“Dunărea de Jos” University of Galați

Doctoral School of Engineering

PhD THESIS

ABSTRACT

STUDIES AND RESEARCH TO ENSURE A SUSTAINABLE EXPLOITATION OF DANUBE SHAD POPULATIONS (*ALOSA IMMACULATA, BENNETT,* 1835) FROM THE ROMANIAN BLACK SEA SECTOR

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CONTENT

KEY – WORDS: Danube shad, Black Sea, Sustainable Development, Shad Fishery Protection, Fishing Indicators, Stocks Assessment, Fishery Management Plan.

INTRODUCTION

Fishery management is based on the knowledge and skills of specialists working in the field of water bio-economy. In order to assess more complex and complete value of all components of the fishery, in terms of diversity and quality of stocks and regeneration rate of bioresources, namely to establish an effective and responsible management, sound scientific data is needed. According to them, fishery managers can make pertinent decisions only through good collaboration with all stakeholders; this will improve exploitation methods, will reduce the risk of overexploitation, the measures of protection and conservation of biodiversity will be respected and the sustainable use of all resources will be ensured (Calin G.P., 2013; Radu E., Maximov V., 2006).

Danube shad is a fish with high economic and socio-cultural value for the communities established in the Danubian-Pontic space. In Romania, shad fishery has a market value of about 1.5 million euro, with average annual catches of 200-500 tonnes. But, since the interest for exploitation and marketing has grown, also the danger is greater for drastical decline of Danube shad populations from the Danube and the Black Sea. The main factors with negative impact on the shad stocks in the Black Sea and the Danube are overfishing and pollution and, also, dam construction (Năvodaru I., 1996). Therefore, it is essential to know the aspects of ecobiology and exploitation conditions of the species, in order to ensure background information for the conservation and management of stocks.

Fish stocks management, including shad stocks, shall be carried out by the knowledge of three essential compartments: life environment - species - exploitation. Having in regard the life cycle carried out in two environments with different salinity, marine and freshwater, respectively the migrations carried out annually at long distances, it is necessary to evaluate the impact of the permanently changing environmental conditions on the stocks.

Exploitation and environment regulations must be associated in such way that the ecobiological and socio-economical objectives of shad fishery can be accomplished in harmony.

The purpose of the thesis is to present the studies and research carried out in the period 2012-2016, in order to substantiate and ensure the sustainable exploitation of the shad populations in the Black Sea.

Main objectives:

- The influence of biotic, abiotic and environmental factors, on qualitative and quantitative structure of ichthyofauna in the Black Sea;
- Ecological and biological peculiarities of the clupeid species from the Black Sea;
- Analysis of catch and fishing effort in the Black Sea during the study period;
- Dynamics of shad populations (growth, recruitment, mortality rate of exploitation);
- Determine management measures to improve sustainable exploitation of fishery resources.

Part II: EXPERIMENTAL WORK

Chapter 6

EVALUATION OF SHAD POPULATIONS’ EXPLOITATION RATE IN THE ROMANIAN SECTOR OF THE BLACK SEA

6.3. Results and discussions

6.3.1. Fishing indicators (catch, effort, CPUE)

The fishing zone covers a total area of 119,168 ha (details in Chapter 4).

Fishing units structure

The gears used for scientific fishing are gillnets, with the following specifications:

- shad gillnets, with no trammel, mesh size *a = 30-36 mm*.

Fishing effort

The commercial fishing of Danube shad in the coastal area of the Black Sea is strongly influenced by climate factors (mainly wind speed) and seasonality. The most productive fishing seasons are late winter and spring. Migration towards the Danube mouths starts in February-March and the highest catches of commercial shad fishery are recorded during this period. In late spring, catches drop to minimum values, being recorded only sporadically.

Experimental fishing was made during three seasons: spring (March, April), summer (June, July) and autumn (September).

The fishing methods are passive, the gillnets are launched perpendicularly on the sea shore, on different depth ranges depending on isolines (0-5, 5-10 and 10-20 m isolines) and seabed profile, they are fixed on the substrate by Danford anchors and signalled using phosphorescent red floats (baloon type).

The duration of one fishing operation varies as follows: approximately 5-25 minutes traveling to the gear set-up site, 25-45 minutes gear set-up, approximately 12 hours soak time, 30-45 minutes removal of fishing gears and 10-25 minutes return onshore or to the base research vessel.

During the two years of experimental Danube shad fishing, the following fishing effort was achieved: 2012 - 38 fishing days, 2013 - 36 fishing days (details in Chapter 4).

In order to determine the CPUE (catch per unit effort), the followig items are used for calculations:

1. Total time frame: 365 days/year;
2. Actual scientific fishing time: 38 days;
3. Fishing units: 1 FU;
4. Fishing gears (zones): 4 gillnets/FU;
5. Number of set-ups (duration 12 hours): 12 hours*38 days = 456 hours/days
6. Fishing effort: 1 FU*456 hours/FU = 456 hours/4 gillnets;
7. Catch in 2012: 266.90 kg;
8. **CPUE in 2012: 266.90 kg/456 hours/ 4 gillnets = 0.146 kg/h fishing/gillnet**
9. Catch in 2013: 6027.35 kg;
10. **CPUE in 2013: 271.60 kg/432 hours/4 gillnets = 0.157 kg/h fishing/gillnet.**

All calculation items and CPUE values are given in Table 6.2. In order to provide additional data to scientific fishing, Table 6.3 shows the calculation items and CPUE for commercial shad fisheries.

Table 6.2. Calculation items and CPUE, scientific fishing

Year	Lucrative time (days)	Fishing effort/day (hours)	Actual time (hours/FU)	FU (no. of boast)	Number of set-ups	Fishing effort/year (hours.gear)	Catch (kg/year)	CPUE (kg/hour)
2012	38	12	456	1	38	456	266.90	0.146
2013	36	12	432	1	36	432	271.60	0.157
Mean	**37**		**444**		**37**	**444**	**269.25**	**0.151**

Table 6.3. Calculation items and CPUE, commercial fishing

Year	Lucrative time (days)	Fishing effort/day (hours)	Actual time (hours/FU)	FU (no. of boast)	Number of set-ups	Fishing effort/year (hours.gear)	Catch (kg/year)	CPUE (kg/hour)
2010	118	12	1416	76	118	18.60	63226	0.043
2011	401	12	4812	86	401	55.95	46160	0.006
2012	357.9	12	4294	42	357.9	102.23	23981	0.009
2013	38	12	456	28	38	16.28	4355	0.029
2014	130.5	12	1566	19	130.5	82.42	1518	0.006
Mean	**209.080**		**2508.8**	**50.2**	**209.08**	**55.096**	**27848**	**0.0186**

After analyzing the data in the two tables, it was noticed that there are significant differences between the CPUE of scientific fishing (0.146-0.157, mean 0.151 kg/hour) and commercial fishing (0,006-0,043, mean 0.0186 kg/hour), the latter recording very low values.

Considering the amounts of Danube shad and the data on fishing effort reported by commercial fishermen to the National Agency for Fisheries and Aquaculture, it was found that the data do not reflect the reality in the field, suggesting that fishermen do not report accurately the catch and fishing effort information.

6.3.2. Stock status assessment of shad population

Population structure analysis on length and weight classes

The starting points for stock assessment of fish populations are length and weight data; they can be regarded as an ”outline” reflecting dynamic interactions between growth, recruitment and mortality rates, essential for fisheries management (Neumann *et al*., 2001).

During 2012-2013, 2,133 Danube shad (*Alosa immaculata*) specimens were caught and measured, amounting to a total biomass of 538.5 kg.

