New Insights on the Management and Restoration of Coastal Mediterranean Lagoons. Case Studies from N. Greece

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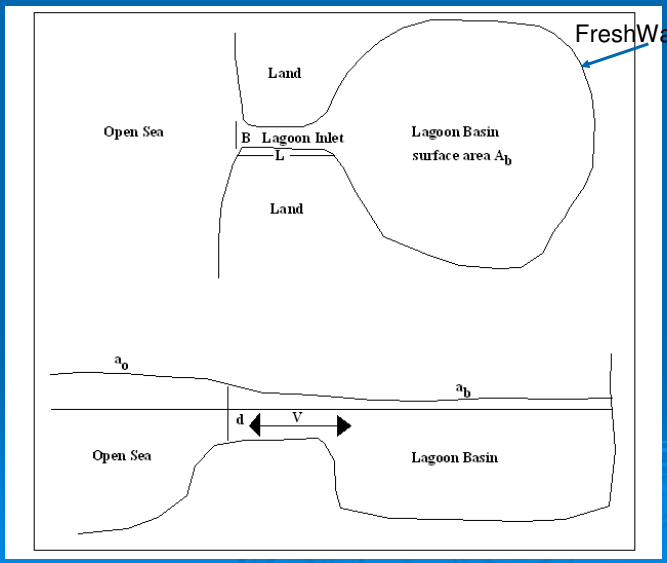
How do we define coastal lagoons?

- ✓ Coastal semi-enclosed basins where intense mixing of fresh and saline water takes place;
- ✓ Areas of high biodiversity favored by the presence of increased salinity gradient;
- ✓ Areas of high fishery productivity due to the cultivation of euryhaline species;
- ✓ Buffer zones for the storage, transformation and transport of constituents from the terrestrial zone (drainage basin) to the adjacent coastal sea;
- ✓ Basins with intense dependence from the prevailing hydrologic, meteorological and oceanographic conditions of the broader area.

Mediterranean coastal lagoons are:

- ✓ Mostly small and shallow in size,
- ✓ Main basin with parallel to coast orientation,
- ✓ Sand bars developed by sediment supply of adjacent river mouth,
- ✓ Forced by low tidal oscillations (Micro-tidal environment);
- ✓ Important water circulation induced by:
  - ❖ Wind stress,
  - ❖ Fresh water inflow,
  - ❖ Density gradients, and
  - ❖ Non-linear interactions between tidal flow and lagoon topography.

Typical Lagoon Example



Emergent Properties of Lagoon Ecosystems

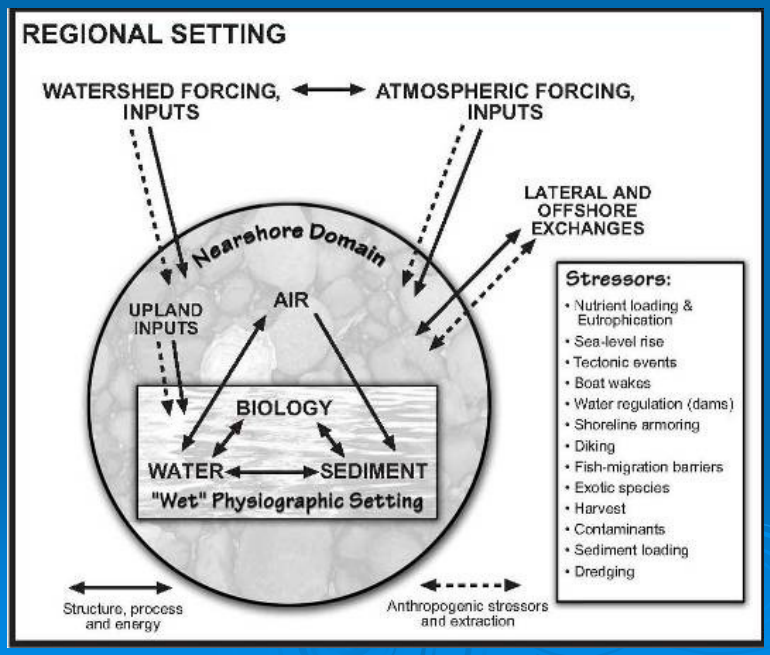
✓Physicochemical processes play a very strong role in organizing and regulating lagoon ecosystems,

✓The structure of lagoon ecosystems is both the consequence of and a factor in the action of ecosystem processes,

✓Viewing lagoon–nearshore ecosystems in a hierarchical context is important to understanding ecological interactions and processes across different scales in time and space.

Fundamental Hypotheses

- Natural processes create structure;
- Structure produces habitat function;
- Functioning habitat supports specific biological organisms and communities;
- These relationships can be confirmed through a conceptual model.



Restoration Strategy for Lagoon Ecosystems

- Restoration projects should be based on carefully designed goals and objectives,
- Programs should take advantage on best interdisciplinary science and technical knowledge,
- Programs should focus on restoration of natural processes that create and maintain lagoon and nearshore ecosystem structure and function,
- Program efforts should promote protection of lagoon habitats and the processes that sustain them,
- Program efforts should include social, cultural and economic values at multiple scales in space and time.

