

How global sensitivity analyses can support fisheries management?

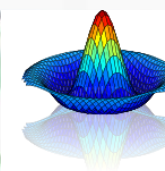
Stéphanie Mahévas, Sigrid Lehuta
EMH Ifremer - NANTES

Jean Couteau
Code Lutin - St Sebastien

Hervé Monod, Claude Bruchou
MIA, Inra - Jouy en Josas

Dominique Pelletier
STH Ifremer - Brest

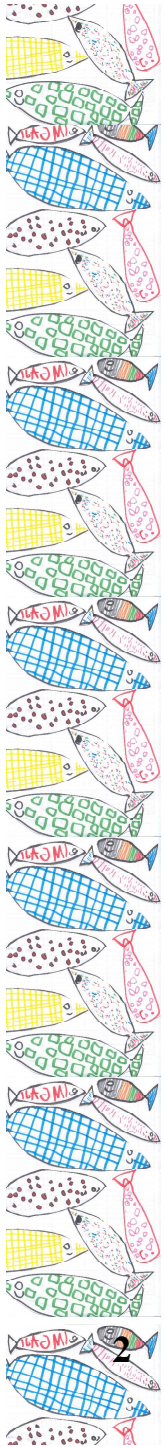
Ifremer



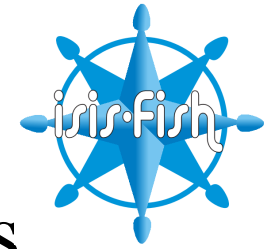
MEXICO
WEXICO


Origin of the work

- ISIS-Fish : an simulation model to investigate the impact of spatial management strategies on fisheries dynamics - Mixed fishery
- Integration of knowledge – different level of quality
- Operational tool (user-friendly interfaces) : as soon as the model is set up, running simulations is easy
- Danger = provide recommendations using outputs without taken into account for the uncertainties in inputs
- Propose some facilities for using an appropriate statistical framework to assess the influence of uncertainties on outputs






ISIS- Fish










 Simulation model of fisheries dynamics
Integration of processes' knowledge

 A modelling and simulation toolbox for which users?

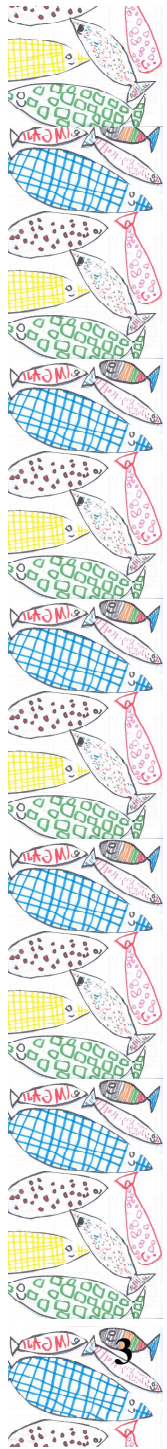
simplicity ↓

-  Modellers : to explore fisheries mechanisms
-  Fisheries scientists : to understand the dynamics of their own fisheries
-  *Managers : to compare management strategies*

 Main features (originality of the model)

-  Mixed fisheries
-  Explicitly spatial
-  Fishermen behaviours
-  bio-economic
-  Assessment of management strategies
-  flexible (knowledge is sometimes uncertain)
-  generic (to adress large questions on fisheries)

(Mahévas et Pelletier Ecological Modelling 2004, Pelletier, Mahévas, Thébaud, Gyuader, Drouineau, Vermard, Ecological Modelling Poussin 2009)



Integration of knowledge

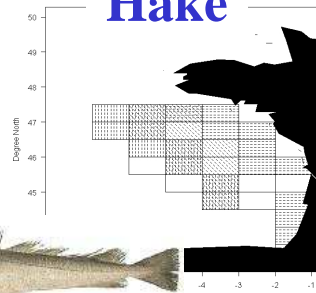
Demersal fishery in the bay of Biscay

Mixed fishery

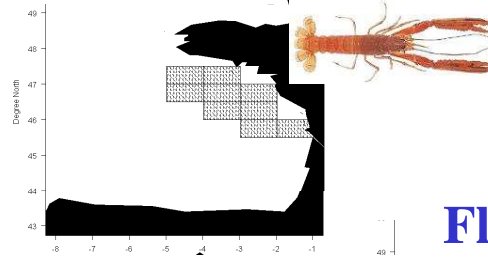
- French and Spanish fleets (single/twin trawl, off and in -shore)
- Hake, Nephrops, Megrim, Monkfish

