SIAM

CLIMATE CHANGE IN PORTUGAL
SCENARIOS, IMPACTS AND ADAPTATION MEASURES
SIAM

EXECUTIVE SUMMARY AND CONCLUSIONS

Edited by
Filipe Duarte Santos
Keith Forbes
Ricardo Moita

Funded by

gradiva

FUNDAÇÃO CALOUSTE GULBENKIAN

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA E DA TECNOLOGIA

CLIMATE CHANGE IN PORTUGAL
SCENARIOS, IMPACTS AND ADAPTATION MEASURES
SIAM

EXECUTIVE SUMMARY AND CONCLUSIONS

Edited by
Filipe Duarte Santos
Keith Forbes
Ricardo Moita

Funded by

gradiva

FUNDAÇÃO CALOUSTE GULBENKIAN

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA E DA TECNOLOGIA

INDEX

Copies may be ordered from:
Ângela Antunes, SIAM
Observatório Astronómico de Lisboa
Edifício Leste, 1.º piso
Tapada da Ajuda
1349-018 Lisboa
Portugal
Telephone: + 351 213616748
Fax: + 351 213616752
Email: aantunes@siam.fc.ul.pt

Citation of this Summary Report should be as follows:
F. D. Santos, K. Forbes, R. Moita (editors), *Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures – SIAM. Executive Summary and Conclusions, Gradiva, Lisboa, 2001*

Cover Image © Tiago Silva
Montado at dusk, Moura

Published: 2001
This publication is funded by Fundação Calouste Gunbenkian

Graphic design: *Armando Lopes*
Printed: *Multitipo – Artes Gráficas, L.da*
Depósito legal: 171 204/01

CLIMATE CHANGE IN PORTUGAL
SCENARIOS, IMPACTS AND ADAPTATION MEASURES
SIAM

Authors

- Filipe Duarte Santos (Project Leader)
  Faculdade de Ciências da Universidade de Lisboa – FCUL
- Keith Forbes (Project Manager and Head, Technical Support Unit)
  SIAM
- Ricardo Moita (Leader, Integration Team)
  SIAM
- **Climate and Climate Scenarios**
  Pedro Miranda (Team Leader)
  Faculdade de Ciências da Universidade de Lisboa – FCUL
  Centro de Geofísica da Universidade de Lisboa

  Anabela Carvalho
  SIAM

  Fátima Espírito Santo Coelho
  Instituto de Meteorologia – IM

  Carlos Pires
  Faculdade de Ciências da Universidade de Lisboa
  Centro de Geofísica da Universidade de Lisboa

  Carlos Ramalho
  SIAM

  António Rodrigues Tomé
  Universidade da Beira Interior
  Centro de Geofísica da Universidade de Lisboa

  Maria Antónia Valente
  SIAM
  Centro de Geofísica da Universidade de Lisboa
- **Socioeconomic Scenarios**
  Pedro Barata (Team Leader)
  Euronatura
- **Sociological Analysis**
  João Ferreira de Almeida (Team Leader)
  Instituito Superior de Ciências do Trabalho e da Empresa – ISCTE

  Filipa Lourenço
  SIAM

  Paula Marisa Pott
  SIAM
- **Water Resouces**
  Luís Veiga da Cunha (Team Leader)
  Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa – FCTUNL

  Vasco Nunes
  SIAM

  Rodrigo Oliveira
  CHIRON, Sistemas de Informação, Lda
- **Coastal Zones**
  Hipólito Monteiro (Team Leader)
  Instituto Geológico e Mineiro – IGM

  Carlos Cachado
  SIAM

  Ana Cristina Cardoso
  SIAM
- **Agriculture**
  Pedro Aguiar Pinto (Team Leader)
  Instituto Superior de Agronomia – ISA

  Ana Paiva Brandão
  SIAM
- **Human Health**
  José Manuel Calheiros (Team Leader)
  Instituto de Ciências Biomédicas Abel Salazar – ICBAS

  Elsa Casimiro
  SIAM
- **Energy**
  Ricardo Aguiar (Team Leader)
  Instituto Nacional de Engenharia e Tecnologia Industrial – INETI

  Hélder Gonçalves
  Instituto Nacional de Engenharia e Tecnologia Industrial – INETI

  Marta Oliveira
  Instituto Nacional de Engenharia e Tecnologia Industrial – INETI

  Maria João Reis
  SIAM
- **Forest and Biodiversity**
  João Santos Pereira (Team Leader)
  Instituto Superior de Agronomia – ISA

  Manuela Branco
  Instituto Superior de Agronomia

  Miguel Bugalho
  Centro de Ecologia Aplicada Baeta Neves

  Maria Conceição Caldeira
  Instituto Superior de Agronomia

  Alexandra Pires Correia
  SIAM

  Alexandre Vaz Correia
  SIAM

  Carlos Souto Cruz
  Câmara Municipal de Lisboa

  Helena de Freitas
  Universidade de Coimbra

  Ângelo Carvalho Oliveira
  Instituto Superior de Agronomia

  José M. Cardoso Pereira
  Instituto de Investigação Científica Tropical

  Raul Mata Reis
  Instituto de Meteorologia

  Maria José Vasconcelos
  Instituto de Investigação Científica Tropical
- **Fisheries**
  Carlos Sousa Reis (Team Leader)
  Faculdade de Ciências da Universidade de Lisboa - FCUL

  Maria Dornelas
  SIAM

  Ricardo Lemos
  SIAM

  Romana Santos
  SIAM
- **Other Contributing Authors**
  Suraje Dessai
  SIAM

  Henrique Oliveira Pires
  Instituto de Meteorologia – IM

  Júlia Seixas
  Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa – FCTUNL

Acknowledgements

We are grateful to the Fundação Calouste Gulbenkian (FCG) and to the Fundação para a Ciência e a Tecnologia (FCT) for funding Project SIAM; FCG from June 1999 to June 2001 and FCT (Projecto PRAXIS/C/MGS/11048/98) from January 2000 to January 2002. We are thankful to the Instituto da Água for funding, in part, the work on Water Resources. Project SIAM is grateful to the Fundação da Faculdade de Ciências da Universidade de Lisboa for managing the disbursement of project funds. We also acknowledge the support received during the execution of the project from the following institutions:

Centro de Estudos de Vectores e Doenças Infecciosas
CHIRON, Sistemas de Informação, Lda
Departamento de Engenharia Florestal do Instituto Superior de Agronomia
Direcção Geral de Energia
Direcção Geral de Saúde
Direcção Regional do Ambiente de Lisboa e Vale do Tejo
EURONATURA, Centro para o Direito Ambiental e Desenvolvimento Sustentado
Faculdade de Ciências da Universidade de Lisboa
Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa
Instituto da Água
Instituto de Ciências Biomédicas Abel Salazar
Instituto de Gestão Informática e Financeira da Saúde
Instituto de Higiene e Medicina Tropical
Instituto de Meteorologia
Instituto Geológico e Mineiro
Instituto Nacional de Engenharia e Tecnologia Industrial
Instituto Nacional de Saúde Dr. Ricardo Jorge
Instituto Superior de Agronomia
Instituto Superior de Ciências do Trabalho e da Empresa
Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre
Max-Plank Institut fur Biogeochemie – Jena, Germany
OBSERVA – Ambiente, Sociedade e Opinião Pública
The Hadley Centre for Climate Prediction and Research, UK
Universidade Complutense de Madrid
World Health Organization's Regional Office for Europe

We thank the Instituto de Meteorologia for supplying a large part of climate observational data presented in this study.

We are also thankful to the Hadley Centre for Climate Prediction and Research, for supplying, through Project LINK, monthly data from a number of GCM simulations, daily data from HadCM3 simulations and daily and monthly data from HadRM simulations. Support given by David Viner, at The Climate Impacts LINK Project (DETR Contract EPG 1/1/68) on behalf of the Hadley Centre and U. K. Meteorological Office, and by Alan Thorpe, at the Hadley Centre, are specially acknowledged. Output from other GCMs was obtained at the IPCC Data Distribution Centre. Special thanks go to Manuel Castro, at the University Complutense in Madrid, and Clemente Gallardo, at the University Castilla-la-Mancha, for supplying output from the PROMES climate simulations. We are also thankful to Jed Kaplan from the Max-Plank Institut fur Biogeochemie, Jena, Germany. Furthermore we wish to thank Pedro Ochôa Carvalho from the Departamento de Engenharia Florestal of the Instituto Superior de Agronomia, Paula Marques, Luís Mira da Silva and Miguel Tristany from the Secção de Agricultura of the Instituto Superior de Agronomia and Ricardo Braga from Escola Superior Agrária de Elvas. We are also thankful to Rui Brás and Ferreira Coelho from the Instituto Hidrográfico, António Brandão Moniz, from the Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa and Ana Cristina Ferreira from Instituto Superior de Ciências do Trabalho e da Empresa, Sofia Moita and Álvaro Silva from Instituto de Meteorologia, Pedro Brito and Luís Rebelo from Instituto Geológico e Mineiro. We also wish to thank Maria João Carvalho, António Joyce, João Farinha Mendes and Ana Estanqueiro, from Departamento de Energias Renováveis of Instituto Nacional de Engenharia e Tecnologia Industrial, Isabel Cabrita from Departamento de Engenharia Energética e Controlo Ambiental of Instituto Nacional de Engenharia e Tecnologia Industrial, and Paula Candeias from the Library of Departamento de Energias Renováveis of Instituto Nacional de Engenharia e Tecnologia Industrial.

We are very thankful to Nuno Lacasta, who was one of the initiators of Project SIAM, currently out of Portugal, for his support and enthusiasm. We also wish to thank João Côrte-Real and Alexandra Oliveira who were members of the team in the initial stages of the Project. Finally we would like to acknowledge the support and professionalism of the Administrative Assistant Project SIAM, Ângela Antunes.

The authors assume full responsibility for any and all errors and inaccuracies in the text.

About Project SIAM

Global climate change represents an unprecedented threat to human and natural systems. Climate is changing as a result of human activities through the emissions of greenhouse gases to the atmosphere and through profound changes in land use. Two broad types of complementary responses can be identified: adaptation and mitigation.

Adaptation is the response to the effects of climate change of the various socio-economic and biophysical sectors upon which it has an impact. In order to develop and initiate adaptation processes, it is first necessary to identify the impacts of climate change. Mitigation attempts to deal with the causes of climate change. The United Nations Framework Convention on Climate Change and its Kyoto Protocol are two major international attempts to address the issue of mitigation.

