

Preliminary assessment of the potential impacts and risks of the invasive cactus moth, *Cactoblastis cactorum* Berg, in the U.S. and Mexico

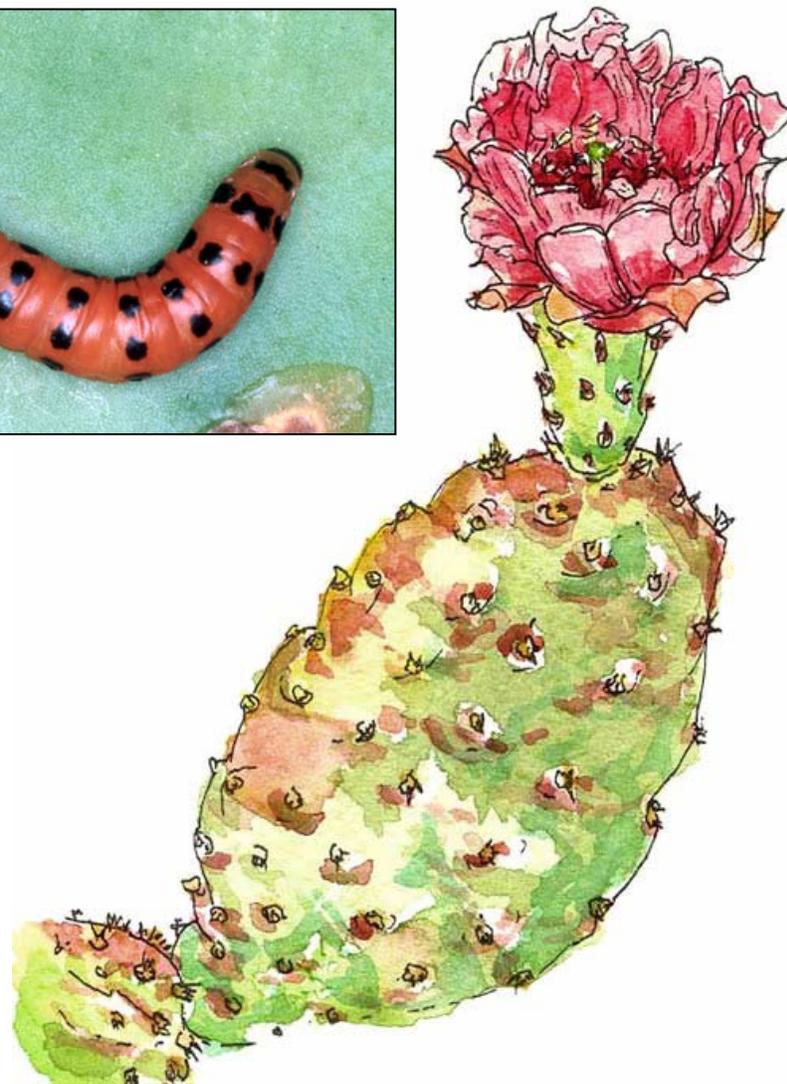
Final Report to the International Atomic Energy Agency, April 25, 2005 © IAEA 2005

By Simonson¹, Sara E.; Stohlgren, Thomas J.²; Tyler, Laura¹; Gregg, William P.^{2*}; Muir, Rachel^{2*}; and Lynn J. Garrett³

¹Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523

²National Institute of Invasive Species Science, U.S. Geological Survey, Biological Resource Discipline, Fort Collins Science Center, Fort Collins, CO 80526, * = NIISS partners.

³Agricultural Economist USDA, APHIS, PPQ- CPHST, Raleigh, NC 27606



Left: The brightly colored larva of the cactus moth *Cactoblastis cactorum* Berg feeds on prickly pear cactus (mainly *Platyopuntia* species). The rapid spread of the invasive cactus moth poses a threat to many valuable native and cultivated prickly pear cactus species in the Southwest United States and Mexico. Photo courtesy of Helmut Zimmermann and Hildegard Klein. *Right:* Yellow beavertail prickly pear, *Opuntia aurea* E.M. Baxter, is a species of conservation concern in Arizona and Utah. Artwork courtesy of Donald Davidson ©2004, Traveling Artist Wildflowers Project, National Park Service, U.S. Department of the Interior <http://www.nps.gov/plants/cw/watercolor/info/opau2-a.htm>