Spatial and seasonal distributions

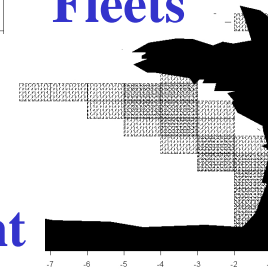
Hake



Nephrops

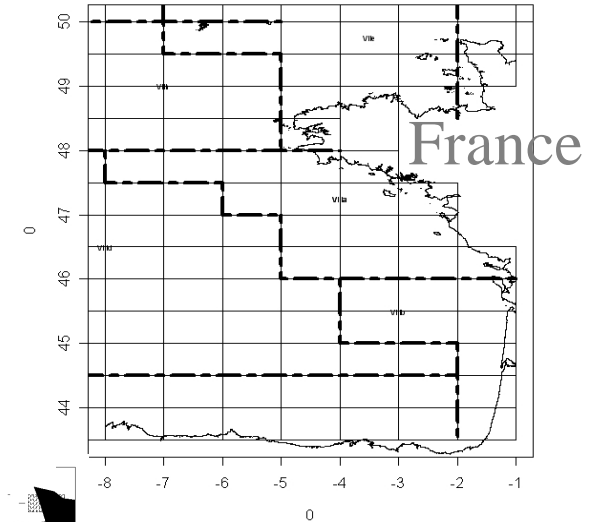
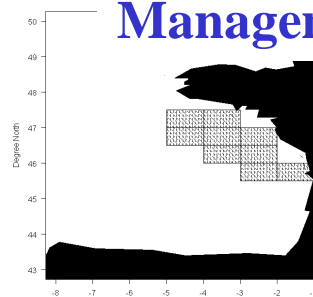


Fleets

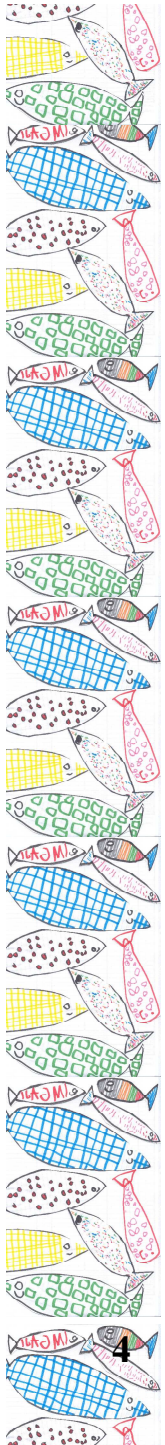


Technical Interactions

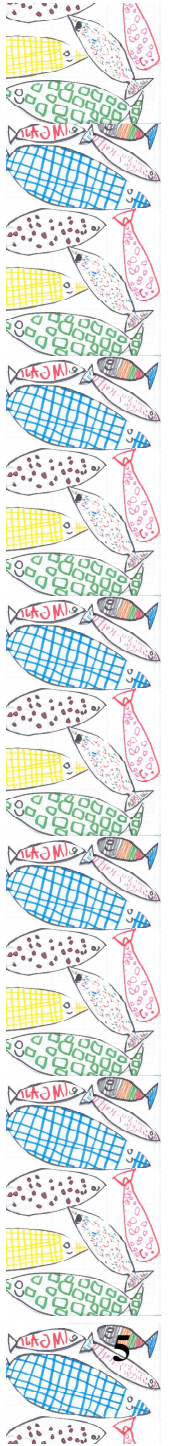
Management



Assessing the impact of management measures : Marine protected areas ? Selectivity ? Seasons ? Zones ?



Dealing with uncertainty in simulation model

- 
- Several types of uncertainty
 - Structure of the model (scale, chronology...)
 - Processes (lack of knowledge in biology, fishermen behaviours, ...)
 - Parameters (estimation errors, observation errors,...)
 - Inputs variables
 - Using the model to provide advises, recommendations,...
 - What is the robustness of the pronostics ?
 - Identification of sensitive factors using global sensitivity analyses
 - Limit the uncertainty analysis to sensitive factors

Global sensitivity analysis

• Non-analytical model – global sensitivity analysis = rational numerical approach

• Local sensitivity analysis (one parameter by one parameter) :

• $2 * (\text{Nb of parameters})$ simulations (min, max)

• Elasticity coefficient for each factor ($[Y(\text{min}) - Y(\text{max})] / Y(\text{ref})$)

• Global sensitivity analysis with few factors – full experimental design

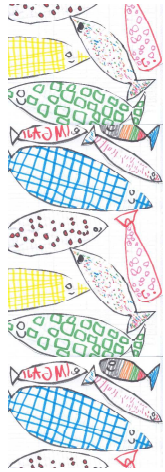
• $2^{\text{Nb of parameters}}$ simulations (min, max)

• Sensitivity coefficient ($\text{Var}(\text{factor}) / \text{Var}(Y)$)

