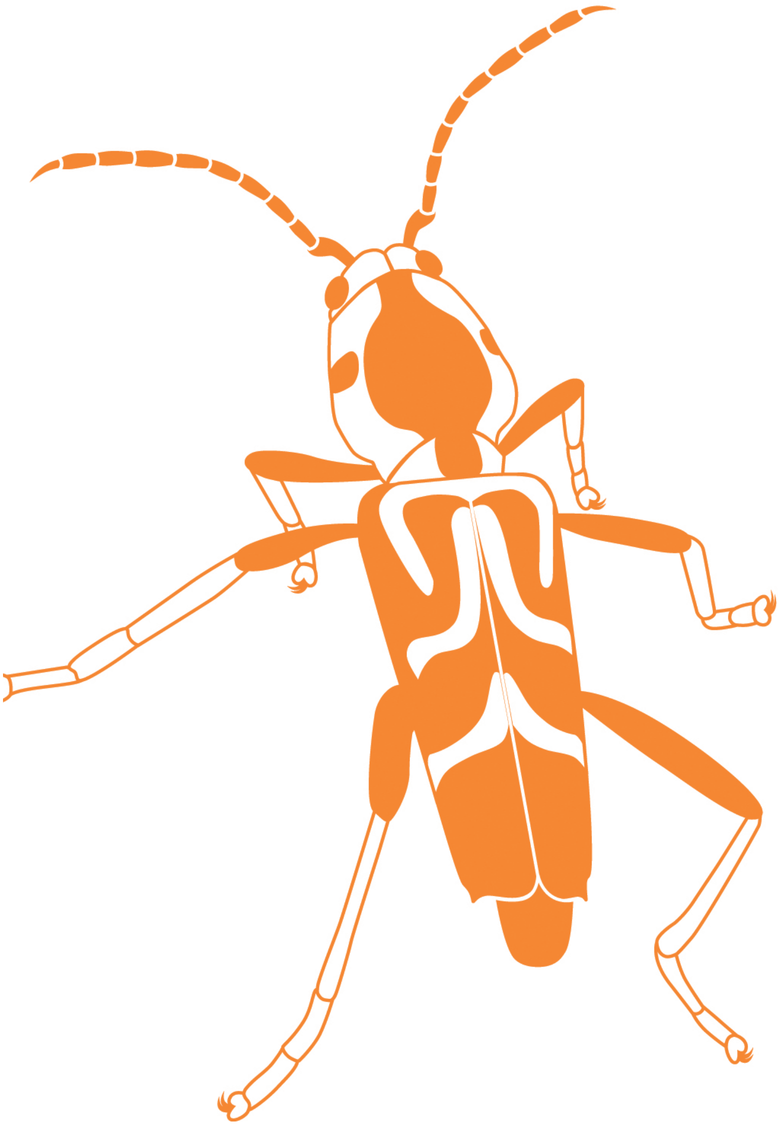
CABI WORKING PAPER 1

Climate Change and Invasive Alien Species

November 2010



Greg Masters
Lindsey Norgrove

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Greg Masters was a senior ecologist with CABI, and now works as a consultant (www.ecologicalconscience.co.uk/).

Lindsey Norgrove (l.norgrove@cabi.org) is CABI's Global Director, Invasive Species, based at CABI Europe-Switzerland.

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"*The adverse impact of* invasive species can impede economic growth and poverty alleviation, as well as threaten food security and biodiversity".

Kathy MacKinnon

World Bank's Lead Biodiversity Specialist

"It is irresponsible, reckless and deeply immoral to question the seriousness of the situation. The time for diagnosis is over and the time for action is now."

Mrs Gro Harlem Brundtland

UN Special Envoy of the Secretary General on Climate Change

Executive Summary

Invasive alien species (IAS) are non-indigenous species that adversely affect, economically, environmentally or ecologically, habitats where they have been introduced, either accidentally or deliberately, outside their normal past or present distribution.

IAS and climate change, with land use change and changes in the nitrogen and carbon cycles, are identified as the top four drivers of global biodiversity loss. Their relative importance depends on the ecoregion being considered. Biodiversity loss is accelerating because of the globalization of trade and increased international tourism. Furthermore, both climate change and IAS can affect production landscapes, reducing crop yields and the provision of ecosystem services. While many articles have identified the drivers of biodiversity loss, they have not considered or modelled the interactions between drivers. For example, land use change creates an empty niche for invasions to occur so together these drivers have a greater impact than separately.

Climate change can facilitate IAS as:

- new species, that may become invasive, will be entering regions due to climate change,
- species hierarchies in ecosystems will change, leading to new dominants that may have invasive tendencies, and
- climate induced stress in an ecosystem will facilitate invasive pathways.

Alternatively, IAS can facilitate climatic stress by increasing ecosystem susceptibility to climatic perturbation, through reducing the number of species and their functional types within the ecosystem.

Recognition of interactions between IAS and climate change

IAS should be recognized as a component of climate change and as such appropriate research strategies, funding mechanisms (for research, technology transfer and interventions such as management, control and prevention), and policies need to be developed and implemented.

Synthesis of previous work

Climate change is an international environmental problem that will alter distributions and abundances of many species, including increasing the ranges, establishment opportunities and consequent impacts of IAS. The synergy between IAS and climate change is complex and poorly understood. The first step is to synthesise previous work recording the singular effects of changes in temperature, Carbon dioxide (CO_2), other greenhouse gases and humidity on IAS and input into climate change projection models to estimate the impacts.

CABI has already developed simple conceptual frameworks of what happens to ecosystems when a species leaves (e.g. extinction) or arrives (e.g. as an IAS) due to climate change. These frameworks were developed in a UK context but now need to be modified and applied in CABI member countries and least developed countries (LDCs). CABI has led fundamental research on how species within an ecosystem respond, in an ecosystem context, to manipulated climate simulating climate change projected for 2050.

Need for fundamental research

Fundamental research also needs to be conducted to look at the interplay of these factors and, for example, to understand the changes within ecosystems to the changes in abiotic factors *per se* and the effects of the changes on IAS pressure. Methods include the use of climate analogues (e.g. elevational gradients in the tropics) to determine IAS ecology in the native range and in invaded ranges to predict future distributions and impacts on ecosystems, integrated modelling studies linking general circulation models (GCMs), climate change scenarios, land cover and land use, species dispersal (indigenous and IAS) and ecosystem impacts, and manipulative field experiments that directly test hypotheses of invasion impacts and climate change. CABI has been involved with all of these areas to address some key questions and themes:

- Where are the known IAS within the LDCs going to spread given several climate change scenarios, what ecosystems will be challenged and what are the implications for ecosystem services and sustainable agricultural production?
- What are the implications of the above scenarios for food security within poor tropical countries?
- Are ecosystems that are already susceptible to IAS also susceptible to climate variability (extreme events in particular) and vice versa? If so, the combined impact of IAS and climate change will be synergistic. Can sustainable management designed for resilience against IAS also be applied to climate change (and vice versa)?
- Which species (currently non-invasive) will develop invasive traits under climate change? Can our knowledge of present IAS traits be used to screen for invasive potential under climate change in currently non-invasive species?

Prioritization

Local climatic change, particularly soil water deficits and rainfall reduction, coupled with the trend towards greater use of marginal land for crop production, will render crops more prone to IAS. Climate change and IAS will therefore interact synergistically, greatly threatening food security in the poorer tropical countries.

With limited resources, understanding the interactive effects of climate change and IAS that have negative impacts on food security and provision of basic needs, such as water and energy, must take priority over biodiversity threats in poorer, tropical countries. In richer temperate countries, resources could be equally divided between these two aims.

Integrated holistic approaches to management and control

Natural and production ecosystems are susceptible to multiple stresses. To develop effective management strategies for IAS influenced by climate change, it is necessary to adopt a holistic interdisciplinary approach, comparing various control methods, be they chemical, cultural, biological or a combination of these three, simultaneously considering the role of crop nutrition and soil management and looking at the use of pest-tolerant crop varieties.

CABI is promoting the development and role of quarantine strategies and facilities. At the regional scale, IAS that can compound the impacts of climate change need to be controlled, for example, a management strategy for fire-prone IAS (e.g. 'flammable' grasses) should be developed and implemented as a priority.

Practitioners need to be engaged for policy to be effective. Capacity to identify IAS is diminishing, largely due to a decline in taxonomic skills and funding. Capacity building, education, research and implementation are needed urgently to mitigate the threats as a '"stop gap' response. Prevention is not possible, but moderate mitigation to 'buy time' is possible. Adaptation strategies and programmes (see below) are the sustainable, longer term, pathways for tackling the climate change and IAS threat. Adaptation strategies need developing and implementing urgently. Mitigation will 'buy time', enabling appropriate sustainable adaptation to be accepted and developed

Adaptation

Adaptive strategies need to involve international co-operation and include research and development on monitoring, prediction, outbreak triggers, risk assessment and management strategies. Such approaches need to be developed at the regional scale

CABI's farmer field schools encourage uptake of indigenous systems developed in other countries such as the Burkinabé Zai system, which improves soil water availability to crops. Other methods involve making weather forecasts available to farmers to enable timely planting, or promoting the use of shorter season or drought resistant crop varieties to cope with rainfall unpredictability.

Studies are needed that develop adaptive strategies appropriate for each sector and each ecoregion. These need to include a greater understanding of the physical and socio-economic consequences of the different adaptive strategies. Adaptation needs to be understood and developed so it is central to policy development in poor tropical countries, it needs to be linked with the Millennium Development Goals and it needs immediate effective implementation. CABI believes that prevention is not possible. Moderate mitigation to 'buy time' is possible, but the threat of transboundary pests enhanced by climate change, for example, is too great for a preventative strategy to be implemented. Traditional transboundary pest management approaches need modification. Integrated pest management (IPM) must be adapted to deal with a changing climate and new pests and diseases.

