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Lower Danube Wetlands System (LDWS)

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1. INTRODUCCIÓN

The Lower Danube River System (LDRS), including the river stretch of 840 km, between Black Sea and Iron Gate II man made reservoir and the associated floodplains, inner and coastal deltas, has worked until late 60's this century and still works, in spite of many deep changes occurred in the last decades, as the key components of the second largest (2.857 km) river in Europe, serving as buffer system between the river catchment and the sea as well as footprint for the economies of the riverine countries: Romania, Yugoslavia, Bulgaria, Republic of Moldavia and Ukraine.

Many internal and external anthropic driving forces have been responsible in the last century for structural and functional changes of the LDRS with significant negative impact on the buffering capacity and on the amount and quality of the provided resources and services.

This case study is dealing with the brief analysis of major changes occurred in the last century, in the downstram wetlands network of the LDRS (hereinafter LDWS), which form almost 80% of the whole system, with the key internal and external driving forces, the assessment of the main economic consequences and of the opportunities for rehabilitation and future management.

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2. STRUCTURE AND SPATIAL DISTRIBUTION

The Lower Danube Wetland System (LDWS) is developed and extended along both sides of the last stretch of 365 km of the Danube River and comprises five major hydrogeomorphological units (HGMU^S) and the respective complexes of ecosystems (landscapes) which are strongly connected through longitudinal and lateral hydrological gradients (Fig. 1):

i. Inner Danube Delta which has developed on the Romanian territory along the river stretch between Calarasi (365 km) and Braila (170 km) and between Southern Romanian Plain and the Dobrogean Plateau over a total surface of 2413 square kilometers. It has as main components the Smaill and Big Islands of Braila (876 square kilometers), the Borcea Island (801 square kilometers) and the lateral flooding areas (736 square kilometers).
ii. River stretch between Braila (170 km) and Ceatal* Ismail (78 km) and the associated flooding areas in a total surface of 701 square kilometers.
iii. Core Danube delta having a spatial distribution between Chilia arm at the north and Tulcea, respectively Saint Gheorghe arm, at the south as well as between Ceatal Ismail at the west and Black sea at the east, with a total surface of 2570 square kilometers.
iv. Secondary Chilia delta which is undergoing an active development process since four centuries ago (MIKHAILOV et al, 1981) in the extreme north-eastern part of coastal Danube Delta has the actual surface estimated at 732 square kilometers and is situated on the Ukrainian territory.
v. Dranov floodplain complex covers 876 square kilometers in the southeastern corner of the Coastal Danube Delta. It has the western and southwestern border with northern Dobrogean hills and Razim Lagoon Lake and southeastern border with the Black Sea.

The last three hydrogeomorphological units and complexes of ecosystems forms together what is called the «Coastal Danube River Delta» with a total surface of 4178 square kilometers.

The current geomorphology of the coastal delta is the result of the long term interaction between the Danube River and north-western part of Black Sea during the Holocene period, beginning some 16,000 years ago (PANIN, 1974, 1998; MIHAILESCU, 1989). At that time, the Sea level was about 9 m higher than our days and the river has formed an estuary. Subsequently, the level of the Black Sea dropped, and a series of sand bars, channels and lagoons were formed, a

* Bifurcation of Danube River into Chilia arm (north) bordering Romania and Ukraine and Tulcea arm (south).

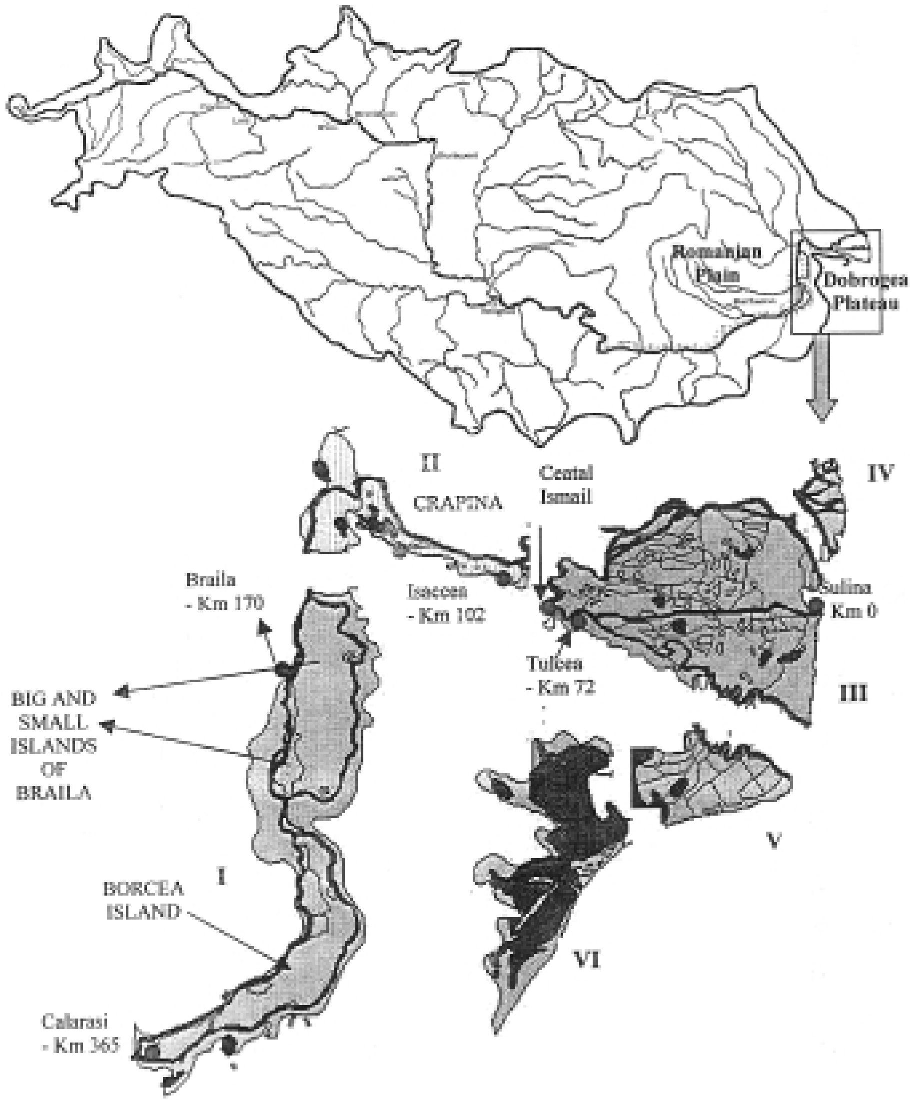

Figure 1.
Srtructure an istribution of wetlands in te former flooding area linked to the Danube River stretch between SULINA and CALARASI (365 Km) - Lower Danube Wetlands systems.
Subunits: I-IV as described in the text.

Main units	*Cod*	*Sectors*	*Area (kpm)*	*Slope*	*Length*	*Width*
Danube floodplain			6404.79			
	0	Calafat-Calarasi	2676.64			
	1	Calarasi-Braila	3026.56			
	2	Braila-Tulcea	701.59			
Danube Delta			4833.9			
	3	Tulcea-Sulina	2725.6			
	4	Chilia	176.15			
	5	Dranov	706.93			
	6	Razelm	1225.22			
Total (area - kmp)			11238.69			

	Land use categories (%)						
Main units	*Arable*	*Pasture*	*Meadow*	*Vineyards*	*Orchards*	*Forest*	*Wetlands*
Danube floodplain	67.13	7.34	0.35	0.52	0.17	15.21	9.27
Danube Delta	7.3	5.58	0	0	0	6.65	80.47
	Non-flooded					*Flooded*	
Danube floodplain	75.52%					24.48%	
Danube Delta	12.88%					87.47%	

process that has continued up to the present day. Currently, about 79% of the coastal delta is at or above the modern sea level and the rest of 21% bellow sea level.

vi. Razim-Sinoe lagoon complex is situated to the south of the coastal delta and has a total area estimated at 1015 square kilometers, of which the limans or flooded valleys and lagoons extends over 863 square kilometers.

