Impacts of Future Climate Change on Selected Indicator Species from Protected Areas in Jordan

Sandy P. Harrison

Professor of Climate Dynamics, University of Bristol, UK

Centre of Research Excellence in Ecology and Evolution, Macquarie University, Australia

Revised version of Deliverable 5: Species-level simulations at individual sites

Report submitted in fulfillment of contract "Technical Assistance for Climate Change, International Specialist" between the *Royal Society for the Conservation of Nature, RSCN on behalf of the Ministry of Planning and International Cooperation / Integrated Ecosystem Management in the Jordan Rift Valley Project and* Professor Sandra Patricia Harrison, Consultant, Hope Chapel House, Hope Chapel Hill, Hotwells, Bristol, BS8 4ND, UK.

December 2010

Executive Summary

Results for simulations with the LPX dynamic global vegetation model, at low (0.5° by 0.5°) and higher (10' by 10') resolution showed decreases in net primary productivity (NPP) and foliar projective cover (FPC) decrease over Jordan by the end of the 21st century, primarily as a result of changes in herbaceous vegetation cover. The simulations also show an increased incidence of fire, measured both in number of fires and burnt fraction, during the 21st century. Runoff decreases over much of the country, although decreases in vegetation cover and hence water uptake by vegetation results in apparent increases in runoff in the region south of the Dead Sea.

In order to investigate the impact of these changes at a local level, a series of simulations using a successional bioclimatic-limits model were made for key indicator species at each of the protected area sites (Al-Yarmouk, Wadi Ibn Hammad, Fifa, Masuda/Rahmmah, Qatar).

At Al-Yarmouk and Wadi Ibn Hammad, the simulations show either small increases or maintenance of woody species at current levels but an overall decrease in productivity caused by larger declines in herb/grass cover. At Fifa, there is little change in woody species but herb/grass cover declines in the latter part of the century. There are very large uncertainties in the climate inputs for the Masuda/Rahmmah site and no coherent pattern of change in the vegetation. There is an overall decline in vegetation cover at the Qatar site.

In combination, the simulations suggest that future climate change will not have a devastating effect on ecosystems in the protected areas but management plans will need to factor in the potential negative consequences of changes in grazing and fire regimes.

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1. Introduction

Analyses of simulated climate changes during the 21st century (Harrison, Report to the *Royal Society for the Conservation of Nature*, 2009) indicate that the climate of Jordan will be subject to increased drought, as a consequence of year-round increases in temperature, during the 21st century. The estimated change is temperature is 3±0.5°C in winter and 4.5±1°C in summer by the end of the 21st century. The climate simulations show little or no change in precipitation to offset these large increases in temperature.

Simulations with the LPX dynamic global vegetation model (*Prentice et al*., in press), at low (0.5° by 0.5°) and higher (10' by 10') resolution showed decreases in net primary productivity (NPP) and foliar projective cover (FPC) decrease over Jordan by the end of the 21st century, primarily as a result of changes in herbaceous vegetation cover (Harrison, Report to the *Royal Society for the Conservation of Nature*, 2010). The simulations also show an increased incidence of fire, measured both in number of fires and burnt fraction, during the 21st century. Runoff decreases over much of the country, although decreases in vegetation cover and hence water uptake by vegetation results in apparent increases in runoff in the region south of the Dead Sea.

To examine the impact of these simulated changes on key indicator taxa at the level of individual conservation areas, a successional bioclimate-envelope model driven by site-specific (individual grid cell) climate data. The indicator species for each site, selected from the field surveys, are representative of the different plant functional types (PFTs) present at each site.

The implications of the simulated changes in vegetation properties, disturbance and runoff for conservation practices are considered, taking into consideration the uncertainties of the climate-model simulations, the spatial resolution of both the climate- and the vegetation-model simulations, and the limited physiological knowledge available for the parameterisation of key species.

2. Description of Modelling Protocol

Between 3-5 representative indicator species were selected for each site (Table 2.1) based on species lists provided by RSCN. Species were chosen to represent the range of different plant functional types (PFTs) present at the site. Only one example of each PFT was used in the simulation.