Adaptation strategies for LDCs need to be developed rapidly to deal with the combined threat of climate change and IAS. This can be delivered by working multilaterally with governments, NGOs, international bodies and research and knowledge transfer institutions to deliver a research, capacity building and knowledge transfer programme

Monitoring and early warning systems

Monitoring and early warning systems are urgently needed to identify, target and implement appropriate management, Monitoring and early warning systems are needed urgently and are being developed. Such systems need to incorporate the impact of climate change on the spread and impact of IAS; for example, work led by CABI on armyworm threats in Tanzania and the role of CABI's Global Plant Clinic in informing farmers of emerging diseases and their management, such as bacterial wilt of bananas in Uganda. CABI can also assist farmers in identifying plant pests and diseases and recommend management strategies.

1. Summary of climate change impacts

The world's climate has changed frequently during human history. Yet the term 'climate change' usually refers to those changes that have been observed since the early 1900s and includes anthropogenic and natural drivers of climate (Box 1). In its third assessment report from 2001, the Intergovernmental Panel on Climate Change (IPCC) concluded that:

"The balance of evidence, from changes in global mean surface air temperature and from changes in geographical, seasonal and vertical patterns of atmospheric temperature, suggests a discernible human influence on global climate. There are uncertainties in key factors, including the magnitude and patterns of long-term natural variability".

The latest IPCC predictions (IPCC 2007) (Box 1) all suggest anthropogenic climate change continuing at an alarming rate; these projections indicate that the warming would vary by region, and be accompanied by changes in precipitation. In addition, there would be changes in the variability of climate, and changes in the frequency and intensity of some extreme climate phenomena.

Box 1: Observed and projected climate changes

Observed

- Global average surface temperature increased over the 20th Century by 0.74 ± 0.18°C
- Eleven of the last 12 years (1995–2006) rank among the 12 warmest years since instrumental records began (1850)
- In the past 50 years, cold days, cold nights and frosts have become less frequent while hot days, hot nights and heat waves have become more frequent
- Snow and ice extent, including mountain glaciers and snow cover, have decreased, consistent with the warming pattern
- The area affected by drought has increased since the 1970s
- Precipitation has increased in eastern North and South America, northern Europe and northern and central Asia but has declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia

Predicted

- For the next two decades there is likely to be warming of 0.2°C per decade
- The projected rate of warming is greater than any observed during the 20th Century
- Global average surface warming will increase by 1.1–6.4°C by 2100 relative to 1980–1999
- Global average water vapour concentration and precipitation will increase during the 21st Century
- Global mean sea level will rise by 18–59 cm between 1990 and 2100
- [illegible]

Already there is evidence indicating climate change impacts on physical and biological systems across the globe. Examples include glacial retreat/shrinkage, permafrost thawing, lengthening of growing seasons, particularly at mid to high latitudes, poleward and altitudinal shifts in organisms' distributions, and phenological shifts (e.g. earlier budburst). Generally, these changes in biological and physical systems were in line with the expected change for directional climate change (Box 2). The probability that the observed changes in the expected direction (with no reference to magnitude) could occur by chance alone is negligible and there is high confidence that recent changes in temperature are having discernible impacts on physical and biological systems (Box 3).

Climate change threatens economic development in many countries, particularly in tropical countries, where climatic variability is already a significant challenge to poverty alleviation. It is essential that key indicators of the onset of climate change impacts are developed and monitored, with appropriate thresholds set to establish not only when action should take place but what type of strategy should be adopted. Considering the Millennium Development Goals as a framework on which to base indicators, poor tropical countries should be helped in developing appropriate indicators, such as measures of poverty reduction, economic development, sustainability, ecosystem impact, status of threatened species, and reform of trade and investment policies.

Box 2: Climate change impacts based on projections to the mid–late 21st Century. These do not take into account any changes or developments in adaptive capacity. *(Source: IPCC 2007, Working Group II)*

Phenomenon and direction of trend	Likelihood of future trends[1]	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems	Water resources	Human health	Industry, environment and society
Over most land areas; warmer and fewer cold days and nights; warmer and more frequent hot days and nights	Virtually certain	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snow melt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand: water quality problems e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, very young, chronically sick and socially-isolated	Reduction of quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most land areas	Very likely	Damage to crops; soil erosion; inability to cultivate land due to water logging of soils	Adverse effects on surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressure on rural and urban infrastructures; loss of property
Area affected by drought increases	Likely	Land degradation; lower yields; crop damage and failure; increased livestock death; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortages for settlements, industry and societies; reduced hydropower generation potential; potential for population migration
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (up-rooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	Salinization of irrigation water, estuaries and freshwater systems	Decreased freshwater availability due to salt water intrusion	Increased risk of deaths and injuries by drowning in floods; migration related health effects	Costs of coastal protection vs costs of land-use relocation; potential for movement of populations and infrastructure; also see 'tropical cyclones', above

[1] based on projections for 21st Century using SRES (Special Report on Emissions Scenarios).

Box 3: Key impacts as a function of increasing global average temperature change

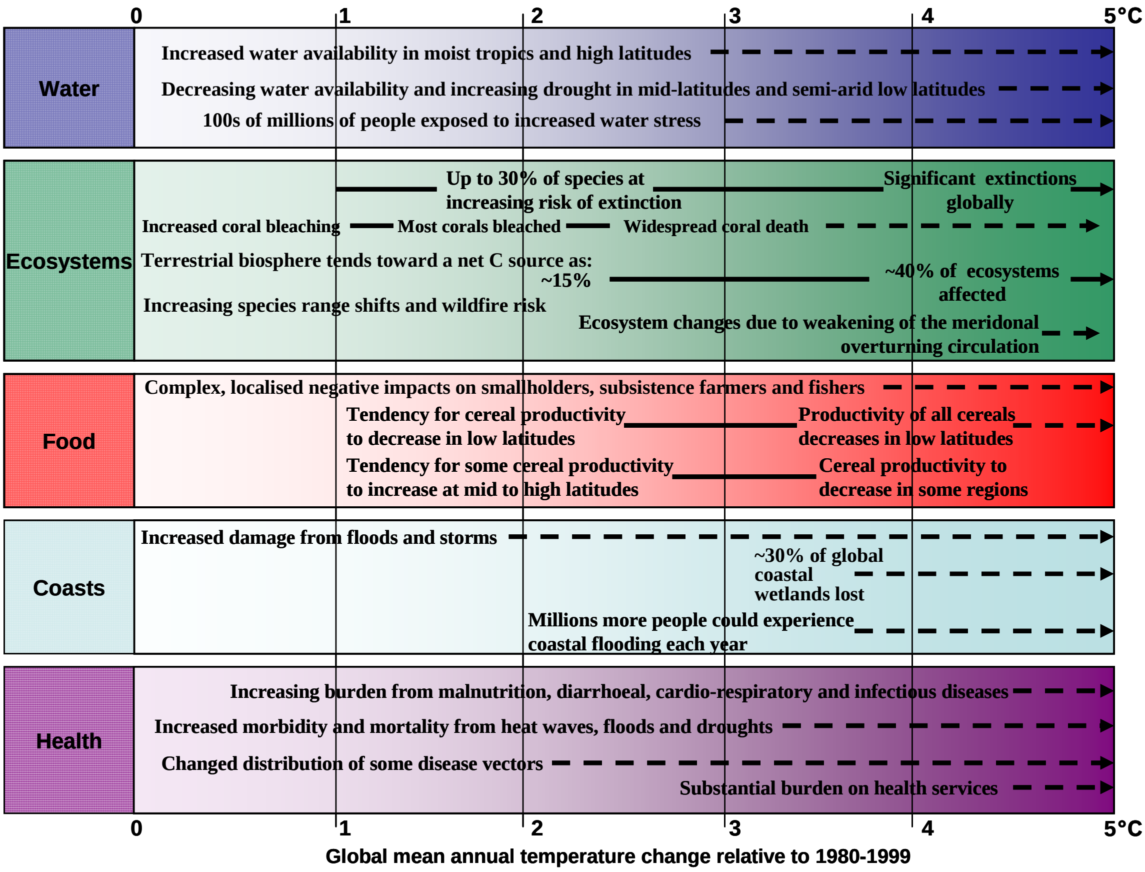


Illustration of global impacts projected by climate changes associated with different amounts of global average temperature increase in the 21st Century. The black lines link impacts; the dotted lines indicate impacts continuing with increasing temperature. Entries are placed so that the left hand side of the text indicates the approximate start of a given impact. Adaptation to climate change is not included in these estimations. All entries are from published studies recorded in the chapters of the IPCC Working Group II Assessment. *(Source: IPCC, 2007)*

2. Invasive alien species (IAS) and new–encounter pests

Domestication of many of the world's important food crops occurred in up to eight centres of origin, referred to as Vavilov centres. These were between the Tigris and Euphrates rivers in modern-day Iraq, in Mexico, Thailand/Myanmar, South America (Peru to Bolivia), the Mediterranean, Ethiopia, northern India and China. Crop domestication selected for traits including: high germination rates; reduced/low toxicity and reduced plant defence mechanisms; changes in biomass allocation to fruits, stem or root, depending on human preference; and phenological changes, usually shortening the time to fruiting. Furthermore, these domesticated plants were planted at high densities. These attributes make crops more vulnerable than their wild relatives to pests and disease outbreaks in their native environment. Within the native range, there are significant risks from pests and diseases in scaling up indigenous plants to plantation scale – one of the best known examples being Henry Ford's attempts to grow rubber (*Hevea brasiliensis*) on a large scale in Brazil, which he abandoned with huge financial losses after South American leaf blight (*Dothiudella ulei*) repeatedly wiped out plantings in the 1930s. Humans have deliberately moved crops, for food, fibre or energy, around the world throughout their history. Crops are cultivated outside their centre of origin, often more successfully because of the reduced risk of pests and diseases.

