TESTING OF OPTIMAL FISHING EFFORT FOR SARDINE IN THE EASTERN ADRIATIC USING SYSTEM DYNAMICS

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Abstract

In this paper Schaefer production model of sardine in the Adriatic Sea is presented using System dynamics methodology. Production models are very simple but they can be good approximation for complex behavior dynamics of biological systems. Sardine population is chosen due to its great economic importance to Croatian fishing. In this paper, Schaefer (1954) production model was used due to lack of appropriate biological data for any other model. The qualitative and quantitative models of observed sardine population have been developed. Different scenarios are made; using available biological data for sardine in the Adriatic Sea. Total fishing effort in relation to stock under exploitation is an essential parameter in the policy of sustainable marine resources management. Using Schaefer and Fox production models (Alegria–Hernandez, 1983), gave some optimal value for the fishing effort for sardine in the eastern Adriatic. Those values are tested using System Dynamics and obtained results are compared. Modeling and simulation enables testing of different exploitation scenarios without endangering sardine real population. The results of testing lower and upper limit for fishing effort (Scenario 1a and 1b) are shown in this paper. Although, available biological data give range of optimal fishing effort it is evident that upper limit reduce sardine biomass below initial state, while lover limit enables increase of sardine biomass.

Keywords: Schaefer production model, sardine population, The Adriatic Sea, System dynamics

Presenting Author's biography

Gorana Jelić-Mrčelić was born on January 24th 1973, Croatia. In January 1996 she acquired the degree of Bachelor of Science in Fishery Sciences at Marine Faculty Split. In June 1996 she acquired the degree of Engineer of Maritime Traffic – Nautical Studies. In July 2000 she acquired the degree Of Master of Sciences at Faculty of Agriculture, University of Zagreb. In November 2004 she acquired PhD in fishery science at Faculty of Agriculture, University of Zagreb. She works at Faculty of Maritime Studies Split, University of Split from June 1996. Now she is senior assistant.
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1 Introduction

There are different models for investigation of the behavior dynamics of fish population. The Schaefer production model is often applied for fishery purpose, particularly for efficient management, of marine biological resources including their protection. Alegria-Hernandez (1983) used Schaefer and Fox production models for sardine population in the eastern Adriatic. In this paper, Schaefer (1954) production model was used due to lack of appropriate biological data for any other model. According to the System dynamics methodology Schaefer production model for sardine population was presented. This short paper comprises only structural, flow diagram and mathematical models of observed population, although comprehensive qualitative and quantitative models were made.

Production models are very simple but they can be good approximation for complex behavior dynamics of biological systems. Change of population biomass (Dudley, 2003), which mathematically matches first derivation, is:

$$\frac{dB}{dt} = \left[(r \cdot B) - (r \cdot \frac{B^2}{CC}) \right] - C \qquad (1)$$

where:
dB/dt - rate of biomass change
r – intrinsic growth rate
CC – carrying capacity
C – catch rate
B – sardine biomass

Catch rate is defined as product of sardine biomass, catchabilty coefficient and fishing effort (Ussif, 2003).

$$C = q \cdot f \cdot B \qquad (2)$$

Initial value for sardine biomass, carrying capacity, catchabilty coefficient and fishing effort are given according to Alegria-Hrenandez (1983).

Several simulation scenarios were made, all in Powersim and DYNAMO program package. Authors decided to give mathematical models in DYNAMO because it was easier to follow the equations, and the results of simulations in Powersim because of better graphical solution.

2 System dynamics models of sardine population in the Eastern Adriatic Sea

The structural model of sardine population was determined based on mental model. It presented all variables included in the model, together with existing causes-consequences links and feedback loops in sardine population system.