• Global sensitivity analysis with many factors – optimized experimental design

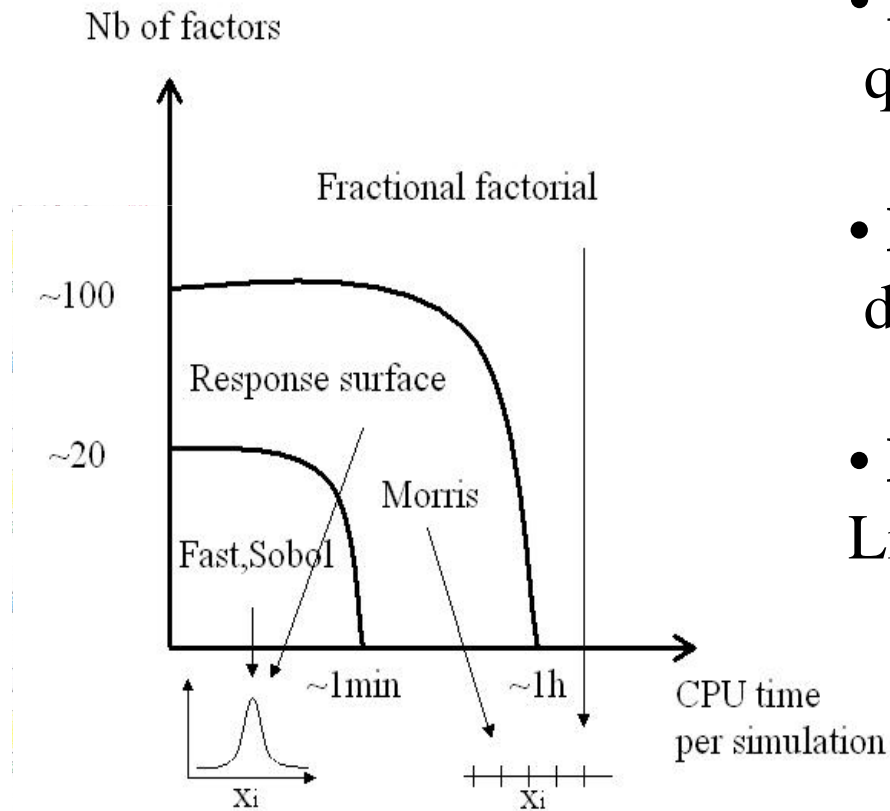
• Each factor is characterized by its range of variation (uncertainty)

• The number of simulations is link to sampling intensity within factors' ranges of variation



Selecting a strategy to explore the model is equivalent to jointly select

- an experimental design (set of simulations)
- a statistical method to analyse the experimental design's outputs



- Few factors and short** simulation time
quasi-continuous exploration of factors

FAST, SOBOL method

- Many factors or long** simulation time
discrete exploration

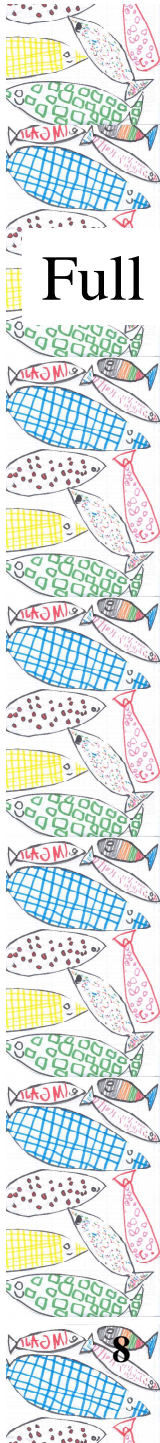
Morris method

- Many factors and long** simulation time
Limited exploration (min, max)

Fractional factorial design

Sensitivity coefficients are derived from aov coefficient estimates





Factor name	Nominal	Binf	Bsup
nephrops,naturalDeathRate		1	0,95
nephrops,reproductionEquation		1	0,95
nephrops,price		1	0,95
nephrops,meanWeight		1	0,95
nephrops,capturability		1	0,95

Full design considering two modalities for each factor (Binf=0, Bsup=1)

Simu	M	Reproduction	Price	MeanWeight	Catchability	RelativeY6	CatchWeight	SSBRelativeY5
1	0	0	0	0	0	7.84470752843988	1881036.3992	21.2263484933522
2	1	0	0	0	0	6.69681961394117	1594150.8920	18.0070973879002
3	0	1	0	0	0	9.1927310051629	2242624.328	24.0364173669246
4	1	1	0	0	0	7.8534188611932	1902422.188	20.3980314209795
5	0	0	1	0	0	7.82092247328178	1878083.578	21.1616983470665
6	1	0	1	0	0	6.67592832053481	1591840.692	17.9508335946425
7	0	1	1	0	0	9.16528101000986	2238734.784	23.9641685926834
8	1	1	1	0	0	7.82923311402626	1899396.984	20.3350166299913
9	0	0	0	1	0	7.82092247328178	2075776.587	21.1616983470665
10	1	0	0	1	0	6.67592832053481	1759402.870	17.9508335946425
11	0	1	1	1	0	9.1000987	2474391.077	23.9641685926834
12	1	1	1	1	0	7.8402626	2099333.509	20.3350166299913
13	0	0	1	1	1	4239378	2072449.594	21.1006040618130
14	1	0	1	1	1	1812187	1757010.702	17.8976850708944
15	0	1	1	1	1	9.13950814250357	2469590.188	23.8960672777244
16	1	1	1	1	1	7.80641722645406	2096191.222	20.2755291275286
17	0	0	0	0	0	7.38831996125177	1807307.862	20.0096539719601
18	1	0	0	0	0	6.30730733158227	1531831.805	16.9748360732622
19	0	1	0	0	0	8.65788772644396	2155188.141	22.6578601258642
20	1	1	0	0	0	7.39662620319111	1828328.552	19.2280363355192
21	0	0	1	0	0	7.36632381050972	1804897.137	19.9499929895077
22	1	0	1	0	0	6.28808249982786	1529908.904	16.9232026626403
23	0	1	1	0	0	8.63259961027176	2151463.146	22.5913010600125
24	1	1	1	0	0	7.37433791009118	1825847.982	19.1701293430429
25	0	0	0	0	1	7.36632381050972	1994886.310	19.9499929895077
26	1	0	0	0	1	6.28808249982785	1690951.947	16.9232026626403
27	0	1	0	0	1	8.63259961027175	2377932.951	22.5913010600125
28	1	1	0	0	1	7.37433791009117	2018042.507	19.1701293430429
29	0	0	1	1	1	7.34533670443393	1991642.380	19.8928095206271
30	1	0	1	1	1	6.26966845584448	1688731.921	16.8736030873832
31	0	1	1	1	1	8.60843523686678	2373442.289	22.5274895814798
32	1	1	1	1	1	7.35308284949648	2014831.296	19.114661434582

