Research on Biological Indices for Ecological Assessment of Water Bodies in Turkey

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In this study, the most suitable biological indices for each biological quality elements and for each water body categories were determined and adapted to Turkish conditions by using the inventory results and monitoring results in Turkey. Totally 218 rivers, 69 lakes, 15 transitional waters and 31 coastal waters were monitored biologically, chemically and hydromorphologically for 4 monitoring campaigns. As a result of this study, various biological indices were proposed, reference conditions for 8 basins, aquatic flora and fauna lists of the country, class boundaries for the proposed indices and ecological status of the monitored basin were determined.

Keywords: Water Framework Directive, Turkey, Water Quality, Ecological Assessment System, Biological Indices

1. INTRODUCTION

Water is one of the most essential requirement for the existence of life on earth. Limited amount of freshwater reserves of the world are under the threat of anthropogenic pressures like continuous population growth, urbanisation, agricultural practices, industrialisation and global warming. These anthropogenic activities results in the limitation of the water use and deterioration of water ecosystems. Regular monitoring of the water quality is essential for ensuring that water resources are suitable for their intended use. Monitoring results should be converted to water quality classes for ensuring the suitability. Water quality can only be accurately assessed by considering the biological, chemical and hydromorphological monitoring results.

The European Water Framework Directive (WFD; Directive 2000/60/EC) states the need to achieve ‘a good ecological status’ by 2015 for all European water bodies (Anonymous, 2000; Uriarte et al, 2009). In order to achieve this, the WFD requires all water bodies to be monitored and their status to be checked at regular intervals (Alvarez-Robles et al, 2007). The WFD has shifted emphasis from chemical measures of water quality to those based on ecology. Chemical and physical

components of water quality are still an integral part of assessment but are regarded as 'supporting elements' for the biology (Free et al, 2002). The basis of the ecological quality estimation according to the WFD is the state of the five biological groups of the aquatic ecosystem (phytoplankton, periphyton-forming diatoms, macrophyte vegetation, macroscopic invertebrates and fish fauna) (Szilagyi et al, 2008). However, the directive is not very specific and provides only general guidance on how to define the proposed ecological classes. One of the major challenges for implementation of the directive is therefore how to define and determine the ecological status of a specific waterbody (Sondergaard et al, 2005). Thanks to their long term biological monitoring history and intercalibration exercise conducted for the harmonisation of member states' ecological assessment systems, EU member states made a great progress for setting up their ecological assessment system.

Studies on harmonization and implementation of EU Water Framework Directive in Turkey were launched in 2011 by the Turkish Ministry of Forestry and Water Affairs (MoFWA). Within the scope of these studies river basin based biological monitoring surveys were initiated in 2012. In the early stages of biological surveys, common indices generally used in academic researches were used. However, these indices do not contain species endemic to Turkey and were not tested whether they correspond to Turkish situation. Thus the resulting ecological status values were considered as inadequate in terms of their confidence and precision. In order to overcome these difficulties and to define the country specific biological indices, a National Project on "Establishment of the Water Quality Ecological Assessment System Specific for Turkey" was initiated in 2014 with the help of Turkish Universities.

Within the scope of the Project, variety of biological indices were tested with the monitoring results of 8 river basins (Sakarya, Ceyhan, Northern Aegean, Western Mediterranean, Western Black Sea, Eastern Black Sea, Aras basins and Lower Euphrate sub basin) representing the different climatic and geographical conditions in Turkey and the inventory results of 25 river basins in Turkey. In this context, 218 rivers, 69 lakes, 15 transitional waters and 31 coastal waters were monitored biologically, chemically and hydromorphologically for 4 monitoring campaigns. Moreover the potential reference sites and reference conditions in the 8 pilot river basins were defined.

As a result of this study, the most suitable biological indices for each biological quality elements and for each water body categories were determined and adapted to Turkish conditions. These indices are as follows: multimetric indices in rivers and lakes, Turkish Benthic Index (TUBI) in transitional and coastal waters for benthic macroinvertabrates; adapted Med-PTI in lakes for phytoplankton; Trophic Index for Turkey (TIT) for phytobenthos (diatoms); adapted IBI (T-IBI) in rivers and lakes , TCFI and EFAI in transitional waters for fish fauna; IBMR in rivers, Lake Leafpacks 2 in lakes for macrophytes; EEI in transitional and coastal waters for macroalgae and angiosperm. Moreover, reference conditions of the reference sites in 8 basins, aquatic flora and fauna lists of the country, class boundaries for the proposed indices and ecological status of the 8 pilot basin were determined.

2. METHOD

In the Project, following stepwise approach was used for establishment of the ecological assessment system;
(i) Monitoring of 8 pilot basins
(ii) Inventory of the studies related with the aquatic flora and fauna for 25 basins of Turkey and preparation of species lists for aquatic flora and fauna of Turkey
(iii) Adaptation of the suitable indices for each biological indices
(iv) Identification of type specific reference sites and conditions for 8 pilot basins
(v) Ecological assessment of pilot basins

2.1. Monitoring Studies

Turkey has 25 river basins and 8 pilot basins shown in Figure 1 were selected to represent different geographic and climatic conditions of country.

