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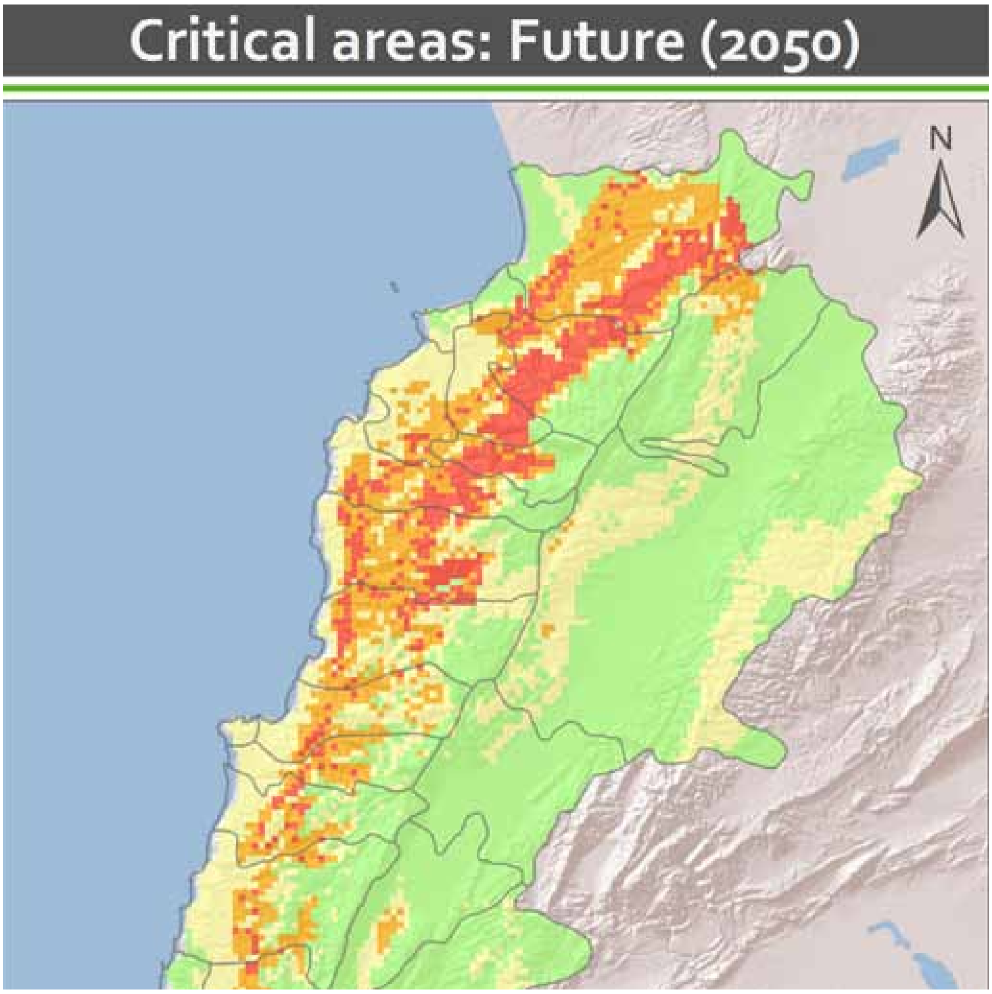

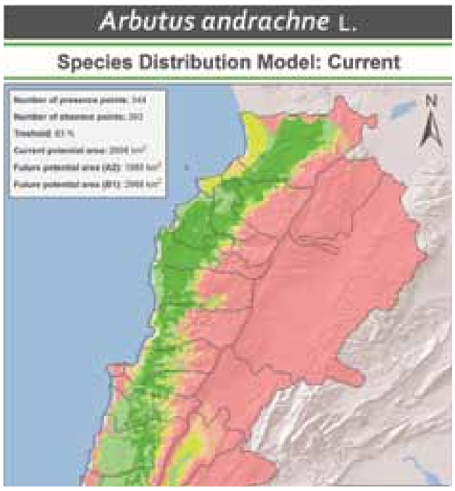

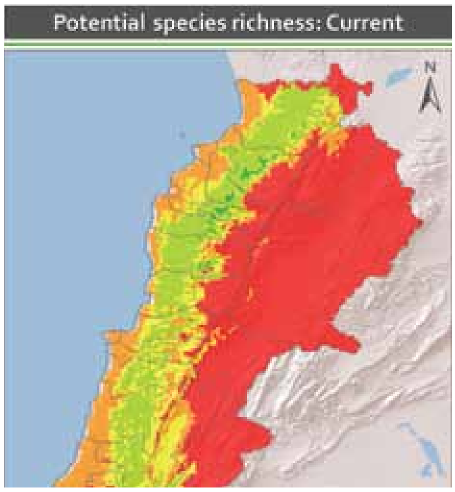

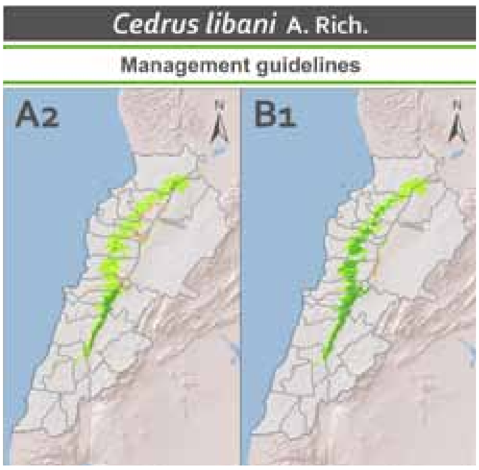

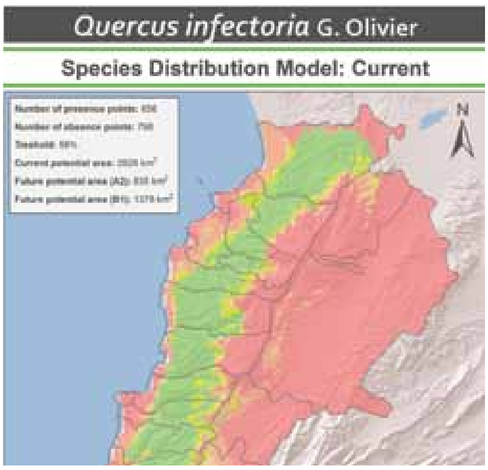

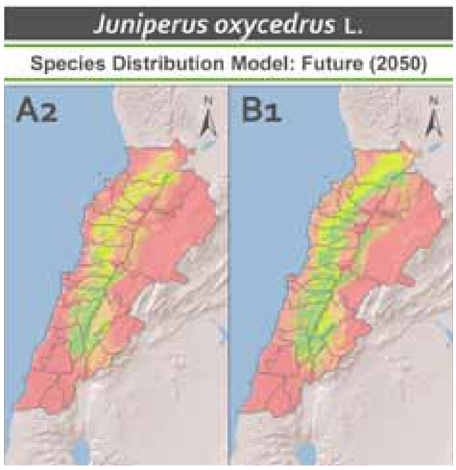

CLIMATE CHANGE IMPACTS ON NATIVE TREE SPECIES DISTRIBUTION IN LEBANON: POTENTIALITY PROJECTIONS TO 2050

CENTER FOR APPLIED RESEARCH IN AGROFORESTRY DEVELOPMENT (IDAF) - UNIVERSITY OF CÓRDOBA

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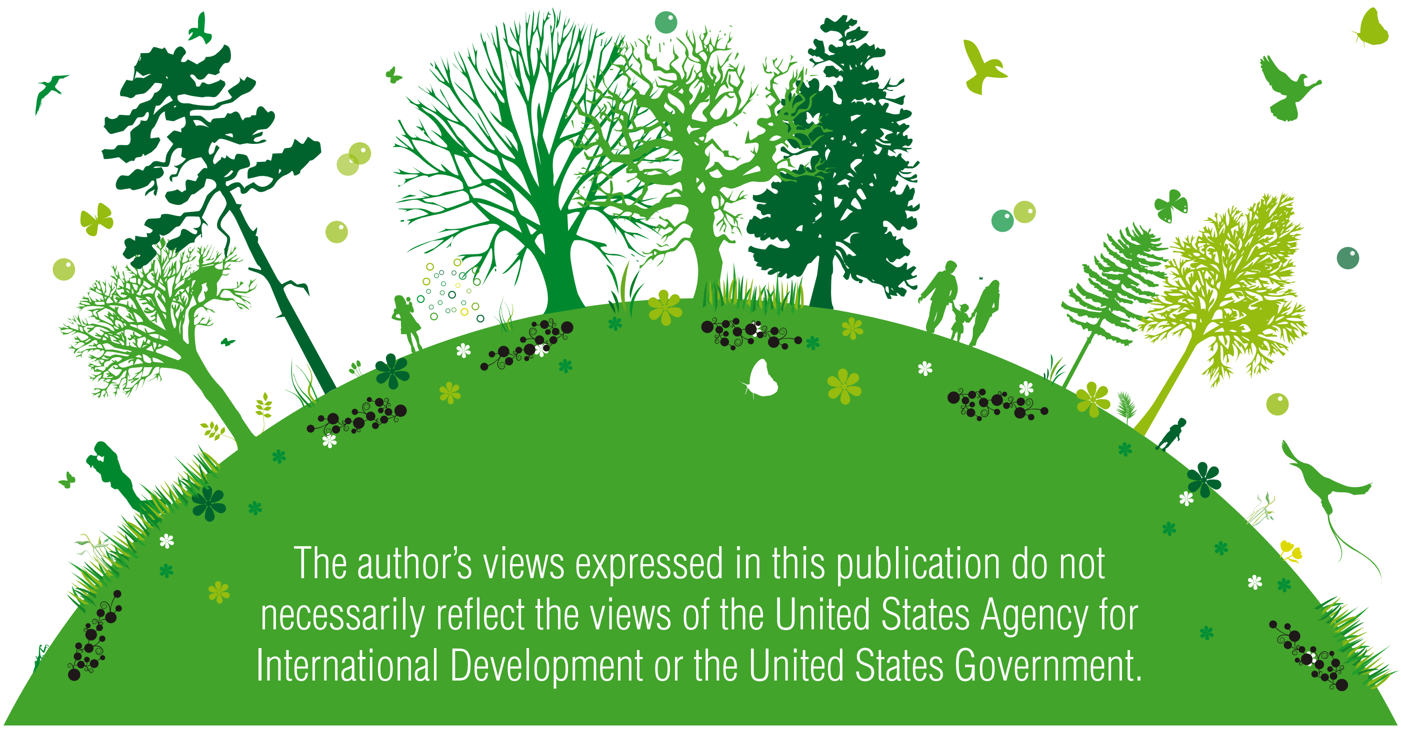

INDEX

1. INTRODUCTION 6

2. OBJECTIVES 7
 2.1 GENERAL OBJECTIVE 7
 2.2 SPECIFIC OBJECTIVES 7

3. METHODOLOGY 8
 3.1 SCOPE 8
 3.2 SCHEME OF WORK 8

4. CLIMATE VARIABLES 9
 4.1 CURRENT CLIMATE VARIABLES 9
 4.2 FUTURE CLIMATE VARIABLES 9
 4.3 VARIABLES SELECTION 10

5. SPECIES DISTRIBUTION MODELS (SDM) 11

6. IDENTIFICATION OF SPECIES PRESENCE / ABSENCE 12

7. SPECIES POTENTIALITY 13
 7.1 OBTAINED RASTER FILES 13
 7.2 OBTAINED SPECIES DISTRIBUTION MODEL 13
  7.2.1 *Abies cilicica* 14
  7.2.2 *Acer syriacum* 16
  7.2.3 *Acer tauricolum* 18
  7.2.4 *Arbutus andrachne* 20
  7.2.5 *Arceuthos drupacea* 22
  7.2.6 *Cedrus libani* 24
  7.2.7 *Ceratonia siliqua* 26
  7.2.8 *Cercis siliquastrum* 28
  7.2.9 *Crataegus spp.* 30
  7.2.10 *Cupressus spp.* 32
  7.2.11 *Juniperus excelsa* 34
  7.2.12 *Juniperus oxycedrus* 36
  7.2.13 *Pinus brutia* 38
  7.2.14 *Pistacia spp.* 40
  7.2.15 *Prunus ursina* 42
  7.2.16 *Pyrus syriaca* 44
  7.2.17 *Quercus calliprinos* 46
  7.2.18 *Quercus cerris* 48
  7.2.19 *Quercus infectoria* 50
  7.2.20 *Styrax officinalis* 52

8. POTENTIAL SPECIES RICHNESS 54
 8.1 MAPS OF POTENTIAL SPECIES RICHNESS 55
  8.1.1 CURRENT POTENTIAL SPECIES RICHNESS 55
  8.1.2 FUTURE POTENTIAL SPECIES RICHNESS. B1 SCENARIO 56
  8.1.3 FUTURE POTENTIAL SPECIES RICHNESS. A2 SCENARIO 57
 8.2 LOSS/GAIN POTENTIAL SPECIES RICHNESS 58
  8.2.1 LOSS/GAIN POTENTIAL SPECIES RICHNESS. B1 SCENARIO 59
  8.2.2 LOSS/GAIN POTENTIAL SPECIES RICHNESS. A2 SCENARIO 60
 8.3 CRITICAL AREAS 61
  8.3.1 CRITICAL AREAS MAP 62

9. APPLICATION OF RESULTS TO RESTORATION AND ADAPTIVE MANAGEMENT IN A CONTEXT OF GLOBAL CHANGE 64
 9.1 ADAPTATION MEASURES PER SPECIES 64
  9.1.1 Abies cilicica 66
  9.1.2 Acer syriacum 67
  9.1.3 Acer tauricolum 68
  9.1.4 Arbutus andrachne 69
  9.1.5 Arceuthos drupacea 70

9.1.6 *Cedrus libani* ... 71
9.1.7 *Ceratonia siliqua* ... 72
9.1.8 *Cercis siliquastrum* ... 73
9.1.9 *Crataegus spp.* ... 74
9.1.10 *Cupressus spp.* ... 75
9.1.11 *Juniperus excelsa* ... 76
9.1.12 *Juniperus oxycedrus* ... 77
9.1.13 *Pinus brutia* ... 78
9.1.14 *Pistacia palaestina* ... 79
9.1.15 *Prunus ursina* ... 80
9.1.16 *Pyrus syriaca* ... 81
9.1.17 *Quercus calliprinos* ... 82
9.1.18 *Quercus cerris* ... 83
9.1.19 *Quercus infectoria* ... 84
9.1.20 *Styrax officinalis* ... 85
9.2 ADAPTATION MEASURES PER CRITICAL AREAS ... 86

10. BIBLIOGRAPHY ... 87

11. ANNEX I. CLIMATE VARIABLES. ANALYSIS AND SELECTION ... 90
11.1 CURRENT CLIMATE VARIABLES ... 90
11.2 FUTURE CLIMATE VARIABLES ... 91
11.3 VARIABLES SELECTION ... 92
11.4 CURRENT AND FUTURE VARIABLES MAPS ... 92
11.4.1 Winter Minimum Temperature: Current ... 93
11.4.2 Winter Minimum Temperature: B1 Scenario ... 94
11.4.3 Winter Minimum Temperature: A2 Scenario ... 95
11.4.4 Summer Maximum Temperature: Current ... 96
11.4.5 Summer Maximum Temperature: B1 Scenario ... 97
11.4.6 Summer Maximum Temperature: A2 Scenario ... 98
11.4.7 Summer Precipitation: Current ... 99
11.4.8 Summer Precipitation: B1 Scenario ... 100
11.4.9 Summer Precipitation: A2 Scenario ... 101

12. ANNEX II. SPECIES DISTRIBUTION MODELS. DESCRIPTION AND EVALUATION ... 102
12.1 STATISTICAL MODELS ... 103
12.2 MODELS DESCRIPTION ... 103
12.3 MODELS EVALUATION ... 105
12.4 POTENTIALITY THRESHOLD ... 106

13. ANNEX III. CLASSIFIED MAPS ... 107
13.1 *Abies cilicica* ... 109
13.2 *Acer syriacum* ... 109
13.3 *Acer tauricolum* ... 110
13.4 *Arbutus andrachne* ... 110
13.5 *Arceuthos drupacea* ... 111
13.6 *Cedrus libani* ... 111
13.7 *Ceratonia siliqua* ... 112
13.8 *Cercis siliquastrum* ... 112
13.9 *Crataegus spp.* ... 113
13.10 *Cupressus spp.* ... 113
13.11 *Juniperus excelsa* ... 114
13.12 *Juniperus oxycedrus* ... 114
13.13 *Pinus brutia* ... 115
13.14 *Pistacia palaestina* ... 115
13.15 *Prunus ursina* ... 116
13.16 *Pyrus syriaca* ... 116
13.17 *Quercus calliprinos* ... 117
13.18 *Quercus cerris* ... 117
13.19 *Quercus infectoria* ... 118
13.20 *Styrax officinalis* ... 118

EXECUTIVE SUMMARY

Numerous studies conducted during the past decade show that climate change is most likely attributable to increased concentrations of anthropogenic greenhouse gases producing effects on climatic patterns. Under this new and changing situation, forest management and policies require new approaches that take into consideration the effects of climate change.

In recent years, governments, institutions, and NGOs in Lebanon are making huge efforts to carry out reforestation programs throughout the country. Taking into account the future potentiality of species currently used in reforestation by placing them under different climate change scenarios is a useful tool to understand which species will thrive in future conditions.

For this purpose, almost seven thousand points of presence and twelve thousand points of absence were identified in Lebanon. Ensemble projections for each species were obtained by adding climatic variables for current conditions and running models with Biomod2 R-package platform for future scenarios.

This study shows the Species Distribution Model for 2050. It takes into account twenty main native species commonly used in Lebanese reforestation, and places them under A2 and B1 IPCC scenarios. In addition, vulnerability classification of Lebanese territory was conducted in terms of species richness loss caused by climate change. This determines the critical areas to be restored and/or protected in terms of species diversity.

Finally, general guidelines for future management and measures for adaptation and mitigation to climate change are proposed for each species and case of potentiality status in the future. In terms of potential species richness loss, specific actions are set for the considered critical areas.

The generated maps and raster files will help the forest manager in decision-making regarding the priority areas for restoration or management and the potential species to be used considering the future effects of climate change.

1. INTRODUCTION

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), climate change is unequivocal and most likely attributable to increased concentrations of anthropogenic greenhouse gases. The same report relates warming for the last three decades to the changes in many physical and biological systems at a global level. Forecasts suggest the effects will persist in the future.

This new and changing situation requires forest policies and management to be reoriented towards species adaptation to climate change. In Lebanon, where global models predict severe climate change and where numerous species grow in one of the most biologically diverse ecosystems, the Mediterranean forest, the knowledge of future climate behavior is an important management tool for the preservation of natural resources.

Therefore, priority should be to expand the knowledge of the vulnerability to and impacts of climate change on Lebanese species richness, so that adaptation can be designed and integrated into policy planning and management of biodiversity. It is with this knowledge that the actions for preservation in a world of changing climate will have the highest impact. However, it is important to keep in mind that the success of any adaptation measures will eventually be conditioned by the correction of the climate-altering causes.

Overall, this work analyzes the potential effects of climate change on key vegetal components in Lebanese ecosystems. It has been carried out with the best available knowledge on climate projections for the 21st century, taking into account the current distribution of target species.

This work aims at supporting the national reforestation program launched in 2010 by the United States Forest Service (USFS) office of International Programs (IP) through the support and funding of the United States Agency for International Development (USAID), implemented through the Lebanon Reforestation Initiative (LRI). This project also continues the collaborations between IDAF and LRI that started in 2012 regarding climate change and species richness.

2. OBJECTIVES

2.1 GENERAL OBJECTIVE

The identification of key areas to be restored and adapted to climate change effects, securing the level of biodiversity, setting a vulnerability classification of Lebanese territory in terms of species richness loss caused by climate change and development of ensemble projections under different climate change scenarios.

2.2 SPECIFIC OBJECTIVES

- Assessment of species richness in Lebanon determining the areas that could sustain more biodiversity than their current status;
- Identification of key areas that will lose more species richness due to climate change;
- Development of ensemble projections under different climate change scenarios (present till 2050) for each selected species, up to a total of around 20 species including endemic and indicator species if possible;
- Proposition of possible treatments and actions to be implemented, aiming at improving the adaptation of these species in key areas.

For this purpose and due to the scope of this project, twenty of the most important species for forest restoration in Lebanon have been assessed:

- *Abies cilicica*
- *Acer syriacum*
- *Acer tauricolum*
- *Arbutus andrachne*
- *Arceuthos drupacea*
- *Cedrus libani*
- *Ceratonia siliqua*
- *Cercis siliquastrum*
- *Crataegus spp.*
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- *Pyrus syriaca*
- *Quercus calliprinos*
- *Quercus cerris*
- *Quercus infectoria*
- *Styrax officinalis*

3. METHODOLOGY

3.1 SCOPE

The study area covers the entire territory of Lebanon, ranging up to 10,452 Km^2. The spatial resolution of the results is 1 Km^2, derived from the characteristics of the climatic raster files used in this study. Presence/absence and current/future potentiality of species has been developed for a grid of 1 x 1 km.

3.2 SCHEME OF WORK

In order to generate ensemble projections, models for the twenty selected species, climate variables, and points of presence/absence were gathered. After treating data, future models were run using a script designed with Biomod2 R-package under A2 and B1IPCC scenarios.

Current and future Species Distribution Models (SDMs) for species potentiality were obtained. A potentiality threshold was calculated for each species depending on whether it is a generalist species or a species with specific needs. The Model also takes into consideration whether the identified presence points are spread throughout the entire potential distribution range of the species or conversely, if the species grow in relict populations without covering all environmental variability. Using this threshold, classified maps of potential/non-potential areas were obtained.

Depending on the possible combinations of potentiality status in current and future scenarios, maps of management guidelines per species were proposed.

To assess vulnerability classification of the Lebanese territory, species richness maps were developed for current and future scenarios. The maps show the number of species that could potentially occur on each cell. Maps of potential loss/gain species richness were generated by subtracting future predictions from current status in both scenarios.

Once these maps were developed, critical areas were identified by making the arithmetic mean of both future scenarios and segmenting the resulting map into severe, important, and moderate classes by applying 75th and 90th percentiles. Areas where severe or important loss occurs are considered critical areas for adaptive management and restoration. **Figure 1** shows the flowchart of this study.

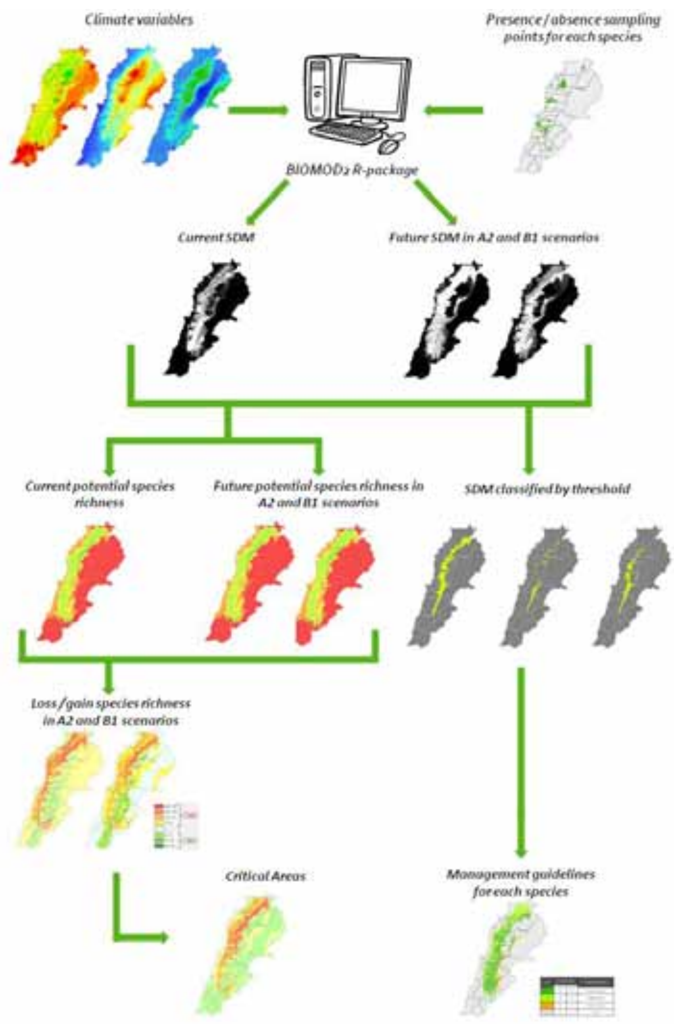


Figure 1. Study Flowchart

4. CLIMATE VARIABLES

4.1 CURRENT CLIMATE VARIABLES

Current climate data were obtained from WorldClim (Hijmans et al., 2005), a set of global climate layers with a 30 arc-second spatial resolution generated through interpolation of real data from weather stations for the period 1950 - 2000.

Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. These variables represent annual trends (e.g., mean annual temperature, annual precipitation), seasonality (e.g., annual range in temperature and precipitation), and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A total of 19 bioclimatic variables were used.

In addition to this, a new set of variables was generated clustering climatic information in seasonal periods, obtaining the minimum, maximum, and average temperature of each season and seasonal total precipitation.

The species distribution models were built upon the bioclimatic variables. These models were used to obtain the current potential surface.

4.2 FUTURE CLIMATE VARIABLES

To obtain more significant climatic variables, a mixed climate model was generated from predictions made by CCCMA-CGCM3 and ECHAM5 global models.

Once the model is defined, the conditions of the factors influencing climate evolution (i.e. the emission scenarios) should be determined. There are four families of scenarios defined by the IPCC (Intergovernmental Panel on Climate Change): A1, A2, B1 and B2. Each one is a combination of demographic, social, economic, technological, and environmental trends.

A2 and B1 scenarios were selected for this study, representing unfavorable conditions and less climate change impact respectively.

The horizon for the prediction of potential distribution is 2050.

4.3 VARIABLES SELECTION

Collinearity analyses were run to eliminate repetitive variables with a strong correlation. The correlation coefficient and the variance inflation factor (VIF) were calculated. The analysis of collinearity was done within the full list of original variables. Variables with $R^2>0.90$ and VIF>9 produced a poor estimation of the correlation coefficient due to collinearity and were deleted (Graham, 2003; Heikkinen et al., 2006).

Three common non collinear variables were selected:

- Winter minimum temperature;
- Summer maximum temperature;
- Summer precipitation.

For further information regarding climatic variables and statistical analysis, see **Annex I.**

5. SPECIES DISTRIBUTION MODELS (SDM)

The variety of techniques accessible to model species distribution can be classified in three groups, depending on the input data:

- Profile techniques which require species presence-only data (i.e. environmental hype-space inhabited by species methods as BIOCLIM, among others);
- Discriminative techniques which require species presence-absence data (i.e. General Linear Model (GLM), Maximum Entropy (MaxEnt), among others);
- Mix modeling approach which uses combined techniques (i.e. Biomod, among others).

To deal with model technique election, Biomod2 R-package (Thuiller et al., 2013) which includes ten SDMs techniques was selected for this assessment. Default settings of biomod2 (version 2.1.15) were used. Biomod2 R-package is a computer platform for developing ensemble SDMs, which works with presence-absence data.

In order to select the most accurate SDM and avoid drawbacks of different individual statistical models, only ensemble models obtained from the linear combination of the ten models evaluated by R-package biomod2 were used.

Models were run ten times per each species and only those that presented higher statistical parameters in all cases were selected. The final SDM was obtained by assembling selected models.

Obtained SDMs are graphical representations of the probability of the presence of a species in a particular geographical location. Each pixel represents the percentage of probability of presence for the species. In order to assist managers in decision making, these maps were reclassified indicating the probability threshold of the species.

This limit is calculated separately for each species from different statistical methods. The choice of appropriate statistical method depends on particular characteristics of the species distribution, the dispersion of its points of presence and absence, and their distribution on the generated model.

See **Annex II** for SDM detailed information.

6. IDENTIFICATION OF SPECIES PRESENCE / ABSENCE

The R-package requires information about current species distribution within the study area. For each species, points of presence were georeferenced. The number of points referenced was dependent on site accessibility, species populations, and security risks. Collection was spread throughout Lebanon and, absence points were evenly distributed in areas presenting unfavorable conditions for species to grow.

Spatial data resolution was respected while establishing presence/absence points by setting only one point per species inside each 1 x 1 Km^2 cell; the same spatial resolution as the climatic data grid.

Points of presence were sampled on the field identifying as many populations possible for each species. To reach areas not accessible by vehicle, field trips were designed covering large areas through dense forests and riversides. A large amount of points were obtained with GPS devices. After processing and downloading points to a GIS platform, cells of the 1 x 1 Km^2 grid were analyzed to ensure that only one point per species was located inside each cell. By using recent orthophotos of Lebanon, homogeneous forest areas were located and additional points of major species were set nearby sampled areas.

In areas not accessible due to the political situation, historical records and analysis of high-resolution images such as Google Earth or Bing Maps were studied. Interviews were conducted with botanical experts in Lebanese flora. Pictures taken in situ by locals were also analyzed to identify species occurring in these remote areas.

A total of 6,767 points of presence and 11,851 points of absence were set. **Figure 2** shows the main location where points of presence were identified.

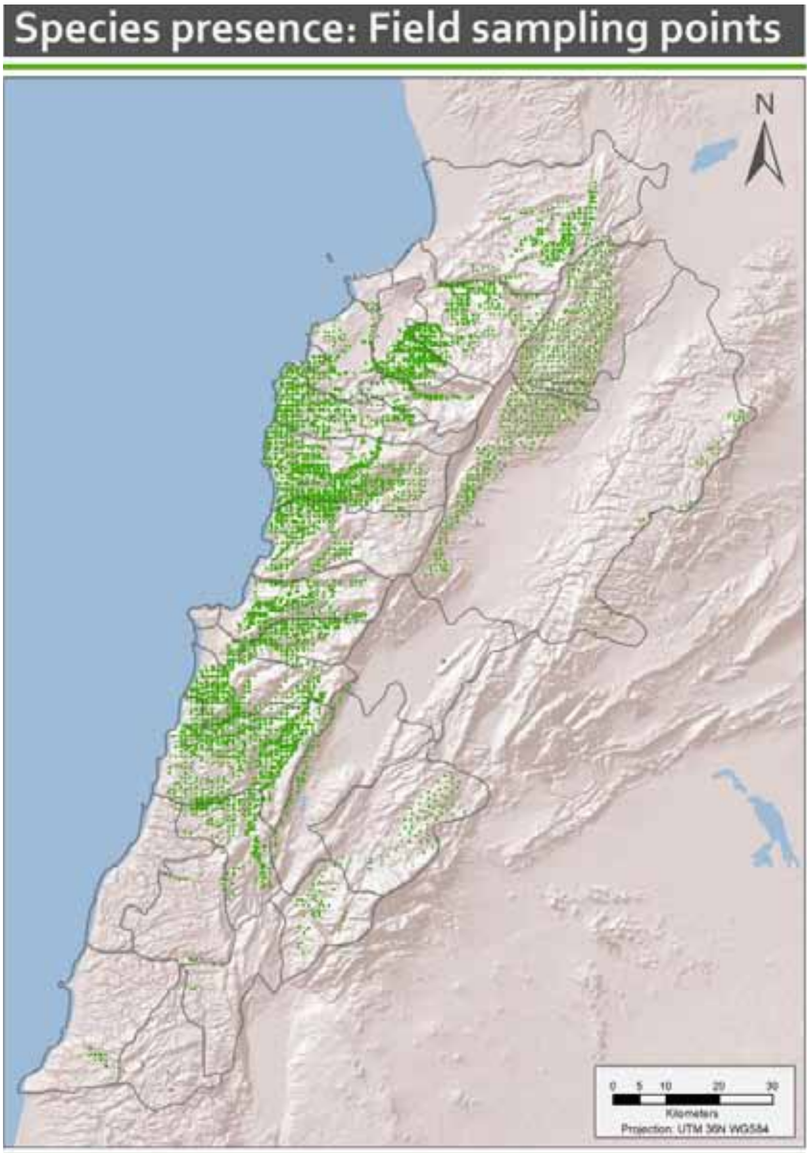


Figure 2. Principal Locations for Presence Points

7. SPECIES POTENTIALITY

7.1 OBTAINED RASTER FILES

Attached to this document are the raster files. Metadata can be delivered on computer format. The information found in these files is listed below:

- Metadata file identifier
- Language
- Character set
- Contact
- Metadata date stamp
- Metadata standard name
- Metadata standard version
- Spatial representation information
- Identification information
- Distribution information
- Application schema information

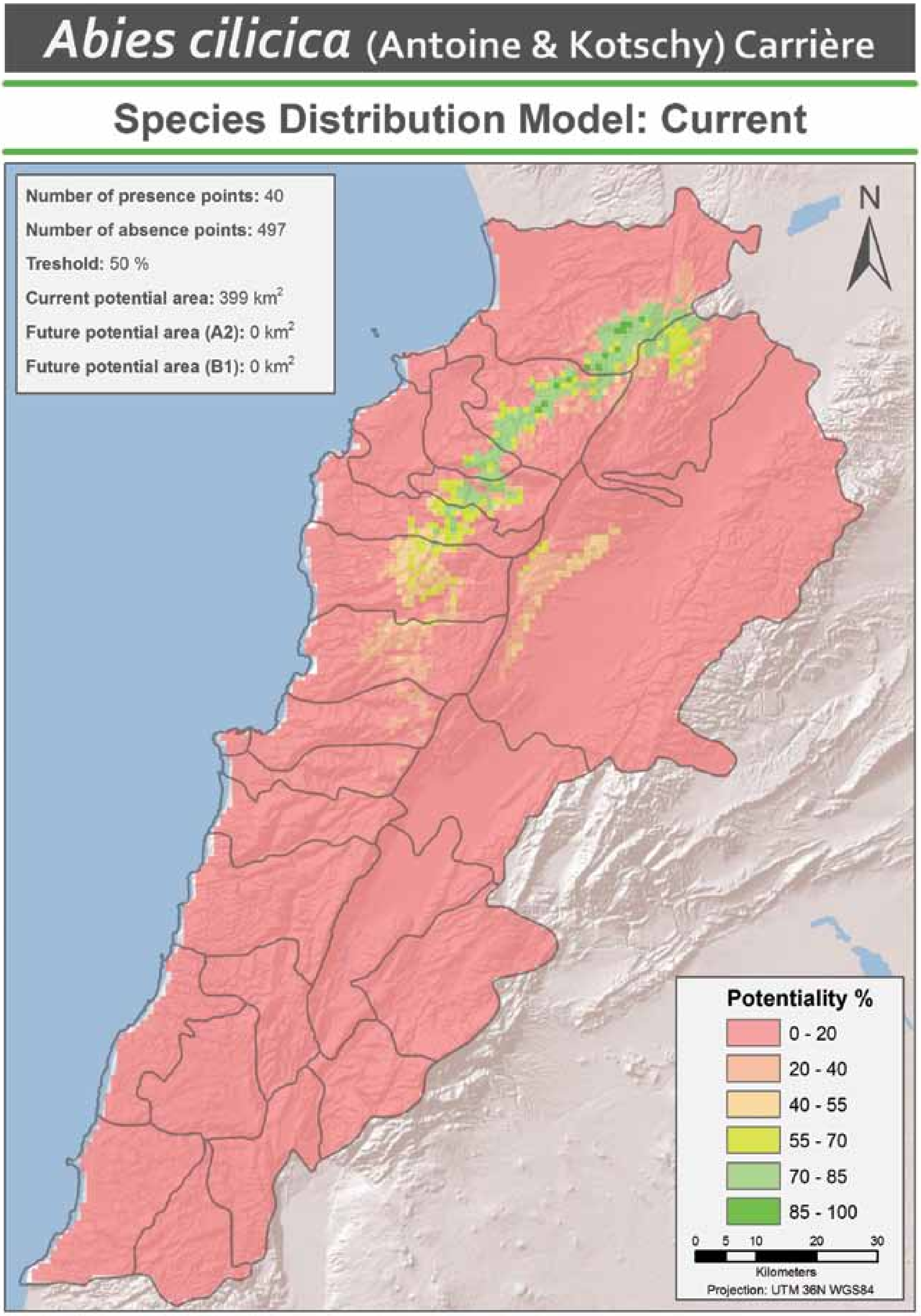
7.2 OBTAINED SPECIES DISTRIBUTION MODEL

The following maps show the current potentiality for the studied species versus the expected future potentiality in 2050.

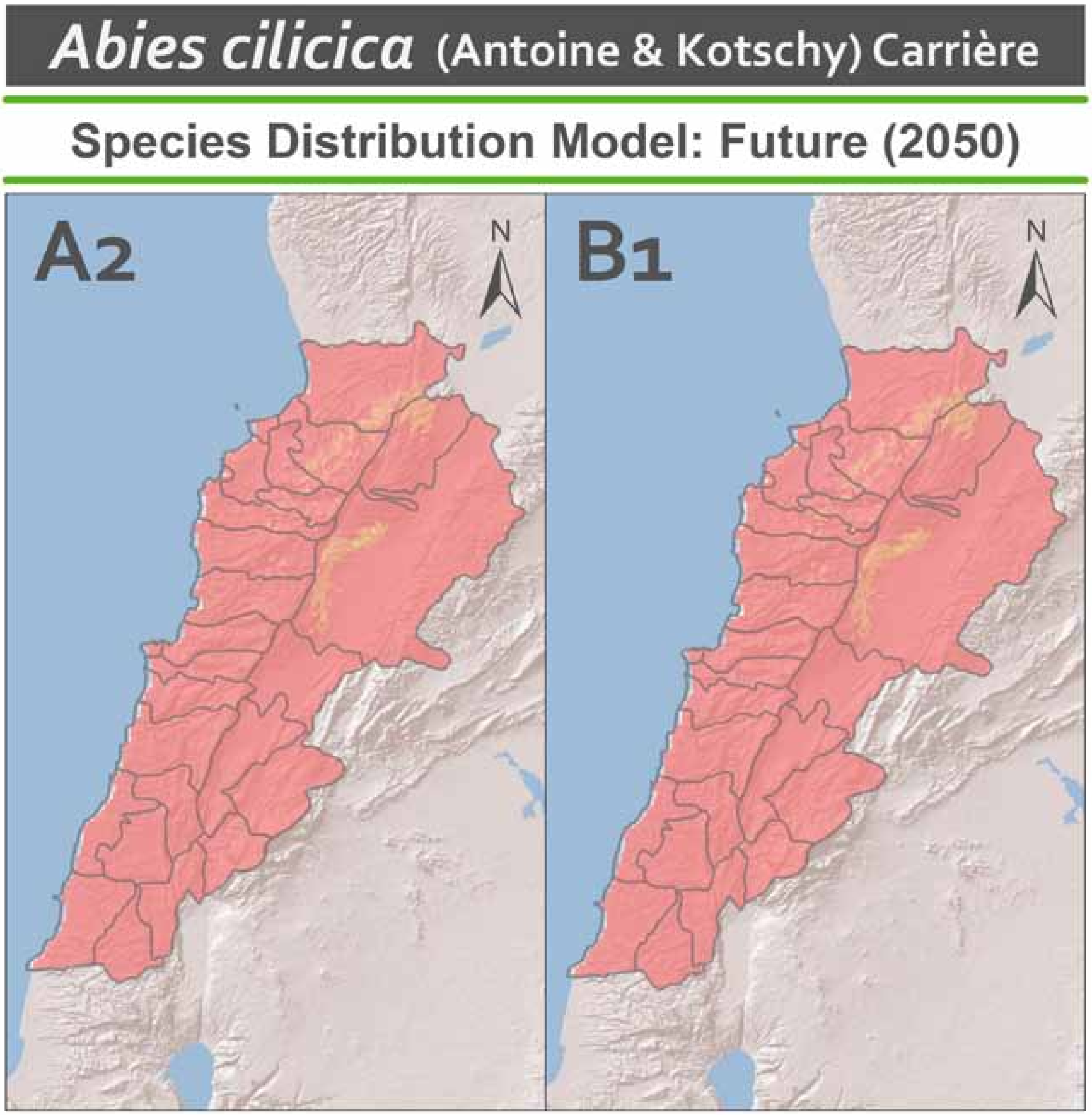
The map legend shows the points of presence/absence identified for the species, the potential threshold and the total potential surface for present situation under both B1 and A2 scenarios.

These maps are classified into six different potentiality classes expressed in percent. In some cases, potentiality threshold is located within the range of values of one class and the limits of potential areas are not defined clearly. For classified maps showing potential or non-potential areas for the species without discerning between potentiality ranges, see **Annex III**.

7.2.1 *Abies cilicica*



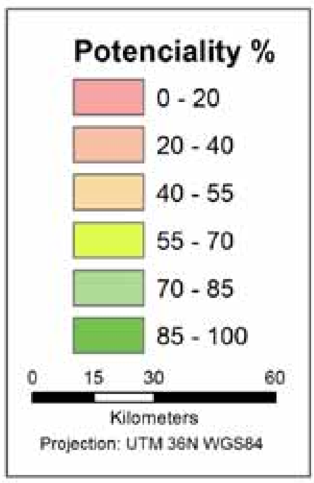
7.2.1 *Abies cilicica*



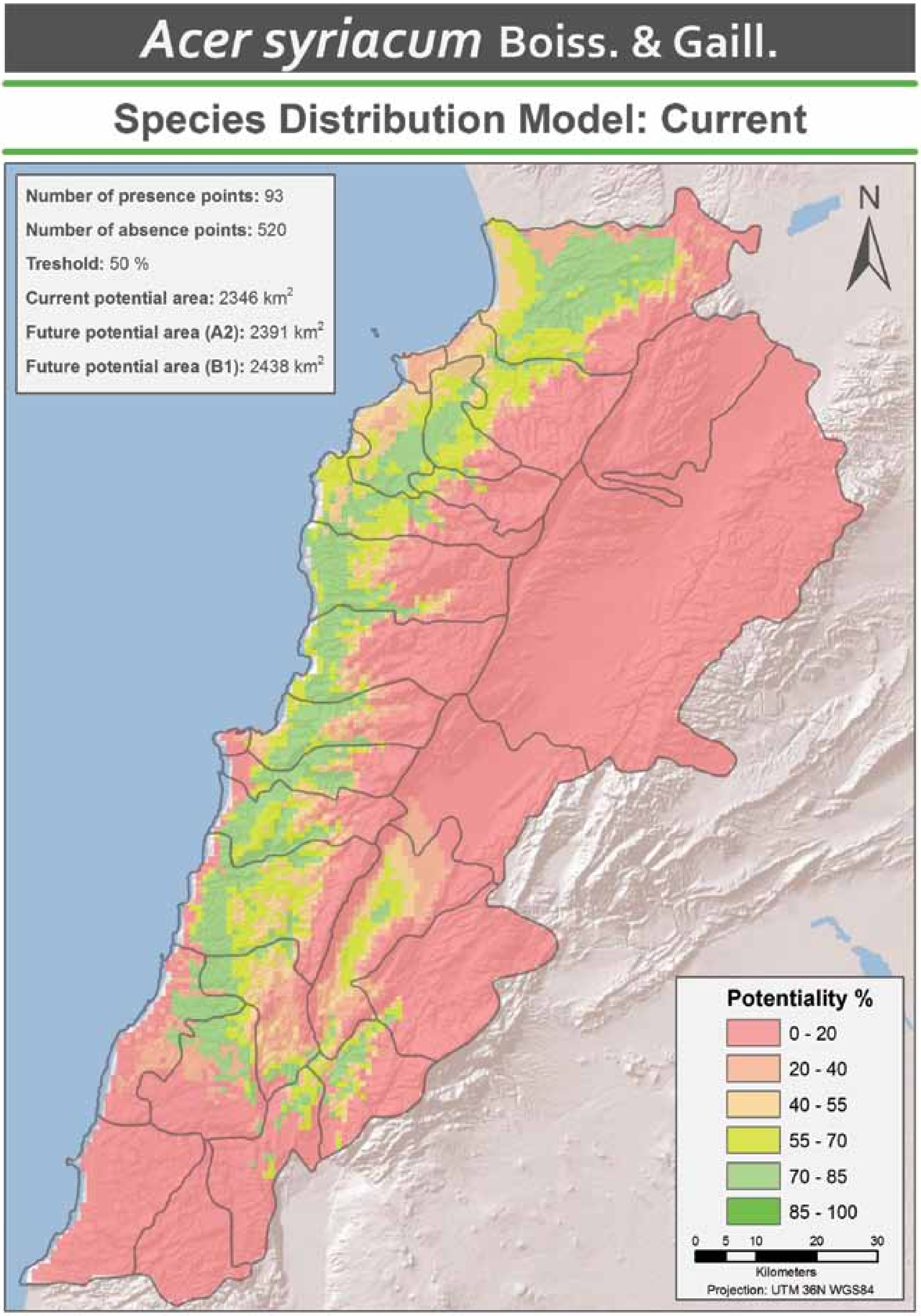
Current status:
Abies cilicica shows current potential area in north Mount Lebanon range, with around 400 Km^2. Small patches of low potentiality are found in eastern slopes (Yammoune area).

Future status:
Taurus fir shows no potential area in any considered scenario. Both situations result in loss of potentiality throughout the entire area of occurrence of this species.

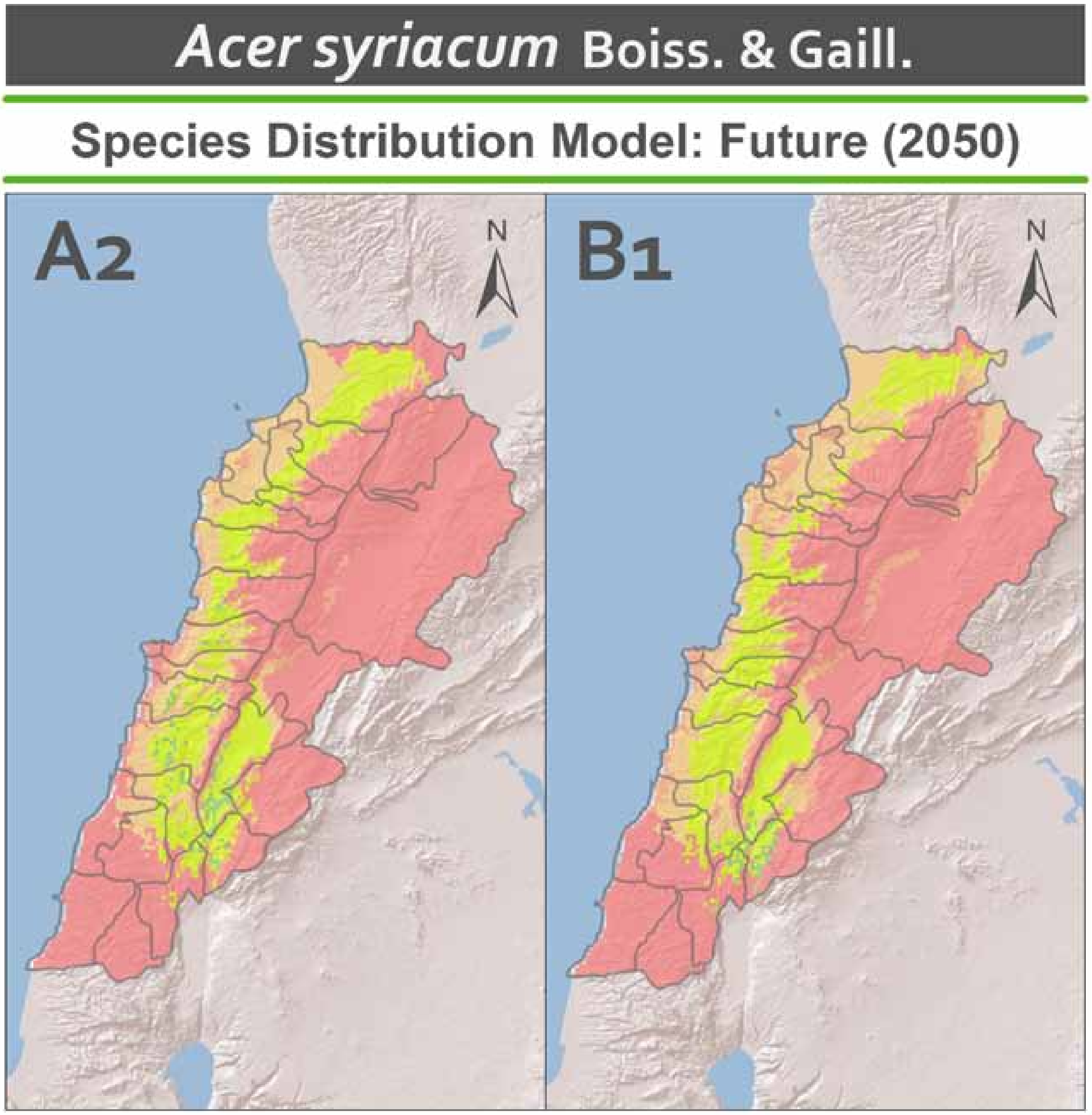
Following the models, this tree will become a non-potential species in Lebanon in the mid-term.



7.2.1 *Acer syriacum*
7.2.2 *Abies cilicica*



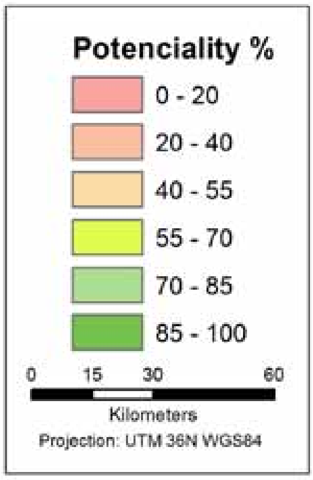
7.2.1 *Abies cilicica*



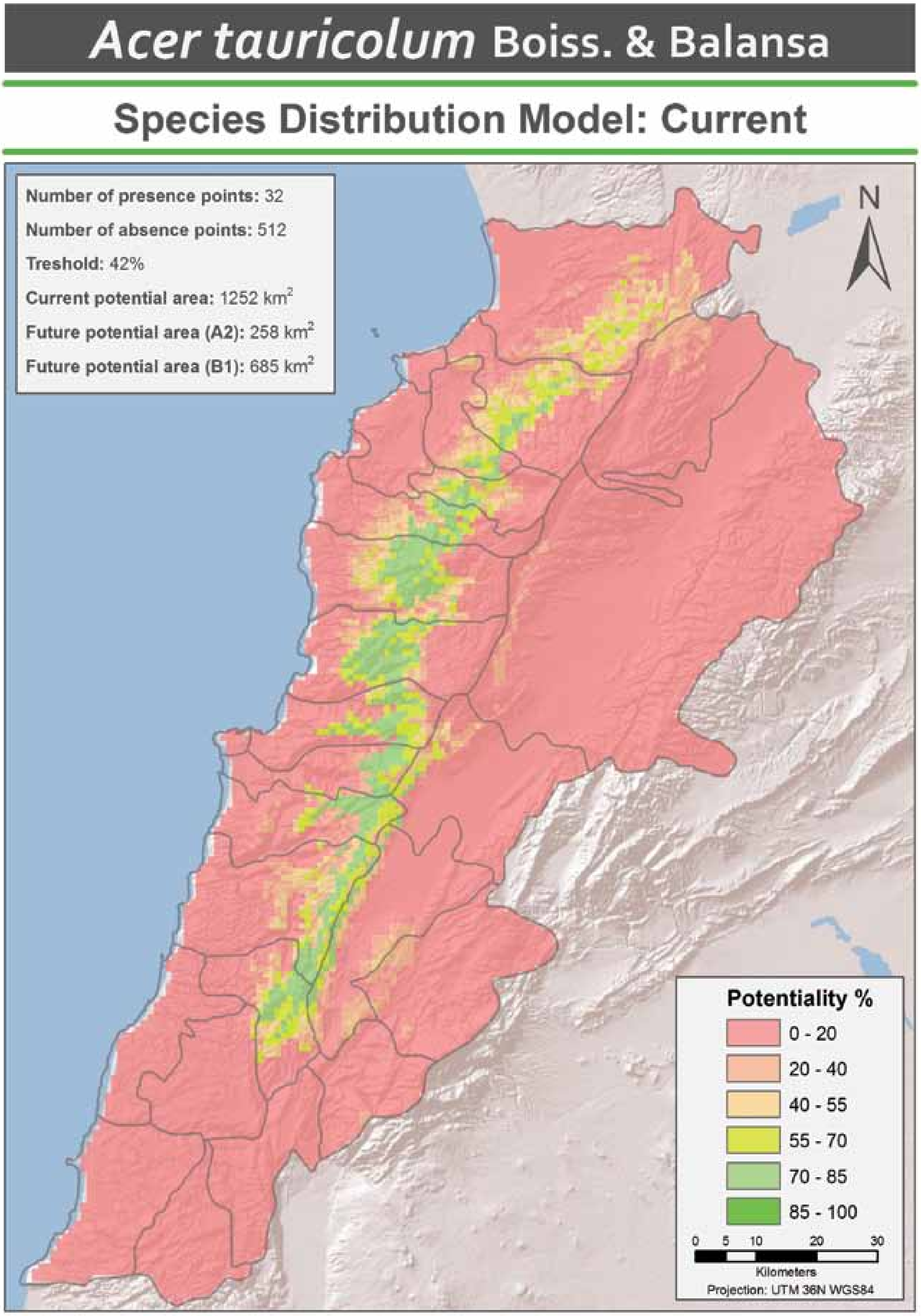
Current status:
Acer syriacum shows current potential area in western Mount Lebanon slopes and some locations in south and west Bekaa, with more than 2,300 Km^2.