Restoration Project Guidelines

Problem Statement

Define Mission and Goals

Pre-Restoration Description

Restoration Planning and Implementation

Post-Restoration Monitoring

Adaptive Management

Restoration Tips

- Study and examine the topography and bathymetry of the lagoon, as this determines internal circulation and mixing
- Ensure the inflow of adequate freshwater into the system, as this determines the residence time of water and substances in the system,
- Study the timing that freshwater enters the system, as higher amounts are preferable during tidal flood and summer period,
- Test the water quality of the inflowing freshwater, and take measures to minimize pollution,
- Study carefully the lagoon mouth dynamics and propose geometric modifications (length, width, depth) or the construction of a second mouth.

Restoration and Conservation Management of Drana Lagoon

Problem Statement

Drana Lagoon re-flooding was achieved by re-opening a communication channel with the open sea.

Define Mission and Goals

a) the restoration of the lagoon's habitats structure and functions, b) the conservation of protected avifauna species, and c) the upgrade of management effectiveness applied in the lagoon's broader area.

Pre-Restoration Description

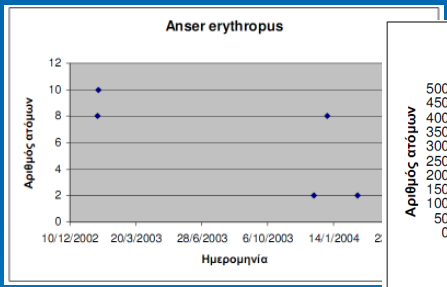
Systematic data collection on broader area (climate, geology, soil properties, habitats, rare and endangered species, birds, terrestrial flora and fauna, fish and benthic flora and fauna, lagoon physicochemical parameters).

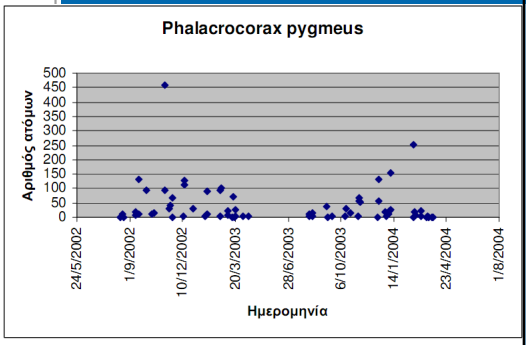
The control gates at the entrance of Drana Lagoon

