Integrated Use of AHP and GIS Techniques for Generating Forest Fire Risk Map in Karacabey Flooded Forest

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BACKGROUND

- Forest fires seriously affect sustainability of forest resources especially in the dry regions covered with fire sensitive tree species.
- The coastline of Turkey from the eastern Mediterranean region to the Marmara Region, about 5.5 million hectares of forest lands are classified as first-degree fire sensitive areas.
- The average of 10,000-14,000 ha forests are burned annually as a result of over 2,000 forest fires occurred in Turkey.

BACKGROUND

- Forest fires reduce the economic value of trees and even cause loss of human lives.
- Besides, forest fires produce great amount of greenhouse gasses (CO_2 and CH_4).
- After fire incidents, fire-damaged trees become more vulnerable to insects and fungus.
- Forest fire risk mainly depends on various factors such as forest vegetation structures, topographic features, and climatic parameters.

BACKGROUND

- Forest vegetation structures such as tree species, crown closure, and tree stage are separate factors that influences forest fire ignition and fire severity.
  - Fire risk increases as coniferous trees increases, while deciduous trees can increase fire resistance.
  - Crown closure has positive relationship with forest fire risk.
  - The fire risk is relatively low at early stages of trees, while risk is very high at young generations
- Topography is an important factor that affects the fire risk.
  - Fire moves least rapidly down slopes and most rapidly up slopes.
  - Besides, the fire risk increases as ground slope increases.
  - In term of aspect, fire risk is higher in south-facing aspects due to high temperature and low humidity
- Climatic parameters such as temperature, precipitation, and wind also play important role in forest fire risks.

BACKGROUND

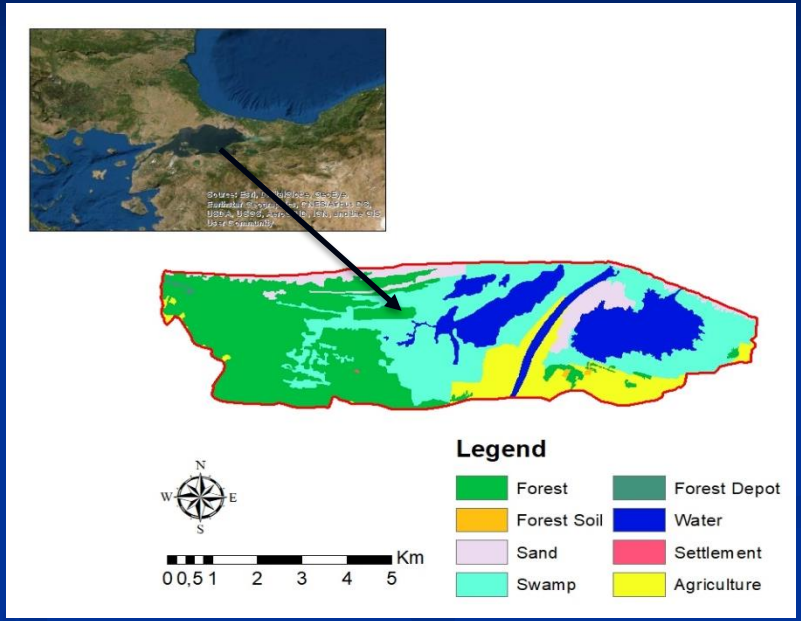
- To minimize the potential effects of fires on forest resources, forest fire risk zones should be determined and necessary precaution measures should be taken in these areas.
- A fire risk zone mapping is essential for an accurate assessment of forest fire problems.
- Forest fire risk maps can be generated based on spatial data layers representing various fire risk factors.
- GIS techniques integrated with Multi-Criteria Decision Analysis (MCDA) provides quick and effective solutions to such complex spatial problems.
- Analytical Hierarchy Process (AHP) is one of the widely used multi-criteria decision-support methods in field of forestry.