Future status:
Syrian maple keeps its potential area in both scenarios, but with lower potentiality values, mainly due to the decrease in precipitation patterns.

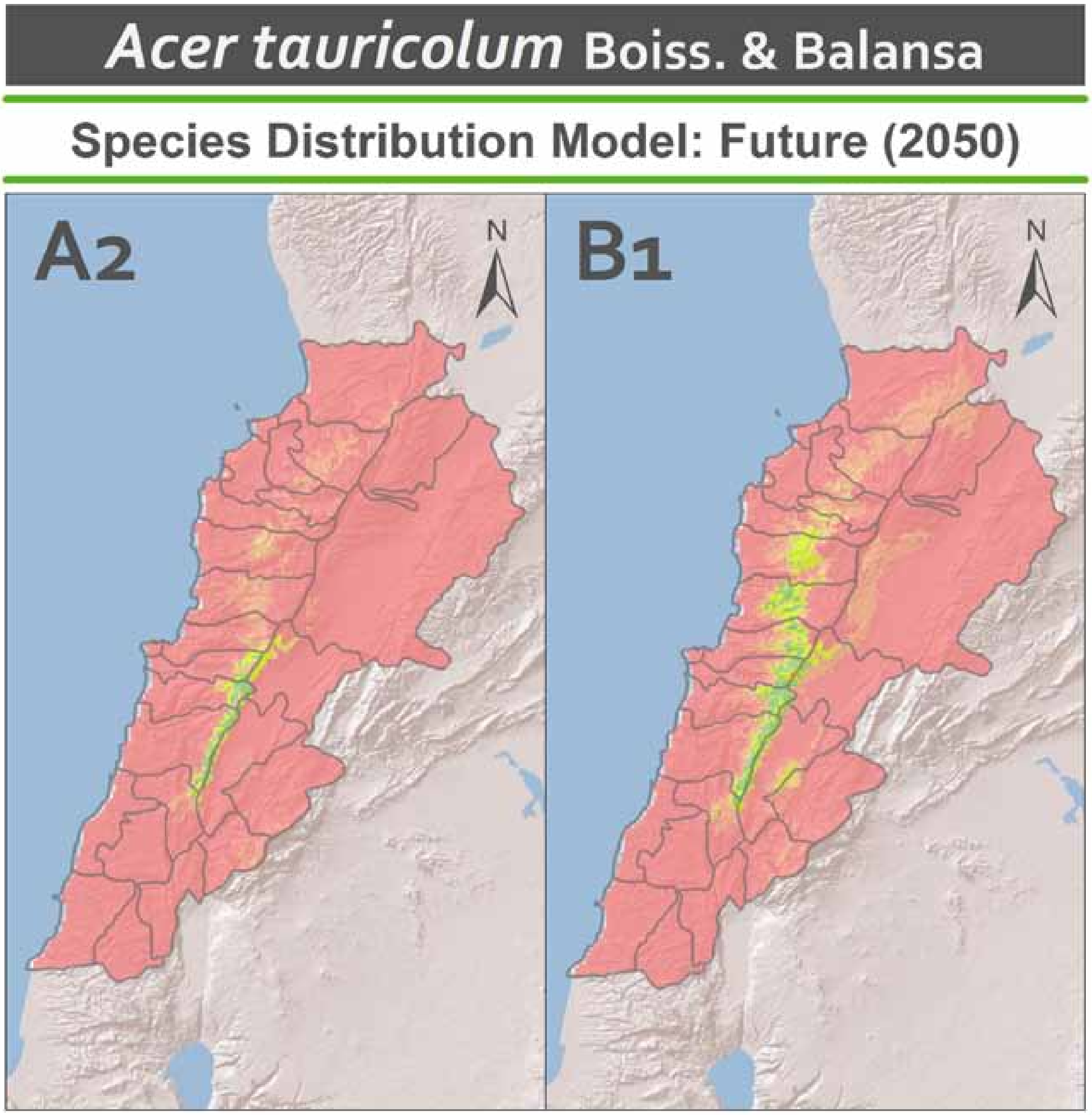
Following the models, this tree will keep its potentiality in southern locations of its potential area, but generally decrease.



7.2.3 *Acer tauricolum*



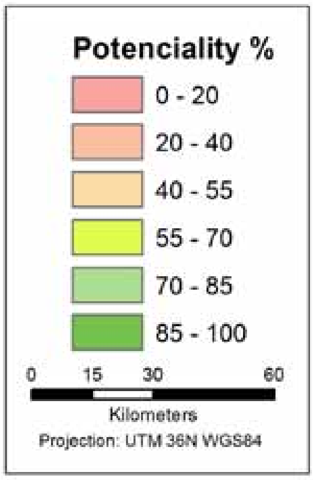
7.2.3 *Acer tauricolum*



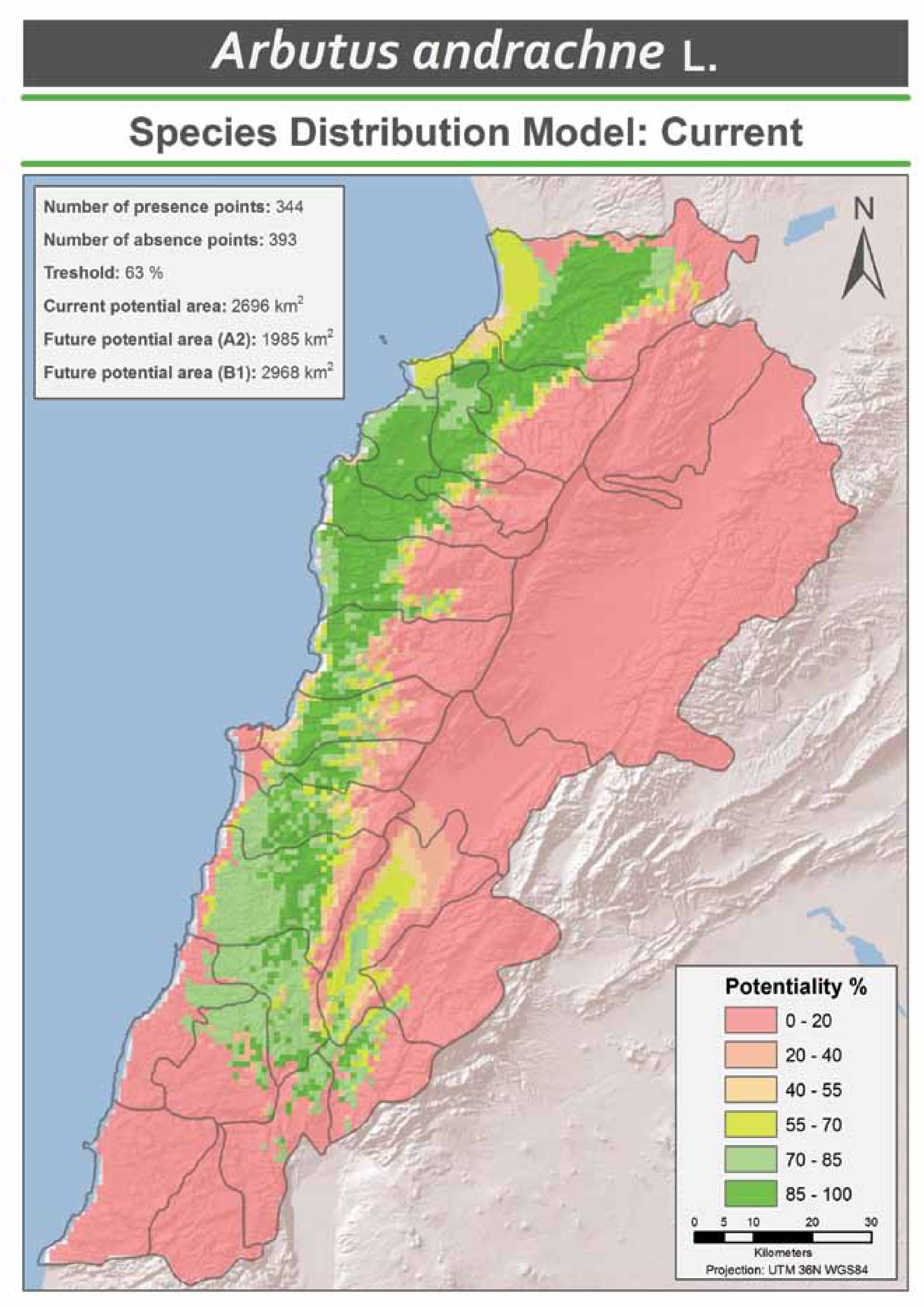
Current status:
Acer tauricolum shows current potential area in the western Mount Lebanon range with more than 1,200 Km².

Future status:
Taurus maple's potential area is drastically reduced in A2, but at least half of it is kept in B1, mainly located in Shouf region in both cases.

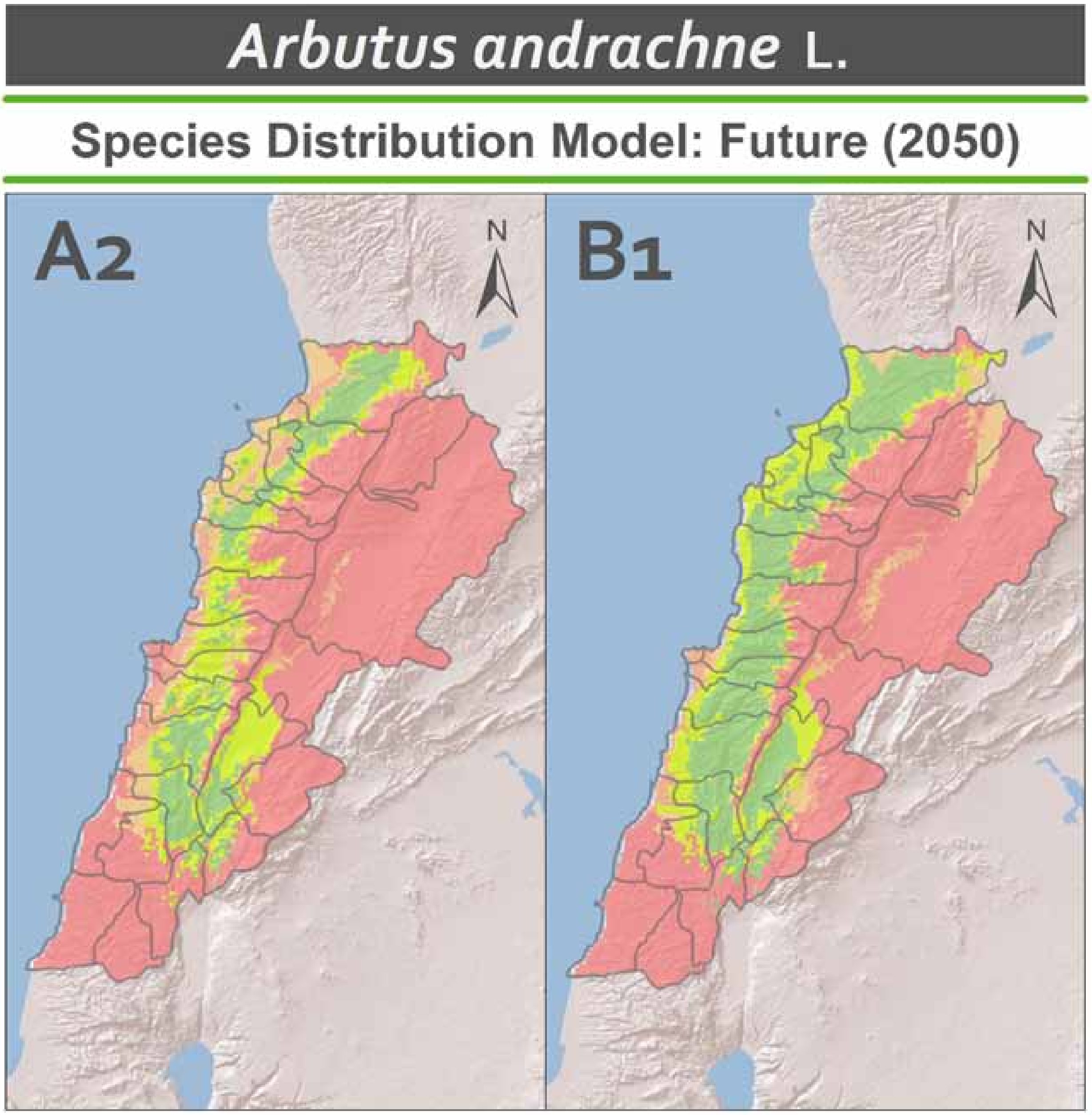
Following the models, this tree will lose potentiality in the northern areas of Lebanon and will keep the central Mount Lebanon and Shouf regions as potential areas in the mid-term.



7.2.4 *Arbutus andrachne*



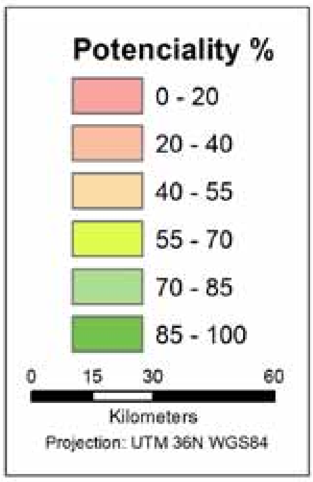
7.2.4 *Arbutus andrachne*



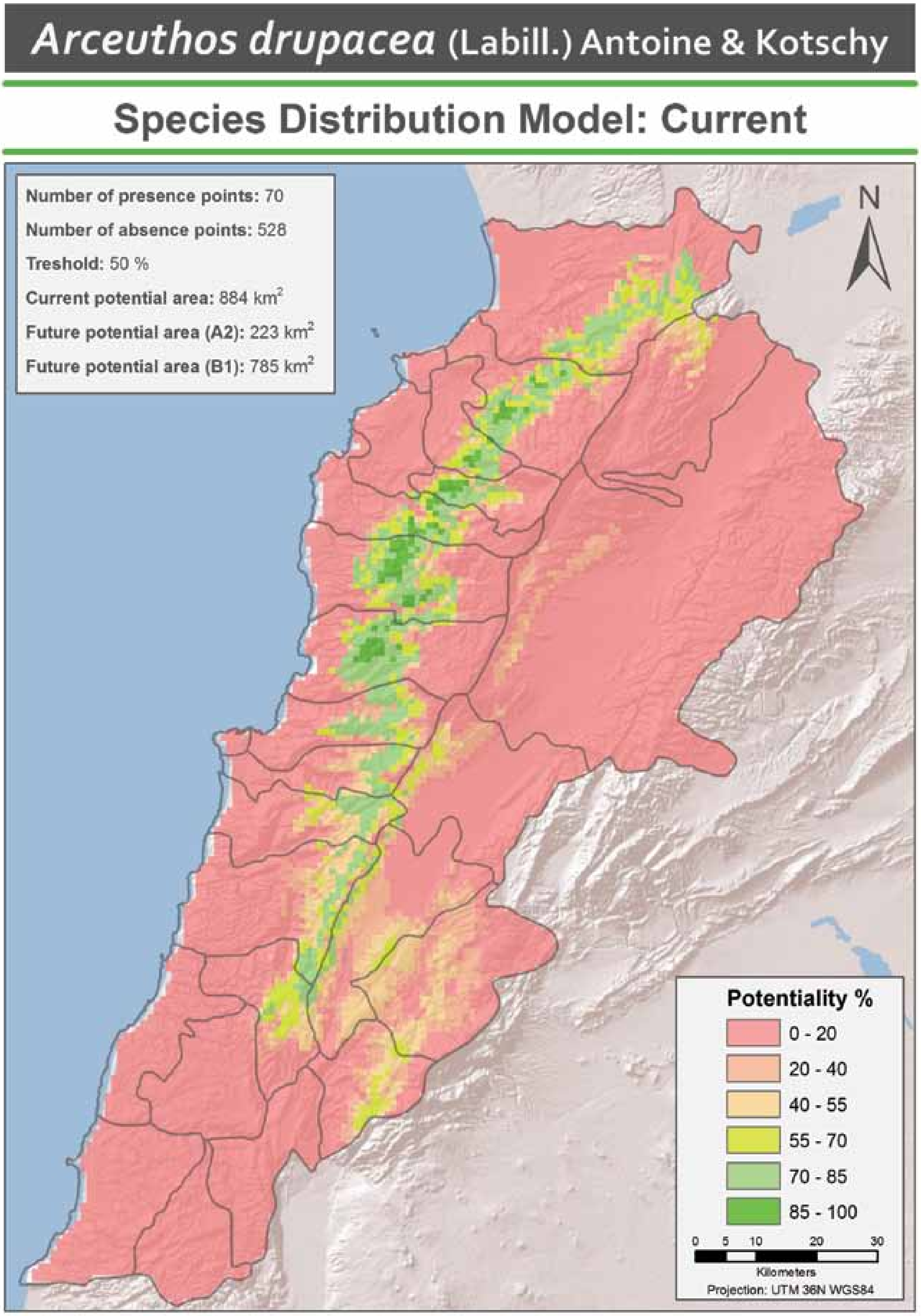
Current status:
Arbutus andrachne shows a current potential area in western Mount Lebanon range and some patches of South-West Bekaa, with almost 2,700 Km^2.

Future status:
The Greek strawberry tree keeps its area of occurrence but its potentiality decreases notably in A2 scenario. B1 scenario keeps a situation close to present.

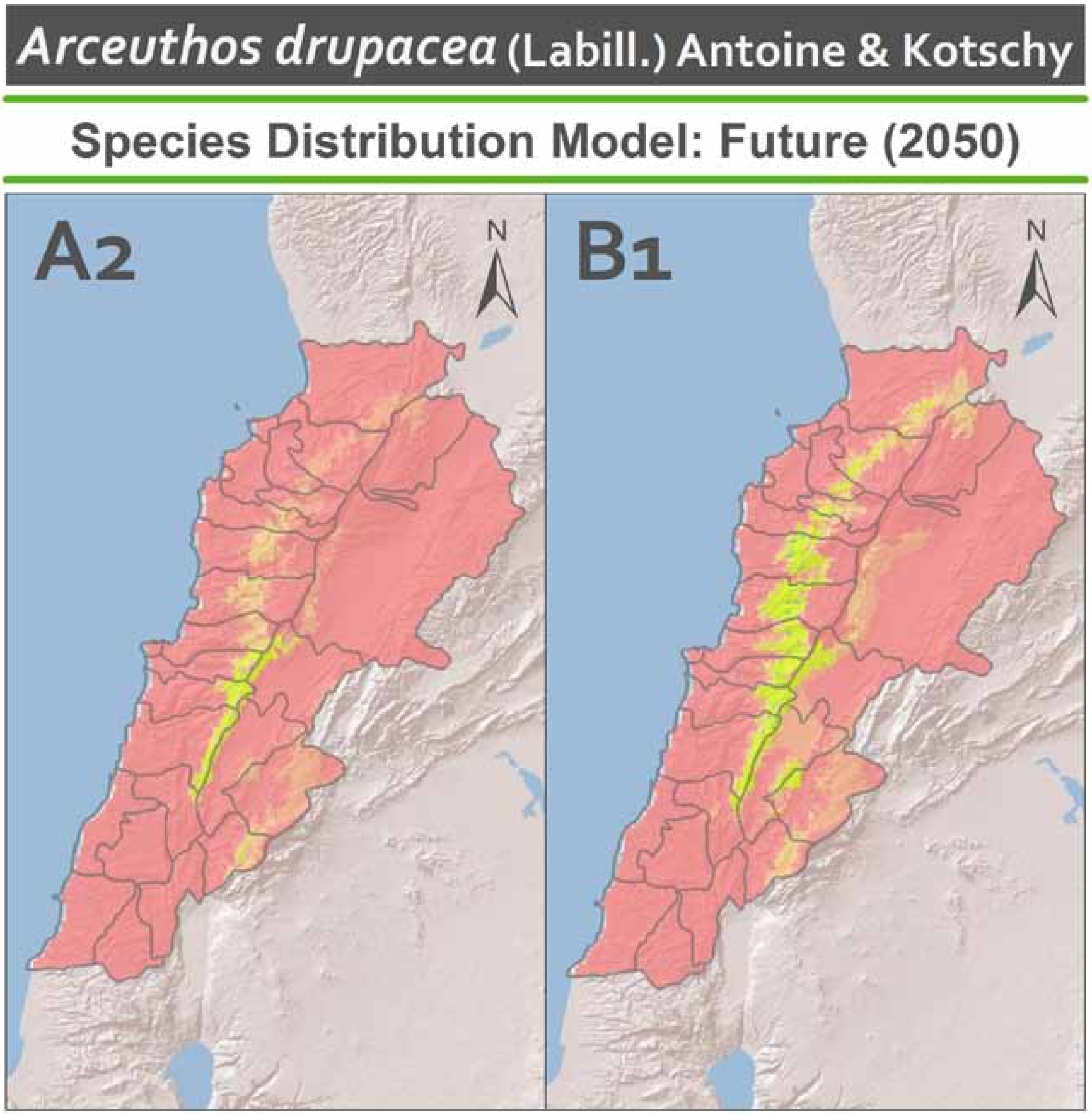
Following the models, this tree will maintain its potential status in the mid-term in terms of its area of current potentiality, increasing partially in West Bekaa.



7.2.5 *Arceuthos drupacea*



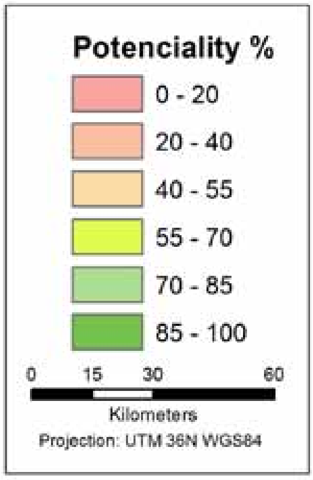
7.2.6 *Arceuthos drupacea*



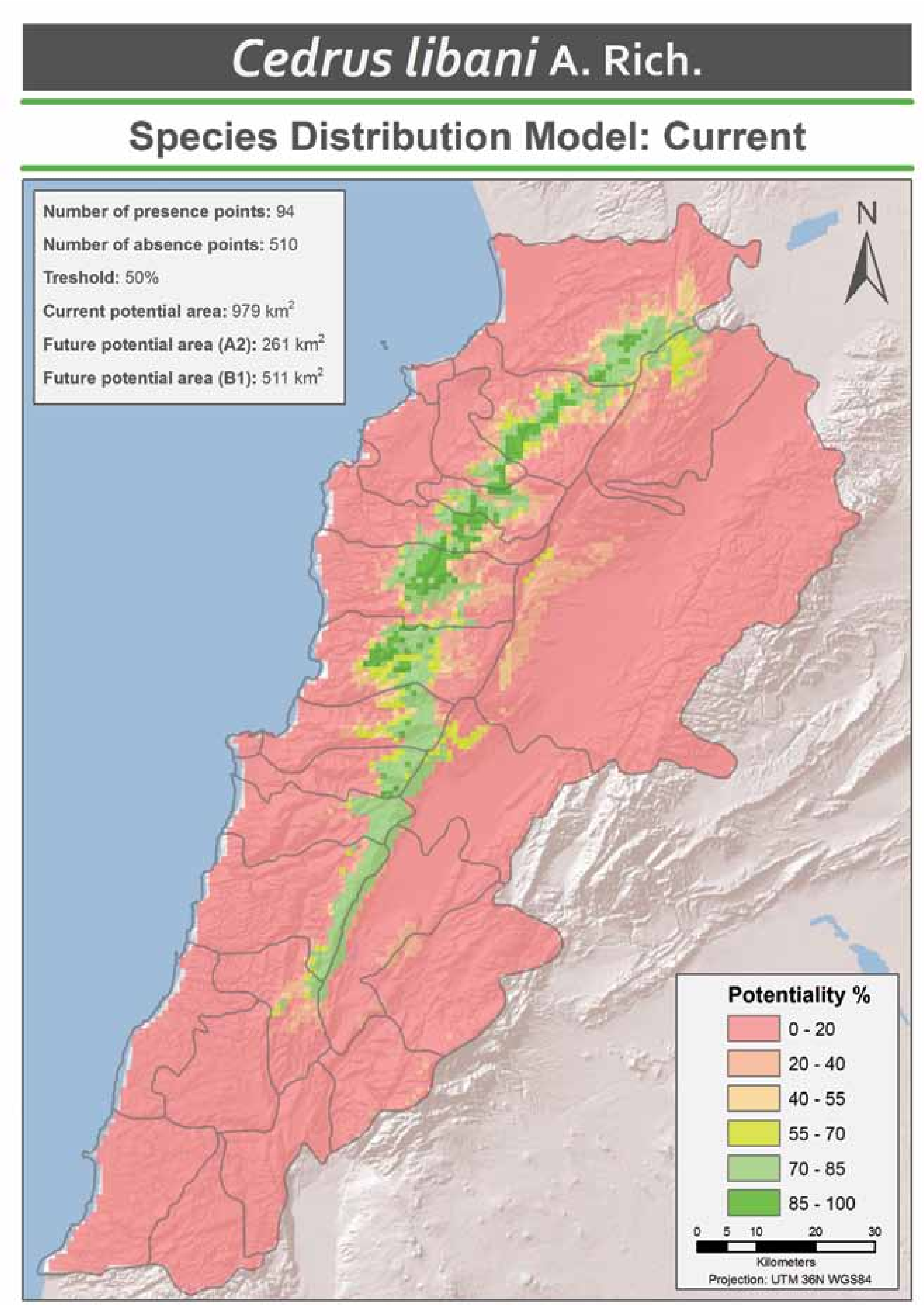
Current status:
Arceuthos drupacea shows a current potential area over a large part of the western Mount Lebanon range despite its low current presence, with almost 900 Km^2.

Future status:
As seen in Annex I: Classified Maps, the B1 scenario shows a new patch of potentiality in Rachaya region for Syrian juniper. In the worst scenario, this species' potentiality migrates to the Shouf region, notably decreasing its potential area.

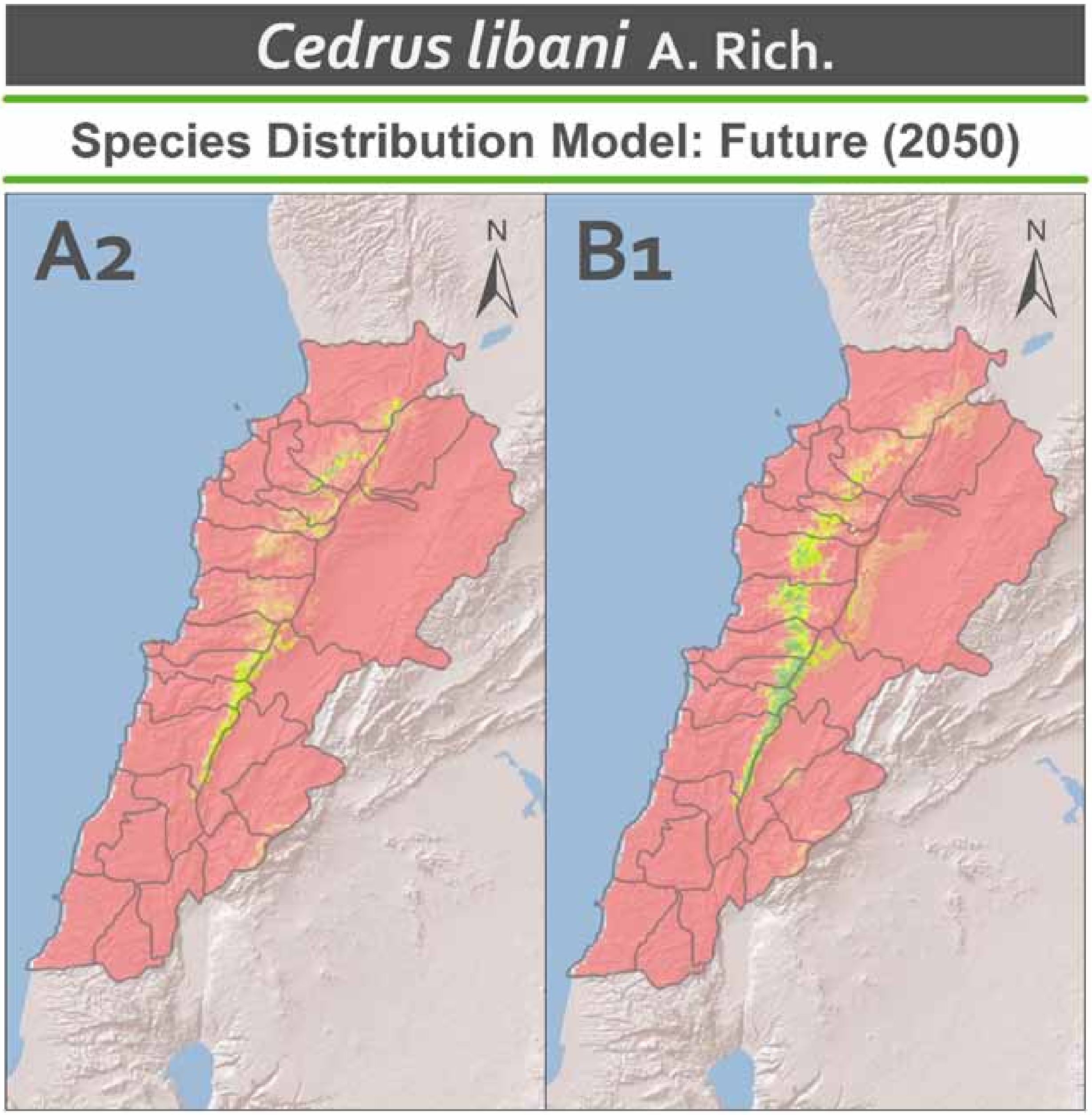
Following the models, this tree will maintain its potential area in better scenarios but in a decreasing value.



7.2.6 *Cedrus libani*

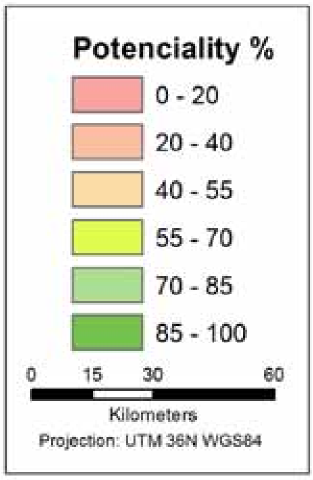


7.2.6 *Cedrus libani*

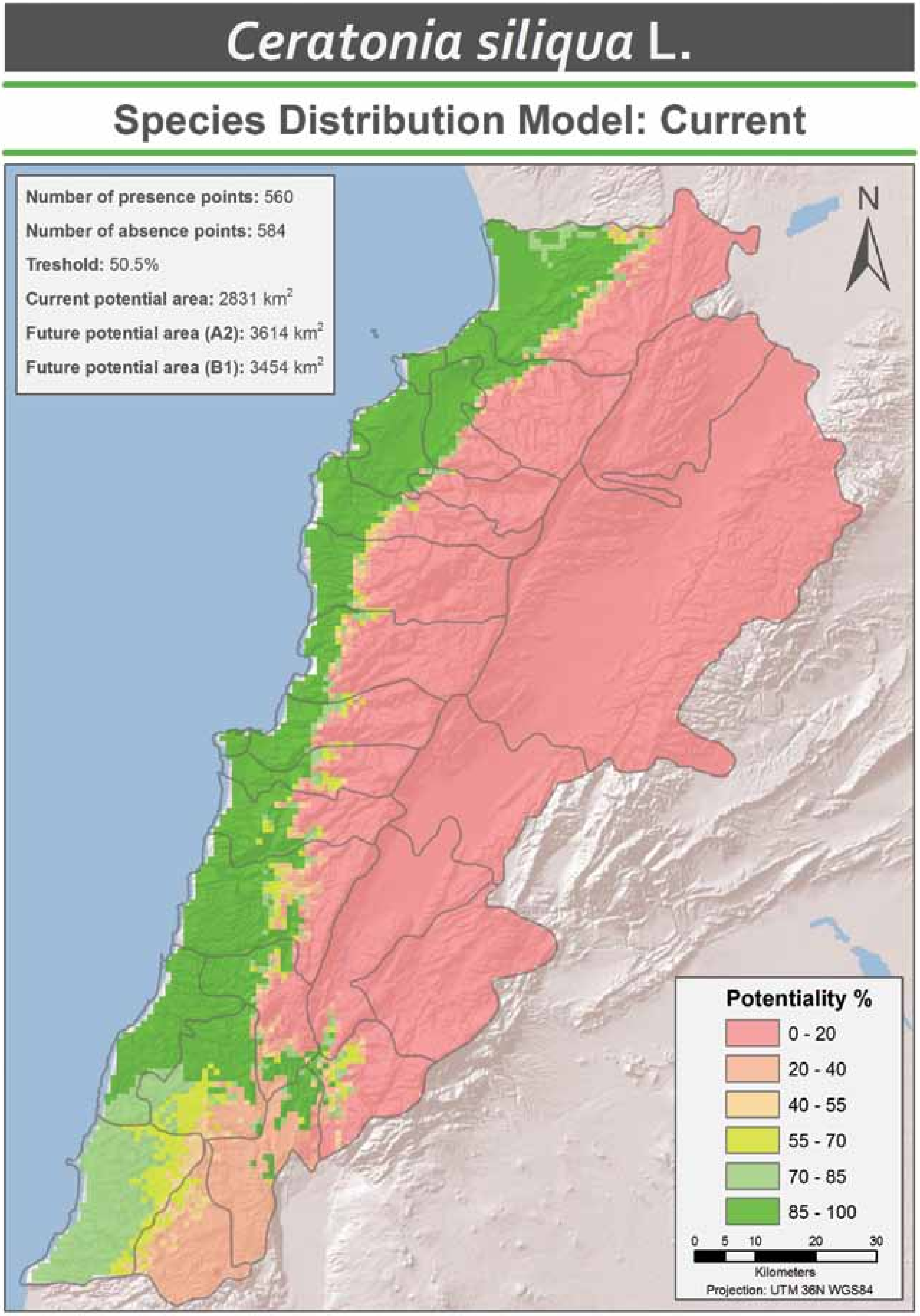


Current status:
Cedrus libani shows a current potential area in a wide part of the western Mount Lebanon range and some patches on the eastern slopes (Yammoune area) despite its low current presence, with almost 1,000 Km².

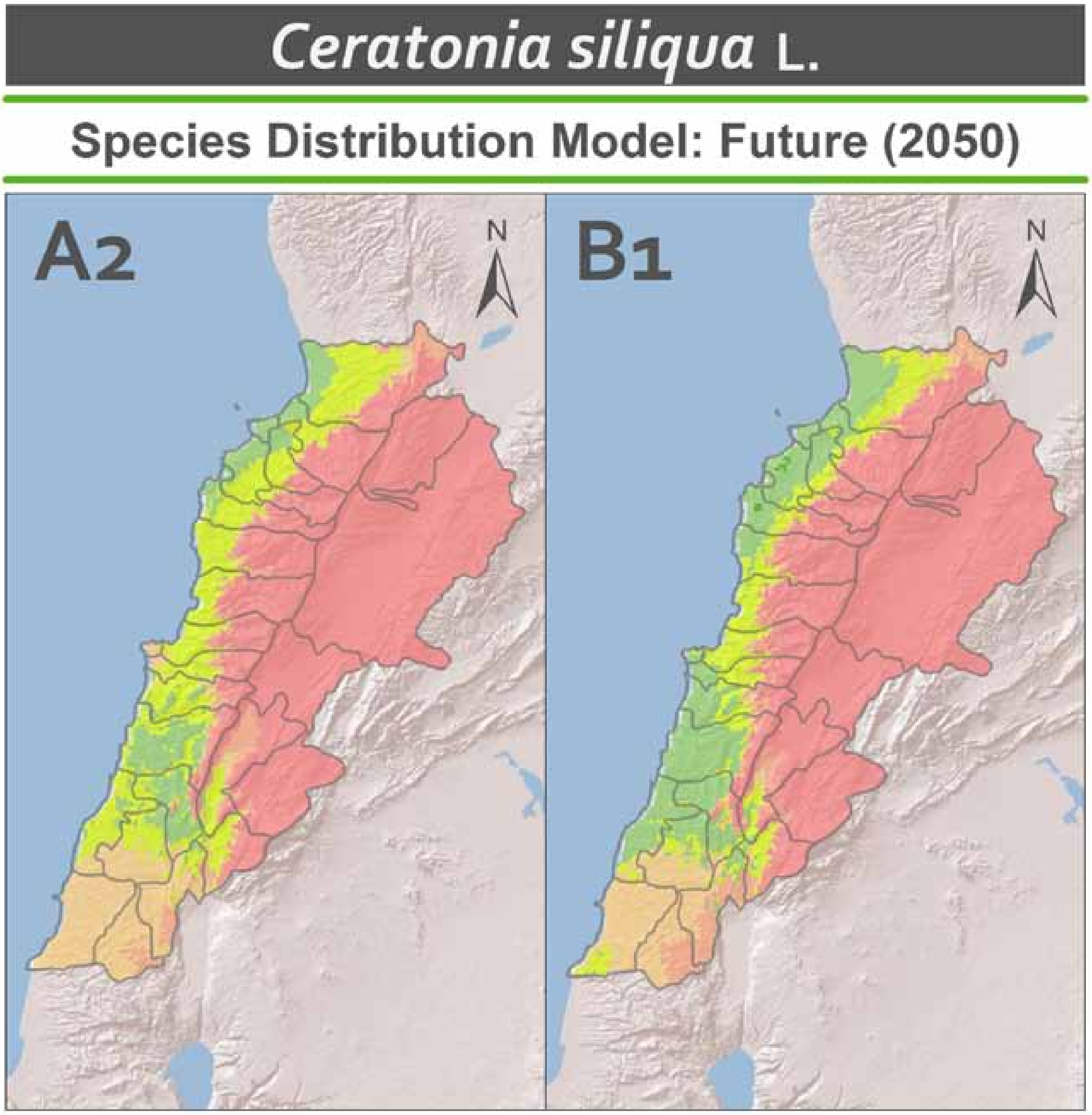
Future status:
Lebanese cedar will lose potentiality area in both scenarios, keeping the most potential spots in the Shouf region, central Mount Lebanon and some isolated patches in the north. Also, some areas in Yammoune region appear as potential.
Following the models, this tree's potentiality area will decrease mainly in the north but keeping almost the same distribution as the current one.



7.2.7 *Ceratonia siliqua*



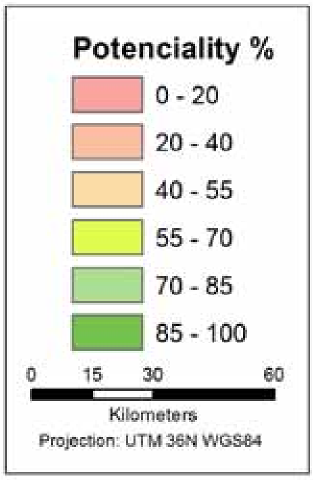
7.2.7 *Ceratonia siliqua*



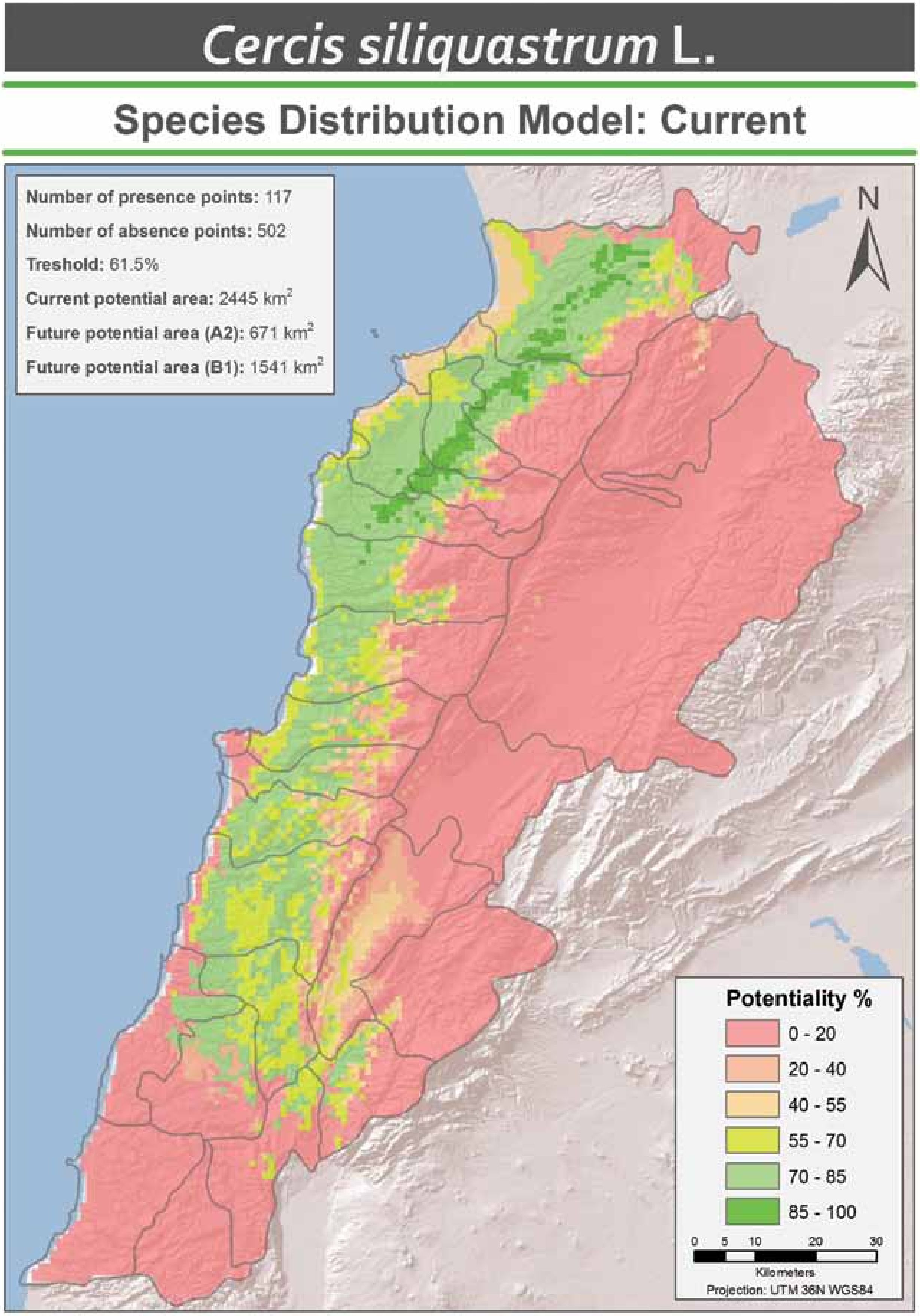
Current status:
Ceratonia siliqua shows a current potential area widely spread through the western part of the country, with more than 2,800 Km^2.

Future status:
Carob tree's potential area will increase in both scenarios with around 3,500 Km^2, mainly due to the expected rise of temperature. Despite this, potentiality values are slightly lower.

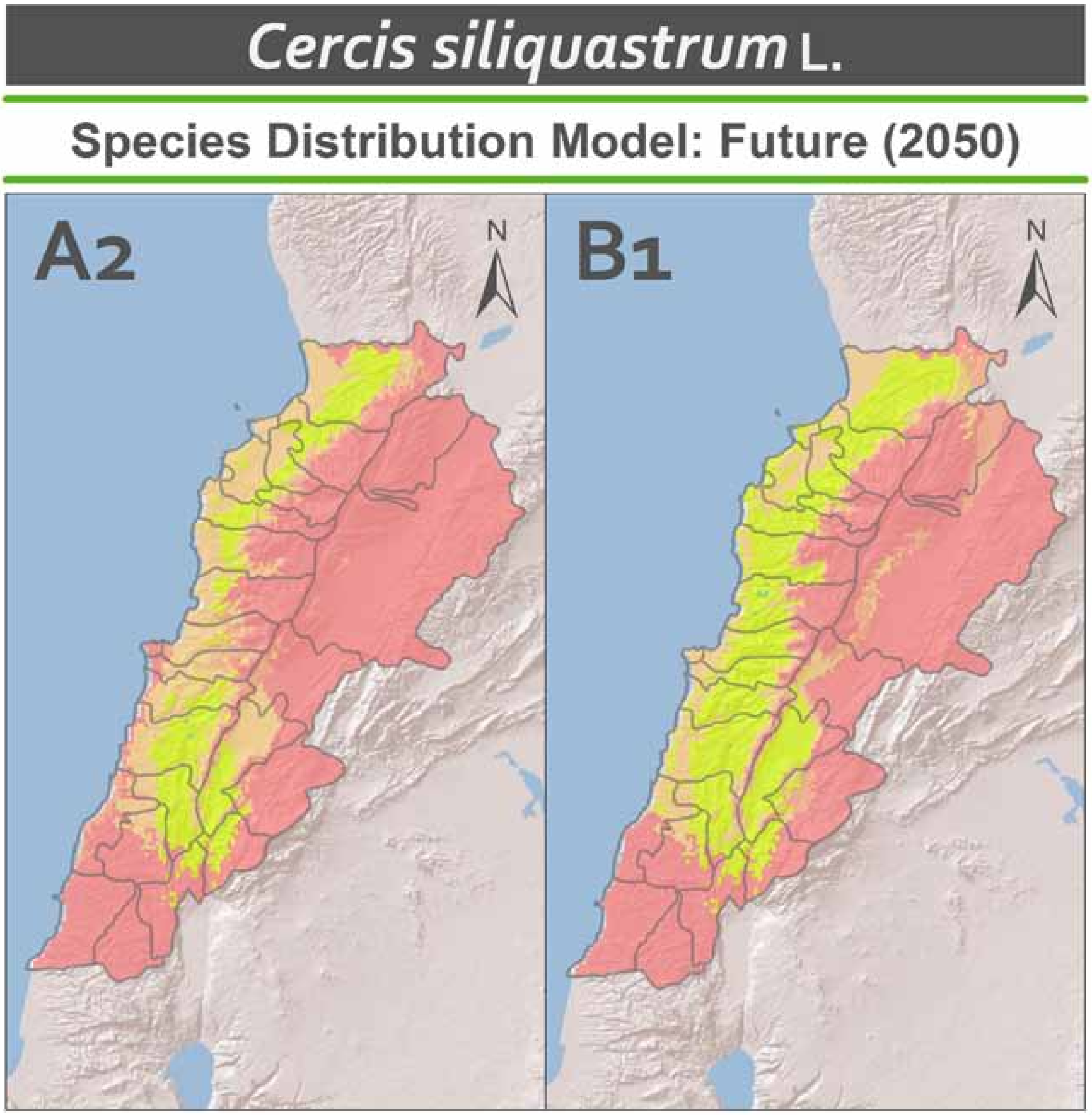
Following the models, this tree's potential area will spread in the mid-term, climbing up in altitude.



7.2.8 *Cercis siliquastrum*



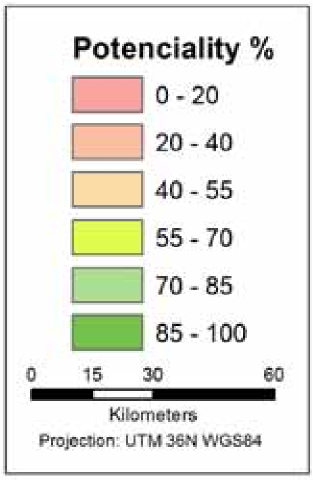
7.2.8 *Cercis siliquastrum*



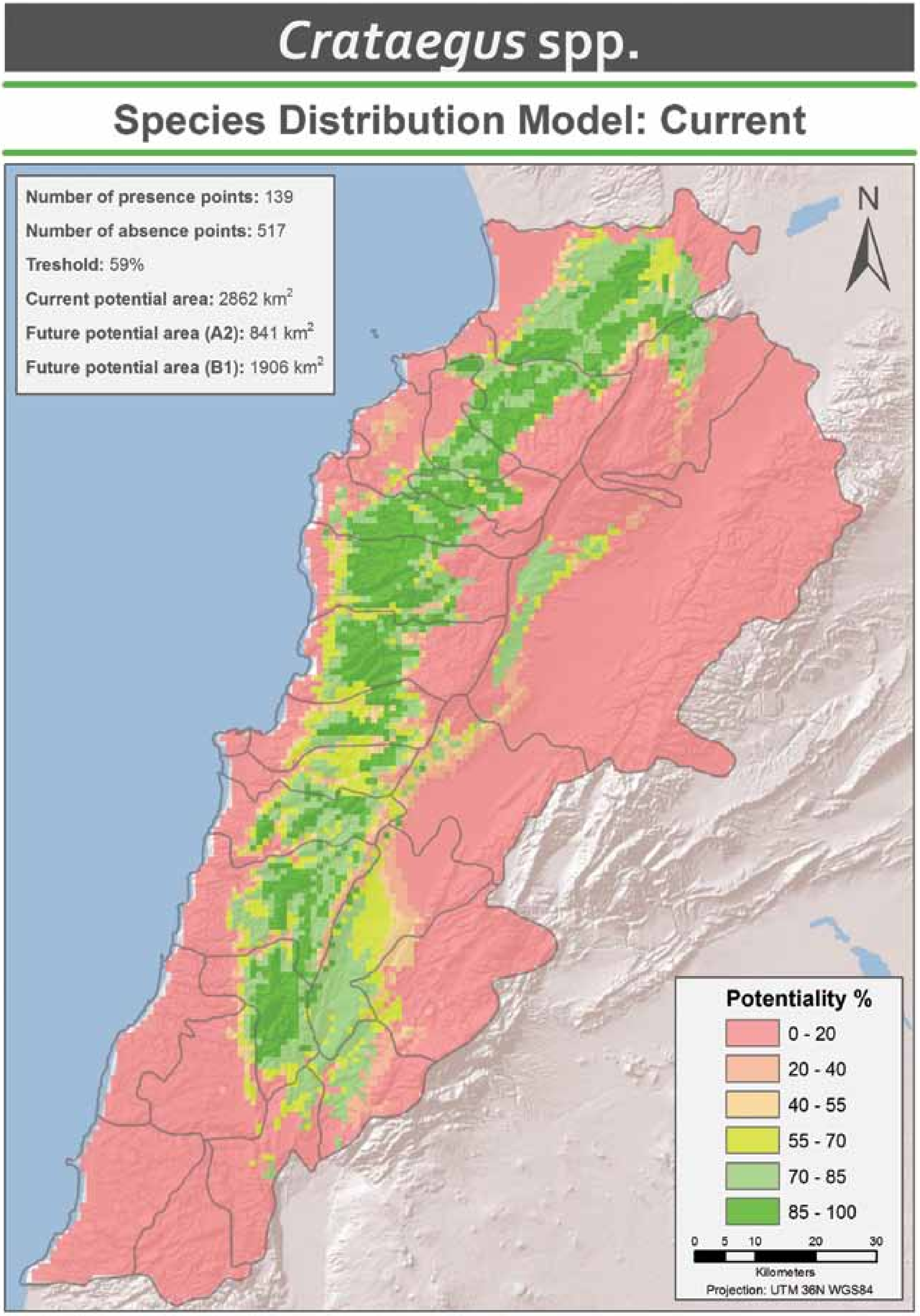
Current status:
Cercis siliquastrum shows a current potential area widely spread through the western part of the country and some areas in the Hasbaya and West Bekaa regions, with almost 2,500 Km^2.

Future status:
Judas tree will significantly lose both potential area and potentiality values in the future (see Annex I for classified map). New areas of potentiality appear in the West Bekaa region.