Preliminary assessment of the potential impacts and risks of the invasive cactus moth, *Cactoblastis cactorum* Berg, in the U.S. and Mexico

Simonson, S.E., T. J. Stohlgren, L. Tyler, W. Gregg, R. Muir, and L. Garrett

Executive Summary:

Cactoblastis cactorum Berg (the cactus moth) has become a serious threat to the high diversity of *Opuntia* (prickly pear cactus) species and throughout the world, both native and cultivated (IAEA 2002). The accelerating rate of spread in the Southeast United States and the biological potential for invasiveness suggests that the cactus moth is likely to become an invasive pest of *Opuntia* in Mexico and the southwestern United States. Damage is predicted to be limited mainly to the *Platyopuntia* species (plants with the typical flat prickly pear pads). We gathered datasets and consulted with experts to assess the threat and potential impact to the many areas where native and cultivated *Opuntia* cacti provide valuable resources for humans, livestock, and wildlife.

If the *Cactoblastis cactorum* spreads to western U.S. desert ecosystems and Mexico, 80+ native *Opuntia* species could be affected, threatening important sources of food, medicine, and emergency fodder. In arid regions, the plants play key roles in ecosystem processes and soil conservation. Preliminary maps and models show vast areas where *Opuntia* resources are significant and habitat conditions are suitable for the invasive cactus moth. Available information suggests that cactus moth establishment and devastating effects are likely across vast areas of the Southwest U.S. and Mexico. The critical timing and large extent of this threat demands immediate, coordinated action to monitor and prevent the spread of this major environmental pest affecting both agriculture and the environment.

Within the next three years, there is a high risk of economic, social, and environmental damage in plantings and native habitats in these areas. *Opuntia* plants maintain a valuable role in agriculture, and in sustaining unique ecosystems and wildlife. Increasing importance of areas in *Opuntia* cultivation and reliance on food and income from products means that invasion by *Cactoblastis cactorum* has the potential to impact large regions, commercial industries, and thousands of subsistence farmers. The potential magnitude of impact on biodiversity and ecosystems requires immediate action.

Response options are limited as chemical pesticides are largely ineffective and potential biological control organisms pose risks to native species. An integrated approach holds some promise for halting or at least slowing the invasion front, including education for prevention, early detection using pheromone traps, mechanical removal of infected plants, and the area-wide application of the sterile insect technique. Although the impact was only partially assessed, available data clearly indicate that social, environmental and economic costs of invasion are likely to be high. An effective response depends on the best available knowledge on history, biology, identification, surveillance and control.

Key findings of this initial impact and risk assessment

1. Economic, social, and environmental damage would be highly significant if *Cactoblastis cactorum* spreads and establishes in the Southwest United States and Mexico.
2. Based on this preliminary assessment of risks and impacts, the likelihood of further spread is high if no effective action is taken in the short term.
3. Threats to *Opuntia* resources span the U.S. and Mexico, along with other areas throughout the world.
4. This assessment highlights a lack of datasets and limitations on data transfer.
5. Surveys are needed for early detection of further spread of the invasive moth, and large scale inventory and monitoring of native and cultivated *Opuntia* resources that are at risk.
6. Data sharing, synthesis, and program support are needed for an integrated effective response.

Table of Contents

Executive Summary:.....	2
Introduction and Objectives:	3
Methods and Scope:	4
Results:	5
Stage 1: Initiating the process of identifying the important pest problems and pathways	5
<i>Step 1</i> Recent events and concerns over the expanding range of <i>Cactoblastis cactorum</i>	5
Stage 2: Assessing pest risk in terms of likelihood	5
<i>Step 2</i> Assess invasive potential of the cactus moth, <i>Cactoblastis cactorum</i>	5
<i>Step 3</i> Previous risk assessments, current status of importations and pertinent pest interceptions	8
<i>Step 4</i> Pest categorization	9
<i>Step 5</i> Assess consequences of introduction	11
Risk Element #1: Climate-Host Interaction	11
Risk Element #2: Host Range	12
Risk Element #3: Dispersal Potential	13
Risk Element #4: Economic Impact	14
Risk Element #5: Environmental Impact	20
<i>Step 6</i> Assess introduction potential	24
Stage 3: Management	25
<i>Step 7</i> Management options and pest risk potential of the cactus moth, <i>Cactoblastis cactorum</i>	25
Conclusions:.....	28
References Cited:	29