OBJECTIVE

- In this study, GIS-based AHP method was used to generate forest fire risk map.
- The method was implemented in Karacabey Flooded Forest which was categorized as a highly protected zone in Turkey

MATERIAL AND METHODS

- The study was Karacabey Flooded Forests with the total area of 3800 ha.
- The flooded forest is located in west of the city of Bursa in Turkey.
- The main land use classes in the flooded forest include forest, flooded forest, swamp, water bodies, agriculture, sand, roads, and open areas. The dominant trees in the region are alder, oak, ashen, poplar, stone pine, and black pine



MATERIAL AND METHODS

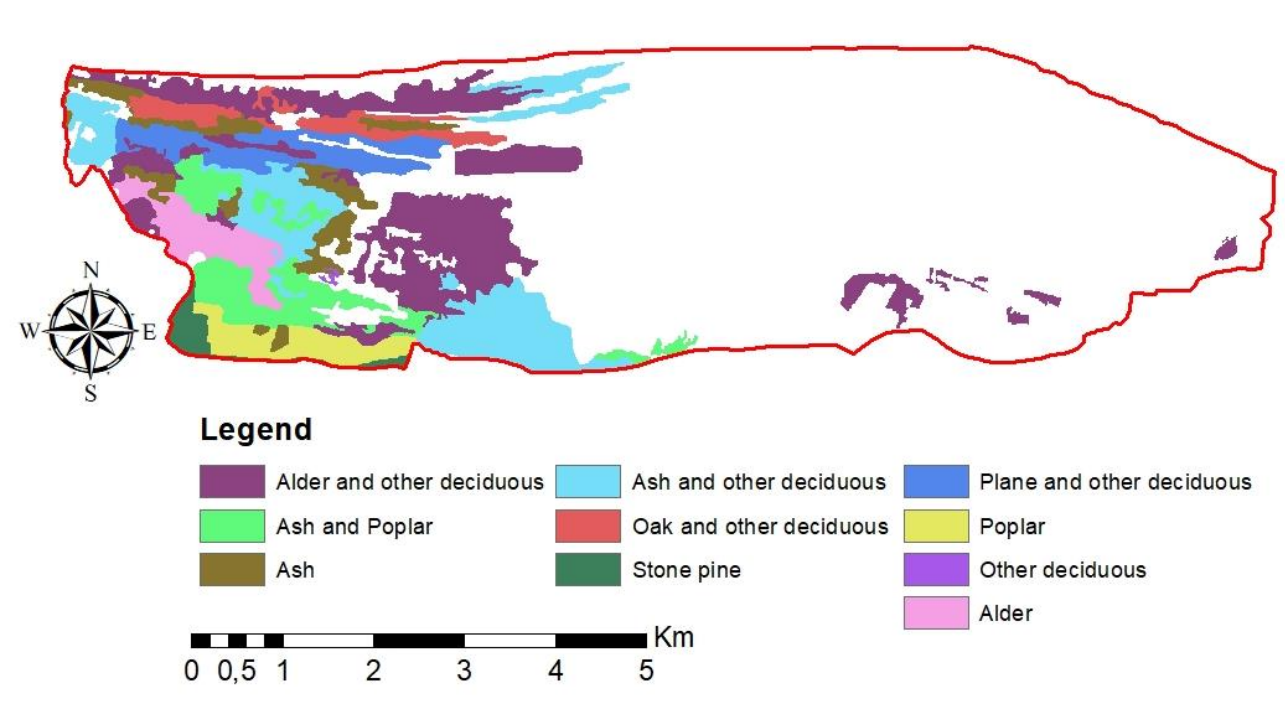
GIS Database

- The forest fire risk map was planned by using GIS-based AHP methods by considering risk factors including forest vegetation structures and topographic features.
- The vegetation factor under climate control was considered instead of directly using data of climatic elements such as temperature and humidity.
- To generate data layers for the risk factors, necessary digital data including forest management maps and topographic maps were obtained from Forest Enterprise Directorate.
- GIS applications were implemented by using ArcGIS 10.4.

MATERIAL AND METHODS

Forest Vegetation Structures

- Forest vegetation structures considered in this study were tree species, crown closure, and tree stage.
- There were total of 10 tree species or species compositions in the study area.



MATERIAL AND METHODS

- The crown closure is as a percent of total ground area covered by the crowns of trees or woody vegetation.
- The crown closure is divided into four classes including bare-land, sparse, moderate, and dense closures.
- The fire risk increases as crown closure increases in the forested areas.

No	Crown closures	Total Covered Ground Area (%)
1	Bare-land	0-10
2	Sparse	11-40
3	Moderate	41-70
4	Dense	>70

MATERIAL AND METHODS

- The tree stages, also defined as stage of forest stand development, are generally categorized under five classes.
- The fire risk is very high at young generations, while it decreases from the mature to over mature stages.