The presence of alien plant species is even used as an indicator of archaeological sites in Europe, where subtle differences in community composition can persist more than a thousand years after site abandonment. However, recent globalization, through increasing trade, transport, travel and tourism, increases the rate of accidental introductions of species to new areas outside their normal distribution and within which they are alien. In other cases, humans have deliberately introduced species to other parts of the world as they expected that this would be beneficial. If the new habitat is similar enough to its native range, the species may survive, reproduce, out-compete native organisms and spread through its new environment, increasing in population density. If this species, introduced intentionally or by accident, rather than being of benefit to humans in this environment has adverse effects, be they economic, environmental or ecological, it is referred to as an invasive alien species (IAS). Some definitions, explanations and examples are given in Boxes 4 and 5, respectively.

IAS are found in all five taxonomic kingdoms and among viruses; of the two million species so far described, up to 10% (200,000 species) have the potential to become significant invaders. Some examples of IAS include the deliberately introduced foxes, cats and rabbits to Australia, which have contributed to the extinction of 22 native mammal species. Black rats have eliminated five bird species on Lord Howe Island, 600 km east of the Australian mainland. Chytridiomycosis, an infectious fungal disease of amphibians, caused by the fungus *Batrachochytrium dendrobatidis*, has been linked to dramatic population declines or even extinctions of amphibian species in western North America, Central America, South America and eastern Australia. The disease has affected 30% of amphibian species globally, and effects include the extinction of seven frog species in recent decades. As well as biodiversity costs, IAS have economic costs. It is estimated that agricultural and environmental weeds cost Australia alone A$4 billion each year and that red fire ants could cost Australia over A$8 billion over the next 30 years if the A$175 million effort to eradicate them is unsuccessful.

Box 4: Definitions of aliens, invasives and new encounter pests

- Alien species (synonyms: non-native, non-indigenous, foreign, exotic): a species, subspecies or lower taxon introduced outside its normal past or present distribution, including any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce.
- Invasive alien species: non-indigenous species that adversely affect, economically, environmentally or ecologically, habitats where they have been introduced, either accidentally or deliberately, outside their normal past or present distribution
- For an alien species to become invasive, it must arrive, survive and thrive.
- New encounter pests and diseases are native pests or diseases that come into contact with a new, introduced exotic host.

IAS can display explosive expansion in areas invaded (Box 5), through achieving exponential population growth and rapid dispersal. Invaders often alter ecosystems by altering hydrology, fire regimes, nutrient cycling, and other ecosystem processes. Potentially, all ecosystems can be invaded. Islands are particularly vulnerable to IAS as they have unique endemic flora and fauna so the risk of species extinction is greater. Urban–industrial areas, habitats suffering from periodic disturbance, harbours, lagoons, estuaries and the fringes of water bodies, where the effects of natural and anthropogenic disturbances are often linked, are also particularly vulnerable to invasions. Evidence suggests that systems with low diversity (e.g. arid ecosystems) are more susceptible to invasion than species-rich systems, although this has proven to be contentious. Anthropogenic (economic) activity, such as agriculture, leads to a disturbance, which increases the susceptibility of most ecosystems to invasion.

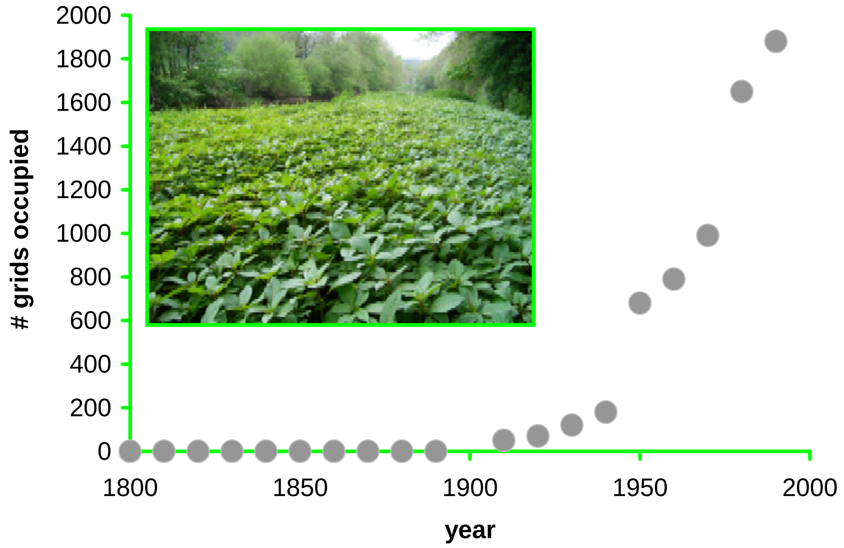
However, clearly, the definition of IAS is and needs to be subjective. It is dependent on human perception. What is considered to have adverse effects by one stakeholder may be considered beneficial by another. So a species can only be judged as an invasive alien within a specific spatial, temporal, economic, environmental and cultural context. Furthermore, different stakeholders within that environment may view the species differently. A common example is from Africa where pastoralists and farmers occupy the same ecoregion. Fast-growing nitrogen fixing legumes may be considered by farmers as a means to increase the nitrogen status of their soils and smother undesirable grassy weeds in their fields. However, pastoralists may regard them as noxious weeds that invade grazing land.

Box 5: Examples of exponential expansion

Privet, *Ligustrum robustum* subsp. *walkeri*, has invaded all the indigenous forests in Mauritius in under 50 years, and was introduced in La Réunion Island in the 1960s. Now, privet represents a serious potential threat to the durability of the native forests of La Réunion. Privet is a rare example of an alien woody species that invades largely undisturbed ecosystems. This species shows all the characteristics of the 'ideal' invader and forms dense thickets that hinder the regeneration of native plants. Privet is a popular ornamental that is spread throughout the world by the horticulture industry. Once established, the fruit is dispersed by birds and other wildlife and is thought to be important in establishing new populations.

Mimosa invisa has shown true exponential expansion by spreading over a large proportion of the Western Ghats in India in the last five years.

Impatiens glandulifera (Himalayan balsam) has shown exponential expansion within Great Britain since 1850, with the graphic below showing the numbers of 10-km^2 grids occupied.



Occurrence of Impatiens glandulifera in 10-km^2 grids within the UK from 1800. (Data from UK National Biodiversity Network)

Native species can also be serious pests. *Striga* is a genus of 28 species of plants in the family Orobanchaceae that are obligate root parasites. They are native to parts of Africa and Asia, predominantly in the arid and semi-arid ecoregions and two species are invasive in the USA. *Striga* spp. stunts plant growth by attacking the roots, competing for water and nutrients. In West and Central Africa, *Striga* spp. devastate many introduced Poaceae cereal crops including maize, sorghum and upland rice and is thus a 'new-encounter pest' as it is absent from the crops' native ranges. Furthermore, *Striga* spp. can cause huge yield losses on native crops, such as finger millet and cowpea. Overall, in the Sahelian and savannah zones of West and Central Africa it causes annual losses of more than US$7 billion and affects 100 million people. Yield losses to *Striga* spp. are negatively correlated with soil nitrogen status. Cultivation of nitrogen-demanding cereals on marginal lands, shortening of fallow cycles and the trend towards continuous cultivation and little use of external soil amendments has increased the area of land infested with *Striga* spp. *Striga gesnerioides* parasitizes cowpea (*Vigna unguiculata*), a member of the legume family (Fabaceae or Leguminosae). This species was also accidentally introduced into Florida in the USA where it was found parasitizing *Indigofera hirsuta*. The cost of control in West Africa is up to US$13,000 million annually.

Desert locust (*Schistocerca gregaria*), is probably the most important locust globally. It has a wide distribution, from North Africa to the Middle East and the Indian subcontinent, and causes huge crop losses. Furthermore, outbreaks are triggered by changes in precipitation. The 1986–89 plague cost more than US$300 million to control. In 2004, more than ten countries in western and northern Africa were invaded by swarms of locusts (Fig. 1), destroying vegetation and crops, and populations also reached the Canary Islands and the Caribbean. Each swarm is composed of millions of individuals, sometimes covering several hectares. More than 2.5 million rural households were at risk of food shortages as over four million hectares of farmland were invaded. In Mauritania, over 1.5 million hectares were invaded and an estimated 80% of crops were destroyed. Not surprisingly, the invasion affected national economies. For example, Morocco spent about US$30 million in defence of an agricultural sector worth US$7000 million in 2002, of which US$1000 million were in export earnings. Ironically, rain, which would normally boost agricultural production, provided perfect climatic conditions for locust reproduction. With increased frequency and severity of precipitation events projected for the future, locust outbreaks are likely to become more common as winter rains in the Sahel may increase breeding.