Size structure

Catches of 2012 comprised shads with mean sizes of 28.9 cm total length and 238 g/individual body weight (Table 6.4) and maxima of 36.6 cm and 550 g/individual.

Of the total 1,123 individuals, scales were collected from 112 specimens for age determination (1,011 individuals were only measured and weighed).

Table 6.4. Age and size structure - 2012 (ind.= individuals)

Age	Population		Total length (cm)		Total weight (g)	
(years)	ind.	%	range	mean	range	mean
2	18	16.07	15.6-23.8	19.7	56-114	85
3	47	41.96	21.5-33.6	27.6	81-320	200.5
4	41	36.60	29.0-35,8	32.4	231-460	345.5
5	6	5.35	32.0-36.1	34.1	340-480	410
Age determination batch	112	100	24.5-32.3	28.4	163-442	260.2
TOTAL batch	1123		14-36.6	28.9	62-550	238

Catches of 2013 comprised shads with mean sizes of 30.7 cm total length and 269 g/individual body weight (Table 6.5) and maxima of 36.5 cm and 476 g/individual.

Of the total 1,010 individuals, scales were collected from 127 specimens for age determination (883 individuals were only measured and weighed).

The mean length of the Danube shad population during 2012-2013 was 29.8 cm, with a total weight of 253.5 g (Table 6.6).

Table 6.5. Age and size structure - 2013 (ind.= individuals)

Age (years)	Population ind.	Population %	Total length (cm) range	Total length (cm) mean	Total weight (g) range	Total weight (g) mean
2	23	18.11	18.2-22.5	20.4	67-104	88
3	52	40.94	23.2-32.5	27,9	115-295	205
4	39	30.70	28.0-35.3	31,7	217-408	312
5	13	10.23	31.5-34.5	33,0	307-467	387
Age determination batch	127	100	25.2-31.2	28,2	163-442	248
TOTAL batch	1010		17.5-36.5	30,7	62-476	269

Table 6.6. Mean biometric data of Danube shad population in the Black Sea

Year	No. of individuals	Total length (cm) Mean	Standard deviation	Total weight (g) Mean	Standard deviation
2012	1123	28.9	5.479	238	117.384
2013	1010	30.7	3.379	269	85.515
TOTAL	2133	29.8	4.429	253.5	101.449

Danube shad individuals caught during the study years comprised 4 generations, namely 2-5 years. The samples were dominated by 3 and 4 year old cohorts (Fig. 6.1; 6.2; 6.3).

Fig. 6.1. Age structure in 2012

Fig. 6.2. Age structure in 2013

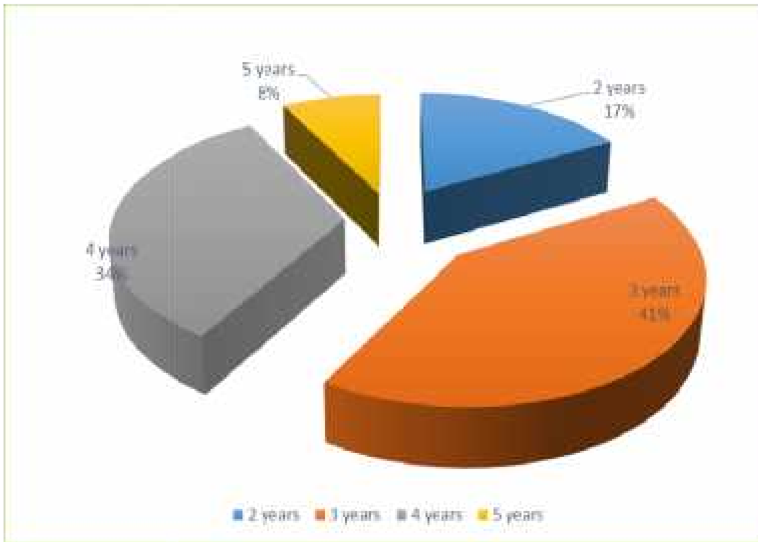

Fig. 6.3. Age structure in 2012 - 2013

Sex structure

The sex ratio for 2012-2013 was subunitary, expressing a dominance of females M/F=0.62 in 2012, M/F=0.62 in 2013). Within cohorts, the number of females increases with age, which accounts for a higher survival rate of females after spawning and a drop in the number of males after the first spawning (Fig. 6.4; 6.5).

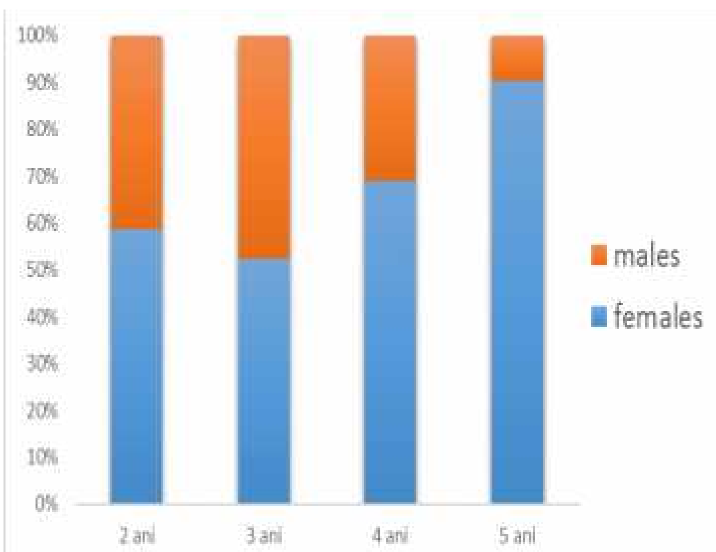

Fig. 6.4. Danube shad sex ratio in 2012

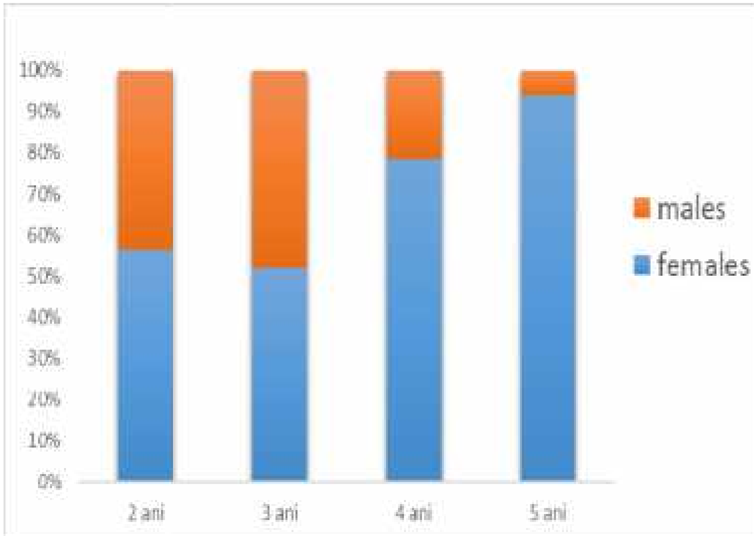

Fig. 6.5. Danube shad sex ratio in 2013

*<u>Danube shad fattening index (Fulton coefficient=TW*100/SL^3)</u>*

The Danube shads caught during the study years had a mean fattening index (2012-1.43), (2013-1.39) close to the mean of 1988-2004 - 1.38 (Năvodaru, 2004). The fattening index of shads increases in a linear manner for mean values of the Fulton coefficient (Fig. 6.6; 6.7).