All interactions effects can be estimated

$$Y \sim (M+Reproduction+Price+W+C)^5$$

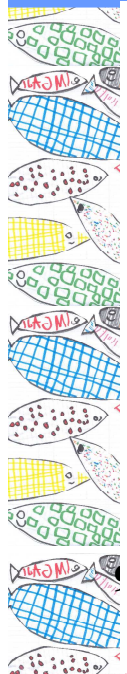
Fractional factorial 2-level design of resolution 5

considering two modalities per factor (Binf,Bsup)

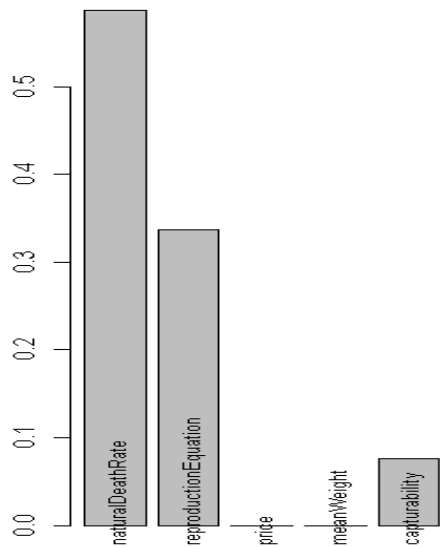
Simu	M	Reproduction	Price	MeanWeight	Catchability	RelativeBY6	BiomassY3	CatchWeightY1	SSBRelativeY5
1	0	0	0	0	0	7.84470752843988	5.45654541914326	1881036.39926196	21.2263484933522
2	0	0	0	0	1	7.36632381050972	4.79469228652062	1994886.31039382	19.9499929895077
3	0	0	0	1	0	7.36632381050972	4.79469228652061	1804897.13797536	19.9499929895077
4									006040618130
5									578601258642
6									641685926834
7									641685926834
8									274895814798
9									748360732622
10									508335946425
11	1	0	1	0	0	6.67592832053481	4.63072958289939	1591840.69234175	17.9508335946425
12	1	0	1	1	1	6.26966845584448	4.07032054992059	1688731.92168077	16.8736030873832
13	1	1	0	0	0	7.8534188611932	5.53422383865651	1902422.18838124	20.3980314209795
14	1	1	0	1	1	7.37433791009117	4.86405200434529	2018042.50739256	19.1701293430429
15	1	1	1	0	1	7.37433791009118	4.86405200434528	1825847.98287898	19.1701293430429
16	1	1	1	1	1	7.80641722645406	5.51715293307611	2096191.22291094	20.2755291275286

Extract combinations of factors modalities to estimate main effects and 2nd-order interactions

