Stream corridors as indicators of watershed land use: A case study in Istanbul

Corredores ribereños como indicadores de uso de suelo de una cuenca: un caso de estudio en Estambul

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SUMMARY

Riparian ecosystems as components of stream corridors provide a range of regulating ecosystem services including water production. Water quality, a component of water production is a major concern in urbanized watersheds. Water quality monitoring has been a very common method of investigating watershed impairment particularly in case of human impacts but it is now clear that hydrologic and ecological parameters may support and improve monitoring studies substantially. In three major watersheds of the Istanbul city (Alibeyköy, Sazlıdere, and Kağıthane) we initiated a large-scale study with the objective of evaluating integration, health, and functionality levels of riparian ecosystems. We combined a thorough field survey study with a GIS assessment to reach this objective. A total of 66 sub-watersheds have been selected in the main study watersheds and survey points have been determined at their outlets. All perennial streams in the study have been surveyed for 5 main categories; ecological water quality, water quality for use, riparian integrity, riparian functionality, and riparian habitat potential. We found that a substantial amount of the streams in or close to urban areas had lost their functionality. Furthermore, around 10 percent of all streams in the peri-urban areas had been channelled. Water quality has also been deteriorated in many streams. For example, average NO_3^{-1} concentration at the urban streams was 76.63 mg L^{-1} while it was 2.67 mg L^{-1} at the forested part of the same watershed.

Key words: urban planning, land use, sprawl, watersheds, stream corridors.

RESUMEN

Los ecosistemas ribereños como componentes de los corredores fluviales proveen un rango de servicios ecosistémicos incluyendo la producción de agua. La calidad de agua, un componente de la producción de agua, es una preocupación relevante en las cuencas urbanizadas. El monitoreo de la calidad de agua ha sido un método comunmente aplicado para investigar el debilitamiento de las cuencas, particularmente a causa de los impactos humanos. Sin embargo, es claro que los parámetros hidrológicos y ecológicos pueden sustentar y mejorar sustancialmente los estudios de monitoreo. En tres grandes cuencas de la ciudad de Estambúl (Alibeyköy, Sazlıdere, and Kağıthane) se iniciaron estudios de gran escala con el objetivo de evaluar los niveles de integración, salud y funcionalidad de los ecosistemas ribereños. Se combinó un trabajo de campo exhaustivo con una evaluación usando SIG para alcanzar tal objetivo. Se seleccionaron 66 sub-cuencas en las principales cuencas de estudio y se determinaron puntos de muestreo en sus salidas. Todos los esteros permanentes fueron evaluados para cinco categorías principales; calidad ecológica del agua, calidad de agua para uso, integridad ribereña, funcionalidad ribereña y potencial de hábitat ribereño. Se encontró que una cantidad sustancial de los esteros en o cerca de áreas urbanas han perdido su funcionalidad. Además, cerca de un 10 % de todos los esteros en las áreas periurbanas han sido canalizados. La calidad del agua también se ha deteriorado en muchos de estos esteros. Por ejemplo, la concentración promedio de NO_3^{-1} en los esteros urbanos fue 76.63 mg L^{-1} mientras que en las áreas forestadas de las mismas cuencas alcanzó solo 2.67 mg L^{-1}.

Palabras clave: planificación urbana, uso de suelo, expansión, cuencas, corredores ribereños.

INTRODUCTION

Stream corridors are living components of the landscape and a major concern from hydroecological point of view. A complex biotic component of stream corridors is riparian ecosystems which provide a wide range of regulating ecosystem services especially around populated regions. Both water quality and quantity may become a concern in urbanized watersheds. Management of urban and peri-urban watersheds becomes more challenging with respect to water production in such cases. It is now widely understood that functional riparian ecosystems can remove large amounts of nitrate and phosphate from the water that flows through them (Gorniak 1993, Hill 1996, Casey *et al.* 2001, Hunter *et al.* 2006). Riparian ecosystems are also capable of trapping sediment runoff from land, enabling bank stability and thus minimising soil loss into watercourses (Tubman and Price 2001, McKergow *et al.* 2004, Kreutzweiser *et al.* 2009). Another benefit of the riparian vegetation is the shading of water surface and thus