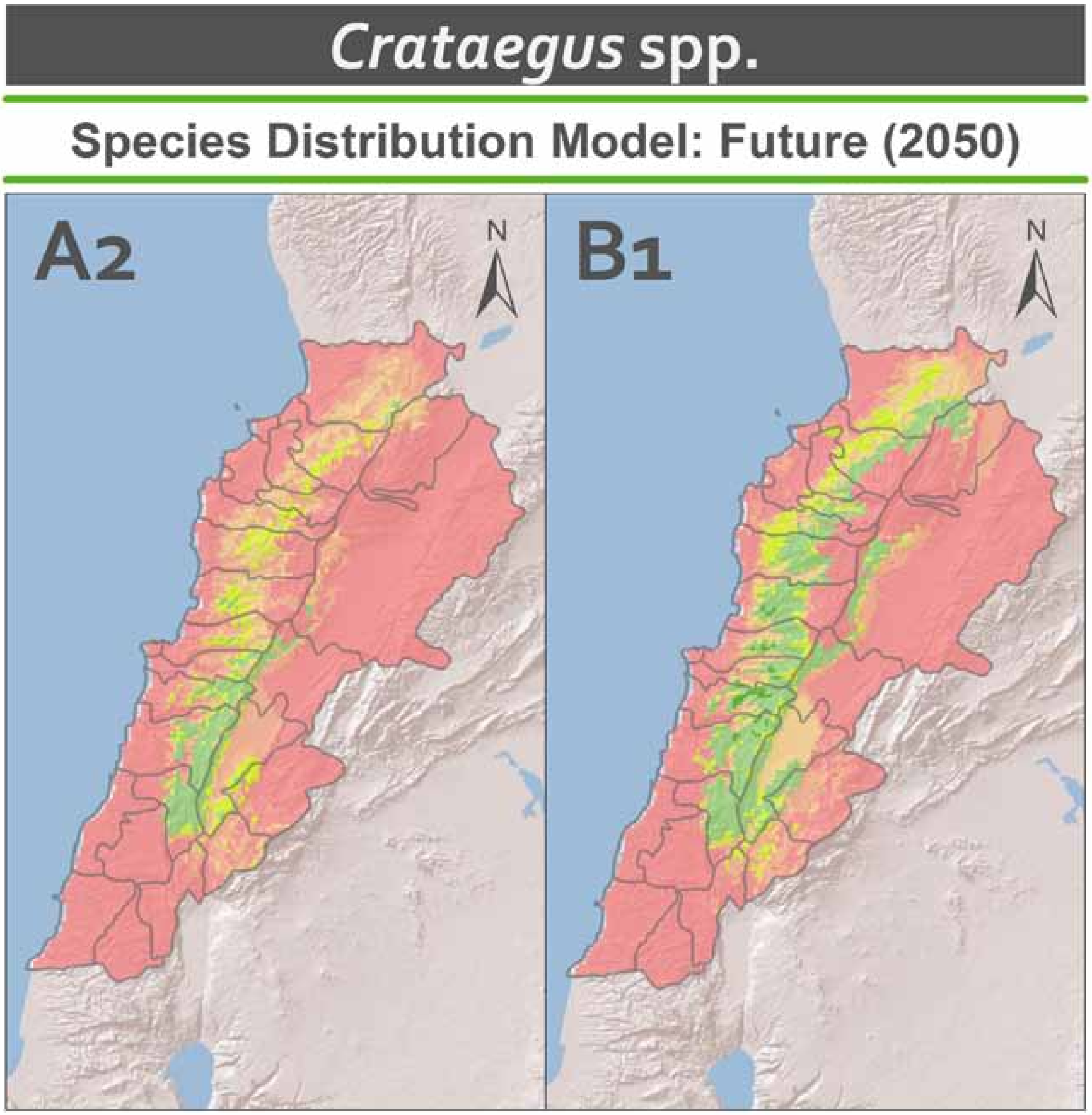
Following the models, this tree will keep a considerable potential surface but lower values of potentiality.



7.2.9 *Crataegus spp.*



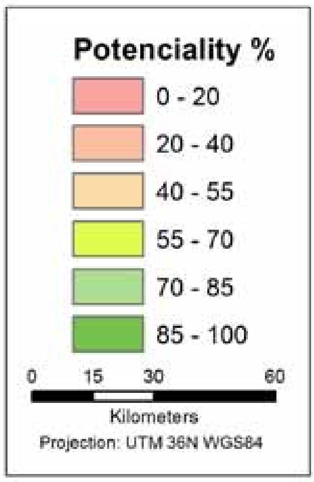
7.2.9 *Crataegus spp.*



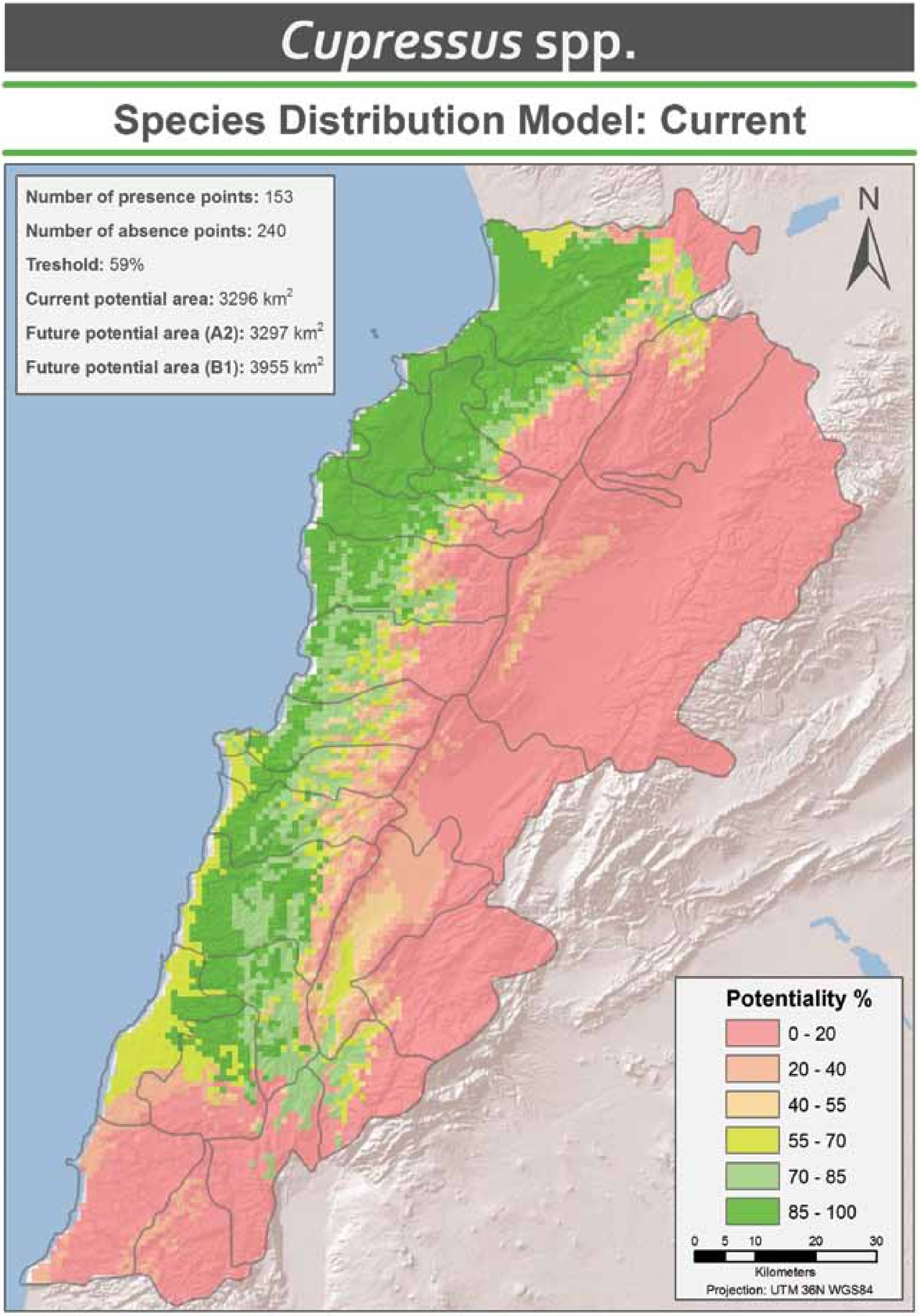
Current status:
Crataegus spp. shows a current potential area widely spread through the Mount Lebanon range, Jezzine, West Bekaa and Yammoune areas, with almost 2,900 Km^2.

Future status:
Hawthorn will lose some potentiality in the future; the highest values appear mainly in the central and southern regions of its potential area.

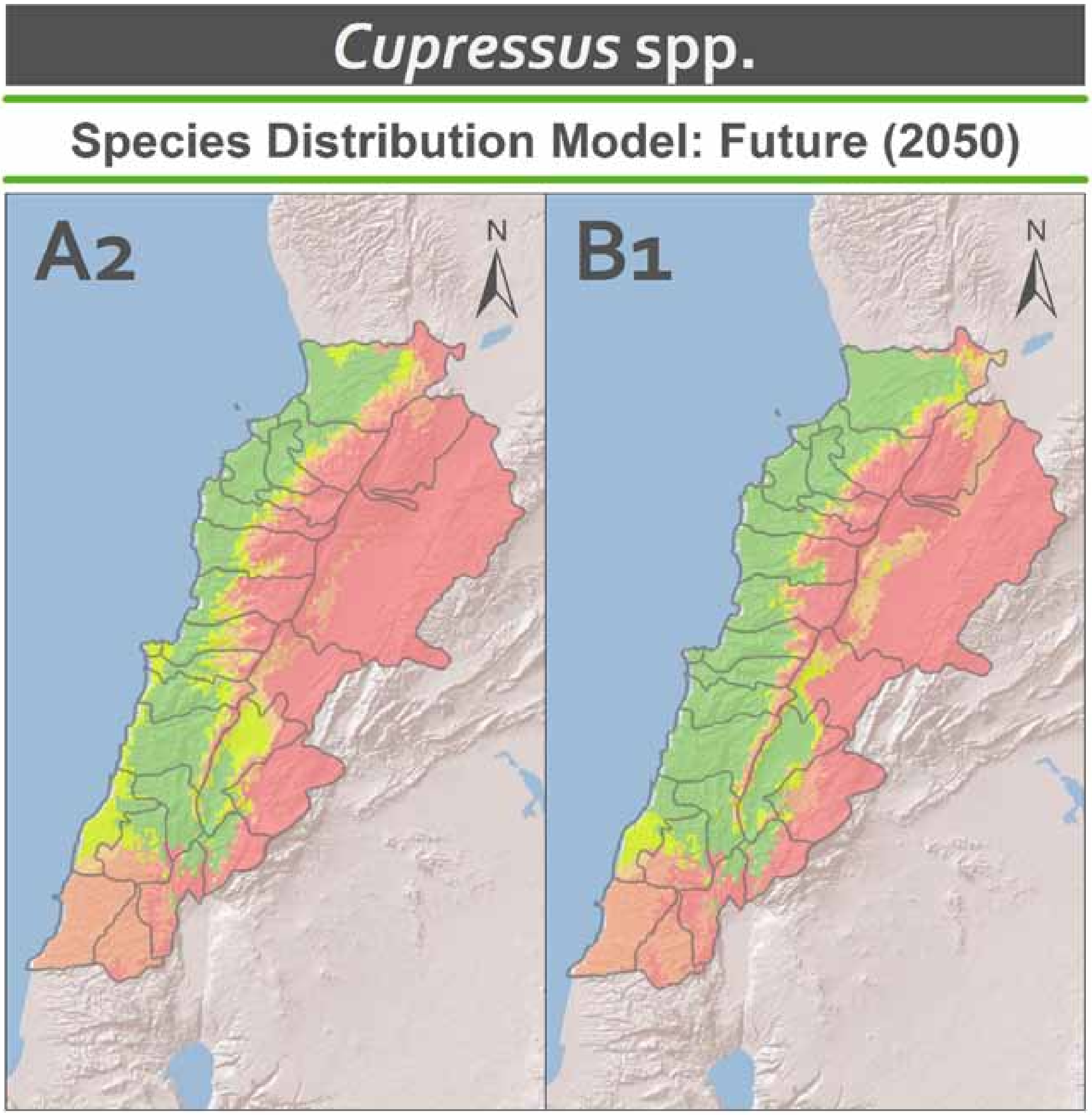
Following the models, this species will keep a considerable potential surface. In the worst scenario, it will decline in the north.



7.2.10 *Cupressus spp.*



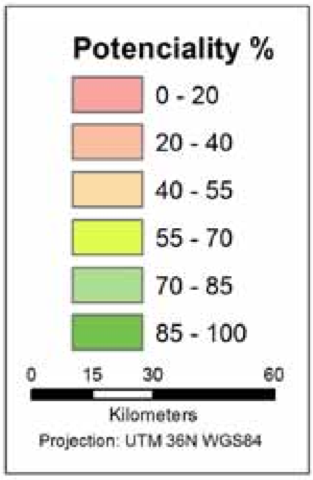
7.2.10 *Cupressus spp.*



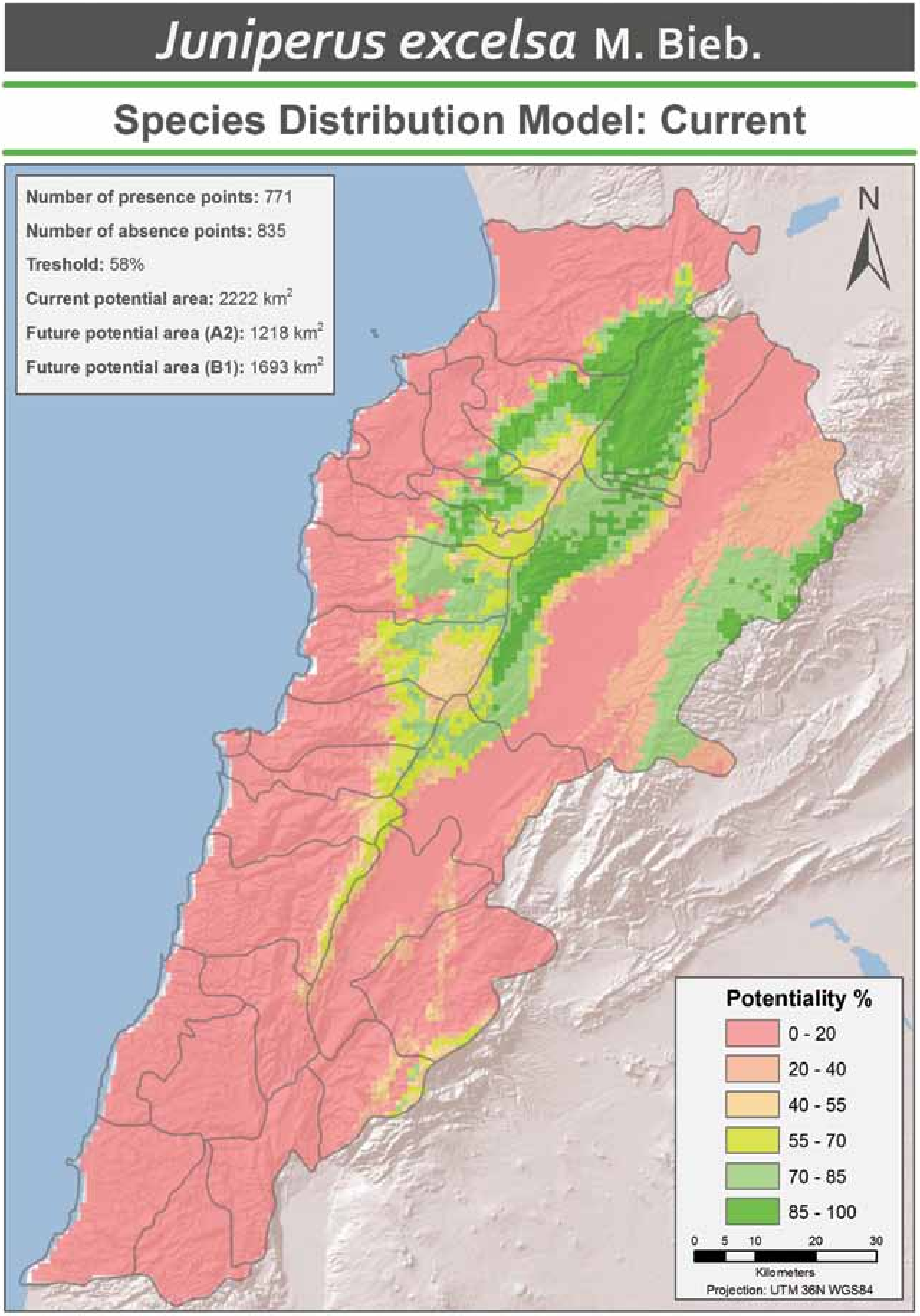
Current status:
Cupressus spp. shows a current potential area widely spread through the western part of the country, mainly in the north, with almost 3,300 Km².

Future status:
Cypress's area of potentiality will increase, gaining new zones mainly in the South and West Bekaa.

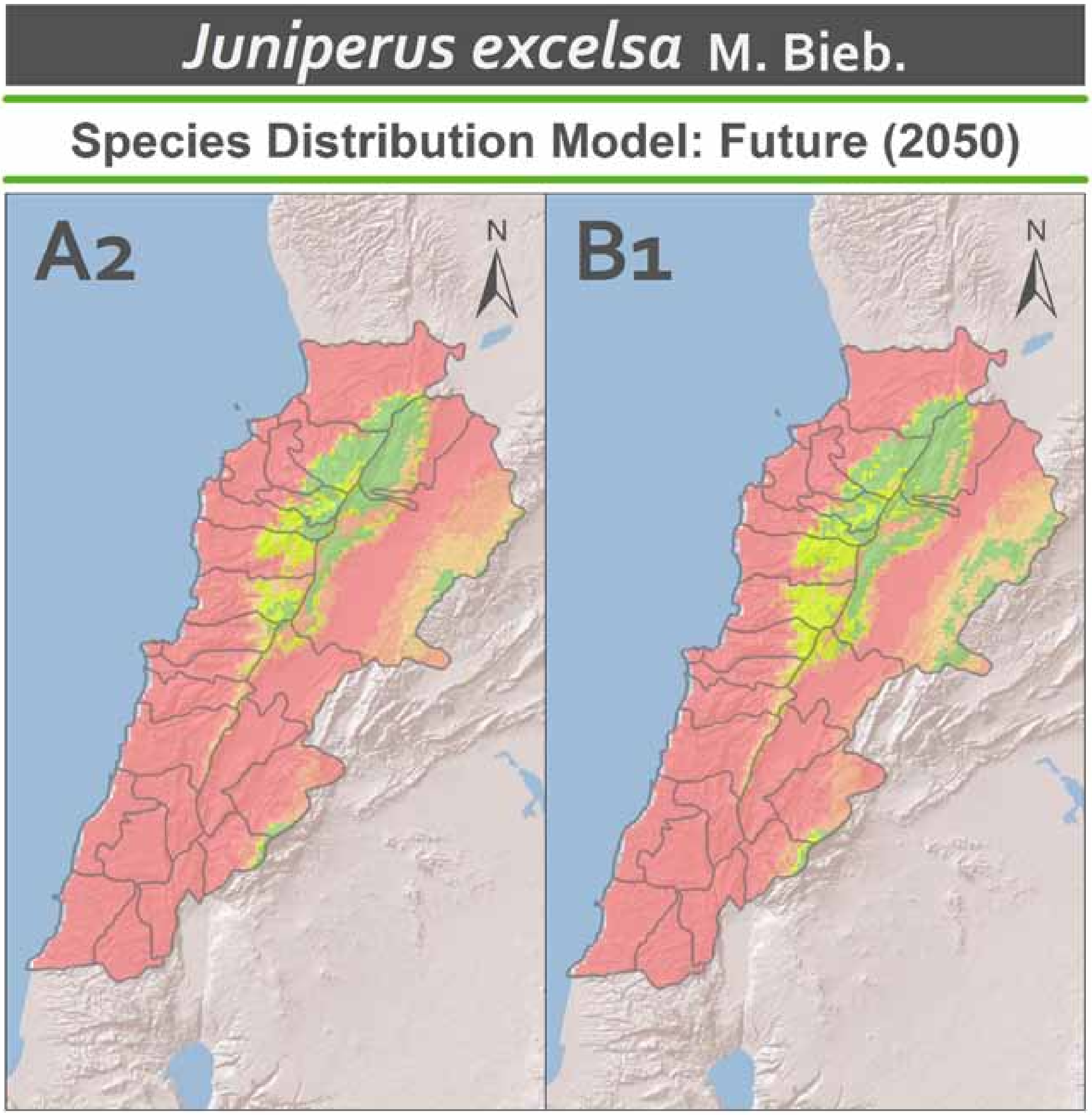
Following the models, this tree's potential surface will remain and increase considerably, spreading throughout the country and in a wide altitudinal range.



7.2.11 *Juniperus excelsa*



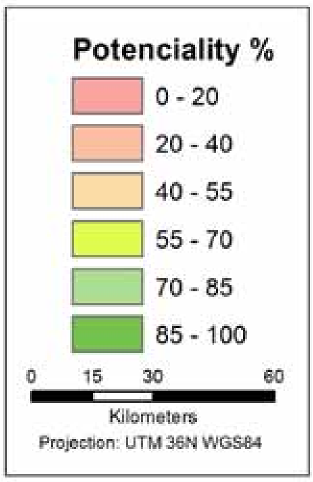
7.2.11 *Juniperus excelsa*



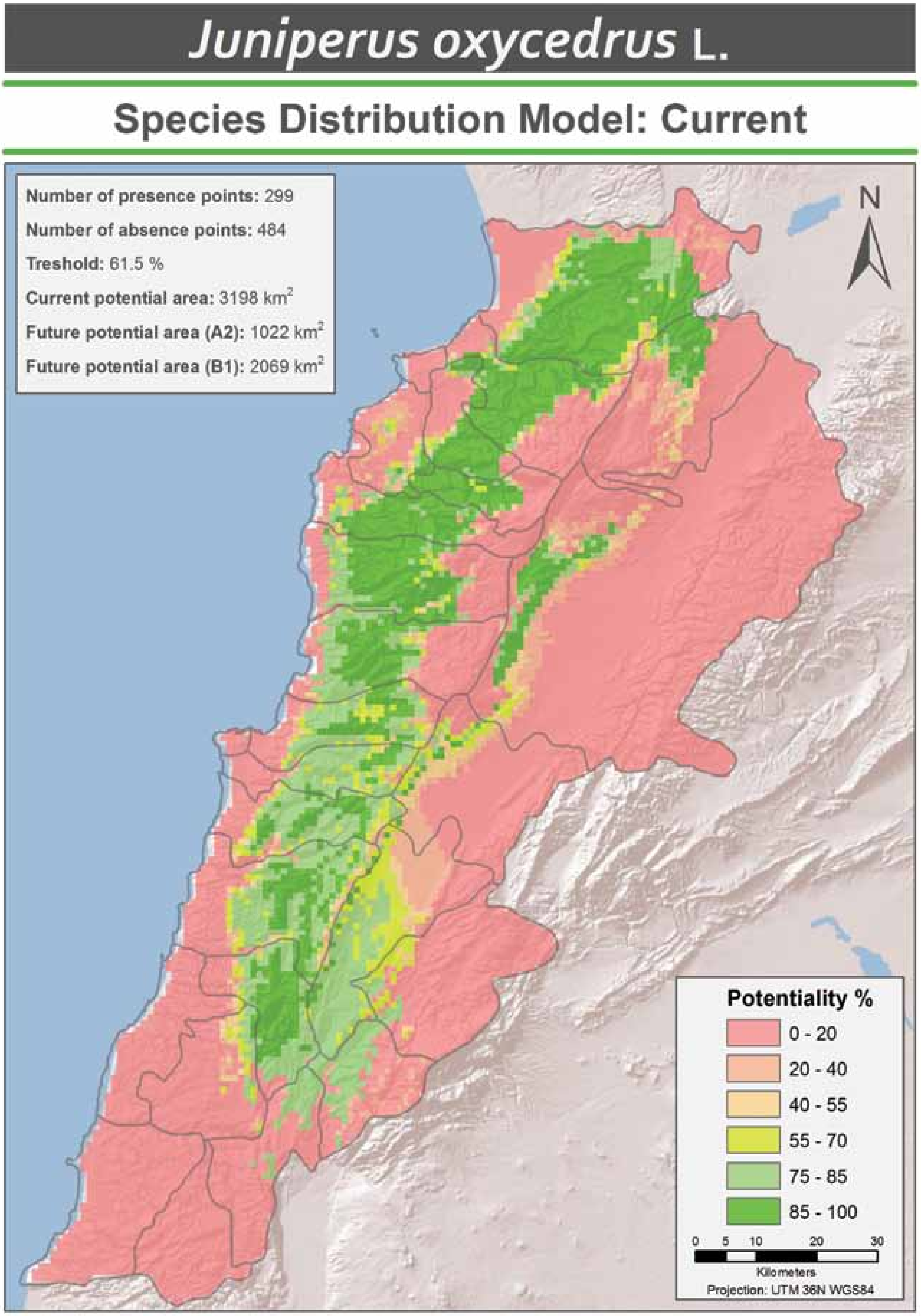
Current status:
Juniperus excelsa shows a current potential area widely spread through northern parts of the Mount Lebanon range, mainly in eastern slopes, and the northern part of the Anti-Lebanon range, with around 2,200 Km^2.

Future status:
Greek juniper will lose some potentiality in the future but keep the same potential distribution, restricted to high altitude areas.

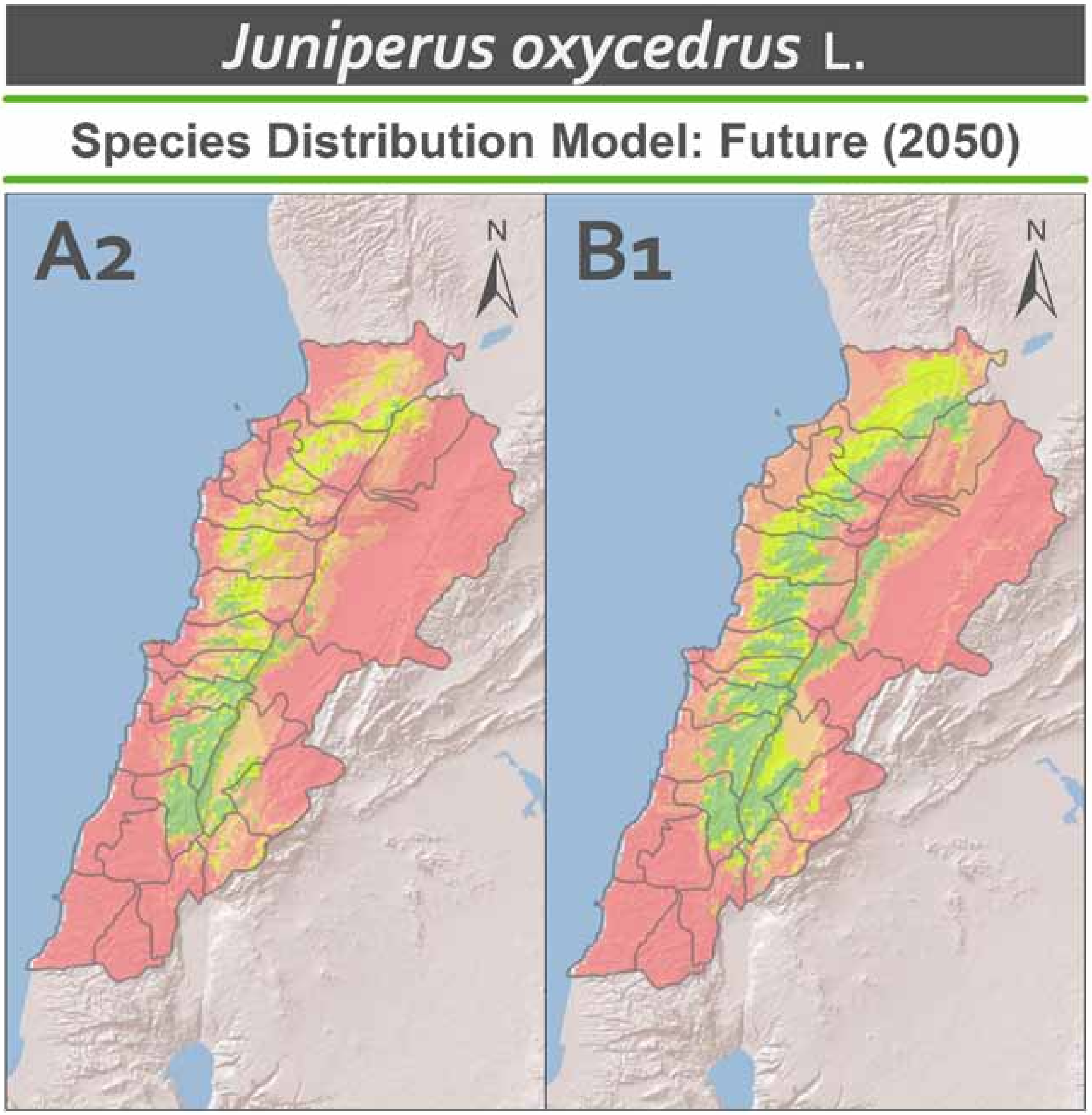
Following the models, this species will continue as potential species for high altitudes in Lebanon but its potentiality will decrease, mainly due to the expected lower precipitation patterns (lower snow reserves).



7.2.12 *Juniperus oxycedrus*



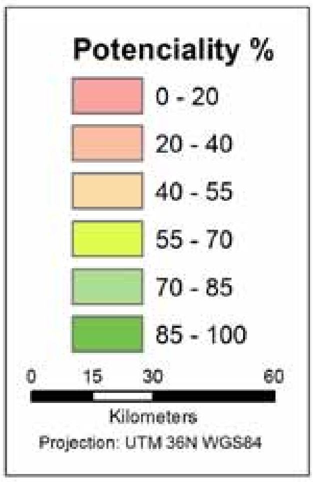
7.2.12 *Juniperus oxycedrus*



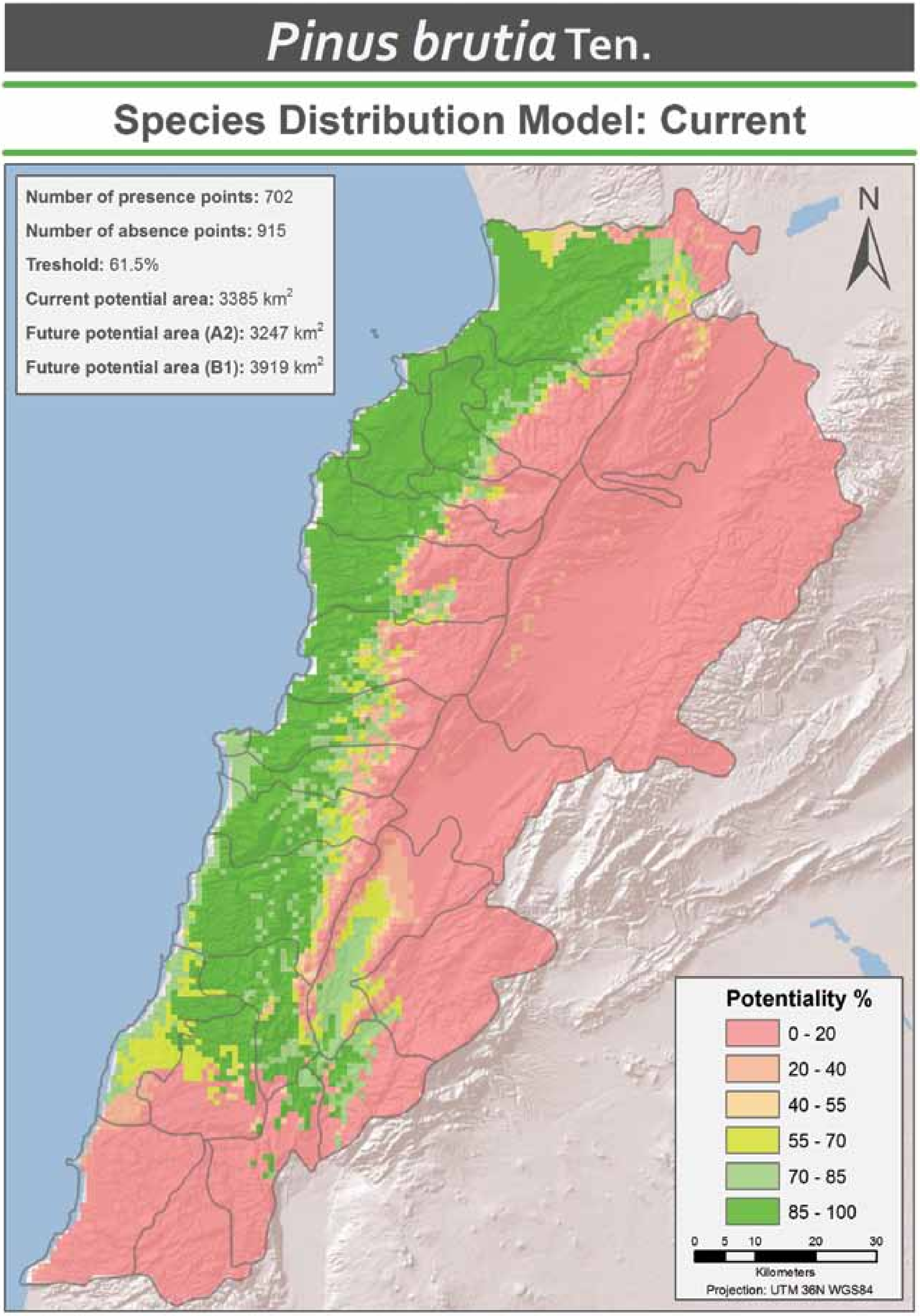
Current status:
Juniperus oxycedrus shows a current potential area widely spread through all the Mount Lebanon range, mainly in the west but also in northern and eastern slopes, with almost 3,200 Km^2.

Future status:
Prickly Juniper will lose more potentiality in the north, but keep a wide potential area surrounding the Mount Lebanon range.

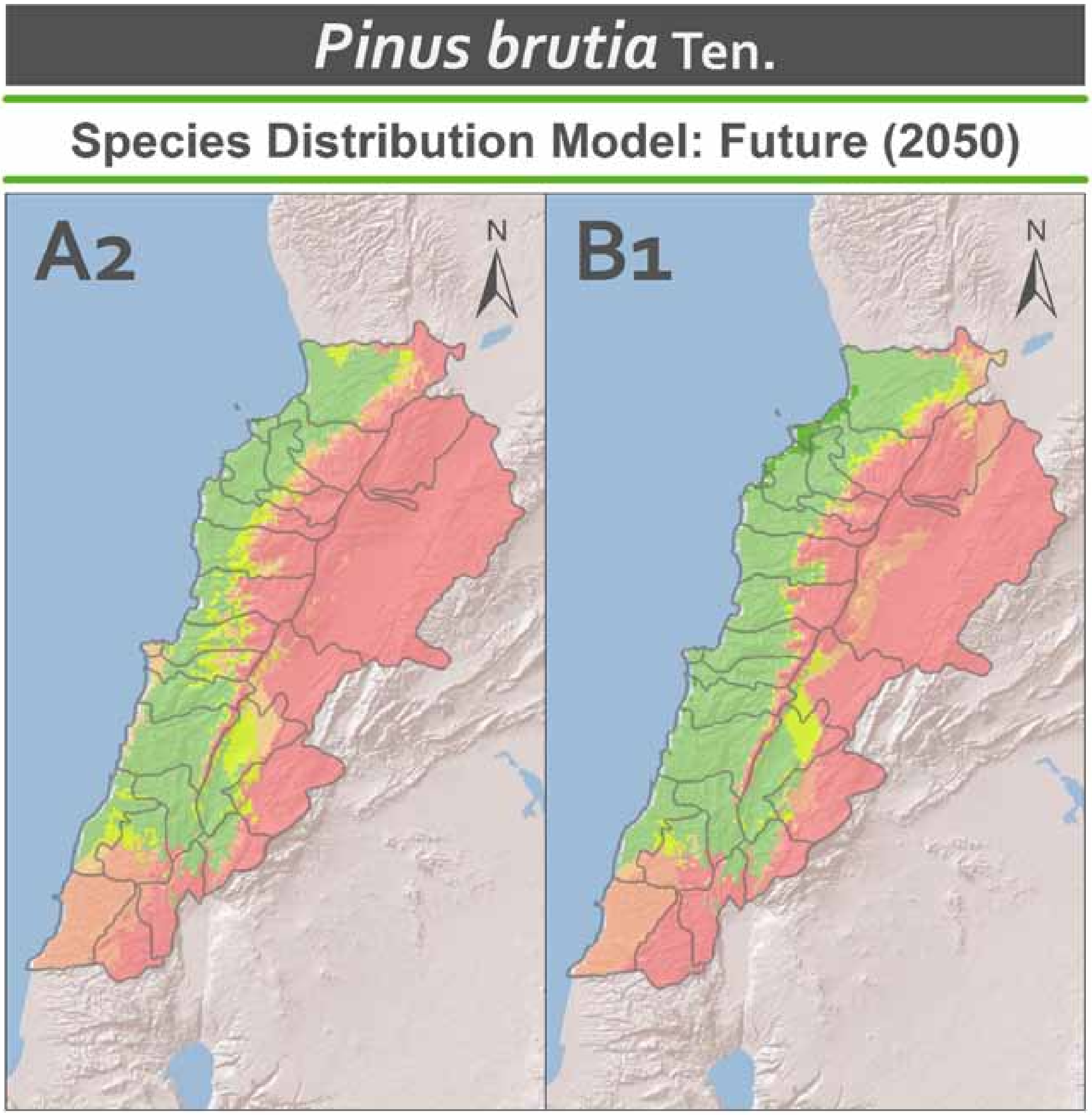
Following the models, this species will continue to have potential but its values will decrease in the north.



7.2.13 *Pinus brutia*



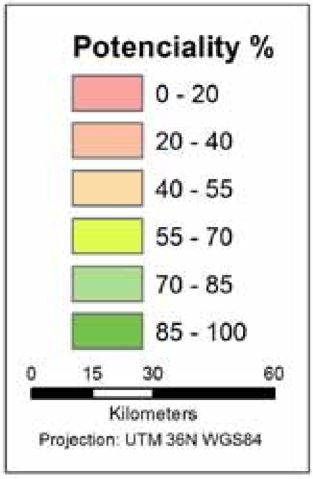
7.2.13 *Pinus brutia*



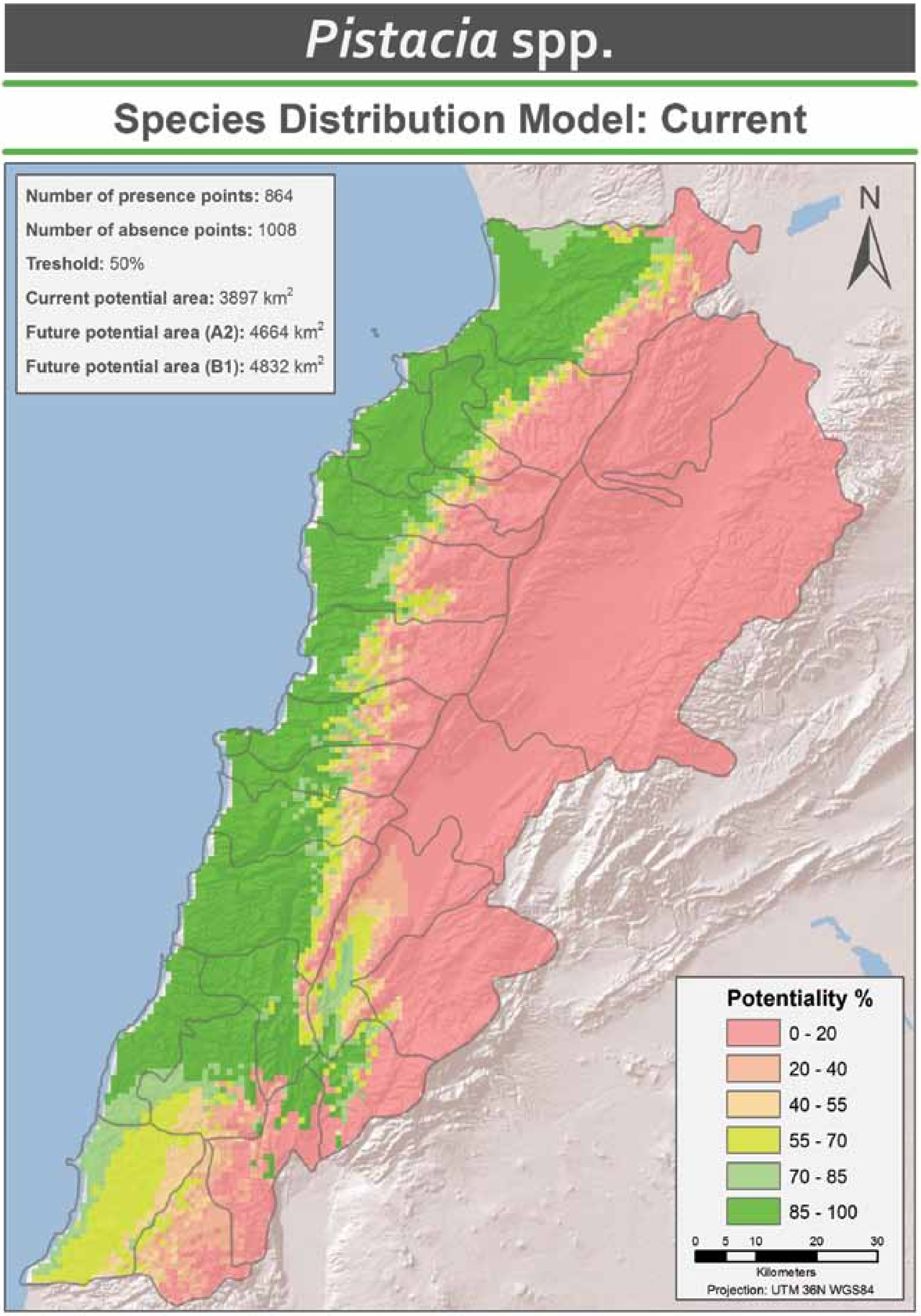
Current status:
Pinus brutia shows a large potential area throughout the western part of the country, with almost 3,400 Km^2.

Future status:
Turkish pine's potential area will increase but its potentiality values will decrease except in small patches in the north.

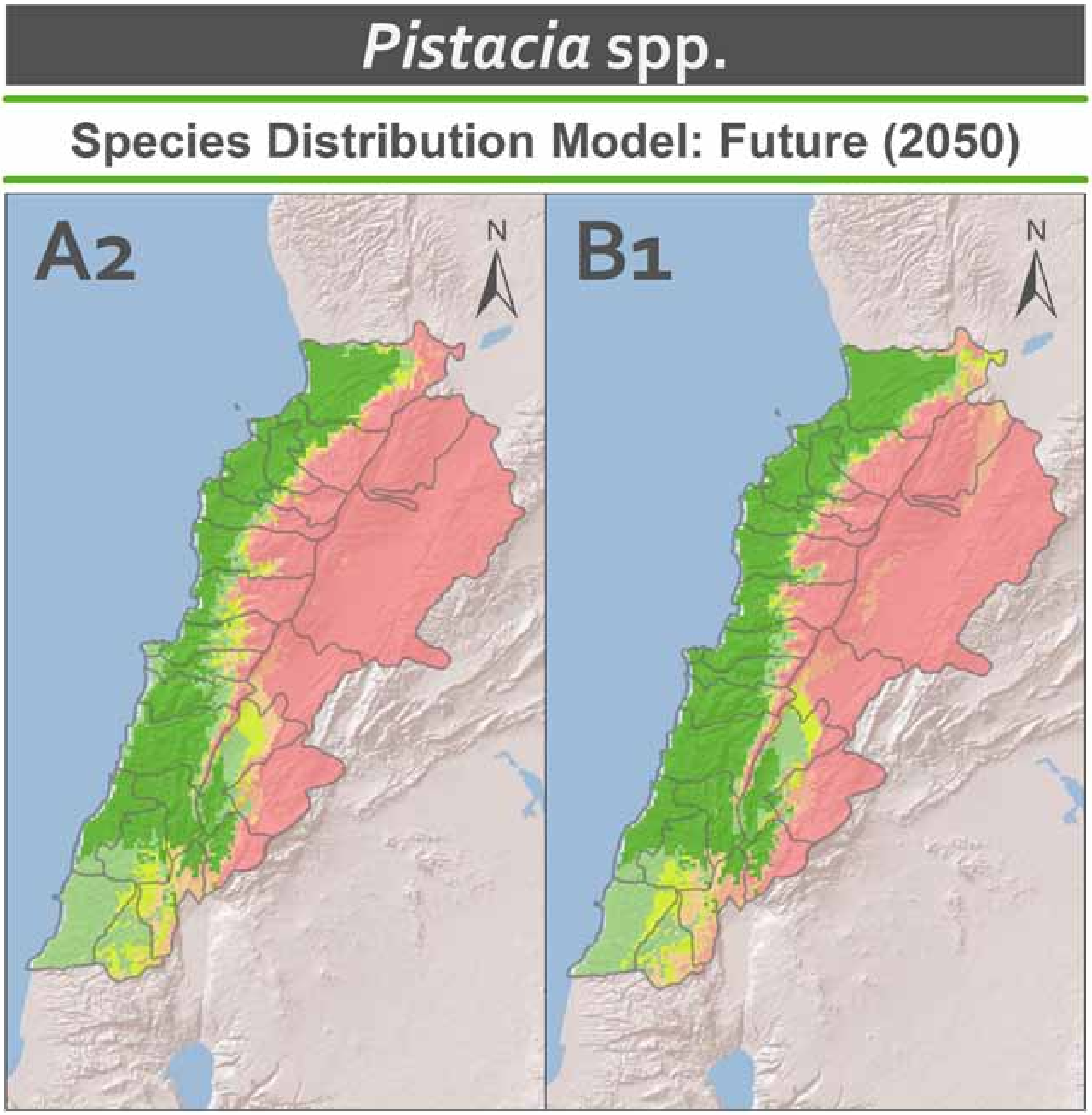
Following the models, this tree will continue being a major potential species in Lebanon, spread through the western slopes of Mount Lebanon and in areas in West Bekaa and Hasbaya.



7.2.14 *Pistacia spp.*



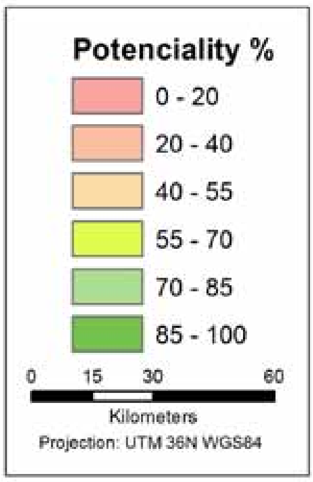
7.2.14 *Pistacia spp.*



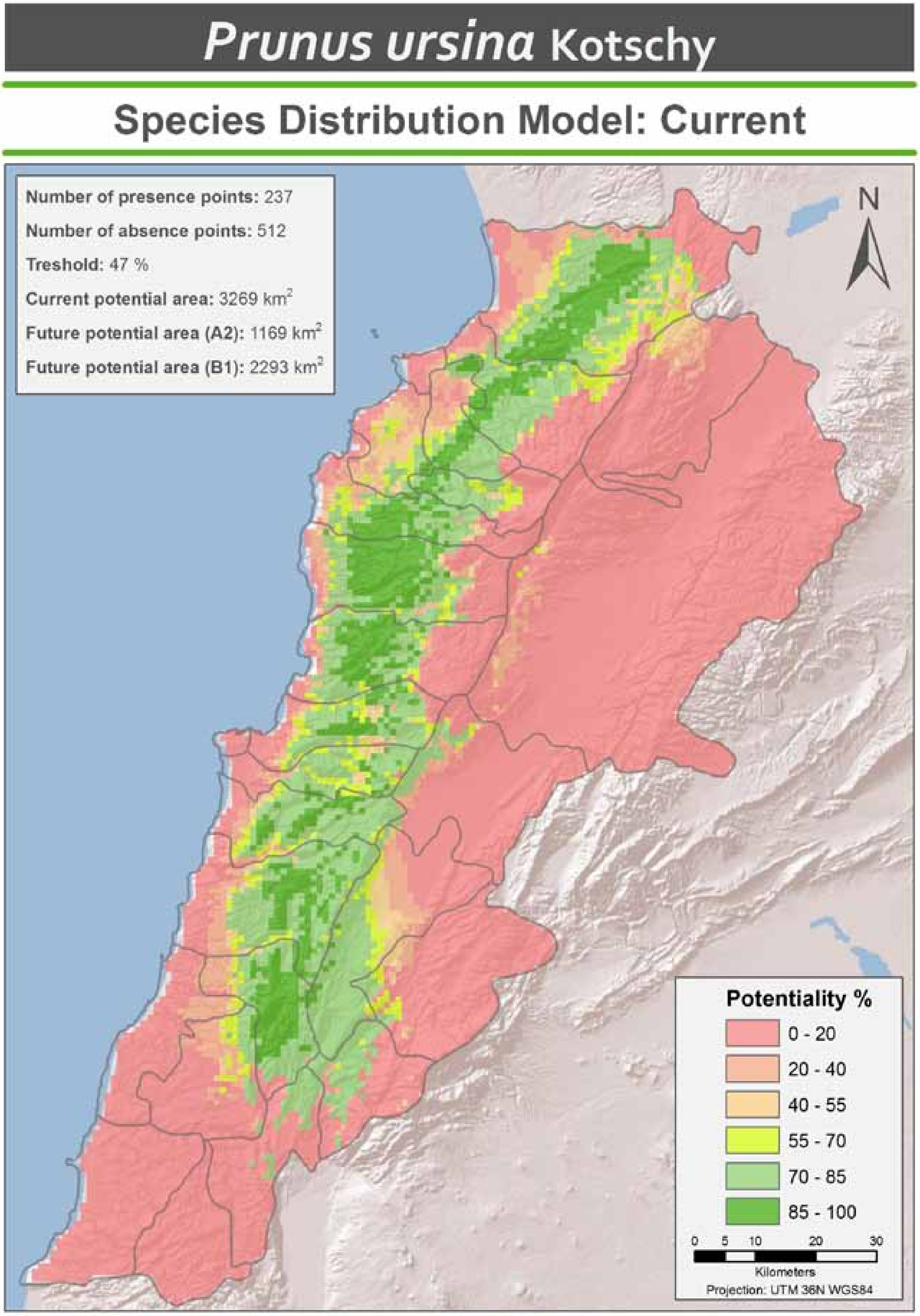
Current status:
Pistacia spp. shows a large potential area throughout the western part of the country, with almost 3,900 Km².

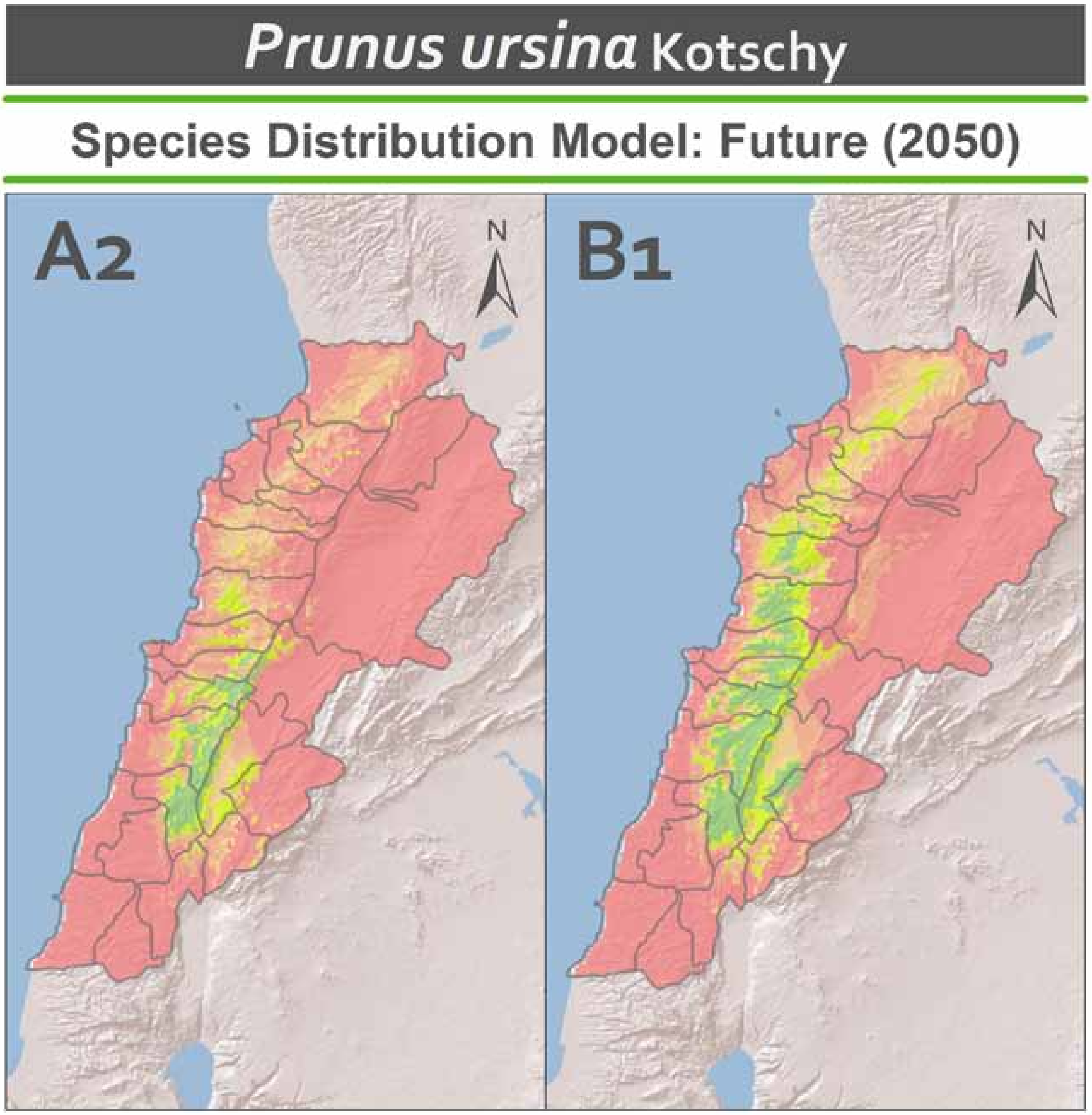
Future status:
Terebinth's potential area will notably increase in both considered scenarios, keeping high values of potentiality.