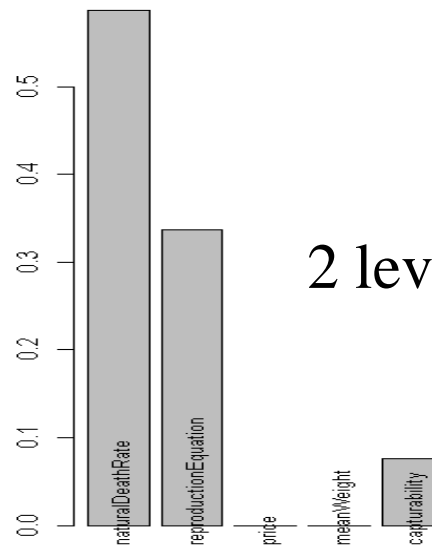
$$Y \sim (M+Reproduction+Price+W+C)^2$$



Complet 2 mod Y5 - SS regle



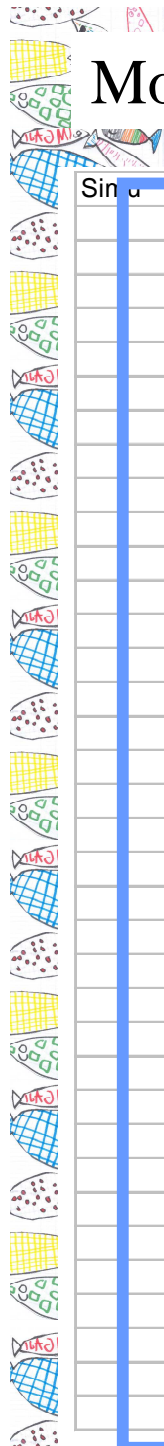
FactFrac5 mod Y5 - SS regle



2 levels = assume linear effects

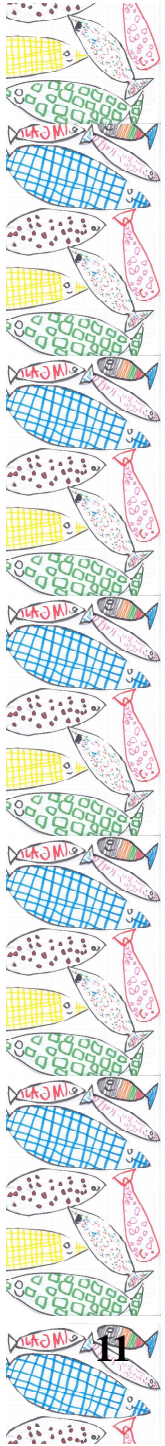
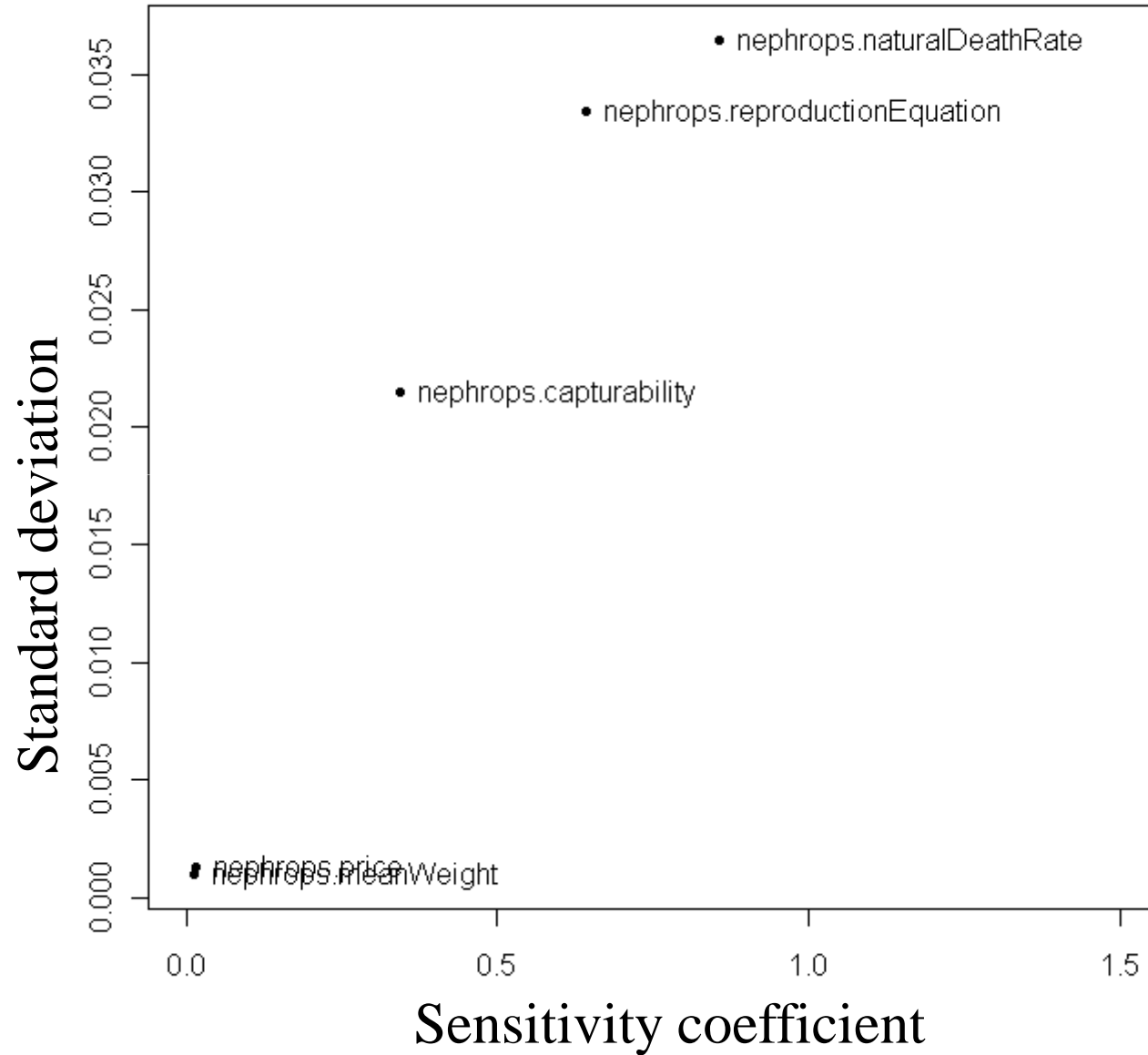
Sensitivity coefficient