The purpose of SIAM is to study and report on what is presently known about the potential consequences of climate change for Portugal in the 21st century. SIAM started in June 1999 with the objective of carrying out the first integrated vulnerability and adaptation assessment of climate change in Portugal. The work focuses on a core set of socio-economic and biophysical impacts and is based on climate scenarios produced by climate models. The project is divided functionally into ten groups. Of the ten groups, seven worked on the impacts and adaptation on specific sectors, namely, Water Resources, Coastal Zones, Agriculture, Human Health, Energy, Forests and Biodiversity, and Fisheries. The remaining groups worked on Climate, Socio-Economic Scenarios, and a Sociological Analysis of Climate Change Issues in Portugal.

About this Report

This report is a summary of the full version of the SIAM Project, which will include the results of the work produced by all the groups mentioned above and will be published in 2002. The SIAM team felt that it would be useful to make available as soon as possible, to the general public and policymakers, conclusions and recommendations of the work done during the last two years. This summary focuses on the researchers' main conclusions regarding the impact of climate change upon various human and natural systems and their main recommendations regarding adaptation measures and priority needs for future research. Readers are strongly urged to refer to the forthcoming full version, especially regarding the details of scientific and methodological issues and references.

This first integrated assessment could not attempt to be fully comprehensive. Future assessments should consider other important sectors such as Insurance, Tourism, Soil and Land Resources and Urban Areas. It was also not possible, during the time available, to extend the assessment to the Autonomous Regions of Açores and Madeira. In this first assessment stakeholders such as, for example, public and private decision-makers were not involved. Furthermore, no attempt was made to evaluate the practicality, effectiveness or costs of potential adaptation measures. These and other issues will be addressed in the second phase of Project SIAM, to be funded by the Direcção-Geral do Ambiente (Ministério do Ambiente e do Ordenamento do Território).

What is climate change?

The weather at a given place and time is the state of the atmosphere in that location and time and to describe it we need to know the values of the meteorological variables, namely, temperature, precipitation, wind, pressure and humidity. The ensemble of weather events in a given location defines the climate in that place. Thus climate is, loosely speaking, the "average weather." More rigorously, climate is the statistical description, in terms of the mean and variability, of the meteorological variables over a period of time ranging from months to thousands or millions of years. The minimum period of time needed to define the climate of a given location, as adopted by the World Meteorological Organization, is 30 years.

Climate change implies a statistically significant variation in either the mean climate or in its variability that occurs for an extended period of time, of the order of decades or longer. Studies of the Earth reveal that its climate has changed all along its history, since about 4,500 million years. Climate change may result from natural internal processes or natural external forcings and also from anthropogenic changes in the composition of the atmosphere or in land use. The United Nations Framework Convention on Climate Change defines "climate change" as resulting directly or indirectly from human activity and defines "climate variability" as climate change attributable to natural causes. The IPCC uses a different definition, namely, "Climate Change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer)," without specific identification of the causes of change.

The earth's environmental history indicates that even small changes in climate can have quite profound consequences for society and environment.

What Causes Climate Change?

We have seen that climate change can have either natural or anthropogenic causes. The most important natural external forcings that induce climate change by affecting the earth's energy balance are changes in solar luminosity and in the parameters that define the earth's orbit around the sun. Changes in the Earth's orbit occur slowly over periods ranging from about 20,000 to 400,000 years and are thought to be responsible for the alternation of glacial and interglacial periods.

Anthropogenic climate change results mainly from changes in the composition of the atmosphere, especially as regards greenhouse gases (GHGs). The most important GHGs in the atmosphere include water vapour (H_2O) (which is the most important), carbon dioxide (CO_2) (the most important GHG whose concentration is being increased by human activities), methane (CH_4), nitrous oxide (N_2O) chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perflourocarbons (PFCs), sulphur hexafluorid (SF_6) and ozone (O_3). GHGs are those that absorb and reemit infrared radiation.

For the global average temperature in the lower atmosphere (troposphere) to be relatively stable over time there must be a balance of the absorbed solar energy and outgoing energy radiated away in the infrared region of the spectrum. This balance depends crucially on the concentrations of GHGs in the atmosphere and also on cloud cover and surface albedo. When the concentration of GHGs is increased, more of the infrared radiation emitted upward from the surface and lower atmosphere is absorbed by the GHGs trapping more energy near the surface and causing the temperature of the lower troposphere to rise. This phenomenon is referred to as radiative forcing. The blanketing effect that results from the presence of GHGs in the earth's atmosphere (natural greenhouse effect) raises the average surface temperature of the earth by about 32°C from –18°C to 14°C.

Since 1750, the atmospheric concentration of CO_2 has increased by 31% to a present value of 365 ppmv (parts per million by volume) and many independent studies confirm that this rise is due to the combustion of fossil fuels (coal, oil and natural gas) and to land-use change, especially deforestation. According to paleoclimatic data, the present CO_2 concentration has not been exceeded in the past 420,000 years and likely not in the past 20 million years.

Combustion of fossil fuels is currently adding more than 6 GtC/year (10^{12} Kg of carbon) to the atmosphere. About 75% of the anthropogenic emissions of CO_2 to the atmosphere during the past 20 years resulted from fossil fuel burning, while the rest was mainly due to land-use change. The increase in atmospheric CO_2 concentration from 1750 to 2000 is responsible for about 60% of the radiative forcing in the atmosphere caused by all the anthropogenic emissions of GHGs during the same period of time. In other words, the increase in CO_2 emissions since the start of the industrial revolution is the main cause (but not the only cause) for the anthropogenic greenhouse effect. Human activities also produce aerosols (mainly from fossil fuel and biomass burning) in the atmosphere, which are short-lived and mostly tend to reduce the global warming effects produced by the anthropogenic GHGs.

Based on the scientific understanding of the greenhouse effect, increasing the atmospheric composition of GHGs should cause climate change and especially global temperature to rise. In order to have physically consistent projections of future climate it is necessary to develop models of the earth's climate system that incorporate the most important physical principles and processes that determine climatic conditions. Presently the most comprehensive climate models, called General Circulation Models (GCMs), involve the coupling between the atmosphere, ocean and sea-ice. They provide a comprehensive representation of the climate system and simulate the evolution of wind, temperature, rainfall, snow cover, soil moisture, sea ice, ocean circulation and other variables for the entire globe over periods of decades to centuries. One way to evaluate the level of confidence that can be placed in such models is to test their ability to simulate past and present climate.

What is a scenario?

Temperature records indicate that the global average surface temperature of the atmosphere has increased since the middle of the 19th century and, during the 20th century, the increase has been 0.6 ± 0.2°C. Most of the warming in the 20th century occurred during two periods, 1910 to 1945 and 1976 to 2000. Current climate model simulations for the 20th century are in agreement with the observed trends in the temperature and indicate that the warming is unlikely to be entirely due to natural causes. Furthermore simulations of the climate using GCMs indicate that most of the observed warming over the last 50 years is likely to have been caused by the anthropogenic increase in GHGs concentrations. It is also very likely that the warming of the troposphere has contributed significantly to the observed sea level rise in the range of 10 to 20 cm, during the 20th century.

Fossil fuel use around the world is expected to continue. It is therefore clear that the concentration of CO_2 and of other GHGs in the atmosphere will continue to increase during the 21st century. These increases are very likely to cause climate change and prudent risk management demands an assessment of the impacts of future climate change.

In order to achieve this goal, reliable and tested climate models are needed. However, we also need to consider future socio-economic and technological developments, since these determine the anthropogenic emissions of GHGs to the atmosphere and have an influence on the nature and magnitude of the impacts of climate change.

In conclusion, a plausible and often simplified description of how the future may develop is needed in order to address the problem of determining the impacts of climate change. These descriptions are called scenarios and are based on a coherent and internally consistent set of assumptions about the key driving forces and interactions. The most important scenarios in climate change studies are the climate scenarios, that present a representation of the future climate, and emissions scenarios, that present a representation of the future emissions of GHGs and aerosols according to different development paths.

The climate scenarios presented in this work involve climate projections based on the simulation of the evolution of the climate system using GCMs. They are not predictions of the future climate because they depend on emissions scenarios which are inherently unpredictable in a deterministic sense because they involve human and social actions.

What are the uncertainties?

It is very important to emphasize that future emissions of greenhouse gases and aerosols, their effects on the climate system and the resulting environmental and economic consequences are subject to uncertainties. The clear presentation of these uncertainties is very important to facilitate the task of the public and policymakers to devise strategies of risk reduction. In an assessment of climate change impacts and adaptation measures there are uncertainties involved in various steps of the assessment process. There are uncertainties in the greenhouse gas emissions scenarios. The climate scenarios result from simplified model simulations of the climate system that cannot capture its full complexity, especially at regional and smaller scales. There are also uncertainties in the socio-economic scenarios needed to estimate future impacts of climate change. Finally there are uncertainties in the assessment of impacts and adaptation measures.

Uncertainty implies anything from high confidence, just short of certainty to informed guesses or speculation. Uncertainty results mainly from lack of information lack of knowledge of the scientific processes, statistical variation, measurement error, variability, approximation and subjective judgement. Some categories of uncertainties can be expressed in terms of probabilities but others cannot. At present, it is not possible to estimate the probability of different projections of the human-induced global warming in the 1900-2100 period. On shorter time scales of the order of 50 years it is now becoming possible to provide a probabilistic forecast of the warming rate. In the present report we have tried to identify the most important uncertainties and to use the set of terms adopted by the IPCC to indicate specific likelihoods: virtually certain (99% or more), very likely (90 to 99%), likely (66 to 90%), medium likelihood (33 to 66%), unlikely (10 to 33%), very unlikely (1 to 10%) and exceptionally unlikely (1% or less).

Recent climate in Mainland Portugal

Mainland Portugal has a mild Mediterranean climate with mean annual air temperatures varying between 7° C in the inner highlands of the central region to 18° C in the southern coastal area. Mean annual precipitation is slightly above 900 mm with a much greater spatial variability. In the northwest mountains the mean annual precipitation is above 3,000 mm (one of the wettest locations in Europe) but in southeast Alentejo it is only of the order of 500 mm.

The mean annual air temperature of the mainland in the period between 1931 and 2000 shows an increasing trend since the 1970s, with the six hottest years in the last 12 years (Figure 1). The data for several climate stations shows two distinct warming periods 1910–'45 and 1976–2000, in agreement with temperature trends observed at the global scale. The observing warming rate since 1976 was significantly larger than during the 1910–'45 period. On the other hand, the increase in mean temperature results from a faster rise of the daily minimum temperature than of the daily maximum temperature. As a result, the diurnal temperature range has decreased in many climate stations.

Precipitation data in the period between 1931 and 2000 shows a generalized but weak decreasing trend that becomes more pronounced after 1976. Since that year there is also a significant difference in precipitation trends between seasons, with a systematic reduction of spring precipitation all over the country, partially compensated by less coherent changes in the other seasons. In all, changes seem to imply a somewhat shorter rainy season.