BOSQUE 33(3): 345-352, 2012
IUFRO Landscape Ecology Conference 2012: Sustaining humans and forests in changing landscapes
Stream corridors and watershed land use

regulating the temperature of aquatic ecosystems (Pusey and Arthington 2003). Biodiversity and habitat provision as well as energy and nutrient benefits of riparian ecosystems have also been quite well documented. With all these mentioned capabilities, the state of a stream corridor can be characterized by three aspects: i) habitat potential, ii) ecosystem integrity and iii) ecosystem functionality.

Habitat potential is determined for single species of a region in particular. However, a broader assessment can be done for groups of species sharing a common habitat. Aquatic habitat is often used in studies of stream habitats based on physical, chemical and biological characteristics. Physical habitat includes parameters such as channel dimension, stream flow and riparian vegetation; chemical variables include water pH and nitrate levels; and biological components serve as indicators of the ecological community that utilize the river, *e.g.* fish and macroinvertebrate species composition and diversity. Whitacre (2004) has identified 11 stream attributes that are included in six stream habitat assessment protocols used by USDA (United States Department of Agriculture) which are: reach length, gradient, sinuosity, percent pools, residual pool depth, bankfull width, bankfull width/depth, D_{50}, fine particle percent, pool tail fine particle percent, and large woody debris in 100 meters.

The term ecosystem integrity is used by Jordan and Vaas (2000) as a defining term of a combination of many components of the system, *e.g.*, the quality of water and physical habitats, the abundance, health, and diversity of aquatic plants and animals, and balance among trophic guilds and functional groups of biota. Karr's (1992) definition of ecological integrity is "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region". As a simple approach ecological integrity defines the distance of an ecosystem from natural conditions or the human impact level in an ecosystem.

Ecosystem functionality is a well-known and studied aspect of ecosystems compared to integrity. In this study it covers the role of riparian components of streams to provide water-related ecosystem services (*i.e.* sediment and nutrient immobilization, flood control).

The above mentioned aspects of stream corridor state can be determined with field surveys combined with water quality monitoring studies. Field surveys that are supported with hydroecologic water monitoring studies -that includes biologic parameters like macroinvertebrates- provide information on many attributes of stream condition. One question that may arise in this context may be "can stream corridor conditions that include riparian areas be handled and evaluated from certain aspects to link with watersheds that they drain?" This linkage can diminish the work load of municipalities and other related public agencies that are responsible for stream corridor maintenance.

The reason for performing this study particularly in Istanbul was the fast urbanization trend of the city that caused deterioration of fluvial systems. More than 10 reservoirs are providing water to Istanbul city with a population of more than 12 million. Watersheds of most reservoirs are under pressure of urbanization and sprawl.

We worked in three important watersheds (Alibeyköy, Sazlıdere, and Kağıthane) of the city towards the objective of linking stream corridors with their watersheds quantitatively. To reach this objective, we combined field surveys, water quality monitoring and GIS assessments.

METHODS

Study area. Study watersheds cover a large area on Istanbul's European side peninsula (figure 1). Alibeykoy and Sazlidere watersheds are draining into reservoirs while Kağıthane creek drains into a well-known estuary called Golden Horn. Croplands constitute a large part of Sazlidere watershed while forestlands at the upper elevations and urban areas at the lower elevations characterize the Alibeykoy and Kağıthane watersheds. The streams draining Kağıthane and Alibeykoy are receiving pollutants that are generated by settlements and industrial activities along the creeks. Flooding is also a major problem at downstream of Alibeykoy and Kağıthane streams because riparian ecosystems are replaced by settlements in many places. The areas of watersheds and their basic properties are given in table 1.

The annual precipitation ranges between 650 and 1,100 mm decreasing southwards. The Black Sea shore receives the highest amount of precipitation. Neogen and Carboniferous formations characterize the geology of the region. Limestone and clay schists exist in Carboniferous zone locally. Andesites and alluvial zones also exist in the region.