Tree Stages	DBH (cm)
Young	< 8
Middle-aged	8-19.9
Maturing	20-35.9
Mature	36-51.9
Over Mature	>52

MATERIAL AND METHODS

Topographic Features

- Digital Elevation Model (DEM) was generated using the contour lines (with 10 m intervals) on topographical maps.
- Slope map was produced based on the DEM (10 x 10 m).
- Then, slope map was reclassified into five classes.
- Finally, the aspect map was produced based on the same DEM.

No	Slope Classes	Slope Ranges (%)
1	Gentle	0-5
2	Low	5-15
3	Medium	15-25
4	High	25-35
5	Steep	>35

MATERIAL AND METHODS

AHP Method

- The fire risk map was developed by GIS-based Analytic Hierarchy Process (AHP) method.
- The AHP method evaluates a set of evaluation criteria and search for the optimal solution among a set of alternative options.
- In the solution process of AHP, the study area was classified into four forest fire risk classes (options): low, moderate, high, and extreme.
- The main criteria were tree species, crown closure, tree stage, slope, and aspect

MATERIAL AND METHODS

- Decision maker's pairwise comparisons were used to generate a weight for each criterion.
- The relative importance between two criteria was measured based on a numerical scale from 1 to 9.
- Firstly, the relative importance values among sub-criteria were evaluated regarding with potential fires risk.
- The higher score was given when the criterion was more important.

Importance Scale	
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

MATERIAL AND METHODS

- The normalized pairwise comparison matrix was used to compute the weighted averages of the sub-criteria.
- Then, “Reclassify” tool under “Spatial Analyst” extension of ArcGIS 10.2 was used to assign weighted average values to the corresponding criteria.
- The ratio of Consistency Index (CI) and Random Index (RI) were computed to check the consistency of the evaluations made for the pairwise comparison matrices.
- The small value of this ratio (<0.1) reveals that consistent results can be achieved from the AHP method.

MATERIAL AND METHODS

- After consistency analysis, “Spatial Analyst” extension of ArcGIS 10.4.1 was used to assign weighted average values (wj) to the corresponding criteria.
- Then, “extAhp 2.0” plug-in was used to combine the weighted averages of the criteria and determine the AHP scores.
- Finally, the forest cover in the study area was categorized according to fire risk classes.