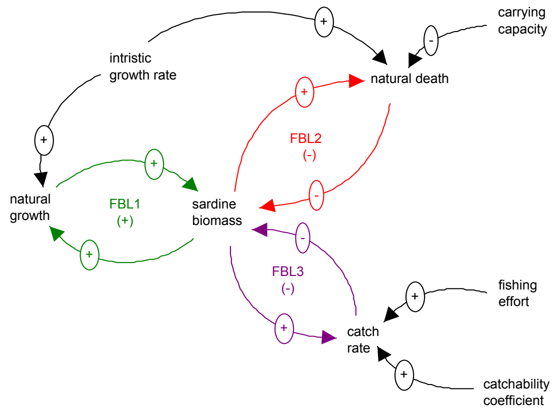

Fig. 1 System dynamics structural model of sardine population in the Eastern Adriatic Sea (Sliskovic, 2007)

System dynamics structural flow diagram of sardine population was presented in Powersim language.

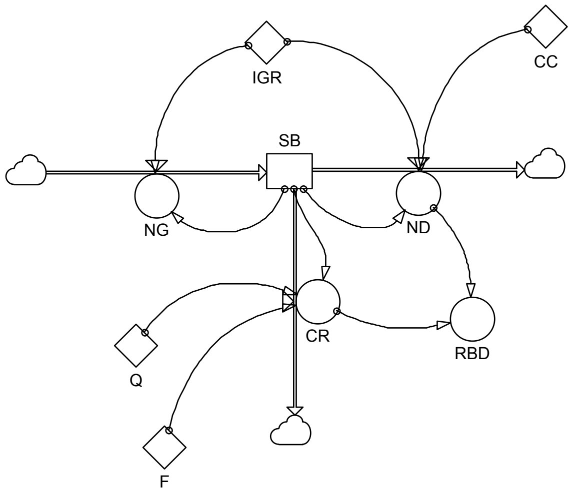

Fig. 2 System dynamics flow diagram of sardine population in Powersim language (Sliskovic, 2007)

Where symbols in Powersim were:
NG – natural growth
SB – sardine biomass
IGR – intrinsic growth rate
CC – carrying capacity
ND – natural death
CR – catch rate
Q – catchability coefficient
F – fishing effort
RBD – rate of biomass decrease.

System dynamics computer model of sardine population was developed in DYNAMO programming package, because authors thought that it would be easier to follow the equation than in any other language.

```
*******************************************
SD computer model of sardine population in the Eastern Adriatic
*******************************************
R DBDT.KL=NG.KL-ND.KL-CR.KL
*                         rate of biomass change
*
L SB.K=SB.J+DT*(DBDT.JK)
*                                sardine biomass
*
N SB=95335
*                         initial sardine biomass
*
R NG.KL= RR*SB.K
*                                 natural growth
*
R ND.KL=RR*SB.K*(SB.K/CC)
*                                  natural death
*
R CR.KL=SB.K*Q*F
*                                     catch rate
*
A RBD.K=ND.KL+CR.KL
*                       rate of biomass decrease
*
C Q=0.0000399
*                       catchability coefficient
*
C F=4115
*                                 fishing effort
*
C CC=190711
*                              carrying capacity
*
C IGR=0.367
*                          intrinsic growth rate
*
SAVE DBDT,SB,NG,ND,CC,CR,RBD,
*
SPEC DT=.01,LENGTH=50,SAVPER=1
*******************************************
```

3 Optimal fishing effort for sardine in the eastern Adriatic

Total fishing effort in relation to stock under exploitation is an essential parameter in the policy of sustainable marine resources management (Alegria-Hernandez, 1983).

Many management systems are based directly or indirectly on fishing effort size which will be applied on some fish stock in order to obtained desired catch level (Rothschild, 1977).

Fishing effort can be defined in terms of the activity of the fisherman to catch the fish or in terms of energy applied or money spent. Simplified this means that fraction of population is removed per each fishing effort unit and at the same time fishing effort is the function of population fishing mortality and catchability coefficient (Alegria-Hernandez, 1983).

Fishing effort is measured in units appropriate for the observed fishery (Clark, 1990). Populations that are harvested when they are near their maximum population size have more resilience to perturbations (such as fishing pressure) than population harvested when at lower population sizes (Haddon, 2001).