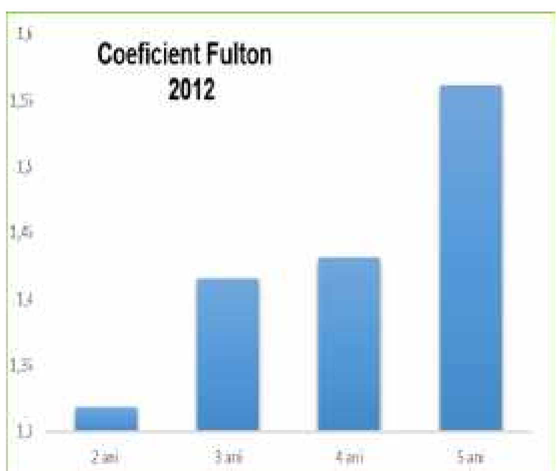

Fig. 6.6. Evolution of the fattening index of *A. immaculata* in 2012

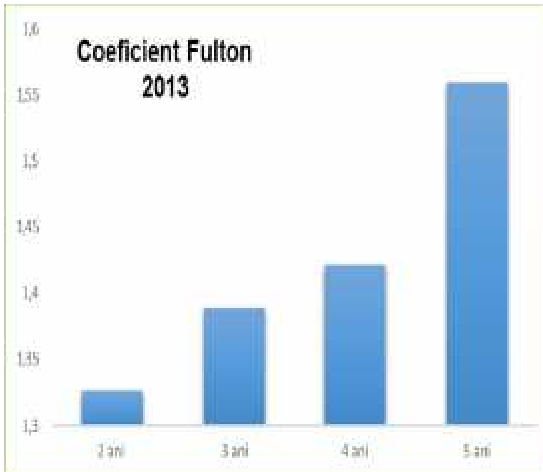

Fig. 6.7. Evolution of the fattening index of *A. immaculata* in 2013

<u>Spatial distribution of Danube shad caught by experimental fishing</u>

The spatial distribution per study years is marked by an increase in the numerical abundance of shad catches from north to east (sector 3 Periboina) and the Danube mouths, respectively, with the highest abundance recorded in the Zaton - Sahalin sectors (Fig. 6.8, 6.9).

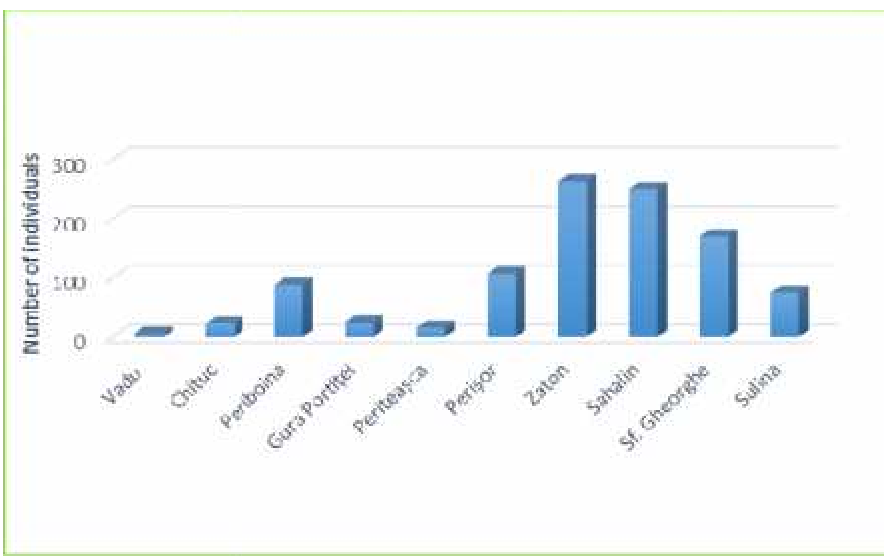

Fig. 6.8. Distribution per sectors of Danube shad catches in 2012

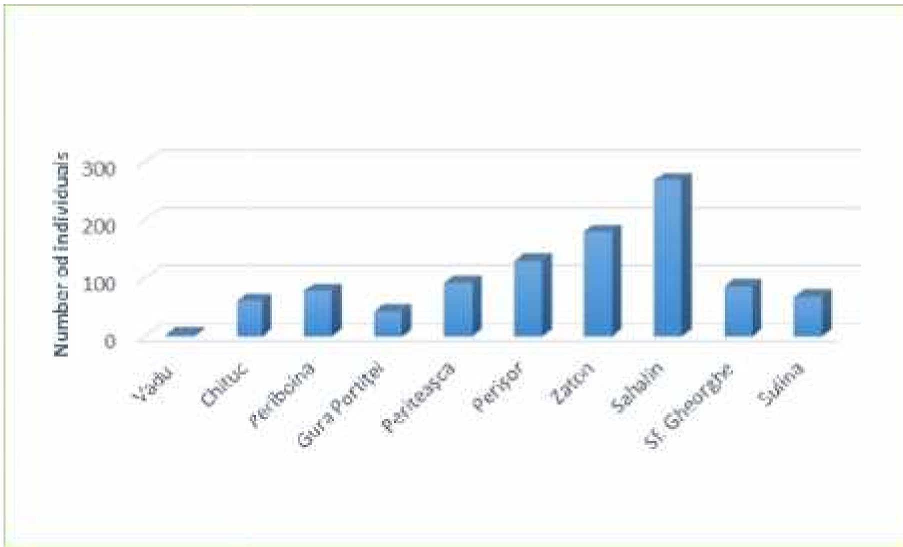

Fig. 6.9. Distribution per sectors of Danube shad catches in 2013

According to scientific and commercial fishing data, Danube shads are present on the Black Sea continental shelf throughout the whole year, with a higher abundance in spring close to the Danube mouths.

Length and weight frequency in Danube shad population

In 2012, the 1,123 shad individuals were grouped into 23 length classes, with lengths ranging between 14.0 - 37.0 cm (class size 1 cm), and 10 weight classes, ranging between 0-500 g, respectively. The highest frequencies in catches were recorded for length classes ranging between 29.0 - 35.0 cm and body weight ranging between 200 - 350 g, respectively. The mean length of individuals was 28.9 cm and the mean weight was 238 g. These values correspond to 3-5 years of age (Fig. 6.10., 6.11.).