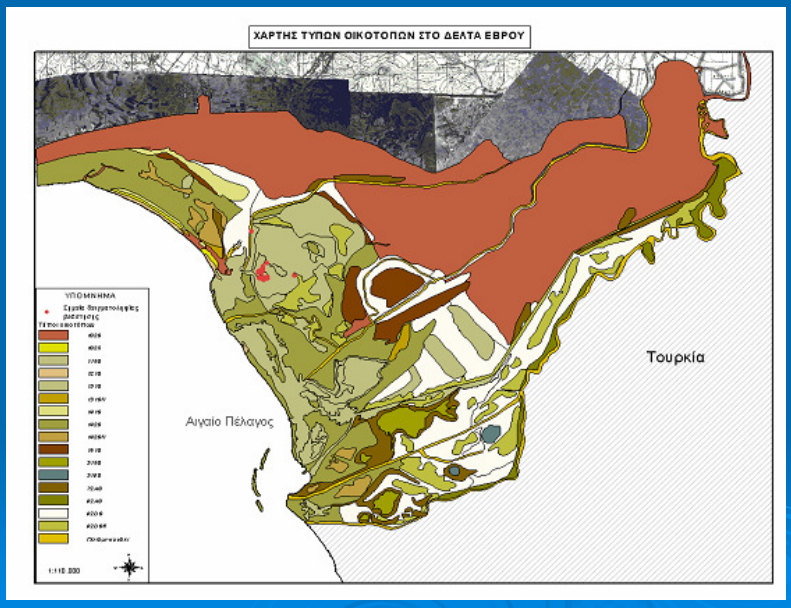
View of the drained Drana Lagoon

Πίνακας 2.3.1. Τα σημαντικότερα είδη πτηνών του Δέλτα Έβρου

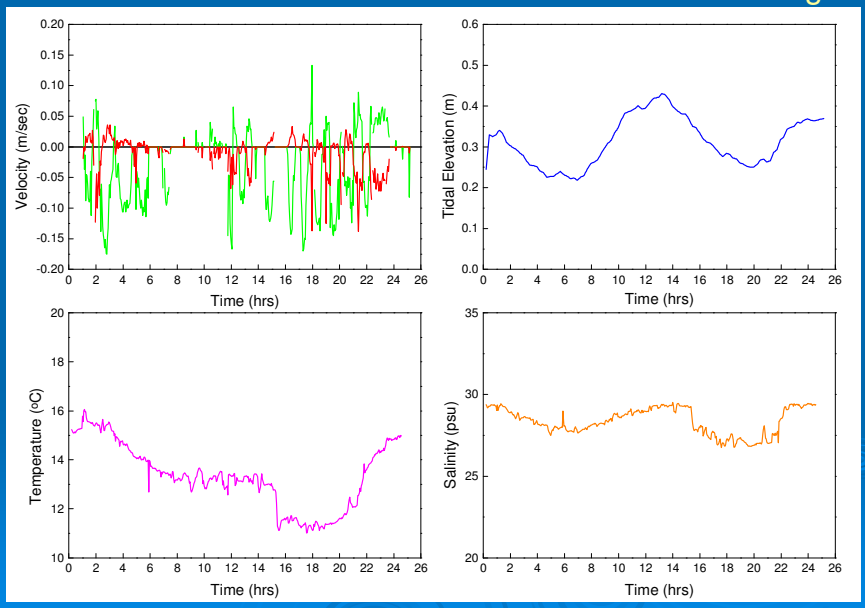
α/α	Είδος	Ελληνική ονομασία	Κόκκινο Βιβλίο*	Παγκοσμίως απειλούμενα*	Παράρτημα I 79/409/ΕΟΚ*
1	*Gavia stellata*	Κηλιδοβούτι			V
2	*Gavia arctica*	Λαμπροβούτι			V
3	*Podiceps grisegena*	Κοκκινοβουτηχτάρι	I		
4	*Podiceps auritus*	Ωτοβουτηχτάρα			V
5	*Podiceps nigricollis*	Μαυροβουτηχτάρι	K		







Abiotic Monitoring

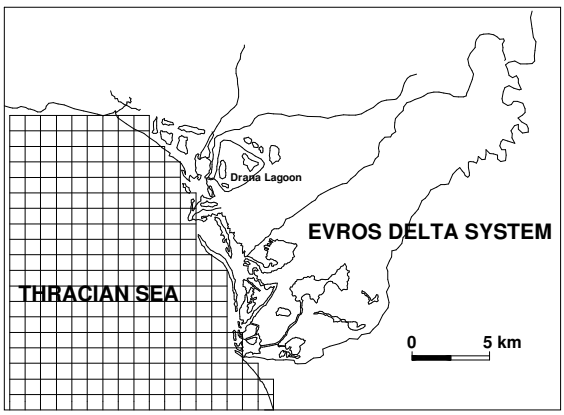


Data Analysis to Understand Physical Processes

Table 2. Summary characteristics of water flow during each tidal cycle sampled at Drana Lagoon..

Tidal parameter	30-10-02	31-10-02	6-11-02	7-11-02	20-11-02	21-11-02
Tidal Range (m)	0.202	0.181	0.206	0.290	0.219	0.294
Ebb Duration (min)	345	321	477	384	228	120
Time to Max. Ebb (min)	105	129	408	111	45	114
Max. Ebb (m s^{-1})	0.175	0.170	1.100	0.264	0.158	0.117
Mean Ebb (m s^{-1})	0.074	0.084	0.090	0.058	0.067	0.040
Flood Duration (min)	405	429	273	366	525	630
Time to max. flood (min)	39	168	93	171	96	111
Max. flood (m s^{-1})	0.078	0.133	0.194	0.185	0.062	0.030
Mean Flood (m s^{-1})	0.008	0.019	0.049	0.074	0.031	0.017
Tidal Range (m s^{-1})	0.253	0.303	1.294	0.449	0.220	0.147
Tidal Mean (m s^{-1})	-0.003	-0.025	-0.042	-0.010	-0.020	-0.006

2-D NUMERICAL MODEL FOR OPEN SEA



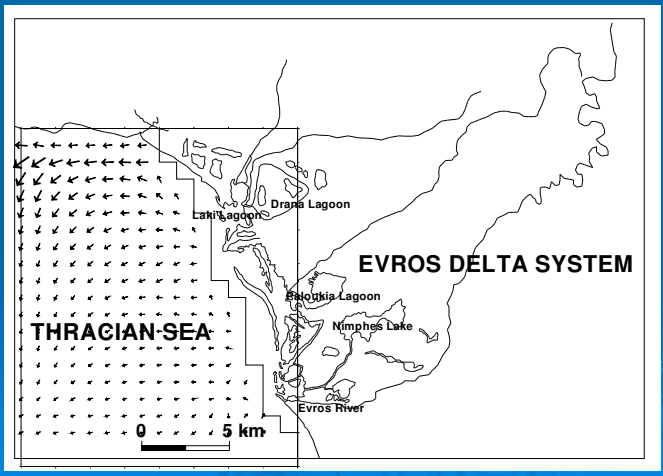
Basic Equations:

- Depth-averaged continuity eq.
- Depth-averaged momentum eq.