Following the models, this species will be a major potential species in the mid-term with both large potential area and high potentiality values.



7.2.15 *Prunus ursina*

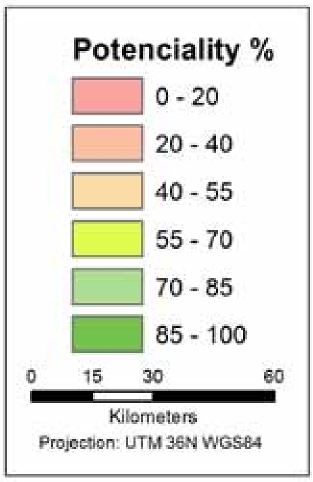




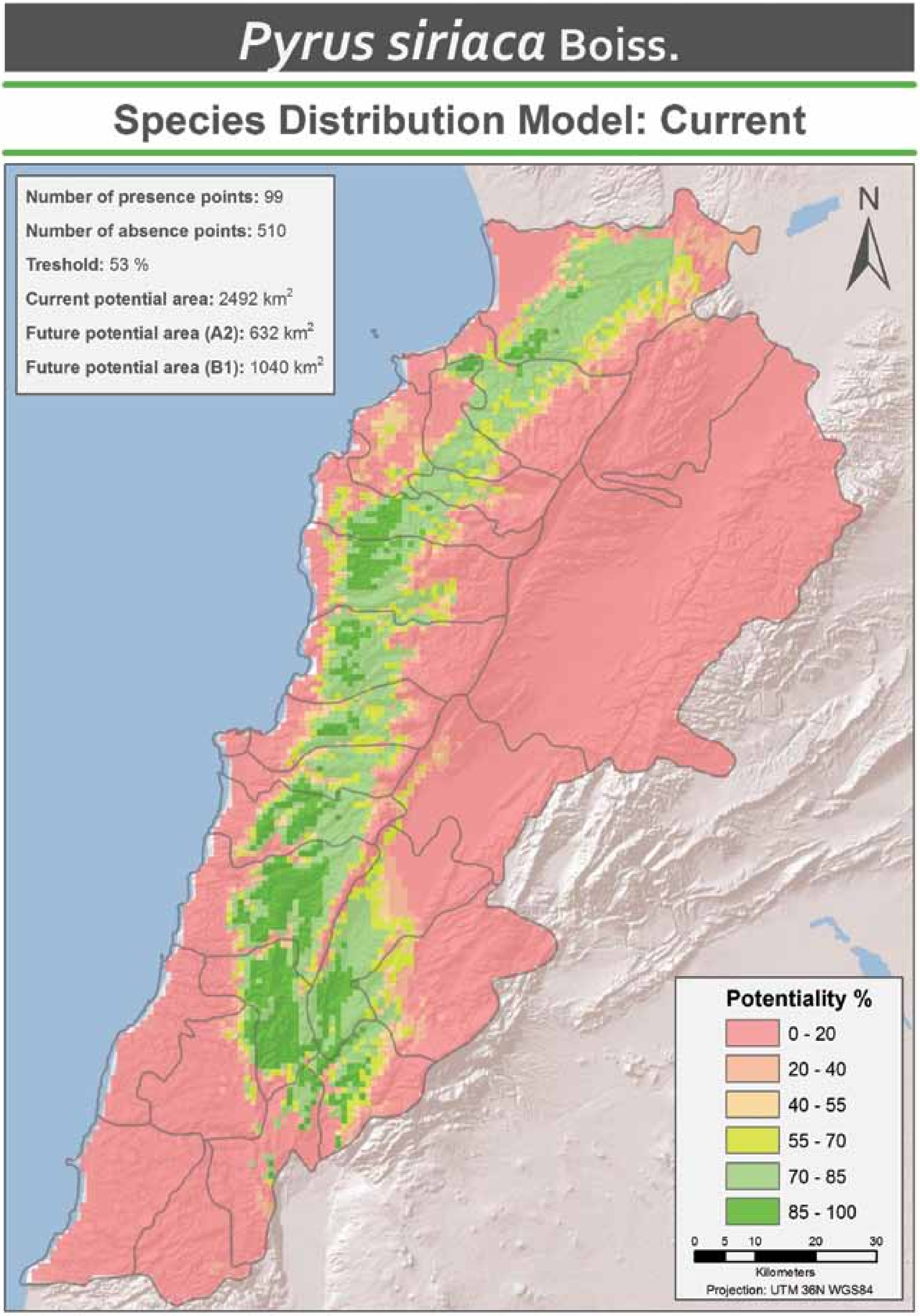
Current status:
Prunus ursina shows a large potential area throughout the western part of the country, with the southern part of the Mount Lebanon range being also potential in high altitudes with almost 3,300 Km^2.

Future status:
Bear's plum's area of potentiality will significantly decrease in both scenarios, keeping more surface in central and south Mount Lebanon.

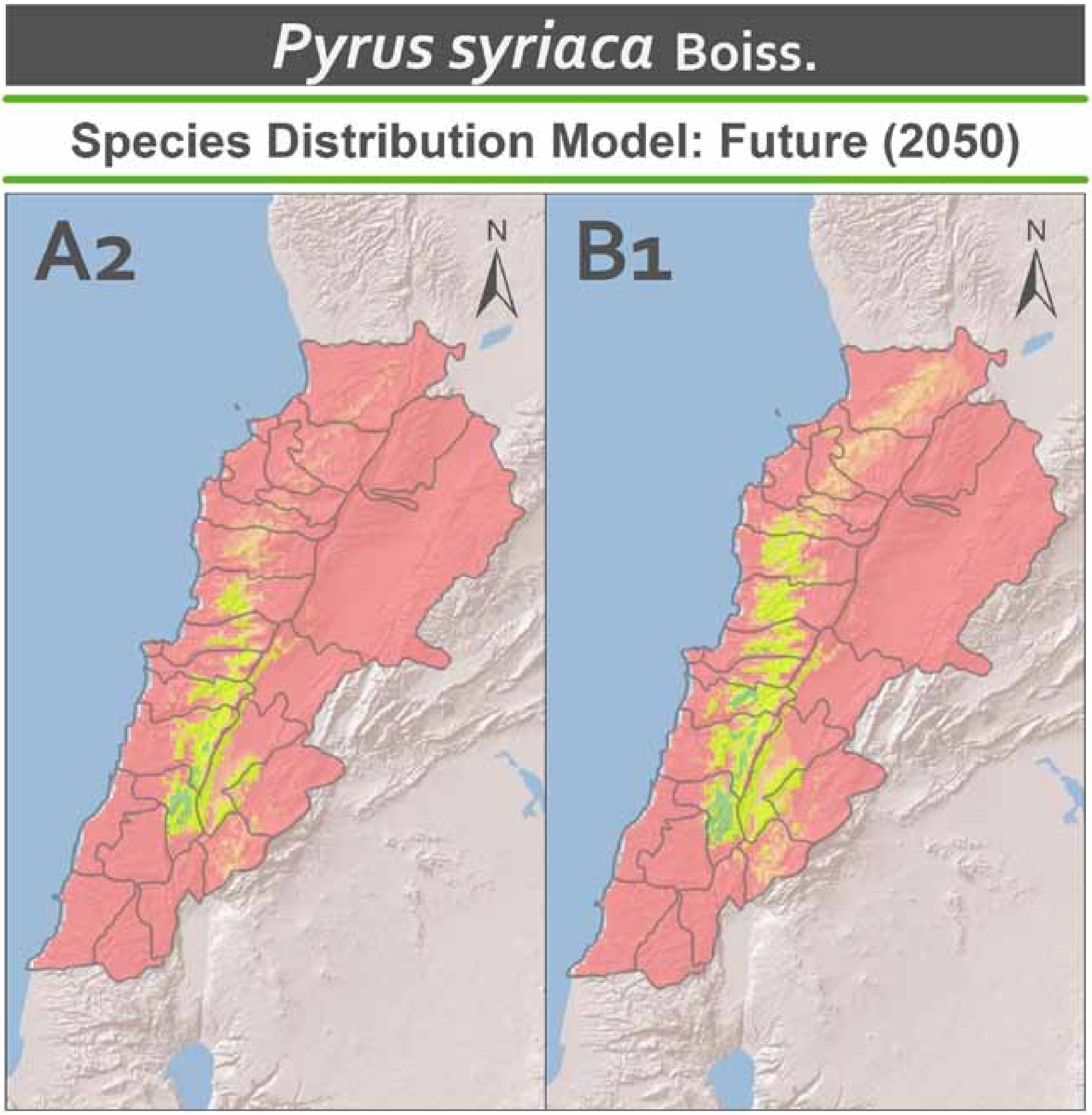
Following the models, this species will lose potentiality mainly in the northern part of the country.



7.2.16 *Pyrus syriaca*



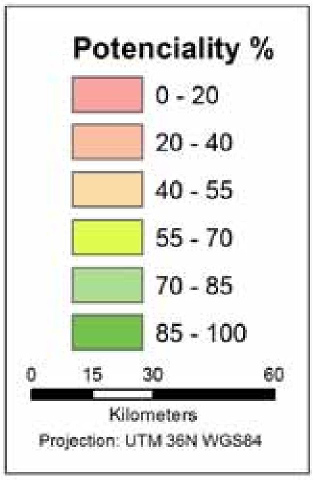
7.2.16 *Pyrus syriaca*



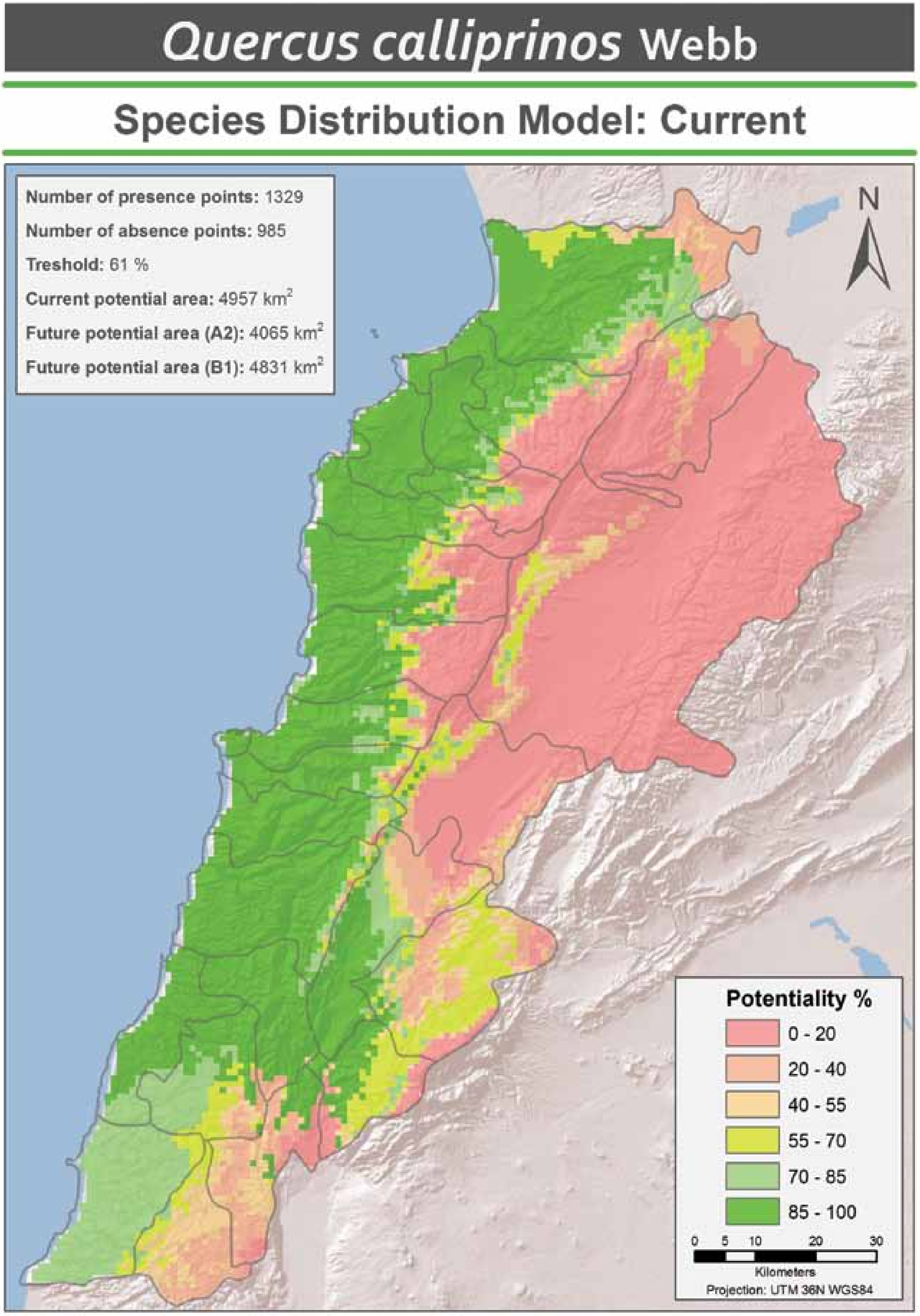
Current status:
Pyrus syriaca shows a wide potential area distributed throughout the western slopes of Mount Lebanon and some sectors of West Bekaa and Hasbaya, with almost 2,500 Km^2.

Future status:
Syrian Pear's area of potentiality will notably decrease in both scenarios, mostly in the north.

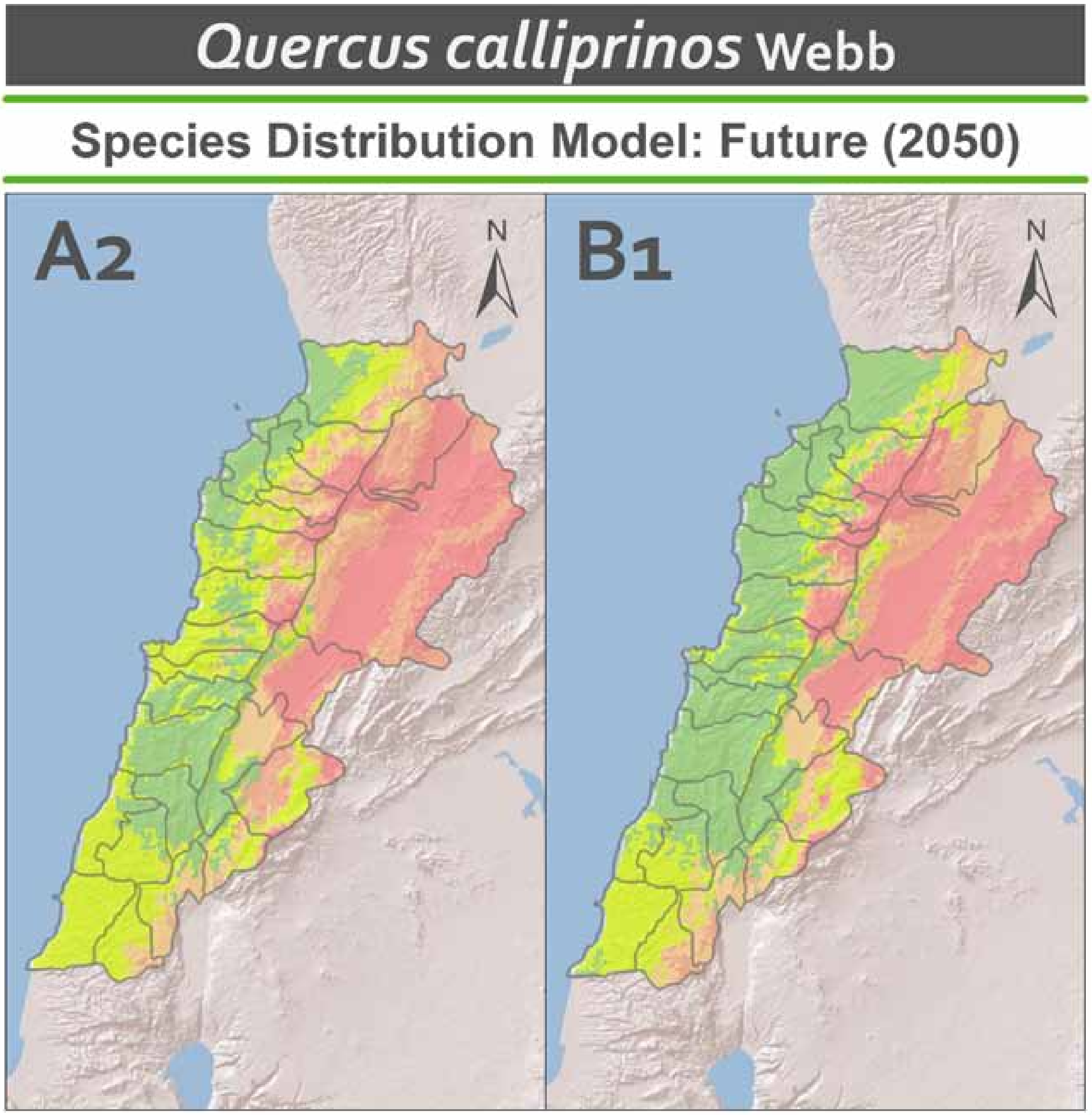
Following the models, this tree will lose potentiality mainly in the northern part of the country. Under future projection, it is no longer potential in these regions.



7.2.17 *Quercus calliprinos*



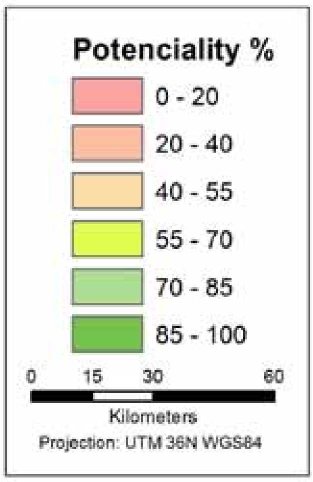
7.2.17 *Quercus calliprinos*



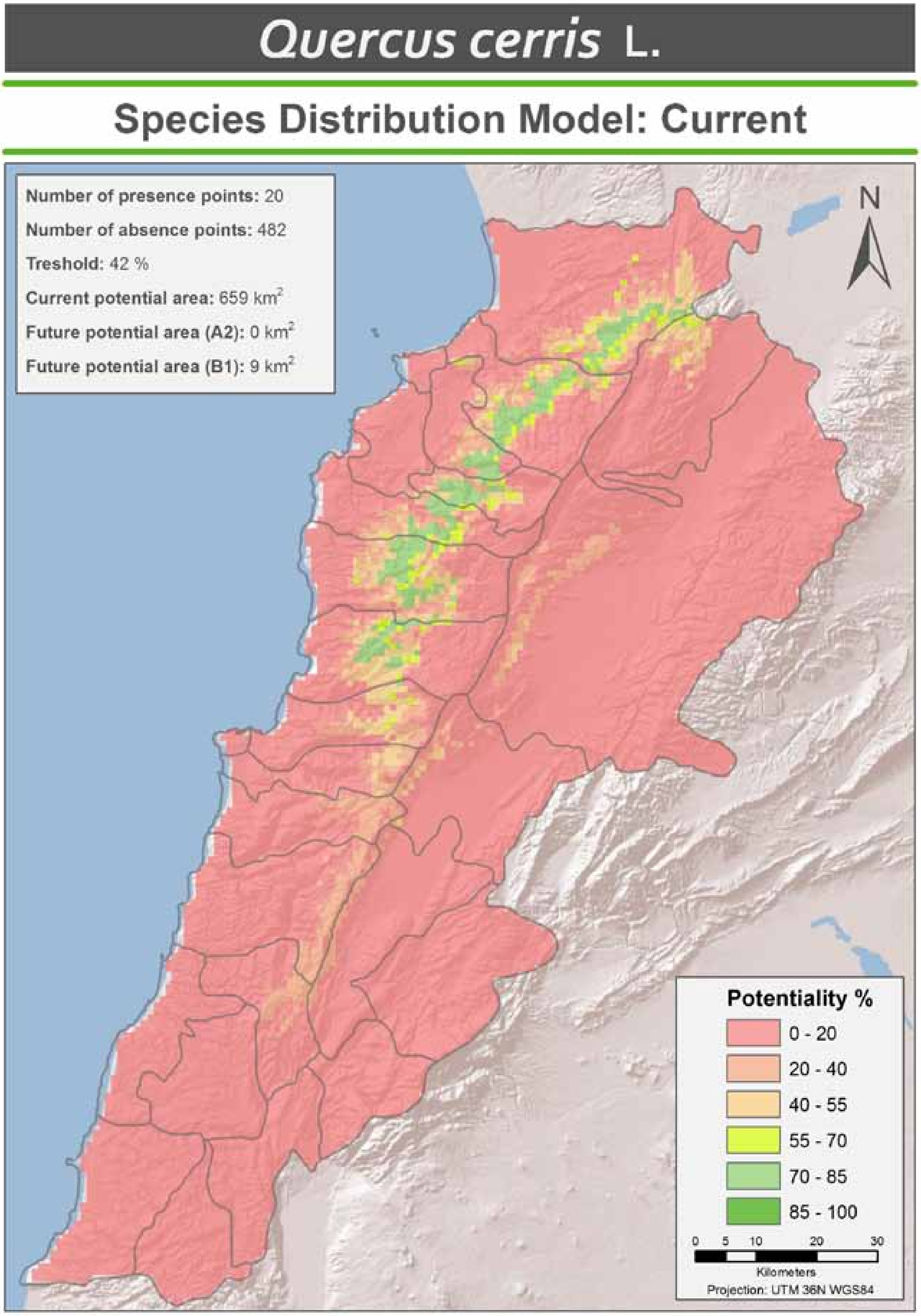
Current status:
Quercus calliprinos shows a wide potential area distributed throughout the western part of the country and areas in West Bekaa, Hasbaya and Marjaayoun, with almost 2,500 Km².

Future status:
Palestine oak will keep its area of potentiality in both scenarios, showing no significant changes in terms of potential distribution.

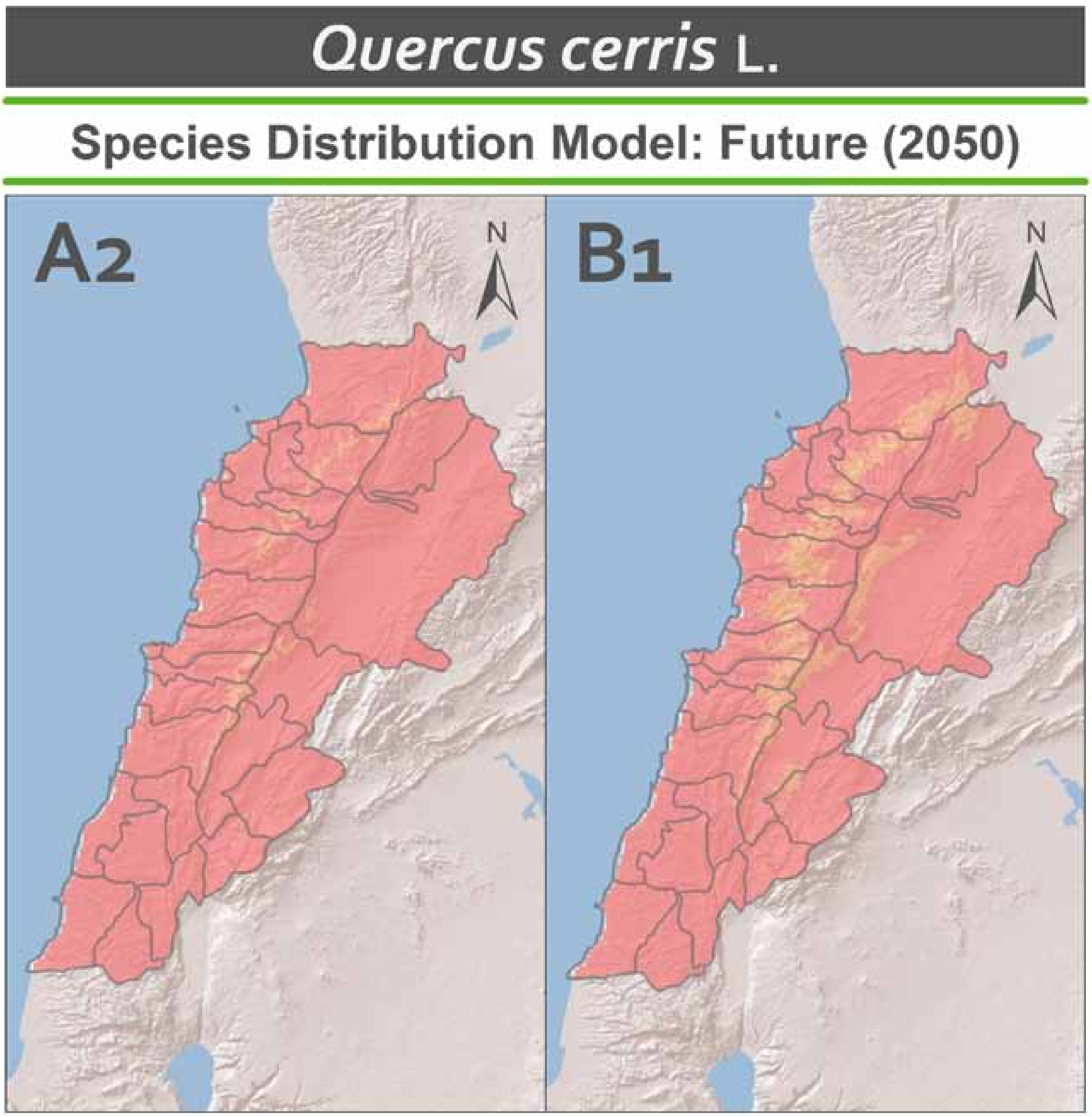
Following the models, this tree will lose potentiality values but keep the same current potential area.



7.2.18 *Quercus cerris*



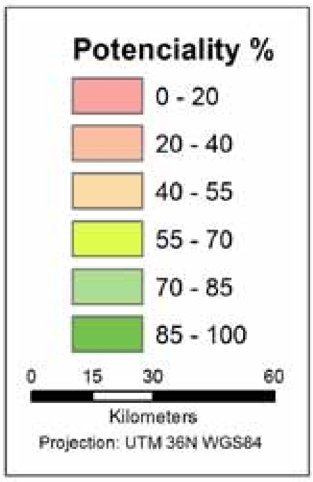
7.2.18 *Quercus cerris*



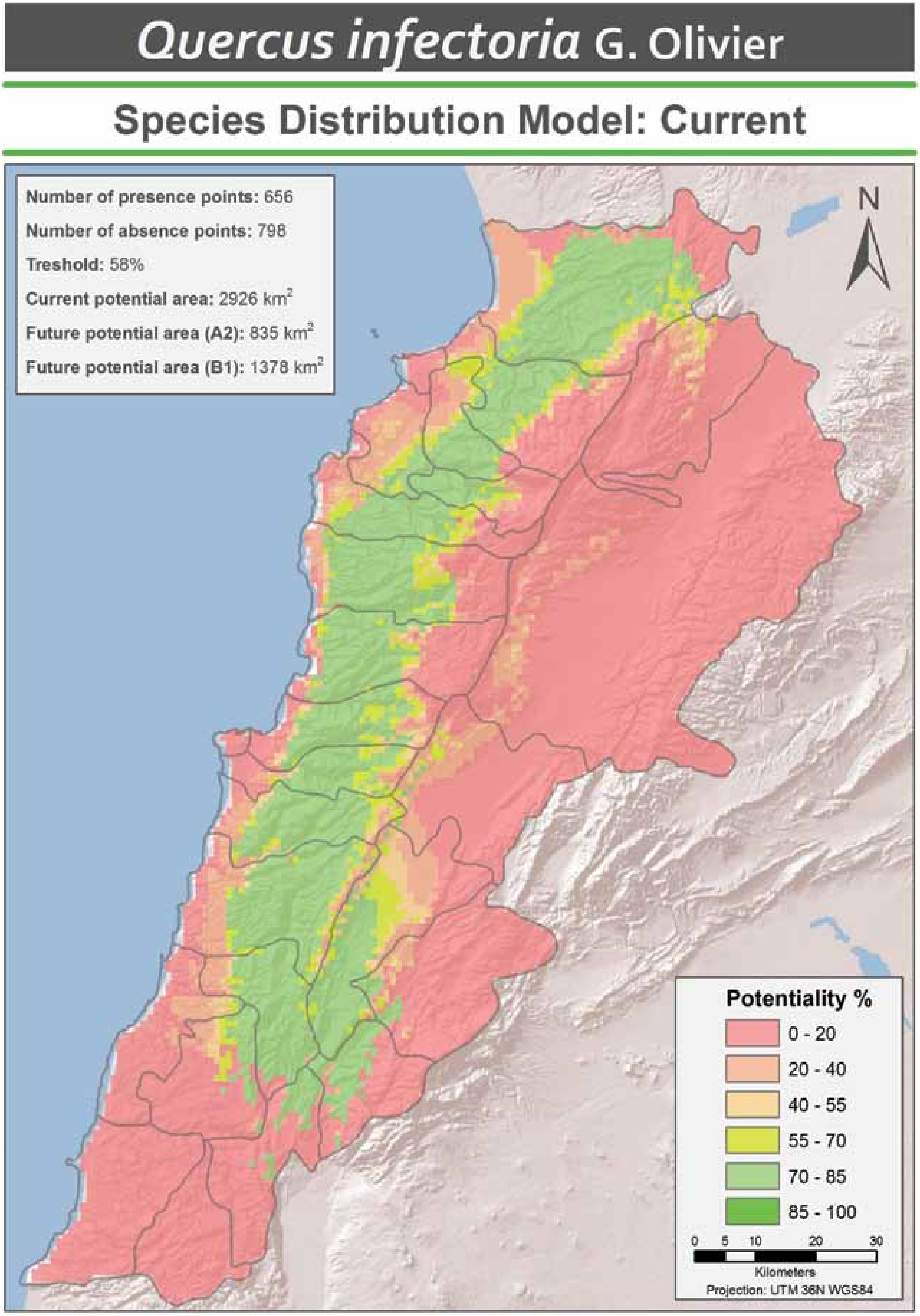
Current status:
Quercus cerris shows a small area of potentiality through central and north areas of the Mount Lebanon western slopes, with less than 700 Km².

Future status:
Turkey oak will drastically lose its potential area of potentiality in both scenarios, keeping just a few patches in the Kesrouane and Jbeil regions.

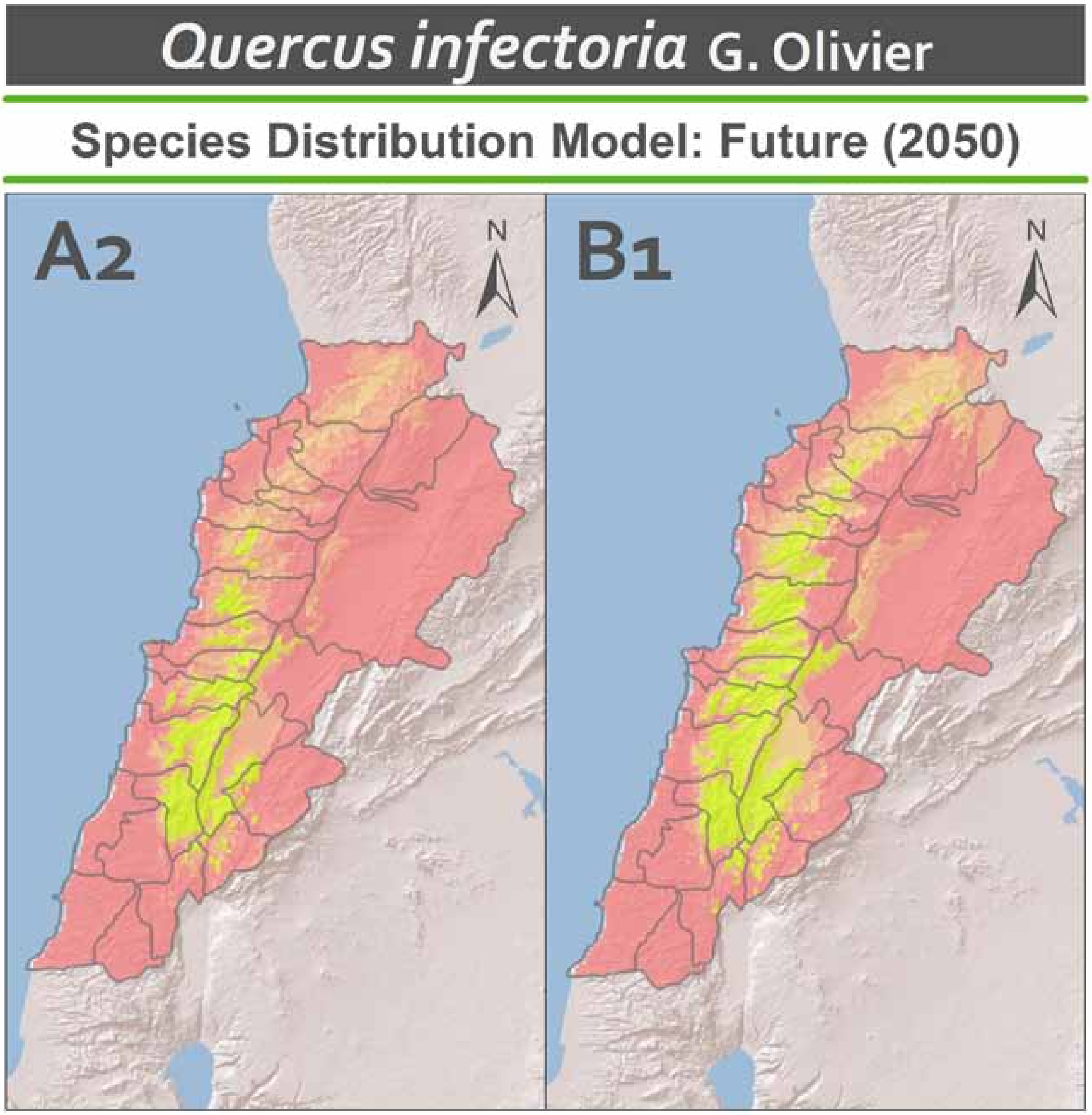
Following the models, this tree will become a non-potential species for Lebanon in the mid-term.



7.2.19 *Quercus infectoria*



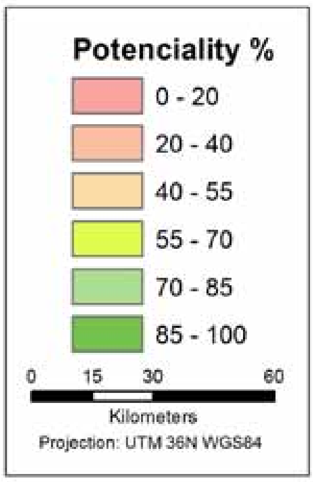
7.2.19 *Quercus infectoria*



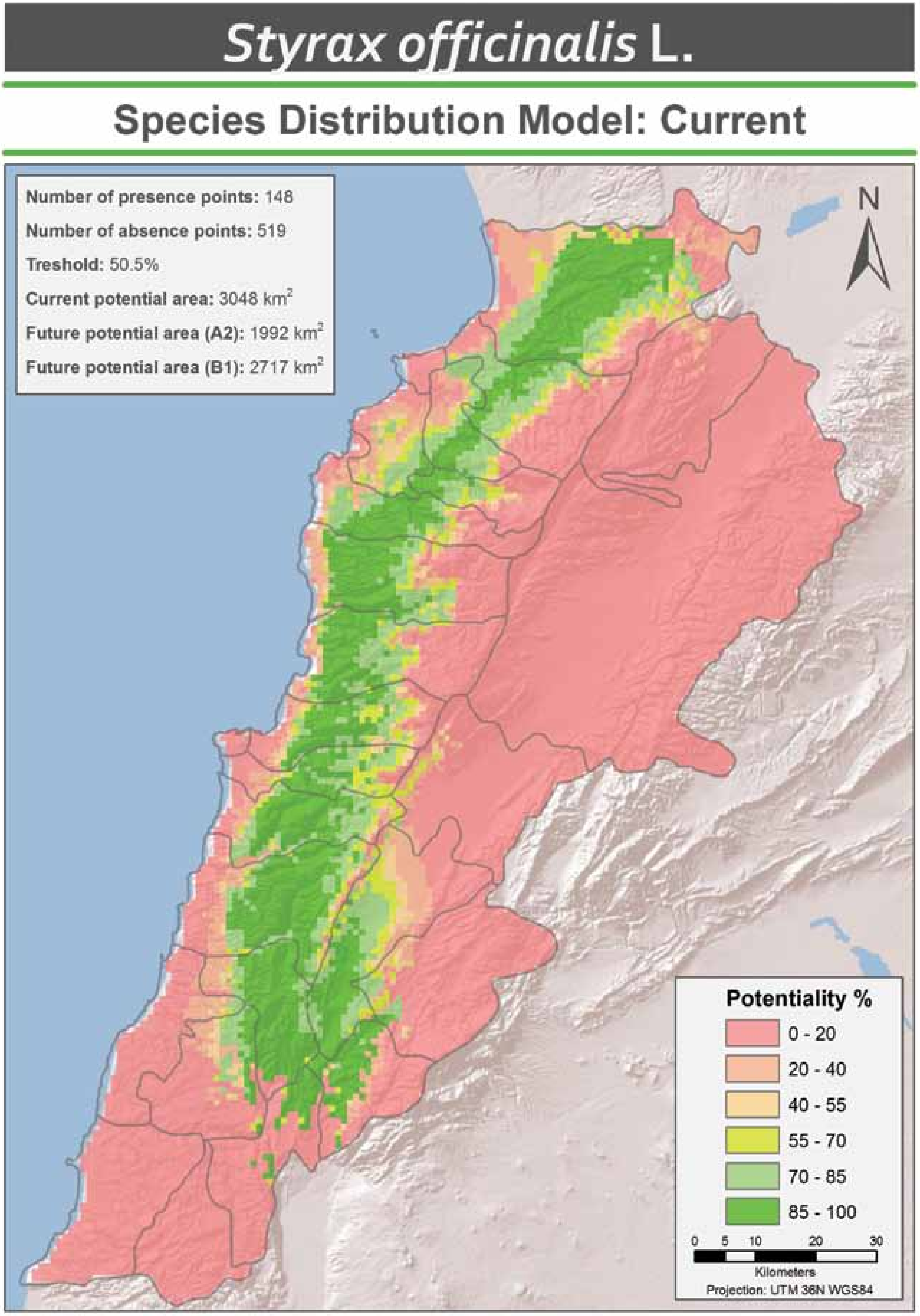
Current status:
Quercus infectoria shows a wide area of potentiality spread through western parts of Mount Lebanon, West Bekaa and areas in Hasbaya and Marjaayoun, with almost 3,000 Km².

Future status:
Allepo oak will lose more potential area in the north part of the country, showing lower potentiality values.

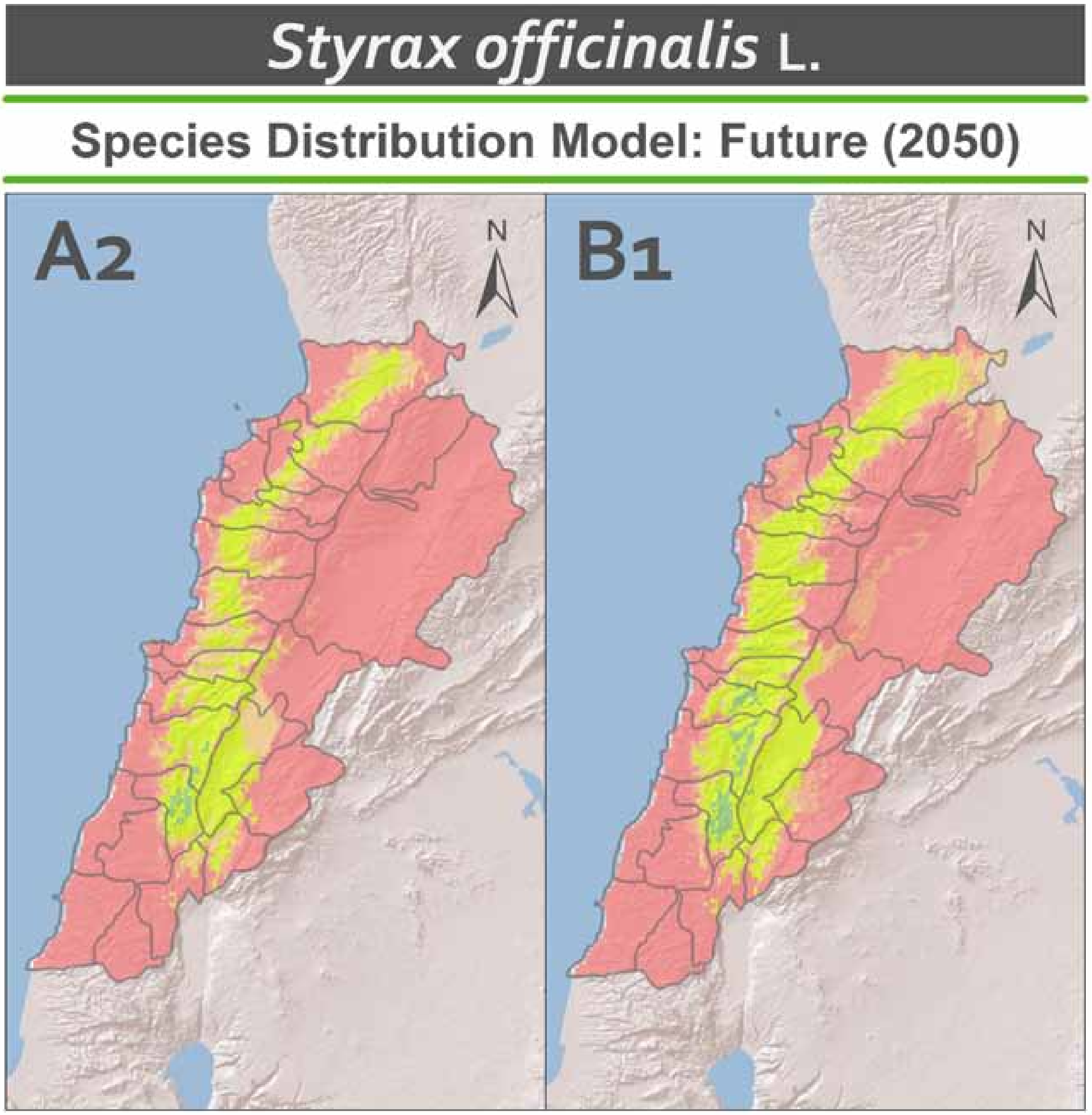
Following the models and the considered variables, this tree will significantly lose potential area.



7.2.20 *Styrax officinalis*



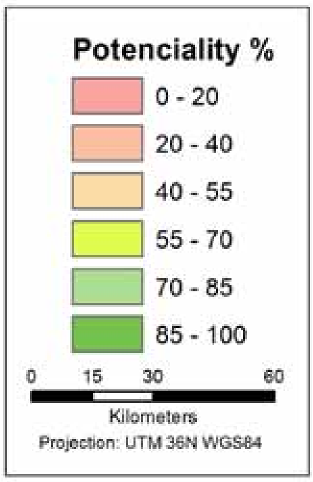
7.2.20 *Styrax officinalis*



Current status:
Styrax officinalis shows a wide potential area distributed throughout the west part of the country and areas in West Bekaa, Hasbaya and Marjaayoun, with around 3,000 Km^2.

Future status:
Styrax will keep its potential surface in the best scenario but its values of potentiality will decrease in the mid-term.

Following the models, this tree will keep almost the same distribution of potential area, but its values of potentiality will decrease.



8. POTENTIAL SPECIES RICHNESS

Potential distribution models are reclassified into two classes, potential and non-potential, by choosing a threshold objectively (see **Table 4, Annex II)**. This simplification allows maps of individual species to be overlapped. This creates a single synthetic map where the value of each point shows the number of potential species in the considered location.

The potential richness maps produced in this work are not biodiversity maps but indicators of how many species have a high potentiality value at each location. Logically, these maps depend closely on the studied taxa. They represent a way of synthesizing the potential distribution models and have been frequently used for diverse taxonomic groups under a global approach (Cumming, 2000; Hortal et al., 2004; Wohlgemuth et al., 2008).

Current and future potential species richness maps have been developed for all combinations of scenarios and models.

Visual interpretation of the maps shows a progressive reduction in the potential species richness with a general deterioration of the conditions to sustain diversity. A higher intense loss gradient is found in the north of the country. This is consistent with predicted climate trends which show a general increase in temperature and a larger decrease of precipitation in the north than the south.

Some areas show low values of potential species richness. This can be interpreted as due to worsened climatic conditions as well as the current absence of flora due to increased human pressure on these regions, mainly agriculture-wise (Bekaa valley and South Lebanon).

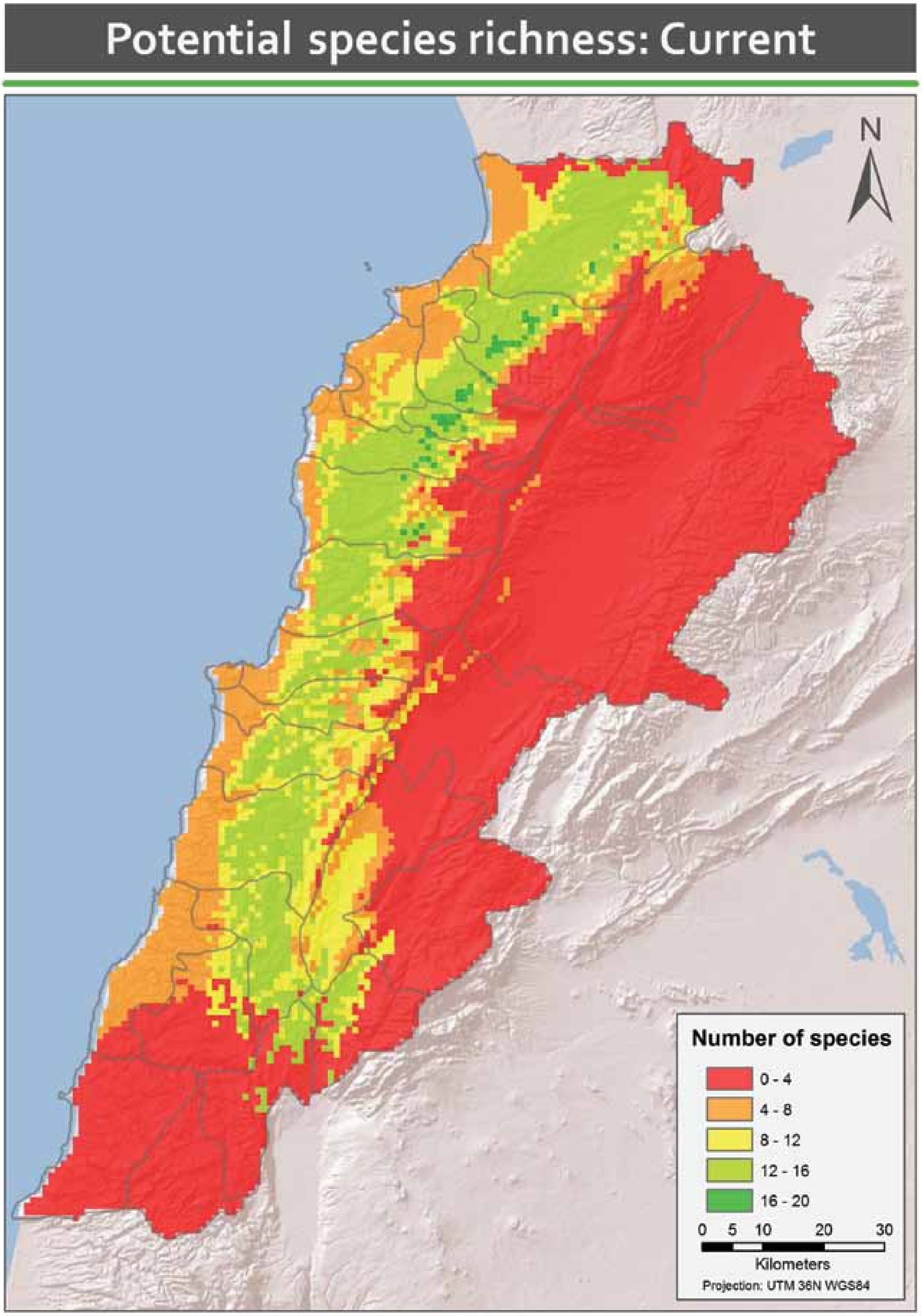
Because they maintain a suitable climate niche for some taxa, areas holding relatively high values of potential species richness throughout the study period can be considered as possible refuge areas. Appropriate taxa may include those not considered in this study (associated flora).

8.1 MAPS OF POTENTIAL SPECIES RICHNESS

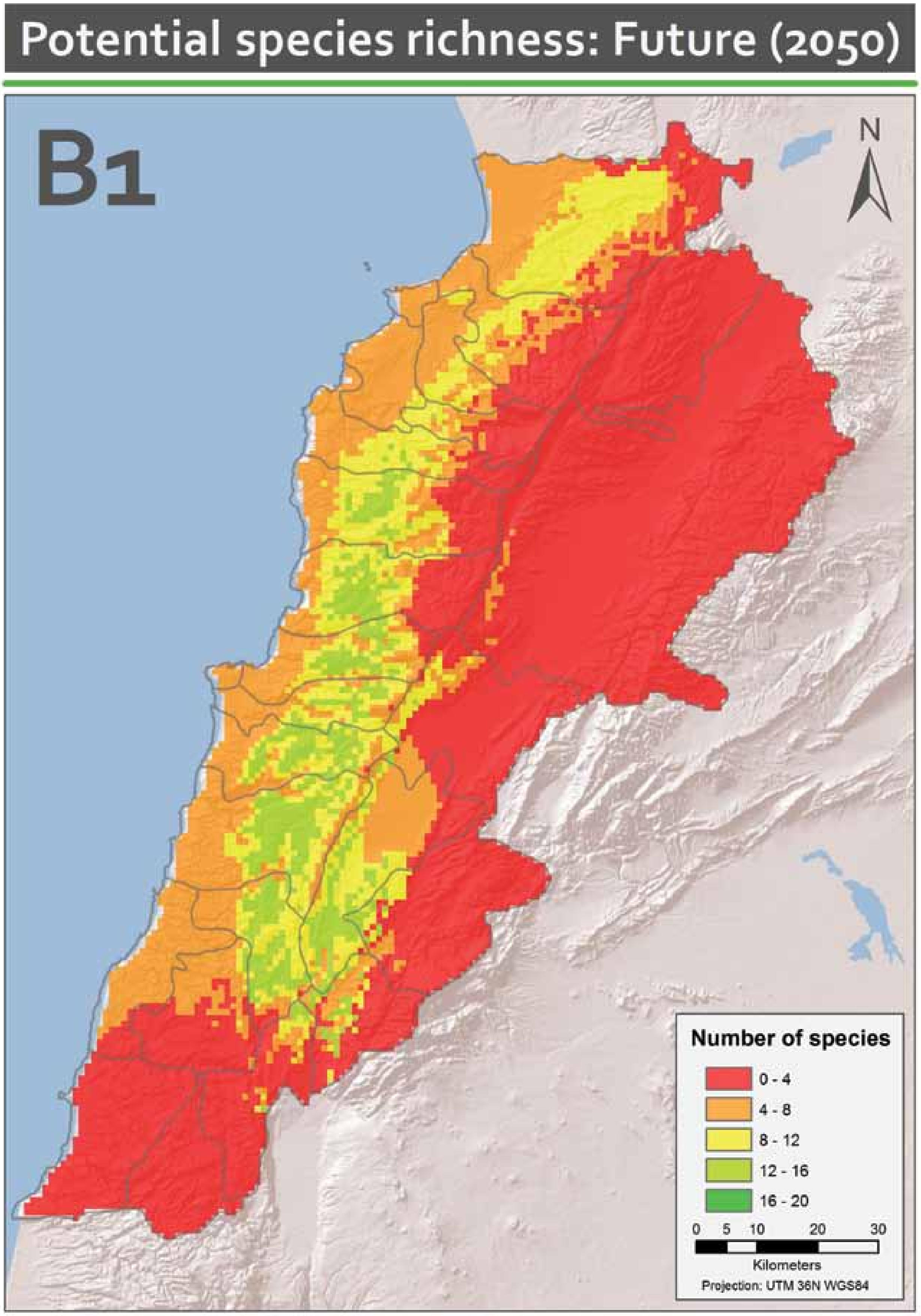
The maps below show the results for current conditions as well as A2 and B1 future scenarios regarding potential species richness.