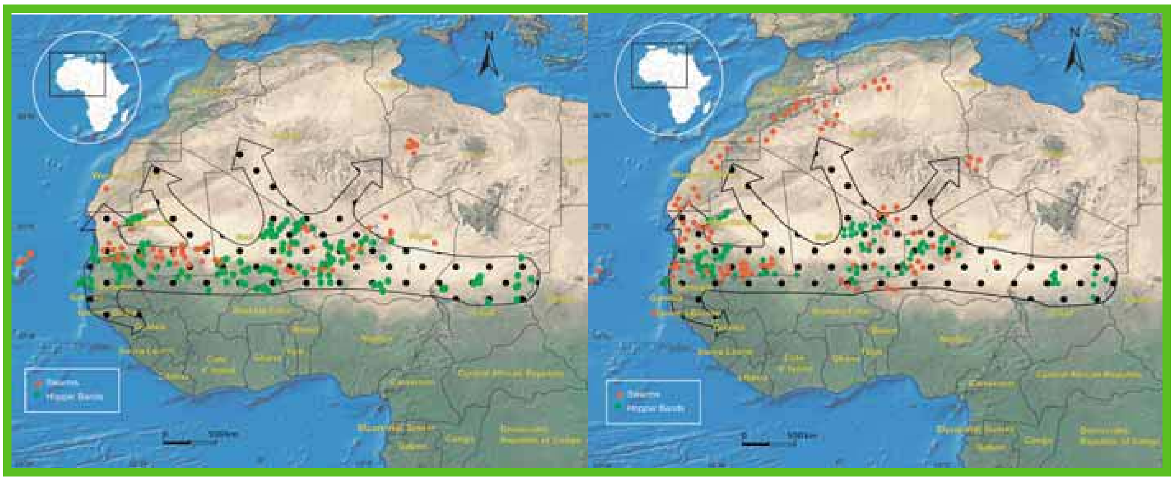


Fig. 1: Locust invasions in the Sahel in 2004; September (left) and October (right). More than ten countries were affected, the worst since the 1980s. *(Source: FAO Desert Locust Information Service, 2004)*

Having discussed climate change and IAS as separate entities, we now consider in the next two sections their interaction and how it affects biodiversity before examining the impacts of IAS and climate change on agriculture.

3. How climate change and IAS affect biodiversity

IAS and climate change are identified with land use change, and changes in the nitrogen and carbon cycles, as the top four drivers of global biodiversity loss. Their relative importance depends on the ecoregion being considered. While many articles have identified the drivers of biodiversity loss, they have not considered or modelled the interactions between these four drivers (Fig. 2).

Climate change, through rising average temperatures, increased variability of rainfall (frequency; intensity), increased atmospheric greenhouse gas concentrations, increased frequency and severity of storms and rising sea level, will affect the invading species, its invasive potential and the invasibility of the host ecosystem, be it native or derived. The greatest impacts of climate change on invasive species may arise from changes in the frequency and intensity of extreme climatic events that disturb ecosystems, making them vulnerable to invasions, thus providing exceptional opportunities for dispersal and growth of invasive species. In many Mediterranean ecosystems, declining rainfall, more severe droughts, and more hot days increase wild fire risk. Certain IAS will benefit from these changes and reinforce them. In the USA, for example, since 1986 longer warmer summers resulted in a four-fold increase in major wildfires and a six-fold increase in areas burned, compared with the previous sixteen years. Changing fire regimes have the strong potential to alter radically ecosystems, leading to switches in vegetation dominance and structure with substantial implications for management strategies and biodiversity.

By definition, IAS must arrive, survive and thrive in their new environment. Climate change will act on all three components of this invasive pathway. Climate and landscape features (including land use and land cover) set the boundaries for the geographical distribution of species and determine the seasonal conditions for growth and survival. Climate change will alter the boundary limits (changing the climate envelope – the climatic space within which a species can survive) and thus will have consequences for the growth, survival and distribution of species. All biological systems have thermal constraints; hence, rising temperatures will have impacts on ecosystems and the species they contain. The extent of species responses to warming is still unknown; idiosyncratic responses are occurring: not all species will respond positively to warmer conditions.

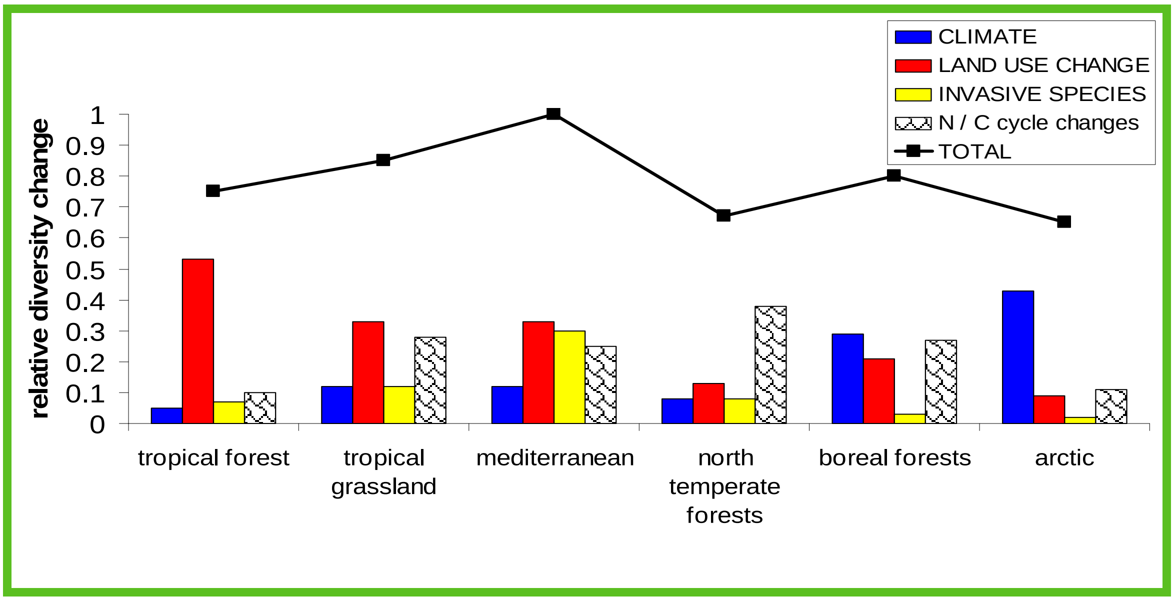


Fig. 2: Predicted diversity changes by ecoregion by 2100 and the four dominant drivers of change. Assumes no interaction between drivers so total (black) = sum of constituents. *(Adapted after Chapin et al. 2000.)*

However, changes in climate may be more conducive to the survival and spread of IAS. Invasions generally have two distinct phases: a quiescent or lag phase, during which ranges shift only slightly, followed by an active or growth phase, during which explosive expansion is triggered. The lag time between the phases can range from decades to a century (as shown in Box 5). Climate change may well provide additional triggers, by creating disturbances within the ecosystem that quiescent IAS can exploit. IAS may rapidly exploit the niches generated by climatic disturbance and the ecological consequences of climatic disturbance to ecosystems. It is therefore imperative that prevention measures consider future interactions and synergies where these may increasingly exacerbate the IAS problem.

Many invasive alien pathogens will also benefit from climate change as rising average temperatures (including warmer soil temperatures) and shorter and milder winters will promote pathogen growth and reproduction, and potentially higher transmission rates. Indirect impacts of climate change will be equally important. For example, warmer shorter winters in cooler temperate regions will stress host species, thereby increasing their susceptibility and benefiting pathogens. Some of these changes will be desirable, for example if the pathogen is a biocontrol agent attacking a weed. However, the net effect could be negative when drought (changed precipitation patterns) and rising atmospheric carbon dioxide (CO_2) are considered. Changes will be complex, with weeds and pest animals interacting in many different ways.

The distributions of some IAS will change, with poleward migrations and movement to zones of higher altitude as regions experience elevated temperatures. Where high altitudinal areas have formed barriers to IAS, increased temperatures in this zone will remove the barrier, hence IAS will be able to arrive in adjacent areas. Indeed, IAS with short life cycles may evolve rapidly in new locations and escape previous climatic limits. An example of this may be cane toads, which are spreading into both hotter and colder regions of Australia than they occupy in their native range in South America. Land use change is also a significant factor. For example, in the tropical uplands, as land availability declines and upland areas warm, people will cultivate land further up mountainsides, creating contiguous crop landscapes, which were separated previously by climax montane vegetation. In the tropical lowlands, there may be a lack of species that can adapt to the higher temperatures to replace those more temperature sensitive species whose ranges are forced to higher altitudes. Possible consequences are significant attrition of lowland tropical biodiversity and/or successful invasion by species able to adapt to hotter conditions.

Replacement of natives by invasive species will be one of the major impacts of climate change, but there will be others such as changing relationships between predators, pathogens and prey (with either native or introduced species), changing fire regimes, and other climate harm to species already threatened by invasive species. As invasive species and climate change are considered two of the main threats to biodiversity, the two operating together could be expected to produce extreme outcomes. Synergistic combinations are likely to lead to significantly increased vulnerability with climate change. Elevated CO_2, increased temperature, changed precipitation patterns and an increased frequency of extreme events such as fire and flooding will all have significant impacts on ecosystems and IAS. Water is likely to be a key variable which will have the greatest impact on facilitating invasion, particularly through reducing the resistance of agricultural and native ecosystems.

Generally, IAS, such as weeds, pests and diseases, are extremely adaptable to climatic variability as shown by their current large latitudinal ranges. IAS also tend to have rapid dispersal characteristics, which allow them to shift ranges quickly in response to changing climatic conditions. As a result, these species could become more dominant in many areas under changing climate conditions.

Climate change will disrupt ecosystems with some native species benefiting (directly or indirectly) and some native species declining either directly due to climate change (increased frequency of climate mediated local extinction) or indirectly through altered competitive balances with surrounding species. Some native species may develop invasive tendencies and dominate their habitats. Plants will disperse across the landscape at different rates; it is likely that those arriving 'first' may dominate ecosystems and inhibit later arrivals, thus behaving like IAS.

3.1 Effects of increasing temperatures

At the poles, glacier and polar ice melt, due to rising temperature, will result in opportunities for IAS to colonize new ice free sites. Flowering plants and grasses have been recorded colonizing Antarctica since the end of the 1990s. A European weed, winter grass (*Poa annua*), has colonized deglaciated areas of Heard Island, Australia, an area previously free of IAS.