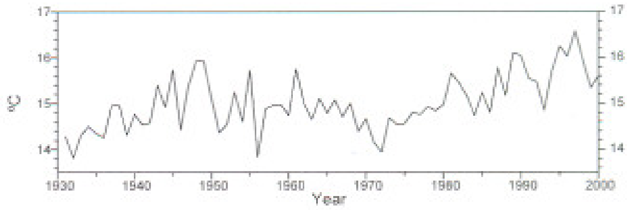


Fig. 1 – Mean air temperature in Mainland Portugal: regional average in the period 1931–2000.

Climate data for the mainland shows a tendency for some increase in the frequency or intensity of extreme weather and climate events in the latter half of the 20th century. Changes are clear in temperature related climate indicators, as a consequence of the observed warming trend, but are less conclusive when one considers precipitation. We note that the number of consecutive dry days shows, in general, an increasing trend. The maximum 5-day precipitation total, which is an indicator of flood producing events, is also increasing. Furthermore the observed climate data shows an increase both in the frequency of heavy precipitation events and in the frequency of severe and extreme droughts, particularly in the southern regions for the last ten years.

Future Climate in Portugal

In recent years, different GCMs have been used to produce climate change scenarios for the 21st century. Given the uncertainty in the emission scenarios, most GCMs implement scenario IS92a, one of the central scenarios selected by IPCC that leads to a doubling of the GHG radiative forcing by the end of the 21st century. Some GCM simulations include the effect of sulphate aerosol emissions.

Time series of mean temperature anomalies (departures from the control scenario) in the Iberian Peninsula obtained from different GCMs implementing scenario IS92a (data available through the IPCC Data Distribution Centre) (Figure 2) show a clear upward trend and a significant warming in the 21st century. The average Iberian temperature increase is of the order of 1°C, comparable with observed data. By 2100 most GCMs project a temperature increase in the interval 4–7°C. As expected, the uncertainty in the temperature anomaly grows with time.

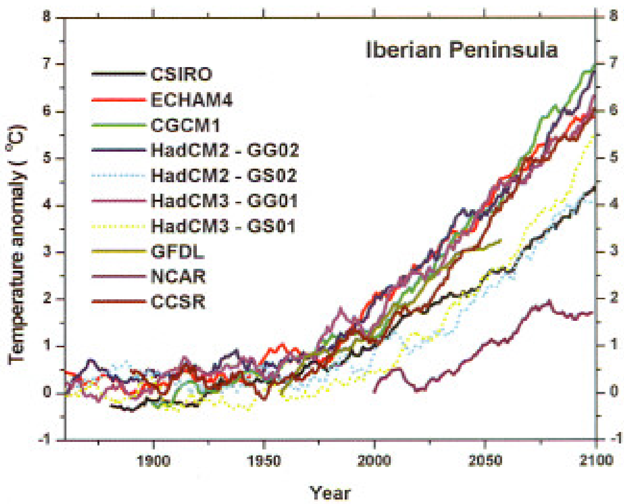


Fig. 2 – Predicted evolution of the mean temperature in the Iberian Peninsula as given by different GCM simulations.

Annual precipitation anomalies were obtained for the period 2070–'99 from the same GCMs, at 3 grid points falling in Portugal (centre and south) and Galiza, Spain (north) (Figure 3). All but one of the model runs indicates a decrease in precipitation. However the magnitude of the decrease is strongly model dependent, particularly in the centre and south. A decrease in precipitation of the order of 100 mm/year appears to be a likely scenario.

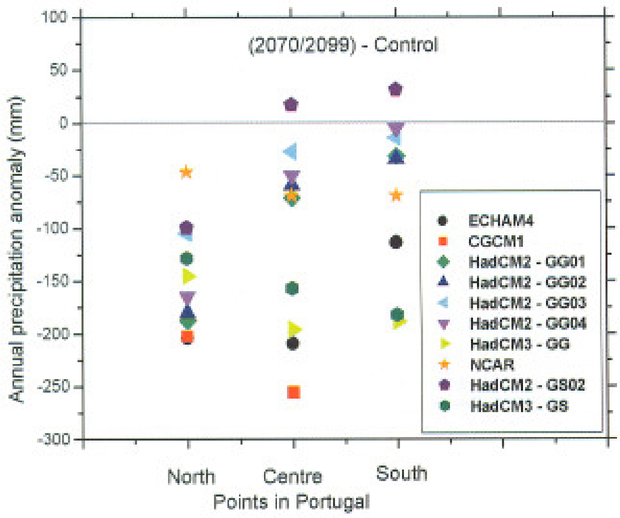


Fig. 3 – Annual precipitation anomalies in western Iberia as given by different GCMs in the three grid points near Portugal. Note that the grid points differ from model to model.

Climate change also affects the annual precipitation cycle. The general pattern of the monthly precipitation distribution, obtained with the same set of GCMs, indicates an increase in winter, a substantial decrease in the spring months, particularly April and May, and weaker signals in the summer and autumn months.

The horizontal resolution of GCMs is typically of the order of 300 km, implying that, at most, only two grid points fall within mainland Portugal. This resolution is insufficient to assess the impacts of climate change in many sectors such as water resources, agriculture and forests. For that reason, this study is mainly based on regional climate change simulations produced by the HadRM model, which is a regional version of the Hadley Centre climate model that was run for the European area, with a horizontal resolution of 50 km and boundary conditions given by one run of the HadCM2 GCM.

The control simulation of the recent climate of mainland Portugal obtained with the HadRM regional model satisfactorily represents the observed climate, with its main spatial variations, although it has a slight cold bias (0.5 to 2°C in the mean temperature) and a slight wet bias. This gives some confidence to the regional climate change scenarios used in the present impact assessment. The HadRM climate change scenario corresponds to the time interval 2080–2100. For this period the projected average minimum temperature in winter (December, January, February) varies between 6 and 16°C while in the control simulation of the present climate it varies between 2 and 12°C. The average maximum temperature in summer (June, July, August) suffers an even greater increase (Figure 4), up to 9°C, reaching more than 38°C in east Alentejo. The number of days with maximum temperature greater than 35°C increases significantly all over the country. In the southeast it increases from 20 (control simulation) to 90

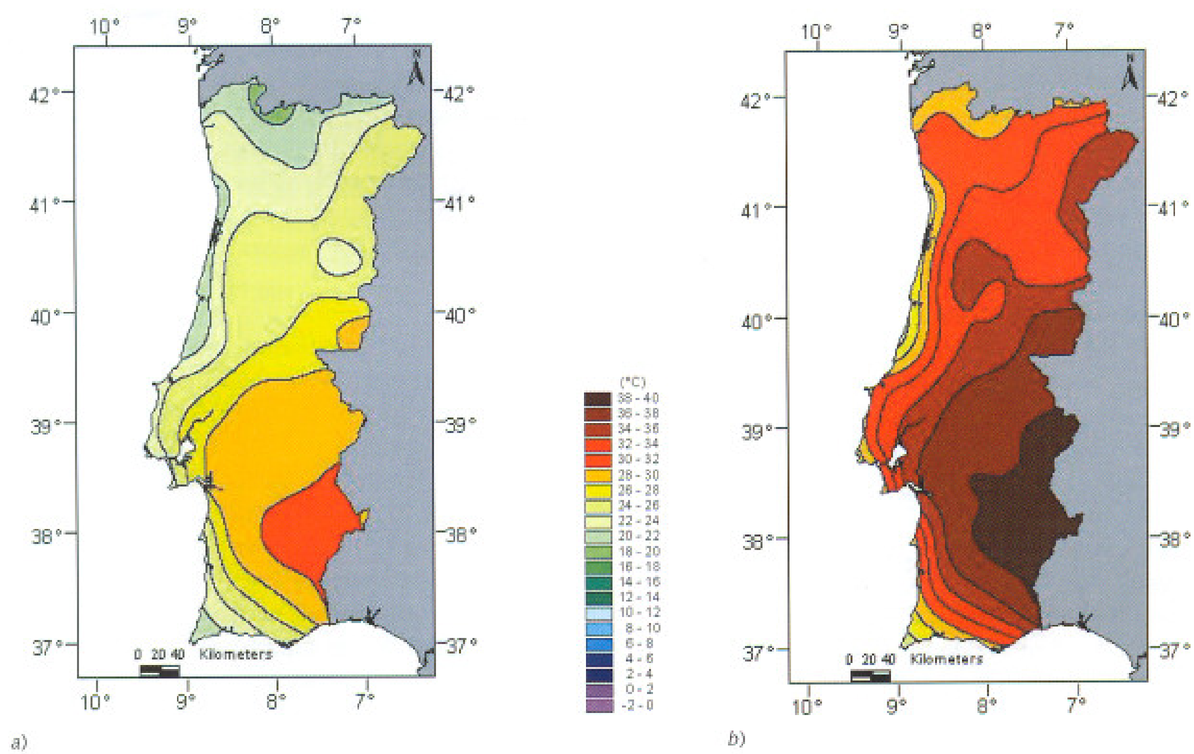


Fig. 4 – Summer (June/July/August) maximum temperature in mainland Portugal obtained with the Regional Climate Model HadRM for the *a)* control run; *b)* increasing CO_2 simulation GG02 (2080–2100 period).

days, while in Lisbon it increases from 8 (control simulation) to 50 days.

The regional model predicts a decrease in the annual precipitation in almost the whole country by up to 15% of the control simulation results in the Alentejo. The precipitation increases in winter by 20–50% and decreases in all other seasons. The most important decreases occur in spring (up to 30%) and in the autumn (35–60%). Furthermore, the accumulated precipitation in heavy rainy days (>10 mm/day) tends to increase and to concentrate in winter. This pattern of change may increase substantially the risk of flooding episodes.

Water Resources

© Tiago Silva

According to the National Water Plan, the average annual precipitation is about 960 mm/yr. The spatial distribution of precipitation in the mainland is very far from uniform, with the Tejo river basin constituting the transition between the wetter north and the drier south. The northwest river basins, north of Douro, experience annual rainfall values of approximately 2,200 mm/yr while the Guadiana basin receives only 570 mm/yr. Precipitation has also a marked seasonal distribution pattern with 70% to 80% falling in the months of November to April. Furthermore, it has a strong inter-annual variability; for example in the 1940–'91 period the mean annual precipitation varied between 550 mm/yr and 1,450 mm/yr.

Portugal shares five river basins with Spain—Minho, Lima, Douro, Tejo and Guadiana—which cover almost 65% of the Portuguese mainland. The annual mean runoff is 380 mm/yr, approximately 40% of the annual mean precipitation. The runoff regime is highly irregular both spatially and temporally. The highest runoff values, of about 1,300 mm/yr, are observed in the northwestern river basins in contrast with the lowest values, of about 160 mm/yr, observed in the Guadiana and Sado river basins. The highest runoff values are observed in February and are followed by a long and dry summer period. The river flow interannual variability is also quite pronounced.