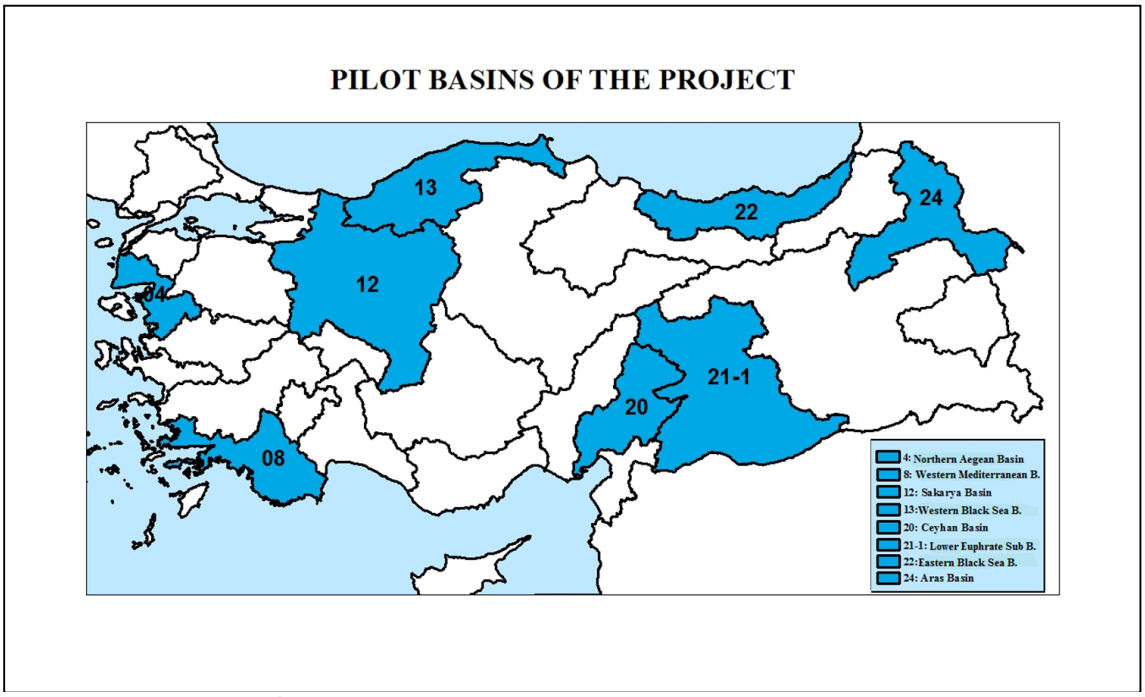

Figure 1. Pilot Basins of the Project

While monitoring points were selected, existing water bodies and water body types of Turkey was used as a background. Monitoring points were selected to represent the biological diversity of the basin considering all the point and diffuse pressures in the pilot basins. At least one monitoring point was selected per water body types in the basin and if the monitoring point for a type was also a reference point additional monitoring point was selected for that water body type. All the natural lakes and reservoirs intended for human consumption in the basins were selected as lake monitoring points. At least one monitoring point was selected per coastal water bodies in the pilot basins. Monitoring points of Western Black Sea Basin is shown in Figure 2.

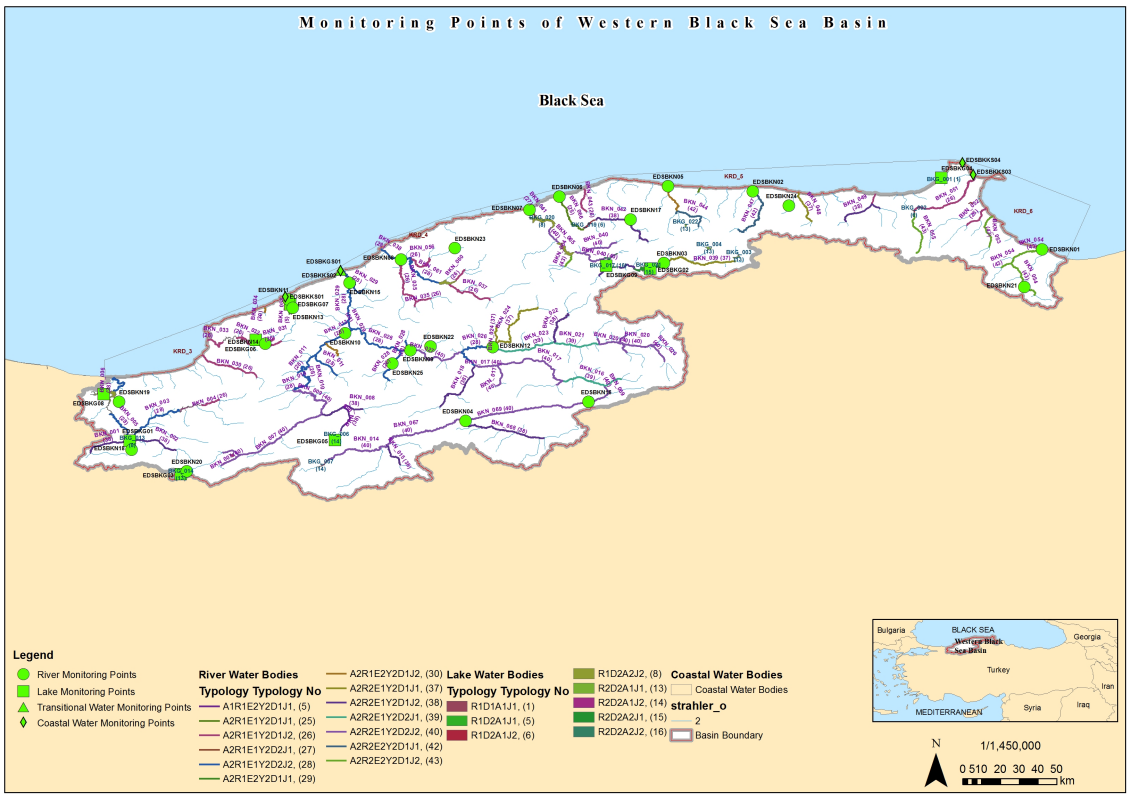

Figure 2. Monitoring Points of Western Black Sea Basin

Total of 4 monitoring campaings were conducted seasonally in selected 218 river, 69 lake, 15 transitional and 31 coastal monitoring points. In the Project, 45 expert, 39 of whom were university staff of biology departments, worked on field and laboratory for monitoring campaigns and in office for index development studies. Within the scope of monitoring activities general chemical, physicochemical, biological and hydromorphological parameters shown in Table 1 were monitored in line with the monitoring related provisions (Article 8, Annex V) of Water Framework Directive.

