NAPPO
North American Plant Protection Organization
Organización Norteamericana de Protección a las Plantas

NAPPO Discussion Document

DD 02: Climate Change and Pest Risk Analysis

Prepared by members of the Pest Risk Analysis and Invasive Species Panels of the North American Plant Protection Organization (NAPPO)

December 2011

Contents

Page

Introduction 3
Scope 3
Definitions and Acronyms 4
1. Background 6
2. An Overview of Climate Change 7
2.1 Global Predictions 8
2.2 Climate Change in North America 9
3. Climate Change Effects on Invasive Species 10
3.1 Climate Change Effects on Entry 12
3.2. Climate Change Effects on Establishment 13
3.3 Climate Change Effects on Spread 16
3.4 Climate Change and Human Activities: Effects on Pest Entry, Establishment and Spread 18
3.5 Climate Change Effects on Pest Impacts 19
4 Global Change – the Interacting of Global Change Stressors 19
5 Climate Change and Pest Risk Analysis 20
5.1 Uncertainty in Climatic and Bioclimatic Models 21
5.2 Climate change models and PRA – issues of spatial scale 22
5.3 Climate change models and PRA – issues of temporal scale 23
5.4 Fit-for-Purpose: PRA as an IPPC Decision-Support Tool 23
6 Legal Aspects of Interpretation of the Role of Climate Change in the Development of PRAs 24
7. Conclusion and Recommendations 25
References 27
Annex 1: The Role of Precaution 33
Appendix 1: Phytosanitary Treaty Background 34

Introduction

It is now widely accepted within the scientific community that our climate is changing at an unprecedented rate due to human activity, specifically due to anthropogenic emissions of greenhouse gases into the atmosphere. The most recent report of the Intergovernmental Panel on Climate Change (IPCC) states that: “warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level” (IPCC 2007). According to model projections, global and regional climate change in this century will be characterized by higher temperatures, altered precipitation regimes and increases in the frequency of extreme events. These changes in climate patterns will directly affect both human and biological systems, including the ability of pests and invasive species[1] to establish and spread in new ecosystems. Accordingly, there is a need for governments and organizations at all levels to deal proactively with climate change, examining the ways in which it may affect their mandate and develop mitigation and adaptation measures if needed. This discussion paper represents the first attempt by the North American Plant Protection Organization (NAPPO) to document the ways in which climate change might affect plant protection activities, and specifically to discuss the implications of climate change for pest behaviour and pest risk analysis.

Scope

The NAPPO Pest Risk Assessment (PRA) and Invasive Species (IS) panels have been charged with drafting a discussion document on the potential for climate change to affect the ability of pests to spread and establish in new areas, including the implications for the current pest risk analysis (PRA) process. This is not intended to be a position statement, but rather a discussion of the ways in which climate change might be relevant to NAPPO business. A working group, composed of members of both panels, was appointed to develop this document.

Specifically, the scope of this assignment is:

- To review the scientific literature on climate change as it relates to the PRA process;
- To draft a discussion document that examines:
    - The potential effects of climate change on the ability of pests to spread and establish in new areas; and,
    - The implications/pertinence of these effects to the current PRA process.

[1] The terms ‘pest’ and ‘invasive species’ have been defined in various ways and the relationship between them has been discussed elsewhere (e.g., IPPC Secretariat 2005; Tanaka and Larson 2006). In this document, we use the definitions provided by the International Plant Protection Convention (IPPC) and the Convention on Biological Diversity (CBD) (See Definitions, below).

Definitions and Acronyms

The definitions for phytosanitary terms and acronyms used in this document are taken, in order of priority, from: (1*)* ISPM 5, 2009. *Glossary of phytosanitary terms*[2]. Rome, IPPC, FAO; (2*)* RSPM 5, 2008. *Glossary of Phytosanitary Terms*, Ottawa, NAPPO; or (3) the IPCC Fourth Assessment Report, *Annex II Glossary* (IPCC 2007). Note the definitions are taken verbatim from their source document.

Adaptation: Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaption exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc. (3).

Anthropogenic: Resulting from or produced by human beings (3).

Atmosphere: The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1 percent volume mixing ratio) and oxygen (20.9 percent volume mixing ratio), together with a number of trace gases, such as argon (0.93 percent volume mixing ratio), helium and radiatively active greenhouse gases such as *carbon dioxide*[3] (0.035 percent volume mixing ratio) and *ozone*. In addition, the atmosphere contains the greenhouse gas water vapor, whose amounts are highly variable but typically around 1 percent volume mixing ratio. The atmosphere also contains clouds and *aerosols* (3).

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the *climate system* (3).

Climate change: Climate change refers to a change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may also be due to natural internal processes or *external forcings*, or to persistent *anthropogenic* changes in the composition of the *atmosphere* or in *land use*. Note that the *United Nations Framework Convention on Climate Change (UNFCCC)*, in its Article 1, defines climate change as: ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes (3).

---

[2] IPPC standards, called ISPMs, or International Standards for Phytosanitary Measures are available on the IPPC website at https://www.ippc.int/IPP/En/default.jsp.
[3] Terms in italics are further defined in the source document; not all of these definitions are provided here. Refer to the original documents for more information.

Climate system: The climate system is the highly complex system consisting of five major components: the *atmosphere*, the *hydrosphere*, the *cryosphere*, the land surface and the *biosphere*, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of *external forcings* such as volcanic eruptions, solar variations, and *anthropogenic* forcings such as the changing composition of the atmosphere and *land-use change* (3).

Entry (of a pest): Movement of a *pest* into an *area* where it is not yet present, or present but not widely distributed and being *officially controlled* (1).

Establishment: Perpetuation, for the foreseeable future, of a *pest* within an area after entry (1).

External forcings: External forcing refers to a forcing agent outside the *climate system* causing a change in the climate system. Volcanic eruptions, solar variation, and *anthropogenic* changes in the composition of the *atmosphere* and *land-use* change are external forcings (3).

GATT (1986-1994): Uruguay Round of the General Agreement on Tariffs and Trade.

IAEA: International Atomic Energy Agency

Introduction: The entry of a pest resulting in its *establishment* (1).

Invasive alien species: An invasive alien species is an *alien species* that by its *establishment* and *spread* has become injurious to *plants*, or that by *risk analysis* is shown to be potentially injurious to *plants* (1)[4].

IPCC: Intergovernmental Panel on Climate Change (3).

IPPC: International Plant Protection Convention (1).

ISPM: International Standard for Phytosanitary Measures (1).

Land use: Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term *land use* is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation) (3).

Mitigation: Technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to Climate Change, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks (3).

NAPPO: North American Plant Protection Organization (2).

---

[4] Note that this definition is provided in Appendix 1 to the IPPC Glossary, *Terminology of the Convention on Biological Diversity (CBD) in relation to the Glossary of Phytosanitary Terms*. The definition given is an IPPC explanation of a CBD definition.

Pest: Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products (1).

Pest risk analysis[5]: The process of evaluating biological or other scientific and economic evidence to determine whether an *organism* is a *pest*, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it (1).

Phytosanitary measure (agreed interpretation): Any *legislation*, *regulation* or *official* procedure having the purpose to prevent the *introduction* and/or *spread* of *quarantine pests*, or to limit the economic impact of *regulated non-quarantine pests* (1).

PRA: Pest risk analysis (1).

RSPM: Regional Standard for Phytosanitary Measures (2).

SPS Agreement: World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures.

WTO: World Trade Organization.

1. Background

NAPPO recognizes that the impacts of climate change on plant health and invasive species management could be an important and far-reaching issue facing risk managers and policy makers alike as climate change will interact with other stressors to affect the distribution, spread, abundance and impact of pests and invasive species. It is generally expected that climate change will worsen the world's invasive species problems, as traits of species that make them invasive often help them adapt quickly and succeed under changing conditions and in disturbed environments (e.g., as a result of extreme weather events like floods, fires and droughts (Low 2008)). However, there is still a great deal of uncertainty inherent in climate change predictions and invasive species behavior, and climate change might cause the emergence of new invasive species while also reducing the impacts of others. How to address this uncertainty in the context of pest risk analysis, and whether in fact there is benefit to be gained or justification for doing so, is still a topic of considerable discussion.

In October 2009, the NAPPO PRA and IS Panels held a joint meeting in Chicago, Illinois, USA, to discuss a number of issues of common interest. It was acknowledged at that meeting that climate change is an issue of increasing concern in the scientific community, and one that has implications for NAPPO's core business. It was agreed that the Panels

[5] Paragraph 4 of Annex A of the SPS Agreement provides the following definition for risk assessment: The evaluation of the likelihood of entry, establishment or spread of a pest or disease within the territory of an importing Member according to the sanitary or phytosanitary measures which might be applied, and of the associated potential biological and economic consequences …. The SPS Agreement does not refer to risk management per se, although the concept is implicit in that the theme of the Agreement is "measures" which result from risk-based decisions. To align itself more closely with the SPS Agreement, the IPPC, in its 1997 revision, incorporated various concepts from the SPS Agreement, including those of transparency and pest risk. But whereas the SPS Agreement uses the term "risk assessment", the IPPC uses the term "pest risk analysis" (PRA).

would work jointly on a discussion document to explore the ways in which climate change might need to be addressed in a NAPPO context.

2. An Overview of Climate Change

Studies of the role of human activities in increasing greenhouse gases began as early as the 1950s, when atmospheric concentrations of carbon dioxide were first monitored in Antarctica and Hawaii (Agrawala 1998). Since the 1970s, serious scientific interest in climate change and its potential impacts on human society has been gaining momentum, and in 1988 the Intergovernmental Panel on Climate Change (IPCC) was created jointly by two United Nations agencies: the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) (Agrawala 1998). The IPCC is a scientific body with worldwide participation that reviews and assesses available information and produces climate change assessment reports at regular intervals. Its purpose is to assess the available information on climate change and provide a clear scientific view of the current state of climate change, and its potential environmental and socio-economic consequences.