$\Delta X, \Delta Y = 500$ m
$\Delta T = 30$ sec

Tide, Wind and Evros River Boundary Forcings

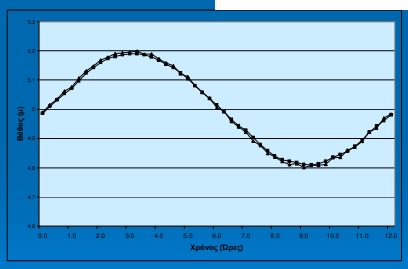
2-D NUMERICAL MODEL RESULTS



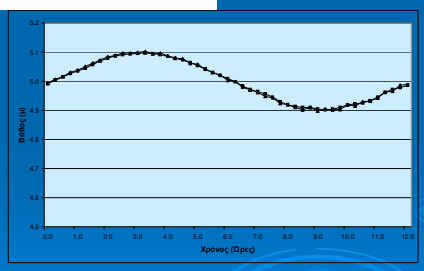
1-D MODEL FOR LAKI LAGOON & DRANA CANAL

Continuity Eq. $$\frac{\partial \eta}{\partial t} + \frac{1}{B}\frac{\partial Q}{\partial x} = 0$$

Momentum Eq. $$\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{\partial Q}{\partial x} = -g\,A\frac{\partial \eta}{\partial x} - g\,A\,S_f$$

