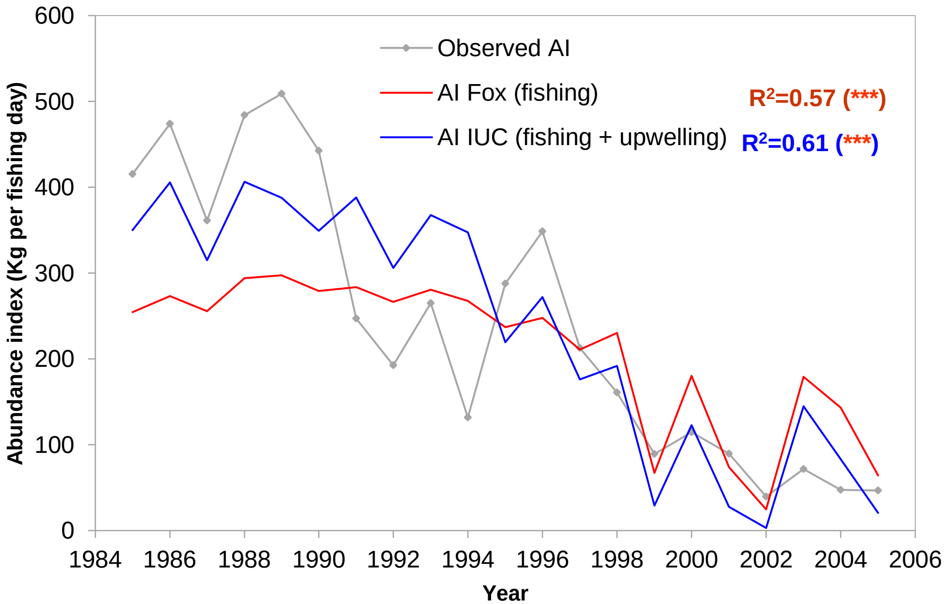
- Stock is close to full exploitation
- Annual catch is strongly affected by the upwelling intensity
- MSY changes according to the upwelling intensity
- For the Fox model, MSY= 9 000 tons



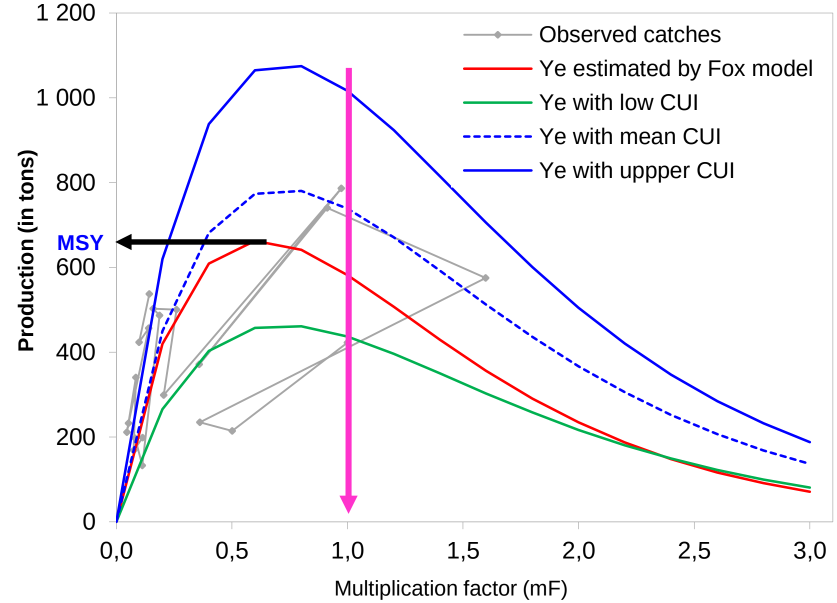
FISHING EFFECTS ON NORTHERN SHRIMP STOCK