Prosopis spp. (mesquite) are leguminous deciduous shrubs native to the southern USA and Central America and grown in Africa and South Asia. The tree's flowers provide a nectar source for bees to produce mesquite honey. It grows quickly, providing shade and habitats for wildlife in areas where other tree species cannot grow. Flour can be made from grinding the dried pods. The wood can be used for tools, furniture and firewood. However, mesquite invades grazing land, out-competing grasses and native flora, is difficult to eradicate, and has needle-like thorns that can puncture footwear and tyres. *Prosopis juliflora* was introduced from Central America as a drought tolerant species suitable for afforestation in arid and semi-arid zones of the Indian sub-continent in the Sind Province, Pakistan, in 1877. To date, it has invaded more than five million hectares (1.8% of the area of the country). This species is spreading at a rate of 25 km^2 per year. By

2020, it is estimated that over 56% of the area in Banni, which currently has a rich biodiversity and grassland ecosystem, will be under mesquite. This species can assimilate and store nutrients in its roots. Hence, root biomass can increase dramatically, enabling trees to regenerate rapidly after cutting and survive environmental stress such as drought and inundation. Root enlargement in mesquite is moderated by temperature with the annual increase in root biomass greater in warmer areas. The increase in root biomass largely determines the weed's ability to tolerate climatic extremes such as high temperature, water scarcity and monsoon winters with water inundation and flooding. This adaptation enables this IAS to predominate over native species that are more susceptible to environmental extremes.

Desert horsepurslane (*Trianthema portulacastrum*) is native to tropical Africa yet considered invasive in tropical and subtropical Australia, Africa and Southeast Asia. It occurs in wastelands, roadsides, lawns, gardens and upland cultivated crops, and in paddy fields if the water supply is low. Occasionally, it is found in perennial crops and pastures, especially in sub-humid and semi-arid regions. Soil temperatures of approximately 35°C lead to synchronized mass germination of seeds of desert horsepurslane. For example, in India, it is the dominant weed in sugarcane and sunflower systems.

A 2°C increase in ambient temperature has been predicted to result in prickly acacia (*Acacia nilotica*) invading inland Australia. This will be exacerbated by farmers switching livestock production from sheep to cattle as a response to the higher temperatures. Cattle are better dispersers of acacia seeds, hence further favouring this IAS.

3.2. Changing precipitation patterns

Precipitation patterns are changing or are projected to change in many parts of the world. Such changes disturb ecosystems and the dynamics of their species, which may not be able to adapt quickly. Wetlands in Wisconsin, USA, with a history of hydrological disturbance have more widespread invasions. Changes in run-off alter wetland water regimes and the floristic composition will be prone to invasion by species such as water hyacinth (*Eichhornia crassipes*) under inundation (see above) and water spinach (*Ipomoea aquatica*) under semi-dry situations.

Climate mediated changes in the precipitation patterns affecting the Cauvery River in India have favoured the establishment of the IAS Asian sprangletop (*Leptochloa chinensis*) and water shamrock (*Marsilea quadrifolia*) in rice paddy fields. These IAS can tolerate fluctuating flooding and residual soil moisture conditions, unlike the native species such as *Echinochloa* sp. (millet). Asian sprangletop has a long life span that enables it to affect rotations such that it competes with mung beans grown after the transplanted rice. Water shamrock is prevalent as it can tolerate the herbicides used to control/eradicate grasses.

A further example is provided by the interaction between native and invasive springtails (Collembola) subjected to climate change on Marion Island, in the south Indian Ocean. In this temperate ecosystem, indigenous and invasive springtails have been shown to differ in the form of their phenotypic plasticity to the extent that warming, as predicted by climate change, promoted survival of dry conditions in the invasive species (through desiccation tolerance) and reduced survival in the native species. The balance between indigenous and invasive under climate change is being affected such that the invasive species is benefiting and replacing the native in the ecosystem.

IAS can also generate sufficient biomass to fuel accelerated fire regimes. An example is buffel grass (*Cenchrus ciliaris*), which causes fire-mediated invasions across inland Australia. This grass increases the fuel load causing hotter, larger fires, thus increasing vegetation homogeneity and killing native plants (e.g. river red gum, *Eucalyptus camaldulensis*).

It is clear that the interaction between precipitation and IAS has the potential to increase extinction risk significantly for many species. The synergy between warmer, drier conditions and productive species can transform host ecosystems with major negative impacts on biodiversity and hence ecosystem structure and function. For example, invasive C4 grasses cause accelerated fire, reduce nutrient availability and lead to forest loss in Asia, Africa and the Americas. The invasion of *Hyparrhenia* sp. (thatching grass) in South America is due to seed availability in post-fire sites, fire-stimulated seed germination and rapid seedling growth.

In West Africa, more than half of the grassland area is burned annually. Yet, the specific dynamics surrounding anthropogenic burning and the savannah landscape remain largely understudied and poorly understood, especially the links between human burning practices, fire regimes and vegetation. Often fire events and the invasion of grasses lead to positive feedback with an initial fire eliminating woody shrubs and the invasion of grasses further increasing the fire risk in the following season due to the large amounts of necromass. Reduced isolated rainfall events and the prolongation of the dry season, coupled with land use changes encouraging grass invasion interact increasing fire risk and further invasions.

3.3. More frequent and extreme weather events

When Hurricane Andrew hit Florida in 1992, it facilitated a population explosion in large feral iguanas. Vine diversity also increased substantially following large scale storm damage there; indeed, IAS vines comprised 34% of the recorded increase in overall vine diversity. IAS vines are able to compete with native vines and negatively affect the regeneration of other natives from a diverse array of sources including pre-established juveniles and resprouts from damaged adults. If tropical storms become more frequent and intense, many exotic vines could benefit. Through slowing regeneration, forest ecosystem vulnerability to future extremes is increased as ecosystem resistance and resilience is reduced.

The enormous disturbance from tsunamis causes severe damage to ecosystems such as mangroves, coral reefs, forests, coastal wetlands, vegetation, sand dunes and rock formations, animal and plant biodiversity and groundwater. One consequence, in addition to the destruction of agricultural systems, has been a promotion of IAS weeds, including the facilitation of prickly pear cactus (*Opuntia* sp.) invasion in nesting habitats of five species of globally important threatened marine turtles. Such events have direct economic impacts.

3.4 Indigenous species becoming 'invasive'

An example of indigenous species becoming 'invasive' is the case of sweet pittosporum (*Pittosporum undulatum*), a local rainforest tree in Australia that is 'invading' eucalypt forest in response to nutrient enrichment and fire suppression. Examples of native species creating problems through changed dominance structures within ecosystems are growing. In North America, spruce beetles (*Dendroctonus rufipennis*) have killed millions of trees and outbreaks have has been associated with warmer temperatures allowing beetles to complete their lifecycle in one year instead of two. The result has been a shift from spruce to grasslands in parts of Alaska. The mountain pine beetle (*D. ponderosae*) has become more abundant with warmer weather and spreads a rust fungus that infects American conifers. This beetle has been predicted to spread north and put at risk high elevation pine stands of great ecological importance. In Europe, pine processionary caterpillars (*Thaumetopoea pityocampa*) are attacking relict stands of Scots pine (*Pinus sylvestris*) in locations that were previously too cold for the caterpillars.

3.5. Reduced precipitation and IAS impacts in a global biodiversity hotspot: South Africa

The Cape Floristic Region (CFR), in the Mediterranean ecozone of southern Africa is one of the nine global biodiversity hotspots in Africa. It contains more than 6000 endemic plant species. The vegetation type is predominantly 'fynbos', dominated by evergreen sclerophyllous shrubs, and maintained by periodic fires. It holds five of South Africa's 12 endemic plant families and 160 endemic genera. The geometric tortoise (*Psammobates geometricus*), the Cape sugar-bird (*Promerops cafer*), and some antelope species are characteristic.

Climate change in this ecoregion is predicted to bring considerable warming and drying to much of this already semi-arid region, with greater frequency and intensity of extreme weather events such as heatwaves, flooding and drought. Southern Africa will see an increase in temperature by approximately 1°C on the coast to more than 4°C in the hinterland such as the Northern Cape in late spring and summer by 2050.

The CFR is expected to suffer extreme climate change impacts with climate projections suggesting that fewer rain events will occur during the dry season, increasing drought stress on plants. Within the CFR there are scattered pockets of a vegetation type called 'the Succulent Karoo', which also continues up the coast to Namibia. The quiver tree (*Aloe dichotoma*) is only found in Namibia and South Africa in the Succulent Karoo with a 2000 km range between 22° and 33° South. In the northern part of the range, quiver trees are dying due to drought and heat stress, while in the southern part of the range they are growing in abundance, with saplings taking root. Yet, this ecoregion is projected to warm by 2–3°C, further endangering the species as a 2°C increase rise in temperature has been shown to shut down photosynthesis.

Drought, increased intensity and frequency of fire and increased temperatures are expected to push many of these rare species towards extinction, such as the riverine rabbit (*Bunolagus monticullaris*) in the Karoo. However, South Africa is one of the worst affected countries in the world when it comes to IAS with many (e.g. *Acacia mearnsii* (black wattle), *Acacaia saligna* (Port Jackson), *Hakea* spp. (hakea), *Lantana camara* (lantana) and *Jacaranda mimosifolia* (jacaranda)) posing a significant threat to native biodiversity and the already scarce water resources.