In the case of encircling gears purse-seine and tuna fishing, by which pelagic fish are caught predominantly by night (sardine and anchovy) and big pelagic fish (tuna) by daylight, fishing effort per day depends on several factors:

- subjective nature (fisherman and crew experience)
- biological characteristic of population
- technical and technological characteristics of fishing unit (Alegria-Hernandez, 1983).

In sardine catch the unit of fishing effort should be calculate as the effective fishing effort of a purse-shiner day or night. For fishing effort calculation in purse-seine herring fishing in Norway suggests the use of the data on effective boat days (Alegria-Hernandez, 1983).

Based on available biological data (Alegria-Hernandez, 1983) optimal fishing effort for sardine in eastern Adriatic should be in range of 4115 and 5292 effective fishing day during one year.

4 Testing of optimal fishing effort

In the model catch is defined as product of fishing effort (f), catchability coefficient (q) and sardine biomass (B). It is common practice to assume catch is proportional to fishing effort and stock size, although this is only the case if the catcahability coefficient doses not vary through time or with stock size (Haddon, 2001).

Initial value for catachability coefficient of 0,0000399 is taken from Alegria-Hernandez (1983). According to the same author value of the optimal fishing effort are between 4115 and 5292 effective fishing days in one year. Scenario 1a tested dynamic behavior of sardine biomass with lower fishing effort and Scenario 1b with higher fishing effort, when all other variable where constant.

4.1 Results of Scenario 1a

In Scenario 1a, behavior dynamics of sardine system was investigated when catch is product of catchability coefficient q=3,99E-5 and fishing effort f=4115 effective fishing days in one year.

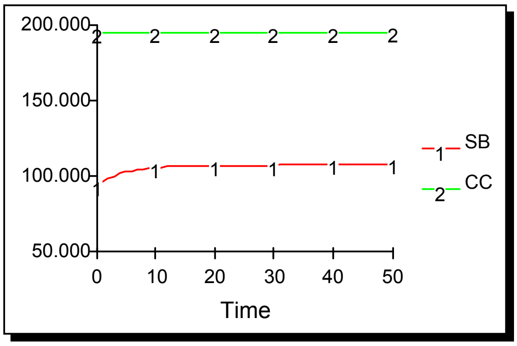

Fig. 3 Results of Scenario 1a for sardine biomass (SB) and carrying capacity (CC)

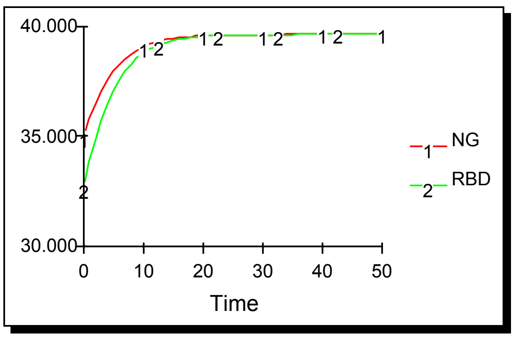

Fig. 4 Results of Scenario 1a for natural growth (NG) and rate of biomass decrease (RBD)

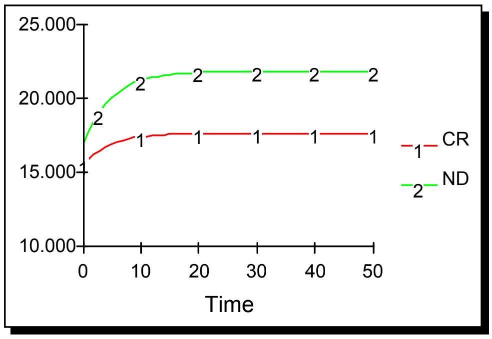

Fig. 5 Results of Scenario 1a for catch rate (CR) and natural death (ND)

In the begging of simulation small increase of biomass is observed (Fig. 3). Increase of biomass results from the fact that natural growth is larger than rate of biomass decrease (Fig. 4). Figure 3 also shows that biomass reach some steady state which is far below value of carrying capacity.