extAhp20 - Analytic Hierarchy Process for ArcGIS

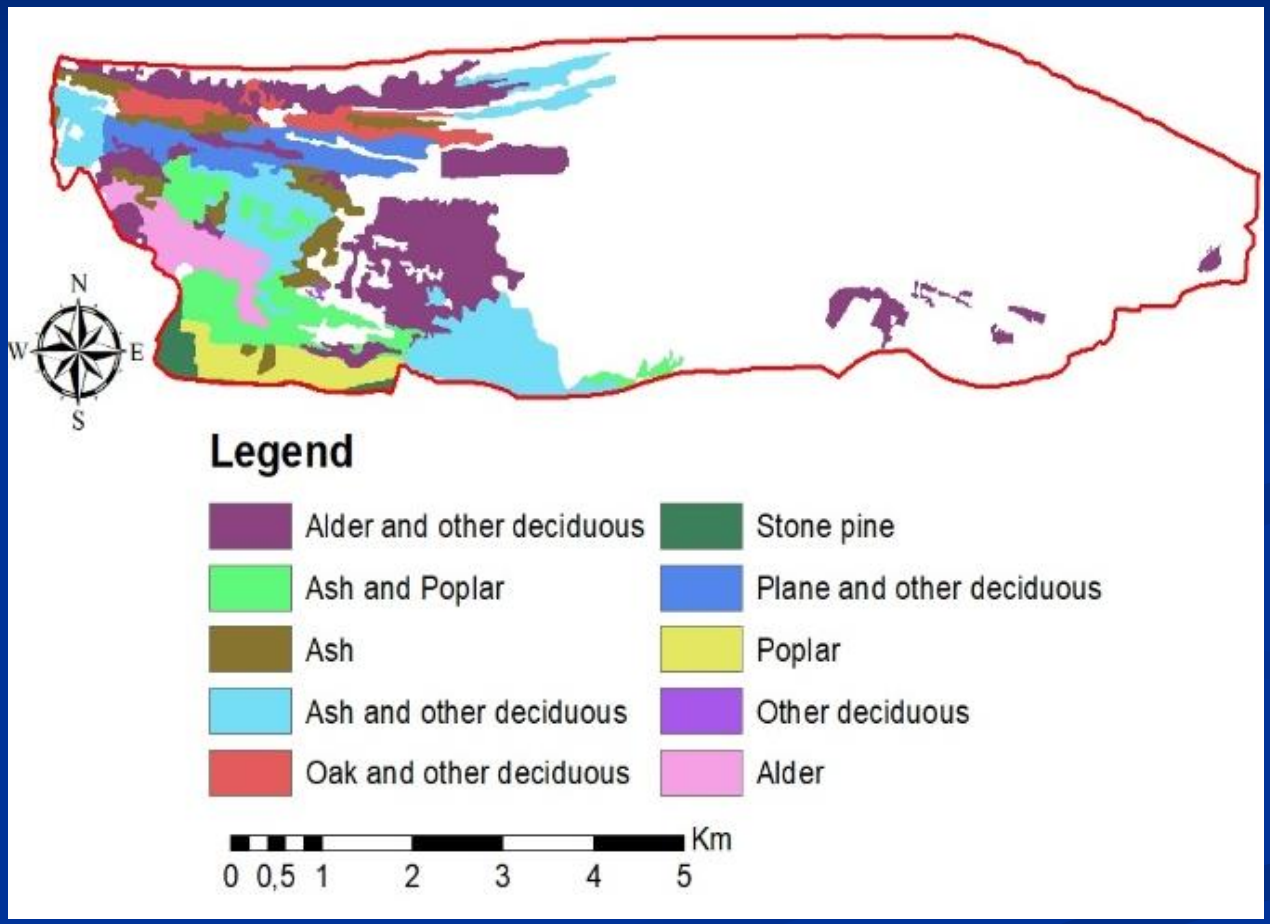
RESULTS AND DISCUSSION

GIS Data Layers

- It was found that there were 10 tree species (or species compositions) in the study area.
- The most common species was Alder and other deciduous trees (31.95%), followed by Ash and other deciduous trees (21.06%) and Ash and Poplar (11.48%).

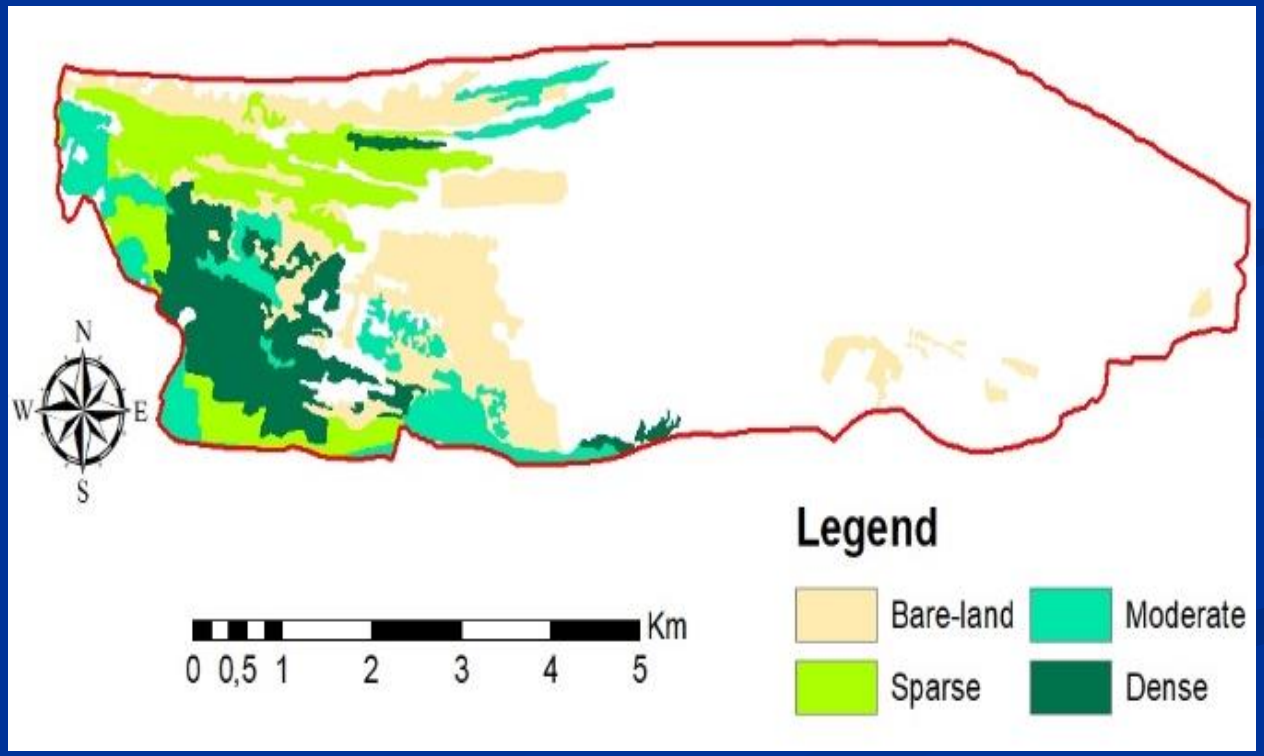
Tree Species Composition	Area (%)
Alder and other deciduous	31.95
Ash and Poplar	11.48
Ash	7.76
Ash and other deciduous	21.06
Oak and other deciduous	5.357
Stone pine	2.37
Plane and other deciduous	8.25
Poplar	5.39
Other deciduous	0.16
Alder	6.22