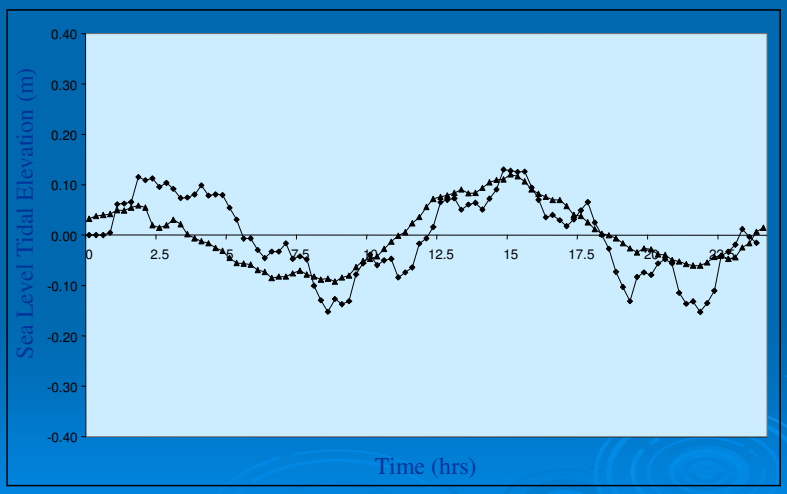


Spring Tides Boundary Condition

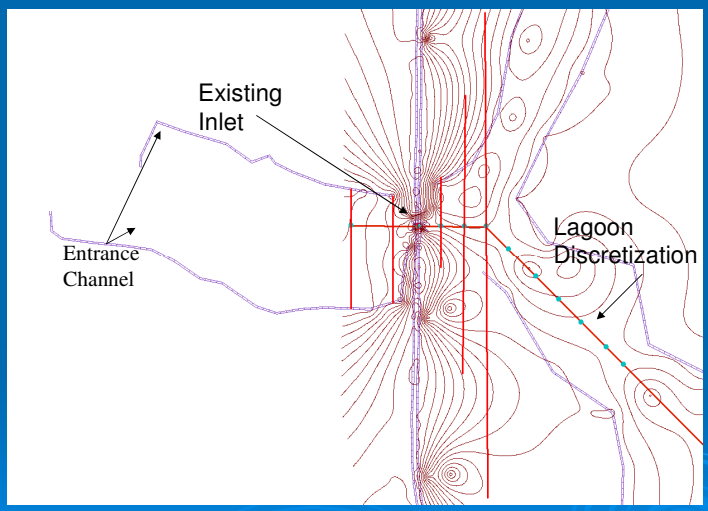


Neap Tides Boundary Condition

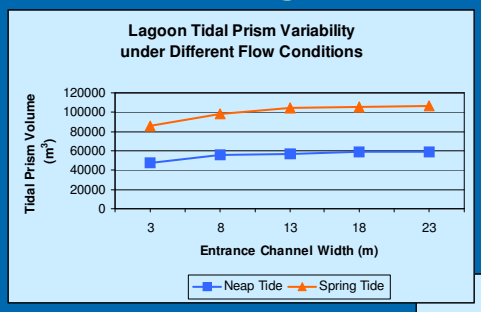
1-D NUMERICAL MODEL RESULTS

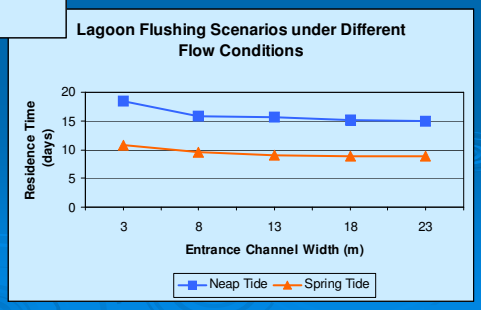


Tidal Inlet Dynamics



Lagoon Flushing Scenarios

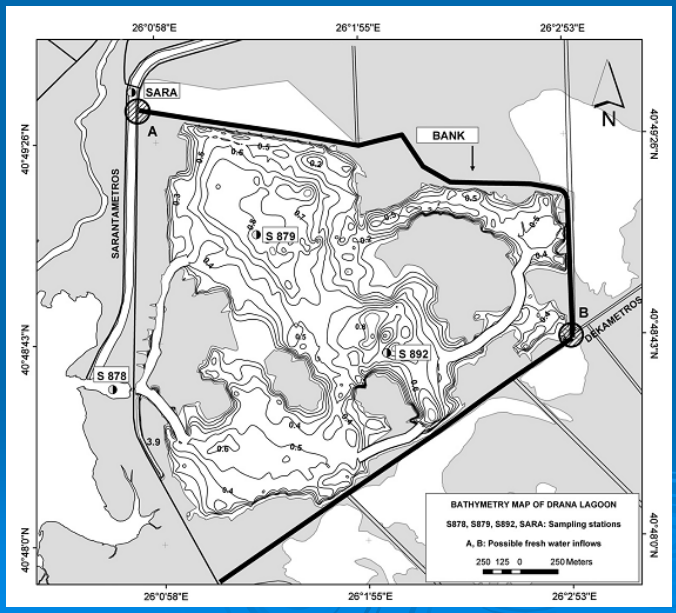




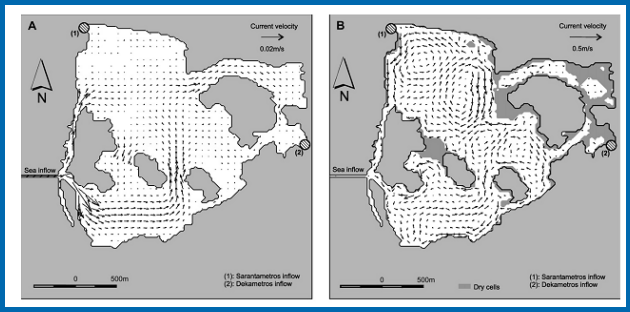
Πώλιρ. Εύρος m	Vmin m^3	Vmax m^3	Vmean m^3	ΔV m^3	Χρόνος Ανανέωσης 24hrs
Πλάτος υφιστάμενης εισόδου : 3m Πλάτος παλαιάς εισόδου : 0m					
-0.1 – 0.1	1,809,611.0	1,918,931.0	1,864,271.0	109,320.0	8,5
-0.2 – 0.2	1,848,879.0	2,026,178.0	1,937,529.0	177,299.0	5,5
Πλάτος υφιστάμενης εισόδου : 8m Πλάτος παλαιάς εισόδου : 0m					
-0.1 – 0.1	1,790,642.0	1,925,247.0	1,857,945.0	134,605.0	6,9
-0.2 – 0.2	1,803,175.0	2,028,218.0	1,915,697.0	225,044.0	4,3
Πλάτος υφιστάμενης εισόδου : 13m Πλάτος παλαιάς εισόδου : 0m					
-0.1 – 0.1	1,785,667.0	1,932,177.0	1,858,922.0	146,510.0	6,3
-0.2 – 0.2	1,796,817.0	2,045,597.0	1,921,207.0	248,780.0	3,9
Πλάτος υφιστάμενης εισόδου : 18m Πλάτος παλαιάς εισόδου : 0m					
-0.1 – 0.1	1,783,180.0	1,936,820.0	1,859,999.0	153,641.0	6,1
-0.2 – 0.2	1,793,781.0	2,057,892.0	1,925,836.0	264,111.0	3,6
Πλάτος υφιστάμενης εισόδου : 23m Πλάτος παλαιάς εισόδου : 0m					
-0.1 – 0.1	1,781,610.0	1,939,708.0	1,860,659.0	158,097.0	5,9