In its Fourth Assessment Report (2007), the IPCC stated that “warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level” (IPCC 2007). Eleven of the twelve years preceding the report (1995-2006) ranked among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The rise in temperatures was shown to be a widespread trend across the globe, being greater at higher northern latitudes, with land masses warming faster than the oceans. Rising sea levels and decreases in snow and ice extent were found to be consistent with warming. It is considered very likely that most of the observed increase in global temperatures in the mid-1900s is due to observed increases in anthropogenic greenhouse gas emissions (IPCC 2007). There is evidence from all continents and most oceans that natural systems are being affected by regional climate changes, particularly temperature increases (IPCC 2007).

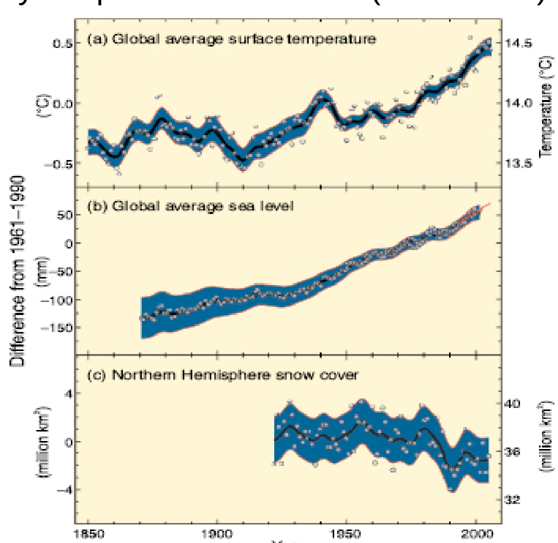

Figure 1: Changes in temperature, sea level and Northern Hemisphere snow cover. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All

differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c) (from IPCC 2007).

2.1 Global Predictions

Warming during this century is projected to be considerably greater than over the last century. The IPCC states that in the absence of strong climate change mitigation policies and related sustainable development practices, it is very likely that greenhouse gas emissions will continue to increase. Over the next two decades, a warming of about 0.2^{o}C per decade is projected for a range of emission scenarios. Even if concentrations of all greenhouse gas and aerosols were kept constant at year 2000 levels, a further warming of about 0.1^{o}C per decade would be expected. After the next two decades, projections will depend increasingly on different emissions scenarios (IPCC 2007).

In addition to overall warming, the IPCC report also makes the following projections:

- Warming will be greatest over land and at high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic Ocean, continuing recent observed trends;
- Snow cover areas will contract, the extent of sea ice will decrease, and thaw depth will increase over most permafrost regions;
- The frequency of heat extremes, heat waves and heavy precipitation will likely increase;
- The intensity of tropical cyclones will likely increase;
- Extra-tropical storm tracks will shift polewards, with consequent changes in wind, precipitation and temperature patterns, and;
- Precipitation will likely increase at high latitudes and decrease in most subtropical land regions, continuing observed recent trends.

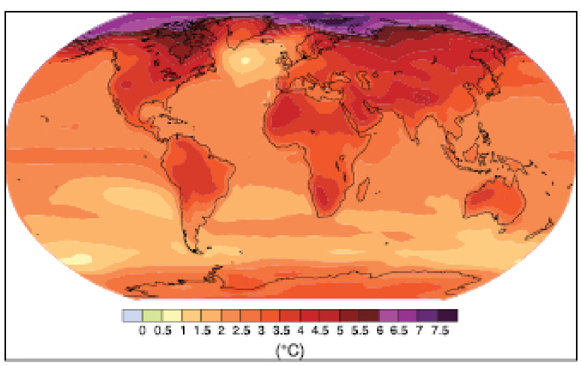

Figure 2: Geographical pattern of surface warming
Projected surface temperature changes for the late 21st century (2090-2099). The map shows the multi-AOGCM average projection for the A1B SRES scenario. Temperatures are relative to the period 1980-1999 (from IPCC 2007).

2.2 Climate Change in North America

Like the rest of the world, North America has been warming significantly over the past 50 years due to the accumulation of greenhouse gases in the atmosphere. However, it is important to realize that climate responds to local, regional and global factors. Therefore, national and regional climate might vary more than the average global climate.

In the United States (US), the average temperature has risen more than 2^{o}F (equivalent of about 1^{o}C) over the last 50 years, and is projected to rise more in the future (Karl et al. 2009). On a seasonal basis, most of the US is projected to experience greater warming in the summer than in the winter, while Alaska experiences far more warming in winter than in summer (Karl et al. 2009). Similarly, in Canada, the average temperature has increased by 1.3^{o}C in the last century, varying regionally, with the northwest experiencing the most pronounced increases (Government of Canada 2008). In Mexico, the mean annual temperature has risen 0.6^{o}C during the last 38 years, while the trend over the last 10 years indicates an accelerated warming of 0.7^{o}C (INE-SEMARNAT 2009). Mean annual temperatures are expected to rise between 2.0-4.0^{o}C until 2050 (INE-SEMARNAT 2006). In all cases, temperature is expected to continue to rise over the next century, with overall increases between about 1.8-6^{o}C, with the extent and rate of warming determined by future greenhouse gas emissions (INE-SEMARNAT 2006; Government of Canada 2008; Karl et al. 2009).

In addition to temperature increases, changes in precipitation have also been observed. In the US, precipitation has increased an average of about five percent in the last 50 years, and projections indicate that northern areas will become wetter while southern areas, particularly in the west, will become drier (Karl et al. 2009). In Canada, wet areas are generally getting wetter, dry areas drier, and the probabilities of both heavy rainfall and drought have increased. The high north experienced a 45 percent increase in rainfall from 1948-2003 due to warmer temperatures, while snowfall overall is decreasing, particularly on the west coast, which adversely affects water availability in the spring (Government of Canada 2008). Other impacts in Canada include permafrost degradation and reduced ice cover in the north, and reduced lake and river levels in the south (Government of Canada 2008). Precipitation projections for Mexico are afflicted with high uncertainty. The available projections used for the fourth national communication of Mexico for the United Nations Framework Convention on Climate Change (UNFCCC) indicate that mean annual precipitation could decline around 11 percent for the country overall (INE-SEMARNAT 2009). Winter precipitation could be reduced up to 15 percent in central regions of Mexico and less than 5 percent in the coastal zone of the Gulf of Mexico until 2080 (INE-SEMARNAT 2006). Based on the same information source, extreme events such as cold fronts could also decrease while tropical storms could increase in their intensity.

All of North America has also experienced the effects of rising sea levels. Over the last century, global sea levels have increased by a mean of 17 centimeters, and are predicted to continue to rise, causing flooding and coastal erosion (IPCC 2007).

Some further examples of projected regional impacts for North America include (IPCC 2007):

- Warming in the western mountains projected to cause decreased snowpack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources;
- In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5 to 20 percent, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilized water resources;
- Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity, and duration of heat waves with potential for adverse health impacts, and;
- Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution.

3. Climate Change Effects on Invasive Species

Climate change and increased climate variability have been demonstrated to have a number of impacts on natural systems, most notably affecting timing of spring events such as leaf unfolding, bird migration, egg laying, and fish migrating into rivers, as well as causing northern and latitudinal shifts in species ranges on land, and shifts in the range and abundance of species in oceans (EFSA 2007; IPCC 2007; Government of Canada 2008). A review of the scientific literature indicates that climate change is expected to alter biodiversity, causing changes in phenology (Hellman et al. 2008; Low 2008; CBD 2009), population dynamics of native species, geographic ranges, structure and composition of communities and functioning of ecosystems (Walther et al. 2009). The same authors state that changes in climatic conditions have already occurred over recent decades and that the above-mentioned phenomena can be observed by now. For example Parmesan and Yohe (2003) and Root et al. (2003) have documented the influence of climate change on species distributions using a meta-analysis technique. Parmesan and Yohe (2003) studied more than 1700 species, demonstrating significant range shifts averaging 6.1 kilometers per decade towards the poles and significant mean advancement of spring events by 2.3 days per decade. According to Parmesan (2006) these independent studies conducted around the globe provide a clear and globally coherent conclusion: “Twentieth-century anthropogenic global warming has already affected Earth’s biota.”

Corresponding to these effects on native species, climate change might equally affect invasive species, causing them to expand into new ranges and affecting the risk associated with them (Hellman et al. 2008; Low 2008; Walther et al. 2009; Bradley et al. 2010). The responses of invasive species to the modifications caused by climate change is expected to be species- and region-specific and made more complex by their interactions and interdependencies (Luck et al. 2011). For example, higher temperatures may benefit those species that thrive in warmer weather and inhibit those that prefer colder temperatures, resulting in a widening or constriction of habitable range depending on a species’ preference. Most of the available literature on climate change and invasive species concerns effects on natural systems; studies of impacts on managed systems are more difficult to find (Ziska et al. 2011). For example, the last national assessment of climate change impacts on the U.S. does not consider invasive species in the chapter on agriculture (Ziska et al. 2011).

While a number of factors may influence changes in biological invasions (e.g., increasing temperature, changing precipitation, increased atmospheric carbon dioxide, altered nitrogen distribution and species interaction), most literature and models on the interaction between climate change and invasive species focus on temperature as a key factor (e.g., Cannon 1998; Harrington et al. 2001; Bale 2002). One reason for this is that temperature is the climate variable for which there is most confidence in predictions of future climate change (Harrington et al. 2001; Houghton et al. 2001); another is its capacity to limit survival, growth and reproduction in plants and many animals, particularly in insects (e.g., Woodward 1987 and Charnov et al. 2003 in Walther et al. 2009). Overall, direct effects of temperature are expected to be more important than other factors for the biological invasion process (Kehlenbeck et al. 2007; Hellman et al. 2008; Shi et al. 2010).