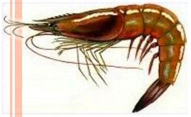
Abundance\Fishing effort\Upwelling



Observed catches and catch equilibrium curves predicted by the two models

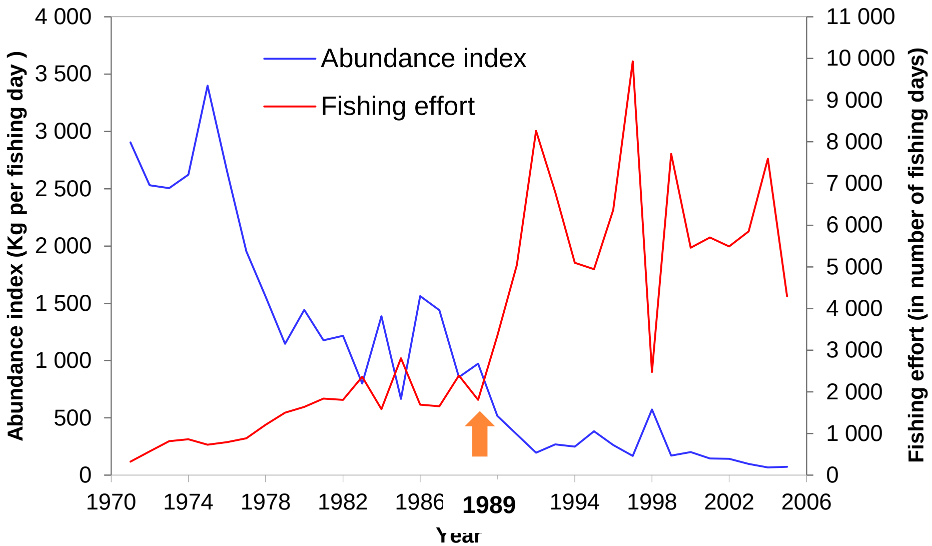


Equilibrium curves of catches are affected by the upwelling intensity. And for all curves, the northern shrimp stock is overfished.