The complex consists mainly of basins, that were originally marine bays (e.g. the well known Gulf of Halmyris at that time) but which, over the last 1500 years, became isolated from the sea by sand bars and dunes resulting from the deposition and eastward drift of sediments from the mouth of the Danube river and the seaward advance of the coastal delta itself over the past 3,000 years (PANIN, 1974).

The diversity of geomorphological features (e.g. river branches, network of subsidiary channels, lakes, levees, floodplains, saline dunes, marshes) and the lateral and longitudinal hydrological gradients in both inner and coastal delta, combined with the diversity of vegetation units (e.g. reed marshes, reed vegetation on floating peat, sedge marshes, saline vegetation, shrubs and herbaceous vegetation, willow formations) explain the former and current ecosystems richness (Table 1) in spite of

TABLE 1
Ecosystem composition inside the large hydrogeomorphologic units of the LDSW at the reference (R) (Antipa 1910) and current (C) states

No.	*Type of ecosystems*	*Hydrogeomorphological units**											
		I		*II*		*III*		*IV*		*V*		*VI*	
		R	*C*	*R*	*C*	*R*	*C*	*R*	*C*	*R*	*C*	*R*	*C*
1.	Running water ecosystems	+	+	+	+	+	+	+	+	+	+	+	+
2.	Shallow lakes and ponds	+	+	+	+	+	+	+	+	+	+	+	+
3.	Marshes	+	–	+	+	+	+	+	+	+	+	+	+
4.	Semi-enclosed bays	–	–	–	–	+	+	+	+	–	–	–	–
5.	Lagoons	–	–	–	–	–	–	–	–	–	–	+	+
6.	Frequently flooded river levees	+	+	+	+	+	+	+	+	+	+	–	–
6.1.	Grasslands	+	+	+	+	+	+	+	+	+	+	–	–
6.2.	Temperate riverine forest	+	+	+	+	+	+	+	+	+	+	–	–
7.	Mixed oak forest (marine levees)	–	–	–	–	+	+	–	–	–	–	–	–
8.	Meadows	+	–	+	–	+	+	+	+	–	–	–	–
9.	Meadows on low marine levees	–	–	–	–	+	+	+	+	+	+	+	+
10.	Dunes	–	–	–	–	+	+	+	+	–	–	–	–
11.	Coastal sand bars	–	–	–	–	+	+	+	+	+	+	+	+
12.	Agricultural polders**	–	+	–	+	–	+	–	+	–	+	–	–
13.	Forest plantations**	–	+	–	+	–	+	–	–	–	–	–	–
14.	Fish ponds**	–	+	–	+	–	+	–	–	–	+	–	+
15.	Human settlements	–	–	+	+	+	+	+	+	–	–	–	–

* As described in the text.
** Human dominated systems created by substitution of the natural ecosystems.

extensive substitution works carried out during the 6th and 7th decades of this century for establishing human dominated ecosystems in the LDRS.

By its total surface of 8307 square kilometers and structural complexity, the downstream wetlands of LDRS was and still remained one of the largest wetland system in Europe. It has been developed as the interface between the Danube River catchment (817,000 square kilometers) and North-Western Black Sea and has provided and is providing a wide range of renewable resources, water purification and flood control, habitats for nesting, spawning and feeding of many migratory bird and fish species, habitats for 1688 plants and 3735 animal species (BABOIANU, 1998; VADINEANU et al, 1998).

3. MAN INDUCED CHANGES

Different policies and management plans have been developed and implemented in the last century at the Lower Danube wetland system. These had a wide range of long term objectives: from the development of waterway transport, flood control and power generation system, irrigation system, improvement of the hydrological regime, substitution of natural and seminatural ecosystems by human dominated and powered systems (e.g. intensive crop and animal farms) to the nature conservation and more recently to the balancing biodiversity and socio-economic development. The approach has moved for a long time from traditional and less intensive use to utilitarian and intensiveness principles and only in the last decade is started to become more integrated and driven by the sustainable principle.

The implementation of the management plans have required gradually, significant structural and functional changes which have been in more or less extent enhaced by the extern driving forces, originated in the whole river catchment and finally they had a strong impact on the Black Sea and regional socio-economic system.

3.1. CHANGES IN SPATIO-TEMPORAL ORGANIZATION OF THE LOWER DANUBE WETLAND SYSTEM (LDWS)

The former ecological structure of LDWS, which have integrated at the end of 19th century more then 90% of natural and seminatural ecosystems, has been very significantly changed during the last century. Structural changes of different degree occurred in all main subunits of LDWS.

They have been designed and implemented as specific actions for the achievement of specific objectives established in the management plans of this large system.

The following types of structural changes may be identified as the most characteristic for the last century:

i. Large hydrotechnical works dealing with the development and improvement of the hydrological network within the system in order to extend and strengthen the water way transport, to increase the connectivity and stimulate water and solid discharges, to improve water quality, biological productivity and in particular to stimulate the fish productivity, to change brackish into fresh water resource for crop irrigation and to control the geomorphological dynamics of coastal delta. In this respect, at the end of 19^{th} and beginning of the 20^{th} centuries, the Sulima arm of the Danube River has been regulated by cutting off the meanders and dredging the river in order to allow maritime shipping to get access to large river harbors (e.g. Tulcea, Reni, Galati) up to Braila (170 km upstream). In the late 70's and beginning of 80's, three major water way transport have been opened, two of them within the core Danube Delta (Caraorman,channel which establish the link between the Caraorman village and South-eastern area former designed for sand exploitation and Sulima arm; Channel 35, which is a shortest route between the Chilia village and Pardina polder, located in north-western coastal delta and Tulcea town) and the third well knows as Danube-Black Sea Canal establishing the direct link between river harbor Cernavoda (320 km) and sea harbor Constanta. In the first decades of the 20^{th} century, based on the best scientific findings of the Romanian limnologist Grigore Antipa in the field of biological productivity of the LDWS, two direct fresh water discharges (Dranov and Dunavat channels: ~ 45 cubic meters per second) have been opened from «Saint Gheorghe» arm to northern part of the Razim-Sinoe lagoon system. Later, these hydrotechnical works have been supplemented with those dealing with the regulation of water mass exchanges between the lagoons and the sea (LEONTE et al, 1956). Following to these structural changes, which in fact led to better hydrological, and hydrochemical conditions, an increase in the fish catches with a factor of two has been recorded (LEONTE et al, 1956; STARAS, 1995). At the beginning of the 70's, it was cutted off the major inlet (Portita) of the Razim-Sinoe complex (except that from the Southern extreme) and it was increased the level of fresh water discharges through Dranov and Dunavat channels in order to change the former lagoon system into a fresh water reservoir of more than one billion cubic meters volume and respectively in a major water resource for supplying the large irrigation system built of that time in north-eastern dobrogean plateau. Large hydrotechnical works have been designed and carried out in the last two decades along Saint Gheorghe arm and seashore, consisting in cutting off the meanders in order to increase water and solid discharges and respectively the shore consolidation against coastal erosion.

ii. In order to facilitate the access in the compact and isolated reed stands and stimulate the efficiency of reed harvesting as well as to improve the conditions for fish species reproduction and development, during 60's and 70's, large enclosures were designed and established especially in the eastern part of core Danube Delta and Dranov complex.

iii. The most extensive and severe structural changes in the LDWS occurred during 60's and 80's by implementing the management plans which were mostly targeted on substitution of the natural and seminatural ecosystems with human dominated ones (e.g. intensive fish and agricultural farms, poplar plantations). However, by the end of 1989, the substitution has been achieved in different extents in the main subunits of the LDWS. In the inner Danube delta, 80% of former ecosystems have been replaced by intensive agricultural farms, 3% into tree plantations and 2% into intensive fish farms. The floodplains associated to the river stretch Braila-Ceatal Ismail have been substituted by intensive crop farms (57%) and fish farms (14%) Fortunately, the program for substitution of large natural areas and intensive exploitation of reed and fish resources in the coastal Danube Delta has been delayed and implemented in less extent than it was planned. By the end of 80's, only 9% of wetlands from coastal delta were replaced by large agricultural farms and tree plantations and almost 7% of them was replaced by intensive fish farms (Fig. 2). It is obvious that the structural changes occurred in the first phases of this long term process prove that the LDWS have maintained the basic characteristics until 50's. This in fact supports the idea to consider that states as the reference sytem for any scenarios dealing with restoration and sustainable management of it.