Tables and Figures:

Table 1 Stages and steps towards an assesment of risks and potential impacts of the cactus moth	4
Table 2 Known distribution of <i>Cactoblastis cactorum</i>	6
Table 3 National and international lists and documents include evidence of the invasive potential	7
Table 4 Summary of U.S. interceptions	9
Table 5 U.S. <i>Opuntia</i> produce imports from Mexico for years 2000-2003	16

Figure 1 This overlay of two predictive maps shows vast areas in the U.S. and Mexico that have a suitable climate and plenty of food species for the cactus moth, <i>Cactoblastis cactorum</i>	12
Figure 2 Summary of <i>Opuntia</i> product imports from Mexico 2000-2003	15
Figure 3 The semaphore cactus (<i>Opuntia corallicola</i>) is an extremely rare species native to Florida that is threatened by the cactus moth	22

Introduction and Objectives:

The cactus moth, *Cactoblastis cactorum* Berg (Pyralidae) is known as the best example of successful biological control of weeds in Australia and many locations worldwide. Detected in Florida in 1989, the cactus moth has established in areas as far north as South Carolina and as far west as the Florida panhandle. In Florida, it feeds on the pads of all six *Opuntia* species (prickly pear cactus), including rare and endangered species that are threatened by the moth. *Cactoblastis cactorum* has been rapidly expanding its range along the Gulf of Mexico, and pathways of introduction to the southwestern U.S. and Mexico likely include both natural dispersal and commercial trade. This assessment report was commissioned by the International Atomic Energy Agency in order to increase awareness of the potential social, economic, and environmental impacts and risks of this invasive species problem. Our objective for this preliminary assessment was to gather available datasets and consult with experts to assess the threat and potential impact of the invasive spread of the cactus moth to the many areas where native and cultivated *Opuntia* cacti provide valuable resources for humans, livestock, and wildlife in the Southwest United States and Mexico.

Methods and Scope:

This assessment of the impacts and risks of the cactus moth, *Cactoblastis cactorum* Berg, in the U.S. and Mexico is an initial step in the complete risk analysis process that is needed to assess and manage the risk of this terrestrial insect pest to ecological, economic, and social values. Important pathways of spread include natural dispersal and many types of human-aided transportation dispersal, not limited to infected cactus plants in nurseries and gardens. Therefore the assessment process for this species is “pest initiated” (pest found in new areas, intercepted at port of entry, etc.), and “pathway initiated” (trade is initiated in a new commodity or location). As discussed at the Interagency Planning Meeting in Miami, December 9-10, 2003, <http://www.invasivespecies.gov/docs/cactoblastis.pdf>, the contents of this assessment include information related to the stages and steps of the Guidelines for Pathway-Initiated Pest Risk Assessments (USDA APHIS 2000). These include six steps for a qualitative risk assessment, and preliminary recommendations for management, the seventh step in the risk analysis process (Table 1).

Assessment of risk is one of three stages in the complete risk analysis process:

Stage 1: Initiating the process of identifying important pest problems and pathways

Stage 2: Assessing pest risk (in terms of likelihood)

Stage 3: Managing pest risk and developing options for an effective response

Assessment of pest risk involves determining which pests and products require quarantine, based on the likelihood of occurrence and the magnitude of consequences. Hazards are characterized in terms of likelihood of entry, establishment, spread and economic importance. In evaluating likelihood, the focus is on ‘scenarios’ or ‘pathways,’ rather than on narrative accounts of the biology of a pest. This requires consideration of the advantages and constraints of qualitative and quantitative approaches used to evaluate likelihood. Qualitative risk analysis approaches are widely used because probability data is not required and potential loss is estimated by making use of a number of interrelated elements including hazards, vulnerabilities, and mitigation's.

International definitions of quarantine pests are used in the assessment process: a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (FAO 1996, USDA 2000).

Table 1

Stages and steps towards an assessment of the risks and potential impacts of the cactus moth

Guidelines adapted from USDA APHIS 2000 <http://www.aphis.usda.gov/ppq/praguide/cpraguide.pdf>

Stage 1:

Initiating the process of identifying the important pest problems and pathways

Step 1 Document initial events and recent concerns about the cactus moth, such as importation of a new commodity or new pathways for introduction.

Stage 2:

Assessing pest risk (in terms of likelihood)

Step 2 Assess invasive potential, of the cactus moth.