Data on bioclimatic limits of the selected indicator species were obtained from the literature (Table 2.2). There is surprisingly little information available on the physiology and bioclimatic limits of most of the species; where species-specific information was not available, generic values for the PFT were used.

Table 2.1. Indicator species for each of the sites

Site	Species	Life form	Phenology
Al-Yarmouk	*Quercus ithaburensis*	broadleaved tree	summer perennating
	Ceratonia siliqua	broadleaved tree	evergreen
	Pinus halepensis	needle-leaved tree	evergreen
	Rhamnus palaestinus	broadleaved shrub	summer perennating
	Avena sterilis	Grass	
	Ophrys sphegodes	Shrub	
Wadi Ibn Hammad	*Ficus carica*	broadleaved tree	deciduous
	Moringa peregrina	Thinleaved tree	
	Grewia villosa	broadleaved shrub	deciduous
	Phoenix dactylifera	tuft tree	
	Epipactis veratrifolia	Shrub	
	Phragmites australis	Graminoid	
	Poa bulbosa	Grass	
Fifa PA	*Acacia tortilis*	broadleaved tree	evergreen
	Tamarix aphylla	broadleaved small tree	evergreen
	Phragmites australis		
	Alhagi graecorum	broadleaved shrub	
	Ochradenus bacatus	broadleaved straggling shrub	
	Salvadora persica	broadleaved small tree	evergreen
Masuda PA	*Juniperus phoenicea*	Reduced-leaved small tree	evergreen
	Ochradenus bacatus	broadleaved straggling shrub	-
	Ziziphus spina-christi	broadleaved small tree	deciduous
	Haloxylon eigii	Reduced-leaved small tree	
	Poa bulbosa	Grass	
	Bromus tectorum	Grass	
	Avena sterilis	Grass	
Rahmmah SCA	*Acacia raddiana*	broadleaved small tree	evergreen
	Acacia tortilis	broadleaved tree	evergreen
	Haloxylon persicum	Reduced-leaved small tree	evergreen
	Ochradenus bacatus	broadleaved straggling shrub	
	Avena sterilis	Grass	
Qatar PA	*Haloxylon persicum*	Reduced-leaved small tree	evergreen
	Tamarix aphylla	Reduced-leaved small tree	evergreen
	Ziziphus spina-christi	broadleaved small tree	deciduous
	Juncus acutus	Graminoid	
	Alhagi graecorum	broadleaved shrub	

Table 2.2. Bioclimatic limits of the selected indicator species

Species	PFT	Cold limit	Heat tolerance	Minimum MAP (mm)
Acacia raddiana	broadleaved small tree	-8	45	50
Acacia tortilis	Evergreen broadleaved tree	-8	45	50
Alhagi graecorum	broadleaved shrub	-15	45	50
Ceratonia siliqua	Evergreen broadleaved tree	-4	35	400
Ficus carica	Deciduous broadleaved tree	-7	35	250
Grewia villosa	Deciduous broadleaved shrub	-7	40	200
Haloxylon eigii	reduced-leaved small tree	-15	No limit	50
Haloxylon persicum	Evergreen reduced-leaved small tree	-15	No limit	50
Juniperus phoenicea	Evergreen reduced-leaved small tree	-15	40	150
Moringa peregrina	Thinleaved tree	-1	30	350
Ochradenus bacatus	broadleaved straggling shrub	-4	35	150
Ophrys sphegodes	Shrub	-15	35	150
Phoenix dactylifera	tuft tree	-18	45	100
Pinus halepensis	Evergreen needle-leaved tree	-20	45	350
Quercus ithaburensis	Summer perinating broadleaved tree	-8	35	150
Rhamnus palaestinus	Summer perinating broadleaved shrub	-7	35	200
Salvadora persica	Evergreen broadleaved small tree	-5	35	250
Tamarix aphylla	Evergreen reduced-leaved small tree	-7	No limit	35
Ziziphus spina-christi	Deciduous broadleaved small tree	-15	No limit	50

Simulations of the growth and competition between individual representative species were made using a successional bioclimatic-limits model.

