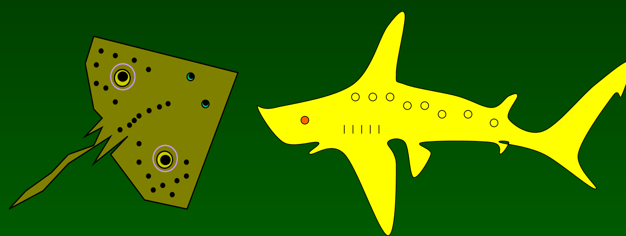
Use of a Leslie matrix for the assessment of the exploitation status of *Raja asterias*, *Raja clavata*, *Scyliorhinus canicula* and *Galeus melastomus*



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Life history

- Stock assessment needs of information on stocks and fisheries, and when we deal with elasmobranch species, often such information is lacking or is partial.
- The approaches based on life history traits can be used for modelling population dynamics in elasmobranchs (Hoenig and Gruber, 1990; Cortés, 1998, 2002; Smith et al, 1998; Simpfendorfer, 1999; Mollet and Cailliet, 2002).

- A demographic analysis (Leslie matrix) that rely primarily on life history parameters was used for the definition of the status of the stock regarding its capacity of self-renewal
- Leslie matrices are based on the Euler-Lotka equation, and needs of the definition of the survival at age, fecundity at age (female pups per female), age at maturity, and maximum reproductive age.

The basic equation is the Euler-Lotka :

$$\sum_{t=0}^{w} l_t \times m_t \times e^{-rt} = 1$$

where *lt* is the proportion of animals surviving to the beginning of a given age class, *mt* the age specific natality, *w* is the maximum reproductive age, *t*=age and *r* is the intrinsic population growth rate

Life tables and Leslie matrices

- It allows estimating the finite or annual rate of change from the estimated values of *r*.
- the offspring number of an individual female belonging to a certain age
- the mean generation length (the average time that occur between the birth of a parent and the birth of their offspring):
- And other estimates as the time needed for the unexploited population for doubling its size and the stable proportion of each age *Pt* in the total demographic distribution of the population
- It is also possible to estimate the intrinsic capacity for increase despite of the particular condition of the environment *rm*

Information needed

- Fecundity at age
- Survival rates at age
- lifespan

Raja asterias

Fecundity at age

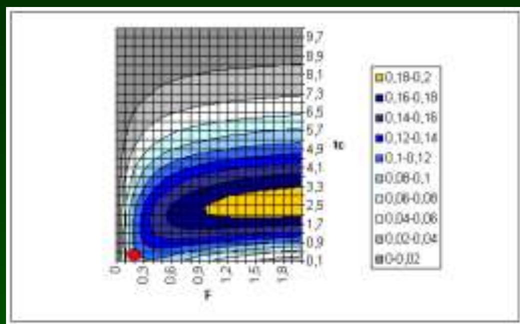
Surviving fractions by age

Stock assessment: *Raja asterias*

Life history table

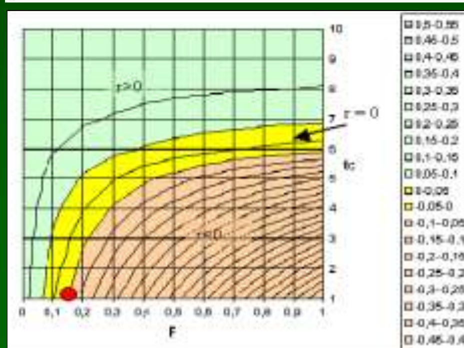
Age (t)	proportion surviving (l_t)	Female pups (m_t)	Reproductive rate ($l_{t+1}m_t$)	$l_{t+1}m_t t$	e^{-rt}	$l_{t+1}m_t e^{-rt}$	
0	1	0	0	0	1	0	
1	0.570638	0	0	0	0.78813617	0	
2	0.325628	0	0	0	0.62115862	0	
3	0.185816	0	0	0	0.48955758	0	
4	0.106034	17	1.02861511	4.11446044	0.38583803	0.39687883	
5	0.060507	27	0.914977991	4.57488996	0.30409291	0.27823832	
6	0.034527	34	0.662010453	3.97206272	0.23966662	0.15866181	
7	0.019703	39	0.435108262	3.04575784	0.18888993	0.08218757	
8	0.011243	46	0.295124315	2.36099452	0.14887099	0.04393545	
9	0.006416	50	0.183053468	1.64748121	0.11733061	0.02147778	
10	0.003661	55	0.201358815	2.01358815	0.0924725	0.01862015	
			3.720248415	21.7292348		1.00	sommatory
			R_0	5.84080212	0.22493322		MUST BE =1
			Net Reprod.rate	G	r_m	2.91135068	
				Generation lenght		t_{x2}	

M=	0.561
r=	0.2381



Contours of yield per recruit

Raja asterias



Contour plots constructed displaying the values of *r* corresponding to different combinations of *tc* and F.