It is generally predicted that invasive species, because of the characteristics associated with invasiveness (i.e., the ability to adapt to rapid changes and disturbances (Walther et al. 2009; Burgiel and Muir 2010)) will be able to respond to climate change better than native species, and that climate change will likely result in an increased number of invasions and increased severity of invasions (Low 2008). In particular, problems caused by pest insects are expected to worsen under climate change (Harrington et al. 2001). According to Harvell et al. (2002), the same is also expected for many wildlife pathogens as warmer temperatures usually increase virulence by promoting growth, reproduction, and higher transmission rates. Nevertheless, it is difficult to generalize predictions of climate change impacts on invasive species as there are examples of species which may benefit from climate change and counter-examples for species which may be affected negatively. The interaction and interdependencies between climatic phenomena, ecosystem processes and human activities make long-term predictions extremely complicated (Cannon 1998).

Most authors predict a variety of consequences for invasive species as a result of climate change. Burgiel and Muir (2010) categorize them into direct and indirect impacts. Luck et al. (2011) examine how the changes in climate variables such as temperature, precipitation and increase of atmospheric CO_2, as well as extreme events, impact weeds, insect pests, pathogens and host plants. Another approach is followed by Walther et al. (2009), who link the consequences of climate change for invasive species to the sequential stages of an invasion process: introduction, colonization, and spread (these terms are equivalent to entry, establishment and spread in the IPPC Glossary, ISPM 5: 2009). Others, such as Hellmann et al. (2008) attribute them to the “invasion pathway”, including: altered transport and introduction and establishment mechanisms of new invasive species; altered impact of existing invasive species; altered distribution of existing native species; and altered effectiveness of control strategies. While most of these authors focus on natural systems, Ziska et al. (2011) consider impacts on agriculture with regard to future food security. The latter as well as Luck et al. (2011) look at the influence of severe weather and precipitation patterns, increasing surface temperature and rising carbon dioxide on the establishment, dominance and spread of the different invasive pathogens, insects and weeds.

In the following sections, the most frequently identified consequences of climate change for invasive species are provided for the sequential stages of the invasion process using the IPPC terminology: Entry, establishment and spread (ISPM 5 2009). Note that entry, establishment and spread represent a continuum in the invasion process and many of the factors described below may be relevant to more than one section. In particular, many of the factors that increase the potential for entry will also be relevant for pest spread within a region. There are also factors which cannot be linked specifically to any of the stages. For example, temperature influences growth and development, survival, fecundity, feeding behavior, range and abundance of many species, in particular insects, which could affect all three stages of invasion (Bale 2002; Luck et al. 2011).

3.1 Climate Change Effects on Entry[6]

Climate change effects on the ability of pests to enter new areas may include:

- The removal of physiological constraints, and modification of dispersal patterns for certain species (e.g., warmer nocturnal temperatures might increase flight activity for moths and aphids, allowing dispersal over greater distances (Walther et al. 2009; Ziska et al. 2011).
- Increased frequency or intensity of extreme weather events such as hurricanes might facilitate long range dispersal of organisms by air (e.g., birds, insects, pathogens and seeds of invasive weeds) and water currents (e.g., marine larvae) carrying them to considerable distances from their native range (Richardson and Nemeth 1991; Hellman et al. 2008). Invasive insects or pathogens could be blown into North America via hurricanes from Africa, South America and the Caribbean (e.g. introduction of soy bean rust). Stronger winds associated with such storms might also be able to spread such pests further into the U.S., into agricultural areas (Ziska et al. 2011).
- Other extreme events such as floods might result in the ability of previously confined aquatic species to migrate to new areas (Walther et al. 2009).
- Extreme weather and altered circulation patterns can increase propagule pressure, enhancing the ability of some invasive species to successfully invade regions that previously received fewer propagules (Schneider et al. 2005; Hellman et al. 2008). Likewise, increased precipitation and frequency of rain events might help certain spores to be more effective in their depositions (e.g., uredidniospores and aeciospores germinate more readily when in contact with free water) (Ziska et al. 2011).
- Droughts in combination with certain invasive plants (*e.g. Pennisetum ciliare*) could change fuel characteristics and in consequence change the frequency, intensity and spatial extent of fires, thus facilitating further invasions (Dukes and Mooney 1999; Dukes 2011; Luck et al. 2011).
- Increased levels of carbon dioxide (CO_2) might affect plant hosts for pests and pathogens, subsequently causing a variety of impacts on host-pest or host-pathogen interactions (Ziska et al. 2011). The growth of kudzu for example is stimulated by rising atmospheric levels of CO_2 (Sasek and Strain 1988 in Ziska et al. 2011). As the plant can serve as an alternative host for Asian soybean rust, CO_2-induced increases in the kudzu canopy could potentially trap more spores of Asian soybean rust and consequently increase the distribution of the pathogen (see also corresponding case study).

[6] Most authors in the scientific literature use the term “introduction” for to the first step of invasion, which is equivalent to “entry” in the IPPC context.

Case Study # 1: Cactus Moth

Larvae of *Cactoblastis cactorum*
Source: Ignacio Baez, USDA.

The cactus moth (*Cactoblastis cactorum*) provides an example of facilitated movement by extreme weather events for Mexico. The arrival of the cactus moth is likely attributable to strong winds during the 2005 hurricane season, which transported the insect from host islands in the Caribbean to Mexico (Burgiel and Muir 2010; Ziska et al. 2011). The cactus moth strongly affects *Opuntia* species cacti as the larvae feeds on the young cladodes that have not become woody, causing physical damage by hollowing them out and destroying them (Zimmermann et al. 2004).

The livelihood of approximately 25,000 Mexican households depends directly on the cactus, from selling its fruits or other plant parts. Revenues from production amounted to 3.84 percent of the agricultural gross domestic product for Mexico in 2006 (Sánchez et al. 2007). In addition, it poses a serious threat to dozens of native *Opuntia* species, which are the dominant elements of most of the semi-arid zones in the high plateau of Mexico. The cactus moth was detected in Isla Mujeres, Quintana Roo in 2006, but was successfully eradicated in 2009 after a collaborative effort lead by the Ministry of Agriculture (SAGARPA) in coordination with the Ministry of the Environment (SEMARNAT) and with international support from USDA and IAEA. Due to the fact that the moth is dramatically expanding its range along the southeastern and gulf coasts of the U.S. (Ziska et al. 2011) it continues to pose a serious threat to Mexico, forcing governmental institutions on both sites of the border to intensify their collaborative efforts to monitor and control the spread on the U.S. side by destroying infested plants and releasing sterile insects. It is difficult to directly attribute invasions like this to climate change, but an increase in frequency and intensity of hurricanes as a result of climate change is likely to favor this type of long distance dispersal event.

3.2. Climate Change Effects on Establishment

Climate change can lead to an increased likelihood of pest establishment through different mechanisms. For example:

- Species from warmer regions that are unable to persist in certain locations due to unsuitable temperatures might be increasingly able to survive and colonize. For instance, species currently constrained by short growing seasons might be able to set fruit or compete with resident species. As changes in temperature favour extended growing seasons, this might alter the dynamic of seed production in plants and the reproductive periods of animal species. For example, (Yamamura and Kiritani 1998 in Harrington et al. 2001) estimated the potential increase in number of generations for a range of insect orders and other invertebrates at 1 to 5 additional generations per year with a 2^{o}C temperature.

- Increased temperatures might favor broad categories of plants in some environments. For example, plants using the C4 photosynthetic pathway are better adapted to warm dry conditions than are C3 plants; thus C4 grasses could become more aggressive invaders in some temperate ecosystems (Ehleringer et al. 1997; White et al. 2001; Luck et al. 2011).

- Warmer conditions are of particular concern in temperate regions because many invasive species have range limits set by extreme cold temperatures or ice. Though there may be regional exceptions, in general, seasonal temperatures are projected to rise disproportionally faster during winter (IPCC 2007). This could be an important factor for many species, including pathogens. For example, rising winter temperature might decrease the mortality rate of pathogen populations, increase the pathogen load and consequently increase their range and distribution (Ziska et al. 2011). Milder winters have been found to favor a variety of pathogens such as powdery mildew (*Erysiphe graminis*) brown leaf rust (*Puccinia hordei*) and stripe rust (*Puccinia striiformis*) (Luck et al. 2011).
- Climate change might also induce stress on native ecosystems and vegetation causing them to be more vulnerable to the establishment and spread of invasive species. Drought causes some plant hosts to be more susceptible to pest attack especially in combination with higher temperatures (Rosenzweig et al. 2001, in Luck et al. 2011). Similarly, the removal of existing vegetation due to high winds or rain during extreme weather events might create bare soil, which is then easier to colonize (Walther et al. 2009).

Case study # 2: Red Palm Mite

The infestation of the red palm mite (*Raoiella indica*) in the Caribbean part of Mexico provides a second example of movement facilitated by extreme weather events. The red palm mite is a major pest of fruit-producing palm trees and other ornamental and forest plants including species such as bananas, ginger and heliconia. It was detected in 2004 for the first time on the American continent in the Caribbean basin in Martinique, from where it spread rapidly over the Caribbean island and neighboring countries. In 2007 it was detected in Florida affecting coconut palm trees (SAGARPA-SENASICA 2010).