Table 1. Monitored Parameters

	Rivers	Lakes	Coastal Waters	Transitional Waters
	GENERAL CHEMICAL AND PHYSICOCHEMICAL PARAMETERS			
1	Temperature	Temperature	Temperature	Temperature
2	pH	pH	pH	pH
3	Electrical conductivity (µS/cm)	Electrical conductivity (µS/cm)	Electrical conductivity (µS/cm)	Electrical conductivity (µS/cm)
4	Dissolved Oxygen (mg/L O_2)	Dissolved Oxygen (mg/L O_2)	Dissolved Oxygen (mg/L O_2)	Dissolved Oxygen (mg/L O_2)
5	-	Secchi Depth	Secchi Depth	Secchi Depth
6	Suspended Solids (mg/L SS)	Suspended Solids (mg/L SS)	Suspended Solids (mg/L SS)	Suspended Solids (mg/L SS)
7	Biochemical Oxygen Demand (BOD) (mg/L O_2)	Biochemical Oxygen Demand (BOD) (mg/L O_2)	Biochemical Oxygen Demand (BOD) (mg/L O_2)	Biochemical Oxygen Demand (BOD) (mg/L O_2)
8	Chemical Oxygen Demand (COD) (mg/L O_2)	Chemical Oxygen Demand (COD) (mg/L O_2)	Chemical Oxygen Demand (COD) (mg/L O_2)	Chemical Oxygen Demand (COD) (mg/L O_2)

9	Total Organic Carbon (TOC) (mg/L)	Total Organic Carbon (TOC) (mg/L)	Total Organic Carbon (TOC) (mg/L)	Total Organic Carbon (TOC) (mg/L)
10	Total Nitrogen (mg/L N)	Total Nitrogen (mg/L N)	Total Nitrogen (mg/L N)	Total Nitrogen (mg/L N)
11	Ammonium (mg NH_4^+-N/L)	Ammonium (mg NH_4^+-N/L)	Ammonium (mg NH_4^+-N/L)	Ammonium (mg NH_4^+-N/L)
12	Nitrite (mg NO_2^--N/L)	Nitrite (mg NO_2^--N/L)	Nitrite (mg NO_2^--N/L)	Nitrite (mg NO_2^--N/L)
13	Nitrate (mg NO_3^--N/L)	Nitrate (mg NO_3^--N/L)	Nitrate (mg NO_3^--N/L)	Nitrate (mg NO_3^--N/L)
14	Total Kjeldahl Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)
15	Total Phosphorus (mg /L P)	Total Phosphorus (mg /L P)	Total Phosphorus (mg /L P)	Total Phosphorus (mg /L P)
16	Ortho Phosphate (mg/L o-PO_4)	Ortho Phosphate (mg/L o-PO_4)	Ortho Phosphate (mg/L o-PO_4)	Ortho Phosphate (mg/L o-PO_4)
17	Salinity	Salinity	Salinity	Salinity
18	-		Dissolved Inorganic Nitrogen (mg/L DIN)	Dissolved Inorganic Nitrogen (mg/L DIN)
19	-	-	Total Inorganic Nitrogen (mg/L TIN)	Total Inorganic Nitrogen (mg/L TIN)
20	-		Dissolved Inorganic Phosphorus (mg/L DIP)	Dissolved Inorganic Phosphorus (mg/L DIP)
21	-	-	Silisium (mg/L)	Silisium (mg/L)
BIOLOGICAL QUALITY ELEMENTS				
1	Phytoplankton and Phytobenthos (Taxonomic Composition, Abundance, Biomass, Chlorophyl *a*)	Phytoplankton and Phytobenthos (Taxonomic Composition, Abundance, Biomass, Chlorophyl *a*)	Phytoplankton (Taxonomic Composition, Diversity, Abundance, Biomass, Chlorophyl *a*)	Phytoplankton (Taxonomic Composition, Abundance, Biomass, Chlorophyl *a*)
2	Macrophyte (Abundance, Taxonomic Composition, Sensitive Species)	Macrophyte (Abundance, Taxonomic Composition, Sensitive Species)	Macroalgae, Angiosperm (Diversity, Abundance, Sensitive Species, Depth Distrubition/Coverage)	Macroalgae, Angiosperm (Taxonomic Composition , Abundance)
3	Benthic Macroinvertebrates (Diversity, Taxonomic Composition, Abundance, Sensitive Species)	Benthic Macroinvertebrates (Diversity, Taxonomic Composition, Abundance, Sensitive Species)	Benthic Macroinvertebrates (Diversity, Abundance, Sensitive Species)	Benthic Macroinvertebrates (Diversity, Abundance, Sensitive Species)
4	Fish Fauna (Abundance, Taxonomic Composition, Age Structure, Sensitive Species)	Fish Fauna (Abundance, Taxonomic Composition, Age Structure, Sensitive Species)	-	Fish Fauna (Abundance, Taxonomic Composition)
HYDROMORPHOLOGY				
1	Flow	Quantity of inlet and outlet flow	Direction of dominant currents	Freshwater flow
2	Groundwater Connection	Groundwater Connection	Wave exposure	Wave exposure
3	Hydrological regime	Residence time	Depth variation	Depth variation

4	Depth and widht variation	Hydrological regime	Structure and subsrate of the coastal bed	Structure and subsrate of the bed
5	Structure and substrate of the river bed	Depth variation	Structure of the intertidal zone	Structure of the intertidal zone
6	Structure of the riparian zone	Structure of the lake shore		
7	River contunity	Quantity, structure and substrate of the lake bed		

Fish fauna, benthic macroinvertebrates, phytoplankton, phytobentos, macrophytes, macroalgae and angiosperm were sampled during biological monitoring studies according to the national and international standardized methods listed in the Amending Directive 2014/101/ EC. Samples of aquatic flora and fauna of the pilot basins were collected from the monitoring points and preserved for taxonomic identifications. Taxonomic identifications were done mostly at species level.

2.2. Inventory of Aquatic Flora and Fauna

All the scientific literatures, academic researches, Project results of the Ministry and related institutions including biological monitoring activities along the country were used for inventory studies.

2.3. Adaptation of Biological Indices

Monitoring results of 8 pilot basin and the result of inventory studies were used for adaptation of the suitable biological indices to Turkish conditions. Widely used international biological indices, intercalibration studies, academic researches and results of the big scale EU Projects were used as starting point. Some of the biological indices were adapted to Turkish situation using aquatic flora and fauna lists of Turkey. A software was developed for the adapted indices of fish fauna, benthic macroinvertebrates, phytobenthos and phytoplankton. Class boundaries for high/good, good/moderate, moderate/poor and poor/bad status were identified by using the monitoring results and inventory studies for each biological quality elements and water body types.

2.4. Reference Sites and Conditions

Type specific reference sites and conditions were identified by using the monitoring results of 8 pilot basin and inventory studies. Reference monitoring points were selected as far as possible from all the point and diffuse pressures in pilot basins. Reference conditions of the water body types for which reference sites exist were identified by using the monitoring results. Reference conditions of the water body types for which reference sites cannot be found in pilot basins, limited amount of historical data and expert judgement were used. Maximum ecological potential values were determined for heavily modified and artificial water bodies.