Leslie matrices

- In alternative to life tables, but obtaining almost identical results, age-structured matrix models as the Leslie matrices, are now frequently used in the assessment of shark populations. (i.e. Hoenig and Gruber,1990).

Data:fecundity and survivals at age

0	0	0	16	26	34	40	46	50	54	54
0.74	0	0	0	0	0	0	0	0	0	0
0	0.55	0	0	0	0	0	0	0	0	0
0	0	0.41	0	0	0	0	0	0	0	0
0	0	0	0.30	0	0	0	0	0	0	0
0	0	0	0	0.22	0	0	0	0	0	0
0	0	0	0	0	0.17	0	0	0	0	0
0	0	0	0	0	0	0.12	0	0	0	0
0	0	0	0	0	0	0	0.09	0	0	0
0	0	0	0	0	0	0	0	0.07	0	0
0	0	0	0	0	0	0	0	0	0.05	0

- The Leslie Matrix can be adapted to include information on fishing mortality at specific ages, or changes in the reproductive schedule
- In order to assess how much influence the changes in the used estimates of the vital rates fecundity at age and mortality rates have on the population growth rate, the software allows the performance of sensitivity analyses

- sensitivity analysis is here reported as the elasticity, which is the proportional (relative) change of sensitivity.
- This choice facilitates the comparisons related to the consequences (impact on the estimates of population growth rate) of small changes in fecundity and on the mortality rates, which are obviously expressed in different absolute scales

- Elasticity analysis allows defining the management choices likely to produce more benefits to the stock, by estimating how much vulnerable is the species to changes in the survival of the juveniles (or for the adults) depending on the characteristics of the species in question (small or large, slow or fast-growing, long or short-lived species).

- The matrices were analyzed using Poptools, which is a versatile add-in for PC versions of Microsoft Excel that facilitates the analysis of matrix population models and simulation of stochastic processes. (http://www.cse.csiro.au/poptools/)

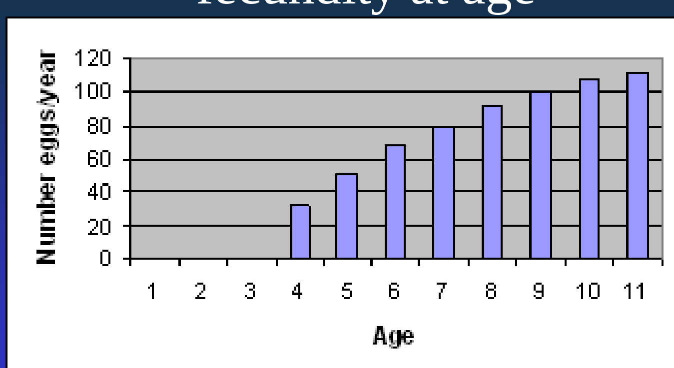
species

- The studied species are two rays *Raja as*terias and *Raja cla*vata, and two catsharks *Scyliorhinus canicula* and *Galeus melastomus*
- Which are the fisheries where the species are involved?

Raja asterias biological parameters

Sex	Fem	Mal
Growth model	VonBertalanffy	VonBertalanffy
Data source	Serena and Abella, 1999;	Serena and Abella, 1999;
L? (growth)	76	72,5
K (growth)	0,41	0,42
t0 (growth)	0	0
length-weight		
a (length-weight)	0,00192	0,00577
b (length-weight)	3,3216	3,0124
sex ratio	0,5	0,5
M	0,3	0,3

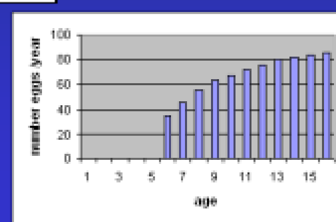
Raja asterias fecundity at age



Raja clavata

Raja clavata

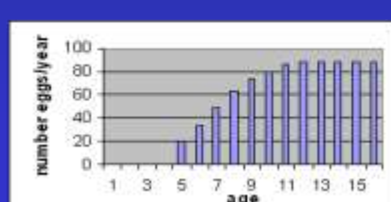
Sex		Fem	Mal
L? (growth)		126,5	116,7
K (growth)		0,098	0,106
t0 (growth)		-0,512	-0,412
Data source		Cannizzaro, 2000	
length-weight			
a (length-weight)		0,00177	0,00358
b (length-weight)		3,3076	3,1243
sex ratio		0,5	0,5
M		0,1568	0,1696