-0.2 – 0.2	1,791,841.0	2,066,715.0	1,929,278.0	274,874.0	3,5
Πλάτος υφιστάμενης εισόδου : 3m Πλάτος παλαιάς εισόδου : 5m					
-0.1 – 0.1	1,694,831.0	2,021,499.0	1,858,165.0	326,668.0	2,8
-0.2 – 0.2	1,559,515.0	2,187,043.0	1,873,279.0	627,528.0	1,5
Πλάτος υφιστάμενης εισόδου : 3m Πλάτος παλαιάς εισόδου : 10m					
-0,1 – 0,1	1,654,084.0	2,066,102.0	1,860,093.0	412,018.0	2,3
-0,2 – 0,2	1,573,183.0	2,267,566.0	1,920,375.0	694,383.0	1,4
Πλάτος υφιστάμενης εισόδου : 3m Πλάτος παλαιάς εισόδου : 15m					
-0,1 – 0,1	1,652,689.0	2,080,232.0	1,866,461.0	427,543.0	2,2
-0,2 – 0,2	1,577,524.0	2,311,758.0	1,944,641.0	734,233.0	1,4
Πλάτος υφιστάμενης εισόδου : 8m Πλάτος παλαιάς εισόδου : 5m					
-0,1 – 0,1	1,694,812.0	2,021,494.0	1,858,153.0	326,682.0	2,8
-0,2 – 0,2	1,640,752.0	2,185,989.0	1,913,370.0	545,237.0	1,8
Πλάτος υφιστάμενης εισόδου : 8m Πλάτος παλαιάς εισόδου : 10 m					
-0,1 – 0,1	1,688,575.0	2,061,120.0	1,874,848.0	372,545.0	2,5
-0,2 – 0,2	1,652,481.0	2,285,584.0	1,969,033.0	633,103.0	1,6
Πλάτος υφιστάμενης εισόδου : 13 m Πλάτος παλαιάς εισόδου : 5 m					
-0,1 – 0,1	1,693,275.0	2,025,620.0	1,859,447.0	332,345.0	2,8
-0,2 – 0,2	1,637,713.0	2,198,806.0	1,918,259.0	561,092.0	1,7
Πλάτος υφιστάμενης εισόδου : 13 m Πλάτος παλαιάς εισόδου : 10 m					
-0,1 – 0,1	1,663,768.0	2,064,234.0	1,864,001.0	400,466.0	2,3
-0,2 – 0,2	1,592,850.0	2,276,395.0	1,934,622.0	683,545.0	1,4