Field methods. A total of 66 sub-watersheds were selected in the three main watersheds and survey points for stream corridors were determined at their outlets. Thirty eight of the sub-watersheds were used for model construction and the rest for model performance test. All perennial streams in the study were surveyed for three main categories: i) ecosystem integrity, ii) ecosystem functionality y

Table 1. Study watersheds and some basic information.
Cuencas bajo estudio e información básica.

Watershed	Watershed area	Reservoir area	Type of use
Sazlidere	194	9.87	Water supply
Alibeykoy	158	4.66	Water supply
Kağıthane	388	NE	NE

NE: not exist.

BOSQUE 33(3): 345-352, 2012
IUFRO Landscape Ecology Conference 2012: Sustaining humans and forests in changing landscapes
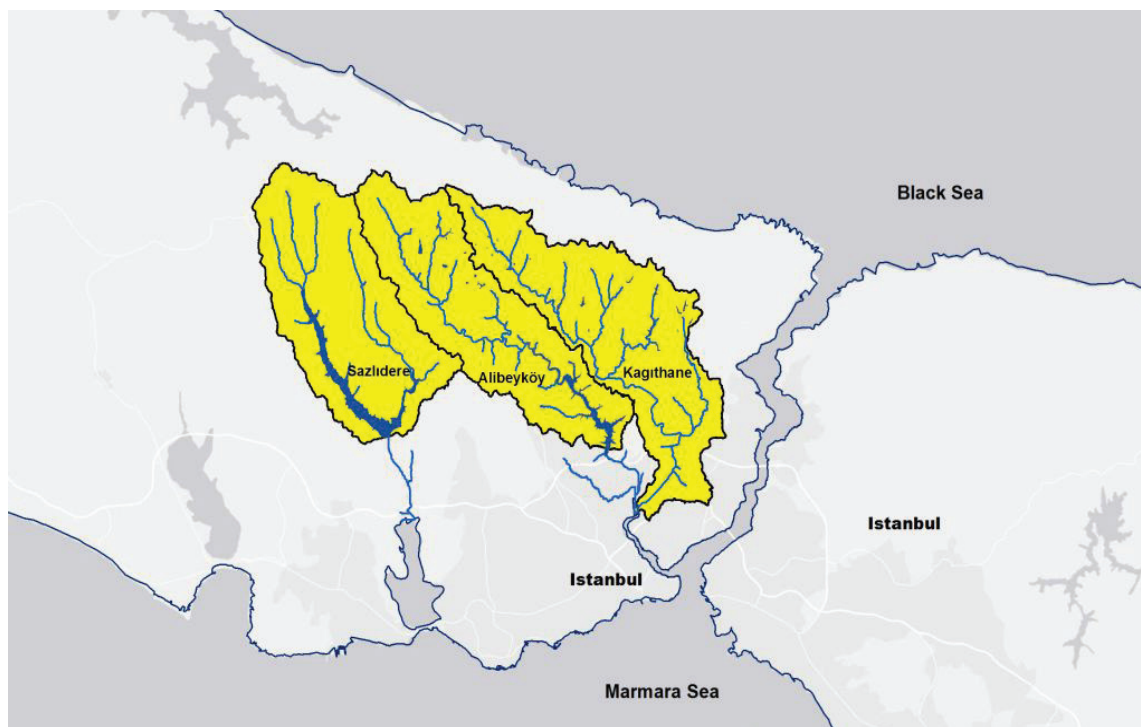Stream corridors and watershed land use

Figure 1. Sazlıdere, Alibeyköy and Kağıthane watersheds from west to east direction.
Cuencas Sazlıdere, Alibeyköy y Kağıthane desde el Oeste al Este.

iii) aquatic habitat potential. Each category was quantified, statistically analyzed and linked with watershed attributes.

The procedures were as follows: field surveys at stream corridors. Field surveys were implemented using a stream channel survey protocol developed for this purpose. It included ecologic and hydrologic attributes. Relevant survey parameters were selected for the three categories (table 2).