Galeus melastomus

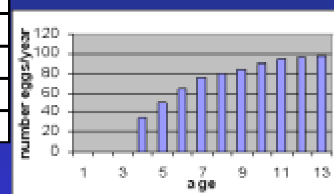
Galeus melastomus

Sex		both sexes
L? (growth)		64.00.00
K (growth)		0.15
t0 (growth)		0
Data source		Fishbase
length-weight		
a (length-weight)		0.0026
b (length-weight)		0,15
sex ratio		0,5
M		0,2



Scyliorhinus canicula

Sex	Fem	Mal
L? (growth)	75,1	87,4
K (growth)	0,15	0,118
t0 (growth)	-0,96	-1,09
Data source	Fishbase	
length-weight		
a (length-weight)	0,004	0,004
b (length-weight)	3,01	3,01
sex ratio	0,5	0,5
M	0,26	0,26



Estimates of *M*

- Use of all the information available, use of several empirical methods and literature

Estimates of fishing mortality

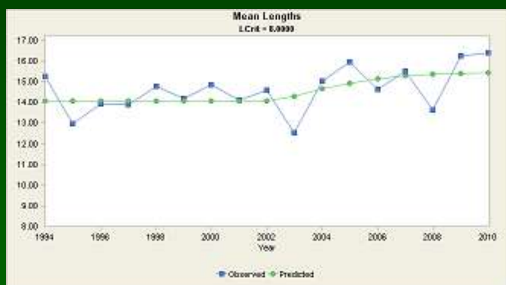
- For *Raja asterias,* a Length Converted Catch Curve was performed with commercial catch collected in the Viareggio Port. An estimate of Z=0.79 was obtained, that corresponds to a fishing mortality rate of *F*=0.49 assuming *M*=0.3

Estimates of fishing mortality

- For the other species, total mortality was estimated with the Gedamke & Hoenig method. For *Raja clavata* *F* was estimated as 0.23 for the most recent years. In the case of *Galeus melastomus*, with the same method, the value of *F* for the last years was 0.37 and for *Scyliorhinus canicula* the estimate of *F*curr was of 0.33.

Gedamke & Hoenig method

- In this approach, the transitional behavior of the mean length statistic is derived for use in nonequilibrium conditions.



AIC: 140.7124

Likelihood: 66.3562

Parameter	Value	STD Deviation
Z 1	0.78192211	0.042763
Z 2	0.61026335	0.042831
Change Year 1	2002.000	N/A
Sigma	11.99354384	2.056900

Raja asterias Y/R

Reference Point Summary Table

Reference Point	F	Yield per Recruit	SSB per Recruit	Total Biomass per Recruit	Mean Age	Mean Generation Time	Expected Spawnings
F Zero	0.00000	0.00000	3344.69319	4383.90780	3.35331	5.79522	1.44885
F-01	0.19970	320.07089	1258.27362	2035.15744	2.49209	5.02702	0.56290
F-Max	0.29040	334.87340	845.61546	1525.61450	2.23160	4.74363	0.38091
F at 40 %MSP	0.18620	314.37595	1337.98334	2130.68566	2.53680	5.07282	0.59767

YPR vs F

F	Catch Numbers	Yield per Recruit	Stock Numbers	Stock Weight	Spawning Stock Numbers	SSB per Recruit	% Maximum Spawning Potential	Mean Age
0.00000	0.00000	0.00000	3.74740	4383.90780	1.68333	3344.69319	100.00000	3.35331
0.05000	0.14208	149.83676	3.35355	3550.39581	1.34466	2580.26207	77.14496	3.09372
0.10000	0.25155	240.17750	3.03792	2912.78269	1.08403	2010.95928	60.12418	2.86518
0.15000	0.33768	292.38897	2.78159	2419.35203	0.88124	1582.46794	47.31280	2.66529
0.20000	0.40680	320.18420	2.57079	2033.10253	0.72182	1256.56610	37.56895	2.49112
0.25000	0.46326	332.40064	2.39536	1727.34085	0.59527	1006.18836	30.08313	2.33957
0.30000	0.51016	334.75562	2.24775	1482.64375	0.49391	811.96599	24.27625	2.20766

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0.30000	0.51016	334.75562	2.24775	1482.64375	0.49391	811.96599	24.27625	2.20766

Raja asterias Y/R the current *F*=0.49 is much higher than the *F*0.1 estimated to be 0.2 and considered as a proxy of *F*MSY and also to *F*max(0.29) and the *F*40%MSP(0.186).