The CFR is susceptible to invasion by tree and shrub species, notably by woody Australian species, and the associated fundamental changes in vegetation structure, function (e.g. nitrogen cycling) and even fire regimes. Climate change modelling suggests that one of these invasive species, silky needlebush (*Hakea sericea*), is resilient to warming with a 2°C warming projected for 2050 indicating a very small reduction in potential geographic range in the CFR. By comparison, indigenous CFR species in the same plant family (Proteaceae) seem susceptible to range loss with comparable climate change, showing significant range reductions in a substantial proportion of endemic species modelled. This small sample of modelling studies suggests that higher fecundities and increased propagule pressure of IAS relative to indigenous species in the CFR under climate change will lead to an increasing impact in this region. The effects of elevated CO_2 on invasive woody species are poorly known, but they do display a significant positive response to this change. Taken together, however, these studies suggest a significant potential interaction in the future that will exacerbate the current IAS problem in the CFR.

4. Impacts of climate change and IAS on agriculture

Agricultural weeds, insect pests and crop diseases are all sensitive to temperature and precipitation and some are responsive to atmospheric CO_2 concentrations. Understanding how climate change will affect IAS pest, pathogen and weed species is important to enable accurate impact assessments of climate change on agriculture. Usually, this understanding comes from scenario modelling and expert opinion. Actual research is lacking. However, a consensus emerges and includes the previously mentioned poleward migration of pests, inter-annual survival increasing (due to milder winters) in temperate regions, increased frequency of outbreaks due to longer and warmer summers, geographic ranges changing so IAS will encounter new agricultural systems, and the balance between organisms will change. As climate changes, patterns of production and trade in agricultural commodities will change as well (Masters et al . 2010), with crops adapted to tropical conditions being grown more competitively in higher latitudes and altitudes. The opportunities for tropical IAS to contaminate such crops in new ranges will also increase. It is expected that climate change would decrease pesticide efficacy, which would necessitate changes to disease forecasting models and disease management strategies. This could involve heavier and more frequent applications, with potential threats to non-target organisms and increased water pollution, as well as increased costs associated with pesticide use. Similar trends are predicted for herbicides in the future.

Climate change will have a range of impacts on agricultural systems and production (Fig. 3; Fig. 4). It is likely that the life cycle of crops will progress (advanced phenology) more rapidly; but with rising temperatures and variable rainfall, crops will begin to experience failure, especially if there is a decrease or increased variability in precipitation. Gains and losses are predicted for crop yields, for example, depending on locality, crop type, production system and, importantly, climate change model adopted (Fig. 3; Fig. 4). Relatively recently, crop models have been integrated with general circulation models (GCMs) for particular increased CO_2 climate scenarios (from the IPCC) and are giving more consistent predictions. However, other disturbance factors, such as the impact of IAS on agricultural systems, have not been factored in.

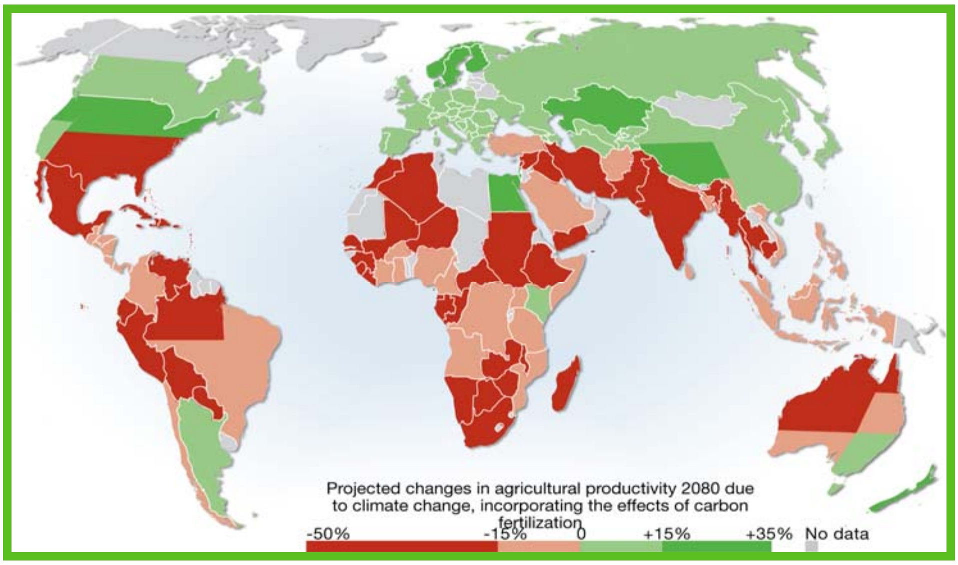


Fig. 3: Projected changes in global agricultural productivity by 2080 due to climate change (and carbon fertilization). Red areas indicate a decrease in productivity and green areas indicate an increase. Tropical areas are generally expected to have biggest decreases in agricultural production. (Graphic by Hugo Ahlenius, UNEP/GRID-Arendal, Projected agriculture in 2080 due to climate change, UNEP/GRID-Arendal Maps and Graphics Library, http://maps.grida.no/go/graphic/projected-agriculture-in-2080-due-to-climate-change)

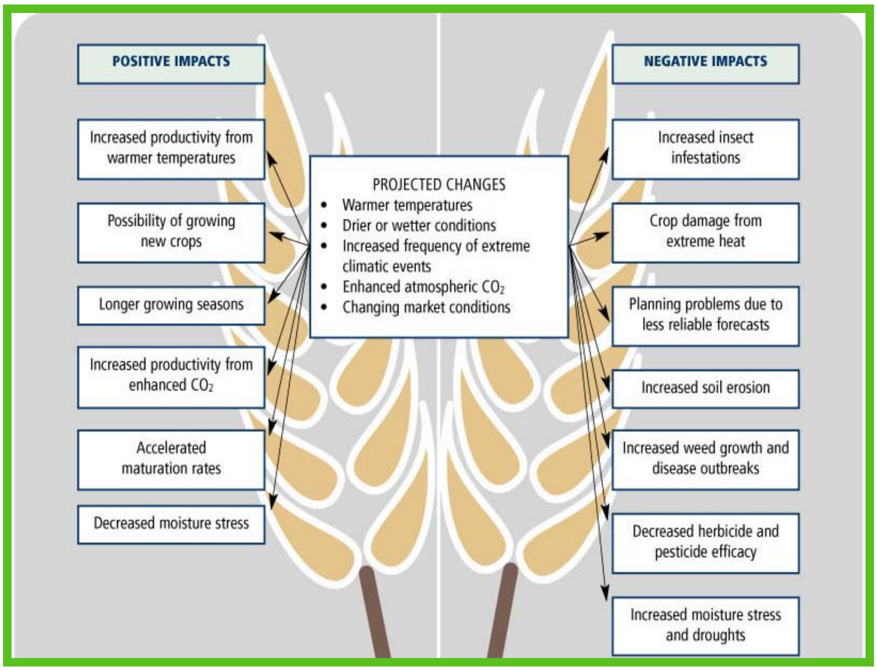


Fig. 4: Potential impacts of climate change on agricultural crops in Canada. Climate promoted invasive species impacts (pests, diseases and weeds) are expected to be increasingly detrimental. (From Climate Change Impacts and Adaptation: A Canadian Perspective: Agriculture www.adaptation.nrcan.gc.ca/perspective/summary_5_e.php. This reproduction is a copy of an official work that is published by the Government of Canada but it has not been produced in affiliation with, or with the endorsement of the Government of Canada).

Increased moisture stress and drought are major concerns for both irrigated and non-irrigated crops. If adequate water is not available, production declines and entire harvests can be lost. While climate change is expected to cause moisture patterns to shift, there is still considerable uncertainty concerning the magnitude and direction of such changes. Furthermore, longer growing seasons and higher temperatures would be expected to increase demand for water, as would changes in the frequency of drought. Water stress, increased temperature and the impact of an increased incidence and abundance of old and new invasive pests, diseases and weeds are almost certainly a major factor in the projected agricultural declines in the tropics (Fig. 4). Invasive insect, disease and weed pests are likely to benefit most from climate change, leading to increased pesticide and herbicide use or greater reductions in yield.

We now consider examples, in terms of climate change impacts, to illustrate further these general points.

4.1. Increasing temperatures

Over 70% of the world's food comes from just nine crops (rice, wheat, maize, potato, barley, cassava, soybean, sugarcane and oats), each of which is cultivated far beyond its natural range. The IPCC (2007) summarized 69 studies on the effects of higher temperatures on three of these: rice, wheat and maize. Mild warming is projected to result in initial increases in crop yields in the temperate regions (Fig. 5). For example, crop models have been integrated with GCMs (multi factor climate projections) and applied to Canada. These demonstrate that corn, sorghum, soybean and wheat yields are expected to increase by 20–124% under climate change, due to the projected temperature increases and increases in CO_2. However, once temperature increases exceed 3°C, yields will decline. Likewise, yields of sunflowers, potatoes, tobacco and sugarbeet will initially increase while peas, onions, tomatoes and cabbage will suffer a decrease in yields. In general, in temperate areas, it is projected that warming will be greatest during the winter months. This reduces the risk of damage to tree fruit and grape rootstocks. However, warmer winters are also expected to create problems for agriculture, especially with respect to pests, because extreme winter cold is often critical for controlling populations.

Also, both droughts and frosts are likely to change in frequency and intensity under climate change, reducing the resistance of trees to insect attack. Through altering the frequency, intensity and duration of flooding, climate change will affect the incidence of episodic recruitment events of invasive species, enabling aggressive species to escape from local, constrained refuges.