Morris method exploring the range of variation of each factor



Simulation	Reproduction	Price	MeanWeight	Catchability	RelativeY6	CatchWeightY1	SSBRelativeY5	
1	0,00	0	0,5	0,83333333	0,16666667	7,732606969	23165128,6	5,326193879
2	0,50	0	0,5	0,83333333	0,16666667	7,143947379	21174807,52	4,910591596
3	0,50	0,5	0,5	0,83333333	0,16666667	7,745058718	22956513,94	5,370522349
4	0,50	0,5	1	0,83333333	0,16666667	7,734294309	22924608,01	5,366469359
5	0,50	0,5	1	0,33333333	0,16666667	7,745243256	21845876,94	5,370586526
6	0,50	0,5	1	0,33333333	0,66666667	7,515508824	21094022,83	5,036433632
7	0,00	0,5	0,5	0,66666667	0	8,472581512	25029913,13	5,954812268
8	0,50	0,5	0,5	0,66666667	0	7,829059051	22883692,57	5,491541403
9	0,50	1	0,5	0,66666667	0	8,465911546	24745159,79	5,988564988
10	0,50	1	0	0,66666667	0	8,478815317	24782876,44	5,993326816
11	0,50	1	0	0,16666667	0	8,491818054	23600583,33	5,998514974
12	0,50	1	0	0,16666667	0,5	8,236104898	22777455,9	5,619459222
13	0,67	0,16666667	1	0,83333333	0,5	6,997366523	20597676,08	4,715106122
14	0,17	0,16666667	1	0,83333333	0,5	7,573523775	22532530,88	5,112876417
15	0,17	0,66666667	1	0,83333333	0,5	8,202510599	24403874,45	5,584360392
16	0,17	0,66666667	0,5	0,83333333	0,5	8,213734318	24437266,94	5,589476313
17	0,17	0,66666667	0,5	0,33333333	0,5	8,225460163	23287634,78	5,594057172
18	0,17	0,66666667	0,5	0,33333333	1	7,987769627	22504473,48	5,255340976
19	0,17	0,33333333	0,5	0,16666667	1	7,571903065	20985596,94	4,951446443
20	0,67	0,33333333	0,5	0,16666667	1	6,996709451	19185815	4,56567897
21	0,67	0,83333333	0,5	0,16666667	1	7,572670617	20765169,47	4,984634653
22	0,67	0,83333333	0	0,16666667	1	7,584394749	20797318,45	4,988056033
23	0,67	0,83333333	0	0,66666667	1	7,57286731	21839426,97	4,984694505
24	0,67	0,83333333	0	0,66666667	0,5	7,798252597	22599640,53	5,30580995
25	0,50	0,66666667	1	0,66666667	0	8,030898551	23473652,75	5,653049899
26	1,00	0,66666667	1	0,66666667	0	7,421553923	21462724,56	5,214014307
27	1,00	0,16666667	1	0,66666667	0	6,850446089	19811112,21	4,771248346
28	1,00	0,16666667	0,5	0,66666667	0	6,860378989	19839837,61	4,774291119
29	1,00	0,16666667	0,5	0,16666667	0	6,870844318	18893204,89	4,778073781
30	1,00	0,16666667	0,5	0,16666667	0,5	6,664113574	18234661,13	4,476136413
31	0,50	0,5	0,33333333	0,16666667	0,5	7,608796945	21042597,08	5,149823089
32	1,00	0,5	0,33333333	0,16666667	0,5	7,031418756	19239698,85	4,749153228
33	1,00	1	0,33333333	0,16666667	0,5	7,604700186	20808338,47	5,180576677
34	1,00	1	0,83333333	0,16666667	0,5	7,593334236	20777238,43	5,1769642
35	1,00	1	0,83333333	0,66666667	0,5	7,582198525	21819507,17	5,173286248
36	1,00	1	0,83333333	0,66666667	0	7,817188991	22606879,35	5,521282638

Morris 7 mod Y5 - SS regle



Fichier Fenêtre Configuration Aide

Simulation

Paramètres Analyse de sensibilité Méthode de la sensibilité Export des résultats Choix de résultats Paramètres avancés Analyse des résultats

Charger une ancienne simulation

as_as_fast_ss_regles_2009-08-28-12-09_0_2009-09-03-10-29_0 [Filtrer] [Remise à zéro du filtre]

Nom de l'analyse de sensibilité is_as_fast_ss_regles_2009-08-28-12-09_0_2009-09-03-10-29_0 Région Golfe de Gascogne

Description

FAST Sensitivity Analysis 5 parameters - no management measure

Nombre d'années 10

Stratégies

- HakeIntermediateGuilvinec
- BenthicIntermediateLesSables
- NephropsIntermediateGuilvinec
- HakeLargeGuilvinec
- BenthicLargeLesSables
- BenthicLargeGuilvinec
- BenthicIntermediateGuilvinec

Populations

nephrops

Règles

GraviteVPUE1LangEtGrossValueOtherSpeciesECOMOD

GraviteVPUE1LangEtGrossValueOtherSpeciesECOMOD

[Ajouter] [Supprimer] [Effacer]