3.2. Changes in hydrology and sedimenthology

The two hydropower dams Iron Gates I and II built after 60^{S} on the Lower Danube River Stretch and the Water course regulation along the river and its tributaries, including floodplain substitution, river bank stabilisation have affected both the hydrological dynamics and sediment discharge downstream.

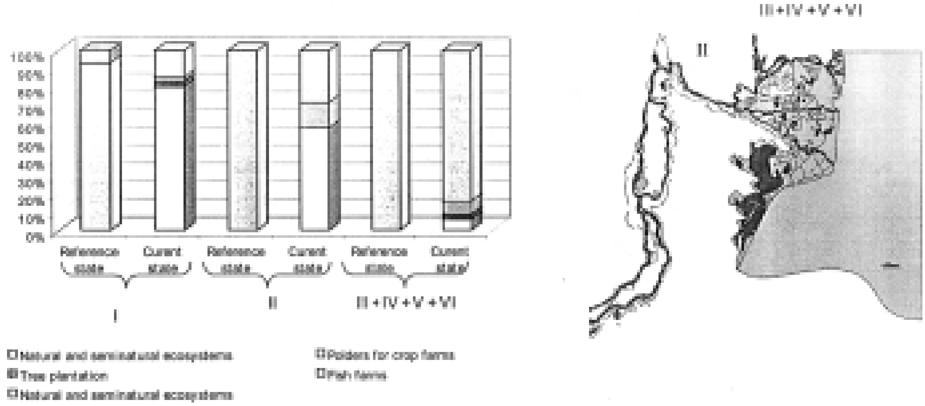

Figure 2.
Changes in the structure of major subunits of the LDWS occurred by substitution of natural into man-dominated ecosystems.
I - Inner Danube delta; II - Braila/Ceatal Ismail Complex;
III+IV+V+VI - Coastal Danube delta; R - reference state; C - current state.

Analysis of the hydrological data recorded over more than 70 years period, between 1921 and 1992, showed no significant changes in the annual water river discharge (BONDAR, 1994). A slight increase of the flow peaks, with about 5% mentioned by Bondar 1996, could be attributed to the loss of wetland area and of associated water retention capacity of floodplain with about 4,5 km^3 (GASTESCU, 1993). The main parameters of the hydrological regime like flood's amplitude, time of occurrence, duration and frequency were also modulated by local structural changes occurred within the LDWS or by managerial practices applied in the fisheries sector. The local hydrological cycles in the substituted ecosystems and surrounding landscapes were affected by diking, which interrupted the surface connectivity of the remained wetlands with the river and also by irrigation practices associated with the lack of drainage system, both leading to water stagnation and soil salinization. Very important were the changes of the discharge distribution between the river arms, of the water circulation within core delta and water exchanges between sea and coastal delta. Water course regulation, including shortcutting river arms as well as dragging existing channels and cutting new ones within delta, led to an increase by 3 times of the water turnover rate of the core delta (BONDAR, 1994) which in fact means a reduction of water retention time in the area from one year to 4 months. Shortcutting of St. Gheorghe arm, aiming to increase with 4-5% the water and solid discharges through the southern corridor of the delta, into Black Sea and consequently to deminish the coastal erosion south to that pint or indirectly to decrease the development rate of the Chilia delta, has led to lower effects (2-3% increase of discharges) then those expected.

The two series of hydrological works made in the Razim Sinoe lagoon system caused important changes to the morphometry, hydrological balance and in the water mass exchanges among lagoons and sea. The water supply from the Danube River increased to 90% of the total supply of about 83 m^3s^{-1}, by cutting and enlarging channels Dranov and Dunavat. By cutting off the main lagoon inlet (Portita) and building a very effective sluice system has been established a north-south gradient of water level which maintain the water flow towards the Sea and limit the inflow of Sea water only to a small area of the Sinoe Lagoon (BONDAR, 1990).

The most important changes in the sediment regime were expressed by decrease of sediment discharge along the river stretch, changes in the sediment load distribution between the river branches and core delta parts as well as alteration of the ratio between siltation and erosion processes. Decreasing sediment discharge from 69,4 10^6 t y^{-1}, at the beginning of the century, to about 53 10^6 t y^{-1}, at the beginning of the 50's, and to less then 30 10^6 t y^{-1} in the late 80's, followed by a slight increase in the last period (BONDAR, 1990; PANIN, 1996) proved to be the main driving force for changing the geomorphology of Coastal Delta. (Fig. 3).

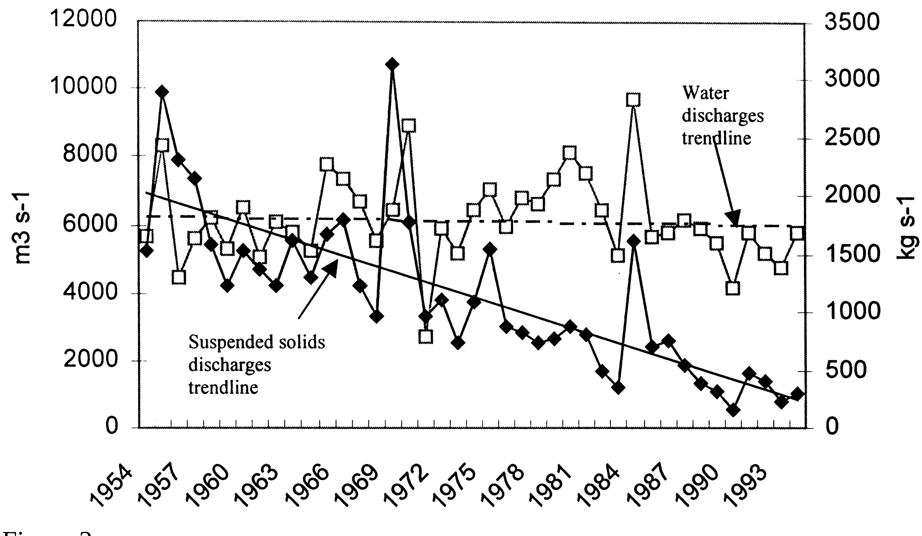

Figure 3.
Dynamics of water and suspended solids discharge of the Danube River into North-Western Black Sea. The points indicate the average water and solid flows between 1954-1994.

These complex changes in hydrological and sedimenthological regimes, both upstream and within coastal delta, disturbed significantly the balance among the siltation and erosion processes at the river mouths. The changes in the grain-size structure and disposal of sediments were accompanied by an increase of the development rate of the secondary delta in the northern part and by an increase of erosion in the southern part, affecting morphometry of sea bank and sand bars like the island of Sahalin.

2.3. CHANGES IN WATER CHEMISTRY, TURBIDITY AND LIGHT AVAILABILITY

The main processes affecting the physical and chemical characteristics of the water systems (water quality) belonging to the LDWS, were the eutrophycation and water salinity transitions. If the first process has a general relevance for the entire LDWS, including the North-Western Coast of the Black Sea, the second one is specific for the Razim-Sinoe lagoon system. Pollution with heavy-metals, pesticides and other pollutants accompanied these changes of the water quality at the LDWS scale.