8. POTENTIAL SPECIES RICHNESS

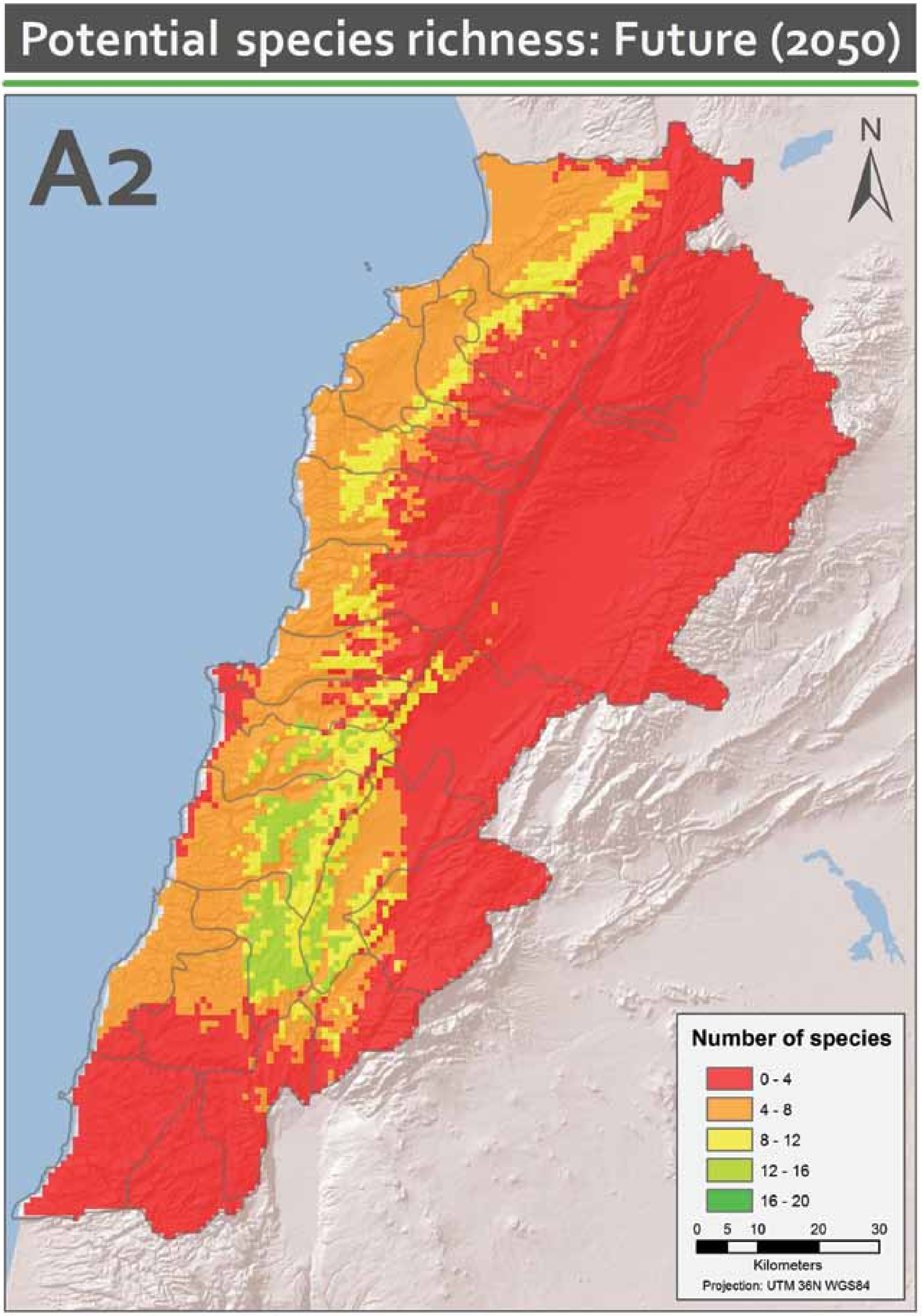
8.1.1 Current Potential Species Richness



8.1.2 Future Potential Species Richness: B1 Scenario



8.1.3 Future Potential Species Richness: A2 Scenario



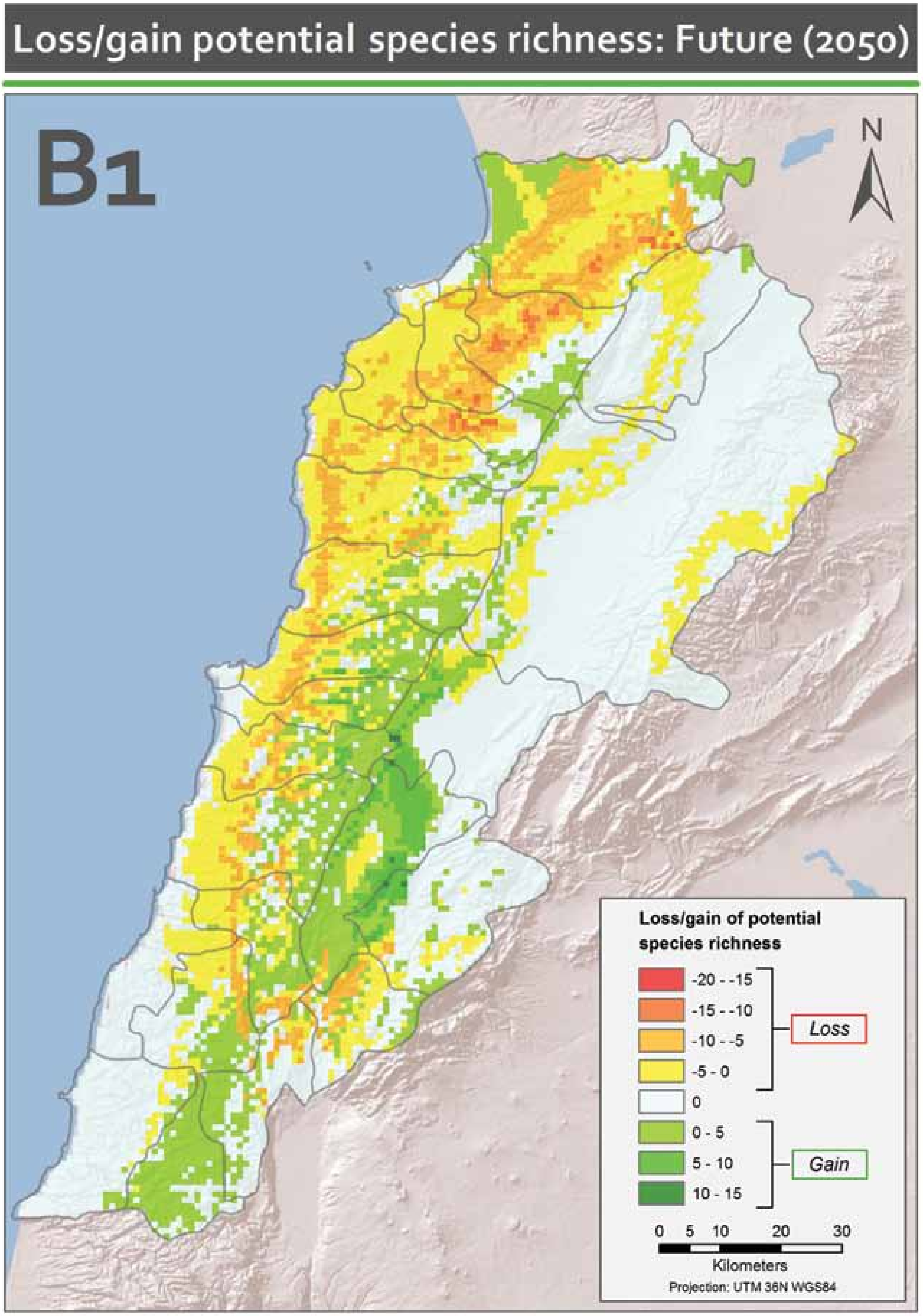
8.2 LOSS/GAIN POTENTIAL SPECIES RICHNESS

Loss/gain potential species richness was calculated by subtracting future potential richness from current potential richness in both scenarios. These maps are classified in seven different classes to show the potential loss or gain in terms of number of species.

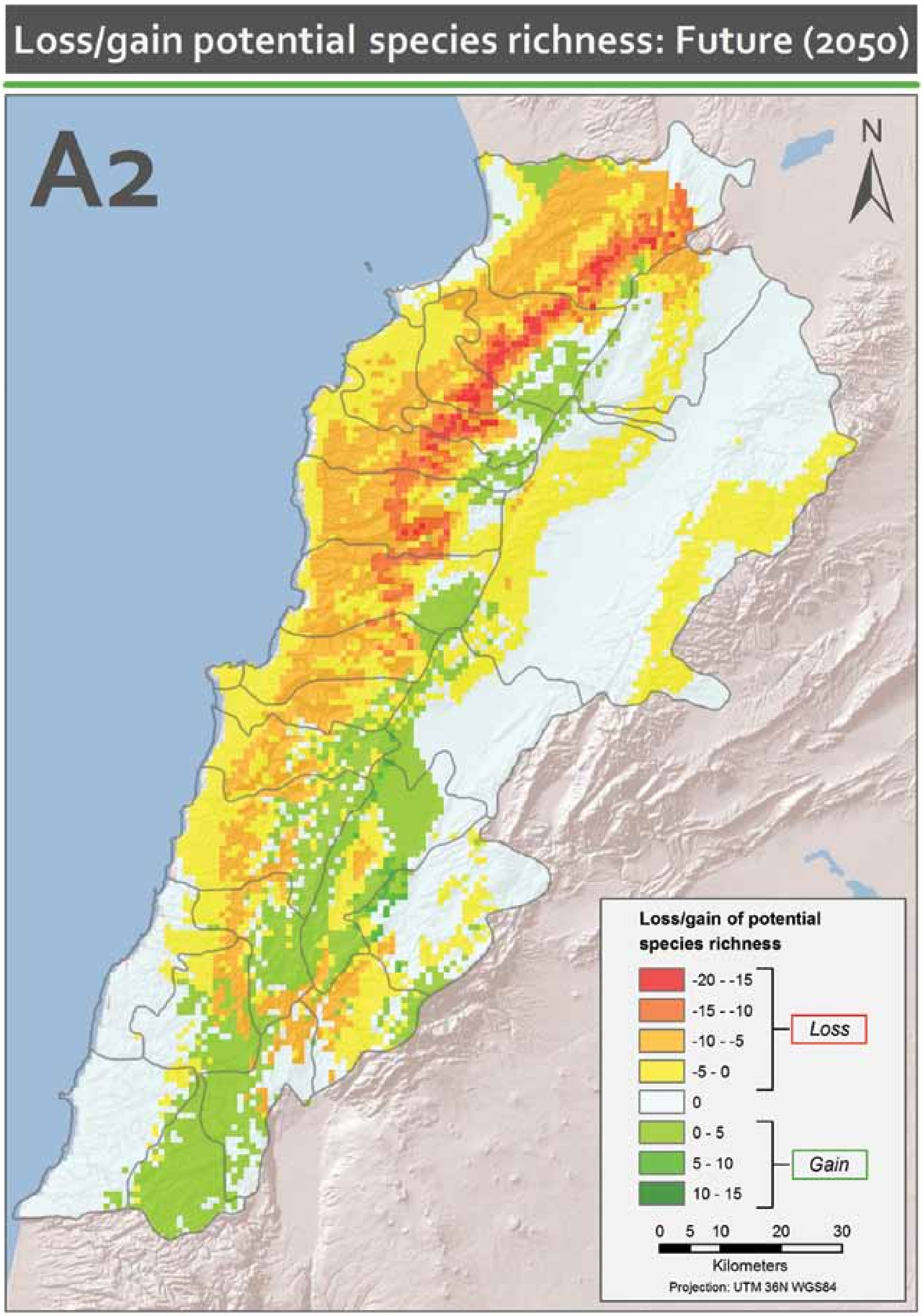
Areas with a future potential species richness decrease are shown with below zero values. This shows that in these places, the number of potential species will be lower than current potentiality.

Locations with a future potential species richness increase are shown with positive values. These areas are identified as future spots where higher potential species richness is expected.

8.2.1 Loss/Gain Potential Species Richness: B1 Scenario



8.2.2 Loss/Gain Potential Species Richness: A2 Scenario



8.3 CRITICAL AREAS

Delimitation of critical areas was performed for each combination of scenarios and modeled according to the following procedure:

- Development of species loss or gain maps by subtracting future potential richness from current potential richness in both scenarios;

- Arithmetic mean of potentiality values of both scenarios;

- Segmentation of resulting map into three classes (Felicísimo et al., 2011):

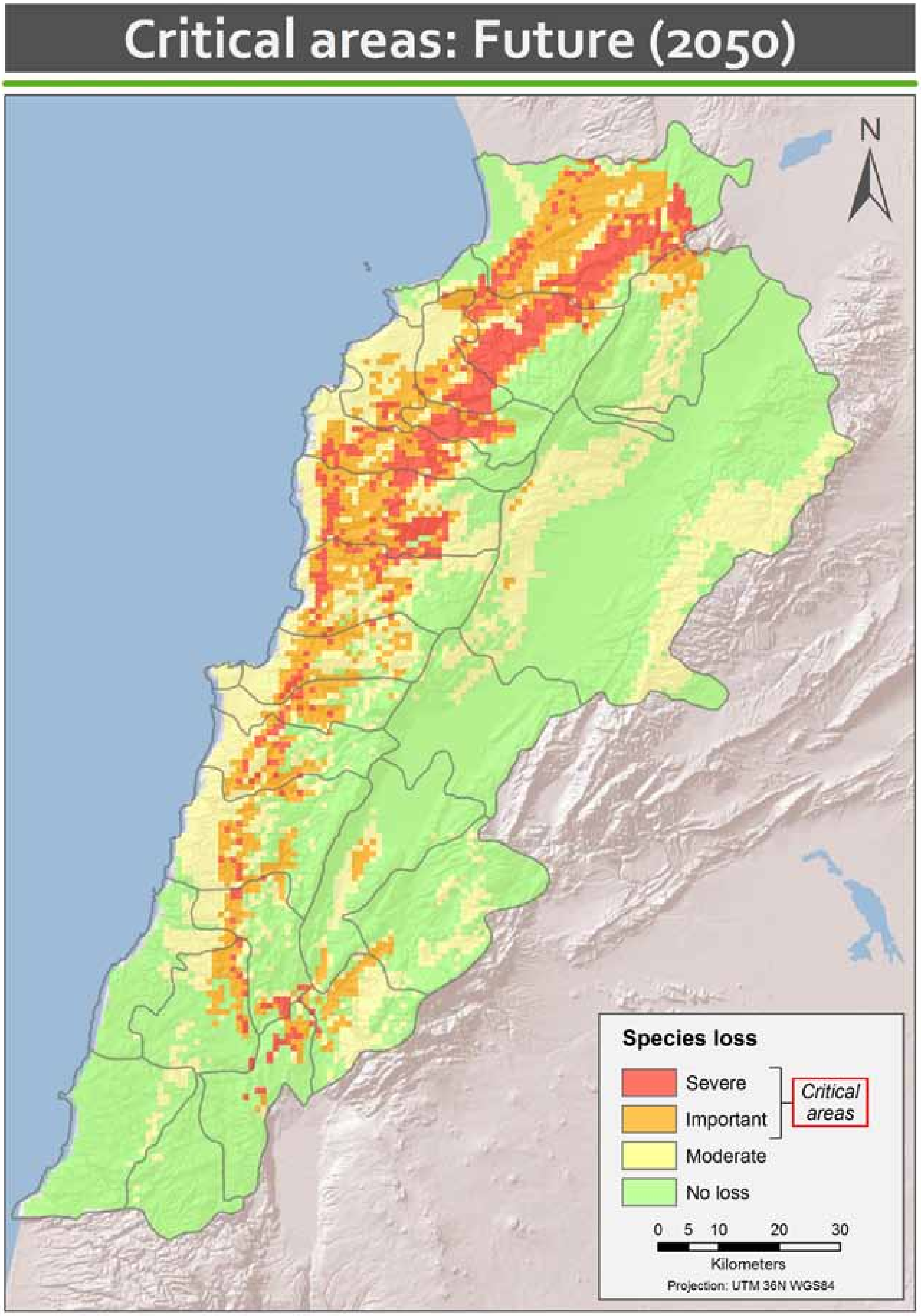
  - Moderate loss or no loss: until 75th percentile of the species differential
  - Important loss: between 75th and 90th percentile of the species differential
  - Severe loss: above 90th percentile of the species differential

Once the loss/gain maps were developed, critical areas were identified by making the arithmetic mean of both scenarios and segmenting the resulting map into three classes by applying 75th and 90th percentiles. These classes were classified as **severe, important,** and **moderate** loss. Areas where severe or important loss occurs are considered as critical areas for adaptive management and restoration.

In this case, 75th and 90th percentile corresponds to climatic niche loss for 3 and 6 species respectively.

A forth class was designated as **no loss**, corresponding to the areas where no loss or slight gains were detected. These areas, in addition to those classified as **moderate**, are not considered critical in terms of ecological restoration under climate change effects.

8.3.1 Critical Areas Map



9. APPLICATION OF RESULTS TO RESTORATION AND ADAPTIVE MANAGEMENT IN A CONTEXT OF GLOBAL CHANGE

Adaptation and mitigation measures against climate change are essential in active forest management in Mediterranean forests. Without intervention, forest species will suffer severe damages, especially those species growing in small and isolated populations (Davis, 1989).

Four main categories of adaptation and mitigation actions can be considered (Millar et al., 2007):

Resistance measures: actions aiming at anticipating future changes to conserve a relatively similar forest status. Defense measures against disturbances and/or conservation of highly valued resources.

Resilience measures: actions designed to absorb a certain level of impact but aiming at returning to prior conditions after the disturbance has occurred, either naturally or through human intervention.

Response measures: actions projected to adapt the ecosystems rapidly to future changes, accommodating to new conditions without keeping the prior status as a principal ecosystem.

Reduction measures: mitigation measures aiming at decreasing greenhouse gases concentration and its climate change effects through carbon sequestrations and renewable energy use.

In terms of forest resources and management, adaptation measures that can be considered in protection instruments include, among others (Felicísimo et al., 2011):

- Inclusion or modification of legal instruments such as catalogs of species and / or threatened habitat types;
- Specific actions included in conservation or management plans for specific taxa and / or habitat types;
- Creation of ecological corridors and other actions to permeabilize the territory and to promote connectivity, reducing forest fragmentation;
- Restoration of degraded ecosystems and adaptation of new potential areas;
- Introduction, reintroduction, and translocation of threatened species;
- Germplasm collection and genebank conservation.

Also, and according to future climate forecasts, the risk of forest fires will increase. Thus, prevention of forest fires and adaptive silviculture must be considered, in addition to the control of overgrazing and human pressure in natural ecosystems.

9. APPLICATION OF RESULTS TO RESTORATION AND ADAPTIVE MANAGEMENT IN A CONTEXT OF GLOBAL CHANGE

9.1 ADAPTATION MEASURES PER SPECIES

Management guidelines were proposed depending on species potentiality at present and under future forecasts (**Table 1**):

Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystems adaptation
D	No	No	No action

Table 1. Management Guidelines Depending on Current and Future Potentiality Status

Management propositions were classified in four classes:

Conservation/Restoration: measures projected for areas where the species is potential and keeps this potential status in the future. Conservation measures are proposed for areas where the species already occurs:

- Legal frame for protection and/or management and creation of protected natural areas covering important populations or specific locations;
- Restoring component species in degraded and disturbed ecosystems;
- In situ conservation: preventive silviculture, habitat maintenance, species recovery programs;
- Enrichment plantations aimed at increasing population density in areas where this factor is defective.

In areas where the species doesn't occur despite being potential, restoration measures are proposed:

- Reforestation.
- Introduction of species and genotypes in forested areas as principal/secondary species.

9. APPLICATION OF RESULTS TO RESTORATION AND ADAPTIVE MANAGEMENT IN A CONTEXT OF GLOBAL CHANGE

Adaptive silviculture: measures projected for areas where species is currently potential but will lose potential status in the future. These actions aim at increasing the resilience of the species against future climate change effects. Main actions:

- Density management: due to site resource demand, climate-related stressors can be mitigated by managing the number of individuals growing in a certain surface. Stand vigor can also be incremented, but related factors such as humidity loss due to wind or direct sunlight under open canopy should be considered;

- Control of threats: exhaustive control of pests and diseases, removal of affected individuals, forest fires prevention measures;

- Ex situ conservation: collections and conservation of germplasm, translocation of high value or threatened species to better locations, etc.

Ecosystems adaptation: measures projected for areas where the species is not currently potential but will obtain potential status in future. These actions aim at adapting and preparing the current ecosystems for future expected changes. Main actions:

- Introduction of associated flora: preparing the ecosystem for new expected species by introducing associated flora of lower steps of ecological succession;

- Favoring new species and genotypes: promoting resilience species and genotypes adaptable to predicted changes. In the first steps, species selection must be done carefully, be limited to short “ecological distances” from the current occurring species, and mainly projected on transition ecosystems.

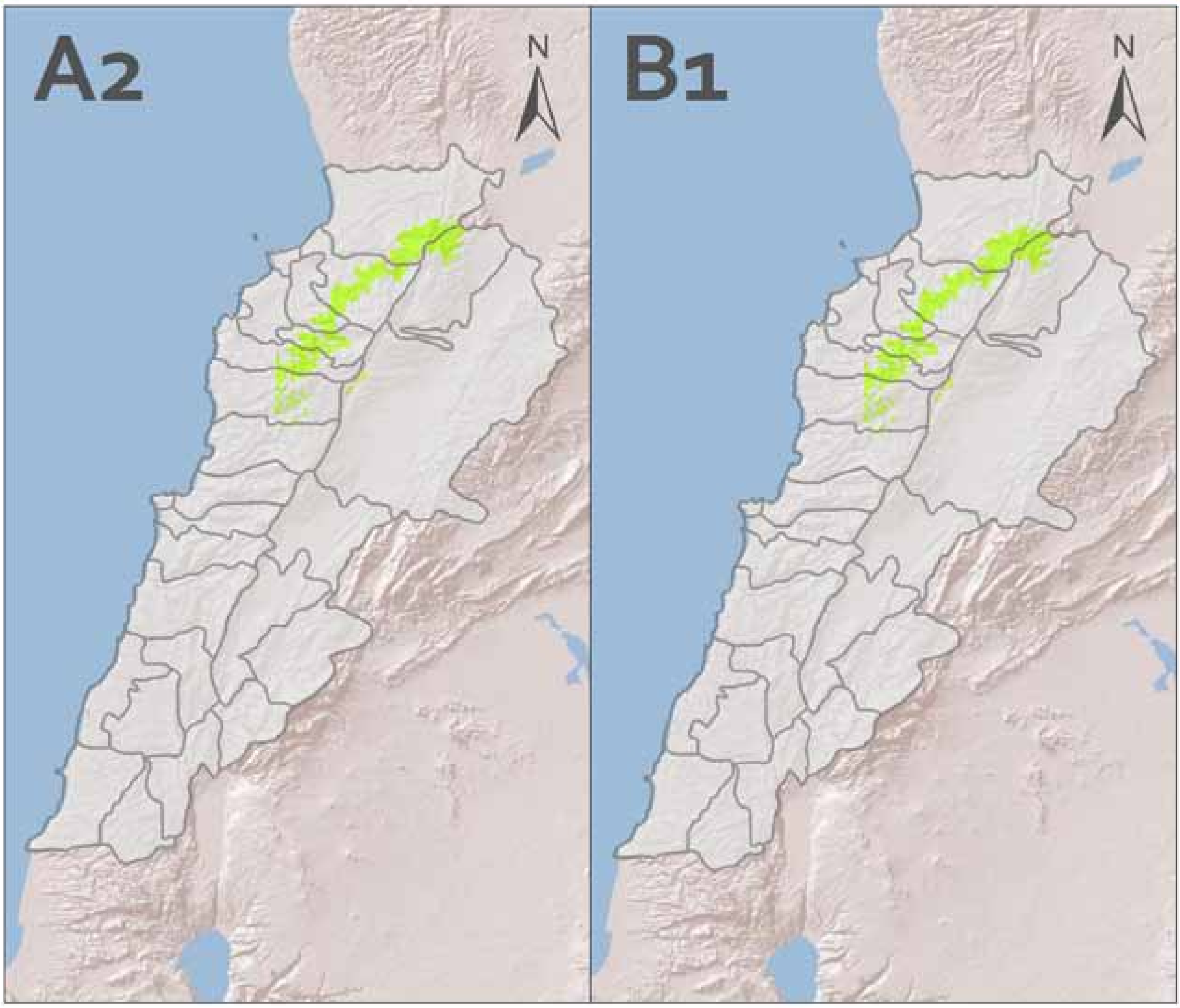
No action: in areas where the species is not potential and will not reach this status in the future, no action is proposed.

The maps of management guidelines per species can be found below:

9.1.1 *Abies cilicica*

Abies cilicica (Antoine & Kotschy) Carrière

Management guidelines



Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

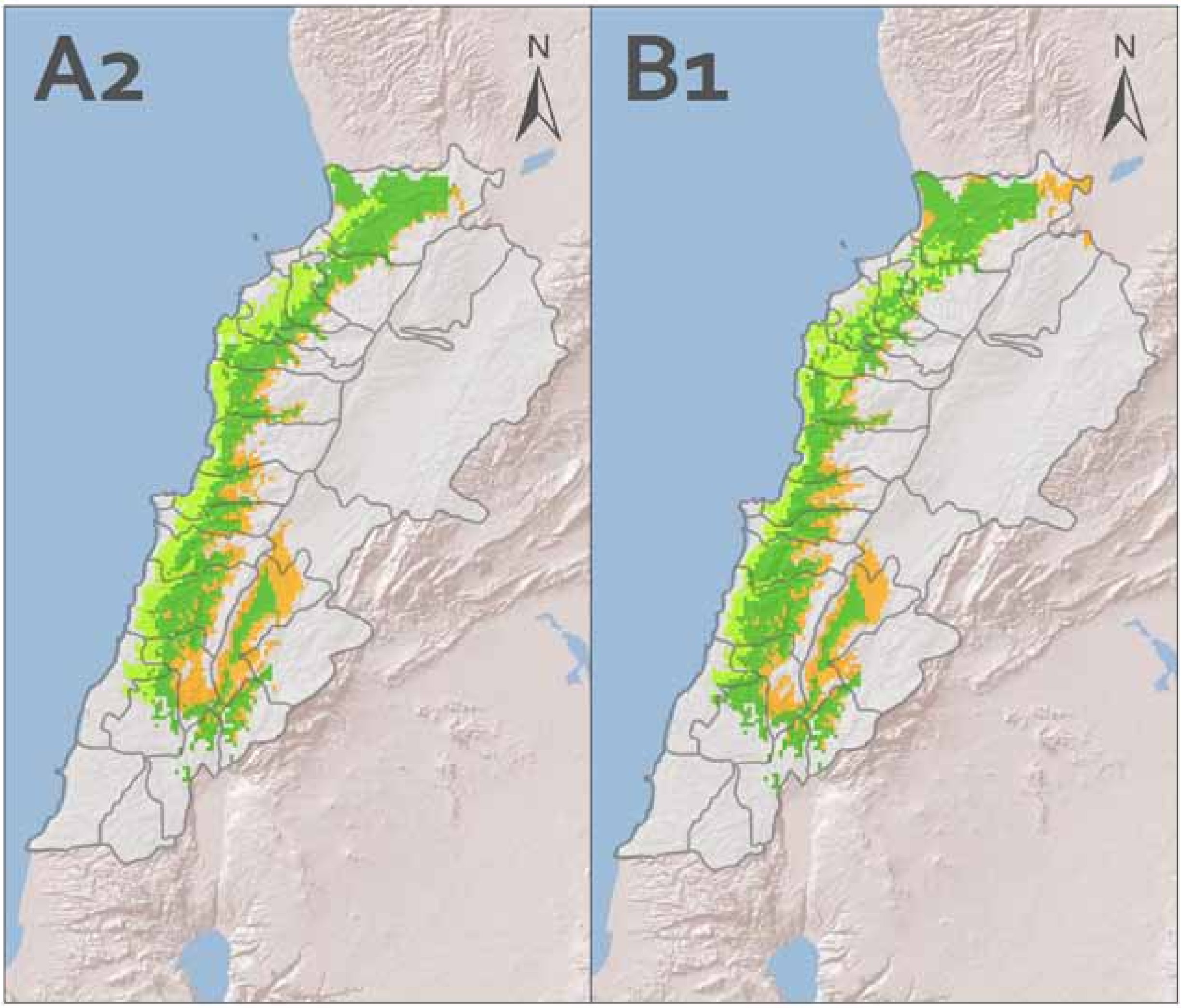
0 10 20 40 60
Kilometers

Projection: UTM 36N WGS84

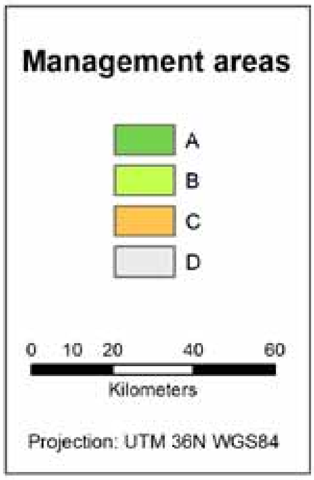
9.1.2 *Acer syriacum*

Acer syriacum Boiss. & Gaill.

Management guidelines



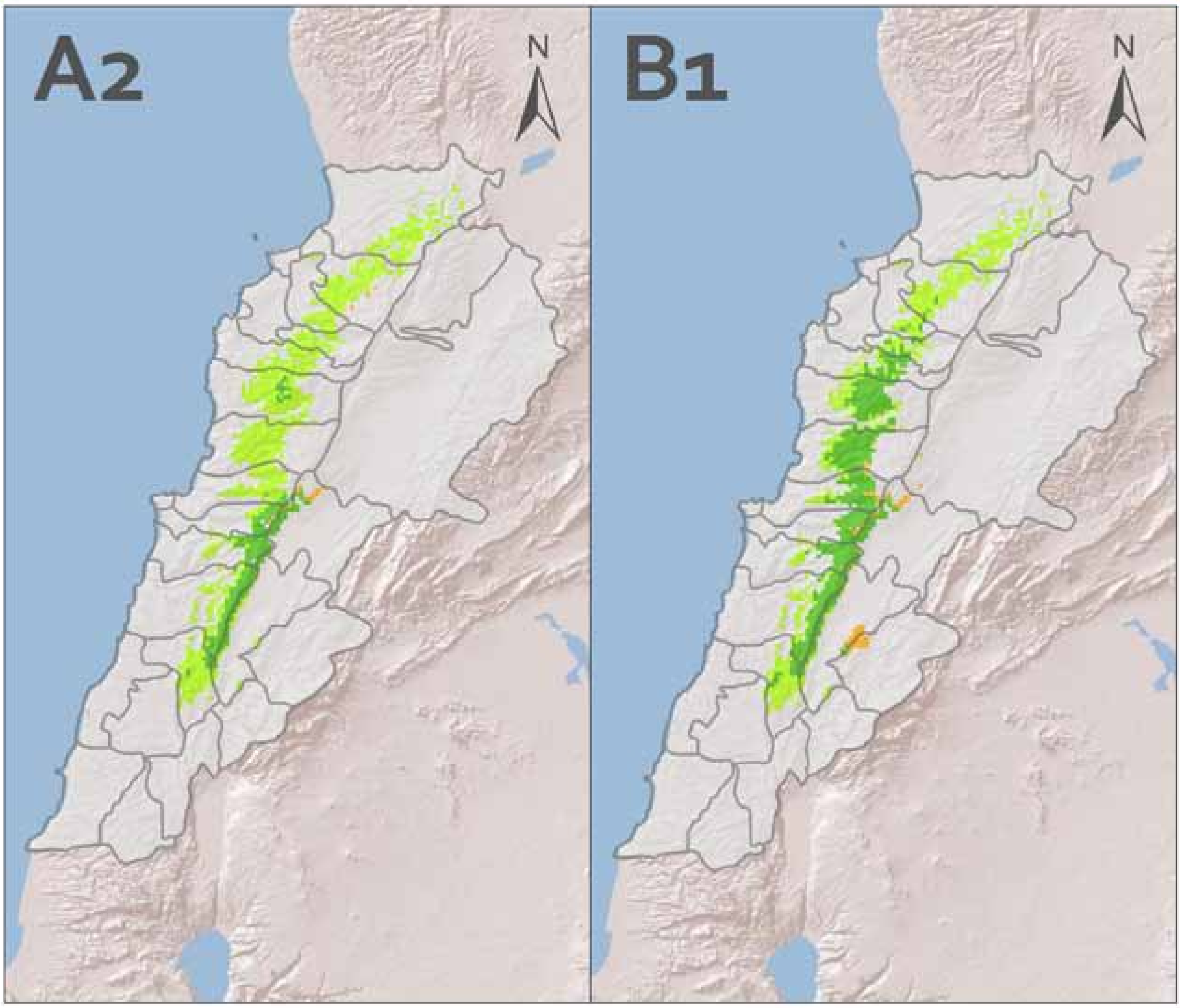
Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action



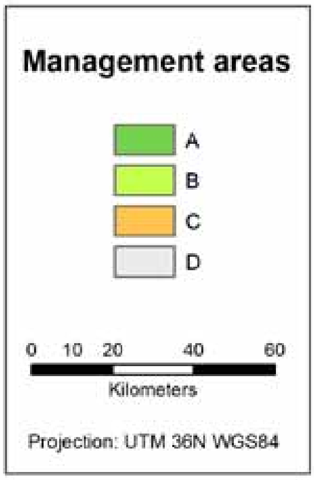
9.1.3 *Acer tauricolum*

Acer tauricolum Boiss. & Balansa

Management guidelines



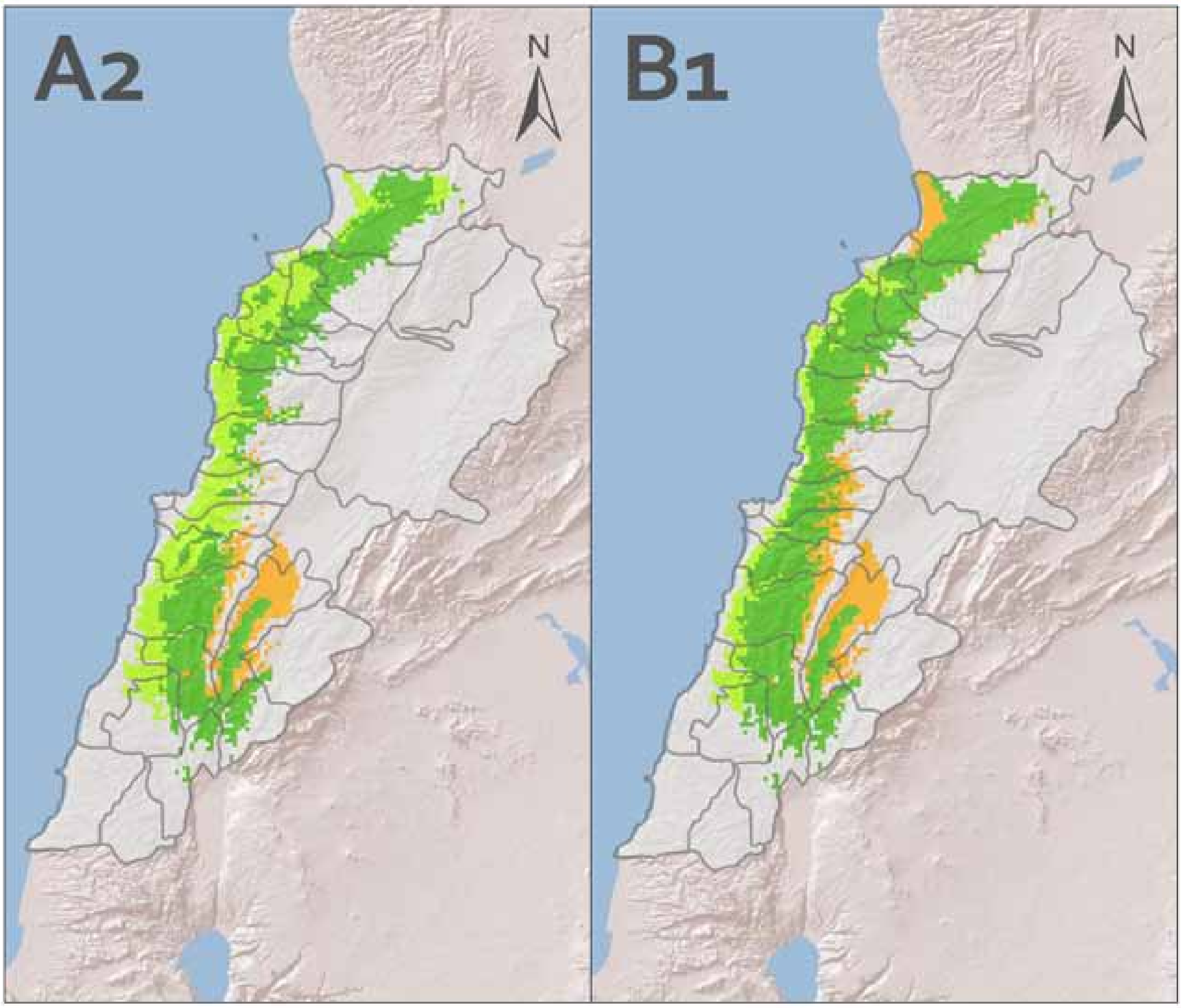
Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action



9.1.4 *Arbutus andrachne*

Arbutus andrachne L.

Management guidelines



Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

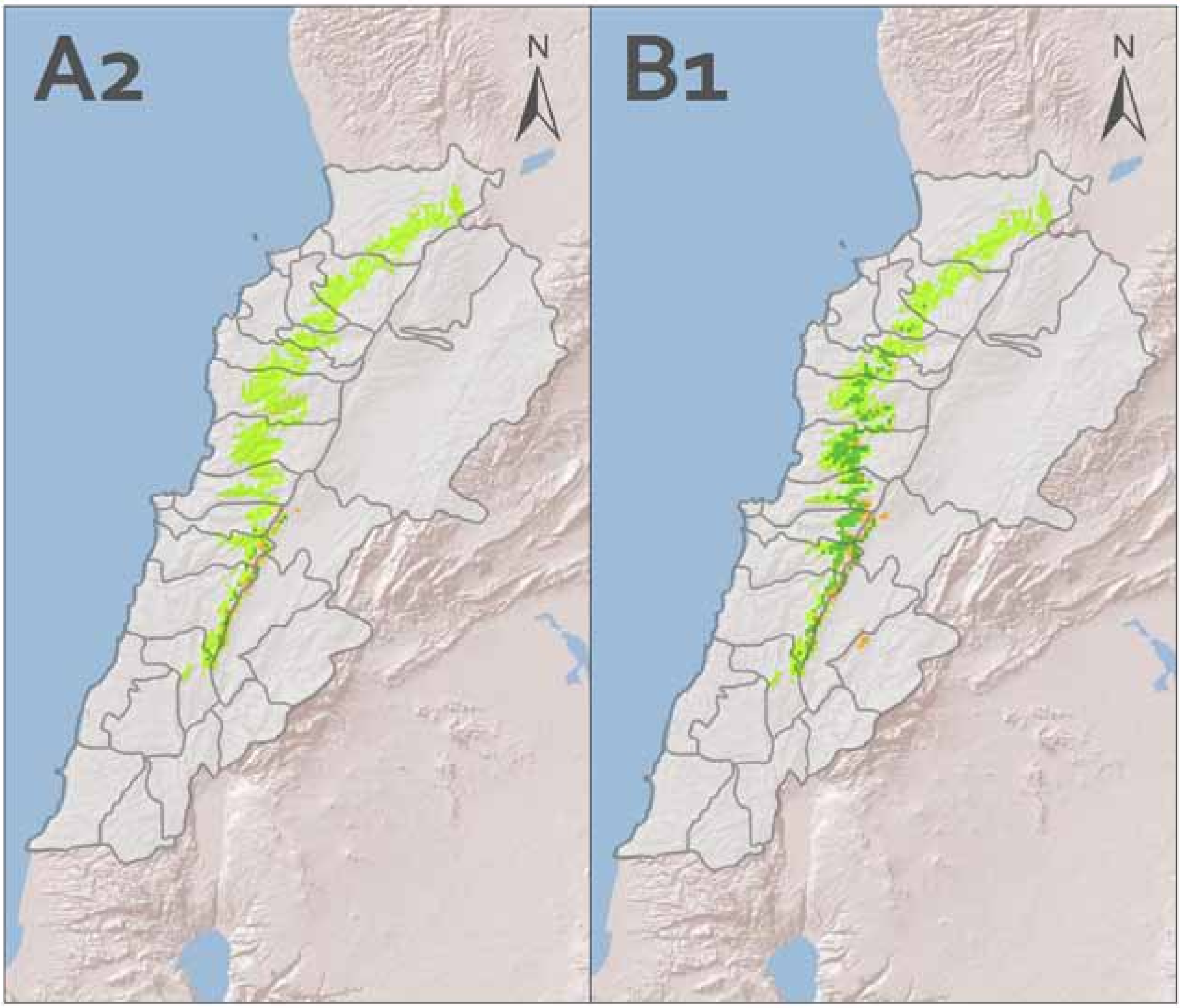
0 10 20 40 60
Kilometers

Projection: UTM 36N WGS84

9.1.5 *Arceuthos drupacea*

Arceuthos drupacea (Labill.) Antoine & Kotschy

Management guidelines



Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

0 10 20 40 60

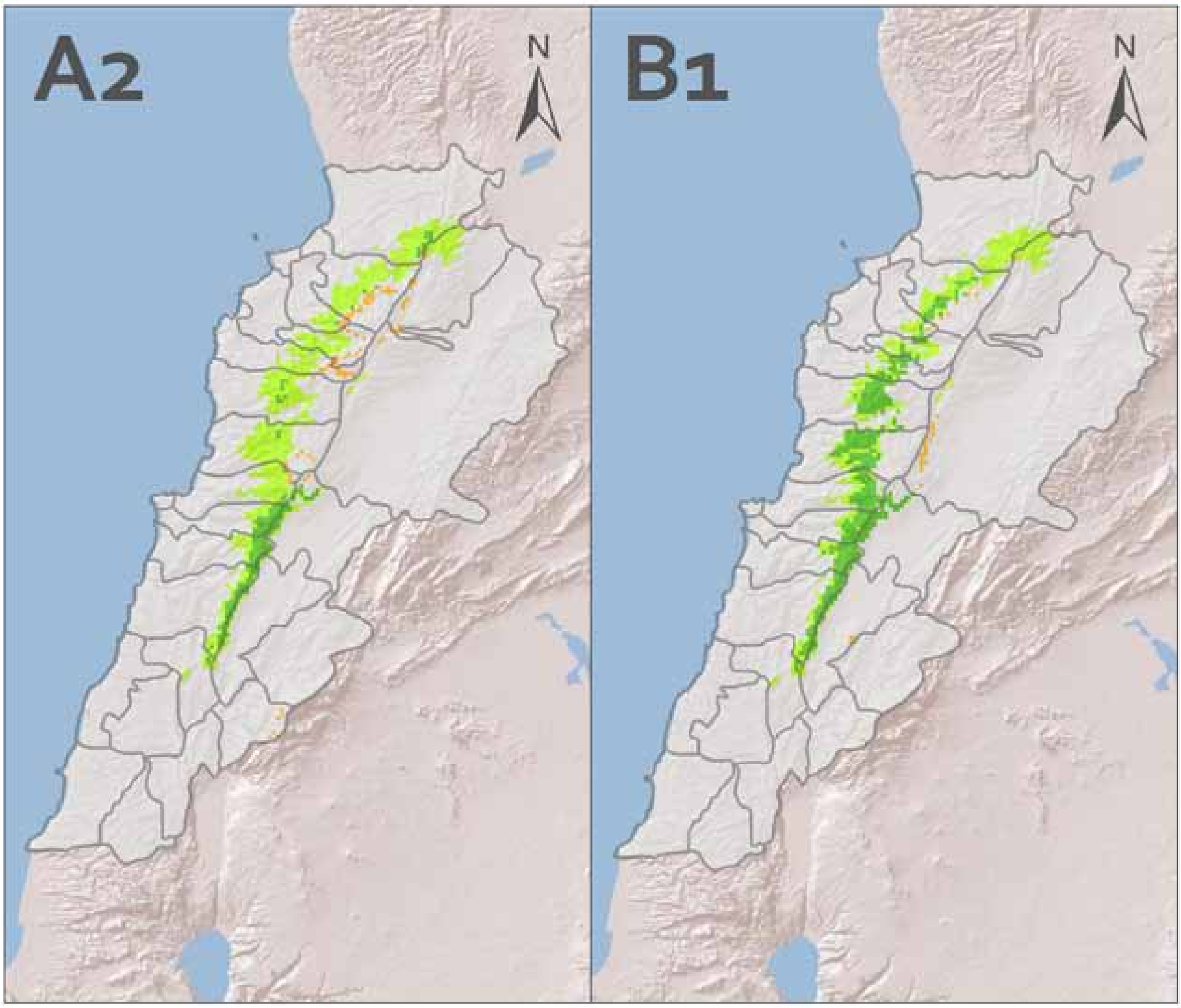
Kilometers

Projection: UTM 36N WGS84

9.1.6 *Cedrus libani*

Cedrus libani A. Rich.

Management guidelines



Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

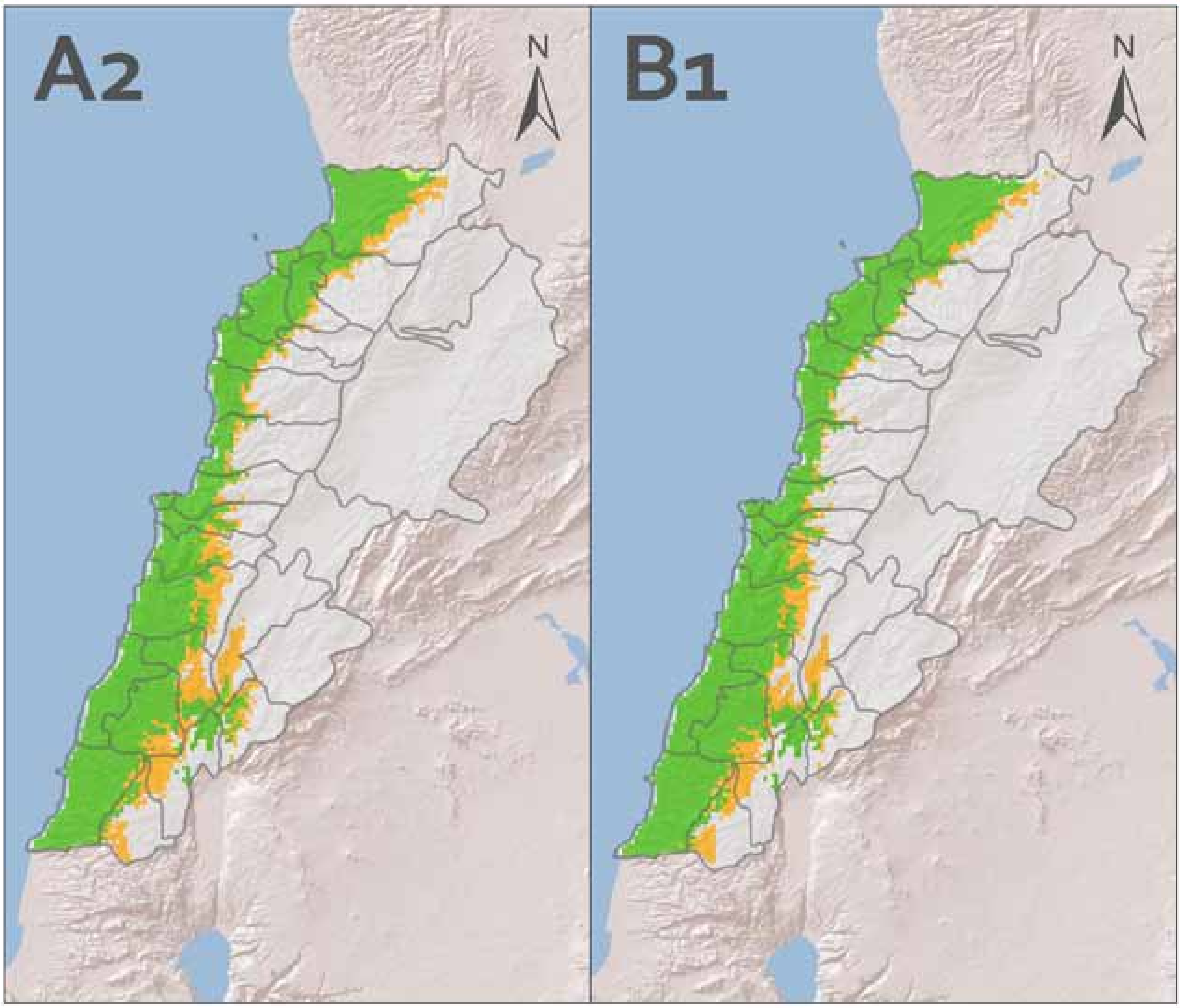
0 10 20 40 60
Kilometers

Projection: UTM 36N WGS84

9.1.7 *Ceratonia siliqua*

Ceratonia siliqua L.

Management guidelines



Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

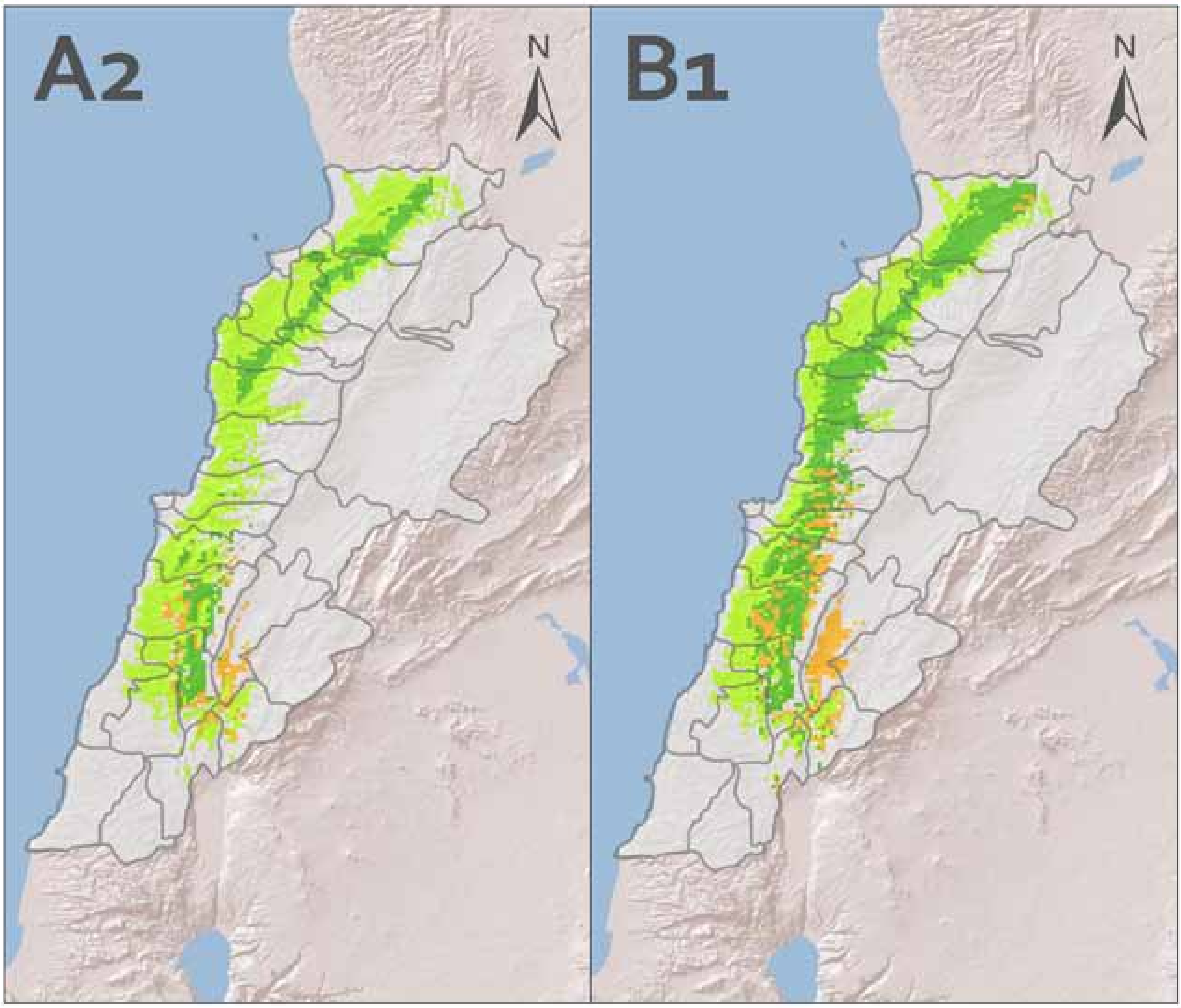
0 10 20 40 60
Kilometers

Projection: UTM 36N WGS84

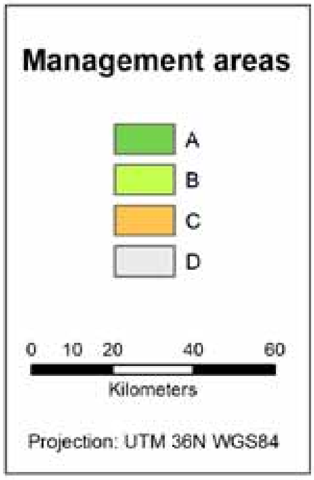
9.1.8 *Cercis siliquastrum*

Cercis siliquastrum L.