Water quality monitoring. The water quality parameters that have been determined on each stream survey section were: Total suspended sediments (TSS), nitrate ($N\text{-}NO_3$), ammonium ($N\text{-}NH_4$), colour, phosphate (PO_4), hardness, calcium hardness, calcium (Ca), magnesium (Mg), HCO_3, alkalinity (A).

Other than these, electrical conductance, pH, oxygen concentration, temperature, and turbidity were analyzed in the field. The Kağıthane watershed included large amounts of forestland and water quality attributes of this watershed were calculated as forested and total area to see the difference.

The water quality monitoring did not have a temporal dimension as the objective was not to evaluate the stream water quality over time. The water quality monitoring part of the study was performed towards two objectives to reveal the water quality condition of the streams and to use water quality as a verification tool. Chemical, physical and ecological (macroinvertebrate population numbers and diversity) parameters were determined to reach the first objective. Two new parameters called ecologic water qua-

lity (WQeco) and water quality for various uses (WQuse) were computed for the second objective. This was to link water quality with stream and watershed attributes. The parameters to compute WQeco were: alkalinity, dissolved oxygen, nitrate, ammonium, phosphate, pH, suspended sediments, turbidity.

The parameters to compute WQuse were: electrical conductance, pH, turbidity, total and calcium hardness, calcium and magnesium ion concentrations. The computation method was to determine the range of a parameter and divide it into a certain number of score ranges. As an example, electrical conductance was split into five ranges and scored as: 0-250 μS cm^{-1} = 0; 250-750 μS cm^{-1} = 1; 750-2,000 μS cm^{-1} = 2; 2,000-3,000 = 3; 3,000-4,000 μS cm^{-1} = 4. The polluted streams got higher WQ scores in this approach. The watershed attributes that have been determined and evaluated were: forest intensity (forint), settlement intensity (settlint), farmland intensity (farmint), road intensity (roadint), area, mean elevation, mean slope, stream density, stream frequency. We used ArcGIS 9.3 for spatial analyses.

Data processing and transformation. The stream survey parameters included both objective (D50, erodibility, etc.) and subjective (shade effects of vegetation, visible human impacts etc.) data. The data was combined to calculate a score for each category. The scoring was done in three steps; frequency analysis was done for each measured or estimated parameter unless well-known classifications

BOSQUE 33(3): 345-352, 2012
IUFRO Landscape Ecology Conference 2012: Sustaining humans and forests in changing landscapes
Stream corridors and watershed land use

Table 2. Survey parameters used for estimating stream state categories.
Parámetros del estudio usados para la estimación de las categorías de los esteros.

AHP (aquatic habitat potential) score	EF (ecosystem functionality) score parameters	EI (ecosystem integrity) score parameters
Shade effect of riparian ecosystem	Land use on both sides of the corridor	Visible human impacts around the channel (bridge, road, recreation, grazing, etc.)
Channel modification	Riparian vegetation composition and density	
Biologic activity in water	Shade level of the riparian vegetation	Intensity of riparian vegetation
Number of pools in 50 meters up and downstream	Width of Riparian zone	Direct impacts to natural stream channel (channelization, digged, restoration measures, widening, etc.)
Number of riffles in 50 meters up and downstream	Frequency of herbaceous plants	
Number of woody debris deposition in 50 meters up and downstream	Leaf area cover of herbaceous plants	Distance to road and settlements
Embeddedness	Herbaceous biodiversity (Shannon index)	Macroinvertebrate and fish population
D_{50} (Medium sediment particle size)	Soil permeability	Herbaceous cover diversity
Bankfull width	Soil erodibility	
Bankfull width/depth ratio	Soil compaction and bulk density	
LWD (Large woody debris) size and deposition		
Sinuosity		
Gradient		

exist like EC, each frequency class (five classes) was given a score, aquatic habitat potential, ecosystem functionality, and ecosystem integrity scores were calculated for 66 stream cross sections (38 model construction, 28 for model test).

Then the categories were transformed into values that are statistically useable (table 3). Transformations were as follows:

SSR transformation is suggested by Zar (1996) and preferred to square root transformation in case of zero values. It is implemented as;

$$p' = \sqrt{p + 3/8} \qquad [1]$$

Where,
p = number to be transformed.