A review of the data on the main nutrients responsible for the trophic state shift of aquatic ecosystem associated to the LDWS (total reactive phosphorous-TRP and dissolved inorganic nitrogen-DIN) showed interesting dynamics for the lower Danube River stretch including three different trends in time (Fig. 4). In terms of the fluctuation domailns for TRP concentration in water, a relatively stable period between 1958/1959 and 1980/1981 was followed by a shift towards a wider range and higher concentrations between 1981 and 1989, suggesting that the period 1980/1982 could be considered the moment of surpassing buffering capacity of the LDWS by the increasing nutrient loads. In this period, TRP increased about 5.7, exceeding by 4.2-32.7 times (VADINEANU et al. 1992) the limiting critical level of 10 μgP l^{-1} (HECKY, 1988). After 1990, the TRP concentrations remained below the maximal values of 250 μg P 1^{-1} (VADINEANU & CRISTOFOR, 1994) as a consequence of diminishing intensive agricultural and industrial activities in the conditions of the socio-economic transition in many countries from the river catchment. On the same period, the DIN:TRP ratio, as a very significant parameter of the trophic state, decreased markedly from values of tens and hundreds, before 1980, towards values below 10 (VADINEANU et al. 1992). This fact shows that the role of phosphorus as limiting factor was gradually replaced by nitrogen, with important effects on the turbidity and light conditions in water. These symptoms of transition towards high trophic changes have been even more prominent in the inner and coastal delta lakes, where nutrient supply from the river entering these aquatic systems interfered with nutrient release from sediments (CRISTOFOR et al. 1993).

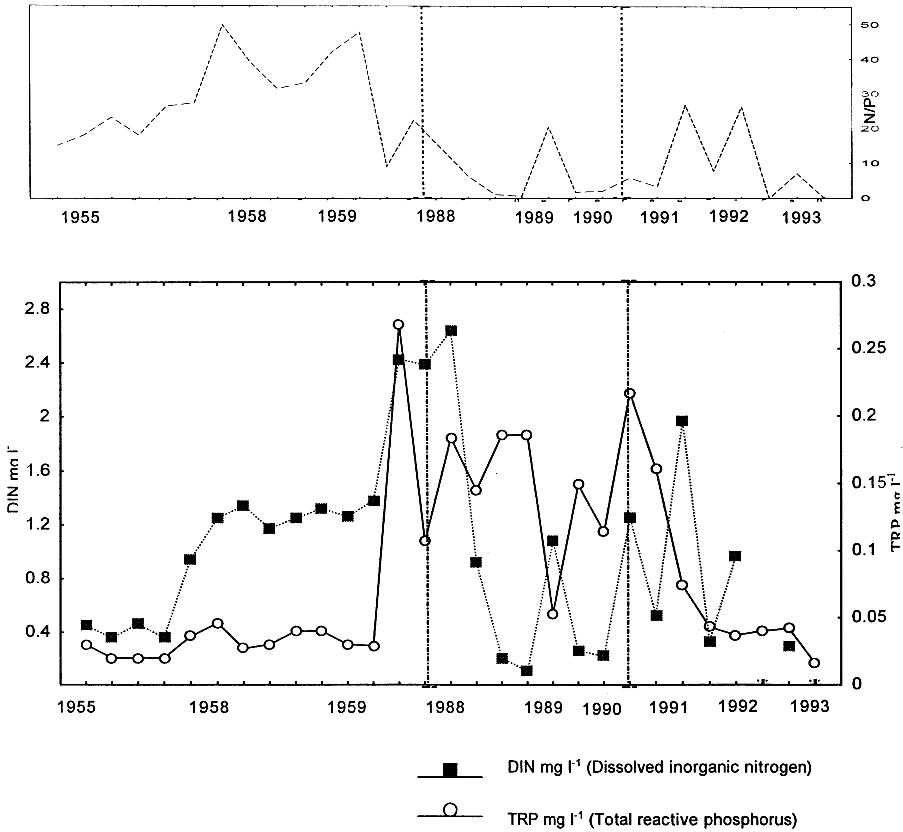

Figure 4.
Dynamic of nutrient concentration TRP mgP 1^{-1}, DIN mgN 1^{-1} and N:P ratio along selected reference and current periods, between 1955/1958 and 1988-1993.

In these conditions, the algal blooms became more frequent and extended in space and time and high amounts of dissolved and particulate organic matter were produced resulting in turbidity increase. The Secchi depth (SD) lowered from values of meters towards 15-30 cm, and its logarithmic expression, the trophic state index (TSI), increased from 40-60 (mesotrophy and early eutrophy) towards 65-85 (hypertrophy). The light availability became scarce especially in the deeper layers of the water column, the euphotic zone remaining limited to the superficial ones. The index of relative transparency, defined as the ratio between SD and water depth, decreased from 0.7-1 (total transparency) to below 0.4, the critical threshold for growth of submerged macrophytes (BOTNARIUC & BELDESCU, 1961) (Fig. 5). This was accompa-

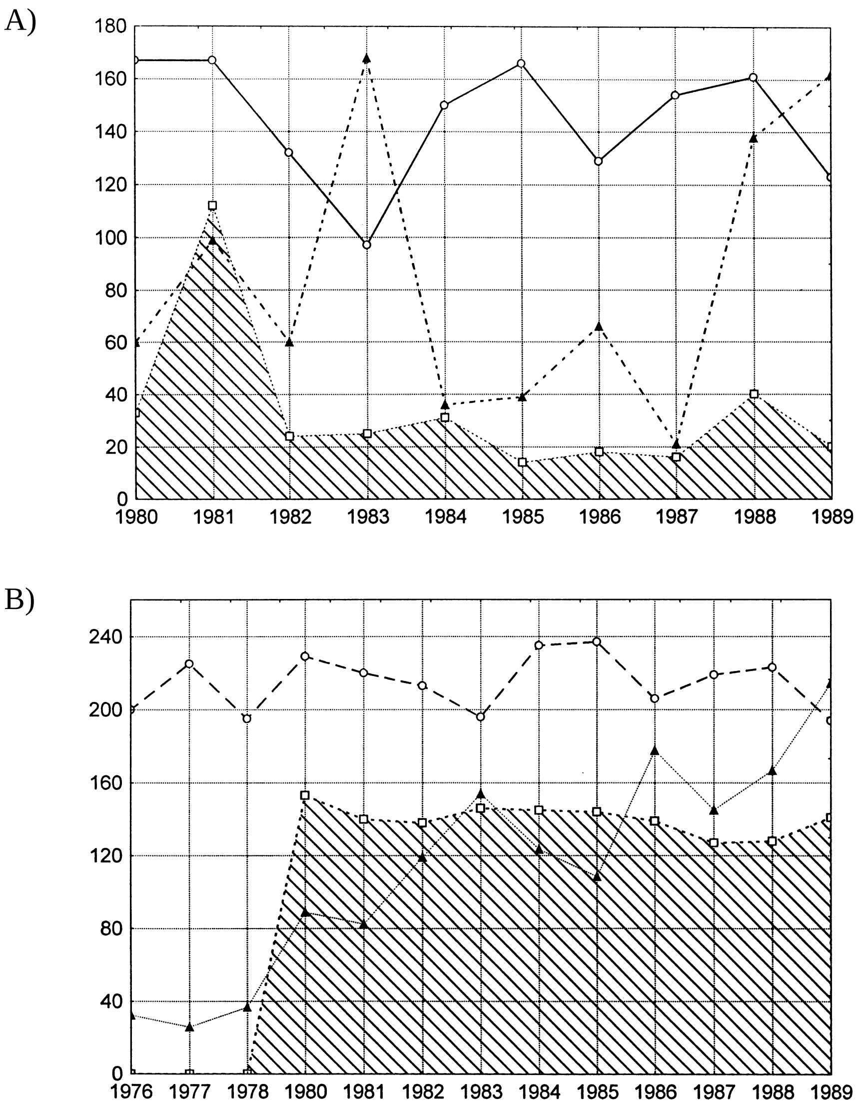

Figure 5.
Dynamic of the main trophic state parameters in the coastal Danube Delta A) shallow lakes in mezo and eutrophy conditions (macrophyte dominated) B) hypertrophic conditions (phytoplankton dominated).

▧ Secchi depth (cm) Shadowed area-

▲ Chl «a» ug 1^{-1}

—o— Depth (cm

nied by the persistent hypoxic or anoxic conditions at the bottom/water interface during the warm season (VADINEANU et al, 1987; CRISTOFOR et al, 1992). Moreever, the dissolved oxygen content in the surface water layers, including effects which led to mass mortality of fish and invertebrates, changed from relative limited dynamics around saturation values to very large dynamics between oversaturation and hypoxy, with serious consequences for the aquatic communities.