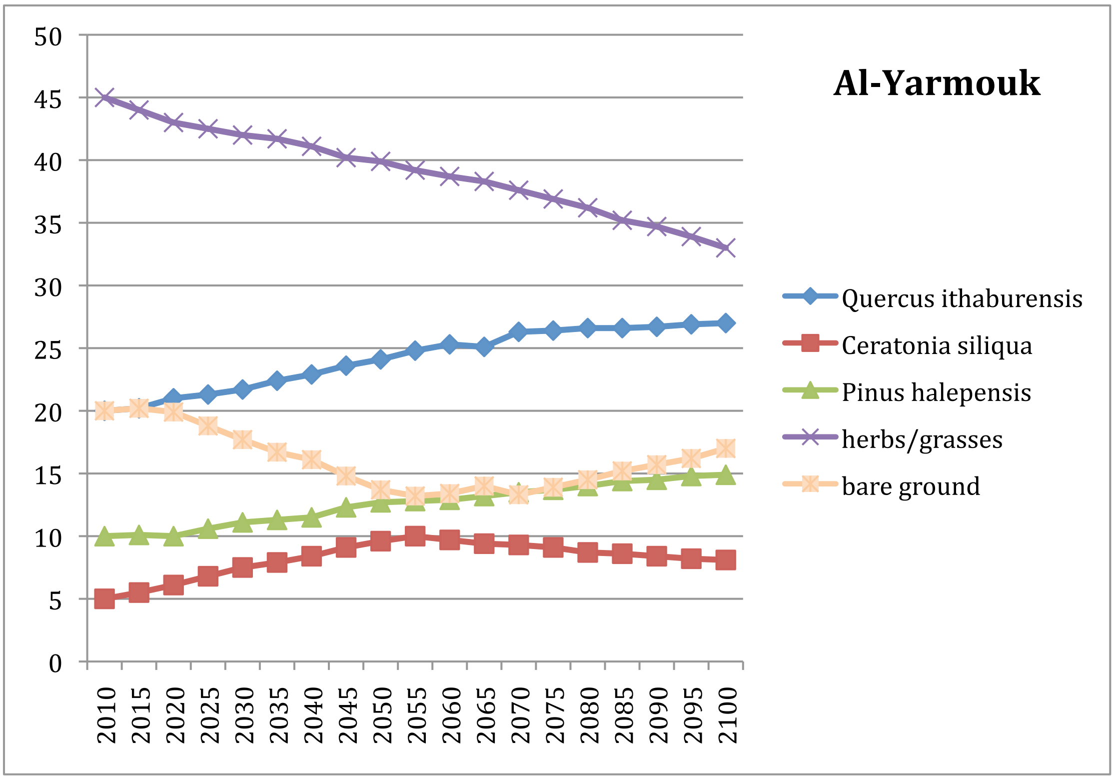
The GSI project provides time-varying changes in climate during the 21st century for seven climate models: CCCMA-CGCM31, CSIRO-Mk30, IPSL-CM4, MPI-ECHAM5, NCAR-CCSM30; UKMO-HadCM3, UKMO HadGEM1 (see Harrison, Report to the *Royal Society for the Conservation of Nature*, 2010 for further details). Climate outputs (mean daily maximum and minimum temperatures, total precipitation, and fractional sunshine hours, wet days, monthly near-surface (10 m) wind speed) for the period 2001 to 2100 from each model were averaged to provide a climate scenario to drive the successional bioclimatic-limits model. CO_2 concentrations (one global value per year) were specified for each run, using the IPCC A1B scenario.

Simulations were run forward from the present day (2010) to 2010 using the mean values of climate parameters from the GSI ensemble. The results are shown as changes in relative abundance, as measured by foliar projective cover (FPC).