Floods are a recurrent problem both in small and large river basins throughout the country. In small river basins they result from intense precipitation events that occur usually in winter and autumn. For larger river basins, like the Tejo or Douro, longer rainfall events are needed to produce flooding.

The total water needs in the mainland are close to 10,000 hm^3. Being the larger and most populated basins, this water volume is mainly needed in those of the Tejo and Douro. Agriculture is by far the most water dependent sector using almost 75% of water resources.

The impacts of climate change on water resources were estimated by establishing scenarios for changes in climatic inputs to a hydrological model from the output of Global Circulation Models (GCMs) and Regional Circulation Models (RCMs). The hydrological model used is a simplified version of the Stanford Watershed Model usually known in Portugal as the Temez model. Its inputs include monthly series of river basin precipitation and potential evapotranspiration. It was calibrated using data from 35 river basins distributed through out the country.

The current climate was characterised using precipitation and temperature data for the 1961–'90 period from 500 rain gauges and 200 climate stations from the Portuguese Meteorological Institute (Instituto de Meteorologia) network and the Portuguese Water Institute (Instituto da Água) network. Data from the Spanish Meteorological Institute covering Spanish territory surrounding Portugal were also included in the dataset.

Climate scenarios were obtained using the HadCM3 global model and the HadRM2 regional model both developed at the Hadley Centre. River runoff in 2050 and 2100 was simulated with the Temez hydrological model for 28 river basins that represent the range of runoff regimes in mainland Portugal.

Impacts of climate change

The main impacts of climate in water resources are as follows (Figure 5):

- The present simulations indicate a progressive reduction in river runoff during the 21st century. This reduction may be small in the northern region but becomes increasingly severe in more southerly latitudes. Furthermore, there seems to be a systematic trend towards a concentration of the river runoff in winter induced by a similar pattern of change in the monthly precipitation distribution.

- The comparison of the simulations using the HadRM2 and HadCM3 climate scenarios shows that the former leads to a wider range of runoff change predictions due to larger anomalies in precipitation and temperature, namely a strong increase in winter precipitation and a strong decrease in the rest of the year.

- By 2100, the annual mean runoff north of river Douro is estimated to change between +5% and –10% according to the HadCM3 model and increase about 10% according to the HadRM2 model.

- By 2100, the annual mean runoff in the Vouga and Mondego basins may be reduced by 15% to 30% according to HadCM3. HadRM2 estimates are uncertain about the direction of change.

- By 2100, the annual mean runoff reduction in the Tejo river basins is estimated to be 10% to 30%, according to the HadCM3 climate scenario. Such reductions imply long periods with low river flows, which are likely to have a strong impact in water availability, particularly for irrigation activities. HadRM2 estimates predict an increase in annual runoff due to a strong increase in winter precipitation.

- Sado and Guadiana stand out as the river basins more vulnerable to climate change. HadCM3 estimates a 60% decrease in annual runoff by 2100. Here the risk of water shortages, summer drought and desertification is very likely to increase.

- River runoff projections for the Algarve river basins are particularly uncertain because of a strong spatial variability of precipitation mainly due to the mountainous range that divides the Algarve basins from the Sado and Guadiana basins. The impacts are likely to be negative, but less pronounced than in the Sado and Guadiana river basins.

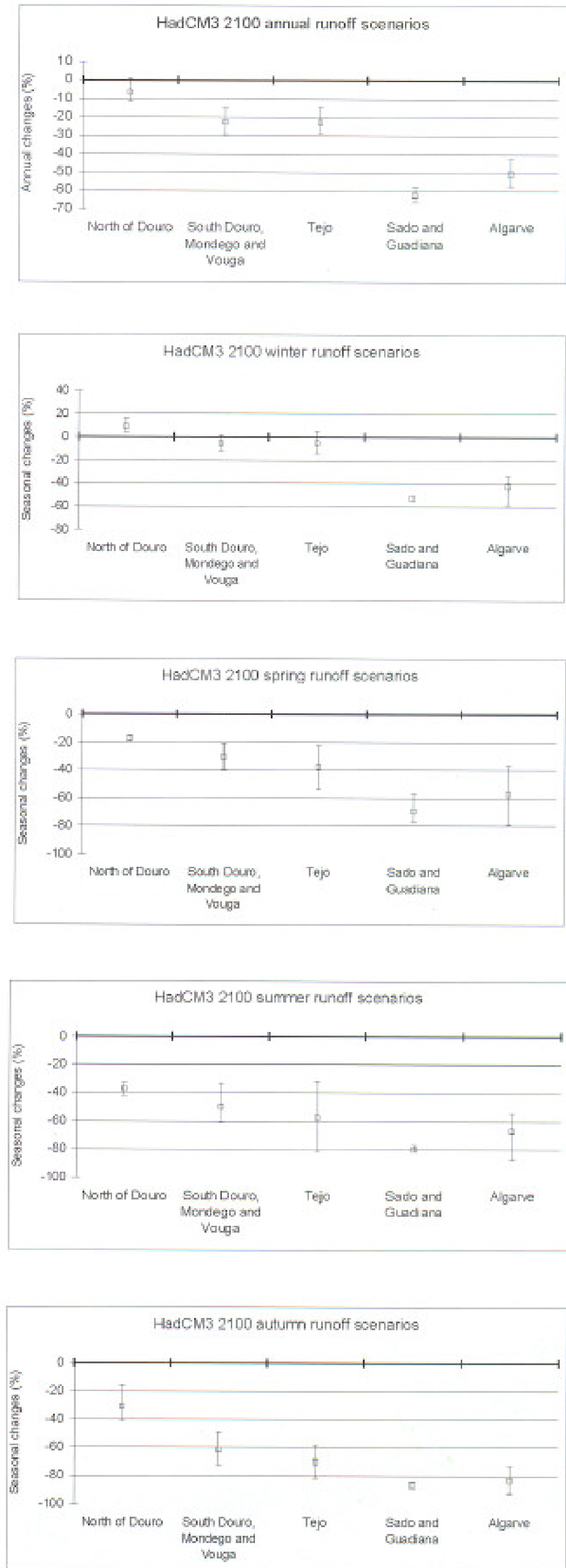


Fig. 5 – Variation of annual and seasonal flow for 2100, relative to the period 1961–'90 of various hydrological basins in continental Portugal, obrtained with the HadCM3 climate scenario.

- The concentration of precipitation in winter and the estimated general increase in the frequency of heavy precipitation events is likely to increase the flood magnitude and frequency, especially in the north.

- Water quality is expected to be degraded by higher water temperatures and by river flow reduction in the summer, particularly in the south.

- The general tendency toward an increase in irrigation water demand, due to various factors including higher temperatures, and the summer reduction of river flows are expected to have a negative impact in agriculture.

We should therefore expect a reduction in the availability of water supplies, an increase of flood risk and an increase of water quality problems risks. The decreased runoff in the Spanish part of the transboundary river basins is likely to accentuate even further the expected decrease of water availability in the Portuguese territory.

Adaptation Measures

The estimated reduction in annual runoff and the increase in the season variability of runoff, together with the probable increase of water demands, will likely increase the stress on water resource systems. This potential increase of water resources vulnerability, together with a greater risk of flooding and of water quality problems, reinforces the need of water management policies based on a solid and in-depth knowledge of water resources.

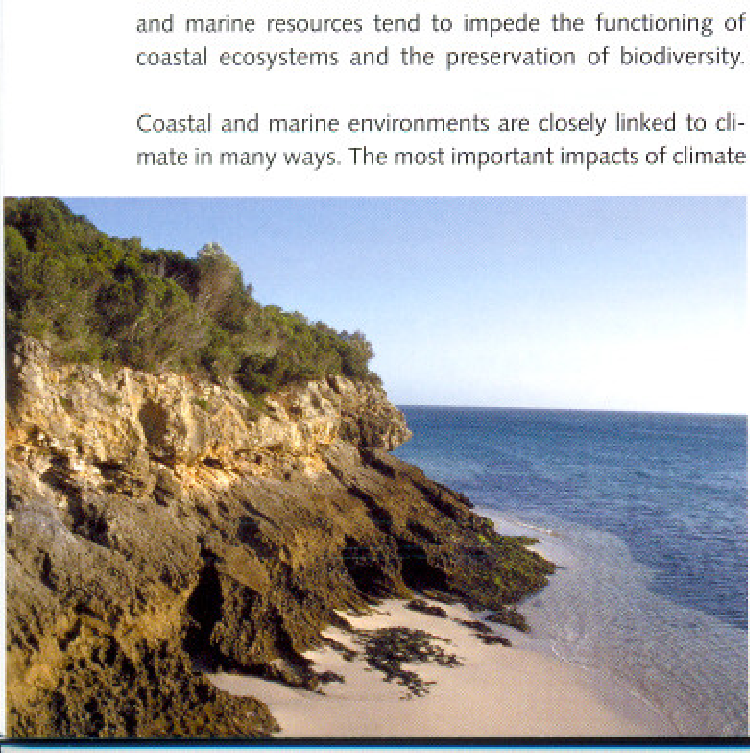
Environmental authorities have long managed water resources systems taking into account the variability of climatic variables and the uncertainty on water demands evolution. Climate change should be added as an additional important factor. The long- held assumption that the historical record is a good indicator of future conditions can no longer be used to define water resources planning and management policies. Environmental authorities should also consider future forecasts of water availability and water demands due to climate change into their decision process.

Coastal Zones

The coastline of mainland Portugal has an extension of approximately 950 km, is morphologically diverse, and can be classified into four main types: beaches, wetlands, hardened and cliffed coasts. Of these four types, beaches and cliffed coasts are dominant with about 591 km and 348 km, respectively.

About to 75% of the population inhabit the coastal zone where most of the larger cities (Oporto, Aveiro, Lisbon, Setúbal, Faro) are located. Coastal population continues to increase and this area accounts for about 85% of the Gross Domestic Product. Increased societal demands for coastal and marine resources tend to impede the functioning of coastal ecosystems and the preservation of biodiversity.

Coastal and marine environments are closely linked to climate in many ways. The most important impacts of climate change on oceans are expected to be increases in sea surface temperature and mean sea level rise. Changes in wave conditions, ocean circulation, salinity and decreases in sea-ice cover can also be expected. It should also be emphasized that the oceans are a significant component of the climate system.


© Alexandre Vaz

The most important of climate change impacts are: a) increased levels of inundation and displacement of wetlands and lowlands; b) accelerated coastal erosion; and c) increased storm surge. Other important impacts are sea-water intrusion into fresh groundwater, and the encroachment of tidal waters into estuaries.

Sea level has already risen by 10 to 20 cm during the 20th century along the Portuguese mainland coast. Previous studies, based on tide-gauge data sets, determined a mean sea level rise of 1.5 ± 0.2 mm/year in Lagos, for a 78 year period up to 1987 and a mean sea level rise of 1.3 ± 0.1 mm/year in Cascais for a 104 year period up to 1987. For the latter location the mean has increased to 1.7 mm/year for 1920–'87 period.