In October 2009 it arrived at Isla Mujeres close to Cancun, Quintana Roo. The insect most likely spread to Mexico by a combination of major storms and hurricanes as well as by infested plants and seeds (Welbourn 2009; Burgiel and Muir 2010). Feeding mites, especially at high densities, cause localized yellowing of the leaves followed by tissue necrosis (Rodrigues et al. 2007; Welbourn 2009).

The pest presents a risk for 264,000 hectares of banana, coconut, palm-oil and date plantations in Mexico (SAGARPA-SENASICA 2010). It also poses a major threat to biodiversity as palm trees are an important component of tropical ecosystems. The outbreak is close to the Biosphere reserve of Sian Kaan, with its collection of various palm tree species, including endemic ones. As illustrated by this and the previous case study, hurricanes are a natural pathway for pests, therefore an increase in frequency and intensity of hurricanes as a consequence of climate change is likely to raise the probability for introduction and dispersal of such pests

Case Study # 3: Kudzu

Kudzu (*Pueraria montana*) is an example of an invasive alien plant predicted to undergo range expansion as a result of climate change in North America. Kudzu is a perennial, deciduous, semi-woody vine native to temperate and tropical Asia as well as parts of Oceania. It was introduced to different regions including central Asia, the Ukraine, Caucasus, southern Africa, South and Central America, and the U.S. (EPPO 2007; USDA-ARS 2011). It is a notorious weed, known in the U.S. as the “plant that ate the south” because of its ability to form dense, ropey mats over ground and trees. Kudzu grows best in areas with mild winters (5-15ºC), hot summers (over 25ºC), and at least 100 centimeters of precipitation annually (CAB International 2007).

In the U.S., the most severe infestations are found in the southeast (Mississippi, Alabama, and Georgia) (Britton et al. 2002). Towards the edge of its range plants might not flower and stems might be killed back to the ground in the winter (Bailey and Bailey 1976). However, an examination of its native and introduced range suggests it is hardy to USDA Plant Hardiness Zone 5 which extends northwards into parts of southern Canada (USDA 1990). Several authors have suggested that its range is likely to expand northwards under predicted climate change scenarios (e.g., Dukes and Mooney 1999; Rogers and McCarty 2000; Zavaleta and Royval 2002).

In addition to warmer temperatures, kudzu has been shown to respond positively to elevated CO_2 concentrations, another predicted effect of climate change (Dukes and Mooney 1999). The discovery of the first and only known wild population of kudzu in Canada in 2009 appears to support these predictions. The well-established population was discovered along the shoreline of Lake Erie just west of Leamington, Ontario, and appears to have been present for several years. It is not clear whether kudzu was deliberately planted at this site or introduced inadvertently via some other pathway, but this is the most northerly population recorded in North America to date. Warming and elevated CO_2 concentrations as a result of climate change are likely to increase the damage already caused by kudzu.

3.3 Climate Change Effects on Spread

Climate change might affect the ability of pests to spread in a variety of ways. For example:

- Accelerated spread of vectors, pests and diseases towards the north is predicted for temperate species, as former climate barriers are no longer effective (Kehlenbeck et al. 2007; Government of Canada 2008; Walther et al. 2009; Willis et al. 2010). The same applies for the Southern Hemisphere in the opposite direction, which means that temperate species are likely to extend their range to higher latitudes. Conversely, cold adapted species might experience restricted distribution (Bale 2002; Luck et al. 2011).
- In addition to latitudinal movement, there is increasing evidence for an altitudinal movement of invasive species. Many invasive plants of lowland ecosystems currently show a distribution limit at an elevation from 1000 to 1500 meters above sea level, which is likely linked to climate. In a warming climate these species might move upwards and in the future also threaten mountain ecosystems (Pauchard et al. 2009; Petitpierre et al. 2010).

Case Study # 4: Mountain Pine Beetle

The mountain pine beetle (*Dendroctonus ponderosae*) provides an example of a native forest pest that has undergone range expansion due to climate warming, in particular due to less frequent and less extreme cold weather events. Native to the forests of western North America, the mountain pine beetle occurs from Mexico to central British Columbia in Canada. It inhabits a variety of pine species, and kills individual trees by boring through the bark to the phloem, where it feeds and lays its eggs.

B.C. Ministry of Forests, Mines & Lands

Tree mortality caused by Mountain pine beetle in Yellowstone National Park
John W. Schwandt, USDA Forest

In the early stages of an outbreak, beetles usually attack unhealthy trees that are already damaged or diseased. However, as beetle populations increase, larger and healthier trees are affected. Until recently, beetle populations have been naturally regulated by temperature, including cold spells in the fall or spring during the most vulnerable stages of development, as well as during sustained periods of sub-zero temperatures during the winter (Régnière and Bentz 2007; Burgiel and Muir 2010).

In recent years, winters in western Canada and the U.S. have been mild, thereby contributing to a population explosion of the beetle with significant loss of pines. In British Columbia, the outbreak of mountain pine beetle has also been exacerbated by warmer summers and less summer precipitation (Burgiel and Muir 2010). These conditions, along with the mild winters, have allowed the beetle to spread to more northern forests, and forests at higher elevations. This has resulted in major losses in timber, with some new areas of infestation incurring mortality of up to 95 percent of the pine canopy (Burgiel and Muir 2010). Other impacts include carbon release from tree mortality, increased probability of forest fires, loss of habitat for local biodiversity, increased soil erosion and run-off and siltation of water bodies (Burgiel and Muir 2010). Experts have directly attributed this outbreak to climate change, and beetle populations are expected to continue to follow existing trends, spreading northwards, eastwards and to higher elevations. This illustrates how climate change might provoke native species to show invasive behavior and cause significant damage.

B.C. Ministry of Forests, Mines &Lands

- Species that shift their ranges into newly suitable habitats more quickly than native species could have a competitive advantage if native populations become progressively poorer competitors for resources in a changing climate (Hellman et al. 2008).
- Established non-native species could become invasive if climate change increases their competitive ability or rate of spread. It is likely that a strong selection for tolerance of local environmental conditions takes place in these initial populations (Hellman et al. 2008).
- Increasing temperatures might affect the ability of some species to move and migrate due to the disruption of thermal thresholds for development and flight. For example, a warmer climate would result in flight thresholds being reached earlier for aphids and moths and result in early and possibly prolonged immigration (Zhou et al. 1995 and Woiwod 1997, in Luck et al. 2011). This may be counteracted by limitations to flight due to upper thresholds being reached more frequently.

- Conversely, an increase in temperature might also affect some species negatively, limiting their ability to establish and spread. For example plant bacteria, which need frost injuries on plants for infection, might decrease with warming temperatures. This illustrates an interaction between climate change, pest and host, which adds another layer of complexity to the subject. In another example, warming temperatures might disrupt closely synchronized activities between host plants and herbivorous insects, decreasing the insect infestation rate and spread (Luck et al. 2011). Although insect populations might initially respond positively to elevated temperatures and shorten their generation time, populations might ultimately decrease if the host plant is negatively affected by increasing temperatures, reducing its carrying capacity for the pest.
- The combination of an increase of temperature and moisture is crucial in the growth and sporulation of a number of invasive pathogens (Ziska et al. 2011). Moisture is also a limiting factor for the spread of certain insects (in the case of the red imported fire ants changes in frequency and distribution of precipitation could facilitate their westward expansion). Conversely, dry conditions and warm temperatures can lead to an increase in insect vector populations which can favor dispersal of plant viruses (Luck et al. 2011).

3.4 Climate Change and Human Activities: Effects on Pest Entry, Establishment and Spread

Climate change might also modify human activities such as production, transport, and tourism in ways that increase chances of new invasions. For example:

- Agriculture and forestry production are highly climate dependant and constitute a large segment of global trade. It is likely that production and trade patterns will be influenced by climate change in different ways, including shifts in global food production and consumption patterns and changes in trade routes (Luck et al. 2011).
- Higher temperatures are reducing Arctic ice during summer, opening seasonal trading routes through the northern oceans and linking the North Atlantic and North Pacific Oceans. This might decrease the use of the Panama Canal and increase cargo traffic through Canadian waters instead (Luck et al. 2011). The opening of the Northwest Passage might result in new opportunities for species introductions to both oceans and affect survival rates of organisms in ballast water (shorter transit time) and on ship hulls (Hellman et al. 2008; Pyke et al. 2008). Canada in particular could receive more exotic species than before by cargo and cruise ships alike. The Arctic region will be unfavorable for a wide range of exotic species, but its low biodiversity and high sensitivity to any kind of disturbances make it ecologically vulnerable; the establishment of only a few species might impact the ecology of the region (Luck et al. 2011).
- Likewise, connection of geographically remote basins through human infrastructure or increased irrigation of agricultural lands to overcome water shortages resulting from climate change could also facilitate the entry and range of new and present invaders (Walther et al. 2009).
- Higher temperatures might increase possibilities for cultivation of new crops, which might lead to the introduction and spread of related pests. It might also increase the demand for the introduction of tropical ornamental plant species for which the climate would have previously been too cold (Luck et al. 2011). For example, there have already been requests from Europe to import seeds of certain Mexican tree species in order to experiment whether they would grow further north under climate change conditions.
- Climate change mitigation policies, focused on the reduction of greenhouse gases without considering secondary effects on biodiversity, might encourage new industries such as biofuel production, which in turn have impacts. Biofuel production will likely increase as climate warms, and might result in the introduction of new crop species to new areas, including genetically modified strains that have potential for escape and invasion (Sheppard et al. in press, in Luck et al. 2011). A variety of invasive species are proposed as biofuels such as giant reed *(Arundo donax),* castor bean (*Ricinus communis*), and pampas grass (*Miscanthus sinensis*) (Burgiel and Muir 2010) and there are also biofuel production efforts underway using jatropha (*Jatropha curcas)* and African oil palm *(Elaeis guineensis),* the latter in Mexico.
- Finally, people might also change their distribution in response to climate change; salt water intrusion, depleted water supplies, land degradation and sea level rise could result in population migration, which will affect pest invasions as invasive species and diseases are known to travel along (Low 2008). In addition, migrants will likely bring crops, domestic animals and ornamental species to their new

destinations, potentially increasing the dispersal of exotic species (Burgiel and Muir 2010).