Raja clavata Y/R

Reference Point	F	Yield per Recruit	SSB per Recruit	Total Biomass per Recruit	Mean Age	Mean Generation Time	Expected Spawnings
F Zero	0.00000	0.00000	9212.88939	0781.46175	5.91344	12.75948	2.33556
F-01	0.07640	332.14719	3779.21592	4881.57569	4.57134	11.58269	1.10466
F-Max	0.10440	344.57438	2786.74104	3756.05490	4.20261	11.18094	0.85397
F at 40 %MSP	0.07860	334.21361	3608.31669	4779.50837	4.54027	11.55041	1.08222

YPR vs F

F	Catch Numbers	Yield per Recruit	Stock Numbers	Stock Weight	Spawning Stock Numbers	SSB per Recruit	% Maximum Spawning Potential	Mean Age
0.00000	0.00000	0.00000	6.48764	0781.46175	2.53008	9212.88939	100.00000	5.91344
0.10000	0.38249	344.31881	4.34370	3910.17737	1.01213	2921.22969	31.70807	4.25685
0.20000	0.55514	286.32622	3.30524	1704.75299	0.44773	1065.36719	11.56388	3.29277
0.30000	0.65211	208.12460	2.71184	865.50105	0.21184	433.84187	4.70908	2.71009
0.40000	0.71428	151.32793	2.33211	494.08483	0.10486	191.55502	2.07921	2.33187
0.50000	0.75757	112.82212	2.06975	308.23888	0.05355	89.62405	0.97281	2.06972
0.60000	0.78947	86.51591	1.87852	205.86118	0.02797	43.72536	0.47461	1.87852

Raja clavata Y/R

the current *F*=0.23 is much higher than the *F*0.1 estimated to be 0.076 and considered as a proxy of *F*MSY and also to *F*max(0.104) and the

*F*40%MSP(0.08).

Galeus melastomus Y/R

Reference Point Summary Table

Reference Point	F	Yield per Recruit	SSB per Recruit	Total Biomass per Recruit	Mean Age	Mean Generation Time	Expected Spawnings
F Zero	0.00000	0.00000	340.31470	604.44943	4.73072	11.02156	1.12319
F-01	0.10910	25.85618	111.10031	275.50673	3.61412	10.50794	0.39962
F-Max	0.15160	26.88426	72.89776	210.33575	3.29614	10.32314	0.27143
F at 40 %MSP	0.08880	24.34187	136.25406	315.60575	3.78689	10.59957	0.48213

YPR vs F

F	Catch Numbers	Yield per Recruit	Stock Numbers	Stock Weight	Spawning Stock Numbers	SSB per Recruit	% Maximum Spawning Potential	Mean Age
0.00000	0.00000	0.00000	5.24200	604.44943	1.24132	340.31470	100.00000	4.73072
0.01000	0.04558	5.04405	5.05316	559.22023	1.13180	306.40271	90.03511	4.60783
0.02000	0.08756	9.29929	4.87701	517.98438	1.03253	276.00468	81.10278	4.48934
0.03000	0.12629	12.87344	4.71247	480.35270	0.94248	248.74299	73.09205	4.37518
0.04000	0.16211	15.85983	4.55859	445.97649	0.86075	224.28195	65.90428	4.26528
0.05000	0.19530	18.33932	4.41449	414.54311	0.78653	202.32298	59.45173	4.15955
0.06000	0.22610	20.38198	4.27938	385.77210	0.71908	182.60044	53.65635	4.05789

Galeus melastomus Y/R, the current fishing mortality rate *F*=0.37 is much higher than the *F*0.1 estimated to be 0.11 and considered as a proxy of *F*MSY and also to *F*max(0.15) and the F40%MSP(0.09).