Coastal erosion is already a widespread problem in much of the mainland coast and has significant impacts on undeveloped shorelines as well as on coastal development and infrastructure. Shoreline retreat of the order of 1 m/year and larger have been observed in extensive areas of the coast. The very pronounced reduction of sediment input into the Portuguese coastal zone due to human management of river basins, especially construction of dams, is likely to exacerbate its vulnerability to climate change in general and particularly to sea level rise. Since the beginning of the 20th century, the flow of rivers of the Iberian Peninsula into the ocean has been reduced by 85%.

From 1990 to 2100 the full range of the Third Assessment Report IPCC scenarios project a sea level rise of 0.09 to 0.88 m with a central value of 0.48 m. Land movements (isostatic and tectonic) should be considered. Recent studies for Europe indicate a sea level global rise of 20 to 105 cm by the 2080s relative to the 1961 to 1990 mean. The highest value in this range is significantly larger than the IPCC range. For the same time period, the Portuguese mainland cost is likely to have an average negative vertical land movement of the order of 5 cm. Combining the two values, suggests a sea level rise of 25 to 110 cm by the 2080s.

The assessment of climate change impacts on the Portuguese mainland coast was based primarily on the use of the reconnaissance technique "aerial videotape-assisted vulnerability analysis" (AVVA). By combining a video record of the coastline, aerial photographs and ground-truth information it was possible to classify the coastal geomorphology and obtain information on the types of coastal environments, land-use, and infrastructures. With the use of an appropriate model and risk maps we estimated the biogeophysical effects for different sea level rise scenarios. With this methodology we determined the potential coastal areas at risk and assessed the impacts and most appropriate adaptation measures, to the accelerated sea level rise.

Impacts of Climate Change

The results presented in the following table were obtained using the AVVA Technique for 975 locations along the mainland coast with an average distance of about 1 km. At each point, we identified the type of coastal geomorphology, shoreline protection, and land use. The points observed were also classified as regards population density (low and high correspond to less and more than ten inhabitants per km^2) and coastal development density. Finally we identified the locations with a risk of land loss and a need for protective actions.

We find that there is a risk of land loss in about 67% of the coastal areas. Protective actions to minimize the impacts of sea level rise are recommended in 24% of the coastal extension. In the present study it was not possible to evaluate the praticality, effectiveness or costs of these actions.

		Points Observed	Km
Coastal geomorphology	Beaches	544	591
	Wetlands	3	3
	Cliffs	320	348
	Hardened	30	33
Protection	Seawall	85	92
	Bulhead	3	3
	breakwater	0	0
	groins	19	21
	jetty	14	15
	harbour	11	12
	no protection	765	832
Land use	Urban	101	110
	residential	87	95
	industrial	19	21
	tourism	24	26
	agricultural	69	75
	shcrubland	541	587
	barren	24	26
	forest	18	20
	no video	14	15
Population density	low	589	640
	high	184	200
	indeterminate	124	135
Coastal development density	Low	593	644
	high	180	196
	indeterminate	124	135
Land at risk	risk of land loss	601	653
	no risk of land loss	296	322
Actions for protection and adaptation	action	215	234
	no action	558	606
	indeterminate	124	135
Type of action	Port upgrade	14	15
	groins	21	23
	seawals	141	154
	retreat	39	42
	no action	682	741

Classification and protective actions along the Portuguese mainland coastal zone at 897 points.

Adaptation Measures

The actual impacts of climate change and, in particular, sea level rise depend strongly on human adaptation to that change. Coastal adaptation can be considered a multi-stage and iterative process. There is clearly a need to increase the capacity to manage the coast, especially in the medium and long time scales, and to include adaptation to climate change into long-term coastal planning.

Adaptation strategies for the coastal zones should shift their emphasis away from hard protection structures of shorelines (such as seawalls and groins) to soft protection measures (such as beach nourishment). Nevertheless, hard protection measures are likely to be unavoidable in areas of high development and high population density. In more threatened areas such as wetlands, coastal lowlands and estuaries, adaptation measures are less effective to prevent losses and changes to coastal ecosystems.

Onshore migration of the ecosystems, with rising sea levels, when stopped by hard sea defences tends to cause coastal squeeze, thereby damaging or destroying the ecosystems. This process should be avoided in favour of managed retreat or realignment of the shoreline.

Continued research on the potential impacts of, and adaptation measures to, climate change for Portuguese coastal zones is clearly required. Particular attention should be given to increasing flood-frequency probabilities, flood risk and damage, erosion effects, saltwater intrusion, encroachment of tidal waters into estuaries and impacts on specific coastal and marine ecosystems.

Agriculture

Weather and climate affect agriculture in many ways, from the biological productivity of agriculture crops, the possibility of executing agriculture operations, the incidence of pests and diseases, to the geographical distribution of crops in a region or country. In Europe, the southern regions, including Portugal, are particularly sensitive to climate variability.

The present crop distribution is conditioned by climate, availability of irrigation water, and soil type. Social and economic influences strongly determine what crops grown if the other requirements are adequately met. Portuguese agriculture is dominated by the European Union Common Agricultural Policy, which seeks to integrate concerns for environmental protection and countryside likelihood.

Although it is expected that the foreseeable climate changes will have important impacts on agriculture it is impossible to predict clear patterns of change in arable land use. Hence, the present work focused on the estimation of climate change impacts on the biological performance of selected crops.

The assessment of climate change impacts on specific agricultural crops was based primarily on the use of crop simulation models of the series DSSAT (Decision Support Systems for Agrotechnology Transfer).

The crops chosen in the present study were wheat and maize since they are two of the most important field crops occupying 7 and 4%, respectively of the overall area of the arable land, which is 3.8 x 10^6 ha. Wheat is a typical dryland crop with a physiological behaviour very similar to the other crops grown in Portugal, namely, oats, barley and rye, and maize is the main irrigated crop with a climatic range very similar to the majority of the irrigated annual crops grown during the warm and dry season. Furthermore, they are also representative as regards responses to increases in the atmospheric CO_2 concentration. Wheat is a C_3 plant that responds more positively to CO_2 increases than maize, which is a C_4 plant.

The DSSAT crop simulations were calibrated for Portugal using the CERES WHEAT and CERES MAIZE models. The former model was validated for the region of Alentejo, with historical data, for the period 1986–'98, obtained from

Direcção Regional do Alentejo and the latter for the region of Ribatejo, with historical data for the same period of time, obtained from Direcção Regional do Ribatejo e Oeste. The climate change scenario used is for the period of 2080–'99 and was obtained from the HadRM2 model.

Impacts of Climate Change

Crop productivity is affected both by climate change and by the change in CO_2 concentration. Higher CO_2 concentrations will directly enhance plant productivity and increase water efficiency. On the other hand, higher temperatures will hasten phenological development of crops and increase the demand for water. The expected decrease in spring and summer rainfall will increase irrigation water requirements and cause water stress in dryland crops. The net effect on yield will depend on relative changes in CO_2 concentrations, temperature, solar radiation and precipitation. In general, warming is expected to lead to suitable planting areas moving northwards.

Results of the analysis are presented below:

- Using the Papadakis agroclimatic classification which categorizes winter severity and summer heat according to the possibility of growing specific crops, we compared the present classification with the classification obtained with the climate scenario obtained using the HadCM3 model in 8 grid points spanning from 41° 32'N to 35° 45'N and from 8° 43'W to 7° 4'W. There were 3 cases where the winter classification "oats" – winter sufficiently mild for oats but not for citrus – was changed for "citrus" – winters sufficiently mild for citrus and subtropical crops – while the other remained "citrus". The changes in summer were more extensive; the cooler summer "wheat cooler" and the intermediate "rice," all changed to "cotton". The most southern latitudes remained "cotton".

- For 2080–'99 at a site near Beja the CERES model, indicated a yield increase of 25% (from a present simulated yield average of 2780 kg ha^{-1}) and an increase in yield variability due to increased water stress, in spite of a shorter crop cycle. Without the CO_2 effect, the yield increase is only 2%. It was found that the large increase in yield variability (from 46–68%) planting 2 weeks earlier (from November 1 to October 15). A simulation of other studies indicate a yield increase in central and northern parts of Portugal and Spain and a yield decrease of 1–3x10^3 kg ha^{-1} in southern Portugal and southern Spain.

- For 2080–'99, at a site near Santarém, the CERES MAIZE indicate a yield increase of 12% (from a present simulated yield average of 12 x 10^3 kg ha^{-1}) using a maize variety that allowed the same crop duration. This was possible due to a simulation of planting on March 15 (instead of April 1). This earlier date was possible due to more favourable germination temperatures in the future climate scenario. The expected CO_2 concentration is partially responsible for the projected yield increase although its effect is smaller than for wheat. The maize yield variability is much smaller than in the case of wheat since an irrigated crop is less influenced by climate variability. The simulation indicates an increase of 30% in the irrigation water requirements, which may be an overestimate since the increased water use efficiency, due to higher CO_2, is not taken into account in the model.

- The absence of operational crop simulation models for other relevant crops in Portugal, such as the perennial crops, vineyards and olive trees, makes it difficult to make quantitative estimations of impacts on productivity. Studies by other authors for Europe indicate that there is a potential for expansion of wine-growing area and an increase in yield variability as regards fruit production and quality. Root crops such as sugar beet are expected to benefit from warming and increase CO_2.

- Since it is very likely that the amount of water available for irrigation will be substantially reduced, particularly in the south of Portugal, agriculture is likely to be squeezed between an increased need for water and less available water.

- Global warming tends to lead to a higher incidence of pests, diseases and weeds, which in some circumstances may become key species thereby causing serious losses. This question for Portugal was not addressed in the present study.

Adaptation Measures

The main adaptation measures to counteract the negative impacts of climate change are changes in planting and harvesting dates, choice and development through biotechnology of varieties better adapted to a warmer and drier climate and adaptation of cultural practices to a drier climate.

In the southern regions of Portugal, where water availability is projected to decrease significantly, crop substitution (subtropical and tropical plants) could be an important strategy for conservation of soil moisture.

Health Sector

During the past three decades, economic progress has resulted in improvements in overall health, and life expectancy. Currently, chronic diseases, such as cancer and disorders of the circulatory system, are the major causes of death. Accidents and asthma are the public health concerns among children.

Despite significant improvements in overall health, progress towards identifying and reducing environmental health hazards has been slow. At present, poor water and air quality pose significant environmental health risks. Population sub-groups that are most vulnerable to environmental health risks include the poor, the elderly, the very young, the immunocompromised, rural communities, who often lack basic infrastructure, and migrant populations.