- a. Is the species new to or not widely prevalent in the area?
- b. Is the species noted as a problem invasive in national or international lists and references?

Step 3 Gather previous assessments and available information.

- a. Identify and cite previous risk assessments.
- b. Discuss current status of importations (of *Opuntia*).
- c. Summarize pertinent pest interceptions at ports in U.S. and Mexico.

Step 4 Pest Categorization and quarantine information.

- a. List pests, the commodity parent species and their quarantine status.
- b. Identify potential associated quarantine pests.
- c. Identify quarantine pests likely to follow the pathway.

Step 5 Assess potential consequences of introduction.

The undesirable outcomes being considered are the negative impacts resulting from the introduction of quarantine pests. For each of these quarantine pests expected to follow the pathway, the potential consequences of introduction are rated

using five risk elements that reflect the biology, host ranges and climatic/geographic distributions of the pests. For each Risk Element, pests are assigned a rating of Low (1 point), Medium (2 points) or High (3 points).

Risk Element #1: Climate-Host Interaction

Risk Element #2: Host Range

Risk Element #3: Dispersal Potential

Risk Element #4: Economic Impact

Risk Element #5: Environmental Impact

In this assessment, the risk elements 4 and 5 are of particular interest as they deal with the economic and environmental impacts.

Cumulative Risk Rating (sum of all Risk Element values)

Step 6 Assess introduction potential for each quarantine pest expected to follow the pathway, including environmental impacts, likelihood of establishment and spread, and economic importance in the area.

Stage 3:

Managing pest risk and developing options for an effective response.

Step 7 Conclusions and comments on management options and recommended prevention measures.

Results:

Preliminary impact and pest risk assessment of the cactus moth in the U.S. and Mexico

Stage 1: Initiating the process of identifying the important pest problems and pathways

***Step 1* Recent events and concerns over the expanding range of the cactus moth**

The cactus moth, *Cactoblastis cactorum* Berg, is native to northern Argentina and parts of Peru and Paraguay, and has been released into many parts of the world for the control of several *Opuntia* species. It was introduced into the Caribbean islands in the 1960's, and by 1989 had found its way to Florida (Habeck and Bennet 1990). By 2003, the cactus moth had established in Florida, Georgia, and along the Atlantic coast almost as far north as Charleston, South Carolina (Hight et al., 2002, Bloem 2003). At the end of 2003 it had spread as far west as Pensacola, Florida, near the Alabama state-line. The pest has moved further and in July, 2004, a population was detected on Dauphin Island, Alabama (Stephen Hight, USDA, pers. comm., 2004). Also in July 2004, the cactus moth was found about 50 miles north of Charleston, SC, in Bull Island, SC (Randy Westbrook, USGS, pers. comm., 2004). Not yet known to occur in the southwestern United States and Mexico (or if present it is not widely distributed), the cactus moth now poses a threat to the high native diversity and agricultural value of *Opuntia* species in those areas.

The main concerns leading to this assessment are the potential devastating effects and the accelerating rate of spread of the cactus moth in the Southeast U.S. First detected in the United States in 1989 in the Florida Keys, it has since spread as far north as Bull Island, South Carolina, and as far west as Dauphin Island, Alabama (Hight et al., 2002, Bloem 2003, Stephen Hight, USDA, personal communication, 2004). All six species of native prickly-pear cactus have been attacked in Florida (Johnson and Stiling 1996, Stiling 2002) and during the past three years the spread rate has accelerated to a significantly higher rate of 158 kilometers per year (Bloem 2003). This increased rate of spread would place the moth at the Louisiana-Texas border by 2007 (a rough estimate based on the continued rate of spread of 158km/year). If unchecked, the spread of cactus moth to the west will negatively impact the prickly-pear cactus rich areas of the southwestern United States (Texas, New Mexico, Arizona, and California), and Mexico.

Opuntia has significant economic and agricultural value. The increasing importance of *Opuntia* species in natural, urban and agricultural landscapes emphasizes widespread vulnerability to the threat of invasion. *Opuntia* resources are particularly valuable in Mexico where cactus is a major agricultural product, a critical subsistence food for millions of Mexicans, a major component of the arid and semiarid ecosystems and an integral part of the culture. In Mexico and the U.S., demand for the prickly pear pad leaves (nopales) and fruit (tunas) includes the fresh and processed food market. The U.S. is an importer of edible prickly pear cactus from Mexico and other countries. Cultivation of prickly pear cactus is of increasing importance in U.S. agriculture as a specialty food crop and as emergency fodder during drought conditions. There is also significant commercial value in the ornamental nursery and landscape industries.