3. Simulated changes in indicator species

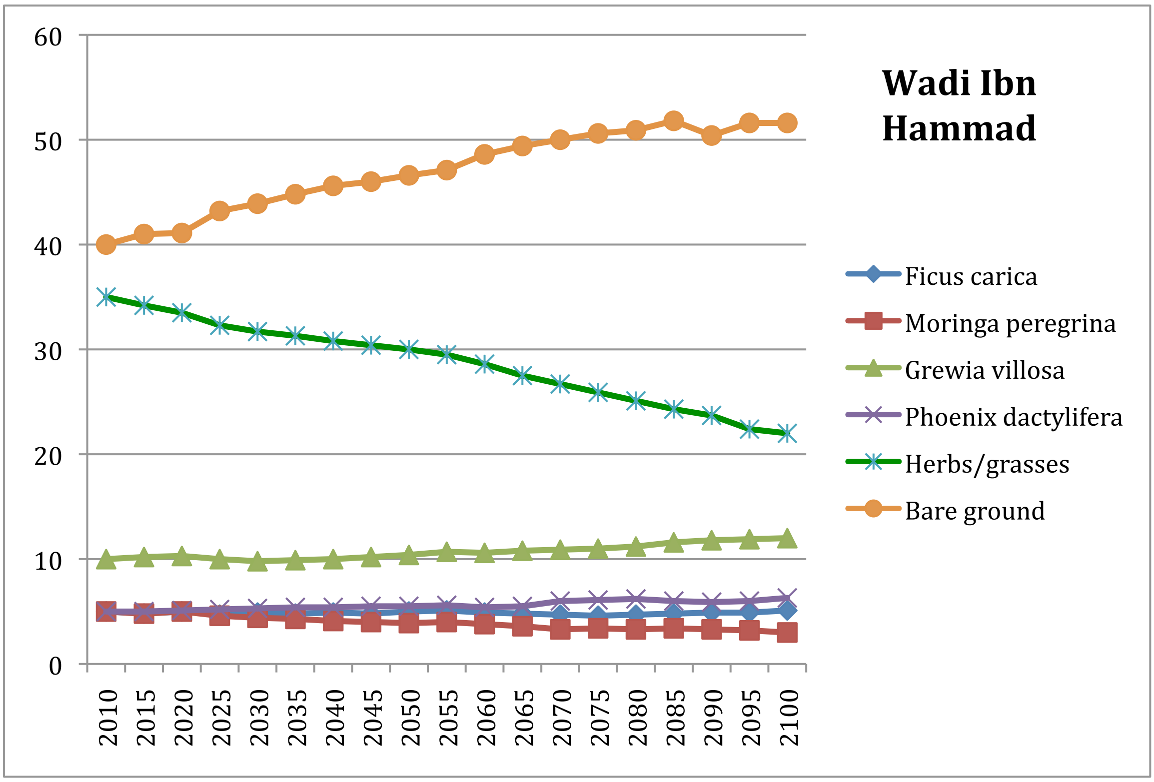
Al-Yarmouk PA. The selected indicator species were: *Quercus ithaburensis*, *Ceratonia siliqua*, and *Pinus halepensis*. A generic herbs/grasses PFT was also included in the simulation. The results show a gradual increase in total vegetation cover over the 21st century by ca 5% (Figure 9.2.1). This value is consistent with the values projected by LPX for this general region. All three of the tree species show an increase in FPC initially. However, while *Quercus ithaburensis*, and *Pinus halepensis* continue to increase during the second half of the century, there is a slight downturn in the FPC of *Ceratonia siliqua* after 2055.