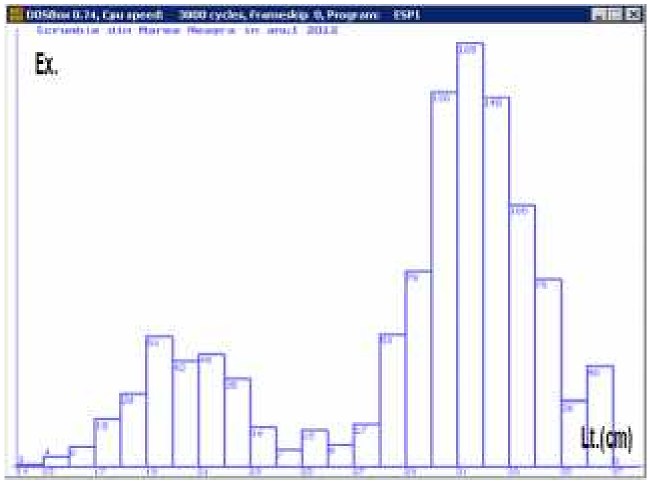

Fig. 6.10. Length frequencies of the Danube shad population in 2012

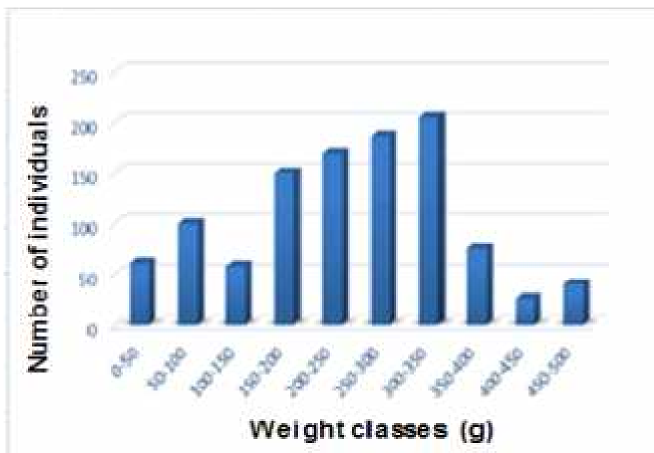

Fig. 6.11. Weight frequencies of the Danube shad population in 2012

In 2013, the 1,010 shad individuals were grouped into 20 length classes, with lengths ranging between 17.5 - 37.0 cm (class size 1 cm), and 10 weight classes, ranging between 0-500 g, respectively. The highest frequencies in catches were recorded for length classes ranging between 30.0 - 34.0 cm and body weight ranging between 200 - 450 g, respectively. The mean length of individuals was 30.7 cm and the mean weight was 269 g. These values correspond to 3-5 years of age (Fig. 6.12, 6.13).

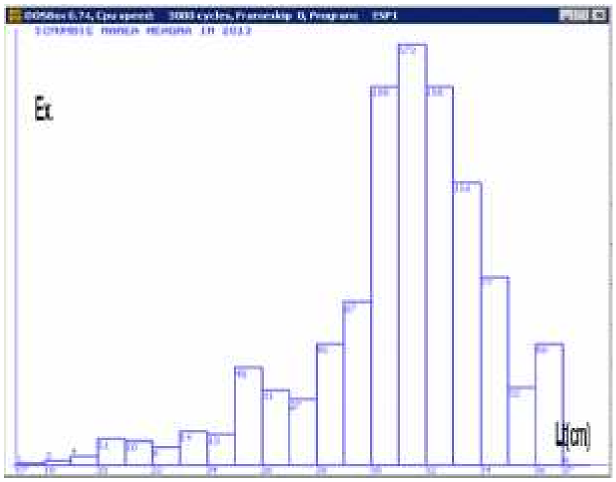

Fig. 6.12. Length frequencies of the Danube shad population in 2013

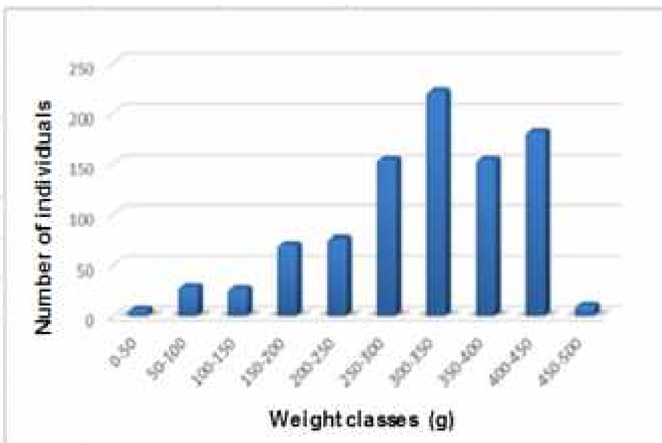

Fig. 6.13. Weight frequencies of the Danube shad population in 2013

Overall, for 2012-2013, the 2,133 shad individuals were grouped into 23 length classes, with lengths ranging between 14.0 - 37.0 cm (class size 1 cm), and 10 weight classes, ranging between 0-500 g, respectively. The highest frequencies in catches were recorded for length classes ranging between 29.0 - 35.0 cm and body weight ranging between 200 - 450 g, respectively. The mean length of individuals was 29.8 cm and the mean weight was 253.5 g. These values correspond to 3-5 years of age (Fig. 6.14, 6.15).

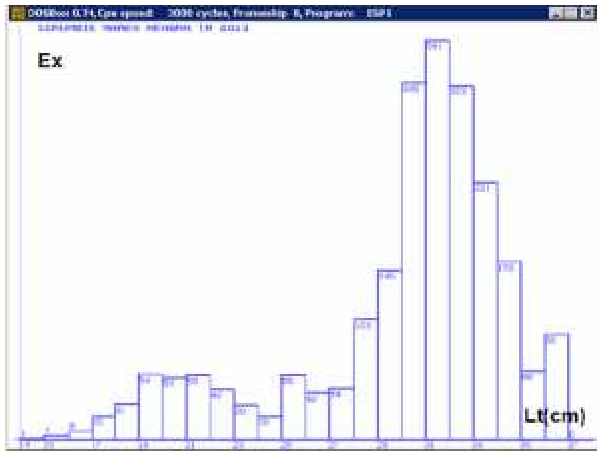

Fig. 6.14. Length frequencies of the Danube shad population in 2012 - 2013

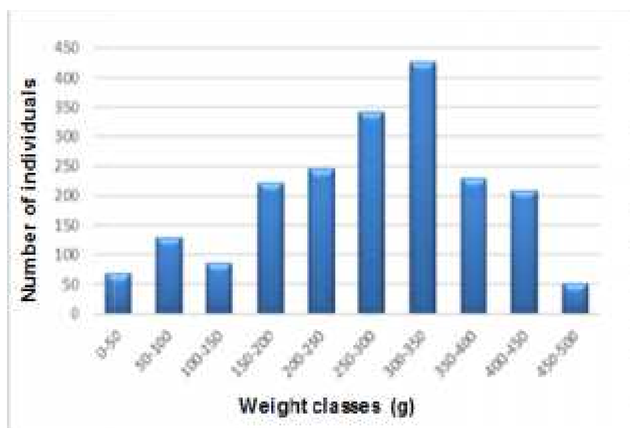

Fig. 6.15. Weight frequencies of the Danube shad population in 2012 - 2013

<u>Estimating growth coefficients: length-weight relationship (Lt-W)</u>

The length of a fish is directly proportional with weight gain, being strongly connected to development stages (early stages, size at first maturity, gonad development, spawning and spawning season) (Serajuddin M. *et al*., 2013). Studying the length-weight relationship helps establishing the equation of recruitment yield (Ricker W.E., 1958; Beverton R.J.H. *et al.* 1957), estimating the number of landed fishes and comparing populations spatially and temporally (Pandey B. *et al*. 1974).

Length and weight parameters are used in calculating fishing gear selectivity and mainly in sizing the mesh, aiming at improving the catch per unit effort.

The values of *a* and *b* coefficients in the equation $\mathbf{W = a * Lt^b}$ for the Danube shad population were determined graphically for each studied year and aggregated for the entire period 2012-2013, using an exponential equation (Fig. 6.16; 6.17; 6.18).