RESULTS AND DISCUSSION



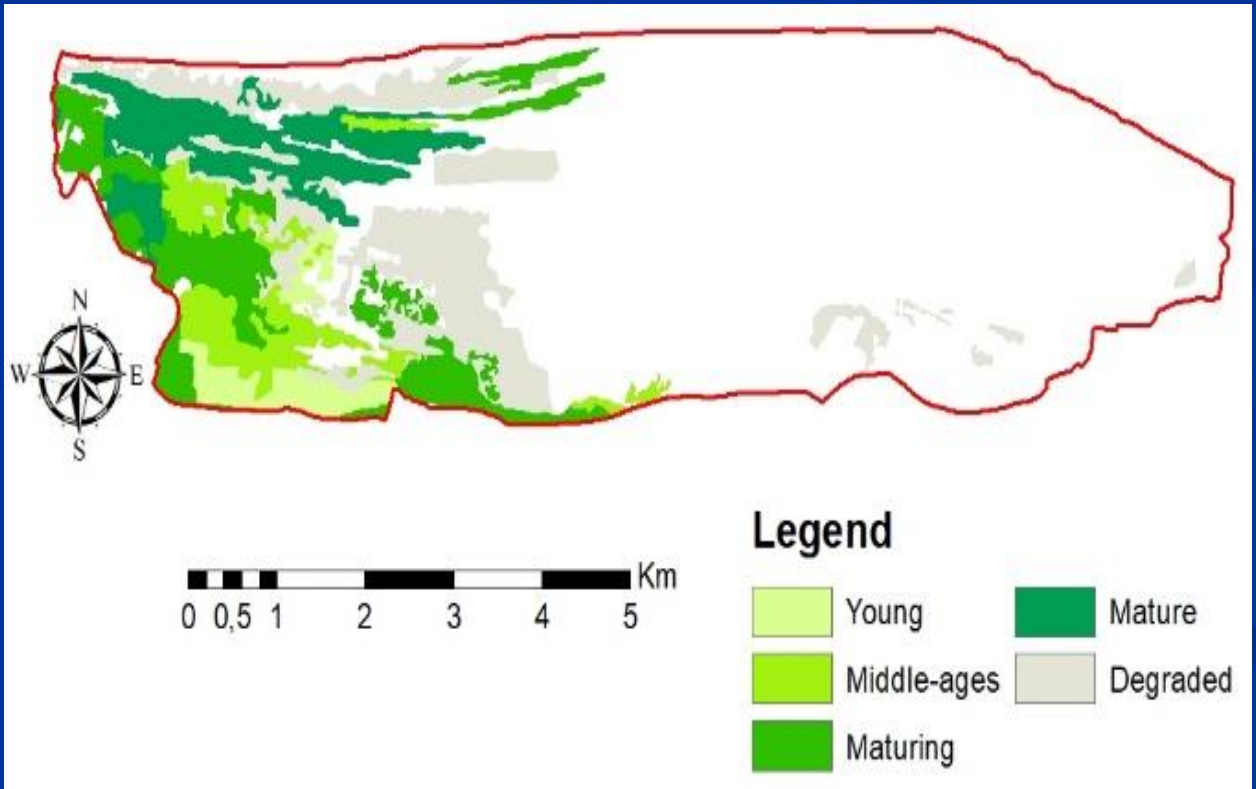
RESULTS AND DISCUSSION

- The results indicated that there was bare-land in 36.54% of the study area, while it was sparse in 23.78% of the area.
- The percentages of the moderate and dense closure were 19.11% and 20.57%, respectively.