Following an extensive literature review, the impacts of climate change upon selective health outcomes were assessed. Key conclusions regarding the impacts assessed are summarised below. Health impacts due to stratospheric ozone depletion, sea level rise, possible food shortages, and international travel were not assessed in the present study.

Impacts of Climate Change

Potential increase of heat-related deaths

Increased deaths due to extreme heat are a direct health impact of climate change. Heat-related deaths are known to occur following heat stress periods in Portugal (figure 6). Future climate change scenarios indicate hotter conditions and more frequent heat stress periods. Such increases are especially pronounced in urban areas, and particularly threatening to the elderly and individuals with cardiovascular disorders and other underlying health conditions. It is also likely that milder winters could decrease mortality, but its quantification is hampered by the difficulty of solely attributing it to weather conditions, and was therefore not assessed.

Potential increase of water and food-borne diseases

Water and food-borne diseases are transmitted to humans when they come into contact with biotoxin and pathogen-contaminated water and foods. Although gastroenteritis is the most common; other health outcomes such as neurological, renal and hepatic disorders; cancer, and possibly death may result from the consumption of contaminated water and food. Water quality and food-borne disease outbreaks are currently significant public health concerns.

Warmer temperatures enhance pathogen growth and survival as well as biotoxin production. Extreme precipitation events have the potential to increase pathogen propagation in water and food consequent to changes such as increased water nutrient concentration, decreased sea water salinity, and sudden alterations of water flow rates. Given current water and food safety management prac-

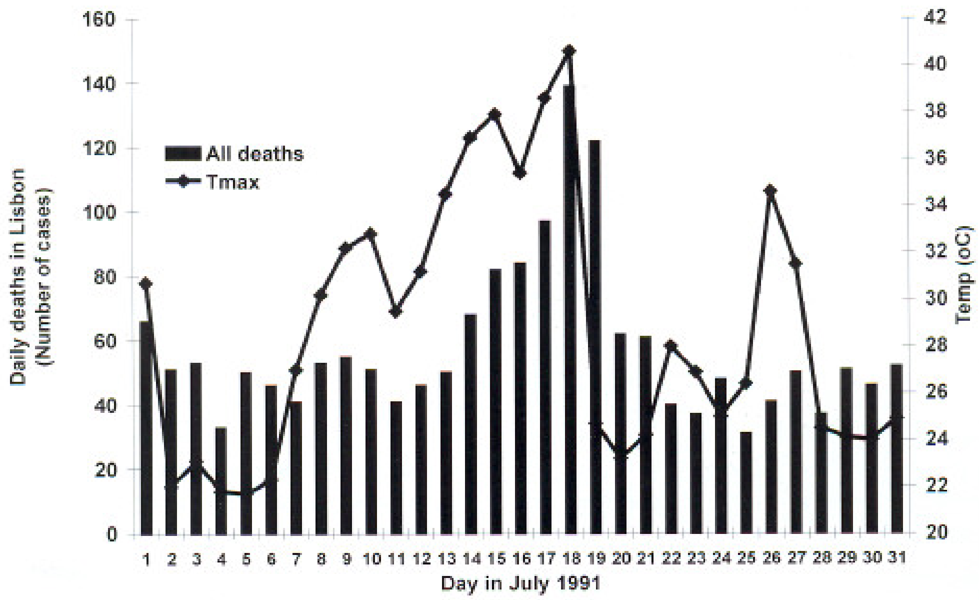


Figure 6: Relationship between daily maximum temperature and mortality in Lisbon during the July 1991 heatwave.

© Tiago Silva

tices, and the increased temperatures and more frequent extreme precipitation events indicated by climate scenarios, potential water and food-borne disease transmission is likely to increase due to higher pathogen survival and biotoxin production.

Potential increases in air pollution-related health effects

Ambient air quality often reaches levels hazardous to public health. If the climate becomes warmer, as indicated by climate scenarios, ambient levels of tropospheric ozone and aeroallergens such as pollen may increase. Higher ambient air levels of these agents may exacerbate asthma and other respiratory diseases, which are already significant public health concerns.

Potential changes to vector and rodent-borne disease risks

Vector-borne diseases are infectious diseases transmitted to humans and other vertebrates by pathogen-infected vectors (mosquitoes, ticks, sandflies, etc.). Similary, rodent-borne diseases are infections transmitted by pathogen-infected rodents. Disease transmission requires the co-presence of reservoir hosts (such as humans, birds and rodents), competent vector (or rodent) populations, and pathogens in sufficient numbers to maintain transmission. Transmission to humans requires human contact (exposure) with the parasite-infected vector or, alternatively, rodent biofluids, such as saliva and urine.

Aspects of climate such as temperature, relative humidity and precipitation can influence disease transmission dynamics by altering vector longevity and development, pathogen development, host distribution and vector (or rodent) habitat.

Increases in temperature and precipitation variability, as indicated by future climate scenarios, are likely to increase the potential risks of vector and rodent-borne disease transmission, particularly Lyme disease, Leishmaniasis, and Leptospirosis. Such climate changes may also favour the potential risk of localised outbreaks of malaria (*Plasmodium vivax*), West Nile virus fever, and Schistosomiasis (bilharzia). Insufficient information precluded any conclusions as to how climate change may affect Mediterranean spotted fever.

Adaptation Measures

Based on the potential adverse health impacts assessed, the following adaptation measures are recommended:

- Planned adaptation measures such as a national early warning system, urban planning to reduce the "heat island" effect, and the use of air conditioning are suggested to reduce population vulnerability to anticipated heatwaves.

- Population vulnerability to water and food-borne disease transmission risk can be reduced if current water and waste management systems are improved, and environmental and disease surveillance initiatives strengthened. Deterioration of current public health infrastructures will undoubtedly lead to increased disease transmission risks, with or without climate change.

- Improved pollution control measures and a national air quality warning system are required to reduce current and anticipated air pollution-related health outcomes.

- Improved disease, vector, and pathogen monitoring and surveillance is needed to better understand vector and rodent-borne disease transmission. Improvements to current basic public health infrastructures will also reduce population vulnerability.

Research Gaps

Insufficient health and environmental data and the significant number of knowledge gaps on the relationship between health and climate has resulted in many uncertainties being incorporated in the assessment. Consequently, no definite conclusions could be reached regarding the magnitude of the change of potential climate change health impacts. Epidemiological research on the relationships between climate and public health is urgently required in order to reduce key knowledge gaps so that more profound national assessments on public health vulnerabilities to anticipated climatic changes can be performed.

Energy

The energy sector is defined in national accounting as the set of activities related to coal, oil, gas, electricity and water supply. During 1990–'95, these activities represented 3.5–4.0% of the gross national product.

As shown in Figure 7, energy consumption (5–6% per year) has increased more rapidly than GNP growth (3–4%) in the last few decades. Portugal has no significant fossil fuel resources, and hydro-power is the only national energy source exploited in significant amounts, resulting in a dependence on imported energy products. Demand has also been rising rapidly, in particular in the service and transportation sectors.

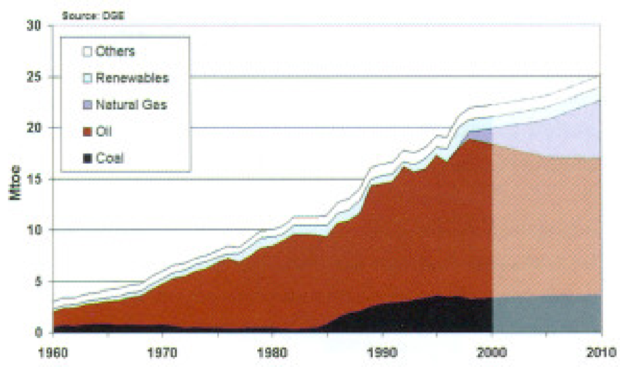


Fig. 7 – Primary energy supply time series for Portugal (2000–2010 values are projections from Direcção Geral de Energia)

Impacts of Climate Change

The sector response to climate change was studied from both the perspective of supply and that of demand.

Supply

- No significant impacts on thermoelectric plants
- Possible benefits for large hydroelectric plants in the north
- Negative effects for mini-hydroelectric plants, and also for large hydroelectric plants in the centre and south
- Increased losses in electricity transport and distribution
- Increased performance of solar systems

Existing thermoelectric power plants are expected to suffer a very small decrease in efficiency (–0.1 to –0.2%), other potential impacts linked to water availability for refrigeration, sea rise, and changed frequency of natural hazards such as floods and storms, were studied but found irrelevant given the specific current characteristics of the energy sector.

© Tiago Silva

Although water availability for electricity generation may decrease in general, large hydroelectric power plants in the north—in particular those situated in the Douro basin—may benefit from increases in winter runoff. In contrast, those situated in the centre and south should diminish production due to a reduction in runoff and increase in evaporation. However the overall result may be positive, considering the specific location and installed power of the plants. Cross-sectorial effects, due to competition for water with municipal uses and agriculture, were found to be small.

An increase in ambient temperature leads to an increase in the resistance of conductors. Both electricity transport (high and medium voltage) and distribution (low voltage) lines will be affected, leading to an additional 1.6% loss of energy during transmission.

Solar systems will benefit from an increase in solar radiation. An improvement in performance of 8% in active water heating systems and of 5–6% in photovoltaic systems is expected.

Demand

- Decreases of space heating requirements in buildings
- Even larger increases of space cooling requirements in buildings
- Small decreases in energy consumption for water heating

The study analysed the thermal performance of buildings, both service sector and residential, using a numerical simulation of several reference buildings for various regions. Social economic scenarios were also considered in detail. Overall increases in annual energy consumption were found (Figure 8) as cooling demand increases offset heating reductions. A decrease of about 3% in energy demand for water heating for domestic and industrial uses was also estimated.

Adaptation measures

In the energy sector, adaptation measures are often difficult to distinguish from those intended to mitigate climate change. Also mitigation measures and policies are bound to have a much greater impact in the sector than those required to adapt to climate change.

Adaptation measures could simply involve an increase in consumption, translating into higher fossil fuel imports. But if increases in energy use are to be controlled, then most adaptation measures that could be taken would involve better management or resizing of energy systems, with respect to current practices and design guidelines, as in the case of large dams, solar energy systems, mini-hydro plants, building insulation and energy saving measures.

Research gaps

Better estimates of the impacts would result from the use of more detailed modelling, as well as case studies, and further consideration of socio-economic scenarios and cross-sectorial synergies. These could include performance studies for specific hydroelectric power plants, agriculture water pumping needs, power transmission at regional scale, water use related impacts in new combined cycle natural gas thermoelectric plants, and non-classical adaptation measures for buildings.

Other issues were simply not yet considered, such as space conditioning within trains and road vehicles. Better and more detailed long-term energy sector scenarios also need to be developed to improve estimates at climate change timescales.