Even the content of dissolved organic matter (DOC) in the river stretch has not exceeded the level of the second class standard, fluctuating between 5 and 20 mg C 1^{-1}, in the floodplain and delta lakes. DOC was far beyond the second class standard, reaching frequently values of 30-80 mg C 1^{-1} (CRISTOFOR et al, 1994).

The changes in the water quality of the Razim-Sinoe lagoon systems included not only similar trends of the above discussed parameters for the floodplain and delta lakes, but also an important change of the water salinity. A gradual decrease of salinity, from 2.6-27.8 g 1^{-1} to 0.5-6.5 g 1^{-l} , altered the hydrochemical conditions in the last 1.5 decades from brackish and marine water towards fresh water. Only the extreme southern part of the lagoon system retained brackish and marine salinity (VADINEANU et al, 1997).

Similarities between the river stretch and the inner and coastal delta lakes in the respect of the values of the most representative parameters of the trophic state, showing a clear eutrophication process at the large spatio-temporal scale of the entire LDWS, suggest the need of carefully using classical indicators of surface water quality.

Pollution with heavy metals became an important problem considered in the last years, not only for the water quality of the river stretch, but also for the ecological effects at large scale of the LDRS, including floodplain, delta and the associated coastal zone of the Black Sea. The data reported for all cross-sections, established along the lower Danube by the Bucharest Declaration, i.e. 5075 μg Pb 1^{-1}, 7-14 μg Cd 1^{-1}, 500-1000 μg Fe 1^{-1}, 10-20 μg Cr 1^{-1}, 25-40 μg Cu 1^{-1}, show that generally the heavy metals content in water has not exceeded the standards for the first purity class (VADINEANU and CRISTOFOR, 1994). The data collected in the last decades, during two well designed expeditions carried out by the Cousteau team (ODY & SARANO, 1992) and by Dutch and Bulgarian experts (BUIJIS, 1990, 1992) and more recently, by a programme for complex monitoring of the effects of the Yugoslavian conflict (unpublished data) have proved that, in spite of several hot spots associated with industrial sources, discharges of main tributaries and with areas adjacent to the war actions, there is still no severe contamination.

In the mentioned contaminated zones, the recorded values exceeded by 9; 36; 44; 125 and 144 times the standard values for concentration in water for

Cu, Pb, Zn, Cr and Cd and by 3 and respectively 6-7 times the references concentrations in sediments for Cr and Pb (unpublished data).

Long term and large distance effects could follow at the LDWS scale taking into consideration the high ability of aquatic communities in the Danube Delta to multiply the flow density of Pb, Mn, Cu, Fe and Zn by 390-4840 times for phytoplankton, by 450-5950 times for epiphyton and by 300-7120 times for submerged macrophytes (NAFEA AL-AZZAWI, 1987; GONZALES R. et al, l 985).

3.4. TAXONOMICAL AND TROPHODYNAMIC CHANGES

The changes in the structure, hydrology and hydrochemistry of HGMU^{S} of the LDWS have been followed by major changes in the composition and spatio-temporal organization or trophodynamic structure of the biocoenoses characteristic to different categories of ecosystems (see table 1) and respectively the distribution of plant and animal species and associations into the system.

Any attempt for a brief description of such complex changes is highly dependent on one side by the huge amount of historical data, most of them derived from sectoral and inappropriate time scale investigation programmes and on the other side by many gaps in data and knowledge concerning some categories of ecosystems.

Under these circumstances it was decided to provide: i) a brief description of major vegetation units from Inner and Coastal Danube Delta and to describe the main trends in the dynamics of that vegetation units as well as, ii) for the shallow aquatic ecosystems, one of the main component of the Coastal Danube Delta and the remnant wetlands in the Inner delta, which were extensively studied in the last four decades it is given a brief presentation of major changes in the composition and spatio-temporal organization of their commun ities.

i. Five large vegetation units, having a relatively balanced reprezentation in the LDWS, have been identified and described:
   1. Reed and marsh vegetation with *Phragmites australis, Typha angustifolia, T. Iatifolia, Scirpus lacustris, Glyceria aquatica, Sparganium ramosum, Schaenoplectus lacustris, Trapa natans, Nuphar luteum, Nymphaea alba, Ceratophyllum demersum* and *Potamogetan pectinatus.*
   2. Meadow vegetation with *Populus alba, P.nigra, Salix alba, S. triandra, S. fragilis* and *Tamarix ramasissima.*

3. Forest steppe with graminaceous and dicotyledonous herbaceous plants and *Querqus pubescens, Q. pedunculiflora, Q cerris, Q. frainetta.*
4. Saline vegetation consisting in *Puccinella distans, Salicornia herbacea, Suaeda maritima, Crambe maritima, Cakile euxina* and *Juncus maritimus.*
5. Steppe vegetation comprising as dominant species *Festuca valesiaca, Agropyron repens, Xrtemisia campestris* and *Bramus mollis.*

The dynamics of the above vegetation units in the last decades shows few major trends:

a) decrease in spatial distribution and simplification of the steppes and forest-steppes by loss Of xeric meadows and halophilization;
b) transition of reed and marsh vegetation units towards meadows with xerophytic ruderal vegetation, riched in vegetal nitrophilous species;
c) extensive substitution of natural vegetation with cultivated species;
d) decline of the natural alluvial forests and their substitutions by plantations of alien and monospecific trees (e.g. *Populus canadensis);* and
e) the rapid extension of saline vegetation in the established polders (e.g. already more than 20% of polders from Inner Danube Delta) (VADINEANU et al, 1998, CIUBUC et al unpublished data).

ii. Due to the significant increase of the available nutrient pools and specific dynamic of N:P ratio since late 70^S and in particular during 80^S a set of changes in the structure of communities occurred (Fig. 4) in the very shallow (h≤ 1.5 m) and shallow (h$\subset$ 1.5 - 3m) aquatic ecosystems from LDWS.
    - The organization in trophodynamic modules of the communities living under mezo and early eutrophic conditions (Fig. 6) has been changed on two directions while the trophic states evolved towards hypertrophy: one specific for the communities living in shallow lakes (Fig. 7) and the second for those living (Fig. 8) in very shallow lakes (h≤ 1.5 m). The very aggregated trophodynamic structure or the homomorph model developed for identification the structural organization of the communities integrated in mezo and eutrophic aquatic ecosystems, consists in 12 trophodynamic modules, two non-living compatiments and three types of food chains-grazzing, detrital and DOC/bacterioplankton based one. It is suggested that the trophodynamic structure had a balanced development and has provided a strong support for fish productivity.

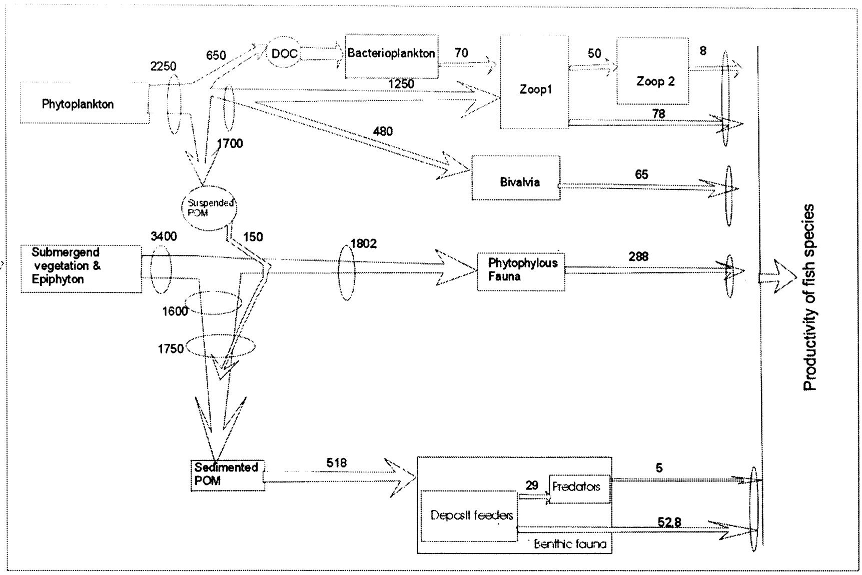

Figure 6.
Trophodynamic structure and density of energy flow in shallow lakes (h ⊂ 1-3m) from LDWS at mezo and eutrophic conditions.
Es - Diluted solar energy; DOC - dissolved organic carbon; POM - particulate organic matter; Zoopl 1 - filter feeder species of Cladocera, Copedopa and Rotatoria; Zoopl 2 - predator species; Bivalvia - Filter feeders; *Unio pictorium; U. tumidus; Anodonta Cygnega; A. complanata; Dreissena polymorpha.*
The number indicates kcal per square meter per years.