Linking stream properties with watershed properties. Significant land use properties for the 66 sub-watersheds (38 model construction, 28 for model test) were determined as intensity values (land use/watershed area) in the three major watersheds. Correlations between forest intensity (forint), settlement intensity (settlint), farmland intensity (farmint), and road intensity (roadint) and stream corridor categories were investigated and significant correlations were determined. Forest, settlement, farmland, and road intensities are easily available data for many public authorities especially for municipalities.

Simple and multiple regression models were developed and compared with two artificial neural networks models. NeuroXL predictor software was used to develop artificial neural networks models. The artificial neural networks1 was a predicting model based on one independent variable while two independent variables were used in artificial neural networks2. Zero based log sigmoid function was used as the activation function. The 0.365 r^2 value became 0.433 after the learning phase for artificial neural networks1 while r^2 value of 0.232 became 0.704 for artificial neural networks2.

These four statistical models were developed by using data from 38 sub-watersheds. The models were tested on data from the other 28 sub-watersheds. The least square errors of models were calculated to find out best model to predict aquatic habitat potential, ecological integrity, and ecological functionality from watershed land use intensities data and vice versa.

RESULTS

Water quality. The upper portion of Kağıthane watershed is covered mainly with forestlands (figure 2). Therefore the water quality of headwater streams was in good condition as expected. The mean values of water quality parameters also showed that the streams draining forested headwaters were receiving large amount of pollutants while passing through urban areas as expected (table 4). The mean total suspended sediment concentrations of steam waters at forested areas were almost one fifth of the remaining part of the watershed. Nitrate and ammonium concentrations were much higher at Kağıthane and Sazlıdere watersheds compared to forested part of Kağıthane and Sazlıdere. Alibeyköy watershed had highest total suspended sediments, ammonium, phosphate, hardness, calcium hardness, calcium, and magnesium values.

BOSQUE 33(3): 345-352, 2012
IUFRO Landscape Ecology Conference 2012: Sustaining humans and forests in changing landscapes
Stream corridors and watershed land use

Table 3. The statistical transformations used for aquatic habitat potential (AHP), ecosystem integrity (EI), ecosystem functionality (EF), water quality for various uses (WQuse), and ecologic water quality (WQeco scores).
Transformaciones estadísticas usadas para AHP, EI, EF, WQuse y valores de WQeco.

	N	Mean	Std. dev.	Kolmogorov-Smirnov Z	Asimp. Sig. (2-way)	Type of data and transformation
AHP	38	4.158	4.918	1.701	0.006	NN SSR
EI	38	6.868	5.576	0.672	0.757	NN SSR
EF	38	10.579	5.976	1.060	0.211	NN SSR
WQuse	38	4.944	2.484	0.610	0.851	NN SSR
WQeco	38	4.389	3.425	1.111	0.169	NN SSR

NN: not normally distributed, SSR: special square root.