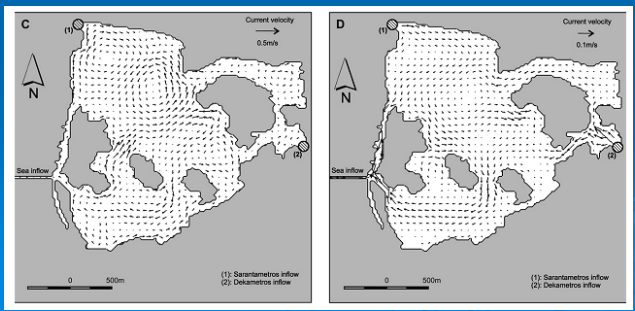
Scenarios to determine exchange volumes, residence time, mouth velocity, tidal range inside the reflooded lagoon.

Bathymetric and Topographic Adjustments

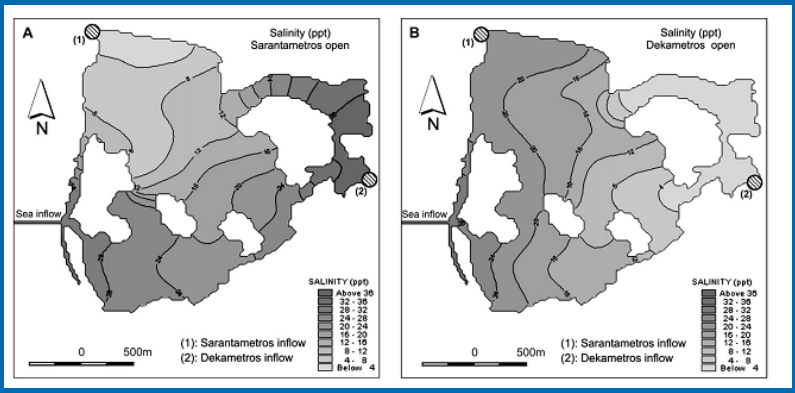


Estimate Lagoon Internal Circulation



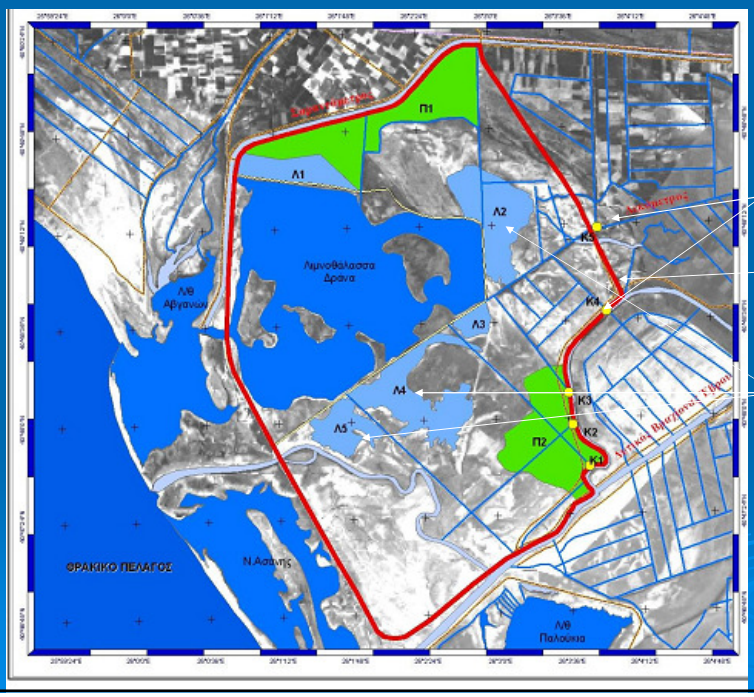


Predict Physical Parameters' Distribution

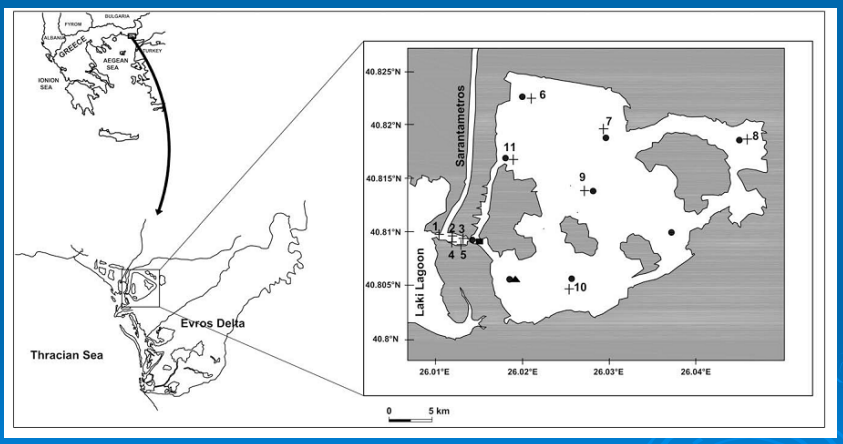


Restoration Planning and Implementation

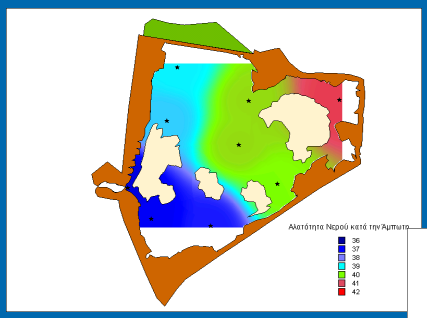
- Widening and deepening existing entrance channel
- Perimetric levee strengthening
- Bathymetry configuration for wintering canals inside the lagoon
- Topographic configuration and embankment for four small islands inside the lagoon
- Development of perimetric wet meadows

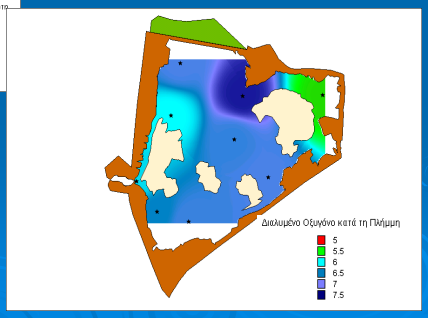


Post-Restoration Monitoring Network



Post-Restoration Monitoring





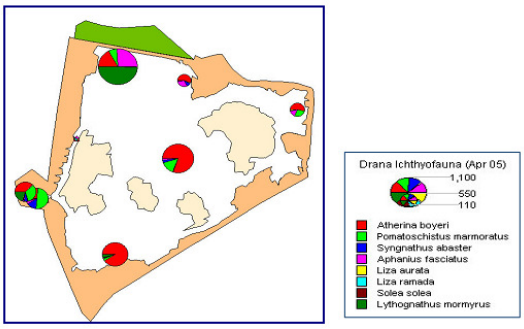
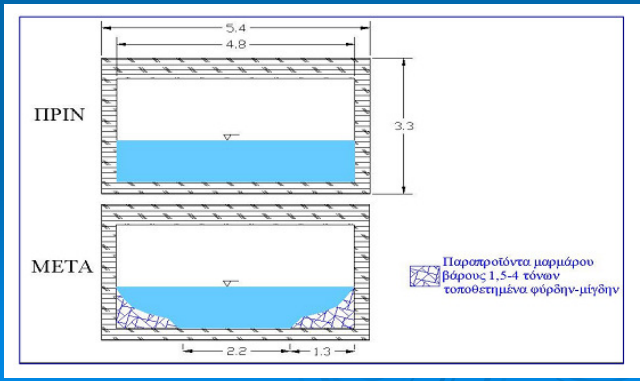


Table 3
The relative abundance (catches per unit of effort, 1000 m^2) of the fish species that have been identified before (January 2003) and after (October 2004, April 2005) the restoration of the lagoon and the percentage of each to the total catch (life cycle: R = resident, M = migrant, S = straggler).