Management guidelines



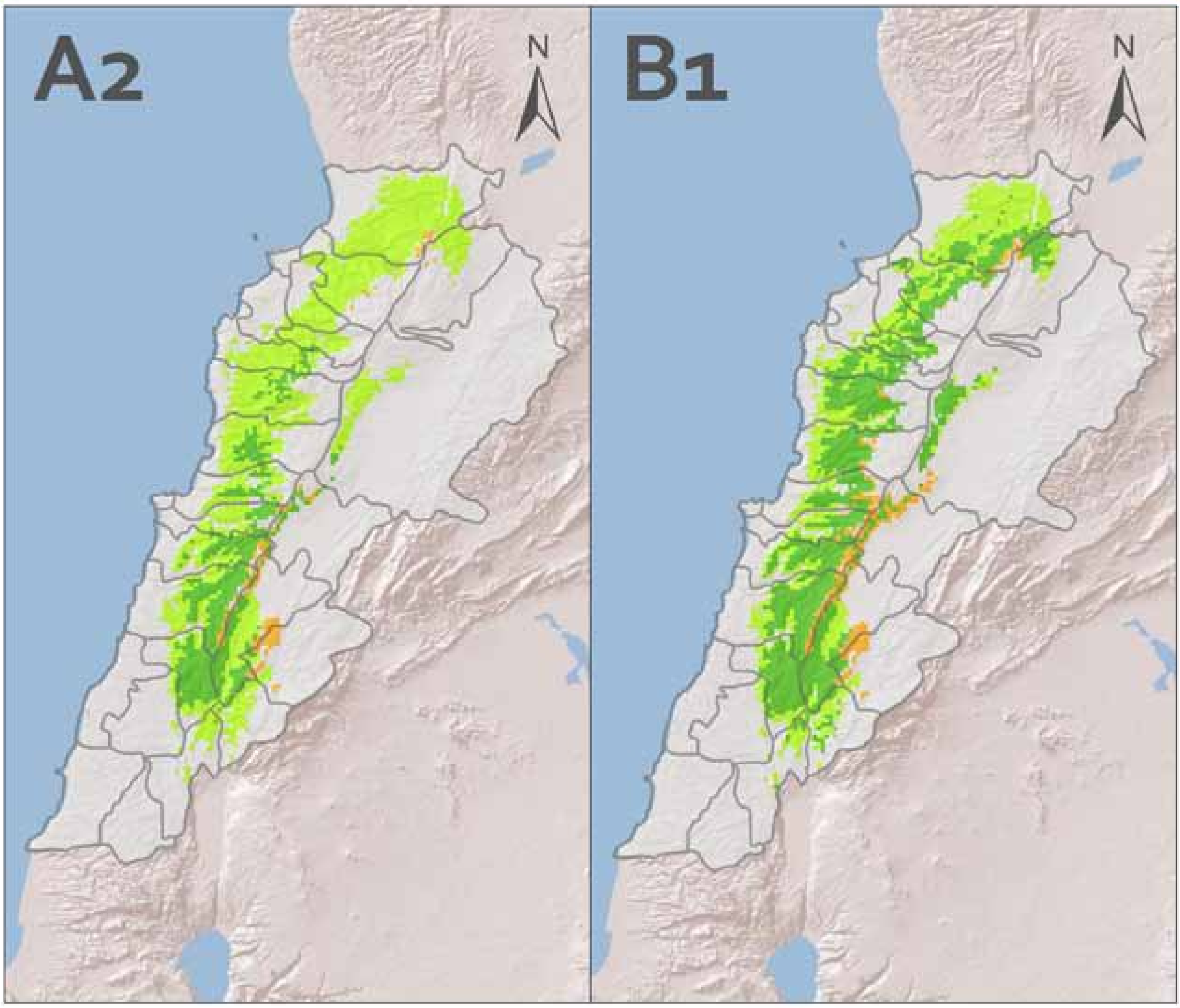
Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action



9.1.9 *Crataegus spp.*

Crataegus spp.

Management guidelines



Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

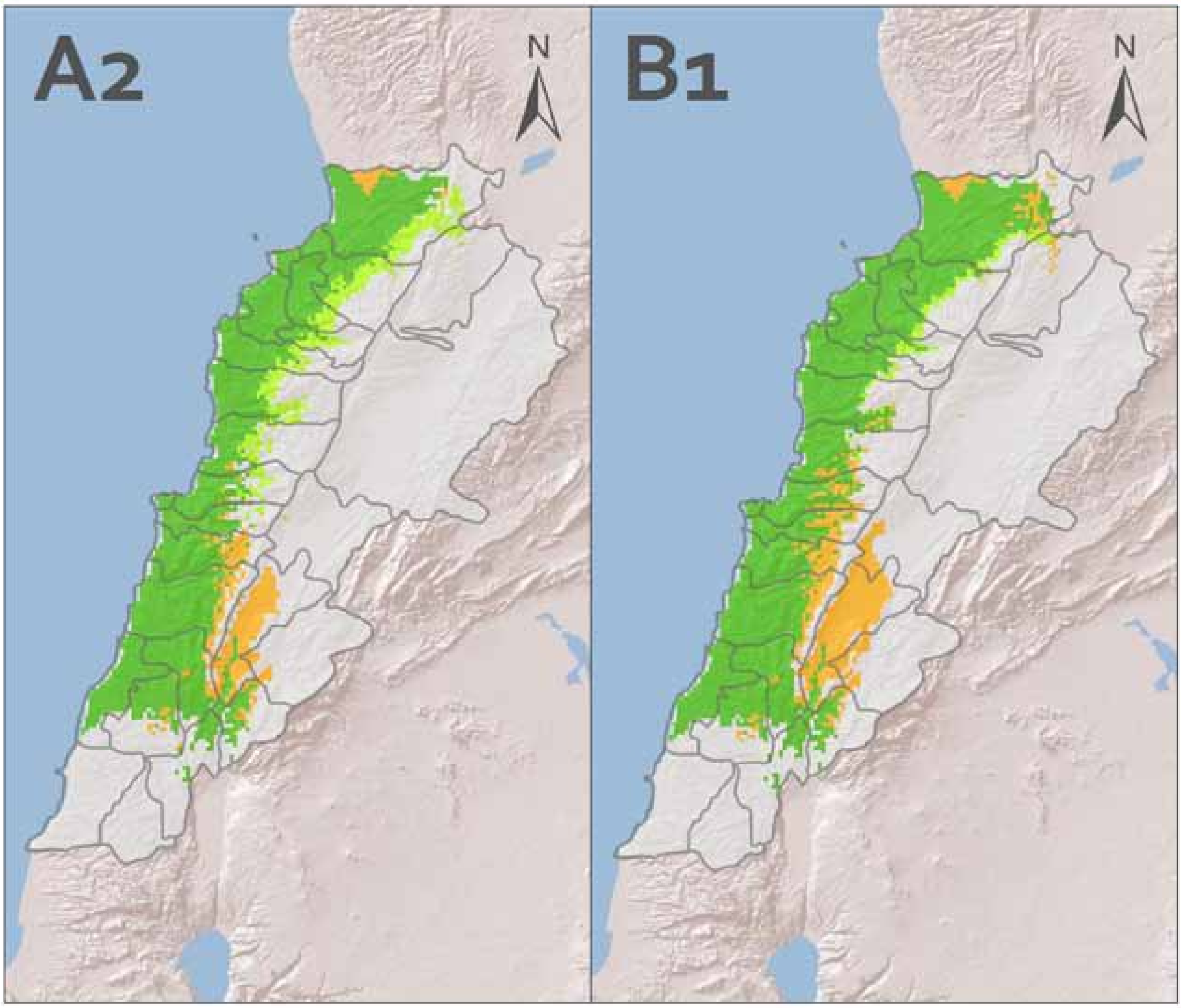
0 10 20 40 60
Kilometers

Projection: UTM 36N WGS84

9.1.10 *Cupressus spp.*

Cupressus spp.

Management guidelines



Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

0 10 20 40 60

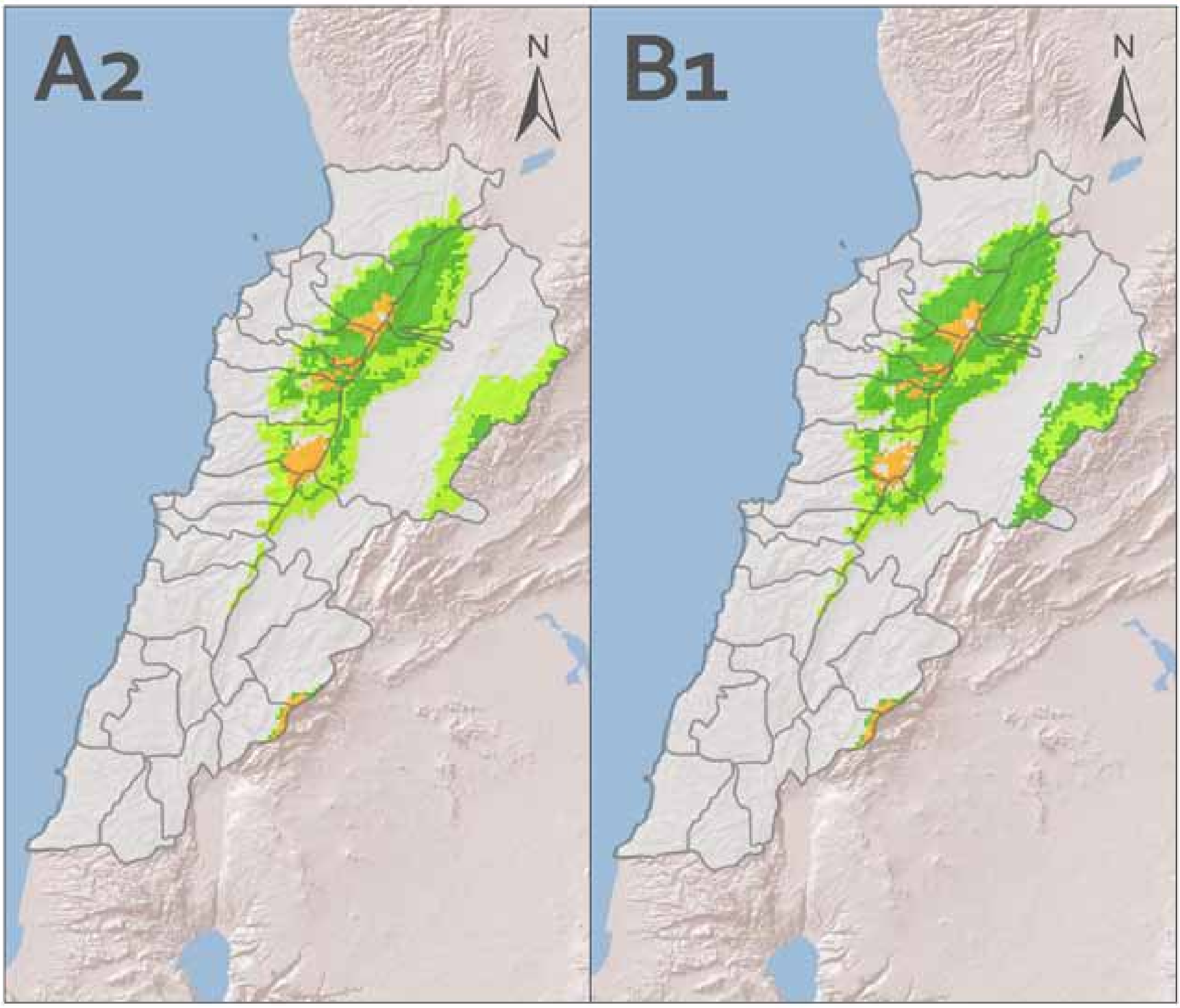
Kilometers

Projection: UTM 36N WGS84

9.1.11 *Juniperus excelsa*

Juniperus excelsa M. Bieb.

Management guidelines



Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

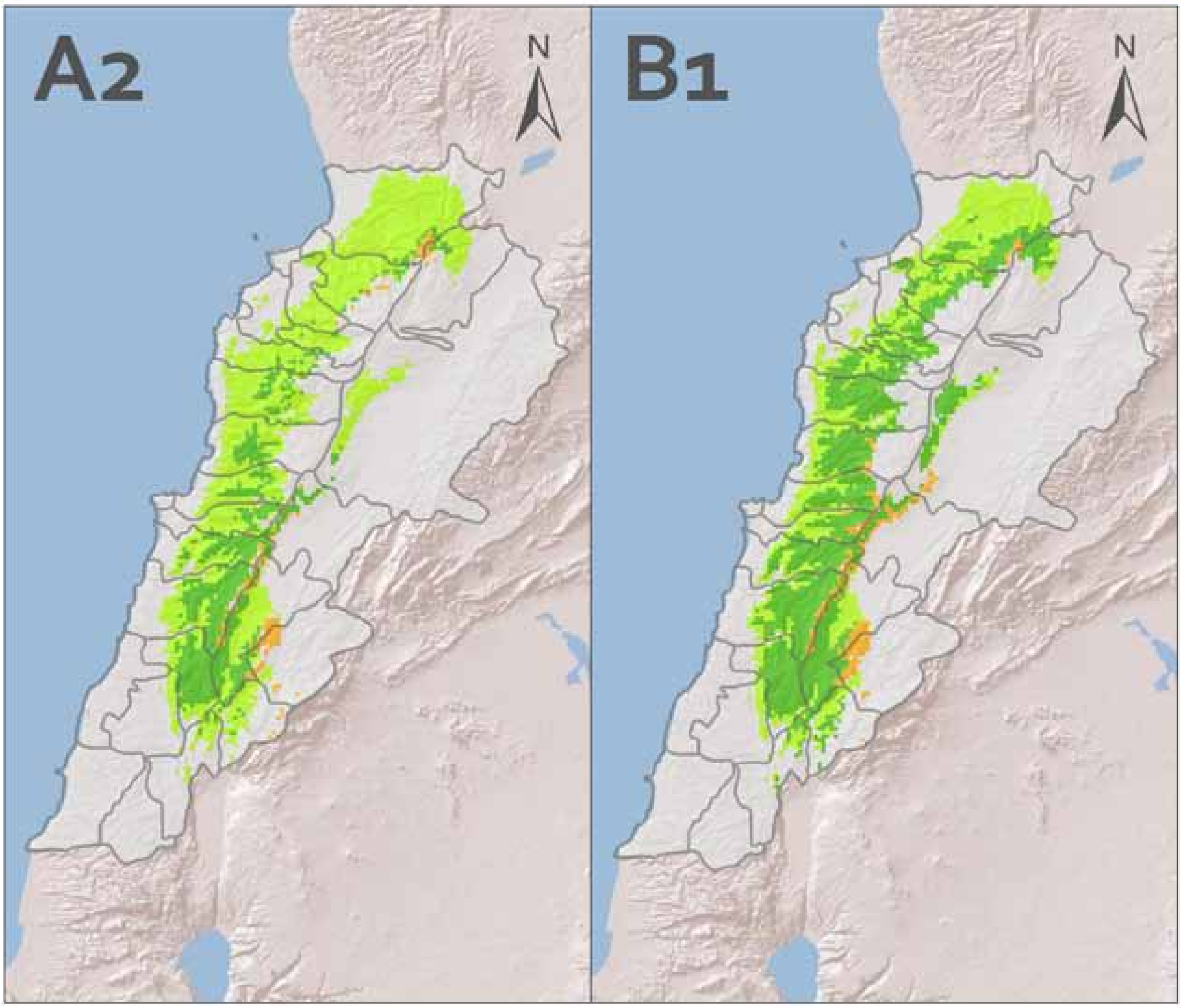
0 10 20 40 60
Kilometers

Projection: UTM 36N WGS84

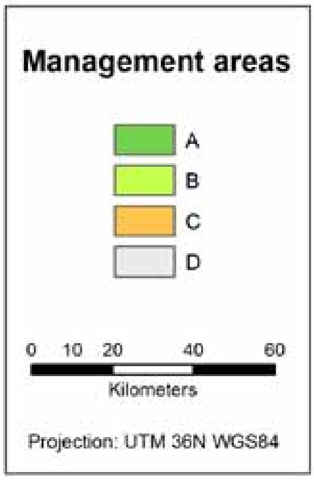
9.1.12 *Juniperus oxycedrus*

Juniperus oxycedrus L.

Management guidelines



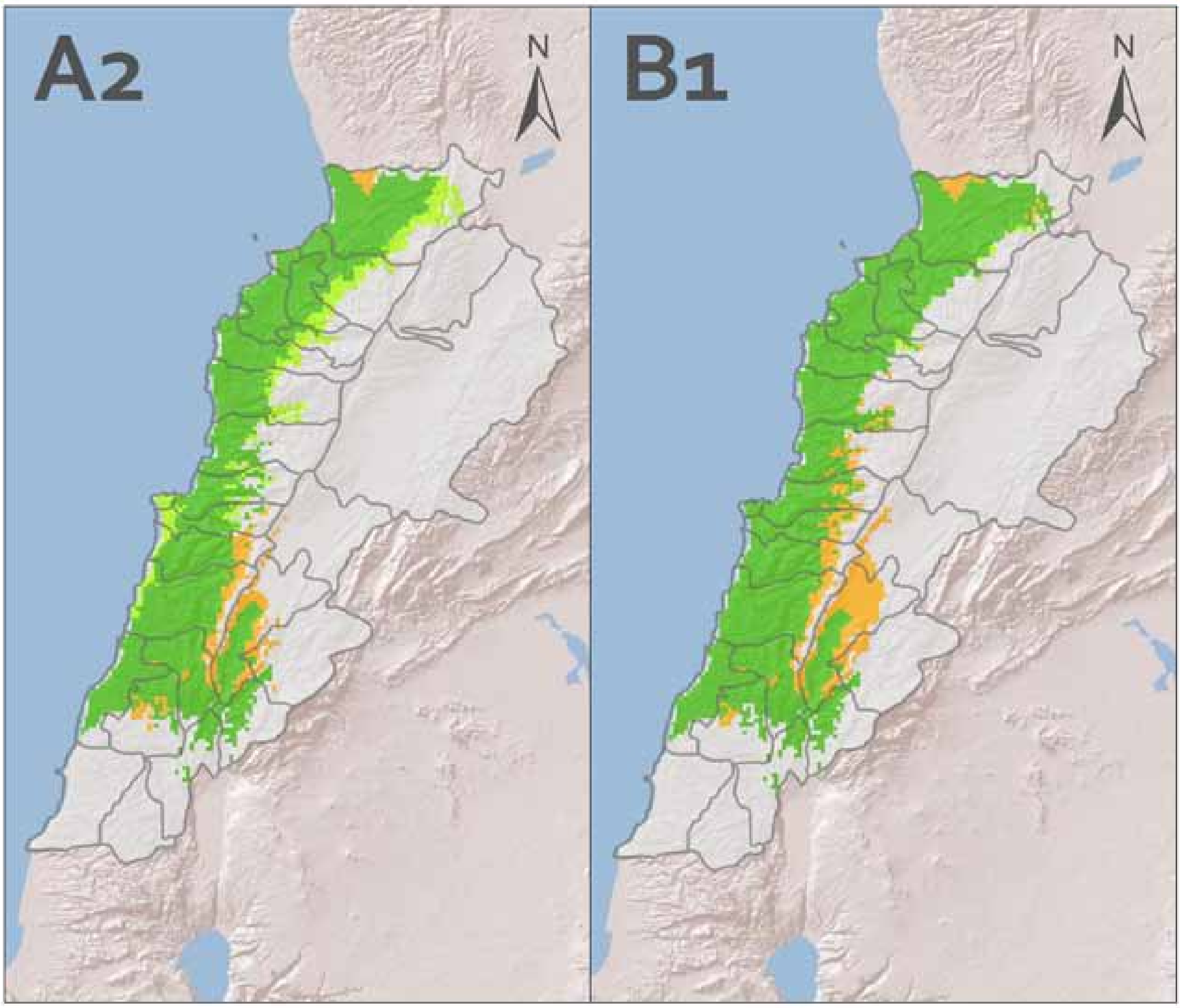
Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action



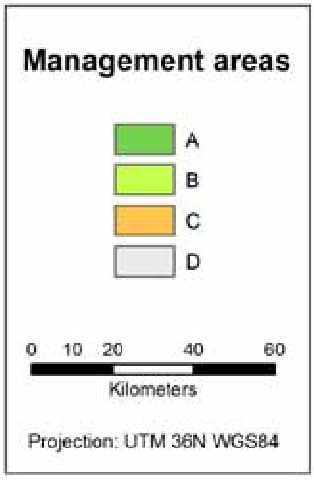
9.1.13 *Pinus brutia*

Pinus brutia Ten.

Management guidelines



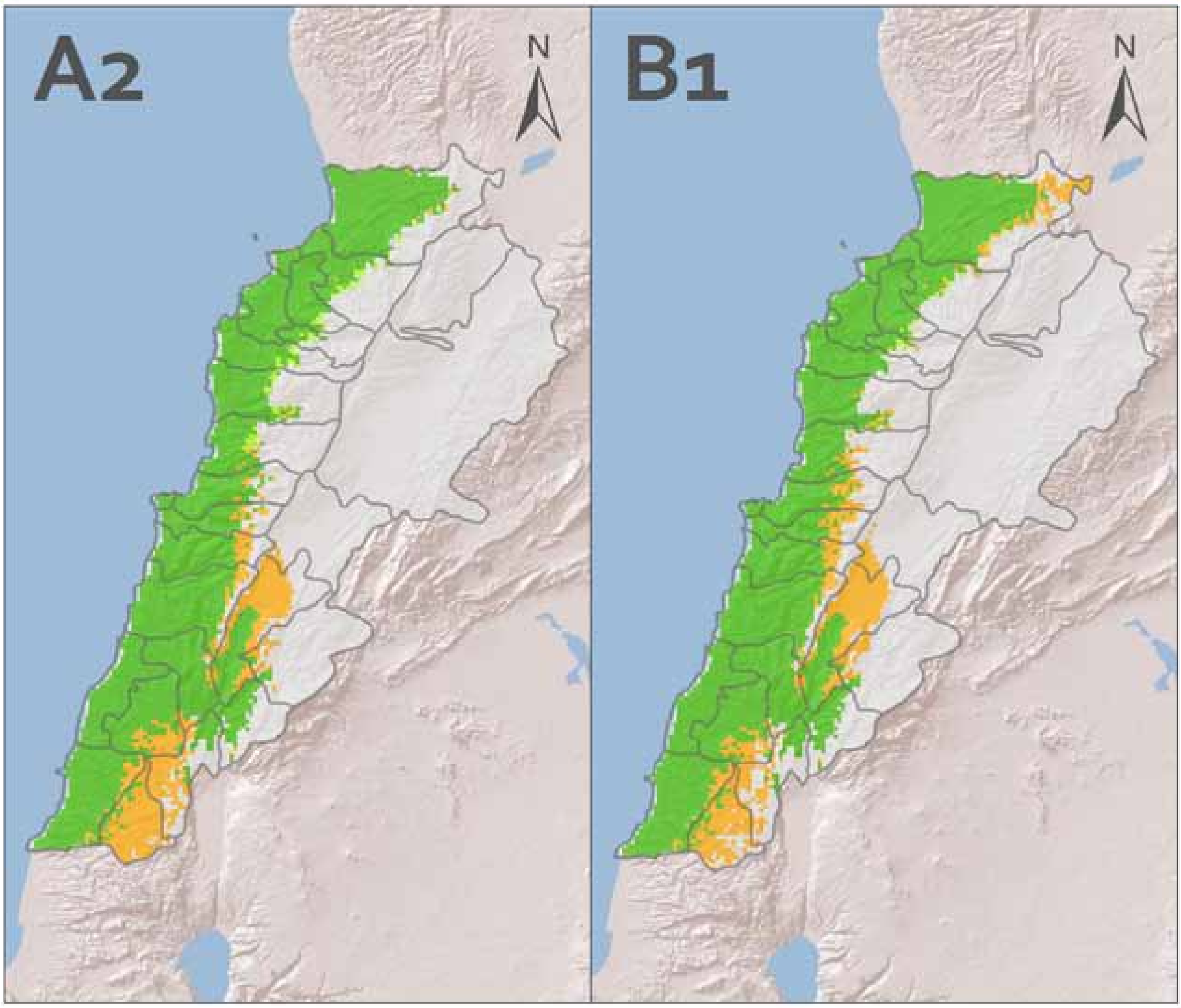
Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action



9.1.14 *Pistacia palaestina*

Pistacia spp.

Management guidelines



Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

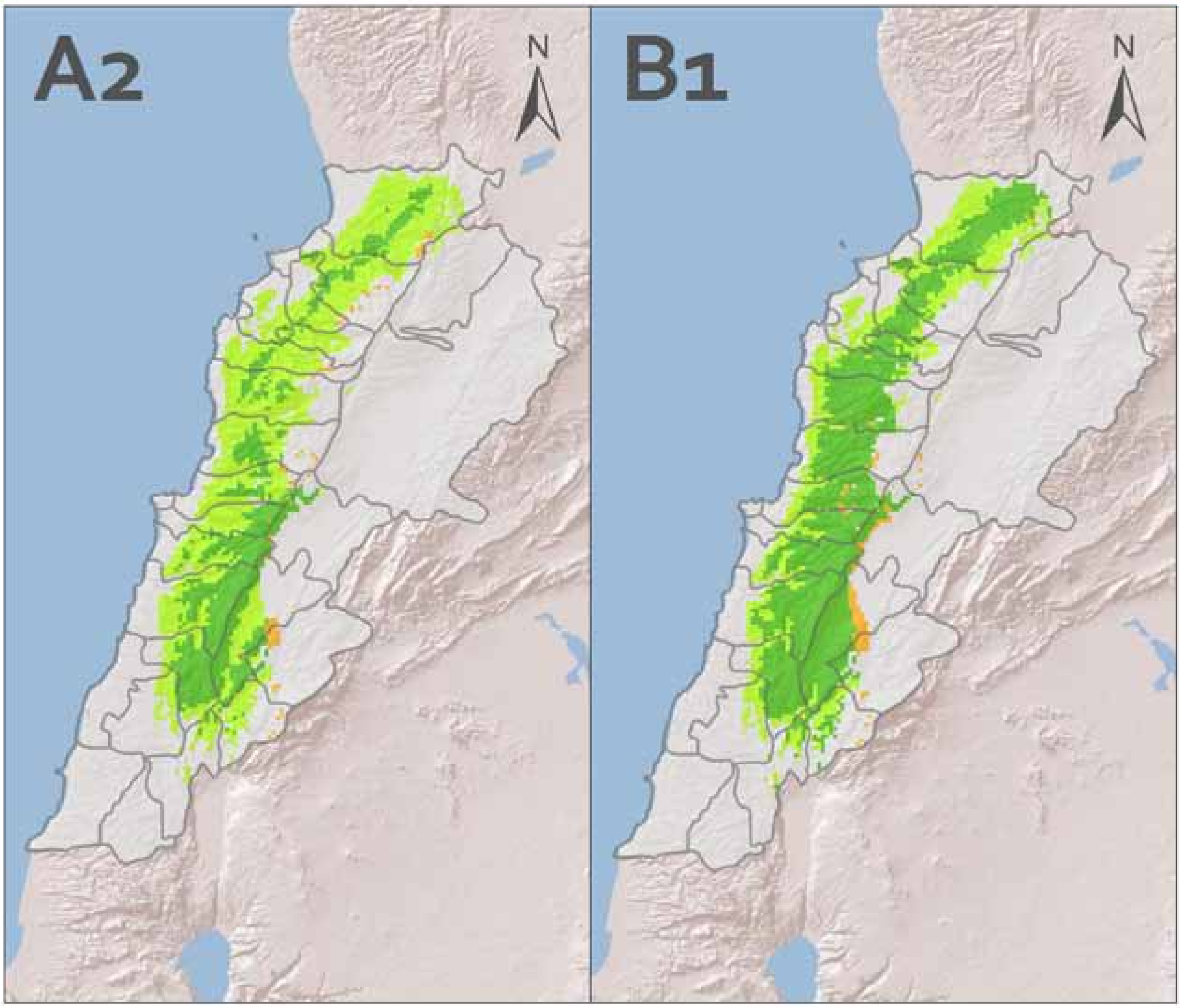
0 10 20 40 60
Kilometers

Projection: UTM 36N WGS84

9.1.15 *Prunus ursina*

Prunus ursina Kotschy

Management guidelines



Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

- A
- B
- C
- D

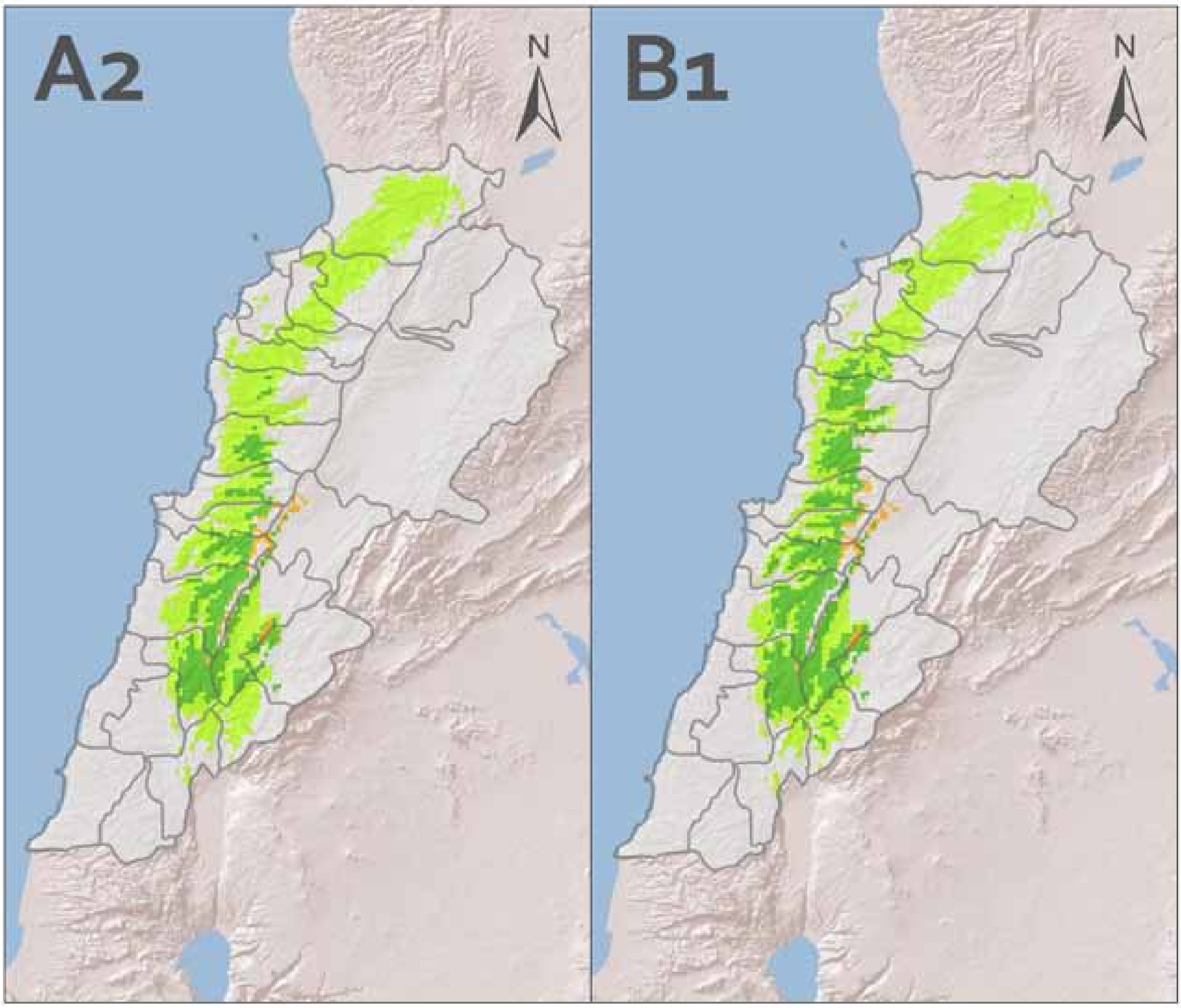
0 10 20 40 60
Kilometers

Projection: UTM 36N WGS84

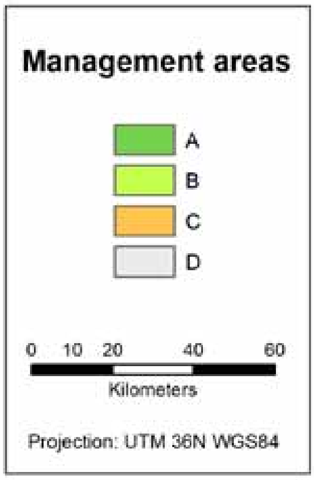
9.1.16 *Pyrus syriaca*

Pyrus syriaca Boiss.

Management guidelines



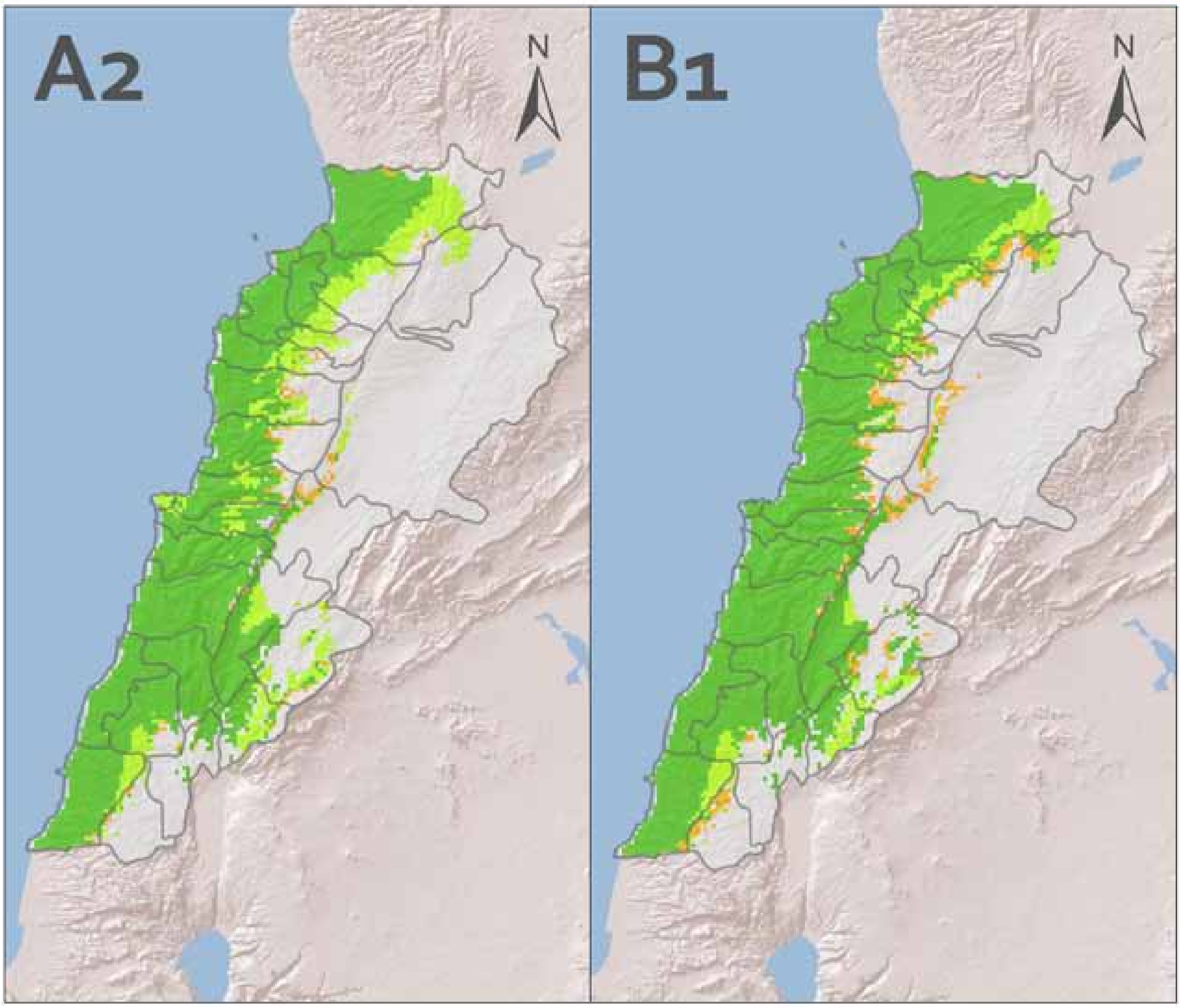
Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action



9.1.17 *Quercus calliprinos*

Quercus calliprinos Webb

Management guidelines



Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

A
B
C
D

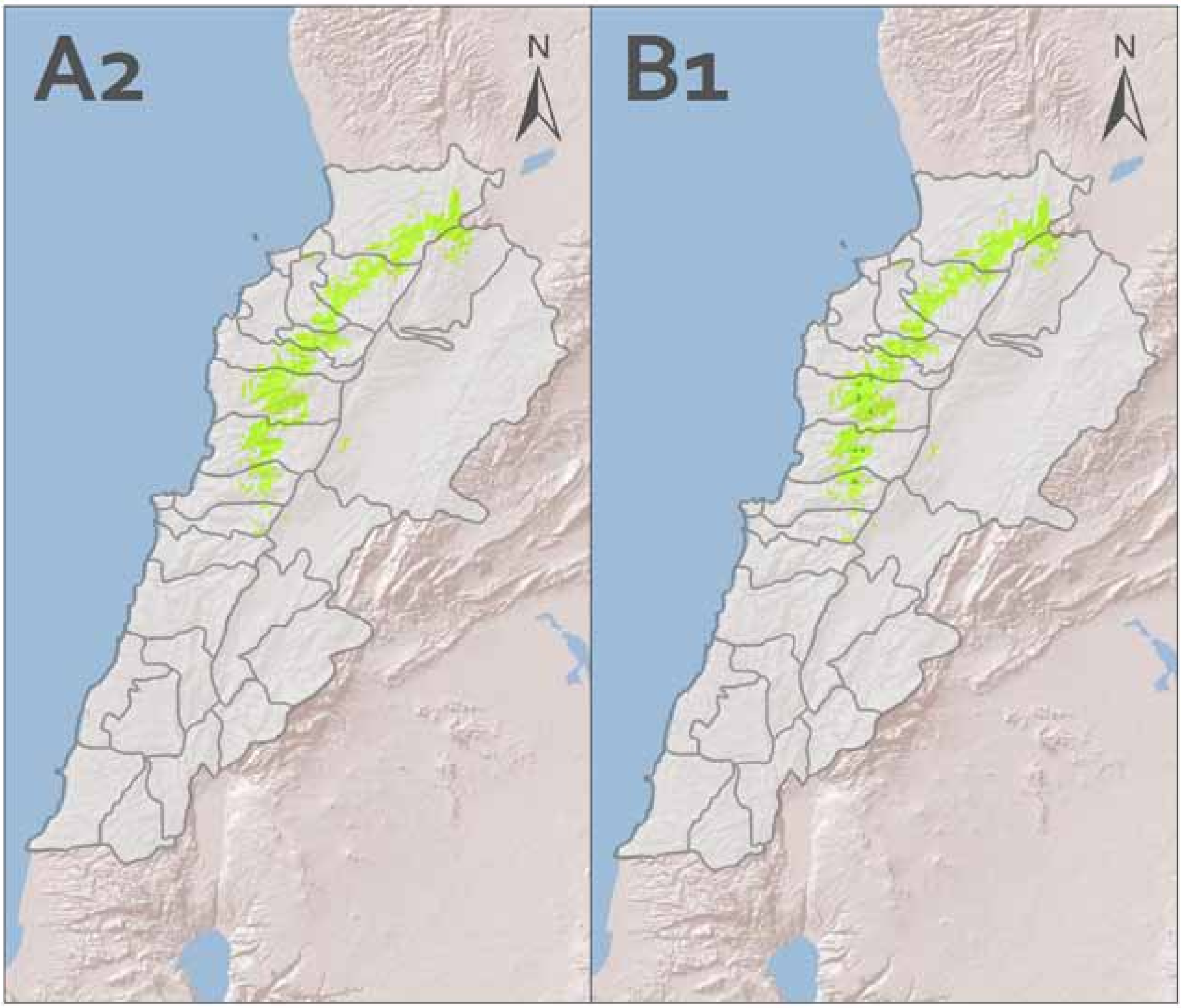
0 10 20 40 60
Kilometers

Projection: UTM 36N WGS84

9.1.18 *Quercus cerris*

Quercus cerris L.

Management guidelines



Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action

Management areas

A

B

C

D

0 10 20 40 60

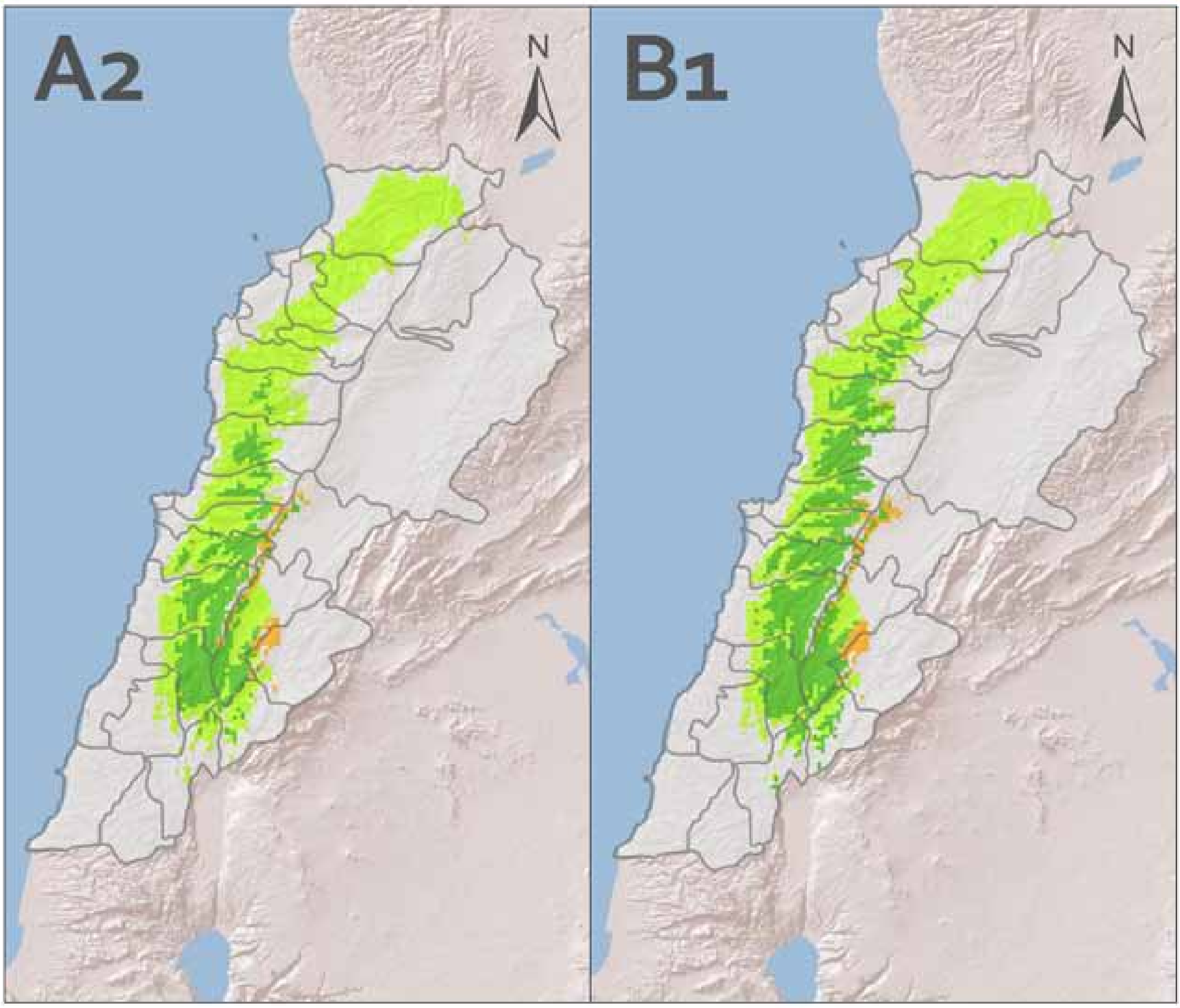
Kilometers

Projection: UTM 36N WGS84

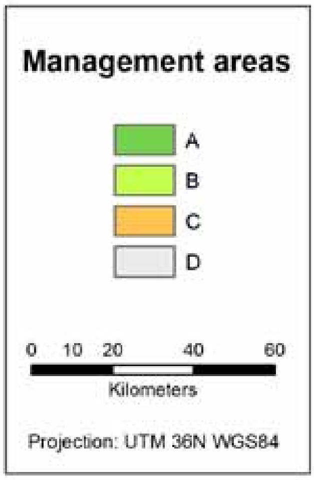
9.1.19 *Quercus infectoria*

Quercus infectoria G. Olivier

Management guidelines



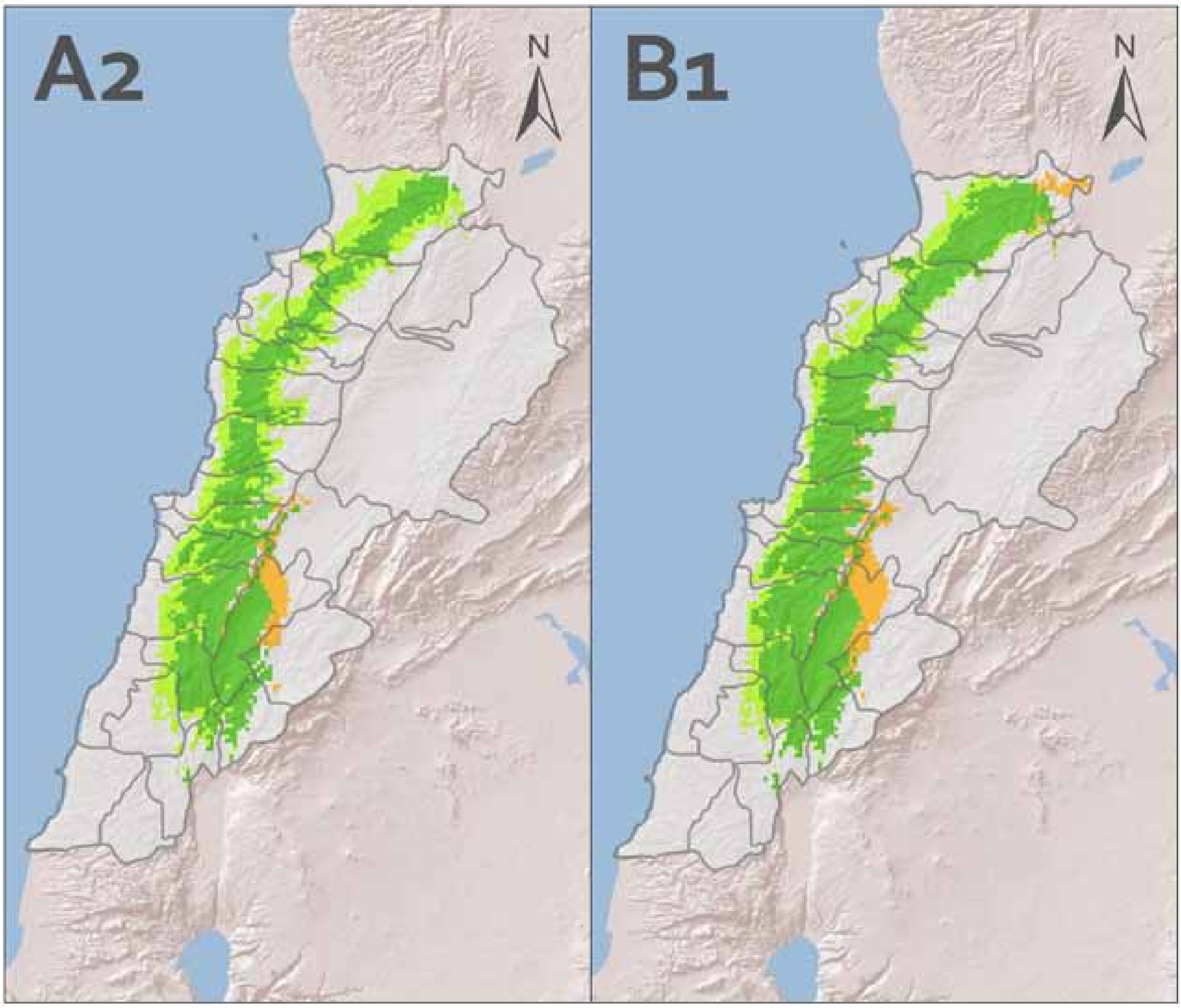
Case	Potentiality status		Management guidelines
	Current	Future	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action



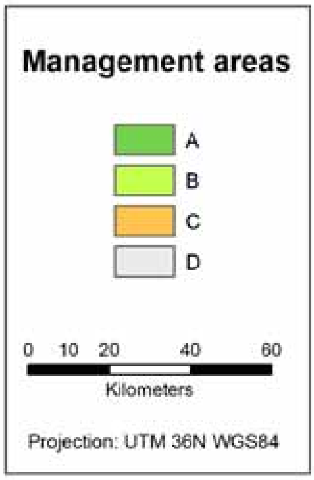
9.1.20 *Styrax officinalis*

Styrax officinalis L.

Management guidelines



Case	Potentiality status		Management guidelines
	Current	*Future*	
A	Yes	Yes	Conservation/Restoration
B	Yes	No	Adaptive silviculture
C	No	Yes	Ecosystem adaptation
D	No	No	No action



9. APPLICATION OF RESULTS TO RESTORATION AND ADAPTIVE MANAGEMENT IN A CONTEXT OF GLOBAL CHANGE

9.2 ADAPTATION MEASURES PER CRITICAL AREAS

In terms of potential species richness loss, specific actions can be identified and proposed for areas considered critical. **Table 2** shows adaptation measures addressing climate change risks and impacts on the forests' species richness (FAO, 2013).

Risk or Impact	Adaptation Measure
Changes in viability of species and varieties in the management area	Adaptation of management plans taking into consideration the changes in the distribution of species (e.g. reduction of the intensity of logging, pruning, charcoaling, etc.).
	Management focused on diversifying composition, age, and structure of the tree component and understory vegetation at stand and landscape levels.
	Planting or promotion of the use of species and varieties adapted to climate.
	Establishment or expansion and management of protected areas for conservation of vulnerable species and habitat types.
	Protection of species at the edges of their ranges as they can better adapt to new climatic conditions.
	Promotion of extensive grazing management to avoid overgrazing and stimulate natural regeneration of affected species.
Species moving towards new areas	When necessary, promotion of the establishment and management of beneficial and associated flora to increase the mobility towards different woodlands.
	Implementation of measures to detect and control invasive species.
Forest fragmentation	Provision of corridors of suitable habitat and size to allow the migration of species and thus maintain landscape connectivity through restoration and reforestation.

Table 2. Adaptation Measures Against Climate Change Effects on Species Richness Loss

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11. ANNEX I. CLIMATE VARIABLES. ANALYSIS AND SELECTION

11.1 CURRENT CLIMATE VARIABLES

Current climate data were obtained from WorldClim (Hijmans et al., 2005), a set of global climate layers with a 30 arc-second spatial resolution generated through interpolation of real data from weather stations for the period 19502000-.

Climate information available is as follows:

tmean = average monthly mean temperature (°C * 10);
tmin = average monthly minimum temperature (°C * 10);
tmax = average monthly maximum temperature (°C * 10);
prec = average monthly precipitation (mm).

Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. These are often used in ecological niche modeling. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation), seasonality (e.g., annual range in temperature and precipitation), and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A quarter is a period of three months (14/ of the year).

They are coded as follows:

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (mean of monthly (max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (* 100)
BIO4 = Temperature Seasonality (standard deviation *100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

In addition to this, a new set of variables was generated clustering climatic information in seasonal periods, obtaining the minimum, maximum, and average temperature of each season and seasonal total precipitation.

Seasonal periods were gathered as follows:

Winter: December, January, and February
Spring: March, April, and May
Summer: June, July, and August
Autumn: September, October, and November

The species distribution models were built upon the bioclimatic variables. These models were used to obtain the current potential surface.

11.2 FUTURE CLIMATE VARIABLES

To obtain more significant climatic variables, a mixed climate model was generated from predictions made by CCCMA-CGCM3 and ECHAM5 global models.
CCCMA (Canadian Center for Climate Modeling and Analysis) is part of the climatic research line developed at the Weather and Environmental Service of Canada. This center conducts research to produce atmospheric and oceanic models, variability, and prediction of climate and carbon cycle, among others. CCCMA has developed a large number of climate simulation models. These models predict climate change and its variability to better understand the processes that govern our climate system. For this study, the 3rd generation of Coupled Global Climate Model, CGCM3 (Available free of charge at http://ccafs-climate.org/) was used.