Stage 2: Assessing pest risk (in terms of likelihood)

***Step 2* Assess invasive potential of the cactus moth**

a. Is the species new to or not widely prevalent in the area?

Yes. The cactus moth pest, *Cactoblastis cactorum*, is new to or not widely prevalent in the Southwest U.S. and Mexico (see Table 2). With a type locality in northern Argentina, the native range of the cactus moth in South America extends from northeastern Argentina through Uruguay, Paraguay and into the province of Matto Grosso in Southern Brazil (Garcia-Tuduri 1971). It was introduced widely as a biological control agent of *Opuntia*, prickly-pear cactus (Cactaceae) in Australia, South Africa, Hawaii, Mauritius, the West Indies, and other areas where prickly-pear cacti exist as an invasive plant species (Neunzig 1997). It is now present in the southeastern United States, Cuba, and other Caribbean islands. In the U.S. it has established along the coast of Florida, Georgia, and South Carolina., and a population was recently detected on a barrier island in Alabama. The moth is not yet documented from Mexico, although there have been interceptions, such as that of an infected *Opuntia* fruit intercepted at the Laredo, Texas airport from Mexico in 1995 (Pemberton 1995, Stiling 2002).

Table 2

Known distribution of the cactus moth, *Cactoblastis cactorum* Berg

(Joel Floyd, USDA, pers. comm., 2004, for more information see Zimmermann et al., 2004)

Africa:	South Africa (introduced 1933), Mauritius (introduced, 1950), Tanzania (introduced, 1958), Kenya (introduced 1966, establishment unconfirmed), Zimbabwe (unconfirmed), Namibia (unconfirmed)
Asia:	Pakistan (introduced 1994, establishment unconfirmed)
Australia:	Australia, (introduced, 1926)
Atlantic Islands:	St. Helena, (introduced, 1971), Ascension Island (introduced 1973)
Pacific Islands:	Hawaii (introduced, 1950), New Caledonia (introduced, 1933)
Europe:	Not known to occur
Central America:	Not known to occur
North America:	Florida (1989 natural dispersal or on imports), Georgia (2000, natural dispersal), South Carolina (2001, natural dispersal), Alabama (2004, natural dispersal)
South America:	Argentina (native), Brazil (native) Paraguay (native), Uruguay (native)
West Indies:	Nevis (introduced, 1957), Antigua (introduced, 1950), Trinidad (1956), St. Kitts (date not available), Puerto Rico, (date no available), US Virgin Islands (date not available), Montserrat (introduced, 1960), Cayman Islands (introduced 1970), Cuba (1980)

b. Is the species noted as a problem invasive in national or international lists and references?

Yes. The cactus moth, *Cactoblastis cactorum*, has become a threat to the high diversity of both native and cultivated *Opuntia* species throughout the world (IAEA 2002). Predicted pathways of invasive spread are from Florida or Cuba to the southern United States (Texas, Arizona, New Mexico, Nevada, California) and Mexico (Soberon et al., 2001), where the economic, social, and environmental effects would be devastating. In vast areas of the Southwest U.S. and Mexico, the cactus moth is recognized as an upcoming invasive threat to prickly-pear cactus (Solis et al., 2004).

Renowned success of this species as a biological control agent lends support for the invasive potential of this organism. In the early 1800s, Australian cattle ranchers imported prickly pear cactus from the Americas with the notion of making them natural fences. The cactus thrived and by the 1920s 24 million hectares (60 million acres) of land were covered by such extensive growth of cactus that about half of the area could no longer be used for agriculture or grazing. In 1925, the cactus moth was imported from Argentina. Many insects were introduced to try to reduce the cactus, but *Cactoblastis cactorum* was the most effective consumer and quickly cleared many *Opuntia* dominated areas. By the early 1930's approximately 90% of the prickly pear population had collapsed (Dodd 1940). All subsequent movement of the cactus moth for biological control derives from the original 40 egg sticks (approximately 2,750 eggs) brought to Australia in 1925 (Bloem 2003).