Figure 3.1. Simulated changes in FPC at Al-Yarmouk



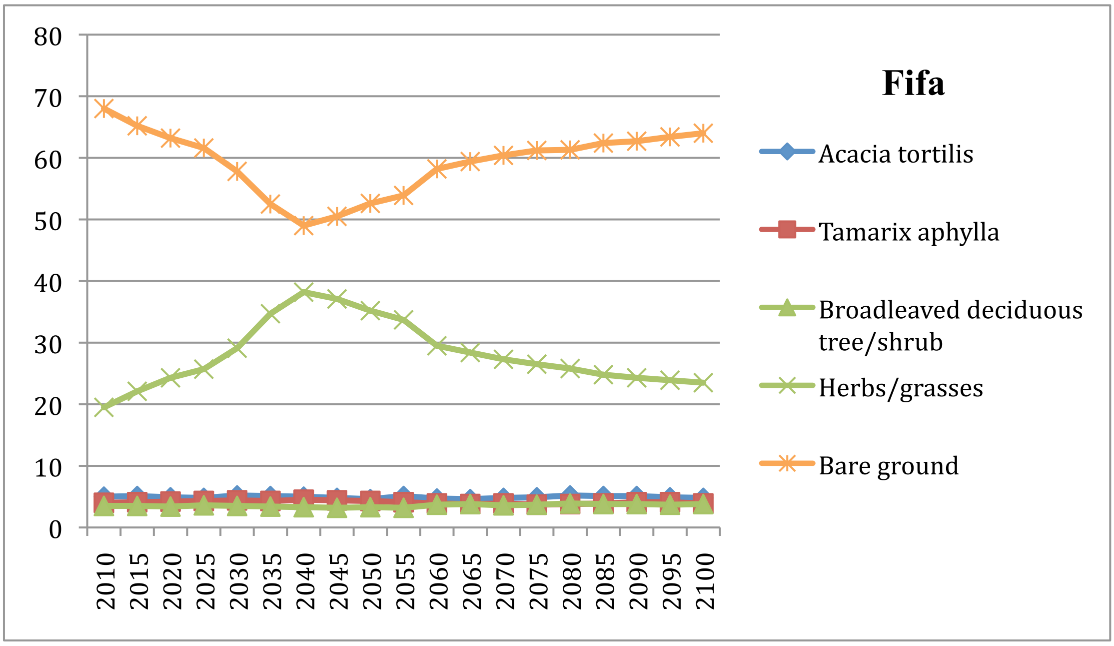
Wadi Ibn Hammad. The selected indicator species were: *Ficus carica*, *Moringa peregrina*, *Grewia villosa* and *Phoenix dactylifera*. A generic herbs/grasses PFT was also included in the simulation. The results (Figure 9.3.1) show no significant change in the cover of trees, but a large reduction in grass and herbaceous species and a concomitant increase in bare ground. The comparatively small changes in tree cover are consistent with the LPX simulation, which also shows no significant change in FPC in this region. The reduction in grass cover reflects increased variability in precipitation and an increase in drought, which in the simulation affects the more shallowly-rooted herbaceous vegetation to a greater extent than the more deeply-rooted trees.

Figure 3.2. Simulated changes in FPC at Wadi Ibn Hammad



Fifa PA. The selected indicator species were: *Acacia tortilis* and *Tamarix aphylla*. A generic deciduous broadleaf evergeen woody PFT and a herbs/grasses PFT were also included in the simulation. The simulations show no significant change in the abundance of trees over the course of the 21st century (Figure 9.4.1). There is a small increase in herbs/grasses in the first part of the century, followed by a decrease in abundance thereafter. There are considerable differences between the climate-model estimates of climate for this region, which results in small changes in the average climate with large uncertainties. The predictions of vegetation change for this region should therefore be treated with some circumspection.

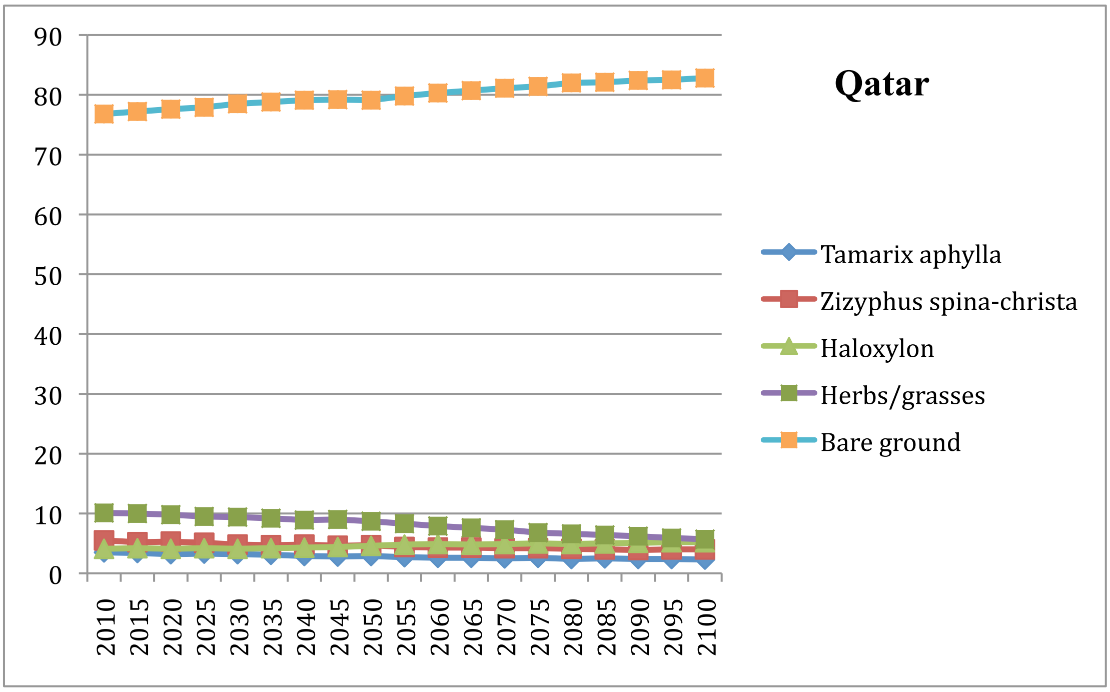
Figure 3.3. Simulated changes in FPC at Fifa