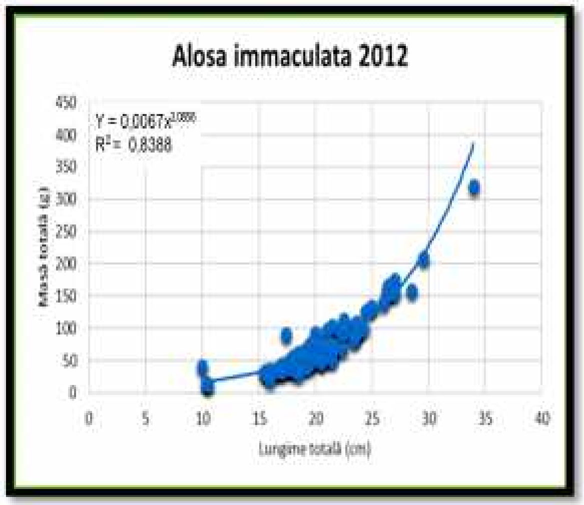

Fig. 6.16. Length-weight regression in Danube shad, 2012

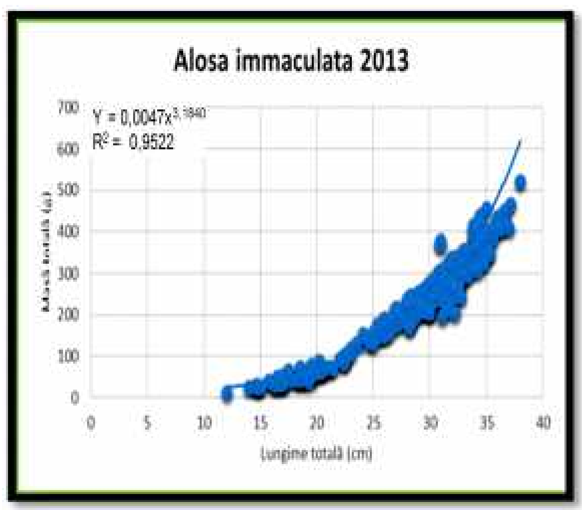

Fig. 6.17. Length-weight regression in Danube shad, 2013

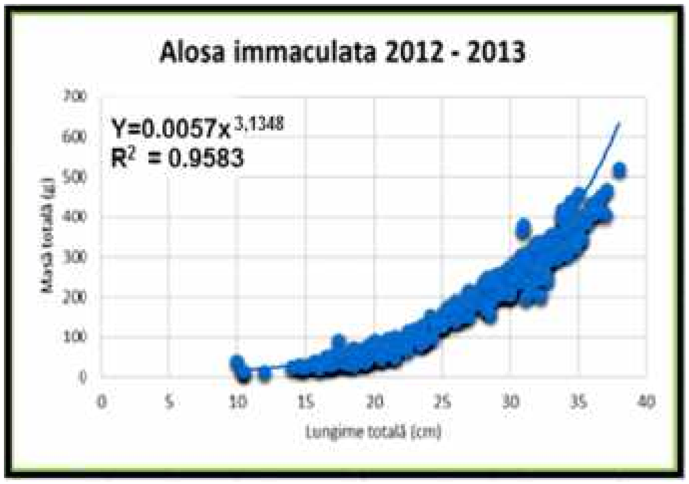

Fig. 6.18. Aggregated length-weight regression in Danube shad, 2012-2013

The *b* index values express the type of growth and, according to literature sources, its values range between 2 and 4 (Bagenal, Tesch, 1978; Weatherley A.H., 1972), but most often around 3 (Năvodaru I., 1997); in addition, this index can be considered as a measure of the environmental living conditions of fish (Battes K. *et al*., 2003), being a generalization of the Fulton coefficient (Pitcher T.J., 1990; Moreau J., 1979). The values of the *a* and *b* growth coefficients resulting from the plots (for each year separately and aggregately for the entire period covered) are centralized in Table 6.7.

Table 6.7. Values of the length-weight relationship *a* and *b* coefficients in Danube shad

Year	a	b
2012	0.0067	3.0856
2013	0.0047	3.1840
Total 2012-2013	**0.0057**	**3.1348**

During the two years of investigations, the values of cofficient *b* were higher than 3. In Danube shad population, the body grows more in weight compared to length, under normal environmental conditions for the development and growth of the species.

For the entire population, overall the study period, the determination coefficient (R^2) resulting from the regression was equal to 0.9583. A mean characteristic value of b

= 3.1348, which indicates an allometric growth for the specimens sampled, namely a positive allometry (b>3).

The value of *b* for the studied samples is close to the values reported in scientific papers dealing with this species in the Black Sea: 3.124; 3.216; 3.067 (Kalayci F., 2007), 3.285 (Savas Y. *et al*.,2011), 3.338 (Ozdaman E., 1995), but higher than the values obtained for the same species in the Danube: 2.457 (Năvodaru I., 1997), 2.487 (Ibănescu D.C. *et al*.,2016), 2.731 (Rozdina D. *et al*., 2013). Knowing the values of the two coefficients, the relationship between the total length and weight (Lt-W) for the Danube shad population during the study period was determined: $\mathbf{W = 0.0057 * Lt^{3.1348}}$.

Study for determining Danube shad stocks and effectives - 2012-2013

In order to estimate the status of Danube shad stocks, 2,133 individuals were sampled during 2012-2013 - biomass 538.5 kg, of which 1,123 specimens, with a total weight of 266.9 kg, were sampled in 2012, and 1.010 specimens, with a total weight of 271.6 kg, were sampled in 2013.

Table 6.8. Structure of samples according to length-weight frequency for the 2012-2013 migration (Lt = total length, W = weight, m.f.t.l.= most frequent total length)

year/ sampling area	Gear	No. of ind.	Weight (kg)	Lt mean (cm)	W.mean (g)	Range (cm)	m.f.t.l. (cm)
Shad total		**2,133**	**538.5**	-	-	14-36.6	32
2012 - Black Sea	Gillnets a=30-36 mm	1,123	266.9	28.9	238	14-36.6	32
2013 - Black Sea	Gillnets a=30-36 mm	1,010	271.6	30.7	269	17.5-36.5	32.5

Growth and exploitation parameters

Based on the samples analyzed for length frequency in scientific fish catches, the growth and exploitation parameters of the Danube shad stock of the Black Sea were estimated by analytical methods, using the ESP software (Table 6.9).

Table 6.9. Growth, exploitation parameters and length-weight relationship - migration 2012-2013 in the Black Sea (abbreviations explained in Chapter 4) ($W = a \times Lt^b$ length-weight relationship, Lt - total length, W - weight, *a* and *b* - regression coefficients)

Sampling year	Gear	Lã	K	to	Lr	Lc	M	F	Z	W = a x L^b	
2012	Gillnets a=30-36 mm	41.5	0.38	-0.35	14	30	0.585	1.13	1.71	0.00477	3.18405
2013	Gillnets a=30-36 mm	41.5	0.38	-0.34	14	30	0.639	1.07	1.71	0.00670	3.08561

The asymptotic length (L∞ = L infinity) of Danube shad generated by the ELEFAN I method, after introducing total length data for the two years of study, was 41.5.

The data obtained are comparable with the ones in literature. Danube shad populations with asymptotic length ranging between 35.74 - 57.38 are characterized by high growth rates in the first years of development (Table 6.10).

Table10. Von Bertalanffy growth parameters for linear growth in *Alosa immaculata*

Area and author	Lã	K	to
Danube (Năvodaru,1997)	48.10	0.2	-1.58
Danube (Rozdina, 2013)	35.74	0.4932	0.3411
Danube (Kolarov, 1980)	57.38	0.1067	1727
Danube (Kolarov, 1983)	40.43	0.2705	-0.218
Black Sea (Prodanov, Kolarov, 1983)	40.43	0.27	-0.218
Black Sea (original data 2012)	41.50	0.38	-0.35
Black Sea (original data 2013)	41.50	0.38	-0.34

The natural mortality instantaneous coefficient (M) of the entire Danube shad population, calculated according to Pauly's empirical equation, using the growth parameters of the Von Bertalanffy formula and the mean annual temperature of the two study years of 13^{o}C, recorded the following values: M=0.585 in 2012 and M=0.639 in 2013.

The length at full recruitment to the exploitable phase (Lc = 30 cm for 2012-2013) was determined after analyzing gillnet selectivity in relation to the frequency of lengths within catches. The calculation of the catch curve used to determine selectivity led to the total mortality instantaneous coefficient (Z = 1.71) for all age groups. Fishing mortality (F) was calculated according to the relationship Z = F+M, in this case F = 1.13 (2012) and F = 1.07 (2013), respectively.