2.5. Ecological Assessments

Ecological assessments of the pilot basins were executed by calculating the ecological quality ratios using the Project outputs including monitoring results, adapted biological indices, type specific reference conditions and class boundaries. Ecological status and potential of the pilot basins were presented as colored maps specified in WFD.

3. RESULTS

The Project resulted in variety of biological indices, shown in Table 2, for each biological quality elements and for each water body category. Since the Project results were too comprehensive to be given in one article, indices of one biological quality element is given here as an example for each water body category.

Table 2. Adapted Indices of the Project

BQE	Rivers	Lakes	Transitional Waters	Coastal Waters
Benthic macroinvertebrates	8 different multimetric indices for 8 basins	Multimetric index for all the basins	TUBI and KGI2 indices	
Phytobenthos	TIT index (Adapted Trophic Index to Turkish conditions)		X	X
Phytoplankton	Adapted PTI	Adapted PTI	X	X
Fish fauna	T-IBI (Adapted IBI) & Shannon Wiener	T-IBI (Adapted IBI) & Shannon Wiener	TCFI, EFAI	X
Macrophytes	IBMR	Lake Leafpacs 2	EEI	

3.1. River Benthic Macroinvertebrates

ASTERICS software was used as a starting point for benthic macroinvertebrates in rivers. The software was run with the data from reference, normal and disrupted monitoring points of each basins. 44 out of 376 metrics which responded best was selected for further studies. Discrimination efficiencies for each metrics were calculated to find out the ideal metrics which discriminate reference and disrupted sites efficiently. As a result of this study, 8 different multimetric indices were selected to be used in 8 basins. The multimetric index for Western Black Sea Basin is shown in Table 3.

Table 3. Multimetric Macroinvertebrate Index for Western Black Sea Basin

Metric	Category
BMWP (Spanish version)	Tolerance
Margalef Bidiversity Index	Diversity

[%] Littoral	Functional
EPT Taxa (%)	Composition

Ecological quality ratios (EQR) were calculated by using the arithmetic mean of the EQR values for these metrics. Reference sites and conditions were identified according to resulting EQR values. Class boundaries were determined considering the 95th percentile values for high/good, 75th percentile values for good/moderate, 25th percentile for moderate/poor, 5th percentile for poor/bad ecological status. Class boundaries for Western Black Sea Basin is shown in Table 4.

Table 4. Class Boundaries for Western Black Sea Basin

Class Boundaries	Class	Percentile
> 0,85	HIGH	>95th
0,72-0,84	GOOD	95-75
0,5-0,71	MODERATE	75-25
0,26-0,49	POOR	25-5
<0,25	BAD	<5

Monitoring results were assessed by using the multimetric index and its class boundaries. Ecological status and potential of the Western Black Sea Basin regarding benthic macroinvertebrates is shown in Figure 3.

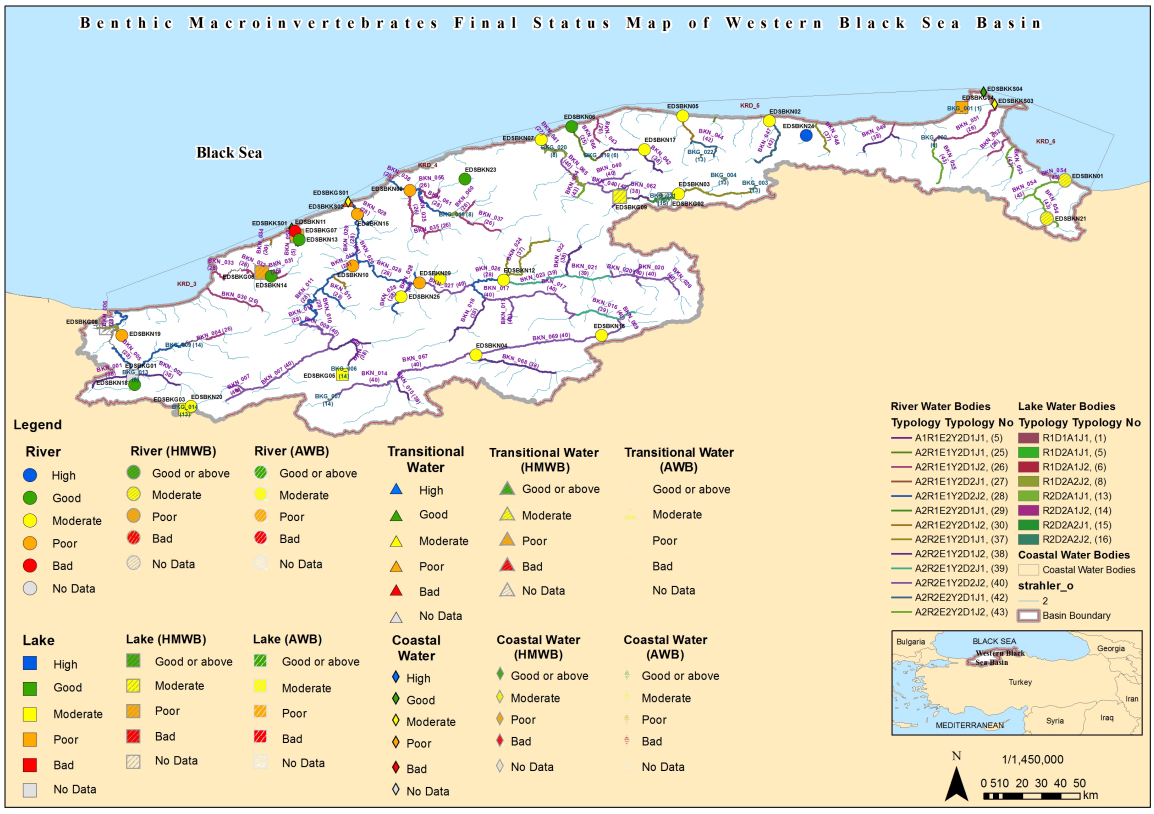

Figure 3. Ecological Status and Potential of Western Black Sea Basin Regarding Macroinvertebrates

3.2. Lake Phytoplankton

Phytoplankton Trophic Index (PTI) (Philips et al., 2013), which is a commonly used index in WFD implementations, was adapted to Turkish conditions for assessment of the phytoplankton data from natural lakes and reservoirs of 8 pilot basin. Phytoplankton biovolume and total phosphorus were used as critical parameters in this study. Optimum, tolerance values and indication values of the phytoplankton species were identified by using the multivariate statistical analysis. Metrics were assessed by using the correlation of the indices' results with the TP values. Figure 4 shows the high level of correlation values for Western Black Sea Basin.