- The rapid transition from meso and eutrophic states to the hypertrophic ones has been accompanied by deep simplification of the trophodynamic structure through loss of trophodynamic modules (e.g. submerged vegetation-epiphyton, phytophylous association, benthic macrophiltrators-bivalvia) and important trophic chains or by diminishing the density of energy flow on some of them (Fig. 7, 8). With an average biomass of 4-7 mgDW* · l^{-1} the phytoplankton has contributed almost 50% to the energy inflow in all aquatic ecosystems during the reference trophic states. In the shallow hypertrophic lakes (h ⊂ 1.5 - 3m), the phytoplankton module alone has concentrated the solar diluted energy. In these ecosystems the average phytoplankton biomass has ranged between 15-30 mgDW · l^{-1} after the year 1982.

* dry weight.

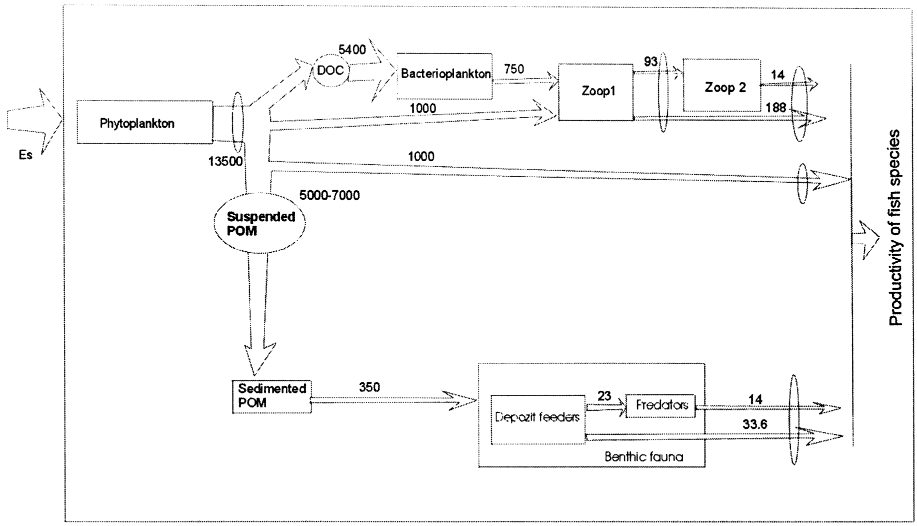

Figure 7.
Trophodynamic structure and density of energy flow in shallow lakes (h ⊂ 1.5-3m) from LDWS at mezo and eutrophic conditions.
Es - Diluted solar energy; DOC - dissolved organic carbon; POM - particulate organic matter; Zoopl 1 - filter feeder species of Cladocera, Copedopa and Rotatoria; Zoopl 2 - predator species.
The number indicates kcal per square meter per years.

In the very shallow hypertrophic lakes the interaction between hydrology, light and nutrient availability during the sprillg flood have favored the growth of submerged vegetation which usual reached the peak of biomass accumulation (550-700gDW · m^{-2}) at the end of warm season. The macrophyte-epiphyton module had an average annual contribution of more than 80% to the total energy inflow in this type of hypertrophic lakes. (VADINEANU et al, 1992, 1989, 1998; CRISTOFOR, 1987).

- The transition of shallow lakes of the LDWS from mezo and entrophic to hypertrophic conditions has involved also deep quantitative and qualitative changes in the taxonomic composition or taxonomic richness of the communities and in particular of each trophodynamic module. In less than five years at the beginning of 80's the species richness of phytoplankton has dropped from more than 250 species of *Chlorophyta* and *Baccilariophta* to less than 50 species of *Cyanophyta* and *Baccilariophyta*. In fact those species, who proved to be under mezo and early eutrophic conditions, very

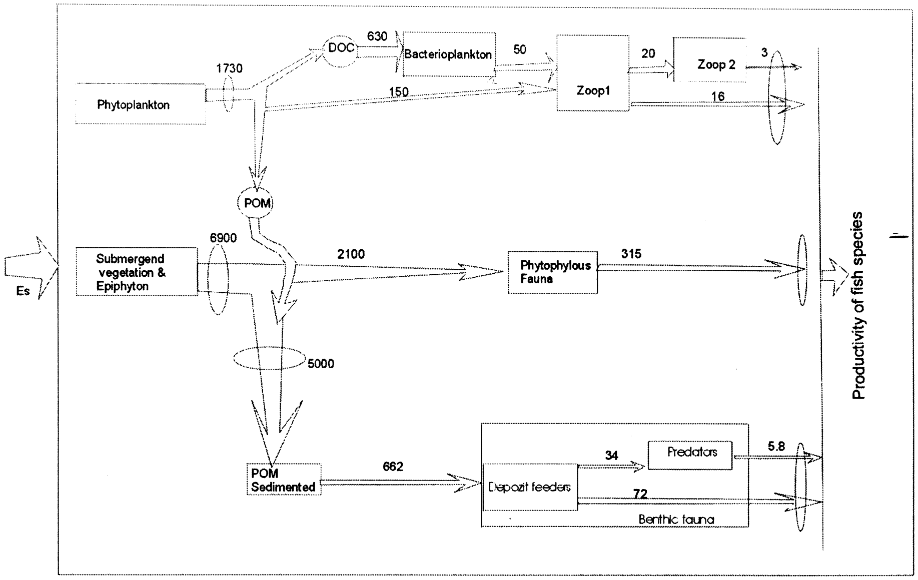

Figure 8.
Trophodynamic structure and density of energy flow in shallow lakes (h ≤ 1.5m) from LDWS at mezo and eutrophic conditions.
Es - Diluted solar energy; DOC - dissolved organic carbon; POM - particulate organic matter; Zoopl 1 - filter feeder species of Cladocera, Copedopa and Rotatoria; Zoopl 2 - predator species.
The number indicates kcal per square meter per years.

efficient competitors for phosphorous sources have been replaced by a limited number of species, most of them colonial cyanobacteria able to compete efficiently for light and gaseous nutrients (N2 and CO2) through morphophysiological and behavioral mechanisms (e.g. heterocysts, flotation). In the phytoplankton dominated lakes, 3-7 species of colonial cyanobacteria have contributed up to 80% to the total biomass and net primary production during the worm season and up to 55% during the cold season. In these lakes, the zooplankton's species richness has been reduced from more than 125 species to less than 4g. The large size dominant species of *Clodocera* and *Copepoda* have been replaced by small size species able to use efficiently the bacterioplankton as food resource. (VADINEANU, et al, 1992,1998). Similar changes have been recorded for macrophytes in the very shallow lakes. The species richness has dropped from 16 to 11 species and that species with vertical growth strategy (e.g. *Potamogeton pectinatus)* or with floating capacity (e.g. *Ceratophythum demersum)* have replaced former species able to compete efficiently for nutrient sources (e.g. *Chara sp., Nittelopsis obtusa, Najas marina)* (CRISTOFOR, 1987).