Although, in the beginning of simulation natural growth is larger than rate of biomass decrease, these two values equals (Fig. 4) as steady state is approaches.

Comparative analysis of natural death and catch (Fig. 5) shows that natural death is larger that catch defined in this manner.

Numerical value of all variable included in model for Scenario 1a are given in Table 1.

Tab. 1 Numerical Results of Scenario 1a

Time	SB	NG	ND	CR	RBD
0	95.335,0	34.987,95	17.043,37	15.652,91	32.696,28
1	97.626,7	35.828,98	17.872,60	16.029,17	33.901,77
2	99.553,9	36.536,27	18.585,20	16.345,60	34.930,80
3	101.159	37.125,48	19.189,46	16.609,20	35.798,67
4	102.486	37.612,42	19.696,15	16.827,05	36.523,20
5	103.575	38.012,17	20.117,03	17.005,89	37.122,92
6	104.465	38.338,52	20.463,95	17.151,89	37.615,84
7	105.187	38.603,74	20.748,06	17.270,55	38.018,61
8	105.772	38.818,49	20.979,54	17.366,62	38.346,16
9	106.245	38.991,83	21.167,33	17.444,17	38.611,50
10	106.625	39.131,42	21.319,15	17.506,62	38.825,77
11	106.931	39.243,59	21.441,55	17.556,80	38.998,35
12	107.176	39.333,59	21.540,01	17.597,07	39.137,08
13	107.373	39.405,71	21.619,07	17.629,33	39.248,41
14	107.530	39.463,45	21.682,47	17.655,16	39.337,63
15	107.656	39.509,62	21.733,24	17.675,82	39.409,06
16	107.756	39.546,53	21.773,86	17.692,33	39.466,19
17	107.837	39.576,01	21.806,34	17.705,52	39.511,86
18	107.901	39.599,56	21.832,29	17.716,05	39.548,35
19	107.952	39.618,35	21.853,02	17.724,46	39.577,48
20	107.993	39.633,35	21.869,57	17.731,17	39.600,74
21	108.025	39.645,32	21.882,78	17.736,53	39.619,30
22	108.051	39.654,86	21.893,32	17.740,80	39.634,11
23	108.072	39.662,48	21.901,73	17.744,20	39.645,93
24	108.089	39.668,55	21.908,43	17.746,92	39.655,35
25	108.102	39.673,39	21.913,78	17.749,09	39.662,87
26	108.112	39.677,25	21.918,05	17.750,81	39.668,86
27	108.121	39.680,33	21.921,45	17.752,19	39.673,64
28	108.127	39.682,79	21.924,16	17.753,29	39.677,45
29	108.133	39.684,75	21.926,33	17.754,17	39.680,49
30	108.137	39.686,31	21.928,05	17.754,86	39.682,92
31	108.140	39.687,55	21.929,43	17.755,42	39.684,85
32	108.143	39.688,54	21.930,52	17.755,86	39.686,39
33	108.145	39.689,33	21.931,40	17.756,22	39.687,61
34	108.147	39.689,96	21.932,09	17.756,50	39.688,59
35	108.148	39.690,47	21.932,65	17.756,72	39.689,37
36	108.149	39.690,87	21.933,09	17.756,90	39.690,00
37	108.150	39.691,19	21.933,44	17.757,05	39.690,49
38	108.151	39.691,44	21.933,73	17.757,16	39.690,89
39	108.152	39.691,64	21.933,95	17.757,25	39.691,20
40	108.152	39.691,81	21.934,13	17.757,32	39.691,45
41	108.152	39.691,93	21.934,27	17.757,38	39.691,65
42	108.153	39.692,04	21.934,39	17.757,43	39.691,81
43	108.153	39.692,12	21.934,48	17.757,46	39.691,94
44	108.153	39.692,18	21.934,55	17.757,49	39.692,04
45	108.153	39.692,24	21.934,61	17.757,52	39.692,12
46	108.153	39.692,28	21.934,65	17.757,54	39.692,19
47	108.153	39.692,31	21.934,69	17.757,55	39.692,24
48	108.154	39.692,34	21.934,72	17.757,56	39.692,28
49	108.154	39.692,36	21.934,74	17.757,57	39.692,31
50	108.154	39.692,38	21.934,76	17.757,58	39.692,34

4.2 Results of Scenario 1b

In Scenario 1b, behavior dynamics of sardine system was investigated when catch is product of catchability coefficient q=3,99E-5 and fishing effort f=4115 effective fishing days in one year.