Scyliorhinus canicula Y/R

Reference Point Summary Table

Reference Point	F	Yield per Recruit	SSB per Recruit	Total Biomass per Recruit	Mean Age	Mean Generation Time	Expected Spawnings
F Zero	0.00000	0.00000	486.62787	577.17346	3.90958	7.81397	1.85654
F-01	0.13000	28.49316	202.19723	264.83026	3.01858	6.81609	0.93517
F-Max	0.18200	29.65595	147.36188	201.73770	2.76321	6.45587	0.72859
F at 40 %MSP	0.13600	28.77371	194.76157	256.36109	2.98661	6.77315	0.90805

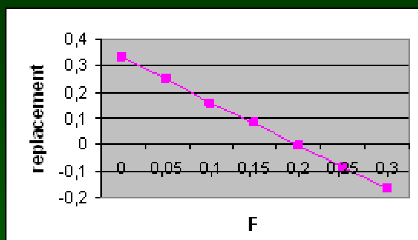
YPR vs F

F	Catch Numbers	Yield per Recruit	Stock Numbers	Stock Weight	Spawning Stock Numbers	SSB per Recruit	% Maximum Spawning Potential	Mean Age
0.00000	0.00000	0.00000	4.21908	577.17346	2.11428	486.62787	100.00000	3.90958
0.10000	0.27215	26.26929	3.28843	312.95186	1.30052	244.81436	50.30833	3.18929
0.20000	0.42912	29.55643	2.72239	184.50558	0.84335	132.64203	27.25739	2.68535
0.30000	0.52997	26.89572	2.35064	117.21634	0.56871	76.65700	15.75269	2.33168
0.40000	0.60013	23.20290	2.09097	79.36460	0.39475	46.73723	9.60431	2.07763
0.50000	0.65100	19.80088	1.90066	56.65708	0.27998	29.75101	6.11371	1.88955
0.60000	0.69150	16.95785	1.75591	42.25000	0.20188	19.59990	4.02770	1.74613

Scyliorhinus canicula Y/R the current F=0.33 is much higher than the F0.1 estimated to be 0.13 and considered as a proxy of FMSY and also to Fmax(0.18) and the F40%MSP(0.14).

RESULTS OF DEMOGRAPHIC ANALYSIS

- *Raja asterias replacement at different levels of F and elasticity analysis*



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0	0,220794	0	0	0	0	0	0	0	0	0
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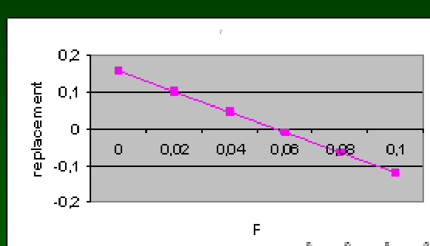
0	0	0	0	0	0	0	1,22E-06	0	0	0
0	0	0	0	0	0	0	0	6,25E-07	0	0
0	0	0	0	0	0	0	0	0	2,15E-08	0

RESULTS OF DEMOGRAPHIC ANALYSIS

- *Raja clavata replacement at different levels of F and elasticity analysis*



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0,152556	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0,152556	0	0	0	0	0	0	0	0	0	0	0	0	0
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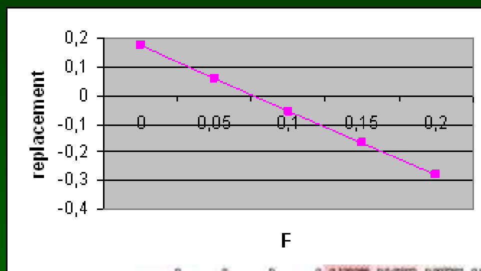
0	0	0	0	0	0	0,046778	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0,004799	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0,000996	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0,000177	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	2,68E-05	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	3,45E-06	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	3,69E-07	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	3,16E-08	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0

RESULTS OF DEMOGRAPHIC ANALYSIS

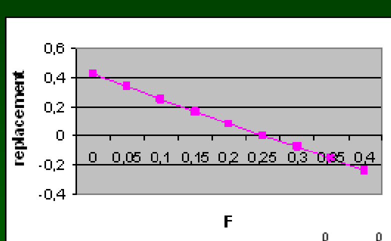
- *Galeus melastomus replacement at different levels of F and elasticity analysis*



0	0	0	0	0,130086	0,041823	0,007302	0,000758	4,72E-05	1,34E-06	4,71E-08	7,30E-10	6,6096E-12	8,27E-14	3,06E-18
0,188198	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0,188198	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0,188198	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0,188198	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0,050112	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0,000108	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0,000007	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	4,91E-05	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1,89E-06	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	4,80E-08	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	8,01E-10	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	8,87E-12	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	6,2996E-14	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	3,06E-16	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

RESULTS OF DEMOGRAPHIC ANALYSIS

- *Scyliorhinus canicula replacement at different levels of F and elasticity analysis*