Land use
- Range land
- Broadleaved forest
- Coniferous forest
- Settlement
- Agriculture
- Rare vegetation
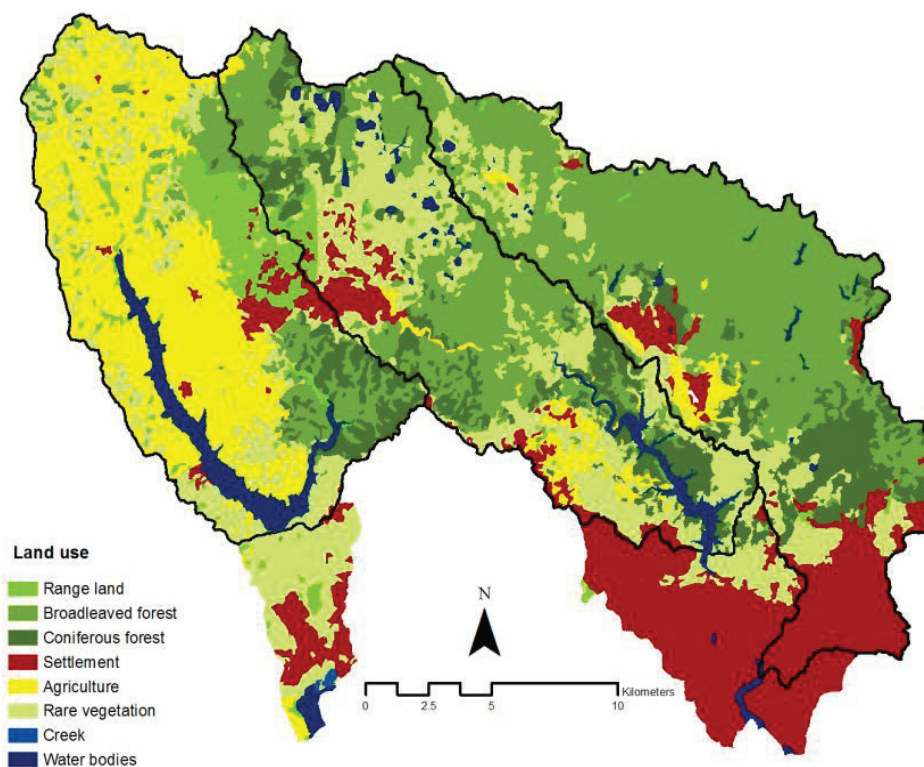- Creek
- Water bodies

Figure 2. Land use in study watersheds.
Uso de suelo en las cuencas bajo estudio.

Table 4. Water quality of streams in study watersheds.
Calidad de agua de los cursos de agua en las cuencas de estudio.

Watershed	TSS mg L^{-1}	N-NO$_3$ mg L^{-1}	N-NH$_4$ mg L^{-1}	Colour cpu	PO$_4$-P mg L^{-1}	H mg L^{-1} CaCO$_3$	CaH mg L^{-1} CaCO$_3$	Ca mg L^{-1}	Mg mg L^{-1}	A mg L^{-1} CaCO$_3$	HCO$_3$ mg L^{-1}
Kağıthane Forested	0.21	2.67	0.26	12.00	4.29	160.00	77.42	31.03	20.15	62.78	76.59
Kağıthane	1.01	76.63	5.08	26.92	5.44	357.00	219.86	88.12	33.46	170.30	207.76
Alibeyköy	1.32	39.16	12.50	16.25	8.17	691.06	440.34	176.49	61.18	228.01	278.17
Sazlıdere	0.57	16.14	0.43	7.50	4.73	548.40	310.40	124.41	58.07	251.85	307.26

TSS: total suspended sediments, H: hardness, CaH: calcium hardness, A: alkalinity.

BOSQUE 33(3): 345-352, 2012
IUFRO Landscape Ecology Conference 2012: Sustaining humans and forests in changing landscapes
Stream corridors and watershed land use

Stream properties - watershed properties linkage. The linear relationships between stream corridor categories (habitat, integrity, functionality) and land use properties are given below (table 5). Significant correlations were determined among the categorized stream corridor categories, water quality scores (WQuse, WQeco) and selected watershed attributes. Farmlands correlated with macroinvertebrate diversity, herbaceous cover, and diversity of surveyed stream sections but no significant correlation was determined for water quality and categorized stream corridor properties (aquatic habitat potential, ecosystem integrity, and ecosystem functionality). Forest intensity and settlement intensity were generally the dominating land use attributes to affect stream conditions but on the opposite directions.

Simple and multiple regression models were determined based on significant correlations. The aquatic habitat potential, ecosystem integrity, and ecosystem functionality were estimated with these regression models and two other artificial neural networks models for the test sub-watersheds. Performances of the models were compared with least squares error method (table 6). The Reg1 in the table represents simple regression, MReg represents multiple regression. Artificial neural networks1 is the one independent and artificial neural networks2 is the two independent variable. Artificial neural network model as explained above.

The simple and multiple regressions had better performance results compared to artificial neural networks models for ecosystem integrity and ecosystem functionality estimations. Aquatic habitat potential estimation was better done with Artificial neural networks2 model.

As the final stage of model application we conducted visual model estimations for the 28 verification sub-watersheds. The ecosystem functionality estimation done by a simple regression equation has been given below (figure 3) with forest intensity as the independent variable.