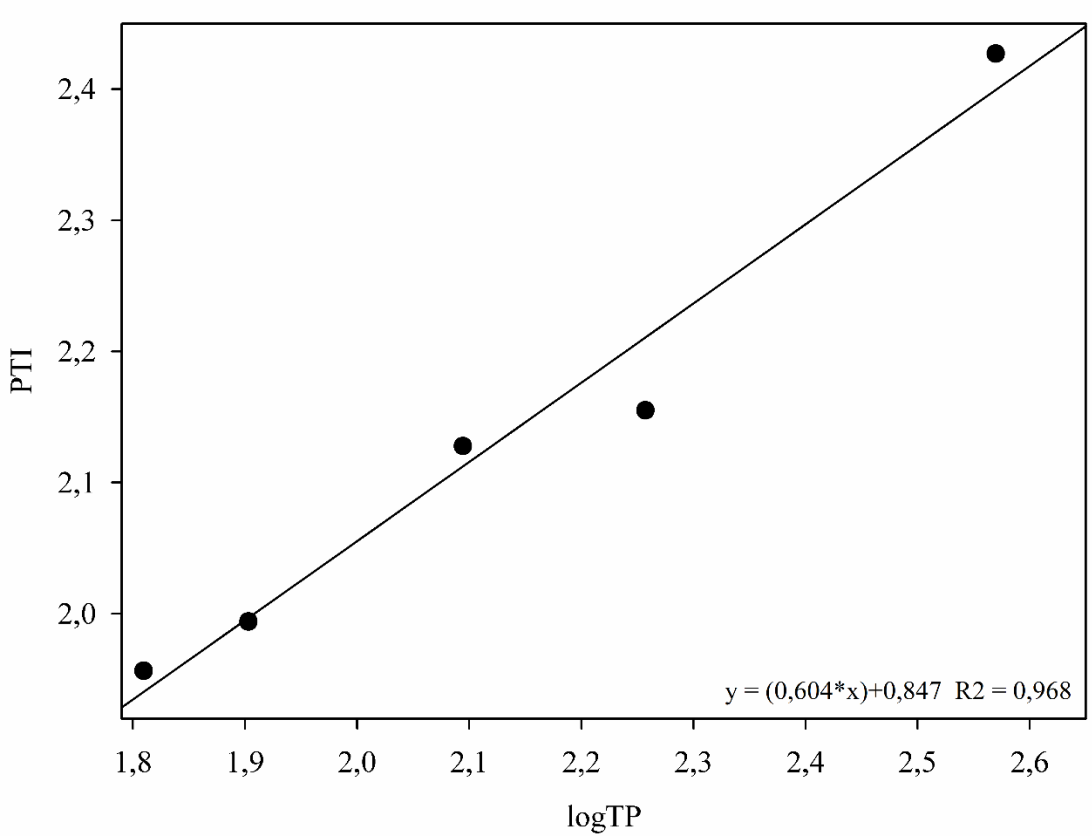

Figure 4. Correlation of the Indices Result with TP Values in Western Black Sea Basin.

Since the number of maximum ecological potential sites were enough, type specific maximum ecological potential values and class boundaries shown in Table 5 were identified for reservoirs. However the number of natural lake were not suitable to identify type specific reference conditions. Expert judgement was used for identification of reference conditions and class boundaries for natural lakes. Ecological status and potential of Western Black Sea Basin's rivers and lakes regarding phytoplankton is shown in Figure 5.

Table 5. Type Specific Class Boundaries for Heavily Modified Lakes

Water Body Type	G/M	M/P	P/B
R1D2A1J1	0,77	0,52	0,34
R1D2A1J2	0,78	0,56	0,35
R1D2A2J1	0,79	0,52	0,34
R1D2A2J2	0,78	0,52	0,34
R2D2A1J1	0,78	0,54	0,35
R2D2A1J2	0,78	0,53	0,35
R2D2A2J1	0,78	0,54	0,36
R2D2A2J2	0,78	0,53	0,37
R3D2A1J1	0,74	0,53	0,37
R3D2A1J2	0,74	0,53	0,37
R3D2A2J1	0,74	0,53	0,37