4.2. Effects of increasing temperatures on IAS in tropical zones

In the tropics, the situation is different. Any increase in temperature is projected to cause crop yield decline in the tropics, even for maize and rice, whose centres of origin are in or close to the tropics, as they are already near the upper limits for optimum growth (Fig. 5). These models do not take into account any increase in crop losses due to increased IAS damage, and the effects of climatic change upon crop–IAS relationships is largely unknown. Climatically induced stress on plants can reduce their ability to resist invaders. Plants stressed by a changing climate may be more prone to insect or pathogen damage, lowering their competitive capacity.

Warmer temperatures may increase damage to crops from plant pathogens as their growth, reproduction and transmission rates increase. Subsistence farmers in the humid tropics grow *Musa* spp., comprising banana, plantain and highland banana. Such species, reliant on asexual reproduction, are prone to pests and diseases. *Mycosphaerella fijiensis* (black Sigatoka leafstreak fungus) is a major constraint in lowland tropical humid areas. It originates from the Pacific, but is now prevalent throughout the tropics and can cause 40% yield loss. It spreads by wind-dispersed ascospores (sexual) and conidia (asexual) and thus is difficult to control. In upland areas, the less virulent yellow Sigatoka (*M. musicola*) is more prevalent. With increasing temperatures, black Sigatoka may expand its range and spread to highland areas currently free of it and replace the less virulent yellow Sigatoka.

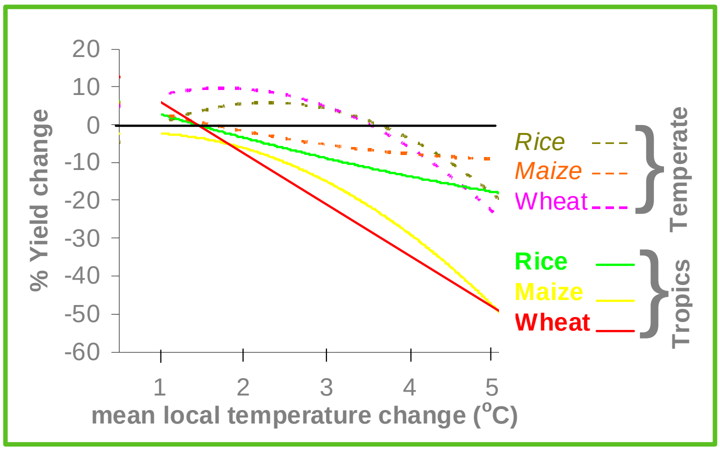


Fig. 5: Comparison of temperature rise on crop yields in temperate and tropical regions. (Adapted from IPCC 2007)

Musa spp. are also host to root nematodes that destroy roots and increase the risk of toppling, particularly after bunch emergence. The nematode *Radopholus similis*, indigenous to Australasia and now widespread through the tropics, is the greatest cause of yield loss in *Musa* worldwide. It is a pioneer root invader, completing its life cycle without a soil phase. Yet, *R. similis* is sensitive to temperature and is currently absent at high altitudes and latitudes. Positive relationships between nematode root damage and increasing temperatures have been established. For example, the highest population density (and so highest reproductive rate) was found at 30°C and there was a strong positive relationship between root damage by nematodes and soil temperature in field trials in Central Africa. Within its current range, increases in temperature up to 30°C will result in increased nematode populations, greater root damage and more crop losses. Increases in temperature at higher altitudes will permit *R. similis* to survive and reproduce in areas currently free of it.

4.3. Effects of increasing atmospheric CO2

Impacts of climate change on pests can be complex. Aphids represent one of the world's major insect pests, causing serious economic damage to a variety of temperate and tropical crops, ranging from grain and brassicas to potato, cotton, vegetable and fruit crops. In the UK, some 30 aphid species are pests of a wide range of arable and horticultural crops, causing potential economic losses in excess of UK£100 million per year as a result of direct feeding damage and the virus diseases which they spread. Aphids are highly fecund insects that not only destroy crops through being herbivores (with rapid, often exponential population increase) but also often transmit crop pathogens. More than half of all known plant viruses are transmitted by aphids and more than 200 aphid species have been reported to transmit viruses. Potato leaf-roll virus (PLRV) and potato virus Y (PVY) cause the most important aphid-borne virus diseases in potato crops, decreasing yields by 50–80% in crops grown from infected seed. The reproductive rate of invasive aphids is greater under elevated CO_2, consistent with climate change predictions. But the aphids are also more vulnerable to natural enemies as elevated CO_2 disrupted and decreased the amount of alarm pheromone produced. Aphids could become less successful under climate change.

4.4. More frequent and extreme weather events

Hurricane Katrina in Mississippi, USA, has enabled invasive weeds to spread, Hurricane Wilma spread citrus canker (*Xanthomonas axonopodis*), a devastating orchard disease, widely in Florida, USA. The 26 December 2004 Indian Ocean earthquake (epicentre off the west coast of the Indonesian island of Sumatra) triggered a series of devastating tsunamis; one of the worst natural disasters affecting Thailand, Sri Lanka, India and Indonesia in particular. In Australia, the northern Queensland banana crop was devastated in 2006 by Cyclone Larry, and Hurricane Dean destroyed the entire banana crop in Martinique and 80% of the crop in Guadeloupe, worth UK£150 million in August 2007. Such disturbances, in tandem with increases in international trade, create a plethora of opportunities for pest introduction and favour rapid colonizers.

5. Climate change, IAS and Africa

Throughout Africa, agriculture is the main sector in the majority of countries, providing on average 60% of all employment and generating over 40% of the foreign exchange economy. Agriculture and food security are therefore critical to the livelihoods and survival of individuals, communities and countries in Africa. Climate change and IAS will have dramatic impacts on food security in Africa; we first consider climate change, then IAS and finally an example of climate change affecting an IAS and the consequences for the environment.

5.1. Impacts of climate change in Africa

The effects of climate change are therefore highly specific to ecoregion and depend on the initial starting conditions, their limiting factors and the projected change. For example, in the Sahel, warmer and drier conditions have led to a reduced length of growing season with detrimental effects on crops. By 2020, up to 250 million people are expected to be exposed to increased water stress due to climate change. Water is the key issue in this ecoregion. If coupled with increased demand for domestic and agricultural use, this will adversely affect livelihoods.

It is predicted that warm sea surface temperatures will lead to increased droughts in equatorial and subtropical eastern Africa as the number of rain events during the dry season will decrease as well as overall annual precipitation. Such changes in precipitation are likely to reduce the annual flow of rivers, for example a decrease of up to 9% for the Pangani river and 10% for the Ruvu river. Warming in the east African region is expected to result in a complete disappearance of Kilimanjaro's glaciers by 2020. A temperature increase of 1.2°C, and the resulting changes in precipitation, soil moisture and water irrigation, would cause large areas of land that now support tea cultivation in Kenya to be too hot for continued tea cultivation.

Box 6: Africa's changing climate

- Global mean surface temperature is projected to increase between 1.5 and 6 °C by 2100
- Sea levels are projected to rise by up to 95 cm by 2100
- Climate change scenarios for Africa indicate future warming will be greatest over the interior of semi-arid margins of the Sahara and central southern Africa
- By 2020, up to 250 million people are projected to be exposed to increased water stress
- By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition
- By 2080, an increase of 5–8% in arid and semi-arid land in Africa is projected

Some areas of eastern Africa have been affected by erratic rainfall creating both droughts and floods, severely disrupting local food production and distribution and creating a risk of waterborne disease outbreaks. For example, Burundi, where it is estimated that 50% of the population survive on less than US$1 per day; was devastated by a drought in 2006 and then flooded in 2007. These extreme events have affected over two million people (approximately 25% of the population). Crops and livestock have been destroyed. In 2007, US$74 million in disaster relief (food and medicine) was spent in Kirundo, the drought hit province of Burundi.

In Ethiopia, drought has become a constant environmental pressure, with lakes and rivers drying up. For example, the Boco River in Fadis has completely dried up due to lack of rainfall and over-exploitation. In this region, farmers have abandoned orange groves and are now existing on food relief. In the Horn of Africa (Sudan, Eritrea and Ethiopia), famine is mainly a result of drought, although in Ethiopia and Eritrea, war was also a contributory factor. Over 13 million people in the two countries faced immediate food shortages in early 2003. In Mozambique, floods in 2000 (the worst for 150 years) left the country's lowlands in the Limpopo River basin inundated for up to three months, affecting the plant resources upon which people relied.

5.2. Impacts of IAS in Africa

According to IUCN, in 2004, 81 IAS were identified in South Africa, 49 in Mauritius, 44 in Swaziland, 37 in Algeria and Madagascar, 35 in Kenya, 28 in Egypt, 26 in Ghana and Zimbabwe, and 22 in Ethiopia; the incidence of IAS throughout the continent is shown in Fig. 5. In some countries there may be under-reporting of the incidence of IAS. Africa spends approximately US$60 million annually on the control of IAS. The African Ministerial Conference on the Environment (AMCEN) plans to raise a further US$265 million to fund various projects related to IAS over 3–5 years. Money is not enough. Strategies are needed to tackle existing and new IAS. A risk/benefit analysis needs to be developed and applied. This would involve investment to look at the balances between the economic, development, ecological, environmental and human well- being costs and benefits. Once a meaningful, comprehensive strategy has been

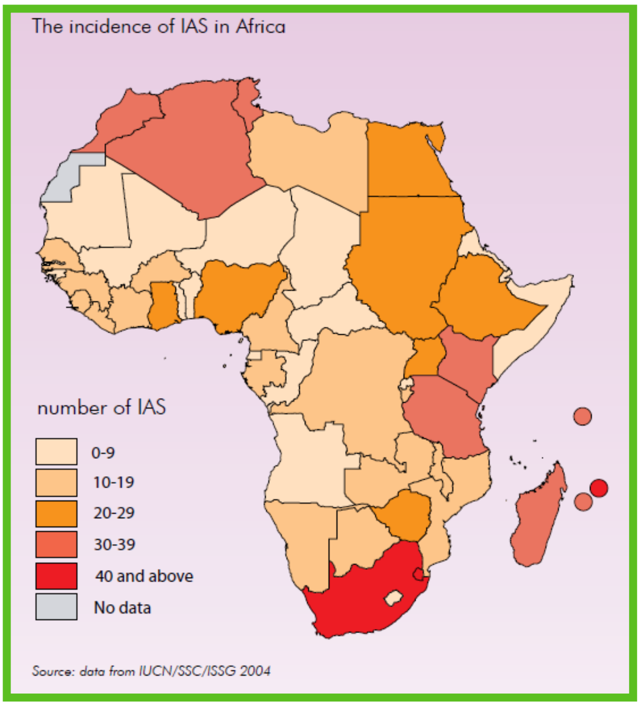


Fig. 6: Incidence of IAS in Africa. Southern and eastern Africa are worst affected. (Reproduced from Africa Environment Outlook 2, Invasive Species Factsheet, www.unep.org/dewa/africa/aeo2_launch/)

developed and applied, it needs to direct policy at the local, regional and continental scale which will become the vehicle for the effective application of management and control practices.