3.5 Climate Change Effects on Pest Impacts

The effects of climate change on pest entry, establishment and spread discussed above will also affect the types and severity of impacts (or consequences, in IPPC terminology) that pests may have in a given area. Dukes (2011) defines the impact of an invasive species as a product of the following three conditions: 1) Size of the distribution range; 2) Abundance in the range and 3) The per capita effect on the ecosystem process. The IPPC guidelines for PRA consider economic, as well as environmental impacts, in terms of both direct and indirect effects (ISPM 11: 2004). Climate change could alter the impact of an invasive species by modifying any of these components. For example, in managed systems, climate change might cause shifts in production patterns, allowing new crops (and therefore new pest assemblages) to be grown in areas where they previously would not have survived. New crops in a given country will result in new pests of concern and potentially new impacts. Climate change might also lead to an overall increase of agricultural pests and higher crop losses if the efficacy of management and control techniques is negatively affected. For example, results of initial studies indicate a potential decline in chemical efficacy with rising CO_2 and/or temperatures for some weeds (Ziska and Goines 2006 and Archambault 2007 in Ziska et al. 2011). In natural systems, climate change might disrupt species interactions as species ranges move at different rates or in different directions and provide potential for entirely new species interactions. In extreme cases, climate-driven invasions could lead to completely transformed (novel) ecosystems where alien species dominate function or richness or both, leading to reduced diversity of native species (Hellman et al. 2008; Low 2008; Walther et al. 2009). As with climate change effects on pest behaviour, effects on pest impacts will be varied, complex, and dynamic and will also be both species- and situation-specific.

4 Global Change – the Interacting of Global Change Stressors

In addition to climate change, a large number of other interrelated factors affect the introduction, spread and impacts of pests and invasive species. These include anthropogenic stressors such as globalization of commerce, waterway engineering, land use changes, intentional stocking, pollution, habitat destruction and fragmentation, and overexploitation, all of which may increase the number or the impacts of invasive species (EPA 2008). In particular, a continued rapid increase in trade of plants and plant products is expected to result in new origins, new pathways and new pests, as well as potentially greater numbers of pests from nations such as China and India which have several different climate zones (EFSA 2007). Which of these many interconnected factors has the most impact will vary from case to case, and will depend on the specific context and the ecosystem at risk. In general, the simultaneous actions of all the intervening pressures are expected to result in synergistic effects, meaning that, in combination, these will have a greater total effect than the sum of their individual effects (Walther et al. 2009). However, scientific understanding of the complexity of climate change and other global change factors, the interactions between them, and the specific effects they could have on pest invasions, is still not well developed. For the purposes of this paper, we have chosen to focus on climate change in particular. The importance of other global change factors is acknowledged, but not discussed in further detail outside this section.

5 Climate Change and Pest Risk Analysis

The fundamentals of risk analysis are well-known and have a long history of practice in other disciplines. However, the systematic application of risk analysis methodologies for sanitary and phytosanitary decision making emerged more recently, mainly as a result the establishment in 1995 of the WTO and SPS Agreement. As the SPS Agreement came into force, governments suddenly became keenly aware of the need for pest risk analysis (PRA) capacity to justify their phytosanitary measures and also to evaluate the measures of their trading partners (See Appendix 1).

Pest risk analysis is an analytical tool that arose from the need for a methodology to characterize and manage pest risk. A PRA evaluates the probability of entry, establishment and spread of a pest in a given area, as well as the magnitude of the impacts it may have and the ability of selected measures to reduce the risk to an acceptable level. For risk to exist there must be an identifiable hazard, an adverse event, and by its nature, some level of uncertainty associated with what is known about the probability and the consequences of the adverse event.

Standards for PRA are well established and have been in effect under the IPPC since 1996. IPPC member countries have a commitment to use the PRA process to evaluate the risk associated with potential pests, and to justify the phytosanitary measures taken against them. Currently, PRAs are conducted based on information related to existing climatic and other ecological conditions and make predictions only about how a pest might behave under the given circumstances. However, growing awareness and concern about climate change in the scientific community has raised questions about the role of climate change predictions in the PRA process. While it is clear that climate change is occurring and will have an effect on the ability of pests to enter, establish, and spread in new environments, there are a number of challenges involved in making specific predictions about climate change and pest behaviour that must be taken into account.

As a result, opinions of the scientific community on whether or not to include climate change in the PRA process differ greatly. Some argue for the consideration of climate change in PRA (e.g., Kehlenbeck et al. 2007; Pyke et al. 2008; Ziska et al. 2011), some vote for a pragmatic case by case approach (Government of Canada 2008), and others consider current PRA sufficiently robust without taking climate change into account (EFSA 2007). A fundamental challenge is the level of uncertainty inherent in climatic and bioclimatic models, as well as issues of spatial and temporal scale and the need for PRA to be “fit-for-purpose”. Each of these is discussed in more detail below.

5.1 Uncertainty in Climatic and Bioclimatic Models

Predictions about long-term climatic processes and effects of climate change are based on mathematical models. The science of climate modeling has been steadily improving over the last several decades, as computer power has increased, along with our understanding of physical climate processes, available datasets, and improvement of computational algorithms. Climate modeling has “matured through finer spatial resolution, the inclusion of a greater number of physical processes, and comparison to a rapidly expanding array of observations” (Bader et al. 2008). Predictions made at the international level are based on averages from sets of models rather than any one individual model, and these climate simulations are extensively tested and subjected to intense scrutiny by hundreds of scientists in various areas of expertise (IPCC 2007; Bader et al. 2008). They provide average predictions for climate change at a global or regional level, that are consistent enough to give the scientific community confidence in broad trends: that climate change is occurring, that temperatures are rising on a global scale, and so on (e.g., IPCC 2007).

However, models by their nature are simulations of the real world, limited by the available data and involving a number of assumptions and uncertainties. A large number of important limitations are acknowledged by scientists working with current climate models, and in fact the construction of metrics for evaluating model performance has become a science in its own right (Bader et al. 2008). Different models still give a wide range of future predictions, highlighting the uncertainty inherent in modeling climate in the future (Mearns and Nychka 2007). Pest Risk Analysis is also a predictive process that involves significant uncertainty, and there is concern that using climate change models in PRAs may increase uncertainty to the point of compromising their utility.

Another pivotal issue in the discussion is the uncertainty inherent in bioclimatic models, also known as envelope models or ecological niche models, which are currently the primary tools for simulating the impact of climate change on species distributions. Bioclimatic models define suitable climate and habitat using species’ geographic distributions and are generally applied to regional risk assessments of the impact of climate change (Bradley et al. 2009).

While proponents of bioclimatic models stress that they are useful for handling complex data sets and provide a spatially explicit assessment of invasion risk at regional scales (e.g., Peterson 2003; Jeschke and Strayer 2008; Bradley et al. 2009), critics voice concern that they are limited because they only consider species-climate relationships and are not able to take into account other factors such as phenotypic plasticity of species (e.g., Jeschke and Strayer 2008 and references therein), nor do they incorporate other abiotic and biotic variables (Sutherst et al. 2007). Furthermore, their ability to forecast the effects of climate change or the spread of invaders has rarely been tested adequately (Jeschke and Strayer 2008). The uncertainty regarding projections for future change, and the type of envelope model selected strongly influences the reliability of the output of these models.

To address the latter, studies often use an ensemble of climate models, predictor variables, and climate change projections (Bradley et al. 2010). This means that researchers use multiple methodologies and climate change projections to forecast suitable habitats, and then combine these results to quantify the agreement (Araujo and New 2007; Bradley et al. 2010). Areas consistently predicted to be at risk of invasion by multiple methodologies and climate projections are assumed to be at higher risk than areas predicted to be at risk by only one or two models. Although model ensembles are likely to lead to a more robust forecast of distribution change than any single global climate model, this type of approach has not been widely implemented and is largely considered untested and controversial.

To illustrate, work by Beaumont et al. (2007) argues similarly by showing that climates simulated by repeatedly using the same climate model were more similar to each other than comparisons with other models. However, when projected into the future, these replicate simulations followed different trajectories and the values of climate variables differed considerably within and among climate models. Their results showed that internal climate model variability can lead to substantial differences in the extent to which the future distributions of species are projected to change. These can be greater than differences resulting from between-climate model variability. The researchers concluded that several climate models, each run multiple times, will likely be required to adequately capture the range of uncertainty associated with projecting species distributions in the future. This will greatly influence the uncertainty found within a PRA if such modeling is used to predict future invasions.

Overall, though modeling is very useful for handling complex data sets and simulating future climate change scenarios and impacts on invasive species on a broad scale, models should be used with caution in the context of a PRA, and critical assumptions, limitations, and the level of uncertainty should be transparent. Generally, models are limited by inaccurate or insufficient biological data. In the opinion of one group of scientists, models "were not considered sufficiently reliable as a predictive tool [in PRA] due to the lack of accurate biological data that provide the key parameters which influence the outcome. They could therefore give a false impression of accuracy" (EFSA 2007).

5.2 Climate change models and PRA – issues of spatial scale

As mentioned above, climate change models generally provide average predictions at a global or regional scale, and spatial resolution might not be sufficiently detailed in some cases to be relevant to the PRA process (EFSA 2007). Likewise, critics of bioclimatic models voice concern that their value for local levels is questionable as data used is of coarse resolution (Hulme 2003). Climatic factors such as temperature and rainfall, as well as CO_2 concentration, ozone concentration, humidity, solar radiation, and other ecological and habitat variables, might all vary on a local or micro-climate level that is significant to the survival and spread of pests and invasive species, but too detailed to be covered by predictive climate models.