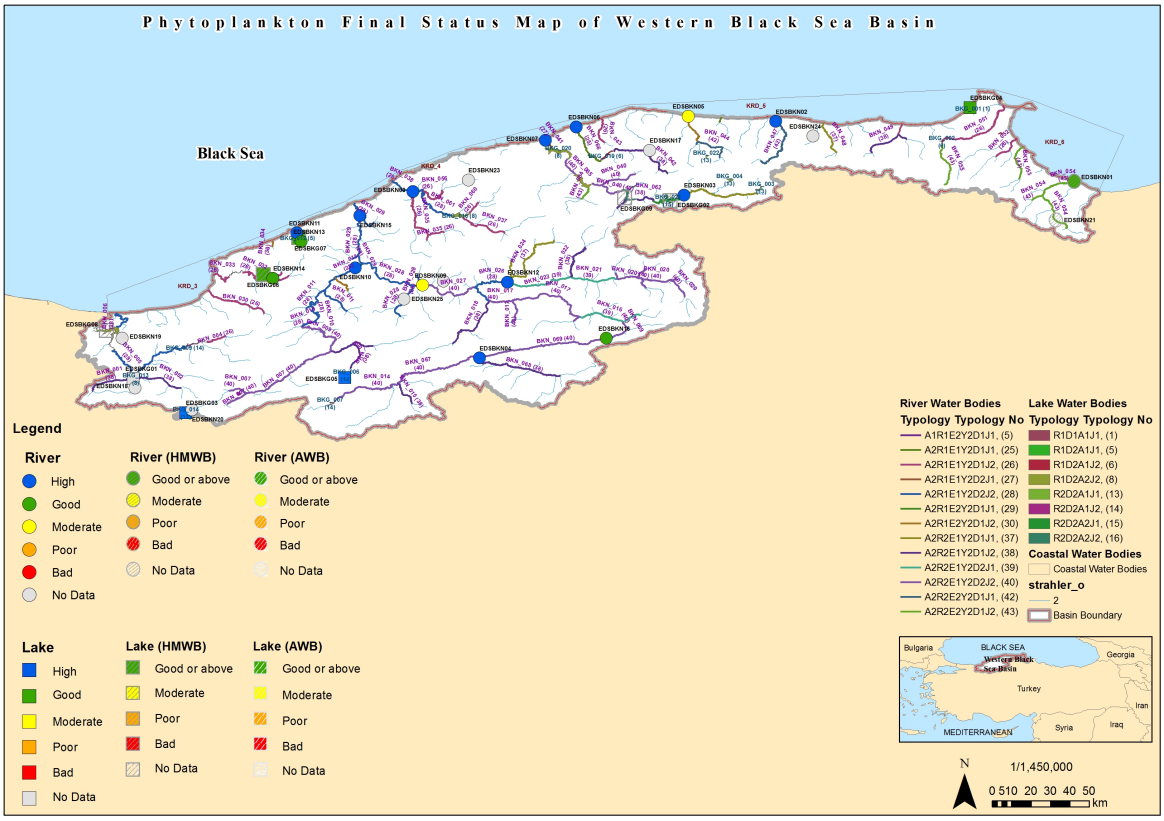

Figure 5. Ecological Status and Potential of Western Black Sea Basin Regarding Phytoplankton

3.3. Coastal and Transitional Waters Benthic Macroinvertebrates

As a result of the Project, a multimetric index called KGI-2, formula of which is as follows, was developed for benthic macroinvertebrates of transitional and coastal waters. Ecological group classification of all the taxa from monitoring studies were done by using the statistical analysis with environmental variables from GI to GV.

$$KGI\text{-}2 = \frac{H' + [5 - (0 \times \%GI + 1.25 \times \%GII + 2.50 \times \%GIII + 3.75 \times \%GIV + 5 \times \%GV)]}{100} \Big/ 2$$

GI – GV : Ecological groups of the benthic macroinvertebrates according to their tolerances from intolerant to opportunistic taxa

One of the sub metric is Shannon Weiner Index (metric 1) and it has different class boundaries for Mediterranean- Aegean Sea and Marmara- Black Sea as shown in Table 6 and Table 7.

Table 6. Shannon Weiner Index Class Boundaries for Mediterranean- Aegean Sea

Ecological Status	High	Good	Moderate	Poor	Bad
H'	4-5,5	3–4	2–3	1–2	<1
EQR	>0,72-1	>0,54-0,72	>0,36-0,54	>0,18-0,36	<0,18

Table 7. Shannon Weiner Index Class Boundaries for Marmara-Black Sea

Ecological Status	High	Good	Moderate	Poor	Bad
H'	3,2-4	2,4–3,2	1,6–2,4	0,8–1,6	<0,8
EQR	>0,80-1	>0,60-0,80	>0,40-0,60	>0,20-0,40	<0,20

KGI-2 results should be in between 0-5. Values close to 0 show bad ecological status while values close to 5 show high ecological status (Table 8).

Table 8. KGI-2 Class Boundaries

Ecological Status	High	Good	Moderate	Poor	Bad
KGI-2	5-4	4-3	3-2	2-1	1-0
EQR	>0,80-1	>0,60-0,80	>0,40-0,60	>0,20-0,40	<0,20

Ecological status and potential values of the coastal and transitional waters of Western Black Sea Basin regarding benthic macroinvertebrates is shown in Figure 3.

3.4. Reference Sites and Conditions

Reference sites for each biological quality elements were determined according to the monitoring results. Type specific reference conditions were identified by using the monitoring results of these sites and expert judgement. Reference sites of Western Black Sea Basin is shown in Figure 6.

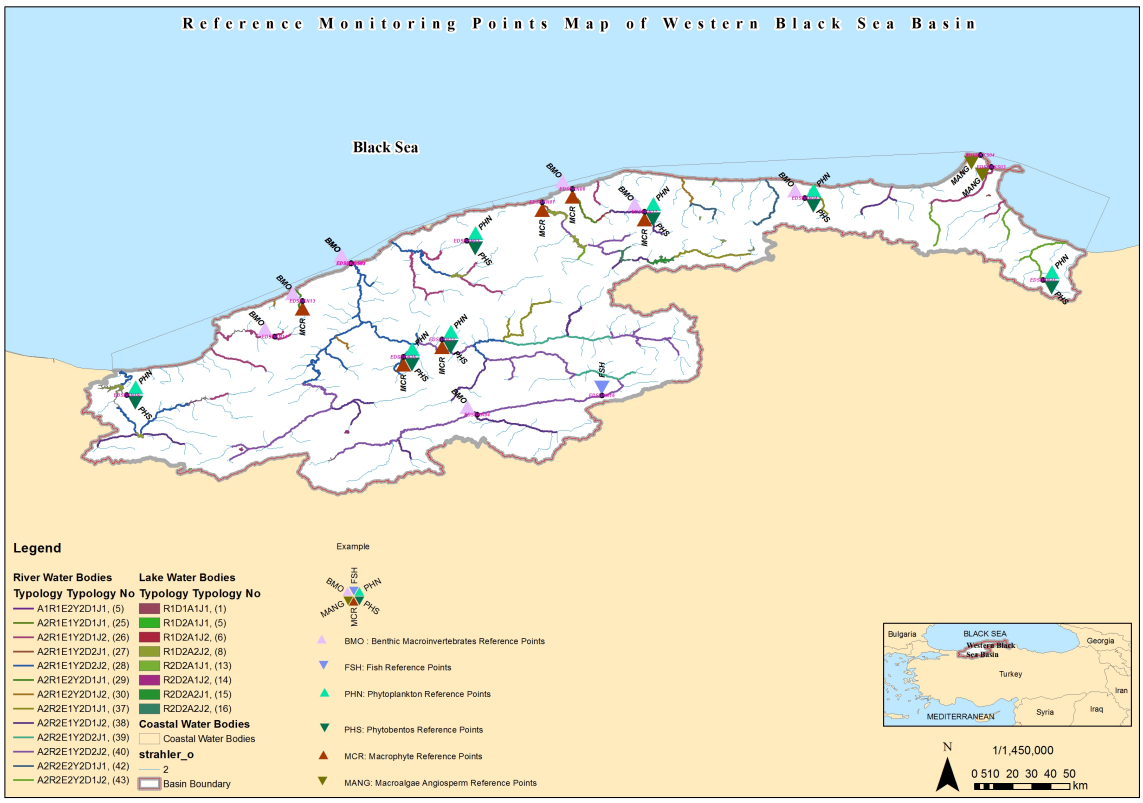

Figure 6. Reference Sites of Western Black Sea Basin.