Characteristic to both phytoplankton or macrophyte dominated ecosystems was the increase of energy transfer as POM up to 5-7 thousands of kcal per square meter per year to the bottom. This phenomenon was strongly linked with oxygen depletion at the bottom-water interface and very severe simplification in species composition of the benthic trophodynamic modules (e.g. 3-5 dominant species of Chironomidae and 2-4 dominant species of Oligochaeta) (BOTNARIUC et al 1987; VADINEANU, 1994).

The above trophodynamic and taxonomic changes have led to significant changes in the quality and availability of food resources for the most valuable fish species.

Consequently the number (28) of species frequently recorded in captures before 1980 has dropped to 19 species and former dominant and valuable species (e.g. *Cyprinus capio* formally contributed with 30% to captures) have been replaced by less valuable species (e.g. *Carassius auratus gibelio* which increased the contribution from 3% to 19%) or alien species (e.g. *Hypophtalmichtys molitrix* which currently contribute with 17% to total fish captures) (STARAS, 1995; VADINEANU et al, 1998).

3.5. FUNCTIONAL CHANGES

There are remarkable quantitative accounts of the structural and qualitative changes occurred, mainly in the last 3-4 decades, in the major categories of ecosystems of the LDWS of which only some have been briefly assessed in the previously paragraphs (VADINEANU et al, 1992, 1998; CRISTOFOR et al, 1987; BOTNARIUC et al, l987; IGNAT et al, 1986; RASNOVEANU et al, 1997; DIACONU et al, 1994; STARAS et al, 1994; ZINEVICI & TEODORESCU, 1990; NICOLESCU et al, 1987).

Most types (70-80%) of the self-maintained and solar powered ecosystem in the upstream I and II subunits of the LDWS have been replaced through hydrotechnical and reclamation works, by intensively human powered system. The process had affected only 16%, instead 38% as it was planned to be achieved by the end of 1980s, of the wetland ecosystems from the coastal Danube Delta. In other words the wide range of natural wetlands former extended upstream the coastal delta have been substituted by 2063 square kilometres of intensive crop farms, 72 square kilometres of intensive fish farms and 93 square kilometres of tree plantation (mostly poplar).

Inside the coastal Danube Delta have been created by substitution about 450 square kilometres of intensive crop farms and tree plantations and 360 square kilometres of intensive fish farms that practically have been abandoned after 1990 or proposed for rehabilitation.

The most affected function of the LDWS was that dealing with the production of renewable biological resources and the water purification. With any or very low input of auxiliary commercial energy, the former wetland ecosystems have been able to provide an average amount of 6,000 t fish per year (maximum recorded 6,448 t per year), up to 144,000 t per year of cereals with an average of 70,000 t per year and have provided annually food for more than 100,000 of animals (mostly cattle. sheeps and pigs) (ANTIPA, 1910).

Significant amounts of reed and reed mace biomass as well as timber have been used by local population for heating households, constructions and traditional manufacturing.

Some of the lost resources have been replaced even in higher amounts by those produced in the intensive crop and animal farms, the others have been produced at much lower level in fish farms and tree plantation.

However it has to be underline the fact that the density of commercial auxiliary energy input for powering the intensive crop farms established by substituting former reed and reed mace marshes or frequently flooded levees is equivalent to 4-5 t respectively 3-3.5 t of crude oil. In spite of these huge cost in terms of concentrated energy the production per hectare has increased with a factor of 1.5-2. The established fish farms have proved to be very inefficient, in most of them the production was below or similar to the amounts used for stocking them.

The structural changes into LDWS have decreased with almost 50% its buffering capacity. This statement is well sustained by the estimated impact on the capacity of nutrient retention.

In this respect it was considered reasonable assumption that annually 60 % of former wetlands have been actively involved in nutrient retention and export (denitrification) and also have been taken into consideration the immissions in LDWS which were recorded for 1980^{S} (600 kt per year for TN[1] and 55 kt per year for TP[2]).

It was also estimated the potential retention capacity of the former wetlands (23% for TN and 13% for TP) based on the established values for coastal Danube Delta (VADINEANU, A.; POSTOLACHE, C., 1998). Under the above

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[1] TN - total nitrogen.
[2] TP - total phosphorus.

circumstances it can be estimated that additional 138 kt N (as nitrogen) and 7.1 kt P (as phosphorus) have been discharged into Black Sea due to loss of wetland ecosystems through substitution carried out in LDWS.

The changes occurred in the water chemistry and especially the shift from mesotrophy to hypertrophy in less than one-decade have been almost totally driven by the external forces identifiable over the entire Danube catchment. Consequently to these changes there were recorded deep changes in the trophodynamic structure of the aquatic communities as briefly described in the previous paragraph (see 2.4). They have also been associated with significant changes occurred in the main ecological processes. The general trend was towards states when primary production reached the maximum potential capacity (12-13 thousands kcal per square meter per year) mostly through «dead end» blue green algae, in the phytoplankton dominated ecosystems and 8-9 thousands kcal per square meter per year in the macrophyte dominated ones (VADINEANU et al, 1999).

Comparing with the level of net primary production the efficiency of primary consumers as energy carriers is very low. Consequently most net primary production ends into sedimented POM[3] and DOM[4] which open two complementary food chains. What is specific to these states is the fact that both POM and DOM compartment are overloaded and the mineralization of sedimented POM is accompanied by hypoxia or anoxia at the bottom-water interface.

As it was pointed out before in this chapter, the benthic food chain were together with macrophytes —epiphyton food chains, the most efficient for fish production under the meso and early eutrophic conditions (see Fig. 6).

Under hypertrophic conditions the systems have lost or diminished severely these two types of food chains and that explains the changes in the structure and productivity of fish species association.

In the same hypertrophic conditions the planktonic food chain have been based mostly on bacterioplankton and microzooplankton while phytoplankton has had directly a minor role due to the lack of proper consumers.

Based on the above data and comments it can be noticed that in all aquatic ecosystems of LDWS it was established a clear dichotomy between the trophodynamic structure and respective food resources on one side and the structure of fish species associations and their ability to use that resources for fish production on the other side.

The attempt for estimation the potential fish biomass and production based on the data concerning the energy density flow (Fig. 6, 7 ,8) along the major

[3] POM - Particulate Organic Matter.
[4] DOM - Dissolved Organic Matter.

Trophic state	*Biomass*[a]	*Production*[b]			*Catch*[b]
		Total	*non pradat*	*ptadat**	
Meso + early eutrophy	670	165	110	55	77-90
Hypertrophic (phytoplankton dominated)	1100	300	210	90	18-26
Hypertrophic (macrophyte dominated)	600	148	100	48	30-32

food chains crossed or potentially crossed by the fish populations and for assessment the difference between these estimates and the recorded fish catches (Table 2) has provided support for the statement (VADINEANU, A., 2000, unpublished data).

While the potential fish production remained at the same order of magnitude in macrophyte dominated ecosystem comparing with that estimated for the reference trophodynamic structure or almost doubled in phytoplankton dominated one, the fish catches have declined more than twice.

It can be said that the aquatic ecosystem of LDWS have been oversupplied with concentrated energy and became much less efficient in providing harvestable resources and habitats for many plants and animals species, after experiencing the qualitative and structural changes described above.

4. PREMISES FOR REHABILITATION AND SUSTAINABLE MANAGEMENT OF THE LDWS

At the end of a long term and large scale process of structural changes in the LDWS, mainly consisting in substitution of natural ecosystems into large polders one may still found the coastal Danube delta which is one of the last Delta system in the world preserving most of the structural and functional characteristics.

At the beginning of 90^{S}, it was well documented and widely recognized by the academic community, public and new established political institutions both the economic and social failure of the previous management plans and the long term and long distance effects emerged after their implementation.

This kind of understanding at national scale has fitted well into the new European and UN policies dealing with the relationship between environment and development and, in particular, with those focused on pollution abatement and biodiversity conservation.

In these circumstances, the governmental decision to manage in future the most important components LDWS-coastal delta (except Chilia Delta) and

Small Island of Braila (remnant wetland of the former inner Delta) as special protection areas and pilot regions for sustainable development had as basic targets not only slowing down and abatement of the environmental degradation, but also the need to establish the framework for a long term and large scale rehabilitation of LDWS and North-Western Black Sea.