Données de population Paramètres des règles

	zone L21E7	zone L21E8	zone L22E6	zone L22E7	zone L23E5	zone L23E6	zone L23E7	zone L24E5	zone L24E6
nephrops G...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nephrops G...	5.98E7	5.98E7	5.98E7	5.98E7	5.98E7	5.98E7	5.98E7	5.98E7	5.98E7
nephrops G...	4977000.0	4977000.0	4977000.0	4977000.0	4977000.0	4977000.0	4977000.0	4977000.0	4977000.0
nephrops G...	2944000.0	2944000.0	2944000.0	2944000.0	2944000.0	2944000.0	2944000.0	2944000.0	2944000.0
nephrops G...	1177000.0	1177000.0	1177000.0	1177000.0	1177000.0	1177000.0	1177000.0	1177000.0	1177000.0
nephrops G...	461000.0	461000.0	461000.0	461000.0	461000.0	461000.0	461000.0	461000.0	461000.0
nephrops G...	195000.0	195000.0	195000.0	195000.0	195000.0	195000.0	195000.0	195000.0	195000.0
nephrops G...	95000.0	95000.0	95000.0	95000.0	95000.0	95000.0	95000.0	95000.0	95000.0
nephrops G...	52000.0	52000.0	52000.0	52000.0	52000.0	52000.0	52000.0	52000.0	52000.0
nephrops G...	58000.0	58000.0	58000.0	58000.0	58000.0	58000.0	58000.0	58000.0	58000.0

Exporter uniquement des simulations

Lanceur de simulation dans un sous processus [Simuler] [Sauver les paramètres de la simulation]

Région chargée 34/51 Mo 09:39

Fichier Fenêtre Configuration Aide

Simulation

Paramètres Analyse de sensibilité Méthode de la sensibilité Export des résultats Choix de résultats Paramètres avancés Analyse des résultats

Saisie des reproductions Saisie des groupes de population Saisie de la capturabilité Migration

Saisie des populations Zones Saisons Saisie des équations

Taux de mortalité naturelle nephrops

Sauver comme modèle

Ouvrir l'éditeur

```
4 else if (group.getId() == 1) return Ktemp*0.25;
5 else if (group.getId() == 2) return Ktemp*0.2;
6 else if (group.getId() == 3) return Ktemp*0.2;
7 else if (group.getId() == 4) return Ktemp*0.2;
8 else if (group.getId() == 5) return Ktemp*0.2;
9 else if (group.getId() == 6) return Ktemp*0.2;
10 else if (group.getId() == 7) return Ktemp*0.2;
11 else if (group.getId() == 8) return Ktemp*0.2;
12 else if (group.getId() == 9) return Ktemp*0.2;
13 else return 0;
```

Poids moyen nephrops

Sauver comme modèle

Ouvrir l'éditeur

```
6 case 2: return Ktemp*0.00904;
7 case 6: return Ktemp*0.0473;
8 case 5: return Ktemp*0.0317;
9 case 3: return Ktemp*0.015;
10 case 9: return Ktemp*0.194;
11 case 4: return Ktemp*0.022;
12 case 8: return Ktemp*0.114;
13 case 0: return 0.0;
14 default: return 0;
15 )
16
```

Prix nephrops

Sauver comme modèle

Ouvrir l'éditeur

```
6 case 2: return Ktemp*20.0;
7 case 6: return Ktemp*60.0;
8 case 5: return Ktemp*50.0;
9 case 3: return Ktemp*30.0;
10 case 9: return Ktemp*80.0;
11 case 4: return Ktemp*40.0;
12 case 8: return Ktemp*80.0;
13 case 0: return 0.0;
14 default: return 0;
15 )
16
```

Sauver Annuler

Continuer vers les engins

Région chargée

32/51 Mo 09:43

Simulation

methode SensitivityCalculatorRMorris

Nom	valeur
r	4
modifR	false

Facteur	Cardinalité
nephrops.naturalDeathRate	7
nephrops.reproductionEquation	7
nephrops.price	7
nephrops.meanWeight	7
nephrops.capturability	7

Export

- SensitivityBiomassReferenceY9.java
- SensitivityBiomassRelativeReferenceY12.java
- SensitivityBiomassRelativeY6.java
- SensitivityBiomassY3.java
- SensitivityCapturesWeightReferenceY7.java
- SensitivityCapturesWeightRelativeReferenceY10.java
- SensitivityCapturesWeightRelativeY4.java
- SensitivityCapturesWeightY1.java
- SensitivityGenitorBiomassReferenceY8.java
- SensitivityGenitorBiomassRelativeReferenceY11.java
- SensitivityGenitorBiomassRelativeY5.java
- SensitivityGenitorBiomassY2.java