Some additional considerations were made on the availability of food to some cohorts correlated to specimens' density, which impacts on growth, by testing the difference from 3 of the value of coefficient *b* in the relationship (Năvodaru I., 1997).

As such, good conditions and favorable densities result in accelerated growth (Fig. 6.19, 6.20), reflected by a value of coefficient *b* close to 3 or higher. In our case, the value of *b* was >3 during the study years.

Fig. 6.19. Von Bertalanffy growth curve in Danube shad in 2012

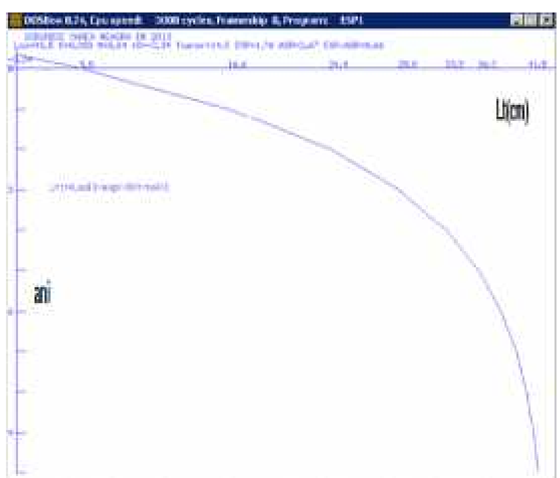

Fig. 6.20. Von Bertalanffy growth curve in Danube shad in 2013

<u>Estimating the status and exploitation of stocks</u>

The status of Danube shad stock expoitation was analyzed by positioning the current exploitation point (Pc) by means of the coordinates expressing length at which fishing selectivity has the value Lc = 0.5 and exploitation intensity (F), on the Y/R diagram resulting from applying the Beverton - Holt model (Fig. 6.21; 6.22).

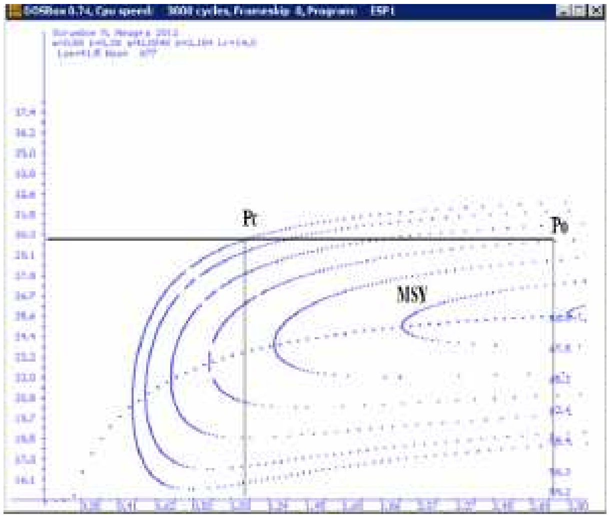

Fig. 6.21. Exploitation analysis by the Beverton - Holt yield per recruit Y/R model for the Danube shad, 2012

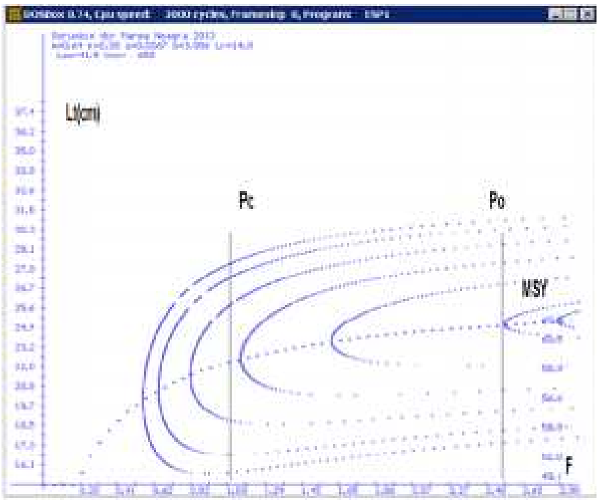

Fig. 6.22. Exploitation analysis by the Beverton - Holt yield per recruit Y/R model for the Danube shad, 2013

The virtual population analysis (VPA) by lengths was performed using the ESP software. Catch data previously determined were used to apply the model: length class frequency set, coefficients *a* = 0.00477 (2012), 0.00670 (2013) and *b* = 3.18405 (2012), 3.08561 (2013) of the length-weight relationship, natural mortality M = 0.585/year (2012) and 0.639 (2013), L_∞ = 41.5, k = 0.38/year.

We further performed a simulation of fishing optimization by modeling exploitation by changing the fishing effort (F) and recalculating the optimal biomass and the maximum sustainable yield (MSY), using the VPA and Thomson-Bell analytical models for the minimum of historical catches. The final data obtained from this analysis are absolute estimates of the stock and fishing mortality, for each length class, graphically shown in Tables 6.11 and 6.12 for 2012-2013.

Table 6.11. Assessing the current state by virtual population analysis in Danube shad, 2012

Lg.min-max -cm-	C mii ex	Xl	N mii ex	F/Z	F	Z	W gr.	Average mii ex	Biom (to)	Cant.p (to)
17.0 18.0	0.899	1.033	152.64	0.087	0.06	0.64	48	16.17	0.78	0.04
18.0 19.0	1.349	1.034	142.28	0.128	0.09	0.67	55	15.67	0.86	0.07
19.0 20.0	1.948	1.036	131.77	0.181	0.13	0.71	60	15.11	0.91	0.12
20.0 21.0	1.761	1.037	120.98	0.172	0.12	0.71	74	14.51	1.07	0.13
21.0 22.0	1.274	1.039	110.73	0.135	0.09	0.68	80	13.94	1.11	0.10
22.0 23.0	1.274	1.041	101.30	0.140	0.10	0.68	91	13.39	1.22	0.12
23.0 24.0	0.375	1.044	92.19	0.047	0.03	0.61	97	12.89	1.25	0.04
24.0 25.0	0.450	1.046	84.27	0.058	0.04	0.62	124	12.44	1.54	0.06
25.0 26.0	0.487	1.049	76.54	0.065	0.04	0.63	152	11.97	1.82	0.07
26.0 27.0	0.525	1.053	69.05	0.072	0.05	0.63	183	11.47	2.10	0.10
27.0 28.0	0.562	1.057	61.82	0.081	0.05	0.64	204	10.96	2.23	0.11
28.0 29.0	2.473	1.061	54.85	0.292	0.24	0.83	219	10.23	2.24	0.54
29.0 30.0	3.260	1.066	46.39	0.377	0.35	0.94	239	9.21	2.20	0.78
30.0 31.0	6.670	1.073	37.74	0.598	0.87	1.46	267	7.66	2.05	1.78
31.0 32.0	6.595	1.080	26.59	0.666	1.17	1.75	289	5.65	1.63	1.90
32.0 33.0	4.496	1.089	16.69	0.666	1.17	1.75	313	3.86	1.21	1.41
33.0 34.0	3.073	1.101	9.93	0.678	1.23	1.82	341	2.49	0.85	1.05
34.0 35.0	2.660	1.116	5.40	0.771	1.97	2.55	369	1.35	0.50	0.98
35.0 36.0	1.162	1.137	1.95	0.793	2.25	2.83	415	0.52	0.21	0.48
36.0 37.0	0.225	0.000	0.49	0.461	0.50	1.08	421	0.45	0.19	0.09
--------	42.043---								27.8	10.0
L00= 41.5 Lc=30.0 M=0.58 K=0.38										
Fmediu (N,L>=Lc)= 1.12 Fmediu (Average, L>=Lc)= 1.13 F(Y/B(L>=Lc))=1.16										

The results show that total mortality rates (Z) differ according to mean length and species’ character. Length classes with higher mortality rates varied considerably during the lifetime of fish. The length classes with higher mortalities were 29.0 - 36.0 cm (2012) and 29.0 - 37.0 cm (2013).