RESULTS AND DISCUSSION

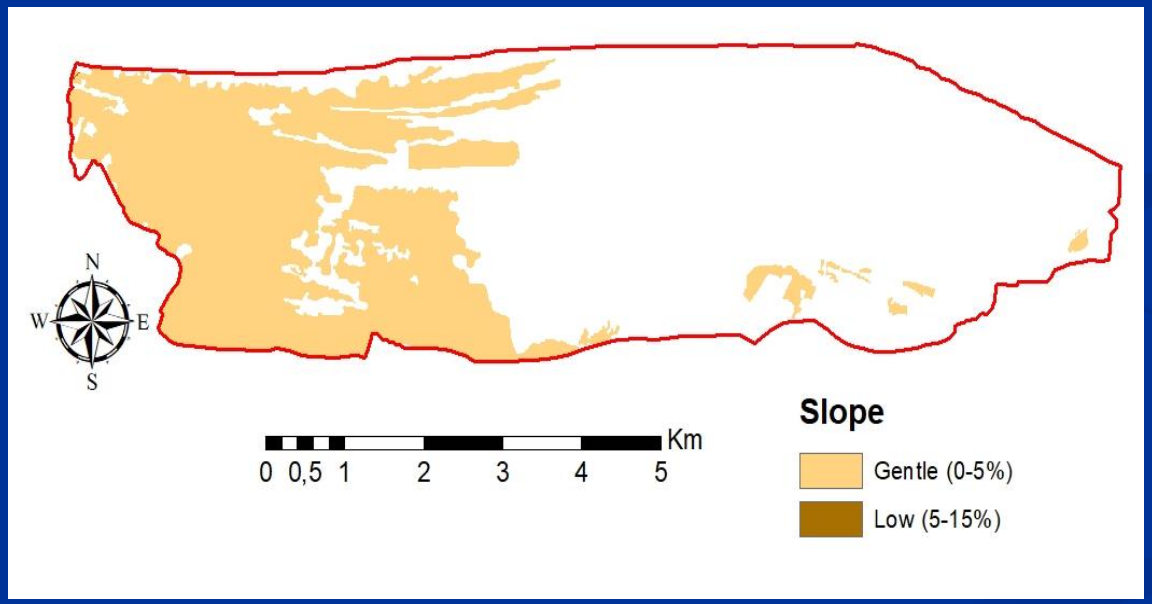
- **The results indicated that 36.54% of the flooded forest was degraded (bare-land)) while 43.25% was covered with the combination of maturing and mature tree stages**