Masuda PA and Rahmmah SCA. These two sites lie in the same climate-model grid box, which is characterized by a high degree of uncertainty with large differences in simulated climates between the models. A single simulation was run using a mixture of the indicator species for the two sites, specifically *Juniperus phoenicia*, *Acacia tortilis*, *Zizyphus spina-christa*, and *Haloxylon persicum*. *Haloxylon persicum* was parameterized as a drought-tolerant small-leaved tree (see Table 7.1.2), but without consideration of the fact that this species uses the C_4 photosynthetic pathway. A generic herbs/grasses PFT was also included in the simulation. The simulation (results not plotted) shows no consistent trends in FPC, either of woody or non-woody species, during the 21st century because the climate inputs show no reliable or consistent trend. It is therefore not possible to predict the likely course of vegetation changes at these sites.

Qatar PA. The selected indicator species were: *Tamarix aphylla*, *Ziziphus spina-christi* and *Haloxylon persicum*. *Haloxylon persicum* was parameterized as a drought-tolerant small-leaved tree (see Table 7.1.2), but without consideration of the fact that this species uses the C_4 photosynthetic pathway. A generic herbs/grasses PFT was also included in the simulation. The simulations (Figure 9.6.1) show a small but consistent decrease in the abundance of woody plants (ca 2-3%) through the 21st century, and a somewhat larger decrease in the FPC of herbs/grasses (ca 5-10%).

Figure 3.4. Simulated changes in FPC at Qatar



4. Summary and Implications

The simulations show very different changes in each of the sites. At Al-Yarmouk PA, tree species (represented by *Quercus ithaburensis*, *Ceratonia siliqua*, and *Pinus halepensis*) experience a small (5%) increase in abundance during the first part of the 21st century and two of the three indicator tree species (*Quercus ithaburensis*, and *Pinus halepensis*) continue to increase during the second half of the century. In contrast, woody species (*Ficus carica*, *Moringa peregrina*, *Grewia villosa* and *Phoenix dactylifera*) do not increase at Wadi Ibn Hammad, but there is a large decline grass and herbaceous species and an increase in bare ground. All of the plant functional types represented at Qatar show a decline in abundance over the century and the site becomes less vegetated. The changes at Qatar are small but probably robust.

Very little confidence can be placed in the predictions of changes in indicator taxa at Fifa, Masuda and Rammah because of the large differences shown by individual climate models at these specific sites.

Lack of information about the climatic tolerances of key species is a major limitation on the assessment of vegetation changes in response to predicted changes in climate over the 21st century. Data on cold hardiness, high-temperature stress, rooting depth and water-use efficiency were available for less than 25% of the indicator species considered in this study. Such data could be obtained either through laboratory or greenhouse experiments, or through bioclimatic mapping of the species distribution (see e.g. Thompson et al., 1999; Huang et al., 2008). A focus on gathering this data would be of considerable use in order to improve future work on the prediction of vegetation responses to climate change.