Examples of IAS include the cassava mealybug (*Phenacoccus manihoti*) which caused cassava yield losses of up to 80%, before it was brought under biological control. The larger grain borer (*Prostephanus truncatus*), native to central America, attacks stored cassava, maize, and a range of other staple food. In Tanzania, it causes US$91 million in maize losses per annum, and in West Africa is responsible for cassava losses of approximately US$800 million per annum. These and other invasive species have been estimated to cause losses in yield of eight of Africa's principal crops amounting to approximately US$12.8 billion per annum.

5.3. Increasing temperatures and the spread of water hyacinth in Africa

Water hyacinth (*Eichhornia crassipes*) is a floating neotropical species which has become invasive both in the tropics and temperate areas. Outside its native range in South America it can quickly grow to very high densities (over 60 kg/m^2) and clogs waterways, preventing movement of boats and fishing activities. Water hyacinth and other water weeds affecting water use currently cost countries in Africa and Asia over US$100 million annually. In the Lake Victoria region of Africa, water hyacinth threatened livelihoods of local communities by reducing fish populations, fouling hydroelectric power turbines, and providing habitats for mosquitoes and snails, the vectors of malaria and schistosomiasis. Water hyacinth was first observed around the lake in 1989; seven years later it had spread to clog approximately 80% of Uganda's shoreline. The weed has been successfully controlled using classical biological control agents (two weevil species, mottled water hyacinth weevil, *Neochetina eichhorniae,* and chevroned water hyacinth weevil, *N. bruchi*) combined with mechanical removal in many locations. The use of a biological control agent in this context is important as chemical options are limited in aquatic environments. The *Neochetina* larvae tunnel into the plant, allowing invasion by opportunistic bacteria and fungi. Additionally, water enters the tunnels and causes the plant mats to sink as the plants deteriorate further. Wind and wave action can accelerate the destruction of the weed started by the insects. This approach has been highly successful; using only biocontrol and mechanical removal in the part of the lake in Uganda, 90% of the weed was cleared from it by 2000. This resulted in reduced cases of disease, increased power generation, and increased production of fish for export (mainly the Nile perch, *Lates niloticus*). Biocontrol is not without risk. The risks of introducing non-native predatory species must be carefully evaluated before they are introduced. These risks include invasiveness by the control agents themselves and unintended effects on non-target species. Biocontrol agents must also be carefully monitored after introduction for any unforeseen environmental changes.

Climate change is likely to increase the global range of water hyacinth. Two factors determining weed growth rates are water temperature and nitrogen concentration; with growth rates maximal at 29.6°C. As temperature rises with climate change, so higher growth rates will occur leading to faster spread within a habitat and opportunities to invade habitats that were too cool for the weed survival before. Water hyacinth has historically been restricted to tropical and subtropical regions, as individual plants are killed by prolonged periods of cold/freezing temperatures. However, predicted climate changes in temperate zones, including increased winter temperatures, fewer frost days, and longer growing seasons, may allow it to persist at higher latitudes.

Another impact of climate change is changed precipitation patterns. In November and December 2006, high levels of precipitation in the Lake Victoria area led to increased nutrient run-off into the water and a resurgence of water hyacinth, particularly in the northwest corner of the lake in Kenya. Future combinations of increased temperature and increased heavy rainfall could have a dramatic effect on the spread and impact of water hyacinth under climate change.

6. CABI, invasives and climate change

CABI (www.cabi.org) is a not-for-profit intergovernmental organization owned by a consortium of 45 member countries and is dedicated to improving people's lives worldwide by providing information and applying scientific expertise to solve problems in agriculture and the environment. CABI currently works in over 60 countries worldwide, in partnership with both public and private sectors.

In 2008, CABI organized three regional consultations with its member countries in Latin America and the Caribbean, Africa, and Asia. As a result, CABI has a mandate to support countries in adapting to climate change and in developing management strategies and policies.

Reducing the spread and impact of IAS is one of CABI's three global themes. The unique combination of in-house experts in publishing, abstracting, databases and web-portals plus in-country scientists and practitioners can build capacity, provide training and deliver knowledge direct to those who need it. Knowledge gaps can be rapidly identified and, working in partnership with donors, CABI bridges these gaps.

CABI's depth of practical on-the-ground experience, and extensive information and knowledge bases, puts it in a unique position to catalyse action by informing, updating and building capacity of member countries, government departments, support groups, individuals and co-operatives, practitioners and researchers to take concerted action to adapt to the new realities caused by climate change and the synergistic interaction with IAS.

CABI can provide a unique focus for future research, delivery, capacity building and knowledge transfer to address the urgent issues encompassed by invasive species and climate change.

CABI is represented at many events and international fora on climate change including:

- Participant in the Food and Agriculture Organization High-Level Conference on World Food Security: The Challenges of Climate Change and Bioenergy, Rome, 3–5 June 2008.
- Expert on the Council of Europe Working Group on Biodiversity Loss and Climate Change.
- Expert at the Capacity-Building Workshop Caribbean Region National Biodiversity Strategies and Action Plans, Mainstreaming Biodiversity and Integration of Climate Change, convened by the Convention on Biological Diversity (CBD) in the Caribbean.

- Participant at conference on The European Union and its Overseas Entities; Strategies to Counter Climate Change and Biodiversity Loss; an official event under the French Presidency of the European Union, July 2008.
- Participant in Rationalising Biodiversity Conservation in Dynamic Ecosystems (RUBICODE), an European Commission (EC) 6th Framework, Coordination Action Network.
- Participant in BACCARA, (Biodiversity and Climate Change, A Risk Analysis), an EC-funded 7th Framework research project involving 15 European teams, coordinated by INRA (l'Institut national de la Recherche agronomique), France. It is developing tools to predict the effect of climate change on forest productivity through changes in tree species composition and pest interactions.
- Reviewer, information provider and contributing author to the Inter-Governmental Panel on Climate Change (IPCC) Working Group II, Fourth and Third Assessment Reports.
- Convenor and chair of workshop on Climate Change and Invasive Alien Species Impacts on Ecosystems at the South African Government Scientific and Political Congress on Climate Change.
- Participant in the IUCN Taskforce on Climate Change and Conservation.
- Participant in a series of international workshops on Terrestrial Ecosystem Responses to Atmospheric Climate Change.
- Invited consultant for the UK Government workshops on Climate Change Implications for UK Species and Habitat Conservation Policy.

CABI is working with partners to develop, lead and deliver a targeted research programme, particularly in poor tropical countries, especially in Africa, to examine impacts and consequences of climate change and IAS. Such a programme will involve determining how to modify current agricultural practices to aid short term mitigation and adaptation and promote long term adaptation through developing new sustainable practices, management strategies and tools and knowledge dissemination to enable farmers and land managers to adapt to the combined threat of climate change and IAS.

7. Relevant articles and presentations by CABI authors

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contact CABI

Europe
CABI Head Office
Nosworthy Way, Wallingford, Oxfordshire, OX10 8DE, UK
T: +44 (0) 1491 832111, **E:** corporate@cabi.org

CABI Europe - UK
Bakeham Lane, Egham, Surrey, TW20 9TY, UK
T: +44 (0) 1491 829080

CABI Europe - Switzerland
Rue des Grillons 1, CH-2800 Delémont, Switzerland
T: +41 (0) 32 4214870

Asia
CABI South Asia
Opposite 1-A, Data Gunj Baksh Road, Satellite Town, PO Box 8, Rawalpindi-Pakistan
T: +92 (0) 51 9290132

CABI Southeast and East Asia
PO Box 210, 43400 UPM Serdang, Selangor, Malaysia
T: +60 (0) 3 89432921

CABI South Asia - India
2nd Floor, CG Block, NASC Complex, DP Shastri Marg, Opp. Todapur Village, PUSA,
New Delhi - 110012, India
T: +91 (0) 11 25841906

CABI Southeast and East Asia - China
C/o CAAS-CABI Project Office
C/o Internal Post Box 56, Chinese Academy of Agricultural Sciences,
12 Zhongguancun Nandajie, Beijing 100081, China
T: +86 (0) 10 62112118

Africa
CABI Africa
ICRAF Complex, United Nations Avenue, Gigiri, PO Box 633-00621, Nairobi, Kenya
T: +254 (0) 20 7224450/62

Americas
CABI Caribbean & Latin America
Gordon Street, Curepe, Trinidad and Tobago
T: +1 868 6457628

CABI North America
875 Massachusetts Avenue, 7th Floor, Cambridge, MA 02139, USA
T: +1 617 3954051