Forest intensity increases as the colour gets darker while ecosystem functionality decreases as the yellow circles gets larger. The yellow circles becoming larger at settlement (*i.e.* Kağıthane low regions) and agriculture-intensive regions (*i.e.* Sazlıdere watershed) is an indication of diminished stream ecosystem functionality in comparison to forest-intensive watersheds. The ecosystem functionali-

Table 5. Correlations among stream corridor attributes and some watershed land use properties.
Correlaciones entre los atributos de los corredores ribereños y las propiedades del uso de suelo en la cuenca.

Attributes	Statistics	Forint	Settlint	Farmint	Roadint
Aquatic habitat potential (AHP)	Pearson correlation	-0.343	0.377*	-0.176	0.304
	P (2-tailed)	0.059	0.037	0.343	0.097
	N	38	38	38	38
Ecosystem integrity (EI)	Pearson correlation	-0.568**	0.408*	-0.125	0.347
	P (2-tailed)	0.001	0.023	0.504	0.055
	N	38	38	38	38
Ecosystem functionality (EF)	Pearson correlation	-0.564**	0.417*	-0.055	0.380*
	P (2-tailed)	0.001	0.020	0.769	0.035
	N	38	38	38	38
Water quality for various uses (WQuse)	Pearson correlation	-0.415*	0.461*	-0.202	0.470**
	P (2-tailed)	0.023	0.010	0.283	0.009
	N	38	38	38	38
Ecologic water quality (WQeco)	Pearson correlation	-0.337*	0.530**	-0.190	0.449*
	Sign. (2-tailed)	0.069	0.003	0.316	0.013
	N	38	38	38	38

*0.05 significance level. **0.01 significance level.

Table 6. Comparison of simple regression, and multiple regression with two artificial neural networks (ANN) models. # represent the lowest errors.
Comparación entre regresiones simples y múltiples con dos modelos de redes neuronales artificiales (ANN). # representan los errores más bajos.

Attributes	lseReg1	lseMReg	lseANN1	lseANN2
Aquatic habitat potential (AHP)	13.71	49.72	42,63	10,02#
Ecosystem integrity (EI)	32.52	11.90#	29,71	114,70
Ecosystem functionality (EF)	16.68#	60.36	20,50	28,28

BOSQUE 33(3): 345-352, 2012
IUFRO Landscape Ecology Conference 2012: Sustaining humans and forests in changing landscapes
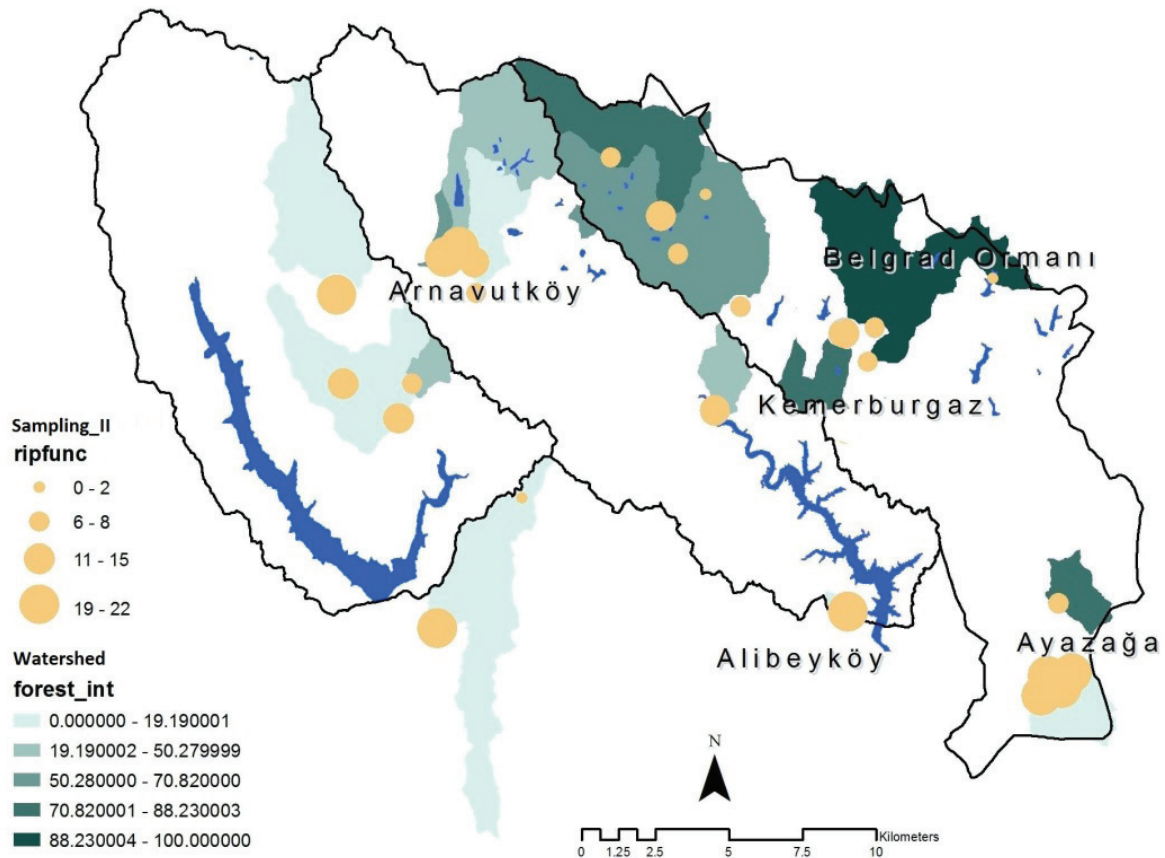Stream corridors and watershed land use