0	0	0	0,1565	0,055248	0,013221	0,002286	0,000273	2,53E-05	1,86E-06	1,04E-07	4,44E-09
0,227556	0	0	0	0	0	0	0	0	0	0	0
0	0,227556	0	0	0	0	0	0	0	0	0	4,6E-10
0	0	0,2275556	0	0	0	0	0	0	0	0	0
0	0	0	0,071055	0	0	0	0	0	0	0	0
0	0	0	0	0,015807	0	0	0	0	0	0	0
0	0	0	0	0	0,002586	0	0	0	0	0	0
0	0	0	0	0	0	0,0003	0	0	0	0	0
0	0	0	0	0	0	0	2,73E-05	0	0	0	0
0	0	0	0	0	0	0	0	1,97E-06	0	0	0
0	0	0	0	0	0	0	0	0	1,09E-07	0	0
0	0	0	0	0	0	0	0	0	0	4,9E-09	0
0	0	0	0	0	0	0	0	0	0	0	-0

- *Raja asterias*

The results of the demographic analysis suggest that the level of *F* (Fcurr=0.49) with the current exploitation pattern (tc<1) do not guarantee sustainability for the stock. A fishing mortality of about 0.2 can be considered the limit in order to guarantee the self-renewal fishing with the current pattern (Lc=<1yr).

R.asterias

- The higher values are found in the survival-at-age cells, suggesting that is in the first ages where smallest changes in vital rates are likely to produce biggest changes in the population growth rate. For this species the analysis suggests that management measures aimed at protecting juveniles (e.g., mesh size increase, nursery area closures) should provide greater benefits to the population than a strategy aimed at protecting adults

- *Raja clavata*. The results of the demographic analysis suggest that the level of *F* (Fcurr=0.23) with the current exploitation pattern (tc<1) do not guarantee sustainability for the stock. A fishing mortality of about 0.05 can be considered the limit in order to guarantee the self-renewal fishing with the current pattern (Lc=<1yr).

R.clavata

- The higher values are found in the survival-at-age cells, suggesting that is in the first ages where smallest changes in vital rates are likely to produce biggest changes in the population growth rate. For this species the analysis suggests that management measures aimed at protecting juveniles should provide greater benefits to the population than a strategy aimed at protecting adults.

- *Galeus melastomus*
- The demographic analysis show that the current level of *F* (Fcurr=0.37) combined with the current exploitation pattern (tc<1) do not guarantee sustainability for the stock. A fishing mortality of about 0.06 is considered the limit in order to guarantee the self-renewal if fishing with the current pattern (Lc=<1yr).

G.melastomus

- The higher values are found in the survival-at-age cells, suggesting that is in the first ages where smallest changes in vital rates are likely to produce biggest changes in the population growth rate. For this species the analysis suggests that management measures aimed at protecting juveniles should provide greater benefits to the population than a strategy aimed at protecting adults.

- *Scyliorhinus canicula*
- The results of the demographic analysis suggest that the level of *F* (Fcurr=0.33) with the current exploitation pattern (tc<1) do not guarantee sustainability for the stock. A fishing mortality of about 0.25 can be considered the limit in order to guarantee the self-renewal fishing with the current pattern (Lc=<1yr).

S.canicula

- The higher values are found in the survival-at-age cells, suggesting that is in the first ages where smallest changes in vital rates are likely to produce biggest changes in the population growth rate. For this species the analysis suggests that management measures aimed at protecting juveniles (e.g., mesh size increase, nursery area closures) should provide greater benefits to the population than a strategy aimed at protecting adults.

Conclusions

- The used approach allowed to modify the Leslie Matrix in order to include information on fishing mortality at specific ages, or simulate changes in the reproductive schedule.
- This was very useful for assessing whether the current levels of F of all the species combined with the current exploitation pattern are able to guarantee sustainability for the stocks.

Conclusions

- **Elasticity allowed identifying the ages at which smallest changes in vital rates can produce biggest changes in the population growth rate**
- **elasticity analyses suggest for all the species that is in the first ages where smallest changes in vital rates are likely to produce biggest changes in the population growth rate**
- ***Y/R* analyses also show the relatively high current *F* values for all the stocks related to the RP F0.1 and suggest that a drastic reduction of *F* should be necessary in order to drive the stocks to more productive and sustainable status.**

	F0.1	Frep	Fcurr
R.asterias	0.2	0.2	0.49
R.clavata	0.08	0.05	0.23
G.melastomus	0.11	0.06	0.37
S.canicula	0.13	0.25	0.33