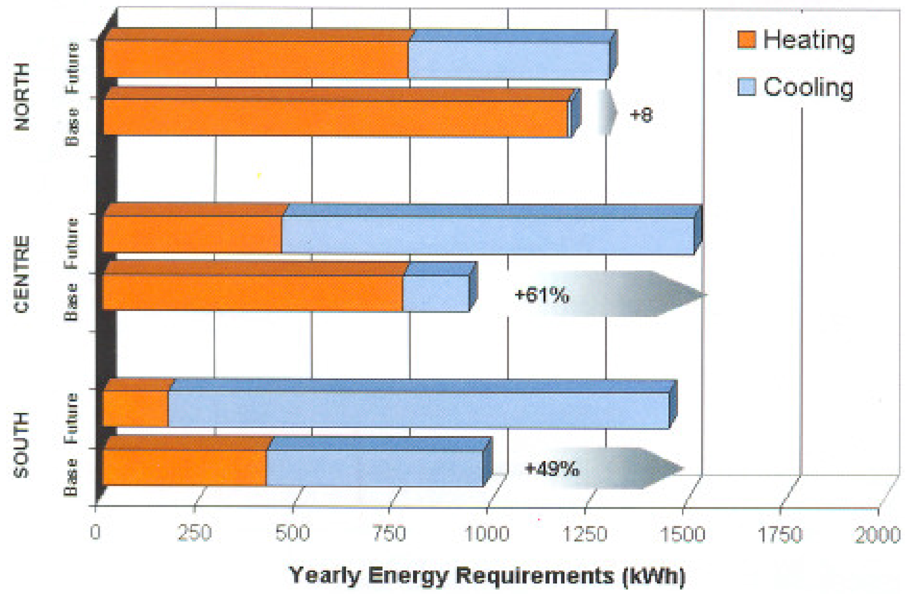


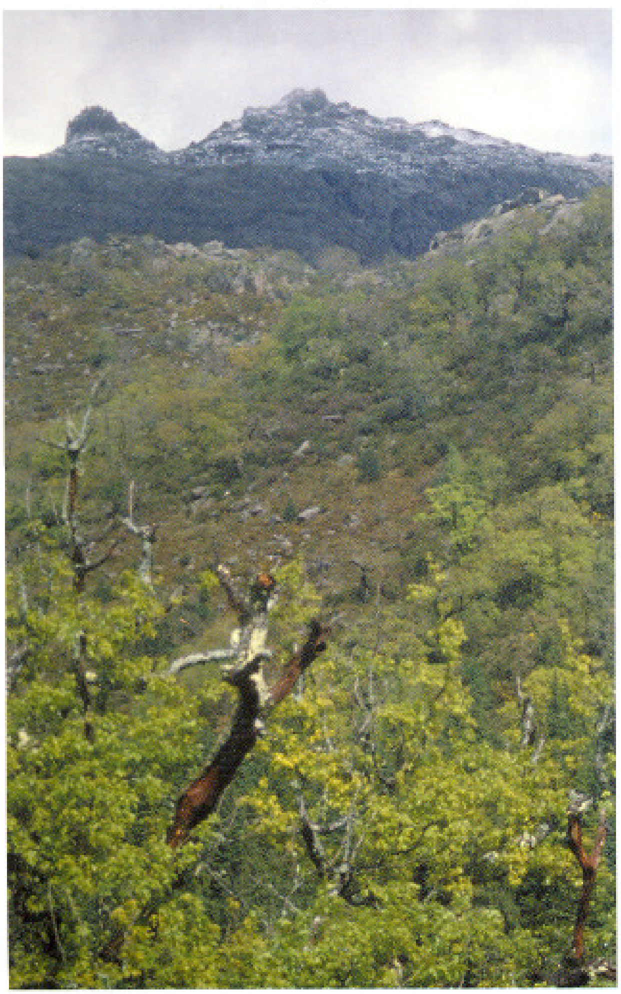
Figure 8 – Impacts on space conditioning in residential buildings.

Forests and Biodiversity

Forests cover ca. 3,200,000 ha in Portugal, i.e. 36% of the total area of the country. The economic importance of the forestry sector is well established, being one of the leading sectors in the whole of the national economy (estimated to be 3.4% of GDP in 1993). Most of the forest land is privately owned: 85% is private property, 3% is owned by the state and 12% belong to the local communities.

In addition to their direct economic value as sources of raw materials, forest ecosystems play an important role as providers of services such as the purification of water and air. It is known that forest may serve as filters for some of the pollutants that are liberated to the environment by human activities. Traditionally forests have been viewed as a source of biodiversity that should be preserved. Native forests and "montados" are the habitat of some rare or endangered species such as *Ciconia nigra* (Black stork) and *Lynx pardina* (Iberian Lynx).

The increasing urbanisation of our society has led to an ever-increasing need for outdoors recreation in forests and associated ecosystems (including hunting and recreation in the fresh water systems associated with forests). Today, the importance of forests cannot be viewed without considering this recreational component even though its economic value is still difficult to quantify.



© Tiago Silva

Impacts of Climate Change

Forest productivity and carbon balance

- Ecosystem functioning and services, industrial raw material production such as wood and cork, as well as the carbon sequestration capacity in forests, depend on primary (plant) productivity. We used a process based model (BIOME-4) to simulate future distribution of potential vegetation types and their productivity. The Net Primary Productivity (NPP) simulation based on an "optimal" distribution of forest vegetation suggested a decrease in NPP in most of the country due to increasing water deficits in the future climate scenario (NPP is the part of total or gross primary productivity not used for plant growth).
- In parts of the country where water availability is not expected to be limiting, warmer winters and elevated CO_2 are expected to increase NPP in the future. Such gains may occur in the cooler and wetter areas of the country as the Northeast where fairly high precipitation is predicted for the future.
- Changes in vegetation indicated by the model would imply substitution of forest types in certain areas, provided there would be enough time for species migration. Since this is unlikely to occur in the time scale of occurrence of future scenario, present vegetation will be under greater environmental stress than today. This was confirmed by simulations with a more complex process-based model (BIOME-BGC), which was used to investigate changes in NPP assuming that present-day forests would remain *in situ* under the future climate scenario.
- The frequency of extreme events such as windstorms, severe droughts or long hot spells, together with increased risk of fire, may increase in the future. Such events will enhance the risk of productivity losses through tree mortality and subsequent land degradation.
- Forests may act as sinks for CO_2 and therefore help in the mitigation of the greenhouse effect resulting from GHG emissions. The present capacity of Portuguese forests to store carbon is high. In the future, however, it may not be as high as it could be under the present climatic conditions due to: (1) decreases or only modest increases in NPP, (2) lower standing biomass due to changes in vegetation and increase in fire frequency and (3) enhanced soil respiration due to warmer winters, thus decreasing the importance of the below-ground carbon store.

Migration and extinction of key forest species

- The changes associated with future climate scenarios will occur too quickly to allow natural tree species migration. In most cases, relocation of species is unlikely to occur without human action, i.e., reforestation with species better adapted to the future environmental conditions. The slow growing species as cork and holm oaks are unlikely to be able to migrate naturally, whereas maritime pine, as

well as some invasive exotic species such as *Acacia* spp. could occupy new locations (e.g. disturbed sites) and outcompete stressed native species, as climate change occur.

- Some tree species may experience severe mortality in the drier edges of the their present range. Changes in the dominance of some species are likely to occur with changes in the boundaries of forest types. Interior and southern regions will be especially susceptible due to increasing aridity. While cork oak may continue to decline in Alentejo, holm oak may resist better to water deficits and persist in open stands with low tree canopy cover as the "montados."

Fire

- A very substantial increase in meteorological fire danger is projected to occur throughout the country. In central and northern Portugal a three- to five-fold increase is expected in the number of days with fire weather index (FWI) values corresponding to very high and extreme meteorological danger conditions. Model results also indicate an expected lengthening of the fire season, with FWI values higher than current levels during the late spring and early fall.

Pests and diseases

- Warmer winters may not change the insect population drastically. Existing population growth rates may, however, be spurred by increasing temperatures, especially for multivoltine species (species that produce several new generations per year), such as aphids and adelgids. In the southern and interior regions, increased aridity may cause more pests damages, namely of woodborers (e.g. *Coroebus undatus, Coroebus florentinus, Platypus cilindrus* in cork and holm oaks and *Phorachanta semipunctata* in eucalypts) and other secondary insects.
- Warmer temperatures, when accompanied by higher humidity, may increase outbreaks of pathogenic fungi (e.g.: *Phythophthora* spp., *Armillaria mellea*), leading either to the death of trees or increasing their vulnerability to pest attacks and drought. Warmer and wetter winters in the north and central regions of the country could increase the risk of invasive pathogens (e.g.: *Ceratocystis fagacearum* in oak trees, *Sphaeropsis sapinea* in pine trees).
- The risk of invasion by tropical or subtropical pests and diseases will increase under the globalisation of commerce and the "tropicalisation" of the climate in Portugal.

Biodiversity and Protected Areas

- Some animal populations, particularly if they have limited geographical distributions, small habitat areas or low number of individuals, may not be able to respond to rapid climate changes, and extinction may occur namely in populations with low reproductive and dispersal capacity.
- Endemic species such as the bat *Nyctalus leisleri* (endemic to Portugal), as well as the Iberian lynx (*Lynx pardina)* and the rodent *Microtus cabrerae* (both Iberian endemisms) may be highly sensitive species. These species are already endangered and will probably go extinct under the pressure of habitat disruption.
- As the climate in Portugal will become warmer, the risk of invasion by alien plant or animal species from warmer regions may pose threat to biodiversity.
- Protected areas were analysed separately for their vulnerability due to their important role in conserving biodiversity. Expected changes in vegetation cover and expansion of semi-arid areas will lead to important changes in habitats and, consequently, dependent species.
- Protected areas were classified on the basis of vulnerability of plant and animal communities (from very high to low vulnerability) and anthropogenic influences as follows:

  Very high – Vale do Guadiana, Costa Vicentina
  High – Douro Internacional, Estuário do Tejo and Montesinho
  Medium – Arrábida, Peneda Gerês, Serra da Estrela, Serra da Malcata, Serra d'Aire e Candeeiros, Sintra-Cascais
  Low – Alvão, São Mamede

Adaptation Measures

Productivity and forest composition, carbon balance

- Forest policies for the sustainable development of the forest sector must reflect awareness of climate change and future climate scenarios.
- Aforestation/reforestation should consider the use of species according to their adaptability to future conditions.
- Use aforestation, tending and harvesting techniques that:
  - avoid extensive soil mobilisation as soil erosion that may be enhanced in future climate scenarios;

- increase water availability throughout the growing season, where increased aridity is expected;
- improve overall resistance to extreme events, such as wind storms, wildfires and severe drought events.