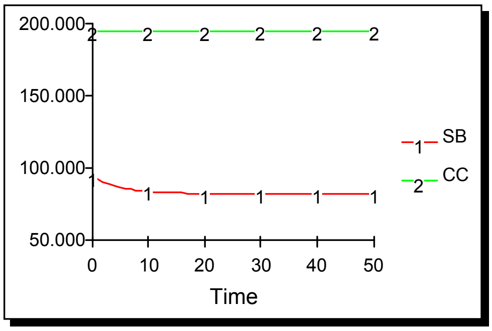

Fig. 6 Results of Scenario 1b for sardine biomass (SB) and carrying capacity (CC)

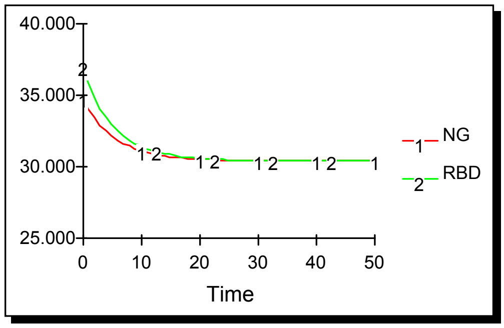

Fig. 7 Results of Scenario 1b for natural growth (NG) and rate of biomass decrease (RBD)

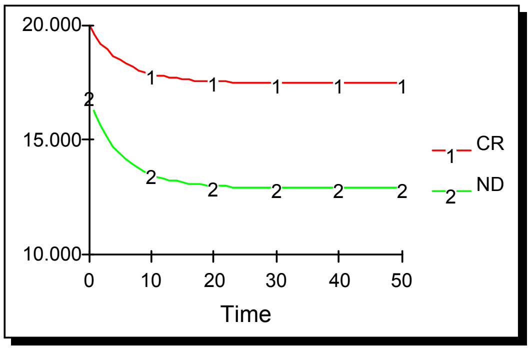

Fig. 8 Results of Scenario 1b for catch rate (CR) and natural death (ND)