3.5. Ecological Status and Potential

All the biological quality elements were assessed separately with the indices developed or adapted in the project and their results were combined by using the “one out all out” principle of WFD. The resulting biological status map of Western Black Sea Basin is shown in Figure 7.

General chemical and physicochemical parameters were assessed by using the national class boundaries published in By Law on Surface Water Quality. Resulting map is shown in Figure 8.

Hydromorphological condition of the monitoring points were assessed by using the field forms produced for this project. By the help of these forms hydromorphological status of the monitoring points were identified as high or good by using the expert judgement and the results were considered during the overall ecological status determination. Ecological status and potential map of Western Black Sea Basin is shown in Figure 9.

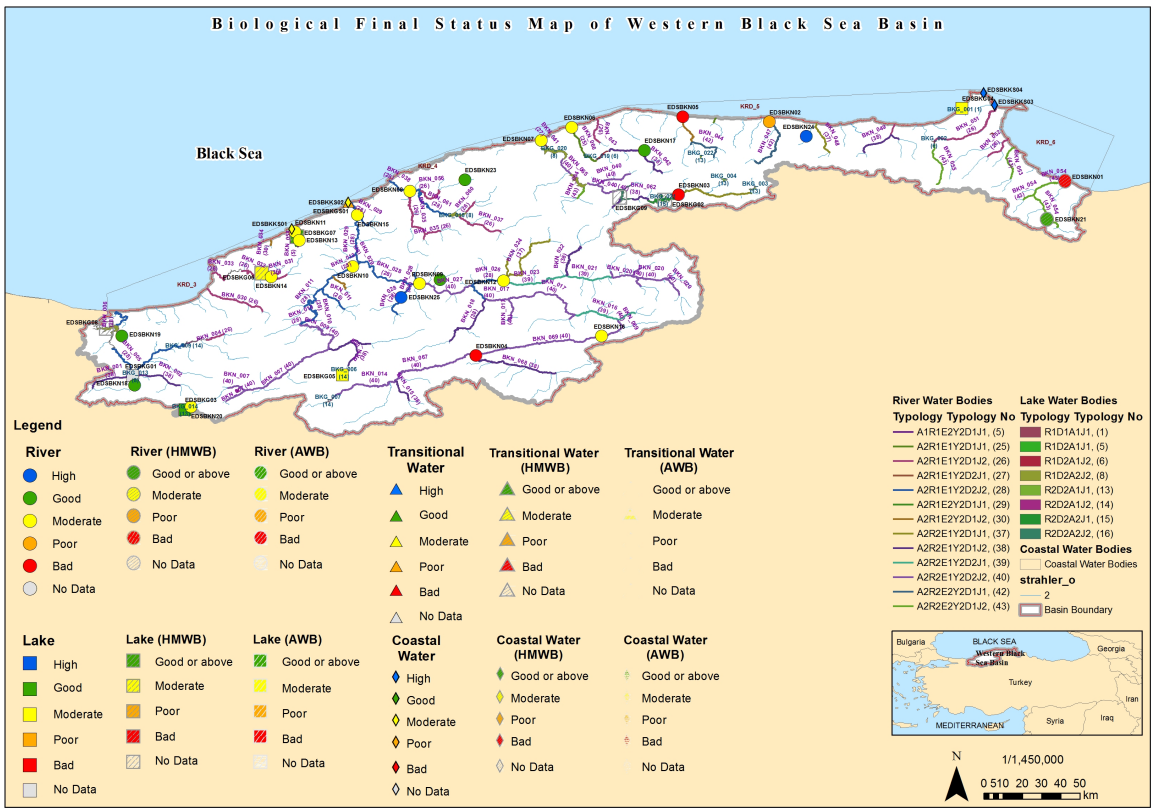

Figure 7. Biological status of Western Black Sea Basin

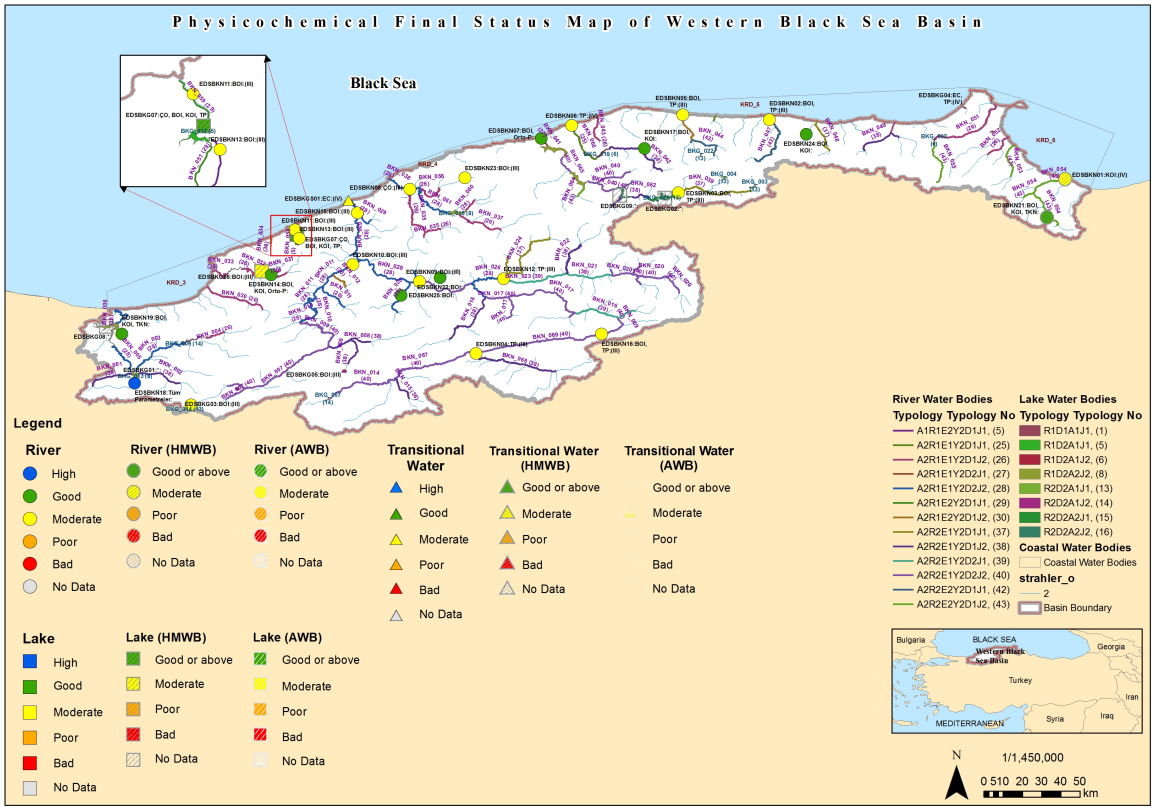

Figure 8. Physicochemical Status of Western Black Sea Basin.

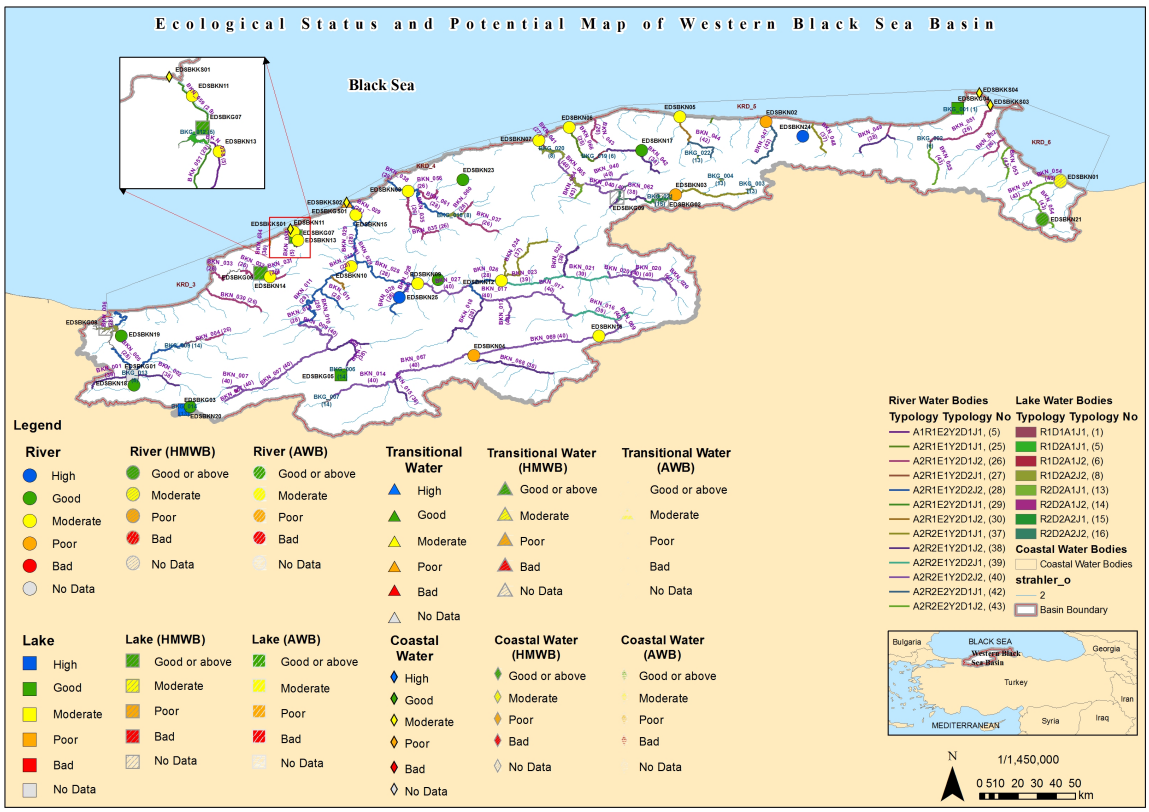

Figure 9. Ecological Status and Potential Map of Western Black Sea Basin

3.6. Main Project Outputs

A final report including all the details of biological indices and 8 basin monitoring reports including the monitoring data of 8 basins were prepared. Index softwares were developed for the benthic macroinvertebrate, phytoplankton, phytobenthos and fish indices. Guidance documents were developed for all the indices developed or adapted for each biological quality elements and for the use of softwares. Species lists of aquatic flora and fauna were prepared for Turkey.

National Water Information System of Turkey is under construction, thus all the data from the Project were stored in Excel files suitable for the architecture of National Water Information System in order to be incorporated in the future.

4. DISCUSSION AND CONCLUSION