Figure 3. EF estimation at the verification watersheds.
Estimación de EF en las cuencas de verificación.

ty is higher in forested watersheds (smaller circles) but in some cases sparse vegetation (brushlands, meadows, etc.) or villages in or around the forest are causing variability in ecosystem functionality.

DISCUSSION AND CONCLUSIONS

Conventional approach to evaluate watershed deterioration bases on water quality monitoring. This is a very effective approach if ecological parameters (*i.e.* macroinvertebrates) are also taken into consideration. However, water quality monitoring can be linked with watershed attributes but not stream corridor attributes especially to assess riparian ecosystems. This study offers a new direction to address this topic with simple and low data demanding models. Basic approach is to evaluate watersheds and their stream corridor properties together. The integrity, functionality, and habitat potential have been taken into account in this study as defining elements of stream corridors. This is an ecological approach because even a channelization can be considered as a stream restoration objective in many cases as it is in Istanbul.

The results of the study were generally in line with recent studies with respect to land use impacts on stream conditions. Positive impacts of forests on suspended sediment concentration have been documented with numerous studies (*i.e.* Bartley *et al.* 2012, Somura *et al.* 2012). In general, suspended sediment concentration was found to be inversely proportional with forest cover percentage in a watershed (Mouri *et al.* 2011). This increase in macro invertebrate diversity in farmlands (Victor and Ogbeibu 1985) is generally attributed to increase in fine sediment supply to the streams (Scarsbrook and Halliday 1999, Niyogi *et al.* 2007). Forest intensity and settlement intensity had also significant impacts on stream conditions.

The study had also practical outputs like simple regression equations. Public authorities responsible of stream restoration work can determine stream channel functionality level estimations without much field work with this approach. The restoration requirements of the streams can be ranked with certain accuracy as ecosystem functionality together with ecosystem integrity, and aquatic habitat potential represents ecological levels of stream corridors.

A large amount of parameters were measured in the field and many of them have been used to combine parameters like ecosystem integrity and WQeco. A wide range of watershed attributes has also been determined to find out the most convenient and practical statistical linkages. With

BOSQUE 33(3): 345-352, 2012
IUFRO Landscape Ecology Conference 2012: Sustaining humans and forests in changing landscapes
Stream corridors and watershed land use

the support of these data, simple and statistically applicable relationships were determined to be used by relevant public authorities. Most municipalities have a certain level of digital maps that may enable them use this approach.

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