The uncertainties associated with the application of climate-model scenarios at a regional scale are large, and these uncertainties become larger when model output is used to predict changes at individual sites. While there is some confidence that there will be increased drought stress on vegetation at a country-level scale, changes in particular regions of Jordan or for individual conservation areas are very much less certain and should be regarded as indicative only. In presenting these results, this report stresses generic outcomes that should be taken into consideration in management planning. Actions to mitigate the impacts of these potential outcomes (e.g. a potential increase in grazing pressure, or in the impact of fire) would have other long-term benefits for ecosystems in the region and therefore their implementation is desirable without the potential benefit they would bring in the face of future climate changes.

5. References

Harrison, S.P. (2009) Future Climate Change in Jordan: An Analysis of State-of-the-Art Climate Model Simulations. Report to the *Royal Society for the Conservation of Nature*.

Harrison, S.P. (2010) Impacts of Future Climate Change on Vegetation, Fire, and Runoff in Jordan. Report to the *Royal Society for the Conservation of Nature*.

Prentice, I.C., Kelley, D.I., Foster, P.N. Friedlingstein, P., Harrison, S.P. and Bartlein, P.J., in press, 2010. Interannual variability of fire and the terrestrial carbon balance. *Global Biochemical Cycles*

Appendix 1: Glossary of Terms and Abbreviations

A1B emission scenario: The A1B scenario is one of the SRES emission scenarios (*see below*) characterized by rapid economic growth, a global population that peaks at nine billion in 2050 and then declines, a quick spread of new and efficient technologies, increased similarity of levels of income and and lifestyle between regions of the world, extensive social and cultural interactions across the world, and a balanced use of fossil and renewable energy resources. It is often used in climate impact assessments because it is considered less extreme than other scenarios (including e.g. business as usual or abrupt termination of the use of fossil fuels) and possibly the most likely outcome of current socio-economic tendencies.

Bioclimatic limits. Limits of the growth of specific plant functional types and/or indicator species related to physiological adaptations to climatic stresses. Such limits include cold hardiness, heat stress and water-use efficiency.

Biome. The term biome is used to describe a major vegetation type, such as boreal forest, Mediterranean scrubland, steppe or hot desert. In modeling, biomes arise as a consequence of the assemblage of characteristic plant functional types. In LPX, biomes are defined in terms of the density of vegetation cover (as defined by total foliar projective cover), the mean height of the vegetation, and the presence or dominance of specific plant functional types.

Burnt fraction. The fraction of a grid cell that is burnt in a specified time period is the burnt fraction. A value of 1 implies that the whole of the grid cell is burnt in the given time period, a value of 0.1 indicates that 10% of the grid cell is burnt in a given period.

C_3 plant: C_3 plants are those that use a form of photosynthesis in which the fixation of light results in a product with three carbon atoms. This was the earliest type of photosynthesis to evolve, and still the form of photosynthesis that is used by circa 85% of vascular plants. C_3 plants favoured under moderate temperatures, with little drought and by high levels of CO_2.

C_4 plant: C_4 plants are those that use a form of photosynthesis in which the fixation of light results in a product with four carbon atoms. This form of photosynthesis is typical of fast growing, high yield plants in the subtropics C_4 plants are favoured under drought conditions, because they have high water-use efficiencies, and high temperatures, and also by low levels of CO_2.

CO_2 fertilization: Plants required CO_2 to grow. The CO_2 fertilization affect is the process whereby plant growth is enhanced at higher ambient CO_2 levels, given that other growth requirements are not limiting. CO_2 fertilization is used in commercial greenhouse activities. As a caveat, although rising atmospheric CO_2 levels may lead to greater natural productivity, or impact on the competition between C_3 and C_4 plants, this increase in productivity is not sufficient to offset the deleterious impacts of rising CO_2 on climate and through this on the biosphere.

CRU. The Climatic Research Unit at the University of East Anglia in the UK produces global gridded climate data sets based on observations from meteorological stations worldwide. The data are gridded using methods which take into account topographic effects on both temperature and precipitation, and allow for infilling in regions with only sparse meteorological station coverage. Nevertheless, the quality of these data sets is affected by site resolution and by the fact that the number of sites is relatively low in the first part of the 20th century.

Ensemble. Results from multiple model runs (either climate-model simulations or vegetation-model simulations) can be averaged together to provide an ensemble average. Ensemble results allow for the diagnosis of robust features of any set of simulations, and also identify regions where the models give different results with respect to either the direction (sign) of the change or the absolute magnitude of the simulated change.