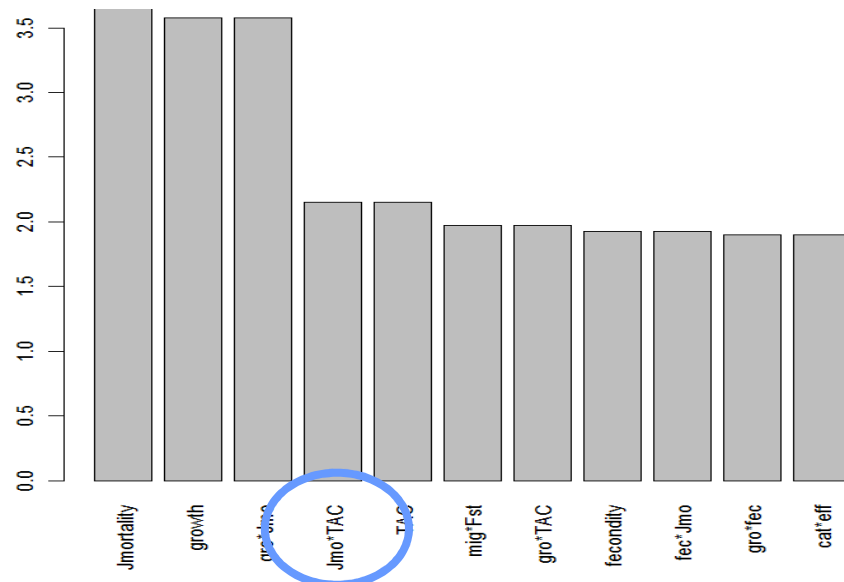
- SensitivityCapturesWeightY1
- SensitivityBiomassY3
- SensitivityCapturesWeightRelativeY4
- SensitivityGenitorBiomassY2

Ajouter
Supprimer
Effacer

Nom	Valeur
pop	nephrops

Is the assessment of TAC efficiency dependant on the uncertainty on fisheries parameters?

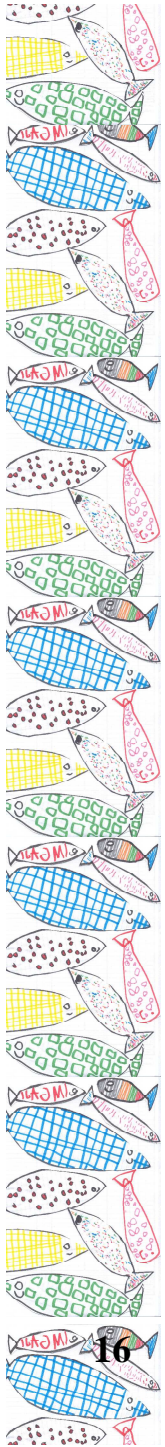
- Pelagic fishery of the bay of Biscay
- 279 uncertain parameters (+-20%) {Min,Ref,Max}
- (full design = 3^{279} 1.308670e+133)
- ~10 minutes per simulation
- Outputs : catches and biomass
- « group screening » + fractional factorial 3-levels+ Partial Least Square model (PLS) : 256 simulations



Large influence of species natural mortality on the pronostic of TAC impact

Conclusions

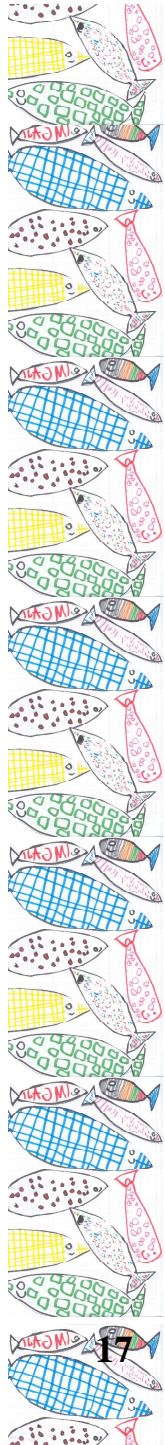
- Global sensitivity analysis is an appropriate tool
 - to simplify uncertainty analysis
 - to explore fisheries functioning
 - to point out some key fishery processes (new observations)
- Facilities in ISIS-Fish to deliver a pronostic of management measure's impact including uncertainties in inputs(for instance fishermen behaviour)
- Investigate the sensitivity of time and spatial scale on the pronostic





Conclusions - Modèle

- Travail de collaboration (multi-compétences)
- Modèle original (spatial, dynamique de flottille, bio-économique)
- Confrontation aux observations (bouclage)
- Processus de modélisation + paramétrisation très long (jusqu'à 1 an)
- De nombreuses applications en cours
 - morue de mer Baltique,
 - poissons plats de Manche
 - sar de Banuyls,
 - hoki de Nouvelle Zélande,
 - pêche mixte côtière d'Australie,
 - sar bouche des bouches de Bonifacio,
 - langouste Iroise
 - lagon sud Nouméa , ...
- Exploration du fonctionnement des pêcheries
- Mise en évidence du besoin d'un retour vers l'observation (nouvelles estimations/observations)



Conclusions

- Poser des éléments de réflexion sur la pertinence du niveau de complexité et de la validité du modèle
 - combiner différents niveaux de complexité – dynamique de flottille, dynamique de population + modèle global
 - pertinence du choix des échelles temporelles de modélisation
- Confrontation permanente entre observer et modéliser : dualité entre approche mécaniste et statistique
- Consolider les connaissances sur la dynamique de flottille et la relation captures~effort
- Pas suffisamment explorer les propriétés mathématiques
- Incertitudes : des avancées mais reste à améliorer l'exploration des domaines de variations (effets non linéaires, prise en compte des corrélations) - Théorie du fossé de l'information