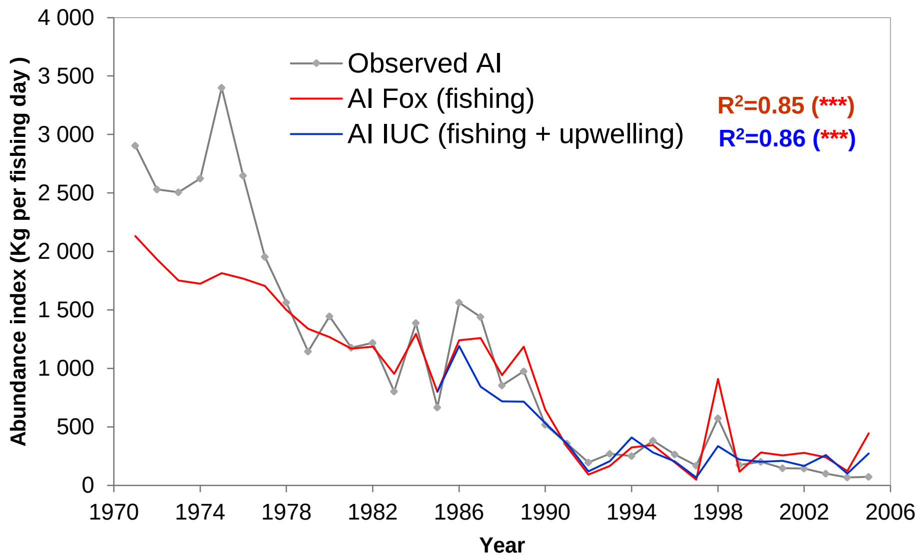


FISHING EFFECTS ON SOUTHERN SHRIMPS STOCK

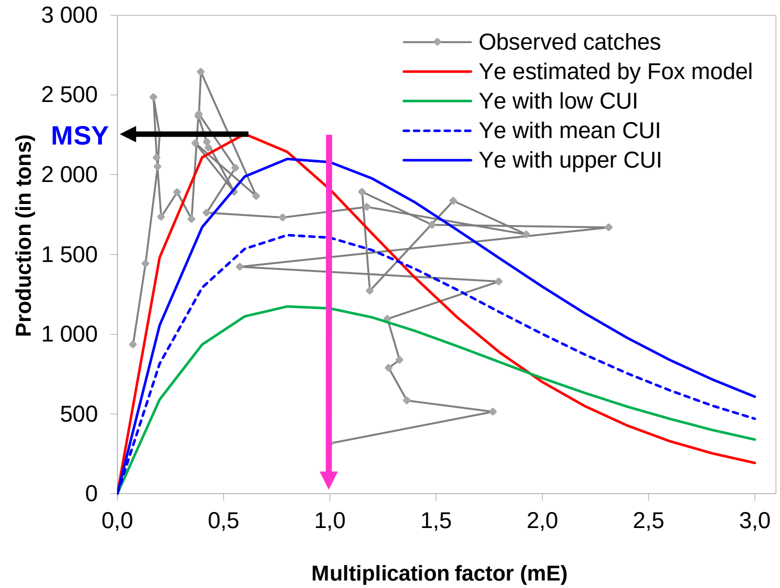
Abundance\Fishing effort



Abundance\Fishing effort\Upwelling



Observed catches and catch equilibrium curves predicted by the two models



Southern shrimp stock is significantly overfished (for the Fox model, MSY = 2 250 tons) and MSY changes according to the upwelling.

SUMMARY OF STOCKS DIAGNOSES

- **Diagnosis of Octopus stock**
  - **Exploitation patterns remain relatively constant.**
  - **Usual Y/R or SPR models provide useful tools for diagnosis.**
  - **Octopus stock is fully exploited or close to overexploitation**
  - **SPR is 25% compared to the unexploited stock.**
- **Diagnosis of shrimp stocks**
  - **Northern shrimps stock**
    - **Stock is overexploited.**
    - **The driving force of abundance seems to be the upwelling intensity.**
  - **Southern shrimps stock**
    - **Stock is strongly overexploited and less affected by environment.**
    - **Fishing induces a 5- to 10-fold reduction in the stock abundance.**
    - **SPR is lower than 10% compared to the unexploited stock.**
- **High variability of MSY depending of upwelling intensity**
  - **For short-lived species, MSY varies according to the upwelling intensity.**

Contents

CONCLUSION

- **What is the variability of the recruitment and biomass of short-lived species stocks?**
  - **Populations' dynamics of Octopus and shrimp stocks are variable from year-to-year, thus drawing away a high year-to-year variability of catches.**
- **What is the part of the variability of Octopus abundance linked to the environment (upwelling)?**
  - **Upwelling intensity influences the Octopus population dynamics.**
  - **Time series approach is a useful tool to study these relationships.**
- **In this variability context, what is the diagnosis on the stocks status?**
  - **Coastal upwelling explains a large part of the year-to-year variability in the abundance of octopus and shrimp stocks. Octopus stock is fully exploited or close overfished and shrimp stocks are overfished.**
- **Consequences for the Management**
  - **Necessity of taking into account of environment, fishing and the dynamics of populations, each being an essential component towards the implementation of improvement plan of octopus and shrimp stocks.**

Prospect

- Taking in account estuaries artisanal fisheries to improve diagnoses of shrimp stocks and to analyze fleet interactions
  - Taking in account artisanal fisheries data
  - Quantify the estuaries artisanal fishing effects on the marines shrimp stocks
- Application of depletion model
  - The annual life-cycle means that assessments have to be carried out on a real time basis if they are to be used to limit fishing effort or catch in the current season.
- Application of multispecies and bioeconomic models
  - In western African area, fisheries exploit several different species.
  - Fishery on point of view Economy?.
- Fishing effects of short-lived species on the ecosystem
  - Decreasing trend in shrimps (*Farfantepenaeus notialis*) abundance has occurred simultaneously in other shrimps populations of the sea.
  - Complex interactions between population structure and fishing

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QUESTIONS ?