For example, one way of improving the informative value of models and identifying regions most at risk for invasive species introductions is to merge regional climate projections with geographic information system layers such as transportation corridors and ports of entry to determine potential hot spots or suitable habitats for a given species and period (Government of Canada 2008). However, if regional models are required, there is the question of climate data availability and quality to be solved as climate data are more readily available at the global level. In case of the application of global climate models statistical downscaling becomes an issue. The use of eco-physiological models for instance requires detailed knowledge of the organism in question and is therefore more applicable to known species (Government of Canada 2008).

5.3 Climate change models and PRA – issues of temporal scale

As with spatial resolution, issues of temporal scale might also be an issue when considering climate change in the PRA process. Climate change models are generally based on 30-yr climate averages, and projections of at least 20 years are needed to make useful comparisons (EFSA 2007; Hellman et al. 2008). By contrast, PRAs often focus on a shorter time frame, as problems with pests and invasive species can be immediate and severe.

Discussions amongst an international group of pest risk assessors at the European Food Safety Authority's Scientific Colloquium in 2007 (EFSA 2007) indicated that there is no standard time frame for the validity of a PRA, although most countries update them on an ad hoc basis as new pest information becomes available. In addition, it was noted that "current" climate conditions used in most PRAs are based on available 30-year climate data for 1960-1990, which might already be out of date and not reflect the current situation (Magarey et al. 2008). In general, a shift towards longer-term time horizons might be appropriate in the PRA process, and the time frame need to be defined explicitly along with the PRA area (spatial scale) in the scope of the document.

5.4 Fit-for-Purpose: PRA as an IPPC Decision-Support Tool

It is important to remember that the purpose of a PRA is to help a member country decide if a particular organism is a pest, and whether phytosanitary measures should be taken to prevent its entry, establishment and spread. Although the process should be transparent and based on sound science, it is not intended to be an extensive exercise in scientific research for its own sake. Countries are often under pressure to make a large number of trade-related decisions in a short amount of time, in a manner that does not unjustifiably disrupt international trade. By contrast, climate and bioclimatic modeling are complex, resource- and time-intensive enterprises, and many risk assessors do not have the time or expertise to undertake them themselves. In some cases, the complexity of an issue or the severity of the potential consequences could make it worthwhile to seek out collaborations and incorporate models into a PRA, but in many cases this might not be necessary.

For example, a simple alternative to bioclimatic models are maps of plant hardiness zones as they don't require the input of biological parameters, or detailed distribution data which in many cases are not available for the species in question. Plant hardiness zones also have limitations, and are much coarser estimates than complex climate models. They are based only on average annual extreme minimum temperatures, while in reality plant survival is influenced by many factors (Magarey et al. 2008). However, climate matching with hardiness zones is a quick and easy method that provides a broad surrogate for potential plant distribution, and does not require a large amount of time or resources.

6 Legal Aspects of Interpretation of the Role of Climate Change in the Development of PRAs

In addition to the scientific challenges involved in considering climate change in PRAs, there are also legal aspects which should be considered. The World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures (WTO SPS) recognizes that member countries have the sovereign right to adopt measures necessary to protect its plant life and health (e.g. appropriate level of protection). At the same time members must ensure that these measures do not constitute an arbitrary or unjustifiable discrimination or a disguised restriction on trade.

To date, five disputes interpreting the role of PRA to justify sanitary and phytosanitary measures have traveled through the WTO dispute settlement process to Appellate Body review. Each has built upon the findings of the previous reports. In each case, phytosanitary measures were challenged in a variety of areas but were ultimately judged to be in violation solely *because of the inadequacy or inability of the risk analysis* to evidence the necessity of the measures under consideration without being overly restrictive. The interpretations of the SPS Agreement found in these reports provide some guidance as to when and where climate change can appropriately be considered in a PRA.

Taken together these reports present the following:

- Articles 2.2 and 5.1 of the SPS Agreement are interconnected. Countries are required to ensure that any phytosanitary measure adopted is applied only to the extent necessary to protect plant life or health, and base measures on scientific principles and sufficient scientific evidence. Thus Article 2.2 provides direction as to the requirements for the development of the risk assessment, that is, to provide sufficient evidence that these obligations have been met. Article 5.1 states that measures must be "based on" a risk assessment. The Appellate Body, in the EC Measures Concerning Meat and Meat Products (Hormones) report, interpreted the use of the term "based on" to imply a relationship between the measure and the risk assessment; one which could only be determined on a case-by-case basis. This conclusion that there must be an objective or rational relationship between a measure and the risk assessment determined on as case-by-case basis is referenced and reinforced in subsequent reports. It is this relationship that evidences that the SPS measure is warranted (WT/DS18/AB/R, WT/DS26/AB/R, WT/DS48/AB/R, WT/DS76/AB/R, WT/DS245/AB/R, WT/DS367/AB/R).
- Similarly, Article 2.3 relates to Article 5.5. In this case, countries, having adopted its appropriate level of protection, must ensure its measures do not discriminate between other member countries or constitute a disguised barrier to trade (Article 2.3). To that end, Article 5.5 lists as a risk assessment objective, the requirement that the assessment evidence that the measure meets those obligations.
- Annex A, paragraph 4 provides the definition of what constitutes a proper risk assessment and in doing so requires an evaluation of "likelihood". In this same report, the Appellate Body determined that the obligation to ensure measures are based on the available and sufficient scientific evidence requirement means that the risk assessment must look at ascertainable risk, i.e. what is "likely" or "probable", not what could be "possible". And in doing so commented "if a risk is not ascertainable, how does a Member ever know or demonstrate that it exists?" Therefore theoretical

uncertainty is not the risk to be assessed according to Article 5.1 and does not satisfy the definition of "risk assessment" set out in Annex A (WT/DS18/AB/R, WT/DS26/AB/R, WT/DS48/AB/R).

- The listing of factors to be considered in the risk assessment was not intended to be a closed list (Article 5.2-3), it merely needs to meet the requirements of Article 2.2, so where appropriate, climate change can be taken into consideration when developing a risk assessment but with the caveat that it must take into account the available scientific evidence, i.e. there must be an ascertainable risk identified; “theoretical uncertainty is not the kind of risk which under Article 5.1 is to be assessed” (WT/DS18/AB/R, WT/DS26/AB/R, WT/DS48/AB/R).
- The precautionary principle is not recognized in the SPS Agreement as grounds for justifying SPS measures, but precautionary measures can be adopted under certain circumstances (SPS Article 5). In this case, the additional information needed for the risk assessment must be developed within a reasonable period of time. Though what is considered a reasonable period of time is not defined, the Appellate Body found that this too must be determined on a case by case basis depending on the particular circumstances in each case, the difficulty of obtaining the additional information, and the characteristics of the particular provisional measures. (WT/DS/AB/R). So whereas the precautionary principle is not contained within the SPS Agreement, the need, under certain circumstances, to take additional precaution(s) is addressed and its provisional approach ensures that the action is not arbitrary or unjustified, and accordingly, a disguised barrier to trade (See Annex A).
- The application of provisional precautionary measures can only be triggered by the insufficiency of the scientific evidence, not by the existence of scientific uncertainty (WT/DS245/AB/R).
- The requirement that there must be a “rational relationship” between the measure and the risk assessment; with this relationship determined on a case by case basis means that a decision to include climate change will also be done on a case by case basis, again – based on the sufficiency of the scientific evidence.
- An important, but outstanding issue is what constitutes “sufficient” when determining what sufficient scientific evidence is as it relates to the ability to conduct a proper risk assessment and/or the necessity to adopt precautionary measures. The ordinary meaning of ‘sufficient’ is ‘of a quantity, extent, or scope adequate to a certain purpose or object’. From this, we can conclude that ‘sufficiency’ is a relational concept as well. The meaning of the term sufficient implies that a rational or objective relationship can be identified. However, the relevant scientific evidence will be considered “insufficient” if the available scientific evidence does not allow for an adequate risk assessment (WT/DS245/AB/R).

7. Conclusion and Recommendations

Overall, it is recognized that climate change is occurring, and will continue to occur into the future. It is clear that it will have significant effects on both biological and human systems, and will affect the ability of pests and invasive species to spread and establish, quite possibly resulting in an increased number and severity of invasions on a global scale.

The interaction of climate change with the other pressures involved in global change including trade patterns will increase the need for PRAs as well as the revision of existing ones to take into account changes in pest distribution and the likelihood of association with pathways (EFSA 2007). However, the decision about whether or not to consider climate change scenarios or incorporate complex models into a PRA will depend on feasibility, fit-for-purpose, and the rigour of the associated scientific support. International agreements (e.g., IPPC; SPS Agreement) and international case law indicate that PRA is intended to provide sufficient evidence that a chosen measure(s) is not arbitrary, unjustified, or a disguised barrier to trade. Therefore, climate change projections within a PRA must be sufficiently robust to meet these requirements. This suggests that the role of climate change in the conduct of PRA will need to be considered on a case-by-case basis.