RESULTS AND DISCUSSION

Topographic Features

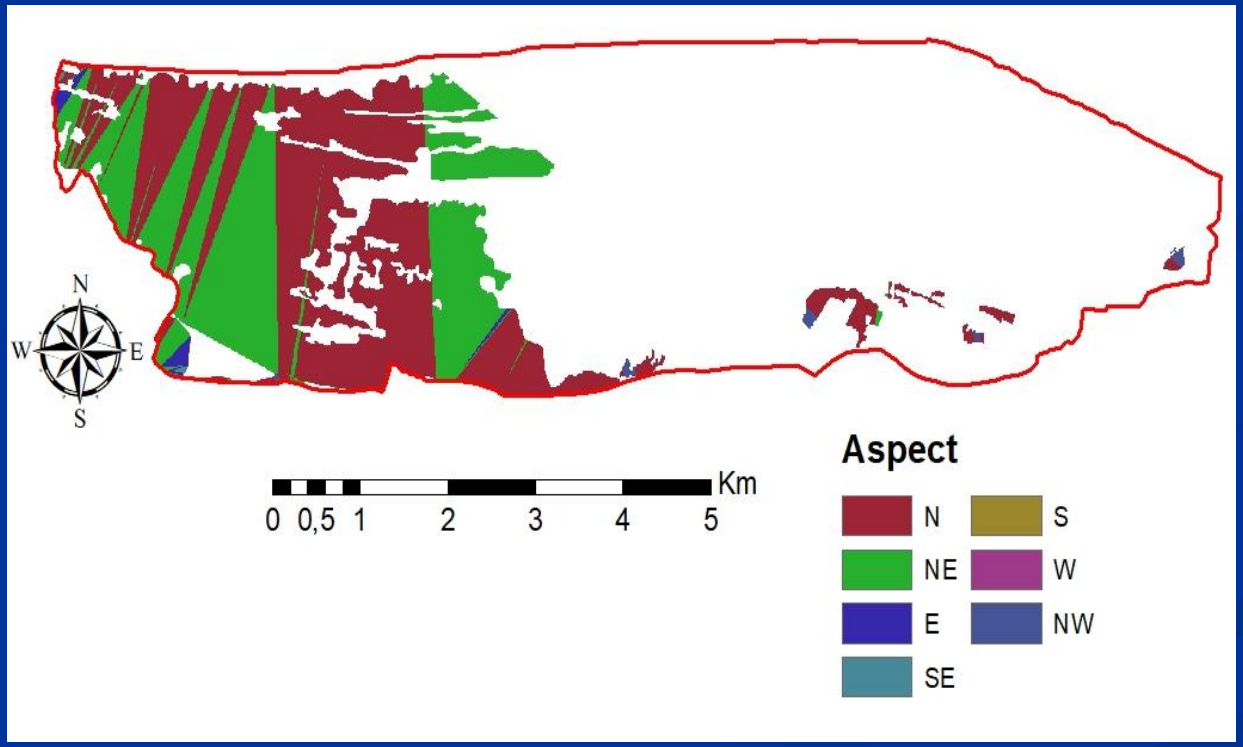
- It was found that there were two slope classes in the flooded forest including gentle and low and almost all of the area (99%) was on gentle slope.



Slope Classes	Area (%)
Gentle	99.0
Low	1.0

RESULTS AND DISCUSSION

- The aspect map of the study area was also generated.
- The results indicated that the most of the land (98%) in the flooded forest was located on north and north-east aspects.



Aspects	Area (%)
N	56,154
NE	42,136
E	1,005
SE	0,098
S	0,001
W	0,003
NW	0,604

RESULTS AND DISCUSSION

AHP Results

- The pure coniferous forest followed by mixed coniferous forest had the highest weighted values.
- Oak, Ash, and other deciduous trees had the lowest values.

Tree Species Composition	Values
Alder and other deciduous	0.10
Ash and Poplar	0.10
Ash	0.06
Ash and other deciduous	0.06
Oak and other deciduous	0.06
Stone pine	0.23
Plane and other deciduous	0.06
Poplar	0.13
Other deciduous	0.10
Alder	0.10

RESULTS AND DISCUSSION

AHP Results

- Forests with dense crown closure had the highest weighted values, followed by moderate crown closure.

No	Crown closures	Values
1	Bare-land	0.09
2	Sparse	0.18
3	Moderate	0.32
4	Dense	0.41

RESULTS AND DISCUSSION

AHP Results

- The regenerated and young stages had the highest weighted values, while mature stage had the lowest values.

Tree Stages	Values
Young	0.28
Middle-aged	0.32
Maturing	0.24
Mature	0.12
Degraded	0.04

RESULTS AND DISCUSSION

AHP Results

- In terms of slope criterion, weighted value was low since slope was mostly gentle in the area.
- The weighted value was similarly low for the aspect criterion since most of the area in the flooded forest was on northern aspects.