ECHAM model has been developed by Max Planck Institute for Meteorology. It was created by modifying global forecast models developed by ECMWF to be used for climate research. ECHAM5 is the 5th generation of the ECHAM general circulation model. MPI-ECHAM5 was recently used in the IPCC Fourth Assessment Report, alongside many other GCMs from different countries. (Available free of charge at http://www.mpimet.mpg.de)

Once the model is defined, the conditions of the factors influencing climate evolution, i.e. the emission scenarios, should be determined. There are four families of scenarios defined by the IPCC (Intergovernmental Panel on Climate Change): A1, A2, B1, and B2. Each of them is a combination of demographic, social, economic, technological, and environmental trends. Their definitions can be found in the Special Report on Emissions Scenarios (IPCC, 2000). For this assessment, A2 and B1 scenarios were used.

The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns in all regions converge very slowly, resulting in a continuously growing world population. Economic development is primarily regionally oriented. Per capita economic growth and technological change are more fragmented and slower than in other storylines (IPCC, 2000). This scenario has been selected due to its moderate unfavorable prognosis. This allows us to consider the potential areas obtained, used with low level of uncertainty, to determine optimal areas of reforestation.

The B1 scenario describes a convergent world with the same global population that peaks in midcentury and declines thereafter. In this scenario rapid changes occur in economic structures creating a service and information based economy. It also assumes reductions in material intensity, and the introduction of clean and efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability. This includes improved equity, but excludes additional climate initiatives. In this scenario, the effects of climate change have less impact and are representative of more favorable predictions for forest ecosystems.

The horizon for the prediction of potential distribution is 2050. Climate data commensurate with the time horizon and the selected scenarios are drawn from the GCM Downscaled Data Portal (www.ccafs-climate.org/), using the Delta method of statistical downscaling. These data were the climate variables used to obtain the future potential surface.

11.3 VARIABLES SELECTION

Before choosing the final variables, a collinearity analysis was run to eliminate repetitive variables from the global list.

Collinearity (Multicollinearity) is a statistical issue which indicates the strong correlation between two or more descriptive variables and induces uncertainty in regression model predictions. Collinearity refers to a linear relationship between two predictor variables, while multicollinearity refers to collinearity between two or more predictor variables. Collinearity affects the estimation of the regression coefficients and induces bias responses between outputs and explanatory variables. Collinearity can be detected by 1) analysis of correlation matrix, and 2) variance inflation factor (VIF) which is calculated as:

$$VIF = \frac{1}{1 - R_J^2}$$

Where R_J^2 is the coefficient of determination.

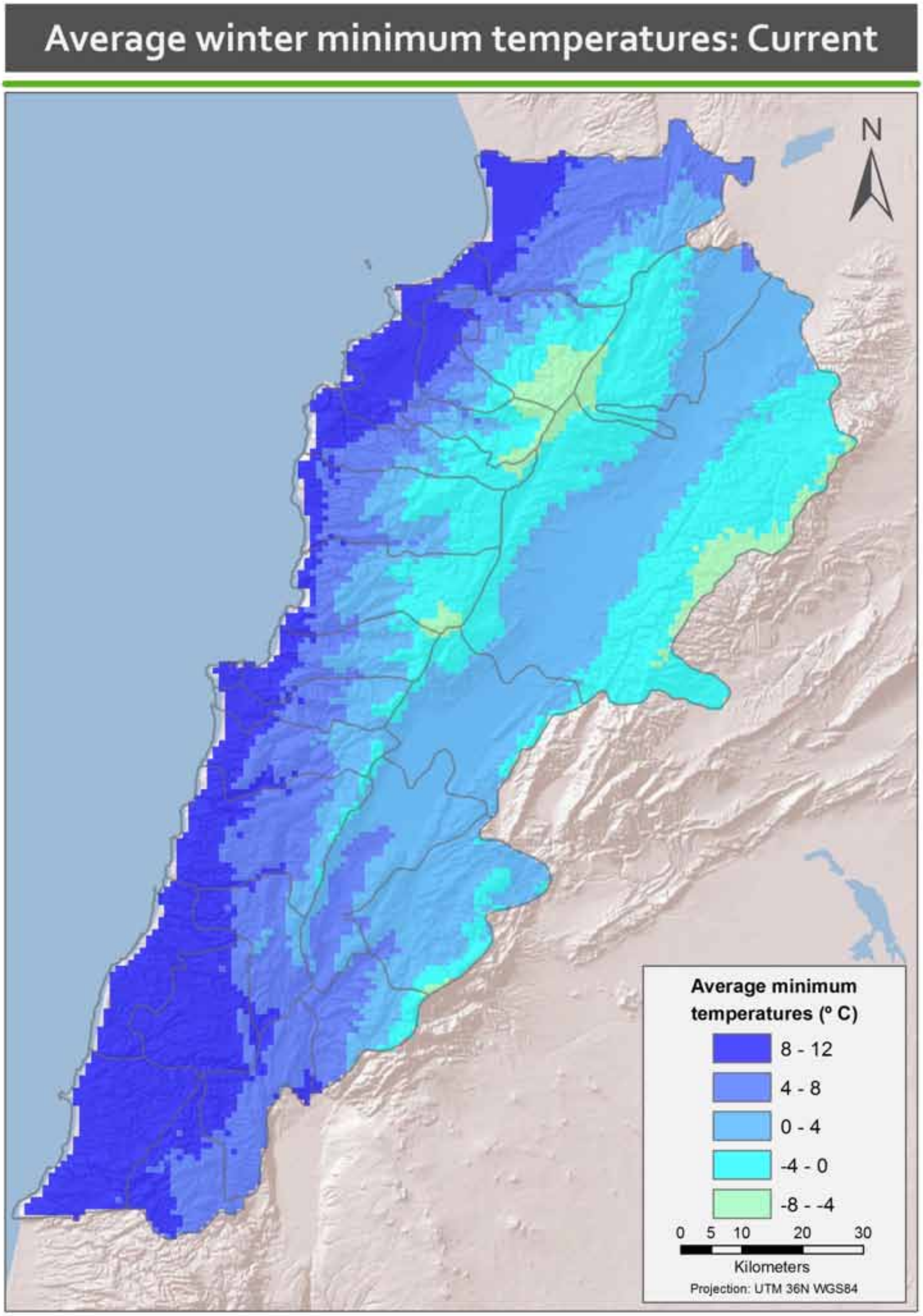
The uncertainty analysis was performed in R (R Core Team, 2012) using the “usdm” R-package (Naimi, 2013). The correlation coefficient and the Variance Inflation Factor (VIF) were calculated. The analysis of collinearity was done within all original variables. Variables with $R^2>0.90$ and VIF>9 produced a poor estimation of the correlation coefficient due to collinearity and were deleted (Graham, 2003; Heikkinen et al., 2006). Three common non collinear variables were found:

- Winter minimum temperature;
- Summer maximum temperature;
- Summer precipitation.

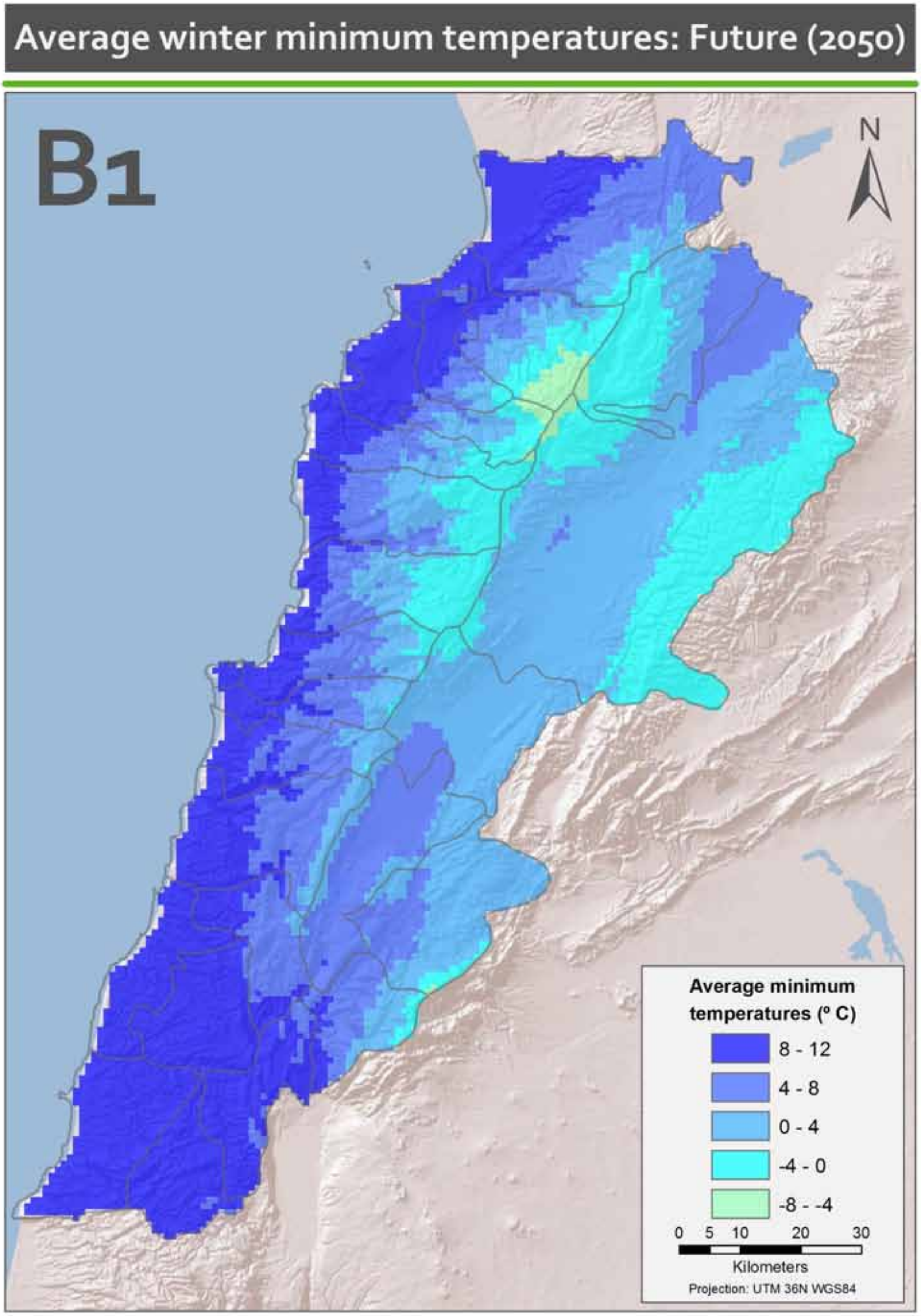
11.4 CURRENT AND FUTURE VARIABLES MAPS

The following maps show the current status of the selected variables and the future models obtained under B1 and A2 scenarios.

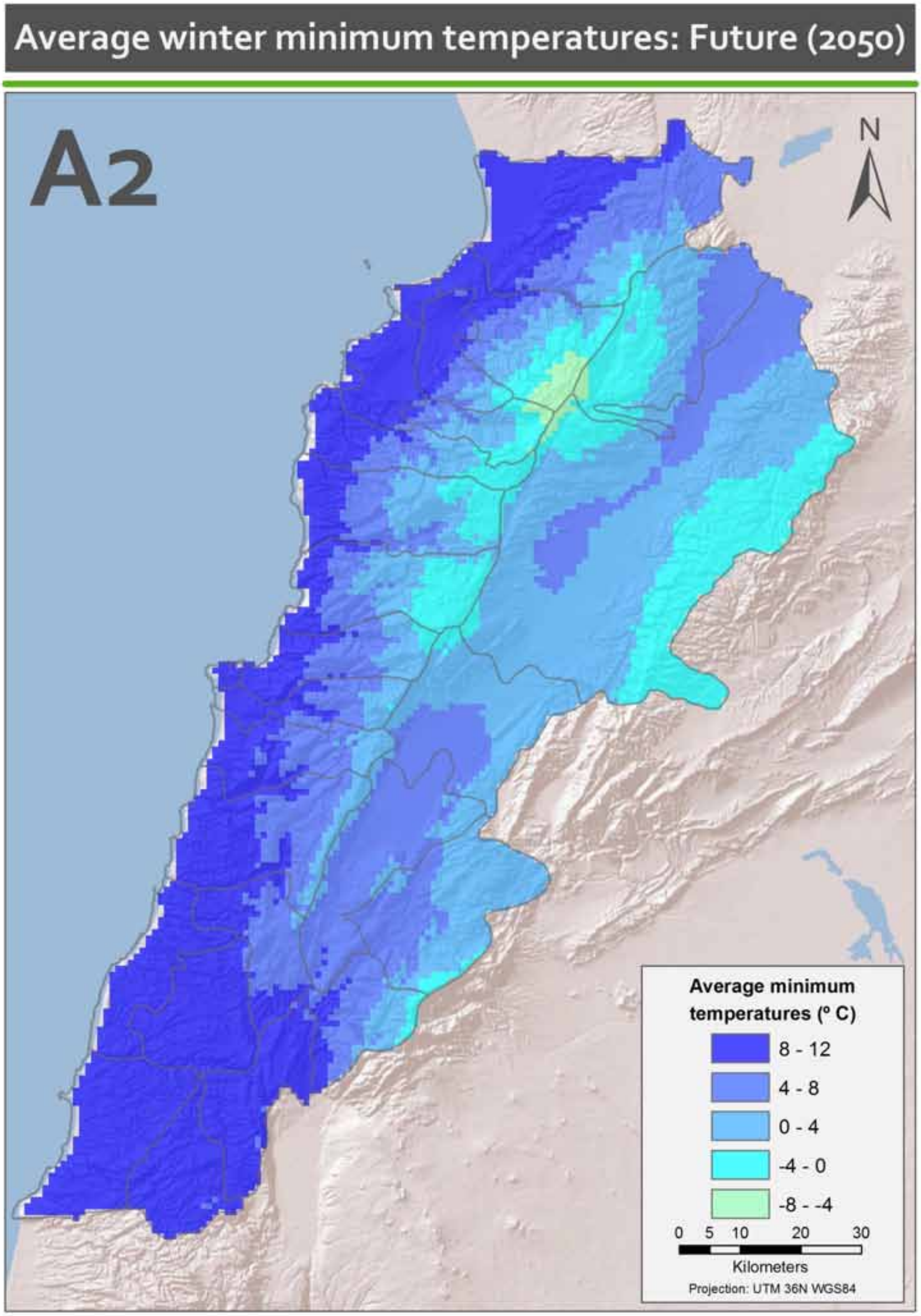
11.4.1 Winter Minimum Temperatures: Current



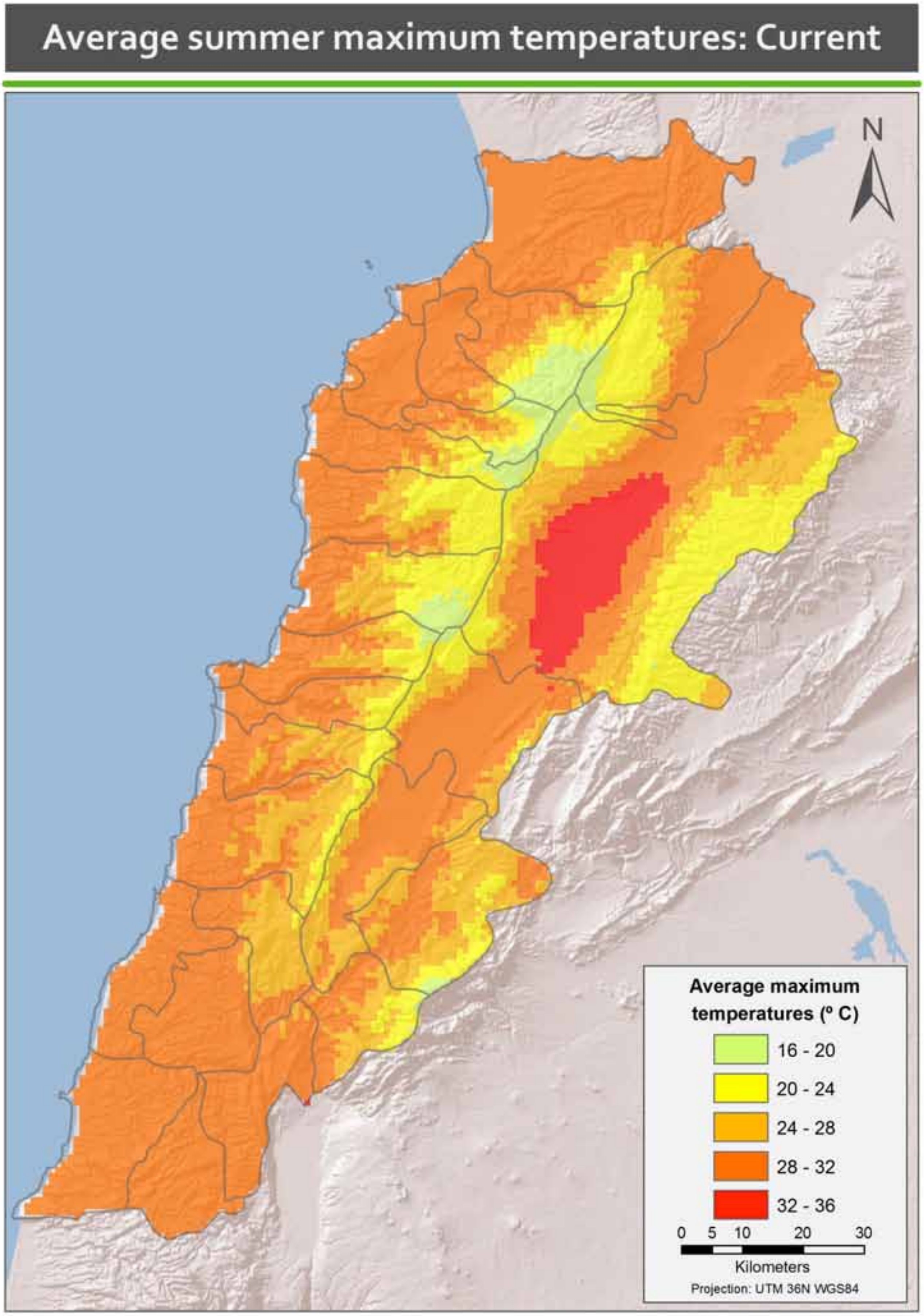
11.4.2 Winter Minimum Temperatures: B1 Scenario



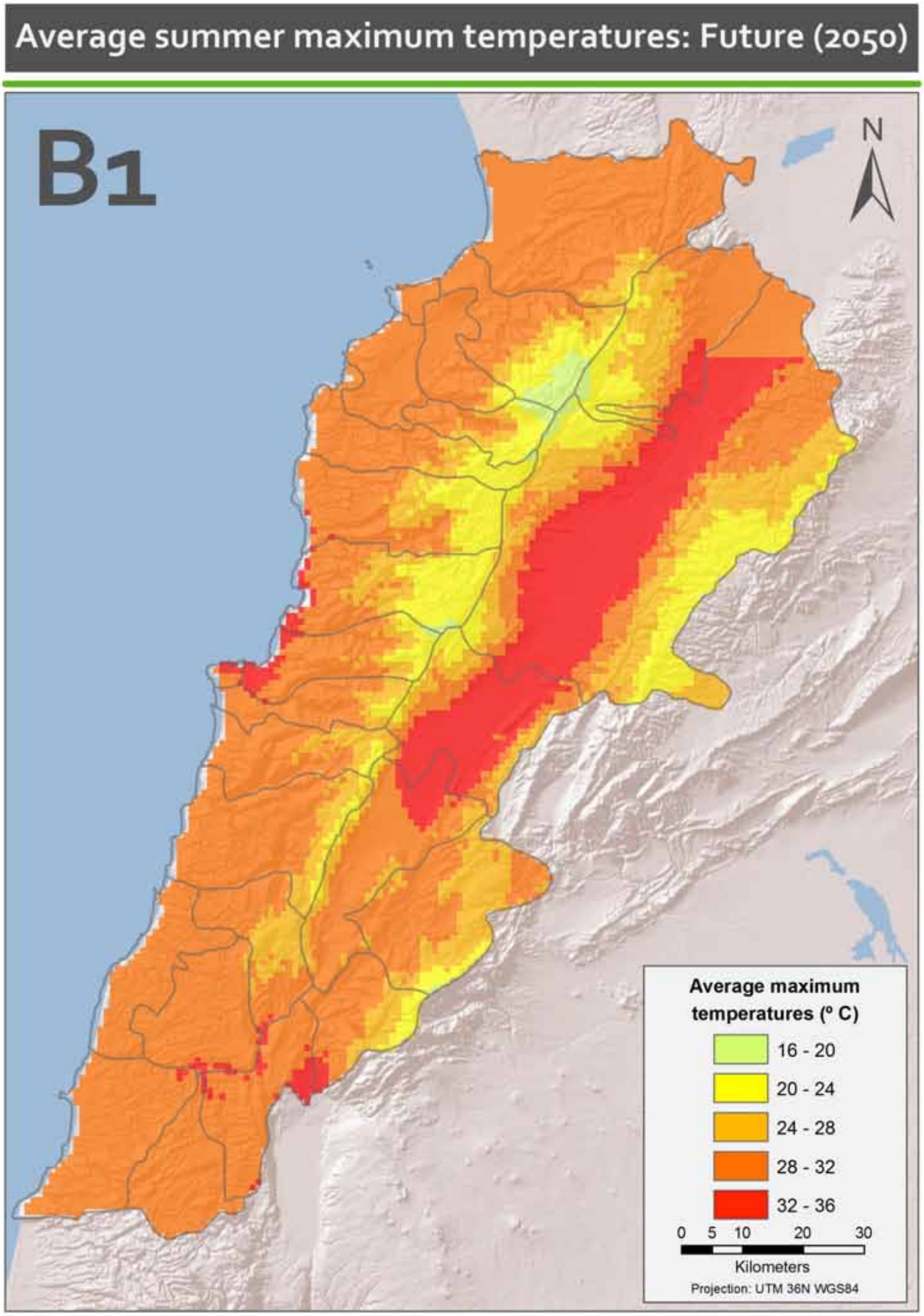
11.4.3 Winter Minimum Temperatures: A2 Scenario



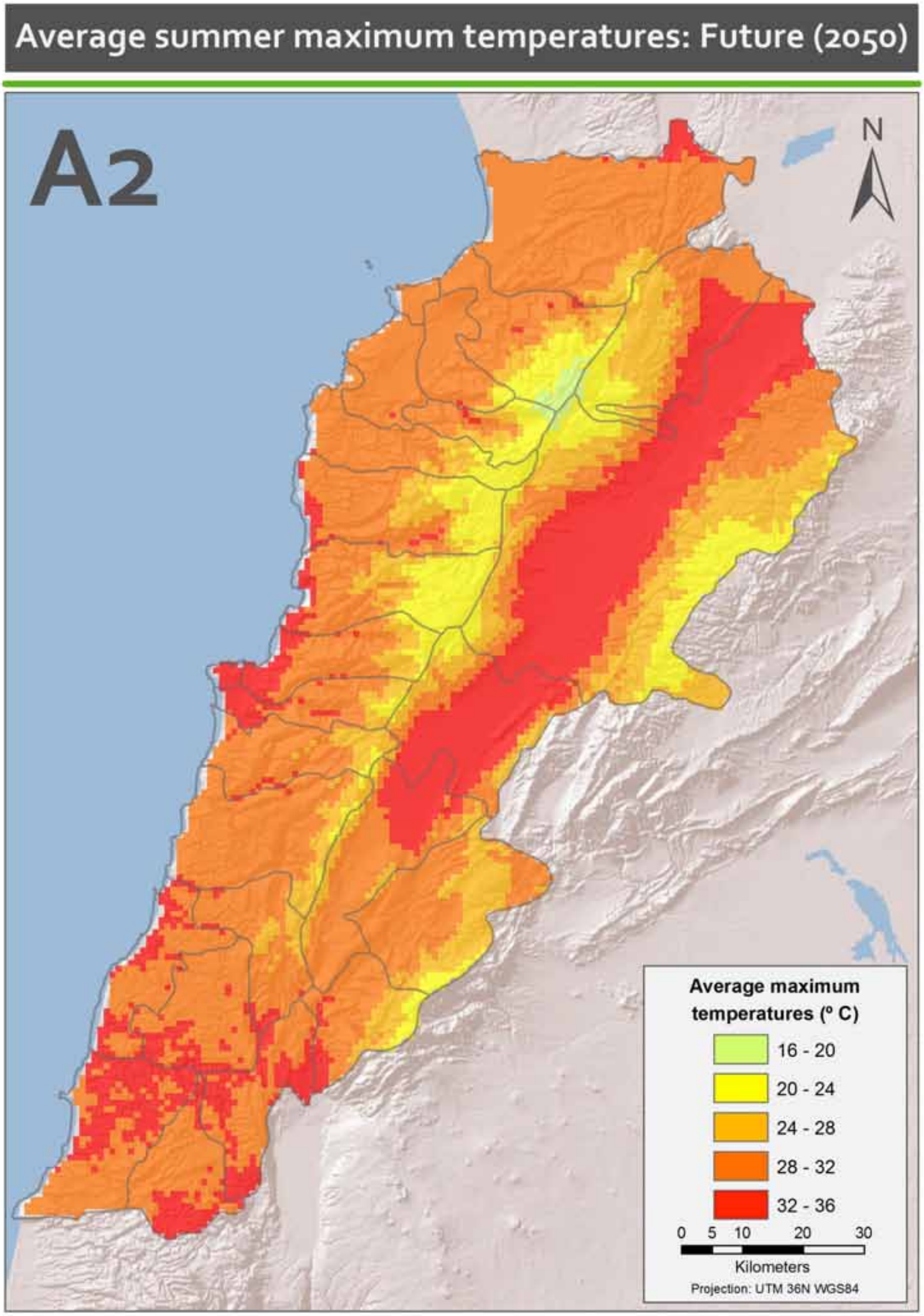
11.4.4 Summer Maximum Temperatures: Current



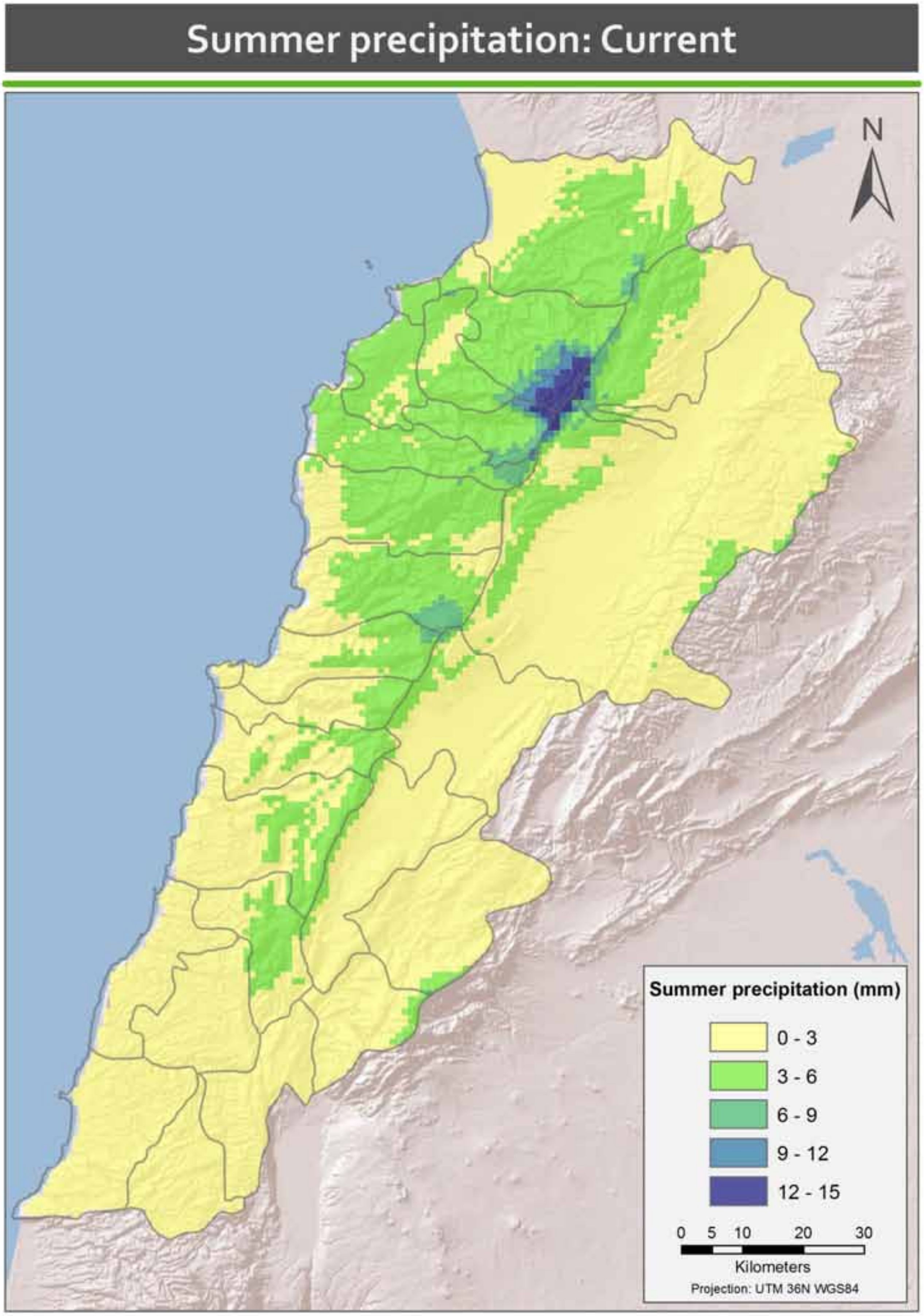
11.4.5 Summer Maximum Temperatures: B1 Scenario



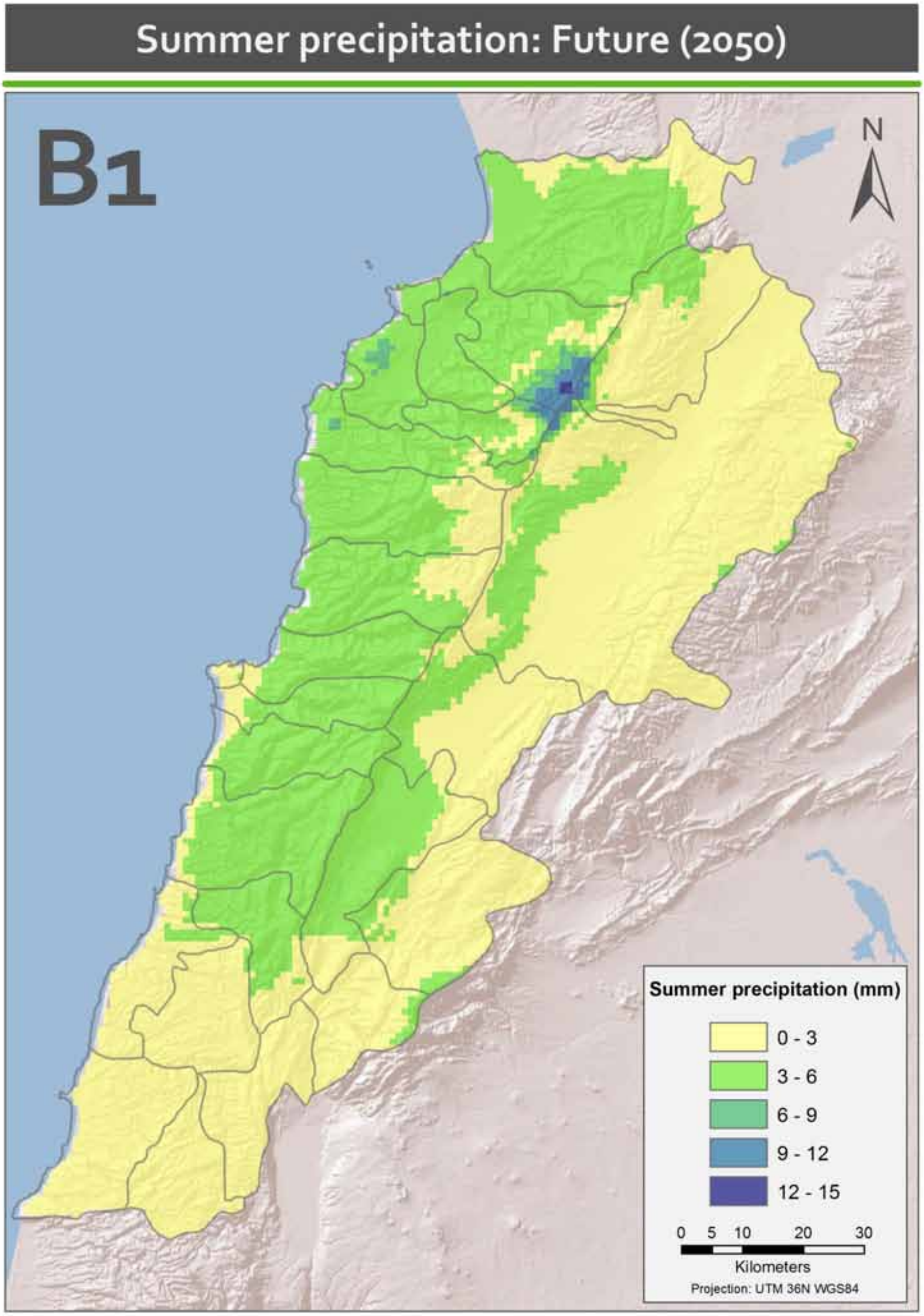
11.4.6 Summer Maximum Temperatures: A2 Scenario



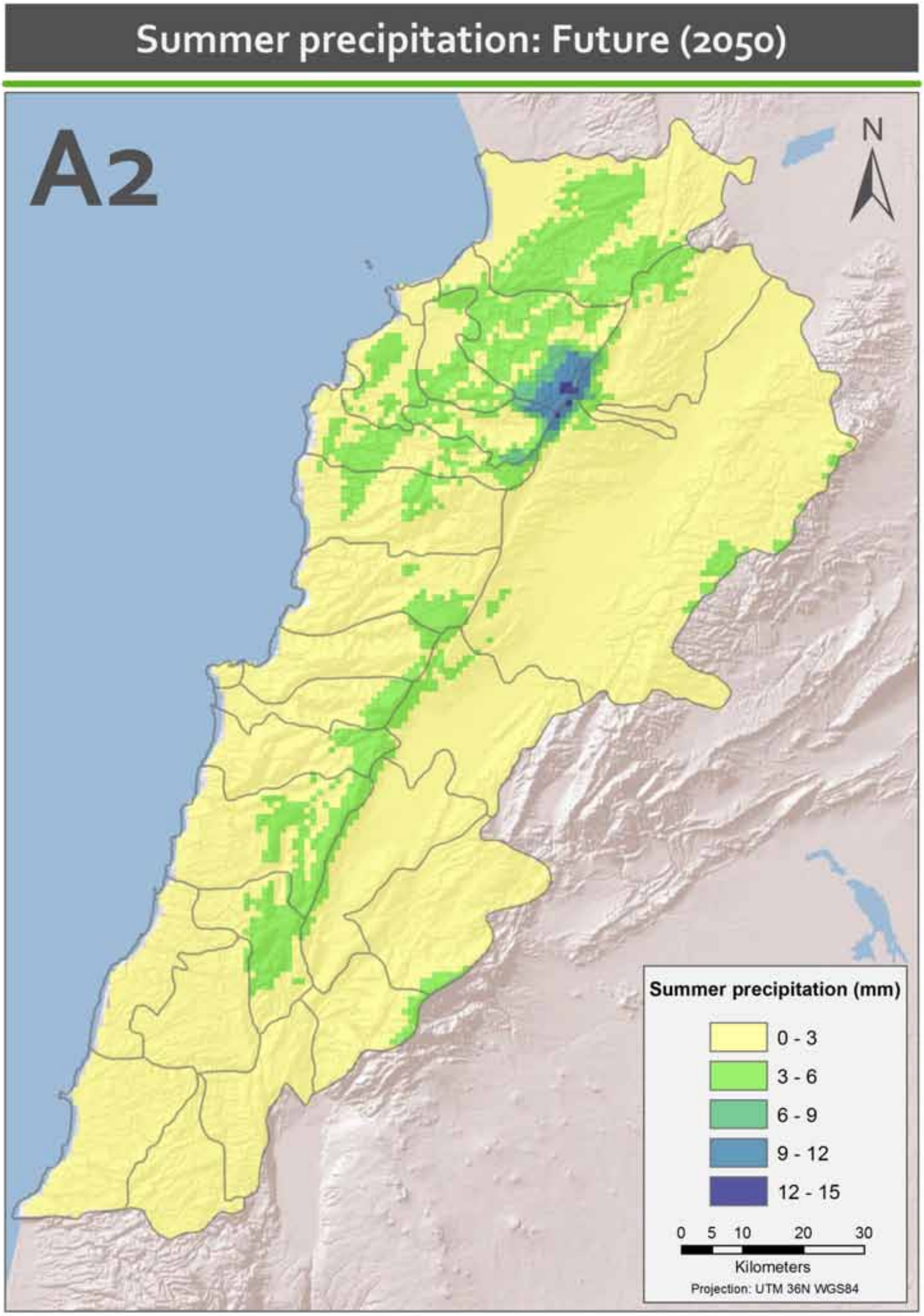
11.4.7 Summer Precipitation: Current



11.4.8 Summer Precipitation: B1 Scenario



11.4.9 Summer Precipitation: A2 Scenario



12. ANNEX II. SPECIES DISTRIBUTION MODELS. DESCRIPTION AND EVALUATION

The variety of techniques accessible to model species distribution can be classified in three groups:

- Profile techniques which require presence-only data, environmental hype-space inhabited by species methods as BIOCLIM, Surface Range Envelope (SRE), distance-based methods as DOMAIN or Ecological Niche Factor Analysis (ENFA).

- Discriminative techniques which require presence-absence data: General Linear Model (GLM), General Additive Models (GAM), Multivariate Adaptive Regression Splines (MARS), Classification and Regression Tree Analysis (CTA), Boosted Regression Trees (BRT), Flexible Discriminant Analysis (FDA), Artificial Neural Network (ANN), Maximum Entropy (MaxEnt), Random Forest (RF).

- Mix modeling approach which uses combined techniques: Biomod, Generalized Regression Analysis and Spatial Prediction (GRASP), OpenModeller.

Moreover, Species Distribution Models (SDM) can also be classified by their algorithms: Regression methods as GAM, GLM, and MARS; Machine-learning methods as ANN, BRT, MAXENT, and RF; Classification methods as CTA and FDA; and Enveloping methods as SRE and BIOCLIM (Guisan & Thuiller, 2005; Elith et al., 2006; Elith & Leathwick, 2009; Franklin, 2009).

To deal with model technique election, Biomod2 R-package (Thuiller et al., 2013) which includes ten SDMs techniques was selected for this assessment. Default settings of biomod2 (version 2.1.15) were used.

12. ANNEX II. SPECIES DISTRIBUTION MODELS. DESCRIPTION AND EVALUATION

12.1 STATISTICAL MODELS

The Biomod2 R-package is a computer platform for ensemble SDMs, which works with presence-absence data and includes ANN, BRT, GLM, GAM, CTA, FDA, MARS, SRE, and RF, and also runs MaxEnt (**Table 3**). The outputs are assessed by the goodness-of-fit. ANOVA and Akaike Information Criterion (AIC) are available for GLM and GAM. The rate of misclassification is used for CTA and RF. Model accuracy is measured by area under the curve (AUC), Cohen's Kappa (k) and true skills statistics (TSS) among others. Biomod2 also tests the influence of each variable in the model by a randomized procedure and displays a variable classification table.

Model	Data	Reference
Biomod2	S	Thuiller et al., 2013
Artificial Neural Networks (ANN)	A	Lek & Guegan, 1999
Surface Range Envelope (SRE)	B	Busby, 1991
Boosting Regression Trees (BRT)	A	Elith et al., 2008
Classification and Regression Trees (CTA)	A	Vayssieres et al., 2000
Generalized Additive Models (GAM)	A	Guisan et al., 2002
Generalized Linear Models (GLM)	A	Guisan et al., 2002
Multivariate Adaptive Regression Splines (MARS)	A	Friedman, 1991
Flexible Discriminant Analysis (FDA)	A	Trevor et al., 1994
Random Forest (RF)	A	Breiman, 2001
Maximum Entropy (MaxEnt)	B	Phillips et al., 2006

Table 3. Model Techniques Ensemble in Biomod2 (Thuiller et al., 2013)

12.2 MODELS DESCRIPTION

Artificial Neural Networks (ANN) is a machine-learning approach widely used to deal with diverse problems (Franklin, 2009). Although the most frequent in ecology is the single layer perception, also named multi-layer feed-forward neural network. This "black box" technique estimates the species occurrence by connecting the known output (response variables) with the inputs (explanatory variables) by a middle step (hidden composite variables). The model establishes linear relation between the explanatory variables and the hidden composite variables which are non-linear related with the response variables. (Lek & Guegan, 1999; Franklin, 2009).

12. ANNEX II. SPECIES DISTRIBUTION MODELS. DESCRIPTION AND EVALUATION

Surface Range Envelop (SRE) is a bioclimatic model similar to BIOCLIM. This model defines the climate range under which the species occurs, sets of environmental variables where the species is present, and then extrapolates the results to similar areas. This is the simple SDM technique (Busby, 1991; Beaumont & Hughes, 2002).

Boosting Regression Tree (BRT) algorithm used in biomod2 was described in Ridgeway (1999) and implemented by Friedman (2001). BRT estimates the species occurrence by fitting numerous single models whose predictions are later ensembled to build a more robust prediction. Each single model is a simple regression or regression tree, i.e. an iterative data partitioning in homogenous groups based on the response. BRT performs a recursive method to build a final model by adding trees and reclassifying the data to highlight poor results by the previous tree model (Elith et al., 2008).

Classification and Regression Trees (CTA) method is based on successive data partitions according to predictions into homogeneous groups in terms of the response. The tree is done by recursive data splitting based on a single explanatory variable. Each data division reduces the variance within the subset. The best CTA model is a mid-way model between the highest variance decrease and the lowest number of singles model (Vayssieres et al., 2000).

Generalized Additive Models (GAM) estimates the species occurrence by fitting a response curve called "smoothers". Smoothers adjust the data into the curve by local fitting to data subsamples. GAM estimates complex relationships between the variables more accurately than linear models. The model fits a single smoother to each variable and results are additively combined (Guisan et al., 2002).

Generalized Linear Models (GLM) is based on fitting a linear relationship between the independent and dependent data. GLM uses linear, quadratic, or polynomial functions to estimate species occurrence. The model selection is done by a stepwise procedure under the Akaike Information Criterion (AIC) or Bayesian Information Criterion (BIC), which delete redundant variables and decrease collinearity (Guisan et al., 2002).

Multivariate Adaptive Regression Splines (MARS) is a linear method which gives different models coefficients according to the optimal values across each level of the explanatory variables. The threshold indicates a modification in the model coefficient, called "Knots", which are defined automatically. It presents similarities with CTA where the data partitioning is replaced by piecewise linear functions and the reduction of the final model complexity is done by deleting irrelevant basic functions. Moreover, it is similar to GAM due to the use of piecewise splines. The advantages of MARS are that it considers local variables iterations, supports large number of explanatory variables, and performs faster than GAM (Friedman, 1991).

Flexible Discriminant Analysis (FDA) uses the MARS function to perform a flexible discriminant analysis for the regression portion of the model. FDA is a supervised classification method which combines different models (Trevor et al., 1994).

Random Forest (RF) builds many de-correlated classification trees and averages them. It constructs the same number of classification trees based on data in the training set, randomly with replacements, with a subset of explanatory variables. Each individual tree is validated with the non-used subset of the data and returns the average predictions of all trees. Variable selection is done by rate of misclassification, for categorical outcome or mean squared error. The difference in errors, between the prediction and the values calculated by the procedure of variable randomization is reflected in the weight of the predictive variable (Breiman, 2001).

MaxEnt is a machine-learning method that estimates the species distribution probability by assessing the maximum entropy distribution, so that the most spread-out or closest are uniform. MaxEnt is performed with only presence data, though it does require background points. It also gives variable comparison and test model accuracy by AUC (Phillips et al., 2006; Phillips & Dudík, 2008).

12.3 MODELS EVALUATION

Model evaluation calculates the model's predictive performance, based on the error evaluation and the quantification of those classified incorrectly. There are two types of errors, commission errors and omission errors. Commission errors classify an absence as presence. Omission errors define a presence as absence. The final model evaluation and the comparison between techniques are done by a statistical assessment of the discrimination capacity of the model. To calibrate the model, an evaluation is done with an independent dataset. However, this rarely occurs and researchers apply other techniques such as data partitioning or cross–validation (Franklin, 2009).

Data partitioning consists of dividing the dependent data in two sets. One set to calibrate the model -training data and another to evaluate the model-testing/validation data-. The optimal data partitioning range depends on the number of predictions (Franklin, 2009); in this case 7525/ was selected to train and test the models. This range was also proposed in other studies (Thuiller, 2003; Thuiller et al., 2003; Thuiller, 2004; Heikkinen et al., 2012).

Data partitioning is a simple cross-validation where dependent data is divided in two sets. Cross – validation consists in dividing dependent data into multiple sub-sets each one with the same number of cases. Later, the model runs the same number of times as the number of sub-sets. Each time a different sub-set is used to test the model performance while the remainders are used as training data.

Model evaluation tests the model predictive performance. The Area Under the Curve of the receiver operating characteristic plot statistic (AUC) was used to estimate model accuracy with presence-absence data. Moreover, Cohen's Kappa (κ) was calculated to estimate the map veracity.

AUC is a threshold independent statistic measure that represents the model's goodness of fit to the data. AUC graphically represents the model discriminative capacity. AUC plots the commission error (1 – sensitivity) in the horizontal axis, versus the omission error (sensibility) in the vertical axis. It ranges between 0.5 – 1, where 1 represents a prefect classification and 0.5 a random classification. Using AUC as an evaluation metric has several advantages: it is possible to compare all SDMs, and it is prevalence- and threshold- independent (Franklin, 2009). Some of the limitations of AUC are that it requires a minimum number of presences, it does not differentiate between omission and commission errors and it gives the same importance to all points across the region while the area of interest is the right top corner of the plot (Lobo et al., 2008).

12. ANNEX II. SPECIES DISTRIBUTION MODELS. DESCRIPTION AND EVALUATION

In order to select the most accurate SDM and avoid the drawbacks of different individual statistical models, only ensemble models obtained from the linear combination of the 10 models evaluated by R-package biomod2 have been used. Linear combination was obtained by weighing the coefficients of each model based on the AUC obtained. For this purpose, models were run ten times per species and only those that presented an AUC higher than 0.95 in all cases were selected. In some species, required AUC was increased due to the positive results obtained in the models and the need to simplify the final assembly.

Lastly, the final SDM was obtained by assembling selected models.

12.4 POTENTIALITY THRESHOLD

Obtained SDMs are graphical representations of the probability of presence of a species in a particular geographical location. Each pixel represents the percentage of probability of presence for the species. In order to assist managers in decision making, these maps were reclassified indicating the probability threshold of the species from which it is considered a potential species.

This limit is calculated separately for each species from different statistical methods. The choice of the appropriate statistical method depends on the particular characteristics of the species distribution, the dispersion of its points of presence and absence, and their distribution on the generated model.

12. ANNEX II. SPECIES DISTRIBUTION MODELS. DESCRIPTION AND EVALUATION

R-package presence-absence model evaluation was used to calculate the threshold. This provides a set of functions useful when evaluating the results of presence-absence models. **Table 4** shows the selected threshold and method used for each species.

Species	Threshold	Method
Abies cilicica	0.50	predicted prevalence=observed prevalence
Acer syriacum	0.50	sensitivity=specificity
Acer tauricolum	0.42	predicted prevalence=observed prevalence
Arbutus andrachne	0.63	sensitivity=specificity
Arceuthos drupacea	0.50	predicted prevalence=observed prevalence
Cedrus libani	0.50	maximizes Kappa
Ceratonia siliqua	0.51	predicted prevalence=observed prevalence
Cercis siliquastrum	0.62	maximizes Kappa
Crataegus spp.	0.59	predicted prevalence=observed prevalence
Cupressus spp.	0.59	maximizes (sensitivity + specificity)/2
Juniperus excelsa	0.58	sensitivity=specificity
Juniperus oxycedrus	0.61	sensitivity=specificity
Pinus brutia	0.61	sensitivity=specificity
Pistacia palaestina	0.5	sensitivity=specificity
Prunus ursina	0.47	predicted prevalence=observed prevalence
Pyrus syriaca	0.53	predicted prevalence=observed prevalence
Quercus calliprinos	0.61	sensitivity=specificity
Quercus cerris	0.42	predicted prevalence=observed prevalence
Quercus infectoria	0.58	sensitivity=specificity
Styrax officinalis	0.51	predicted prevalence=observed prevalence

Table 4. Threshold And Method Used For Each Species

12. ANNEX II. SPECIES DISTRIBUTION MODELS. DESCRIPTION AND EVALUATION

The same thresholds were used for the representation of the future SDM maps for each species. The description of each method is found below:

Sensitivity=specificity: criteria for optimizing the threshold choice are selected by finding the threshold where sensitivity equals specificity. In other words, by finding the threshold where positive observations are just as likely to be incorrect as negative observations. When threshold is optimized by the «sensitivity=specificity» criteria, it is correlated to prevalence. This gives rare species much lower thresholds than widespread species. As a result, when this method is used, rare species may give the appearance of inflated distribution (Manel, 2001).

Maximizes (sensitivity + specificity)/2: This criterion chooses the threshold that maximizes the sum of sensitivity and specificity. In other words, it minimizes the mean of the error rate for positive and negative observations. This is equivalent to maximizing (sensitivity + specificity - 1), otherwise known as the Youden's index, or the True Skill Statistic. Note that while Youden's index is independent of prevalence, using Youden's index to select a threshold does have an effect on the predicted prevalence, causing the distribution of rare species to be over predicted.

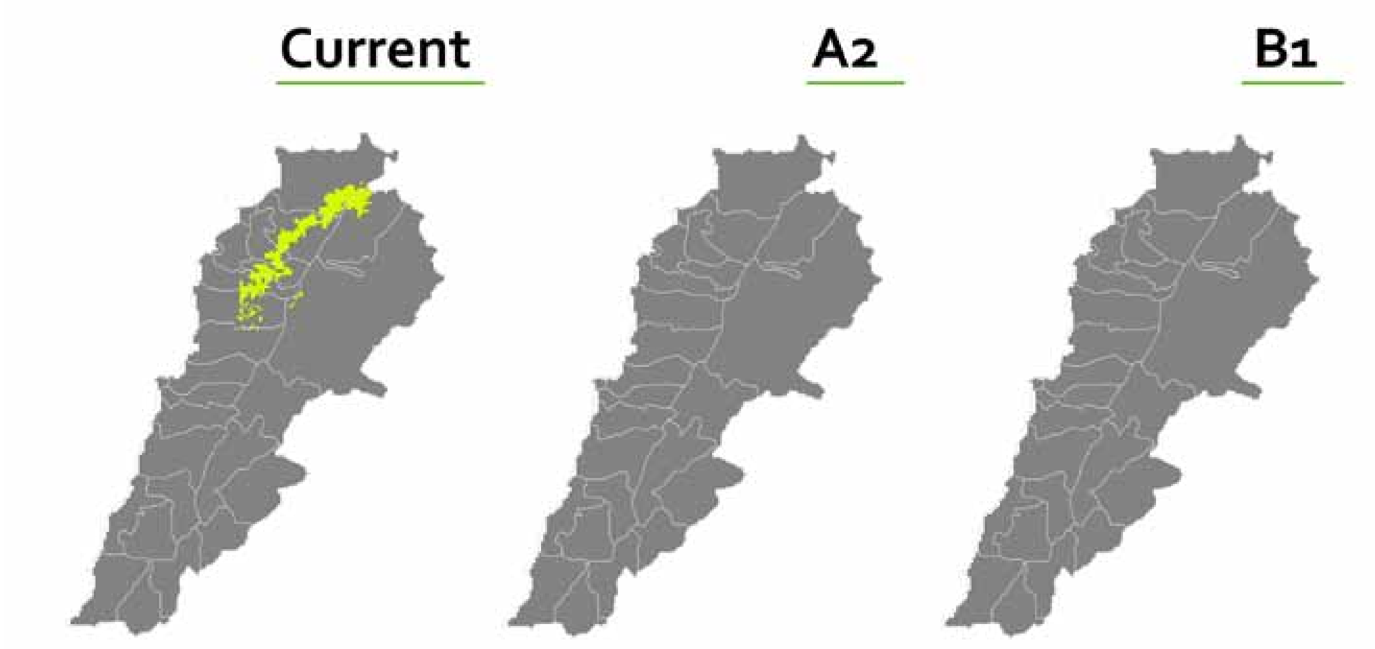
Maximizes Kappa: The criteria for optimizing the threshold choice are to find the threshold that gives the maximum value of Kappa. Kappa makes full use of the information in the confusion matrix to assess the improvement over chance prediction.

Predicted prevalence=observed prevalence: This criterion serves to find the threshold where the predicted prevalence is equal to the observed prevalence. This is a useful method when prevalence preservation is of prime importance.