- The over-exploitation of forest resources should be avoided in order to maintain carbon balance and soil fertility under a harsher environment.
- Tree improvement programmes in order to increase the genetic potential of some forest species to adapt to higher temperatures and increased water stress.
- Improve the carbon sink capacity of Portuguese forests through aforestation / reforestation, avoiding land degradation, protection of old-growth forests and using the longest rotations possible in silviculture as well as promoting the useful life span of forest products to enhance carbon sequestration.
- Measures for the prevention and forest fires (see following section) and of land degradation, as these will exacerbate any negative effects of climate change and may enhance the risk of local extinction or decline of native key forest species, especially in the interior and South;
- Development of appropriate land management models that avoid depopulation and desertification (e.g., adequate agro-forestry) in future climate scenarios and promote alternative livelihoods for the population in those areas.

Fire

The future viability of important segments of the forest industry, the lives and property of people living in forested areas, and the natural and cultural resource values of several of the country's protected areas, may be at stake with enhanced meteorological fire danger. The following measures are suggested to diminish this risk:

- Afforestation of areas expected to suffer more severe warming/drying ought to be avoided. Development of regional forest plans where substantial areas are allocated to networks of fuel breaks. Fuel breaks do not have to be devoid of vegetation and unproductive, but will require special-purpose protective silvicultural practices, with a strong emphasis on fuel management programmes;
- Optimisation of landscape-level patterns of fuel harvesting in order to further break up large-scale continuity of forested areas;
- Diversification of the range of species used in commercial forestry, with an emphasis on deciduous broadleaf species;
- Implementation of programs for controlled burning in a safe and sustainable manner including its use for scrubland and pasture management;
- Discarding the current systematic fire suppression/avoidance policy in protected areas and the reintroduction of fire in such areas to prevent fuel build-up;
- Regulation of housing developments in the forest-urban interface and in predominantly forested areas is very important. This will reduce the levels of fire fighting effort necessary for the protection of human life and property in such areas, releasing human and material resources for more effective forest protection.

Pests and Diseases

- The appropriate national agencies should maintain databases and improve the monitoring and prevention measures in order to make an earlier detection and identification of pests and diseases of plants and plant products that may become noxious under the future conditions and prevent their introduction across the national boundaries.
- Increase scientific knowledge about best integrated pest management strategies for the most important and dangerous pest and diseases, promote the divulgation to the stake holders and the implementation of those strategies in the field.

Biodiversity and Protected Areas

- Rapid implementation of actions proposed in the recently produced National Strategy for the Conservation of Nature and Biodiversity.
- Wise management of the matrix between existing protected areas allowing the movement of organisms is essential to future preservation of species in protected areas.
- Connecting corridors between different reserves could enhance the migration between them promoting not only species richness increase due to rapid
- Population movements inside and outside but also gene fluxes between areas.
- Impeding invasive alien species where they further contribute to the decline of native species and biodiversity.

Research Gaps

Although the research on forests and forestry is increasingly focussed on the impacts and the adaptation and mitigation measures regarding climate change, further research is needed regarding:

- The response of individual species and forest ecosystems to changes in climate and development of models essential for improved simulations of the sustainability of forests and forestry;
- The impacts of hypothesised increase in forest fire frequency on productivity and carbon balance of forests;
- How the country can maximise its reliance on the capacity of forests to sequester carbon in order to mitigate the impact of GHG emissions;
- The socio-economic impacts of ecological changes in forests;
- The impact of changes in forest composition and health in some forest ecosystem services and the inter-sectorial impacts.

Fisheries

The climate scenarios used in this study indicate an increase in sea surface temperature by as much as 4°C across the Portuguese continental coast by the end of the 21[st] century. Changes in wind patterns are also expected to occur and are likely to cause significant modifications in the upwelling (the rise of sub-surface cold, nutrient-rich layers) regime along the west continental coast. The average intensification of the wind may also contribute to an increase in water turbulence, with potential impacts on the abundance and distribution of marine organisms and their food.

Three species were considered: sardine (*Sardina pilchardus*), bluefin tuna (*Thunnus thynnus*) and the common octopus (*Octopus vulgaris*). The option for these species was based on their biological and ecological characteristics and their economic interest (Figure 9).

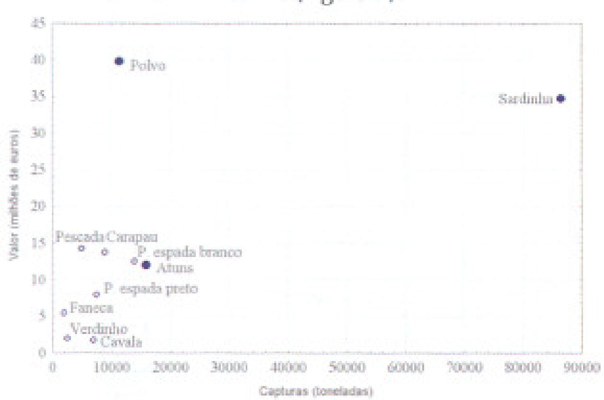


Fig. 9 – Landings and values of diverse species.

© Carlos Sousa Reis

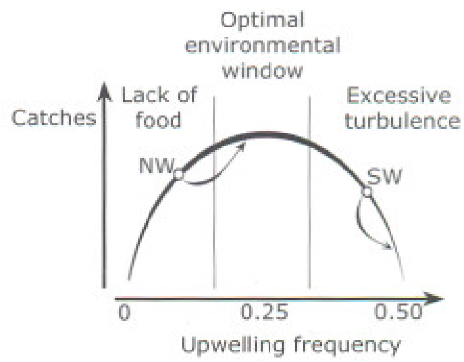


Figure 10 – Forecasted impacts of changes in the summer upwelling frequency on the catches of sardine. NW: Northwest Coast; SW: Southwest Coast.

Impacts of Climate Change

Sardine

The projections of climate evolution in Portugal suggest that an increase in average summer upwelling frequency is expected for the Northwest coast (Viana do Castelo–Peniche). This increase is likely to be beneficial for juvenile and adult sardine feeding, as it further optimises environmental conditions (Figure 10). On the other hand, non-significant variations in colder months will probably ensure that larvae remain close to the shore, where they have better chances of surviving. Spring Lasker events (consecutive days with weak wind-generated turbulence) may become less frequent but they may still be sufficiently frequent so as to not affect larvae survival rates since spawning occurs mainly from late autumn to early spring. Together, these conditions are likely to enhance sardine production along the Northwest coast.

A totally different scenario is predicted for the Southwest coast (Peniche–Cape S. Vicente). Here, the strengthening of spring and summer upwelling (which is nowadays already intense) is likely to produce extreme turbulence and a light-limited phytoplankton population, resulting in a reduction of primary productivity. As a consequence, mortality during the early stages of life may increase, thereby weakening annual recruitment (young specimens that join the exploited stock) to fisheries.

Along the Algarve coast, it is expected that sardine abundance will not change because no modifications in the upwelling and turbulence regimes are foreseen.

Bluefin Tuna

It is likely that an increase in sea surface temperature will considerably alter the population dynamics of *T. thynnus*. Although the full set of biological and physico-chemical characteristics that define spawning areas and reproductive success is so far unknown, it seems reasonable to forecast an enhancement of recruitment and a recovery in bluefin abundance in the next decades, based on the events that ocurred during the last period of warming.

Apart from altering production, ocean warming might also allow bluefin to extend its summertime trophic migrations further northward, into new feeding grounds. The Northern Seas may again become populated with *T. thynnus*, at the same time that small warm-water pelagics (e.g. sardine) replace characteristically autochthonous species (e.g. herring).

Octopus

Current knowledge shows that temperature strongly influences *Octopus vulgaris* metabolic activity, and consequently feeding and growth rates. Therefore, higher sea temperatures during autumn are likely to allow young planktonic octopuses to grow faster and thereby increase their chances of survival, provided that there is enough food available. Starvation and cannibalism may become more important, while the risk of predation may be diminished due to the shortening of the planktonic phase.

During winter and spring, adverse environmental conditions may become less frequent, thereby reducing the probabilities of mortality. Enhanced sea bottom salinity and temperature may allow individuals to remain closer to shore and to grow even in winter. Consequently, population biomass is likely to be enhanced.

Adaptation Measures

Sardine

The adoption of distinct management decisions for the three regions in which the Portuguese coast was divided (Northwest, Southwest and Algarve) is probably the best policy to deal with the different changes in distribution and abundance of sardine. Efficient management policies must be enforced in order to maintain catches close to the stock's maximum sustainable yields, namely by regulating fishing effort, mesh size, bans, etc., and considering market policies.

Bluefin Tuna

The success of adaptation measures to changes in bluefin abundance due to climate change can only be possible if the recommendations made by the International Council for the Conservation of Atlantic Tunas (ICCAT) are enforced by all the countries that exploit this marine resource, since it is currently being overfished. Namely, minimum catch sizes must be respected, as well as total allowable catches and fishing bans.

Remote sensing and tagging experiments may also become helpful in designing management policies, since changes in the distribution patterns of bluefin due to environmental changes will probably require a reallocation of fishing effort.

Octopus

Traditional fishing techniques for octopus (mainly with clay pots) should be encouraged as a response to the predicted increase in this species' abundance. As opposed to the combination of trawling and traps, traditional techniques are more sustainable, since bycatch is less significant, only large specimens are caught, and the loss of fishing gears is less harmful to the environment (lost pots are even beneficial, since they provide new homes).

Research Gaps

The main difficulties in predicting future impacts of climate change on fished species lie in the fact that many aspects of (current and past) environmental influence on the distribution and abundance of marine organisms are still not clear. Unknown processes of parasitism, predation and competition may also develop, leading to unexpected population dynamics. Consequently, it must be stressed that nearly all the conclusions drawn in the present study are attached to much uncertainty.

Further investigation of current data records should be continued, as long as laboratory experiments, when necessary. *In situ* estimations of recruitment success would also provide significant insight on the importance of environmental factors, apart from better quantifying recruitment variability.

Nevertheless, the major gap in the present study was the restriction to only three species. Numerous marine groups were not represented, such as mammals (e.g. dolphins), elasmobranchs (e.g. sharks), crustaceans (e.g. lobsters), demersal finfish (e.g. congers), flatfish (e.g. sole), etc. Portuguese freshwater species were not discussed either, as well as migratory species such as eel, lamprey and shad. It is highly likely that these species will be severely affected by climate change, namely by the reduction of rainfall and by the increase of surface temperature. The disequilibrium of freshwater ecosystems should thus be addressed promptly, in order to mitigate the more adverse consequences.

In conclusion, it is highly likely that the abundance and distribution of some species will be afected, being "replaced" by others that are nowadays regarded as uncommon. In this context, there should be made an effort to increase the flexibilility of management measures applied to marine resources, along with the promotion of a greater opening in the market of fish products.

ISBN 972-662-815-6