The working group recommends that NAPPO take a “fit-for-purpose” approach for the inclusion of climate change scenarios and models in PRAs, with the decision made and transparently documented on a case-by-case basis. In particular:

- The decision as to whether or not to include climate change in a PRA should be based on an initial assessment of the complexity of the issue, the relevance of climate to the phytosanitary issue at hand, and whether or not there is sufficient scientific evidence to show a causal link between climate change and the risk being assessed.
- A brief statement documenting this decision could be included in the PRA, to indicate whether or not climate change was explicitly considered, along with a brief explanation as to why or why not.
- Information on climate data used in a PRA should be included and properly referenced regardless of whether climate change scenarios are explicitly considered. Climate is typically defined as a 30-year average of weather (hence the 30-year climate normal) and most climate maps and classification systems commonly used in assessing potential establishment and spread are based on 30-year averages. It would be helpful to document this where possible (e.g., “this map was developed using 30-yr climate data from 1960-90”).
- The time frame for which the PRA is considered to be “current” could be specified in the document, indicating that an update will be required after a particular amount of time. Currently, most PRAs are updated on an ad hoc basis when new information becomes available; a default stale date could increase transparency and help to ensure that PRA conclusions aren’t relied upon past their expected date of validity. One possible approach might be to link default stale dates to climate data used (e.g., PRA conclusions based on climate data from 1970-2000 would be valid until 2030, using the 30-year climate principle); however, stale dates can be based on other factors as well (e.g., new information about the biology of a pest, changing production practices, etc.). It may be useful to consider a list of conditions under which a PRA should be updated.

References

Agrawala, S. 1998. Context and early origins of the Intergovernmental Panel on Climate Change. Climatic Change 39: 605-602.

Araujo, M. B. and New, M. 2007. Ensemble forecasting of species distributions. Trends in Ecology & Evolution 22: 42-47.

Bader, D. C., Covey, C., Gutowski, W. J., Held, I. M., Kunkel, K. E., Miller, R. L., Tokmakian, R. T. and Zhang, M. H. 2008. Climate models: An assessment of strengths and limitations. U.S. Climate Change Science Program, Synthesis and Assessment Product 3.1. U.S. Department of Energy, Washington, DC, USA.

Bailey, L. G. and Bailey, E. Z. 1976. Hortus Third: A Concise Dictionary of Plants Cultivated in the United States and Canada. McMillan Publishing Co., New York, New York.

Bale, J. 2002. Herbivory in global climate research: direct effects of rising temperature on insect herbivores. Global Change Biology 8: 1-16.

Beaumont, L. J., Pitman, A. J., Poulsen, M. and Hughes, L. 2007. Where will species go? Incorporating new advances in climate modelling into projections of species distributions. Global Change Biology 13: 368–1385. doi:1310.1111/j.1365-2486.

Bradley, B. A., Blumenthal, D. M., Wilcove, D. S. and Ziska, L. H. 2009. Predicting plant invasions in an era of global change. Trends in Ecology and Evolution 25: 310-318.

Bradley, B. A., Wilcove, D. S. and Oppenheimer, M. 2010. Climate change increases risk of plant invasion in the Eastern United States. Biological Invasions 12(6): 1855-1872.

Britton, K. O., Orr, D. and Sun, J. 2002. Kudzu. Pages in R. V. Driesche, B. Blossey, M. Hoddle, S. Lyon and R. Reardon (Eds.), Biological control of invasive plants and weeds in the eastern United States. USDA Forest Service - Publication FHTET - 2002-04, Morgantown, WV, USA. 413 pp.

Burgiel, S. W. and Muir, A. A. 2010. Invasive species, climate change and ecosystem-based adaptation: Addressing multiple drivers of global change. Global Invasive Species Programme (GISP), Washington, DC, US, and Nairobi, Kenya. 55 pp.

CAB International 2007. Crop Protection Compendium. CABI. [Online] Available: http://www.cabi.org/compendia/cpc/index.htm [Cited 2011].

Cannon, R. 1998. The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. Global Change Biology 4: 785-796.

CBD 2009. Connecting biodiversity and climate change mitigation and adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. Technical Series No. 41. Secretariat of the Convention on Biological Diversity, Montreal, QC, Canada. 126 pp.

Dukes, J. S. 2011. Climate Change. Pages 113-117 in D. Simberloff and M. Rejmanke (Eds.), Encyclopedia of Biological Invasions. Encyclopedias of the Natural World. No 3. University of California Press, Berkeley, CA.

Dukes, J. S. and Mooney, H. A. 1999. Does global change increase the success of biological invaders? Tree 14: 135-139.

EFSA 2007. Pest risk assessment. Science in support of phytosanitary decision-making in the European Community. Summary Report, EFSA Scientific Colloquium10, 06-07 December 2007. European Food Safety Authority (EFSA) Parma, Italy. 200 pp.

Ehleringer, J., Cerling, T. and Helliker, B. 1997. C4 photosynthesis, atmospheric CO2 and climate. Oecologia 112: 285-299.

EPA 2008. Effects of climate change for aquatic invasive species and implications for management and research. United States Environmental Protection Agency (EPA), National Center for Environmental Assessment, Office of Research and Development, Washington, DC, USA.

EPPO 2007. Data sheets on quaratine pests. Pueraria lobata. EPPO Bulletin 37: 230-235.

Government of Canada 2008. Integrating climate change into invasive species risk assessment / risk management. Workshop report. Policy Research Initiative, Ottawa, Canada. 22 pp.

Harrington, R., Fleming, R. and Woiwod, I. 2001. Climate change impacts on insect management and conservation in temperate regions: can they be predicted? Agricultural and Forest Entomology 3: 233-240.

Harvell, C. D., E., M. C., Ward, J. R., Altizer, S., Dobson, A. P., Ostfeld, R. S. and Samuel, M. D. 2002. Climate warming and disease risks for terrestrial and marine biota. Science 296(5576): 2158-2162.

Hellman, J. J., Byers, J. E., Bierwagen, B. G. and Dukes, J. S. 2008. Five potential consequences of climate change for invasive species. Conservation Biology 22(3): 534-543.

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J. and Xiaosu, D. 2001. Climate Change 2001. The Scientific Basis. Cambridge University Press, Cambridge.

Hulme, P. E. 2003. Biological invasions: winning the science battles but losing the conservation war? Oryx 37(2): 178-193.

INE-SEMARNAT 2006. México. Tercera Comunicación Nacional ante la Convención Marco de las Naciones Unidas ante el Cambio Climático. S y G Editores S.A. de C.V., 254 pp.

INE-SEMARNAT 2009. Mexico. Cuarta Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático. S y G Editores S.A. de C.V., 274 pp.

IPCC 2007. Climate change 2007: Synthesis report. Contribution of working groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R. K. and Reisinger, A. (eds.)]. IPPC, Geneva, Switzerland. 104 pp.

IPPC Secretariat 2005. Identification of Risks and Management of Invasive Alien Species using the IPPC Framework. Proceedings of the Workshop on Invasive Alien Species and the International Plant Protection Convention, Braunschweig, Germany, September 22-26, 2003. FAO, Rome, Italy.

Jeschke, J. M. and Strayer, D. L. 2008. Usefulness of bioclimatic models for studying climate change and invasive species. Annals of the New York Academy of Sciences 1134: 1–24.

Karl, T. R., Melillo, J. M. and Peterson, T. C. (Eds.) 2009. Global climate change impacts in the United States. A State of Knowledge report from the U.S. Global Change Research Program. Cambridge University Press, Washington, D.C., USA.

Kehlenbeck, H., Schrader, G. and Unger, J.-G. 2007. Climate change: More vector transmitted plant pests? Presentation at: Proceedings of Vector-Borne Diseases: Impact of Climate Change on Vectors and Rodent Reservoirs, Berlin, Germany, September 27-28, 2007, Berlin, Germany.

Logan, J. A., Regniere, J. and Powell, J. A. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment(1): 130-137.
Low, T. 2008. Climate change & invasive species - A review of interactions. November 2006 Workshop Report. Biological Diversity Advisory Committee, Department of Environment, Water, Heritage and the Arts, Government of Australia, Canberra, Australia. 30 pp.

Luck, J., Campbell, I., Magarey, R., Isard, S., Aurambout, J.-P. and Finlay, K. 2011. Climate change and plant biosecurity - Implications for policy. Pages ?-? in Springer Biosecurity Handbook. Draft Manuscript Book Chapter submitted 20 May 2011.

Magarey, R. D., Borchert, D. M. and Schlegel, J. W. 2008. Global plant hardiness zones for phytosanitary risk analysis. Scientia Agricola 65(Special Issue): 54-59.

Mearns, L. and Nychka, D. 2007. Uncertainty in model simulations. The Weather and Climate Impact Assessment Science Program. University Corporation for Atmospheric Research. [Online] Available: http://www.assessment.ucar.edu/uncertainty_models/ [Cited 2011].

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution and Systematics 37: 637–669.

Parmesan, C. and Yohe, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37-42.

Pauchard, A., Kueffer, C., Dietz, H., Daehler, C. C., Alexander, J., Edwards, P. J., Arévalo, J. R., Cavieres, L. A., Guisan, A., Haider, S., Jakobs, G., McDougall, K., Millar, C. I., Naylor, B. J., Parks, C. G., Rew, L. J. and Seipel, T. 2009. Ain't no mountain high enough: plant invasions reaching new elevations. Frontiers in Ecology and the Environment 7(9): 479-486.

Peterson, A. T. 2003. Predicting the geography of species' invasions via ecological niche modeling. Quarterly Review of Biology 78: 419–433.

Petitpierre, B. C., Kueffer, C., Seipel, T. and Guisan, A. 2010. Will the risk of plant invasions into the European Alps increase with climate change? Presentation at: Neobiota 2010 Conference - Biological Invasions in a Changing World, from Science to Management, University of Copenhagen, Denmark.

Pyke, C. R., Thomas, R., Porter, R. D., Hellman, J. J., Dukes, J. S., Lodge, D. M. and Chavarria, G. 2008. Current practices and future opportunities for policy on climate change and invasive species. Conservation Biology 22(3): 585-592.