Slope Classes	Values
Gentle	0.04
Low	0.12

Aspects	Values
N	0.05
NE	0.10
E	0.10
SE	0.14
S	0.21
W	0.10
NW	0.10
N	0.05

RESULTS AND DISCUSSION

AHP Results

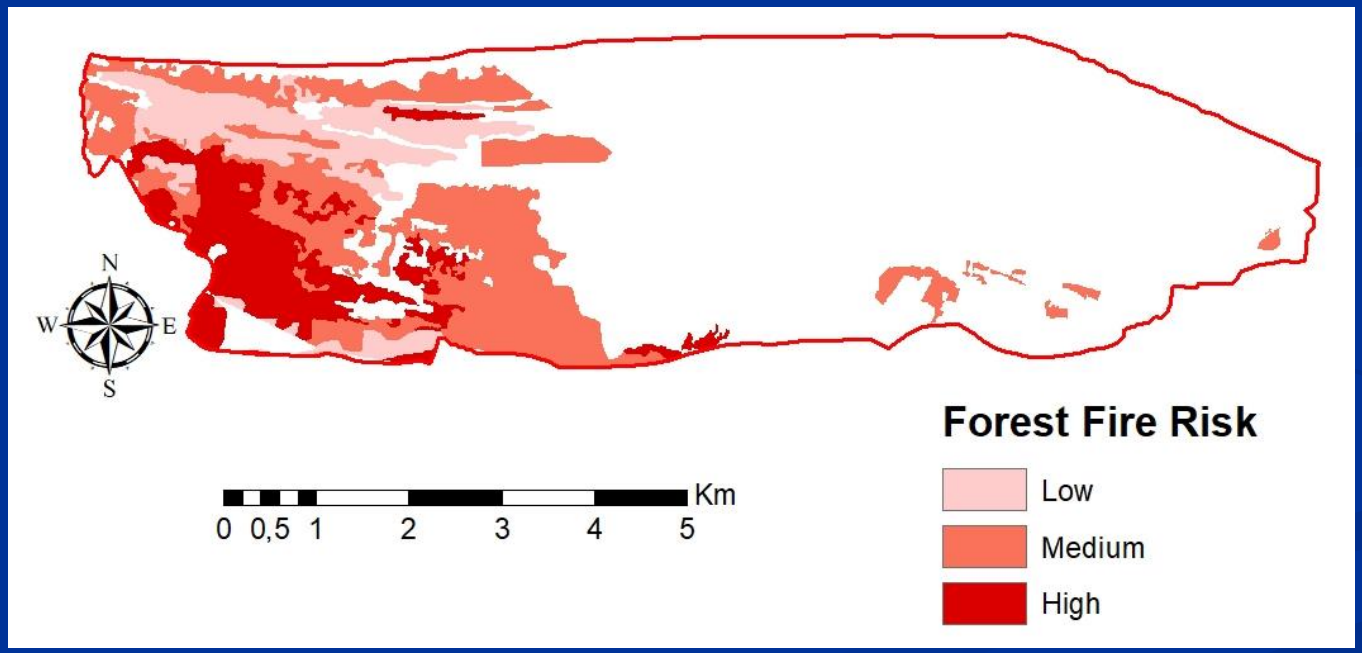
- The weighted averages of the criteria were combined and foret fire risk map was generated by using “extAhp 2.0” tool in ArcGIS 10.4.1.
- The result indicated that the most effective criterion was tree species, followed by tree stages.
- Crown closure and slope criteria had the similar effect of fire risk, while aspect had the least effective criterion on forest fire risk.

Criteria	Weighted Values
Tree species	0.28
Crown Closure	0.19
Tree Stage	0.22
Slope	0.19
Aspect	0.13

RESULTS AND DISCUSSION

AHP Results

- Based on the GIS-based AHP method, 25.28% of the flooded forest area was of high fire risk, while 53.17% and 21.55% was of medium and low fire risk, respectively.



Fire Risk	Area (%)
Low	21.55
Medium	53.17
High	25.28

CONCLUSIONS

- Forest fires cause long term impacts on forest ecosystems and result in important economic losses.
- It is critical to determine the forested areas with fire risks and thereby taking necessary precaution measures to minimize the damages on forest resources, especially on protected ecosystems such as flooded forests.
- In this study, GIS-based Multi-Criteria Decision Analysis (MCDA) using AHP method was used to generate forest fire risk map for Karacabey Flooded Forest in the city of Bursa in Turkey.
- Tree species, crown closure, tree stages, slope, and aspect were considered as fire risk factors in the solution process.

CONCLUSIONS

- The results revealed that GIS-based AHP method can provide fire managers with s quick and effective prediction of forest fire risk that can contribute taking necessary action for minimization of fire damages on the forest ecosystems.
- Possible future studies may include considering additional fire risk factors such as distance to road network, distance to residential areas, and climatic parameters in developing fire risk maps.

Thank you for your attention…