Tab. 2 Numerical Results of Scenario 1b

Time	SB	NG	ND	CR	RBD
0	95.335,0	34.987,95	17.043,37	20.130,06	37.173,44
1	93.149,5	34.185,87	16.270,91	19.668,59	35.939,51
2	91.395,9	33.542,28	15.664,05	19.298,31	34.962,36
3	89.975,8	33.021,12	15.181,06	18.998,46	34.179,53
4	88.817,4	32.595,98	14.792,68	18.753,86	33.546,54
5	87.866,8	32.247,13	14.477,74	18.553,15	33.030,89
6	87.083,1	31.959,48	14.220,61	18.387,66	32.608,27
7	86.434,3	31.721,38	14.009,51	18.250,67	32.260,18
8	85.895,5	31.523,64	13.835,39	18.136,90	31.972,29
9	85.446,8	31.358,99	13.691,24	18.042,17	31.733,41
10	85.072,4	31.221,58	13.571,52	17.963,11	31.534,62
11	84.759,4	31.106,69	13.471,82	17.897,01	31.368,83
12	84.497,2	31.010,48	13.388,62	17.841,66	31.230,28
13	84.277,4	30.929,82	13.319,06	17.795,25	31.114,30
14	84.093,0	30.862,11	13.260,81	17.756,29	31.017,10
15	83.938,0	30.805,23	13.211,97	17.723,57	30.935,54
16	83.807,7	30.757,41	13.170,98	17.696,05	30.867,04
17	83.698,0	30.717,18	13.136,55	17.672,91	30.809,45
18	83.605,7	30.683,31	13.107,60	17.653,42	30.761,02
19	83.528,0	30.654,79	13.083,24	17.637,01	30.720,26
20	83.462,6	30.630,76	13.062,74	17.623,19	30.685,93
21	83.407,4	30.610,52	13.045,48	17.611,54	30.657,02
22	83.360,9	30.593,45	13.030,94	17.601,72	30.632,66
23	83.321,7	30.579,06	13.018,68	17.593,44	30.612,13
24	83.288,6	30.566,93	13.008,35	17.586,46	30.594,81
25	83.260,7	30.556,69	12.999,64	17.580,57	30.580,22
26	83.237,2	30.548,06	12.992,30	17.575,61	30.567,91
27	83.217,4	30.540,78	12.986,11	17.571,42	30.557,52
28	83.200,6	30.534,63	12.980,88	17.567,88	30.548,76
29	83.186,5	30.529,45	12.976,47	17.564,90	30.541,37
30	83.174,6	30.525,07	12.972,75	17.562,38	30.535,13
31	83.164,5	30.521,38	12.969,62	17.560,26	30.529,87
32	83.156,0	30.518,27	12.966,97	17.558,46	30.525,43
33	83.148,9	30.515,64	12.964,73	17.556,95	30.521,68
34	83.142,8	30.513,42	12.962,85	17.555,67	30.518,52
35	83.137,7	30.511,54	12.961,26	17.554,60	30.515,85
36	83.133,4	30.509,96	12.959,91	17.553,69	30.513,60
37	83.129,8	30.508,63	12.958,78	17.552,92	30.511,70
38	83.126,7	30.507,50	12.957,82	17.552,27	30.510,09
39	83.124,1	30.506,55	12.957,01	17.551,72	30.508,74
40	83.121,9	30.505,75	12.956,33	17.551,26	30.507,59
41	83.120,1	30.505,07	12.955,76	17.550,87	30.506,63
42	83.118,5	30.504,50	12.955,27	17.550,54	30.505,81
43	83.117,2	30.504,02	12.954,86	17.550,27	30.505,13
44	83.116,1	30.503,61	12.954,52	17.550,03	30.504,55
45	83.115,2	30.503,27	12.954,22	17.549,83	30.504,06
46	83.114,4	30.502,98	12.953,98	17.549,67	30.503,64
47	83.113,7	30.502,73	12.953,77	17.549,53	30.503,29
48	83.113,1	30.502,52	12.953,59	17.549,41	30.503,00
49	83.112,7	30.502,35	12.953,44	17.549,31	30.502,75
50	83.112,3	30.502,20	12.953,32	17.549,22	30.502,54

In this Scenario behavior dynamics of sardine biomass is different form Scenario 1a. In the beginning of the simulation sardine biomass decreases, and after some time reach steady state as in Scenario 1a (Fig. 6). Although, steady state is reached in Scenario 1b the value of steady state is lower than in Scenario 1a.

As a results of larger fishing effort the greater catch is obtained (Fig. 8) and consequently larger rate of biomass decrease (Fig. 7).

As biomass is approaching steady state, rate of biomass decreases equals natural growth (Fig. 7).

In this case, comparing catch value and natural death, it is noted that catch portion in total death is larger than natural death (Fig. 8). However, in this scenario, biomass reaches steady state, after initial decrease which is far below crying capacity (Fig. 6).

5 Conclusion

Although very simple, Schaefer production model enables investigation of complex behavior dynamics of fish population. Schaefer production model is applied on sardine population in Eastern Adriatic by System dynamics methodology.

Modeling and simulation enables testing of different exploitation scenarios without endangering sardine real population.

Qualitative and quantitative models are developed using available biological data for initial values of the variables.

Although, available biological data give range of optimal fishing effort it is evident that upper limit reduce sardine biomass below initial state, while lover limit enables increase of sardine biomass. Based on the results of these two scenarios it can be concluded that for every desired level of sardine biomass optimal fishing effort exists.

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