In this respect since 1991, the Romanian part of coastal delta (580,000 ha including sea shelf up to the isoline of 20 m depth) has been integrated in the UNESCO-MAB network of Biosphere Reserves and more recently (december 1998) it was established the border Danube Delta Biosphere Reserve covering the whole coastal delta.

Since 1991, coastal Danube delta became also part of the World Heritage and Ramsar networks and in the last year the LDWS has been accepted as main component in the national and international networks for long term ecological research and integrated monitoring.

By taking into account the outputs of two international programmes implemented in the last decade in the Danube River and Black Sea basins it can be said that in spite of many other constrains, there're available the basic elements for development the Decision Support System as the operational infrastructure for sustainable management of LDWS.

In order to have a correct view of the effects emerged from structural and functional changes in the LDWS, in particular, or that occurred in the whole Danube River Catchment it is estremely important to extend the analysis in the Black Sea. It is also crucial to take into account not only the local effect of given structural or functional change in the LDWS but also the long distance and cumulative effects.

This approach may provide all necessary elements for better economic valuation and cost benefit analysis of the alternative solutions and measures in the management of LDWS which in turn should help to avoid the mistakes done till now. By taking into consideration that the functioning of the LDWS it is also driven by the immision[S] which comes from all over river catchment it will be helpful for policy and decision makers to understood that the appropriate local measures should be sustained by those established for the entire catchment.

The assessment and synthesis of a huge bulk of historical data and information, concerning the Black Sea, have been documented that since late 1960's the dynamic of this system has been mostly determined by the nutrient enrichment through the discharges of main tributaries. The specific symptoms of the eutrophication and the biological effects occurred very clearly in 1970s (GOMOIU, 1977; PETRAN et al, 1977; BODEANU, 1984; ZAITZEV 1992; COCIASU et al, 1990).

In less than one decade the *Phyllophora* and *Cystoseira* (macro-algae) based ecosystems of the Black Sea's northwestern shelf almost has disappeared.

The bottom waters of the northwestern shelf become seasonally hypoxic or anoxic and most of the benthic species have died. The impact of eutrophication of northwestern Black Sea was very severe on fisheries, water quality, tourism and species richness.

A very rough estimation in monetary terms, of the loss in the amount and diversity of renewable resources and in the field of tourism has reached two billion USD annually. Declining of use-values of the Black Sea and in particular of the North-Western shelf system has a significant impact on the socio-economic systems of the Black Sea countries and in particular of those from Romanian, Ukraine and Bulgaria.

The pollution sources inventory conducted during the preparatory work for the Black Sea Strategic Action Plan has provided data on the inputs of the dissolved nitrogen and phosphorus compounds to the Black Sea in 1995. The data have enabled the estimation of the contribution of coastal and non-coastal countries to the nutrient discharge in the Black Sea. The estimates show that Romania contribute with 27% and 23% and non-coastal countries: Austria, Belarus, Bosnia, Croatia, Czech Republic, Germany, Yugoslavia, Hungary, Slovakia, Slovenia and Republic of Moldavia with 30% and 26% to the total nitrogen and respectively phosphorous discharges in the Black Sea (TAPPING et al, l 998). Romania and non-coastal countries of which most are danubian countries contributes with more than 50% of total waterborne load.

Studies of nutrient balance in the Danube River basin suggested that about half the nutrients discharged to the river are from agriculture, 25% from industry and 25% from house holds (Final Report EU/AR/102A/91-1997).

The long-term goal of the programme for controlling eutrophication was established by the Black Sea basin countries and it requires that the trophic and overall pollution status of the sea to be established at the level recorded for 1960S. The intermediate goal requires for all Black Sea basin countries to be brought and maintained the nutrients discharges at the level recorded in 1997 which means that Danube discharges do not exceed 16KtP (as phosphorus) and 300 ktN (as nitrogen) (VADINEANU et al, 1998; EPDRB, 1995).

In order to achieve the above goal it was agreed by the Black Sea basin countries (including danubian countries) to promote the low cost measures for controlling nutrient discharges. A series of estimates shows that half of nutrient discharged to the Danube River are from agricultural farms and that both erosion/runoff and base flow are strongly influenced by nutrient stock in the top soil as well as the coastal Danube delta has undertaken a significant role of nutrient retention and losses (sedimentation, denitrification, renewable resources exploitation etc), which reached 23% for TN and 13% for TP from total inputs (VADINEANU, A.; POSTOLACHE, Carmen, 1998). Based on these estimates it has to be accepted that the most affordable measures are those dealing with the erosion protection, reforestation, diverse agricultural landscape development and with optimizing nutrient enrichment in soil, on one side, and those with wetlands rehabilitation and reconstruction on the other side.

The low cost measures may be grouped into four general categories:

i. Reform of agricultural sector and rural development which has to require the development of multifunctional farms with well developed network of ecotones for diffuse pollution control, biodiversity conservation and integrated pest control; intensive fish farms to be replaced by semi-natural fisheries; intensive crop and animal farms should be subjected to discharge permits.
ii. Rehabilitation and reconstruction of former wetlands networks along the main tributaries and in particular along the Danube River.
iii. Improvement and development of the system of waste water treatment at point sources through the use of alternative solutions among which the «artificial wetlands».
iv. Use of phosphate free detergents.

It is obvious that all types of measures should be implemented in order to achieve the goal. In this context, the rehabilitation of the most affected subunits of the LDWS, in particular the inner Danube Delta, and the sustainable management of whole system of LDR, should be considered as key targets in the national and regional strategies and policies.

In order to achieve the intermediary objectives which deals with trophic conditions rehabilitation of both coastal Delta and Black Sea, there's a need for TP and TN reduction of the current annual discharges with 40%. In the case of Romania, which is one of the major contributor to the total Danube River discharges, that means to achieve a TN and TP immisions reduction by 80kt respectively by 6kt. As it was pointed out above, all the envisaged measures should be used in order to achieve the objective, but the contribution of one or another measure should be established according with the long term cost effective solutions. In this respect there're enough arguments to accept that the rehabilitation of wetlands in the LDRS and the ecotones in the agricultural sector, are the most cost effective solutions. The preliminary data (VADINEANU et al, unpublished) concerning the rehabilitation of l 20,000 ha of former foodplains in the LDWS (20,000 in the coastal Delta and 100,000 ha in the Inner Delta and Crapina-Jijila Complex) and 30,000 ha along the river stretch between Calarasi and Iron Gates reservoir, shows that the retention and export capacity of LDRS can be increased with 44 kt of TN and 3.6kt of TP. That means a 55% and 60% contribution to the total reduction Romania has to achieved for TN and TP immissions into Black Sea.

lt has to be stressed that the proposed solution is relying on the substitution of current human dominated system (mostly crop farms) into seminatural wetlands. In fact that means to replace the commercial energy dependent ecosystems which have the monetary input ≥ than the outputs (see the details in III.4 this book) and which have severely impacted coastal Delta and the Black Sea, with solar powered ecosystems having the auxiliary input negligible or << than the output and also provide a strong positive effect on the rehabilitation of trophic conditions in coastal Delta and Black Sea.

A very rough estimation of the cost for reconstruction of 150,000 ha of wetlands in the LDRS, from which 120,000 ha in the LDWS, shows that would be a need for about 300 mill. USD investment to implement the most appropriate technical solutions for achieving the objective. The applied ecological research for identification the areas and designing the wetlands network to be recovered in the LDRS, is in an advanced stage of implementation and can already provide the support for designing the effective reconstruction works. However, the process itself it is expected to last for minimum five years.

It has been also estimated that this particular investment may provide for local Socio Economic System an annual economic benefit of more than 75 mill. USD (especially by tourism, fisheries, traditional manufacture, traditional agricultural practices, flood control, biodiversity conservation).

Very significant long term and long distance (Black Sea region) economic benefits are expected also from tourism, fisheries and biodiversity conservation.

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