Evergreen. Plants which retain their leaves for the whole of the year are considered to be evergreen and are thus distinguished from plants which retain their leaves only during the warmer part of the year (cold-deciduous or summergreen) or during the wet season (drought deciduous, or summer perinating).

FPC. Foliar projective cover (FPC) is the proportion of ground area covered by leaves. In the LPX model, it is calculated separately for each plant functional type.

GSI. GSI is the Global Scale Impacts of Climate Change Project, which is funded by the QUEST (Quantifying and Understanding the Earth System) programme of the UK Natural Environment Research Council (NERC) of the UK. The key aim of QUEST-GSI is to better quantify the impacts of climate change in a consistent way across the entire globe, and for a range of sectors such as: water resources, flooding, crops and human health. The GSI project is producing a set of future climate scenarios, characterized by a given magnitude of global warming by a set date, using pattern-scaling techniques (*see below*). More information on the GSI project is available from http://www.met.reading.ac.uk/research/quest-gsi/.

Indicator species. An indicator species is one which is characteristic of a specific ecosystem and/or plant functional type, and which shows specific physiological characteristics or climate adaptations. Indicator species are used in this study as guides to the behaviour of specific plant functional types under 21st century climate change, based on their presence and importance within the ecosystems represented at the sites in Jordan.

IPCC: the Intergovernmental Panel on Climate Change. The Intergovernmental Panel on Climate Change publishes major summaries of what is known about climate change and climate change impacts, based on analysis of specially commissioned simulations with state-of-the-art climate models and a consensus review of the scientific literature. The Assessment Reports are subject to considerable scrutiny, by the scientific community, by invited experts, and ultimately by nominated representatives of the world's governments. See http://www.ipcc.ch/ for a further description of the process and the products of these assessments.

LPX. LPX (Land-surface Processes and eXchanges) is a fire-enabled dynamic global vegetation model (DGVM) which explicitly simulates vegetation dynamics, competition between a suite of plant-functional types (PFTs), and land-atmosphere exchanges of water and CO_2. The model is described in Prentice et al. (in revision) and has been extensively benchmarked at a global scale.

Multi-model estimates or ensembles. Differences in climate sensitivity and in individual parameterisations mean that individual climate models can produce different responses to the same global radiative forcing. It is common practice within IPCC and other climate-change assessments to use an ensemble of models and to provide estimates of the climate change based on averaging the results of all the models. These estimates are known as multi-model estimates or ensemble estimates. The estimate may be expressed as a numerical average (with standard deviation) or as a range.

NCEP. The National Center for Environmental Prediction , USA. NCEP produces climate data sets, based on the assimilation of ground-based observations within a high-resolution climate model framework. Such re-analysis data sets are not subject to the problems of uneven data coverage (in space or time) inherent in observation-onlu based data sets, and so are widely used by the impact modeling community.

NPP. Net primary productivity is equal to the difference between the rate at which plants in an ecosystem capture and store chemical energy through photosynthesis (gross primary productivity, GPP) and the fraction of this energy that is used by plants for cellular respiration and maintenance of existing tissue (i.e. gowth respiration and maintenance respiration). Generally, both the gross and net primary productivity of terrestrial ecosystems are expressed in terms of mass of carbon per unit area per year (g $C/m^2/yr$).

Plant functional type (PFT). A PFT is a grouping of different plants which have similar characteristics, make similar use of resources and serve the same function within an ecosystem. PFTs are used widely in global vegetation models in order to simplify the biological and ecological complexity of real-world systems. PFT classifications are generally based on life-form (e.g. tree, shrub, herb, grass graminoid), leaf form (e.g. broadleaved, needleleaved), phenology (e.g. evergreen, deciduous) and bioclimatic tolerance (e.g. frost-tolerant, frost-intolerant).

Runoff. Runoff is water that travels over the surface of the land, either as surface runoff or channeled into streams and rivers. It represents that part of precipitation which is not returned directly to the atmosphere through evaporation, taken up by plants (and ultimately returned to the atmosphere through transpiration) or percolates into the deep groundwater.