No	Family	Species	Common name	Life Cycle	January 2003		October 2004		April 2005	
					Pre-flooding		Post-flooding			
1	Atherinidae	*Atherina boyeri* (Risso, 1810)	Big-scale sand smelt	R	–		872.9	23.7%	2,205.7	49.1%
2	Cyprinodontidae	*Aphanius fasciatus* (Valenciennes, 1821)	South European Toothcarp	R	4.0	0.4%	78.4	2.1%	547.3	12.2%
3	Gobiidae	*Knipowitschia caucasica* (Berg, 1916)	Kaukasian Goby	S	–		16.5	0.4%	–	
4		*Pomatoschistus marmoratus* (Risso, 1810)	Marbled Goby	R	60.0	5.6%	1,790	48.6%	806.2	18.1%
5	Mugilidae	*Mugil cephalus* (Linnaeus, 1758)	Flathead grey mullet	M	8.0	0.7%	206.3	5.6%	31.3	0.7%
6		*Liza ramada* (Risso, 1826)	Thinlip mullet	M	621.0	57.5%	–		45.6	1.0%
7		*Liza aurata* (Risso, 1810)	Golden grey mullet	M	353.0	32.7%	19.6	0.5%	–	
8		*Liza sallens* (Risso, 1810)	Leaping mullet	M	10.0	0.9%	99.6	2.7%	–	
9	Poeciliidae	*Gambusia affinis* (Baird & Girard, 1853)	Mosquitofish	R	23.3	2.2%	–		–	
10	Soleidae	*Solea solea* (Linnaeus, 1758)	Common Sole	M	–		3.3	0.1%	25.0	0.6%
11	Sparidae	*Lithognathus mormyrus* (Linnaeus, 1758)	Striped seabream	S	–		–		665.9	14.9%
12	Syngnathidae	*Syngnathus abaster* (Risso, 1827)	Black-stripped pipefish	R	–		598.1	16.2%	168.6	3.8%

Adaptive Management

The small number of fish species inhabiting the lagoon might be the result of the recent restoration and/or the above adverse conditions. Another reason for the small number of species caught could be related to the increased water flow observed at the lagoon mouth during the flood and ebb tidal phases, and also in the presence of a smooth bank in the concrete waterspout that connects the entrance channel with the lagoon.



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Fish fauna recovery in a newly re-flooded Mediterranean coastal lagoon

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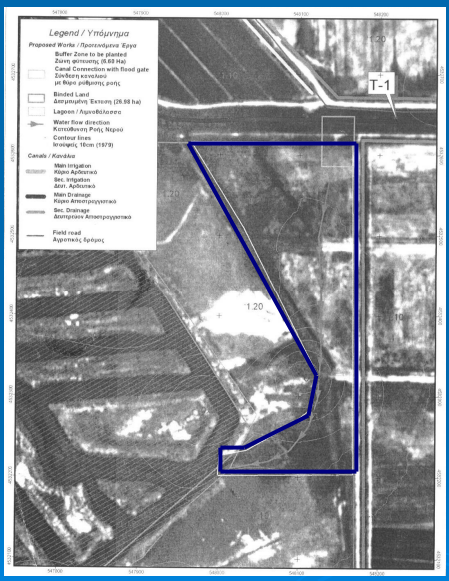
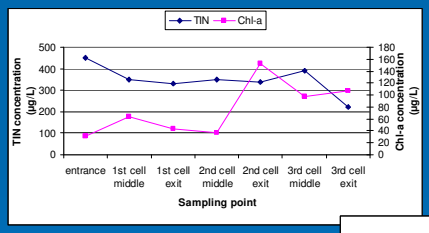
ABSTRACT

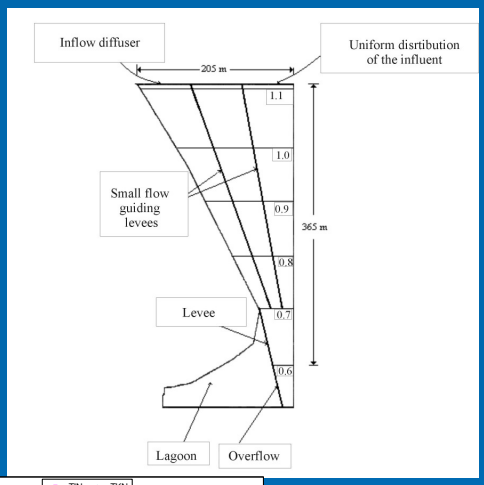
Drana Lagoon, located at the NW site of Evros River Delta, was drained in 1987 and re-flooded in 2004 within the framework of an integrated wetland restoration project. This study presents the results of a monitoring program of the lagoon's oceanographic, water quality and fish fauna characteristics, during the pre- and post-restoration period. Results depict the presence of high salinity water (up to 41) due to seawater intrusion, strong evaporation in its interior and inadequate freshwater inflows. Overall, nutrient

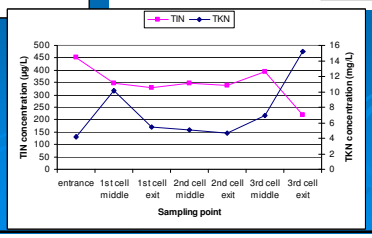
Constructed Wetlands as Buffer Zones



Free-water surface constructed Wetland Development in three cells to process an inflow of 550 m^3/d







CONSTRUCTED WETLAND DESIGN FOR ERATINO LAGOON