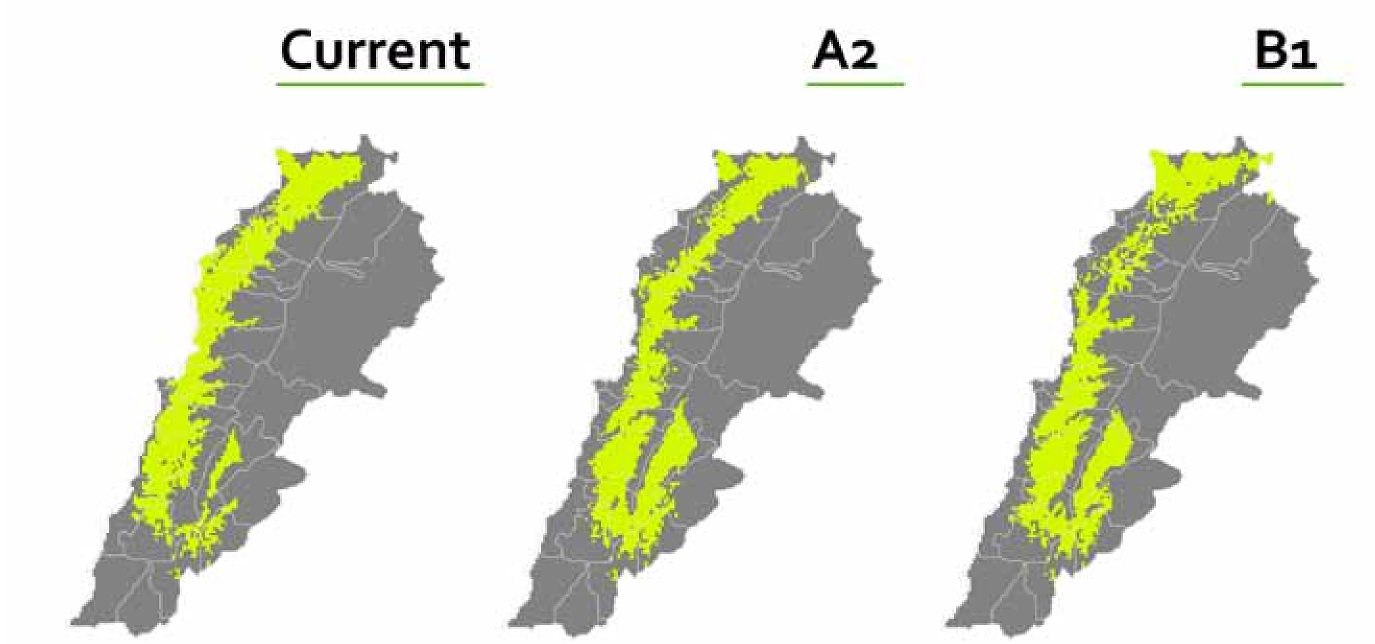
13. ANNEX III. CLASSIFIED MAPS

The SDM maps found in section 7 are classified into six different potentiality classes expressed in percent. In some cases, potentiality threshold is located inside the range of values of one class and the limits of potential areas are not defined within that class. This annex shows the SDM maps rated above and below the threshold calculated for each species, showing the areas where the species is potential or non-potential for the considered scenarios.

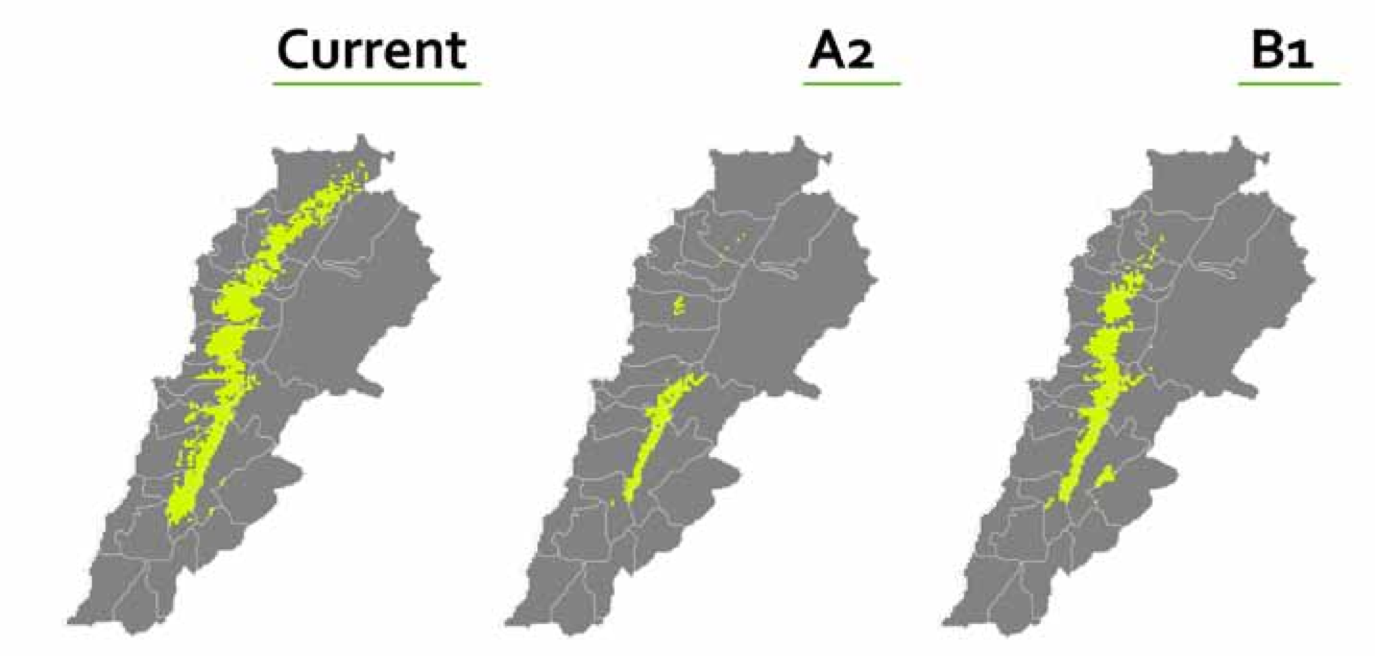
13.1 *Abies cilicica*



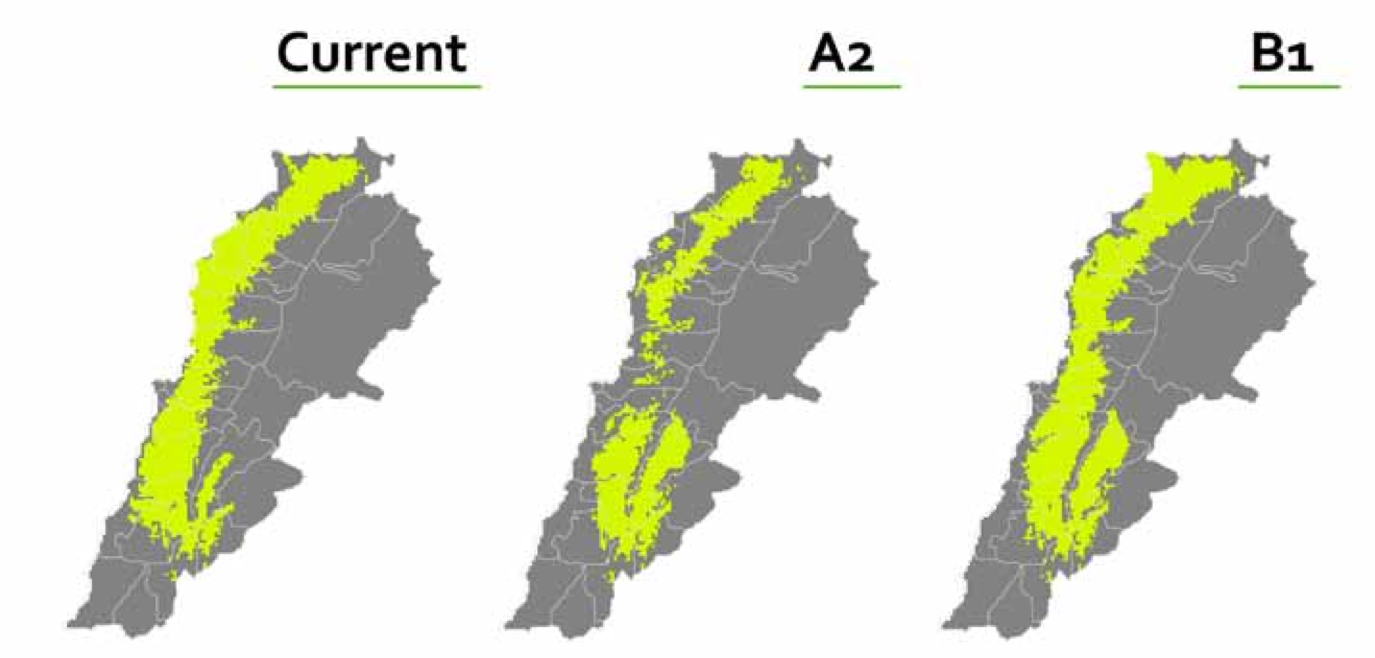
13.2 *Acer syriacum*



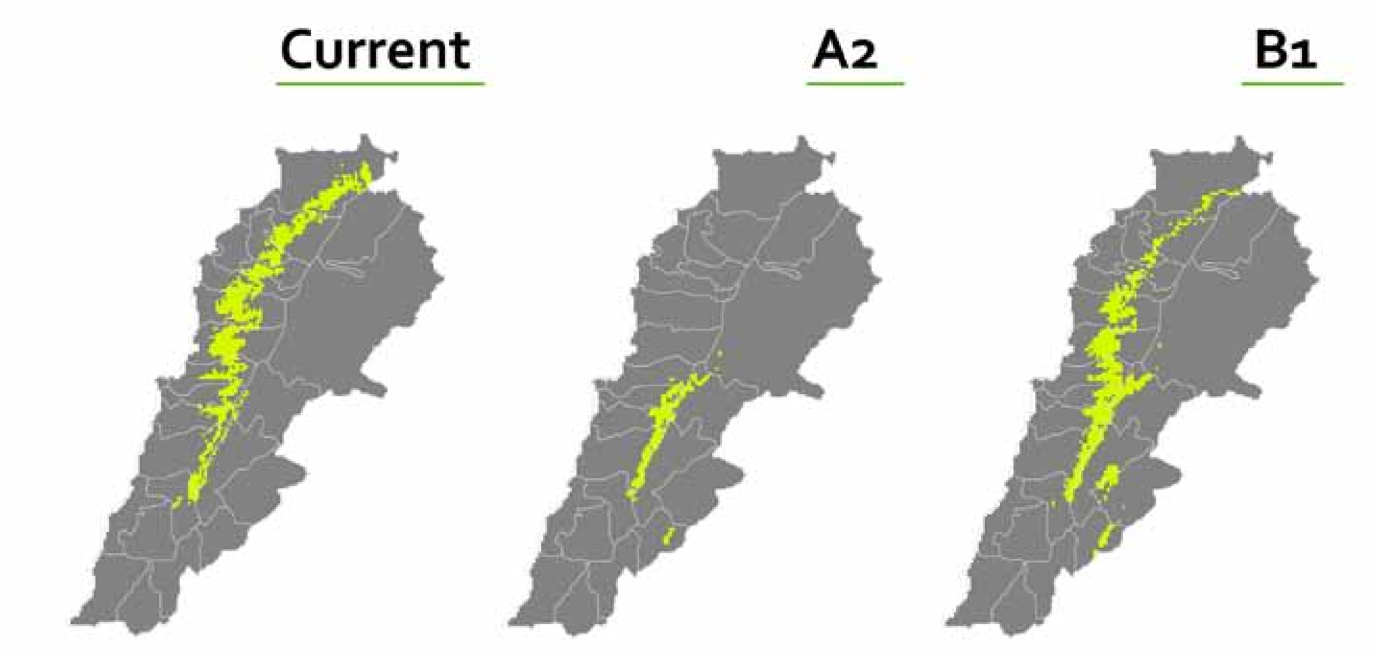
13.3 *Acer tauricolum*



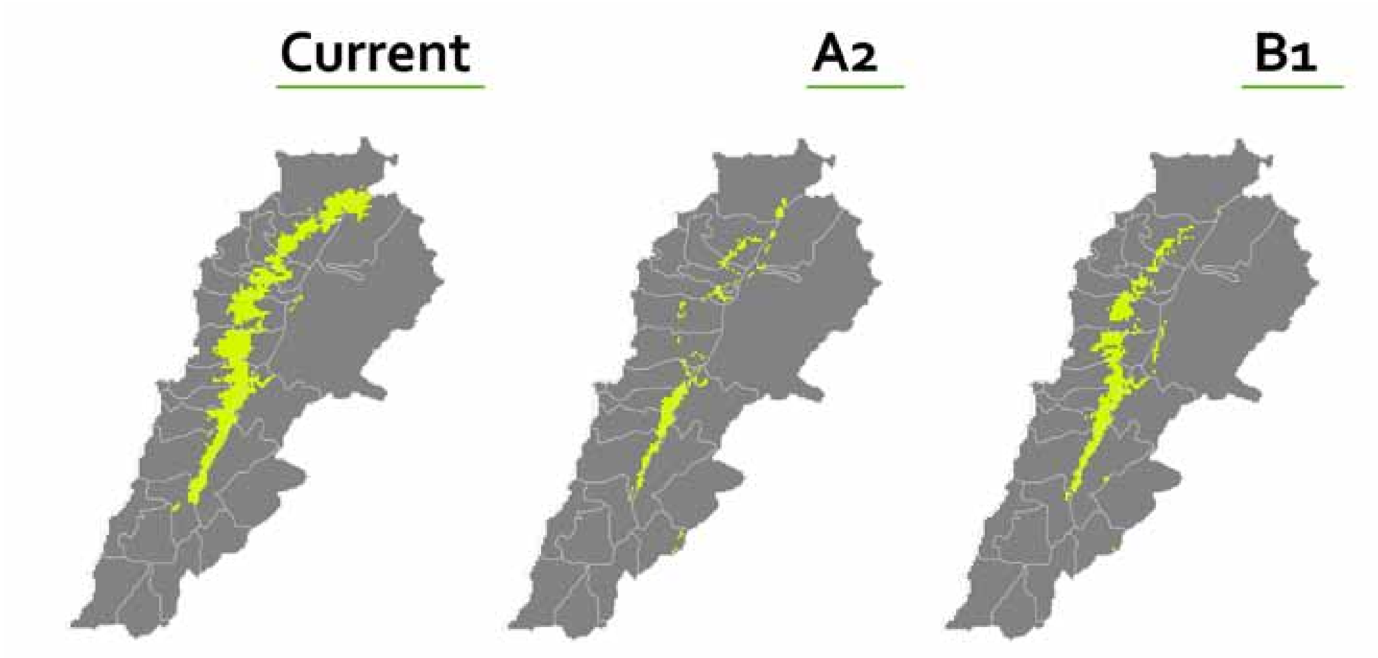
13.4 *Arbutus andrachne*



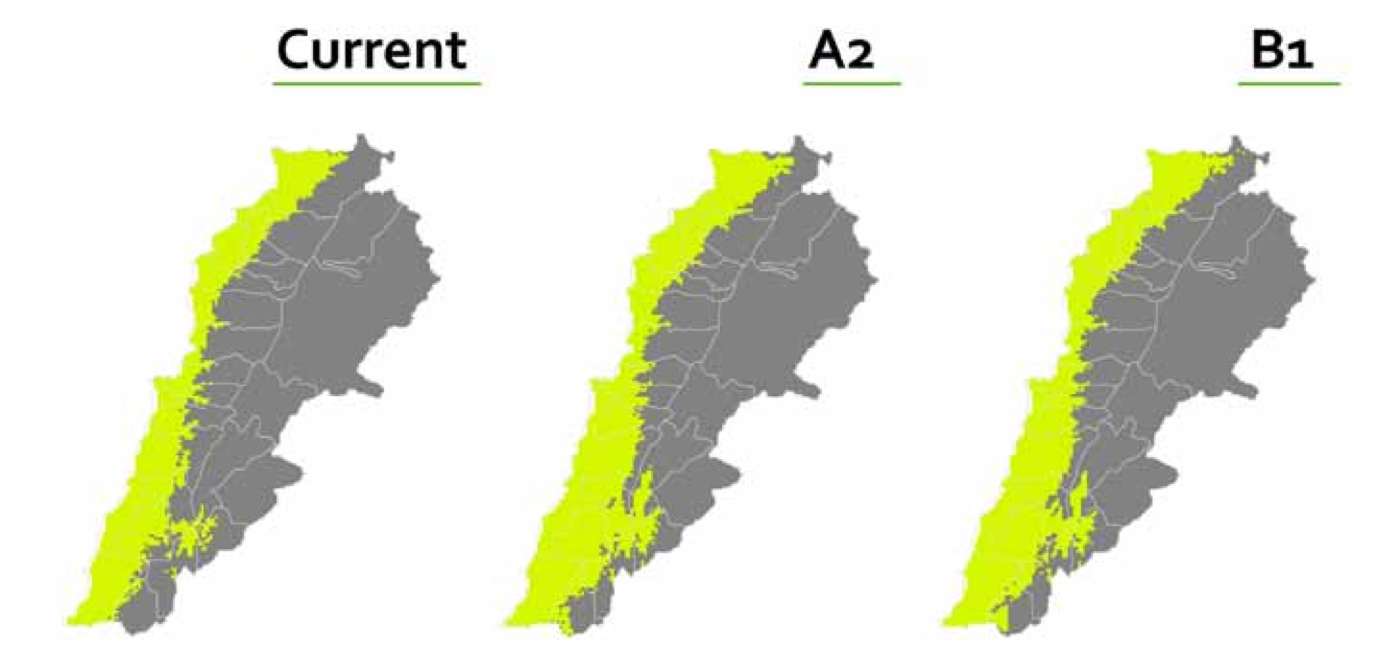
13.5 *Arceuthos drupacea*



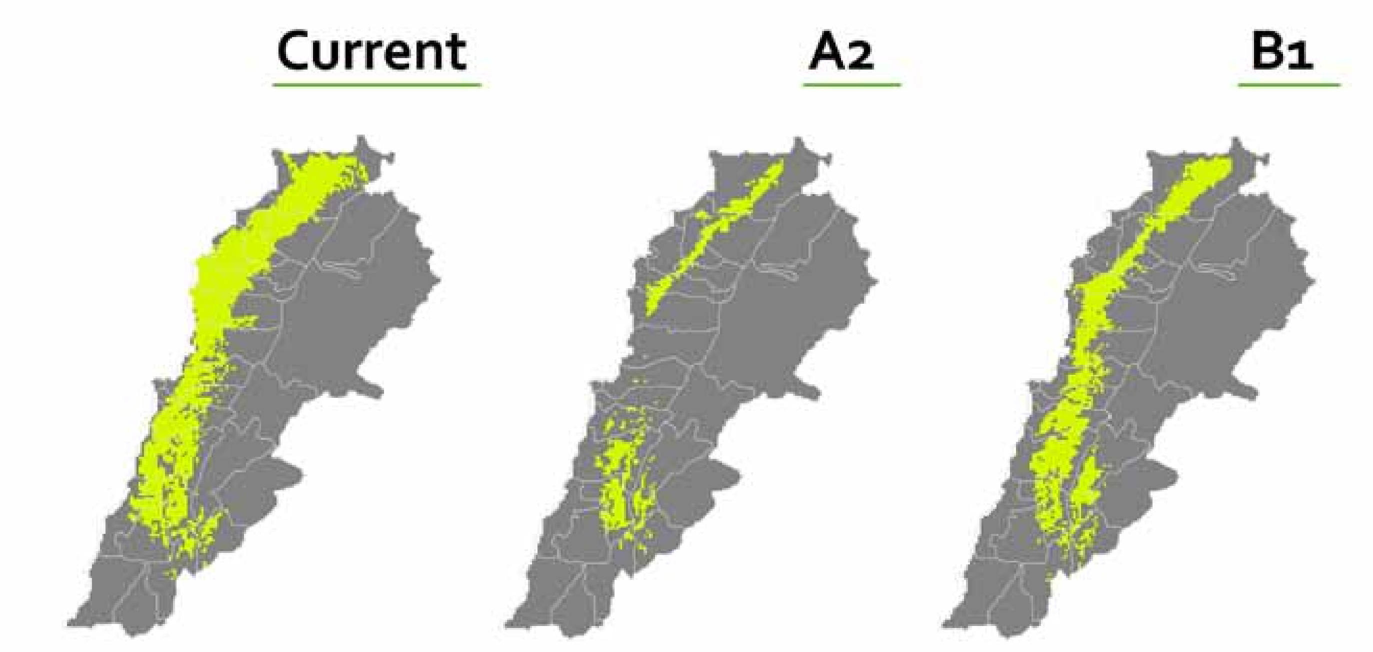
13.6 *Cedrus libani*



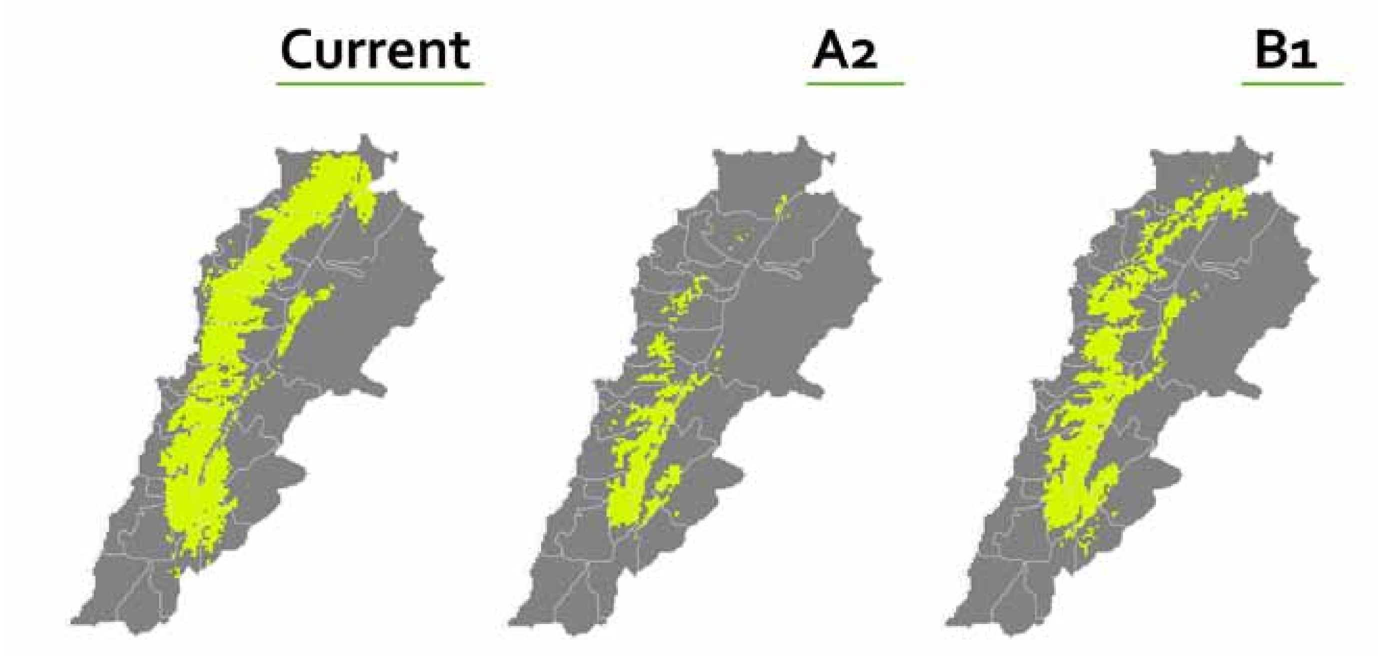
13.7 *Ceratonia siliqua*



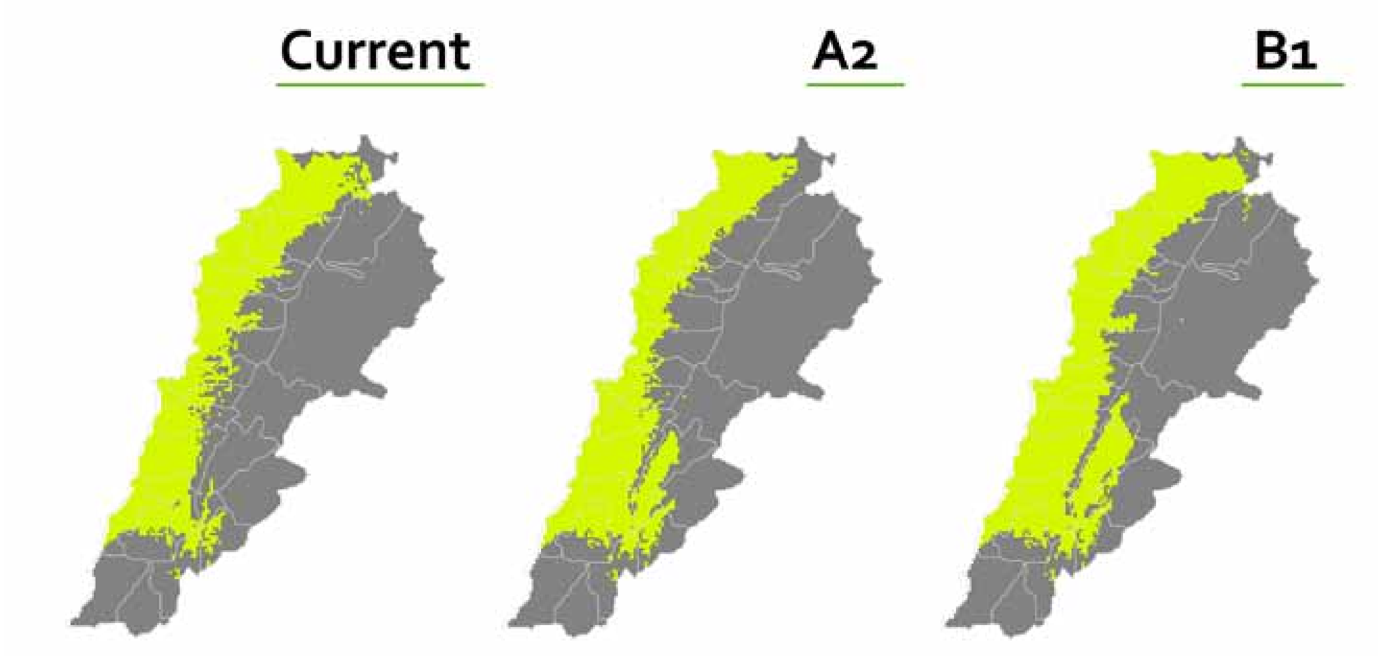
13.8 *Cercis siliquastrum*



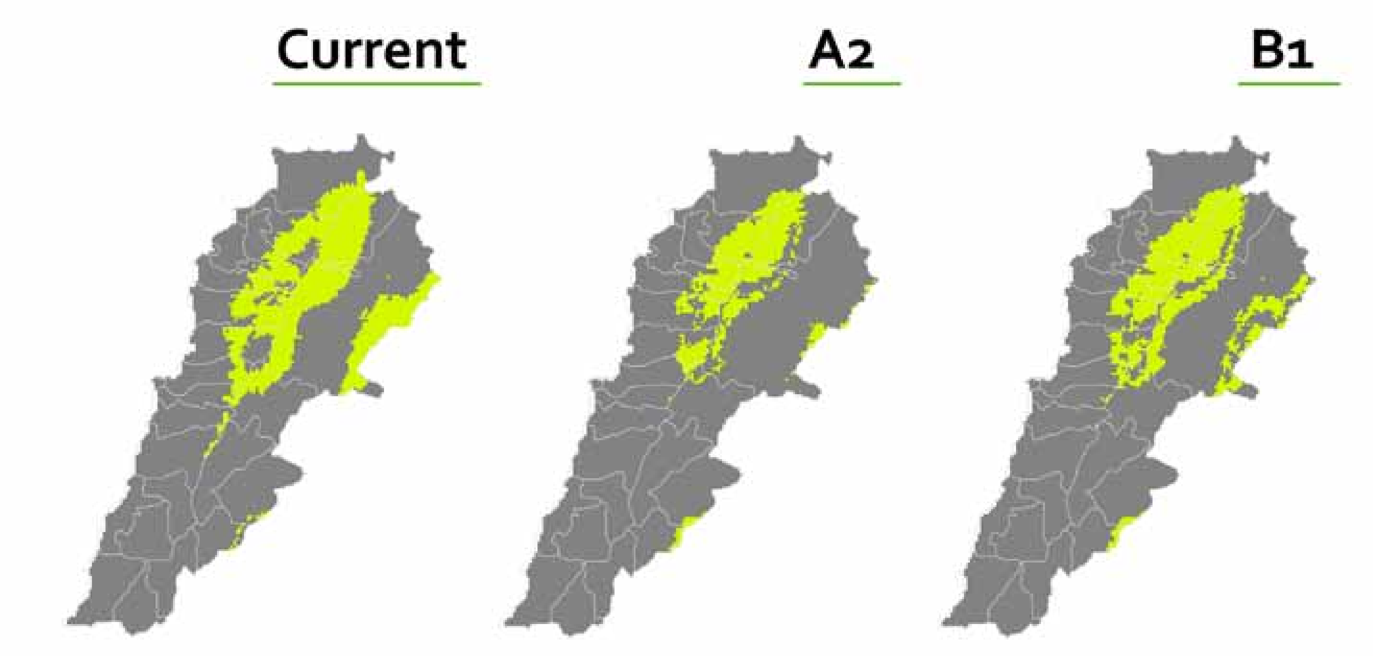
13.9 *Crataegus spp.*



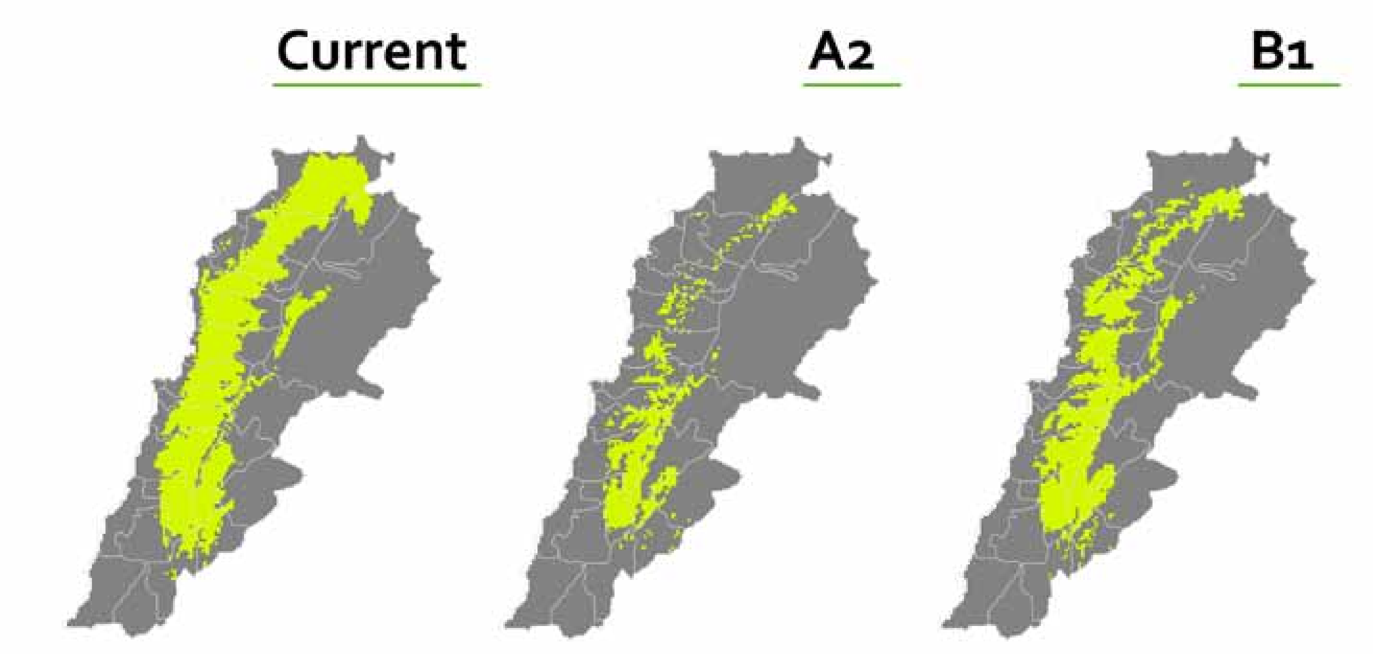
13.10 *Cupressus spp.*



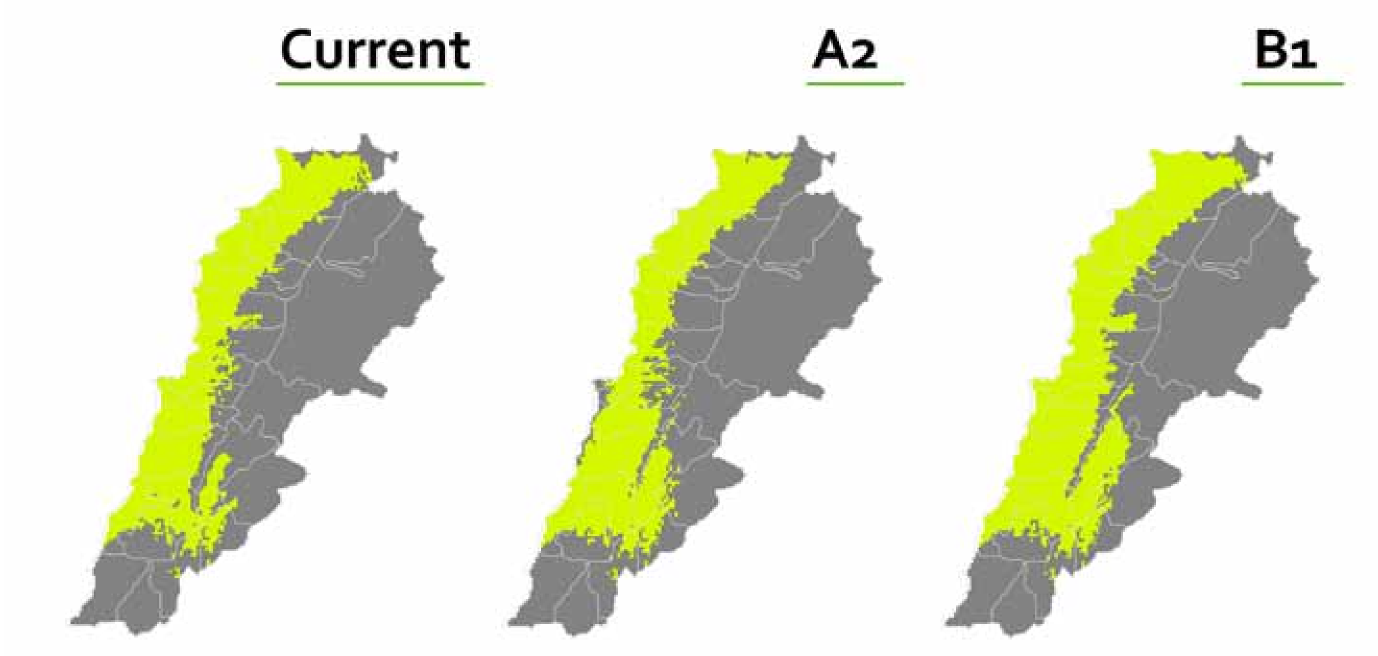
13.11 *Juniperus excelsa*



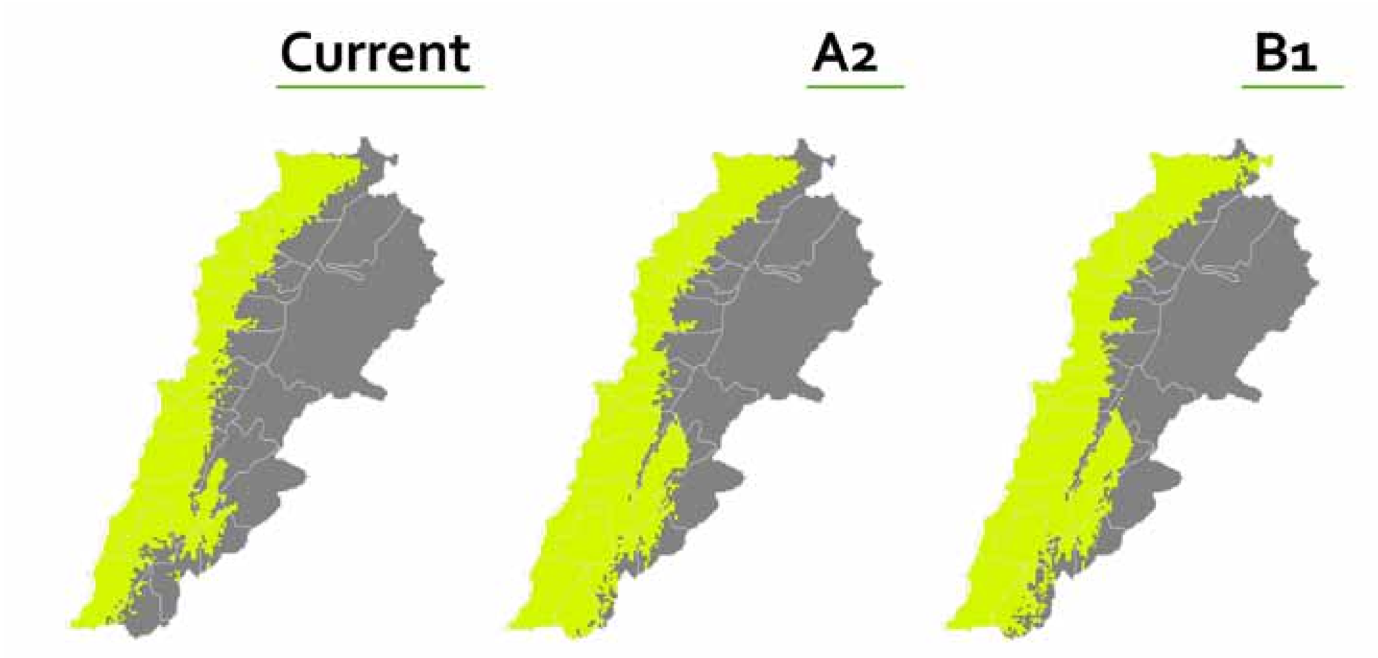
13.12 *Juniperus oxycedrus*



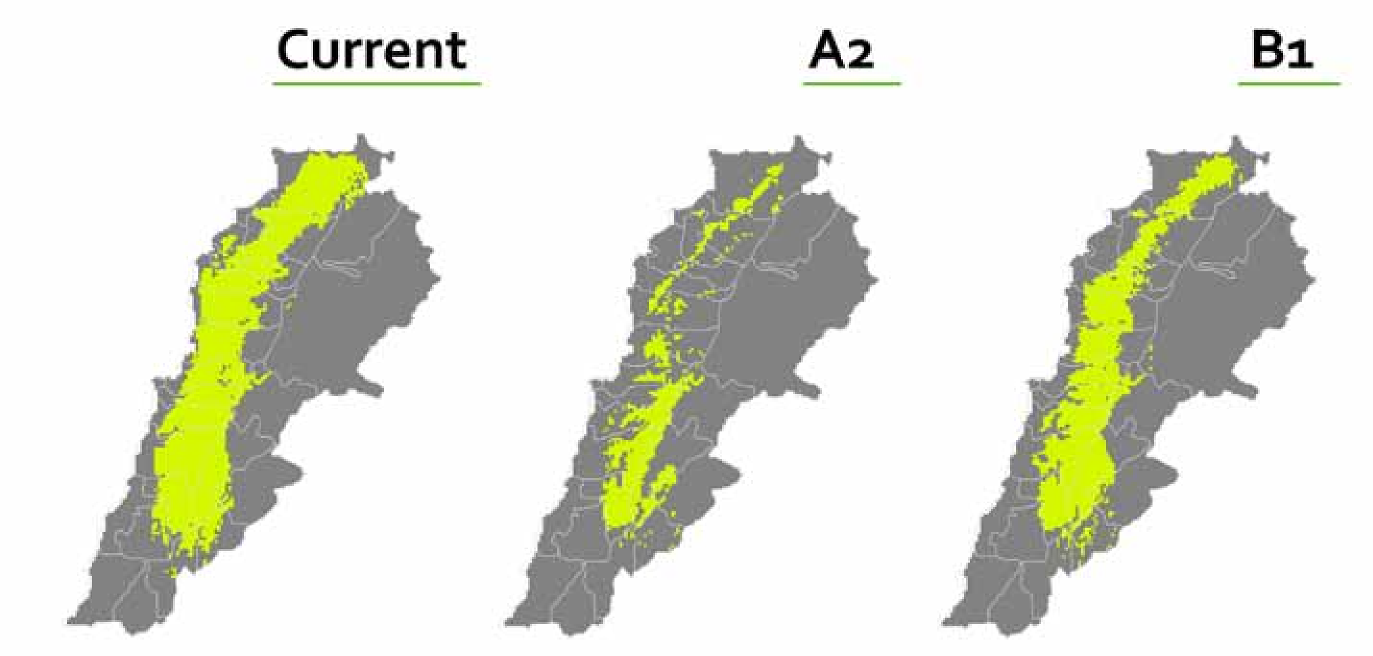
13.13 *Pinus brutia*



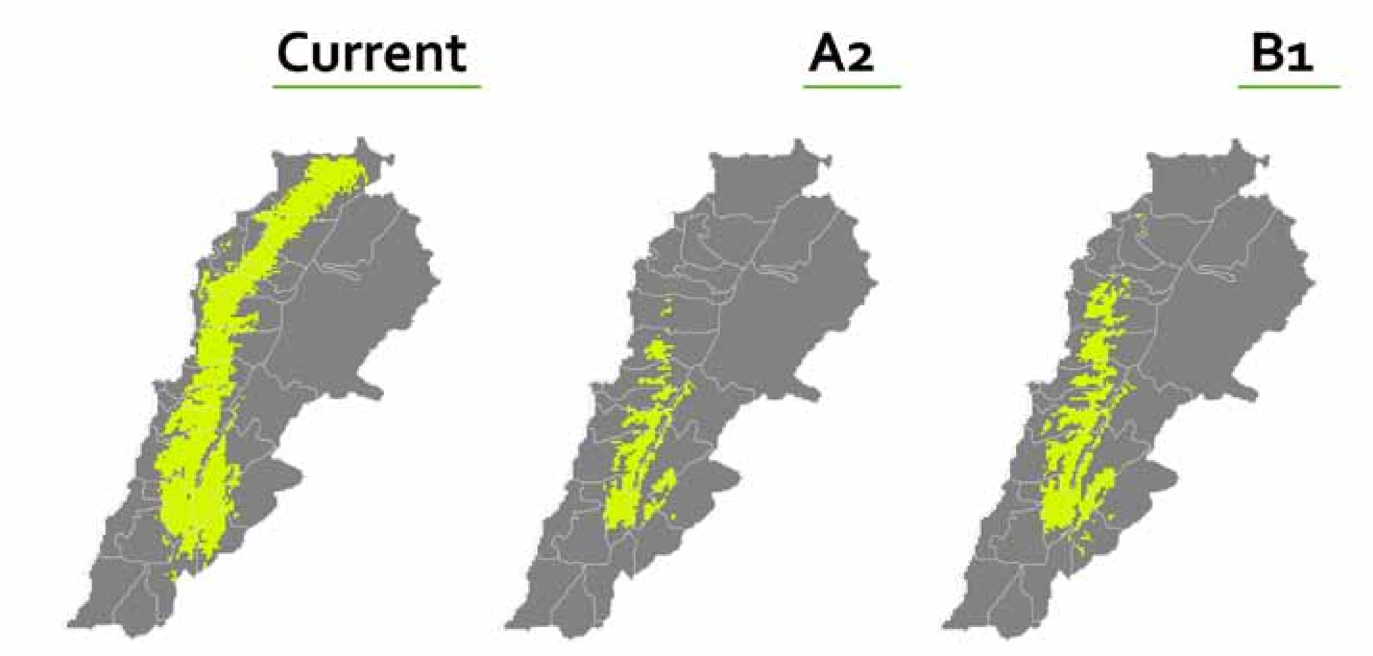
13.14 *Pistacia palaestina*



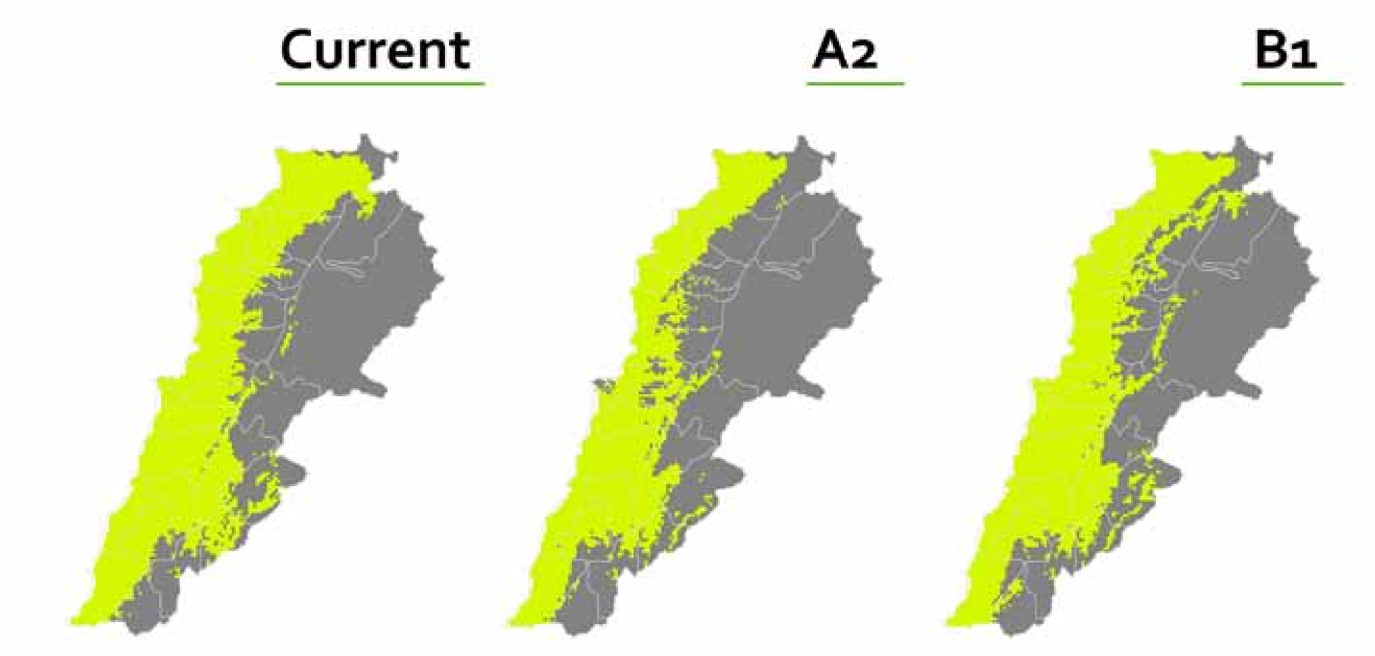
13.15 *Prunus ursina*



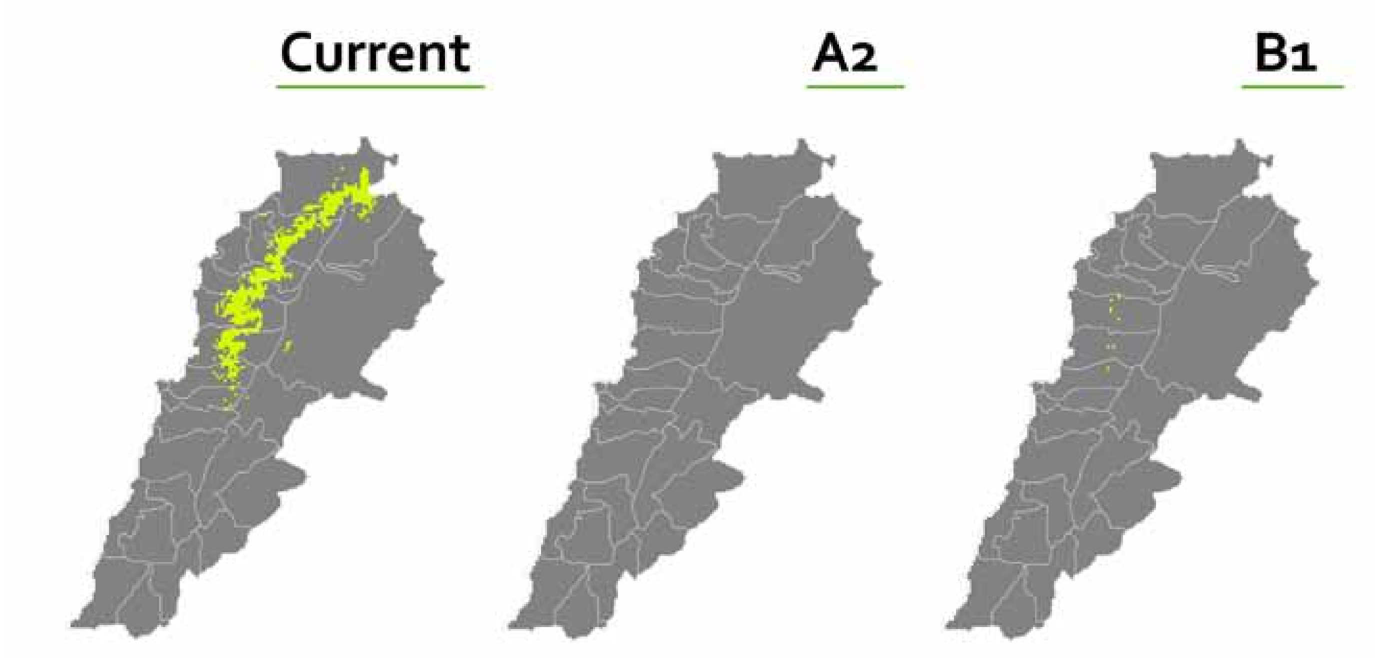
13.16 *Pyrus syriaca*



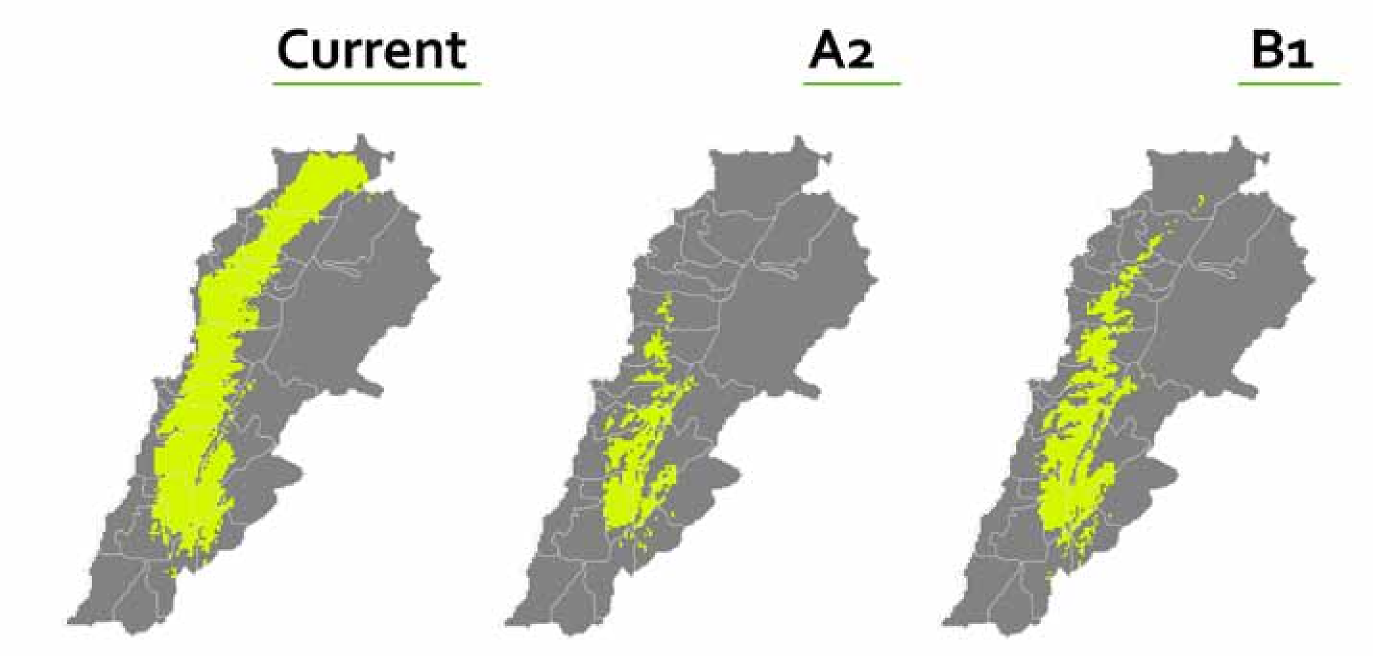
13.17 *Quercus calliprinos*



13.18 *Quercus cerris*



13.19 *Quercus infectoria*



13.20 *Styrax officinalis*