Basin based biological monitoring studies was started in 2012 by the Ministry. Before that biological monitoring activities were conducted by universities in a specific river, lake, transitional or coastal water bodies. Basin wide biological monitoring studies were very rare and in very few basins. Thus the biological data has always been a problem for Turkey. First of all this Project is the first comprehensive study aiming to collect monitoring data from 8 basin and inventory data from 25 basin.

This Project was also the first trial on development or adaptation of biological indices to Turkish conditions and determination of reference sites and conditions. The results of this study brings a new way of thinking to the instutions of the country regarding the importance of biological quality elements during the process for ecological assessment of water quality. This Project is recognised as an important first step for establishment of the ecological assessment system in Turkey and it revealed that finalisation of this process requires long term biological data from all over the country. Outputs of the Project will be used by the future studies and Projects of the Ministry and by the academic studies related with ecological assessment of water quality. The resulting ecological assessment system will produce more precise and accurate ecological quality values than commonly used ecological assessment systems not suitable for Turkey. Besides, the Project provided the inspiration to the Ministry for preparation of a legislation in order to standardize the sampling and analysing the biological quality elements and ecological assessment system.

Moreover the project guided MoFWA to define the next steps for finalising the ecological assessment system such as establishment of the reference monitoring network in 25 basins of Turkey, definition of type specific reference conditions for all types, definition of the ecoregions of Turkey in order to revise the typology system in Turkey.

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