Table 6.12. Assessing the current state by virtual population analysis in Danube shad, 2013

Lg.min-max -cm-	C mii ex	Xl	N mii ex	F/Z	F	Z	W gr.	Average mii ex	Biom (to)	Cant.p (to)
17.0 18.0	0.037	1.036	174.63	0.003	0.00	0.64	45	18.49	0.83	0.00
18.0 19.0	0.110	1.037	162.78	0.010	0.01	0.65	50	17.96	0.90	0.01
19.0 20.0	0.184	1.039	151.19	0.016	0.01	0.65	58	17.40	1.00	0.01
20.0 21.0	0.405	1.041	139.89	0.036	0.02	0.66	72	16.82	1.21	0.03
21.0 22.0	0.295	1.043	128.73	0.028	0.02	0.66	72	16.23	1.16	0.02
22.0 23.0	0.405	1.045	118.07	0.039	0.03	0.66	101	15.63	1.58	0.04
23.0 24.0	0.479	1.048	107.68	0.048	0.03	0.67	110	15.00	1.65	0.05
24.0 25.0	0.994	1.051	97.61	0.098	0.07	0.71	146	14.32	2.10	0.15
25.0 26.0	1.288	1.054	87.47	0.129	0.10	0.73	159	13.56	2.15	0.20
26.0 27.0	1.325	1.058	77.52	0.140	0.10	0.74	176	12.76	2.25	0.23
27.0 28.0	0.920	1.062	68.04	0.107	0.08	0.72	205	11.97	2.45	0.19
28.0 29.0	2.062	1.067	59.47	0.225	0.19	0.82	209	11.10	2.32	0.43
29.0 30.0	3.203	1.073	50.32	0.335	0.32	0.96	235	9.96	2.34	0.75
30.0 31.0	6.185	1.079	40.75	0.537	0.74	1.38	264	8.33	2.20	1.63
31.0 32.0	6.553	1.088	29.24	0.621	1.05	1.69	286	6.26	1.79	1.87
32.0 33.0	5.227	1.098	18.69	0.658	1.23	1.87	308	4.26	1.31	1.61
33.0 34.0	3.240	1.111	10.74	0.654	1.21	1.85	345	2.68	0.93	1.12
34.0 35.0	2.687	1.128	5.79	0.742	1.84	2.48	367	1.46	0.54	0.99
35.0 36.0	1.399	1.151	2.17	0.801	2.58	3.22	422	0.54	0.23	0.59
36.0 37.0	0.184	0.000	0.42	0.439	0.50	1.14	417	0.37	0.15	0.08
--------	37.181---								29.1	10.0
L00= 41.5 Lc=30.0 M=0.64 K=0.38										
Fmediu (N,L>=Lc)= 1.05 Fmediu (Average, L>=Lc)= 1.07 F(Y/B(L>=Lc))=1.10										

Using the growth and stock exploitation parameters, the sustainable catch was estimated by the Thompson-Bell model. The maximum sustainable yield (MSY) was 10.97 tons (2012) and 11.67 tons (2013). However, this sustainable catch should be considered indicative, whereas the samples were collected experimentally, using a smaller mesh size (the legal allowed mesh size is 32 cm) compared to commercial fisheries (Table 6.13; 6.14).

Table 6.13. Fishing optimization by the Thompson-Bell model in the Danube shad, 2012

x	Cant.p	Biom	Biom(Tc)	Fm	Zm	F/Z=(la 36.0cm)
0.10	2.89	46.13	23.32	0.11	0.70	0.08
0.30	6.36	38.32	15.91	0.35	0.93	0.20
0.50	8.18	33.70	11.67	0.58	1.17	0.30
0.70	9.19	30.70	9.05	0.81	1.40	0.37
0.90	9.79	28.60	7.31	1.03	1.61	0.43
1.00	10.00	27.75	6.64	1.13	1.72	0.46
1.20	10.31	26.34	5.58	1.33	1.92	0.51
1.40	10.51	25.19	4.77	1.53	2.11	0.54
1.60	10.66	24.22	4.14	1.71	2.30	0.58
1.80	10.76	23.38	3.62	1.90	2.48	0.61
2.00	10.84	22.63	3.20	2.08	2.67	0.63
2.20	10.89	21.96	2.84	2.26	2.85	0.65
2.40	10.93	21.35	2.53	2.44	3.03	0.67
2.60	10.96	20.79	2.27	2.62	3.20	0.69
2.80	10.97	20.28	2.04	2.80	3.38	0.71
MSY= 10.97 corespunzator lui x=2.80						

Table 6.14. Fishing optimization by the Thompson-Bell model in the Danube shad, 2013

x	Cant.p	Biom	Biom(Tc)	Fm	Zm	F/Z=(la 36.0cm)
0.10	2.75	44.82	21.94	0.11	0.75	0.07
0.30	6.13	38.19	15.52	0.34	0.98	0.19
0.50	7.98	34.21	11.76	0.56	1.20	0.28
0.70	9.06	31.62	9.38	0.78	1.41	0.35
0.90	9.75	29.80	7.77	0.97	1.61	0.41
1.00	10.00	29.08	7.14	1.07	1.70	0.44
1.20	10.39	27.87	6.13	1.25	1.89	0.48
1.40	10.68	26.89	5.35	1.42	2.06	0.52
1.60	10.91	26.07	4.72	1.59	2.22	0.56
1.80	11.09	25.37	4.21	1.75	2.39	0.58
2.00	11.25	24.75	3.78	1.91	2.55	0.61
2.20	11.38	24.20	3.41	2.07	2.71	0.63
2.40	11.49	23.70	3.09	2.22	2.86	0.65
2.60	11.59	23.25	2.81	2.38	3.01	0.67
2.80	11.67	22.83	2.57	2.53	3.17	0.69
MSY=	11.67	corespunzator lui x=2.80				

Table 6.15. Estimating the exploitation status and measures for optimizing the current status for the Danube shad in the Black Sea (2012-2013) (Fc = current effort, Lc = length at first catch, Cc = current catch, Bc = current biomass, Fo = optimal effort, Co or MSY = optimal catch or maximum sustainable yield, Bo = optimal biomass, Y/Rc=yield per current recruit, Y/Ro = yield per optimal recruit)

Year	Gear	Fc	Lc	Cc tons	Bc tons	Fc→Fo (Fo/Fc)	Fo	Y/Rc	Y/Ro	Bo tons	Co MSY tons
2012	Gillnets a=30-36 mm	1.13	30	10	27.8	2.48	2.80	55	62	20.3	10.97
2013	Gillnets a=30-36 mm	1.07	30	10	29.1	2.36	2.53	49	51	22.8	11.67

6.3.3. Estimation of sustainable shad catches for the years 2012, 2013

The length structure of the Danube shad sampled in the Black Sea comprises specimens within the length range 14-36.6 cm, with a mean weight ranging between 266-271g/ex. and a mean length of 28.9-30.7 cm.

The dominant length classes ranged between 29.0 - 35.0 cm, representing about 75% of the total samples.

The optimal biomass of the exploitable stock in 2012, estimated by Virtual Population Analysis (VPA), is 20.3 tons, corresponding to a an optimal catch (MSY) of 10.97 tons.