Régnière, J. and Bentz, B. 2007. Modeling cold tolerance in the mountain pine beetle, Dendroctonus ponderosae. Journal of Insect Physiology 53(6): 559-572.

Richardson, C. H. and Nemeth, D. J. 1991. Hurricane-borne African locusts (Schistocerca graegaria) on the Windward Islands. GeoJournal 23: 349–357.

Rodrigues, J. C. V., Ochoa, R. and Kane, E. 2007. First report of Raoiella indica Hirst (Acari: Tehuipalpidae) and its damage to coconut palms in Puerto Rico and Culebra Islands. International Journal of Acarology 33(1): 3-5.

Rogers, C. E. and McCarty, J. P. 2000. Climate change and ecosystems of the mid-Atlantic Region. Climate Research 14: 235-244.

Root, T., Price, J., Hall, K., Schneider, S., Rosenzweig, C. and Pounds, J. 2003. Fingerprints of global warming on wild animals and plants. Nature 421: 57-60.

SAGARPA-SENASICA 2010. Tríptico de Acaro rojo de las Palmas (Raoiella indica). Vigilancia Epidemiológica Fitosanitaria. Comité Estatal de Sanidad vegetal de Chiapas, Chiapas, Mexico.

Sánchez, A. H., Cibrián-Tovar, J., Osorio, J. and Aldama, C. 2007. Impacto económico y social en caso de introducción y establecimiento de la palomilla del nopal, Cactoblastis cactorum en México. Organismo Internacional de Energía Atómica (OIEA) y la Dirección General de Sanidad Vegetal, México, 43 pp.

Schneider, R. W., Hollier, C. A., Whitam, H. K., Palm, M. E., McKemy, J. M., Hernandez, J. R., Levy, L. and DeVries-Paterson, R. 2005. First report of soybean rust caused by Phakopsora pachyrhizi in the continental United States. Plant Disease 89: 774.

Shi, J., You-Qing Luo, Y.-Q., Zhou, F. and He, P. 2010. The relationship between invasive alien species and main climatic zones. Biodiversity and Conservation 19: 2485–2500.

Sutherst, R. W., Maywald, G. F. and Bourne, A. S. 2007. Including species interactions in risk assessments for global change. Global Change Biology 13: 1843–1859.

Tanaka, H. and Larson, B. 2006. The role of the International Plant Protection Convention in the prevention and management of invasive alien species. Pages 56-62 in F. Koike, M. N. Clout, M. Kawamichi, M. DePoorter and K. Iwatsuki (Eds.), Assessment and Control of Biological Invasion Risks. Shoukadoh Book Sellers, Kyoto, Japan and IUCN, Gland, Switzerland.

USDA-ARS 2011. Germplasm Resources Information Network - (GRIN) [Online Database]. National Germplasm Resources Laboratory. [Online] Available: http://www.ars-grin.gov/cgi-bin/npgs/html/tax_search.pl [Cited 2011].

USDA 1990. USDA Plant Hardiness Zone Map. USDA Miscellaneous Publication No. 1475. [Online] Available: http://www.usna.usda.gov/Hardzone/ushzmap.html [Cited 2011].
Walther, G.-R., Roques, A., Hulme, P. E., Sykes, M. T., Pyšek, P., Kühn, I., Zobel, M., Bacher, S., Botta-Dukát, Z., Bugmann, H., Czúcz, B., Dauber, J., Hickler, T., Jarošík, V., Kenis, M., Klotz, S., Minchin, D., Moora, M., Nentwig, W., Ott, J., Panov, V. E., Reineking, B., Robinet, C., Semenchenko, V., Solarz, W., Thuiller, W., Vilà, M., Vohland, K. and Settele, J. 2009. Alien species in a warmer world: risks and opportunities. Trends in Ecology & Evolution 24(12): 686-693.

Welbourn, C. 2009. Pest alert: Red palm mite Raoiella indica Hirst (Acari: Tenuipalpidae). Florida Department of Agriculture & Consumer Services, Division of Plant Industry. [Online] Available: http://www.freshfromflorida.com/pi/enpp/ento/r.indica.html [Cited 2011].

White, T., Campbell, B., Kemp, P. and Hunt, C. 2001. Impacts of extreme climatic events on competition during grassland invasions. Global Change Biology 7: 1-13.

Willis, C. G., Ruhfel, B. R., Primack, R. B., Miller-Rushing, A. J., Losos, J. B. and Davis, C. C. 2010. Favorable climate change response explains non-native species' success in Thoreau's woods. PLoS ONE 5(1): e8878.

WT/DS18/AB/R 1998. Australia - Measures Affecting Importation of Salmon. [On line: www.wto.org].

WT/DS26/AB/R, WT/DS48/AB/R 1998. EC Measures Concerning Meat and Meat Products (Hormones). [Online: www.wto.org].

WT/DS76/AB/R 1999. Japan - Measures Affecting Agricultural Products. [Online: www.wto.org].

WT/DS245/AB/R 2003. Japan - Measures Affecting the Importation of Apples. [Online: www.wto.org].

WT/DS367/AB/R 2010. Australia - Measures Affecting the Importation of Apples from New Zealand. [Online: www.wto.org].

Zavaleta, E. S. and Royval, J. L. 2002. Climate change and the susceptibility of U.S. ecosystems to biological invasions: Two cases of expected range expansion. Pages 277-342 in S. H. Schneider and T. L. Root (Eds.), Wildlife Responses to Climate Change – North American Case Studies. Island Press, Washington, DC, USA.

Zimmermann, H., Bloem, S. and Klein, H. 2004. Biology, history, threat, surveillance and control of cactus moth, Cactoblastis cactorum. Food and Agriculture Organization of the United Nations (FAO) & International Atomic Energy Agency (IAEA), Vienna, Austria. 40 pp.

Ziska, L. H., Blumentha, D. M., Runion, G. B., Hunt, E. R. J. and Diaz-Soltero, H. 2011. Invasive species and climate change: an agronomic perspective. Climatic Change 105: 13-42.

Annex 1: The Role of Precaution

There is an international debate regarding the role of *precaution* in the regulation of plant pest risk. It is focused on a concept known as the precautionary principle. This principle, simply put, states that harm to the environment, should be avoided in advance. As with a risk-based approach, it emphasizes prevention rather than a curative approach, but it goes further than seeking protection from known or suspected risks. Although there is not one definition of the precautionary principle, it generally asserts that the lack of evidence of risk or harm does not mean that something is not risky or possibly harmful therefore more precaution should be taken where information is lacking. In other words, it holds that uncertain risk requires forbidding a potentially risky activity until it can be demonstrated that the activity poses no (or an acceptable) risk.

While recognizing the rights of sovereignty in regards to the determination of what constitutes an appropriate level of phytosanitary protection (acceptable risk), the crafters of the SPS Agreement sought a balance in its requirement that measures taken be applied only to the extent necessary and must not be maintained without sufficient scientific evidence. To that end, the requirement that measures be based on risk assessment was intended as a countervailing factor to balance the shared, but sometimes competing, interests of facilitating trade while protecting plant, animal, and human life and health. The exception, found in Article 5.7, that recognizes the role of precaution, where relevant scientific information is insufficient, is the provision that allows such action to be taken with the caveat that the information needed to conduct an objective risk assessment will be developed in a timely manner. So whereas the precautionary principle is not contained within the SPS Agreement, the need, under certain circumstances, to take additional precautionary measures is addressed and its provisional approach is intended to ensure that the action is not arbitrary or unjustified, and accordingly, a disguised barrier to trade.

A properly done risk assessment not only provides decision-makers and stakeholders with a clear estimation of the risk and potential for harm, but it also provides an awareness of any information that might be lacking and the significance of that insufficiency to the conclusions drawn. Properly used, *precaution* is the means to account for and address the lack of sufficient scientific evidence. More importantly, when it is determined that phytosanitary, or quarantine, level action is necessary; it provides the evidence that the measures chosen are legitimate.

Appendix 1: Phytosanitary Treaty Background

The SPS Agreement is a treaty established to promote international trade by ensuring that members' sanitary and phytosanitary measures are not a disguised barrier to trade while continuing to recognize a member's sovereign right to determine its own appropriate level of phytosanitary protection. Although the SPS Agreement prefers that member countries to adopt international standards; a member country can choose impose stricter measures if it can show that these are necessary to achieve its appropriate level of protection. For phytosanitary issues, the SPS Agreement identified the IPPC Secretariat as the party responsible for developing international standards for plant health issues. Standards it has developed to date include standards for the conduct of pest risk analysis.

The IPPC itself is also a multilateral treaty deposited with the Director General of the Food and Agriculture Organization of the United Nations. Its purpose has always been to foster international cooperation in the control of pests of plants and plant products and prevent their spread between countries. Originally adopted in 1951, it was revised in 1997 to reflect the role of the IPPC in relation to the SPS Agreement and its Secretariat was created.

Countries which adhere to IPPC standards are presumed to meet their obligations under the SPS Agreement and therefore are considered safe from dispute challenges. If a member country chooses not to base its phytosanitary measures on relevant international standards, or in cases where an applicable standard does not exist, that country is required to verify that the measures imposed are necessary, transparent and based in science by way of an assessment, as appropriate to the circumstances, of the risks posed to plant life and health. Such scientific justification is the role of PRA. PRA is the methodology required to estimate the potential for entry, to cause harm, ascertain the level of protection and strength of measures needed.

The WTO (as well as the IPPC and NAPPO) has a dispute settlement system. Members have agreed that if they believe a fellow-member has adopted a trade policy or measure that is not valid, they will not take action, but instead make use of the dispute settlement rules and procedures. Arbitration of such disputes has interpreted and clarified the requirements of the SPS Agreement.