The optimal biomass of the exploitable stock in 2013, estimated by Virtual Population Analysis (VPA), is 22.8 tons, corresponding to a an optimal catch (MSY) of 11.67 tons.

The exploitation status by analytical modeling of the Yield per Recruit (Y/R) is characterized by **overexploitation**, considering the selectivity of the mesh size (30 mm), which leads to a length at first catch of 30 cm. Given the exploitation rate, it is estimated that stocks are being overexploited, due to values higher than 0.5 which were recorded (E = 0.660 in 2012 and E = 0.625 in 2013, respectively).

Whereas we are dealing with a migratory stock, for practical reasons and due to the uncertainties of the different assessment models, it is not recommended to increase fishing effort or reduce the mesh size, but only to perform a sustainable fishing which avoids catching specimens below the allowable size pursuant to legal regulations in force.

Chapter 8

GENERAL CONCLUSIONS AND PERSONAL CONTRIBUTIONS

The most important conclusions resulting as a follow-up of the research performed are given below:

- In 2014, worldwide, approximately 167.2 million tons of aquatic organism were produced by catch and culture, of which 55.86% by fresh water and marine fishing and 44.14% by aquaculture.
- A drop of Danube shad catches in the FAO 05 and FAO 37 areas was recorded, the sharpest in Romania, where catches in the Black Sea reached only 2 tons in 2014;
- Water chemistry throughout the study period recorded normal values;
- From the hydrological point of view, the values recorded had non-significant variations compared to previous years;
- The current status of Romanian fisheries indicates the occurrence in catches of a great number of fish species (more than 20), of which small sized fishes are the base (sprat, anchovy, whiting, horse mackerel, gobies), as well as larger species (turbot and Danube shad). We must point out the low share of dogfish, garfish, bluefish, and the re-occurrence as isolated individuals of blue mackerel and Atlantic bonito;
- The increasing trend in Black Sea catches of the past four years (2012-2015) was not due to fish fauna, but to the emergence of the economic operators' interest for the manual and beam trawl harvesting of the rapa whelk (*Rapana venosa*), whose catches increased year by year, from approximately 10% / 2010, to 65% / 2012, 89% / 2014 and 92.02 %/2015 of the total catch recorded at the Romanian Black Sea coast;
- The peak season for Danube shad fishery in Romanian Black Sea waters is during February - March, and is performed with fixed gillnets with mesh size 32-36 mm set at 2-12 m depths;
- In 2014, the number of fishing vessels in the Romanian Black Sea continued to drop: 158 vessels were recorded, of which 123 were active;

- The total number of commercial fishermen in Romanian Black Sea coastal waters dropped progressively year by year, from 447 people in 2011, to 304 people in 2014;
- Danube shad catches in the Danube Delta area reached their peak in 1975 (2,500 tons), while the minimum was recorded in 1999 (23 tons), with peaks of 1,000 tons/year and approximately 500 tons/year in recent years;
- From the Danube shad migration point of view, 2014 is very similar to the historical minimum of 1999 (23 tons);
- During the studied period, 2,133 individuals of the species *Alosa immaculata* were measured and weighed;
- The age structure for the two study years (2012-2013) comprised 4 cohorts (generations), with ages comprised between 2 and 5 years old. The dominant cohorts were the 3 year old (41.96-40.94%), followed by 4 year old (36.60-30.70%);
- The sex ratio during the study years was subunitary, with a dominance of females;
- The Danube shads caught had a medium fattening index (2012-1.43), (2013-1.38), close to the mean of 1988-2004 (1.38);
- According to scientific and commercial fishing, shads are present on the Romanian continental shelf of the Black Sea throughout the year, with higher abundances in spring, close to the Danube mouths;
- Overall, for 2012-2013, the 2,133 shad individuals were grouped into 23 length classes, with lengths ranging between 14.0 - 37.0 cm (class size 1 cm), and 10 weight classes, ranging between 0-500 g, respectively. The highest frequencies in catches were recorded for length classes ranging between 29.0 - 35.0 cm and body weight ranging between 200 - 450 g, respectively. The mean length of individuals was 29.8 cm and the mean weight was 253.5 g. These values correspond to 3-5 years of age;
- The relationship between the total length and weight (Lt-W) for the Danube shad population during the study period was determined: $W = 0.0057 * Lt^{3.1348}$;
- The asymptotic length ($L\infty$ = L infinity) of Danube shad generated by the ELEFAN I method, after introducing total length data for the two years of study, was 41.5;
- The natural mortality instantaneous coefficient (M) of the entire Danube shad population, calculated according to Pauly’s empirical equation, using the growth

parameters of the Von Bertalanffy formula and the mean annual temperature of the two study years of 13°C, recorded the following values: M=0.585 in 2012 and M=0.639 in 2013;

- The virtual population analysis (VPA) by lengths was performed using the ESP software. Catch data previously determined were used to apply the model: length class frequency set, coefficients *a* = 0.00477 (2012), 0.00670 (2013) and *b* = 3.18405 (2012), 3.08561 (2013) of the length-weight relationship, natural mortality M = 0.585/year (2012) and 0.639 (2013), $L\infty$ = 41.5, k = 0.38/year;
- The length classes with higher mortalities were 29.0 - 36.0 cm (2012) and 29.0 - 37.0 cm (2013);
- The optimal biomass of the exploitable stock in 2012, estimated by Virtual Population Analysis (VPA), is 20.3 tons, corresponding to a an optimal catch (MSY) of 10.97 tons;
- The optimal biomass of the exploitable stock in 2013, estimated by Virtual Population Analysis (VPA), is 22.8 tons, corresponding to a an optimal catch (MSY) of 11.67 tons;
- The exploitation status by analytical modeling of the Yield per Recruit (Y/R) is characterized by **overexploitation**, considering the selectivity of the mesh size (30 mm), which leads to a length at first catch of 30 cm. Given the exploitation rate, it is estimated that stocks are being overexploited, due to values higher than 0.5 which were recorded (E = 0.660 in 2012 and E = 0.625 in 2013, respectively).
- Measures proposed for the protection of Danube shad:

  The need to elaborate a common strategy of the countries involved in exploiting the shared fish stocks of the Black Sea basin, which should be the background for analyzing the trends and applying the precautionary principle for sustainable fisheries;

  Continuing the research aiming at improving the knowledge on population dynamics, seasonal migration between aquatic basins (Black Sea, Danube) and the influencing factors. A wider and more open communication between scientists, managers, decision makers, fishermen etc. is required, with the aim of improving fisheries management.

The originality of this PhD thesis relies on:

- Analysis of FAO statistics elaborated in 2014, with a synthetic and relevant characterization of the fishing and aquaculture sector worldwide and in Romania, during 2008-2014;
- Overview of the Danube shad taxonomy, morphology and ecobiology;
- Detailed outline of all research methods and materials used in order to write this PhD thesis. Moreover, statistical and mathematical modeling methods (ESP software) were used to estimate the growth parameters, mortality rates and stock size of Danube shad of the Romanian Black Sea coast;
- Description of the fishing area, its location and characterization. The Black Sea area was analyzed from the climate, hydrochemistry, hydrology and hydrobiology point of view for the period covered by the study years;
- Establishing and analyzing the biological parameters for a commercial Black Sea species (length class, weight class, age structure and frequency of occurrence in catches) for two consecutive years;
- Assessing the current state of Danube shad population by calculating the catch per unit effort (CPUE), estimating mortaliy rates, analyzing cohorts and stock prediction;
- Underpinning a management plan and elaborating a set of measure proposals for the sustainable exploitation of Danube shad fishery.