The cactus moth, *Cactoblastis cactorum* Berg, continues to have an impact in the native range as a common pest of (*Opuntia ficus-indica*) cultivations in the Northeastern region of Argentina (Lobos et al.,

2002). It is also a problem pest in many other countries where it was introduced as a biological control agent. In South Africa cactus pear growers follow a rigorous control program against the cactus moth in order to stay in production. If neglected for a few seasons, entire plantations of *Opuntia ficus-indica* (fruit and fodder) and *Opuntia robusta* (fodder) have been destroyed by the moth. Damage to invaded plants is often exacerbated by secondary bacterial infections that can kill large plants in a single season. However, while commercial plantations of *Opuntia ficus-indica* are significantly impacted by the cactus moth in South Africa, it is also considered a beneficial biological control agent against various non-native *Opuntia* species that have become an invasive problem there. In Australia *Opuntia stricta* has been reported as rare, even in places where it once formed a continuous cover (Stange 1995). In northeast Cuba it was documented that “within a few days of the initial discovery, all the plants of the patch had died and the pads had dried up” (Hernandez and Emmel 1993). In Hawaii, seedling plants of *Opuntia megacantha* were observed to be eaten to the ground (Fullaway 1954).

The most serious threats, however, are to the many wild species of *Opuntia* in the Caribbean and Central and North America, particularly in Mexico which has the highest diversity of species, a globally important biological resource. It will be virtually impossible to control or even contain this invasive moth once it has naturalized in the wild, which may be the final blow to several endangered *Opuntia* species (IAEA 2002). Furthermore, it is predicted to be particularly damaging to new species with which it has not previously been associated, including many valued cactus species in Mexico and the U.S.

The threat of the cactus moth to other important regions of the world should not be ignored. Countries like Tunisia, Spain, Italy (Sicily), Algeria, Israel, etc. have large cultivations of *Opuntia ficus-indica* and the arrival of the cactus moth in these countries could be devastating. The value of cactus to combat desertification and its use on marginal lands is widely recognized and any limitation imposed on such developments may deprive people of a tool to improve rural livelihood in resource-limited countries.

Table 3

The cactus moth is recognized as a harmful invasive species by many agencies and organizations, and national and international lists and documents include evidence of the invasive potential.

Mexican National Commission on Biodiversity (CONABIO) <i>Cactoblastis cactorum</i> , una nueva plaga de muy alto riesgo para las opuntias de México http://www.conabio.gob.mx/institucion/conabio_espanol/doctos/cactoblas.html
Invasive species.gov Species Profile on <i>Cactoblastis cactorum</i> (Berg) Cactus moth, Prickly pear moth http://www.invasivespecies.gov/profiles/cactmoth.shtml
USDA-APHIS Cactus Moth - Pest Detection and Management Programs Weekly Notice (January 19, 2004 - page 4) [U.S. Department of Agriculture, Animal & Plant Health Inspection Service]
Invasives Alert: <i>Cactoblastis cactorum</i> http://tncweeds.ucdavis.edu/alert/alrtcact.html , http://tncweeds.ucdavis.edu/products/gallery/cacca1.html
Cactus Moth (<i>Cactoblastis cactorum</i>) Planning Meeting Interagency planning meeting, December 9 - 10, 2003 in Miami, Florida. Hosted and Sponsored by USDA, APHIS, PPQ with Co-sponsors: US Geological Survey and USDA, Agriculture Research Service, with the Interagency Committee on Invasive Terrestrial Animals and Pathogens (ITAP)
Expanding Geographical Range of <i>Cactoblastis Cactorum</i> (Lepidoptera: Pyralidae) in North America [Florida Entomologist Journal, September 2002 (vol. 85, No. 3, pp 527-529)]
Cactoblastis Cactorum in North America: Proceedings of a workshop for assessment and planning - 2000 [Florida Entomologist Journal, December 2001 (vol. 84, no. 4, pages 465-751)]
<i>Cactoblastis cactorum</i> [European and Mediterranean Plant Protection Organization (EPPO) Alert List] http://www.eppo.org/QUARANTINE/Alert_List/insects/cactoblastis.htm
Case Study 3.8 - Spread of a Biological Control Agent, <i>Cactoblastis cactorum</i> , in the Caribbean Basin [CAB International on behalf of the Global Invasive Species Program] http://www.cabi-bioscience.ch/wwwgisp/gtc3cs8.htm
North American Plant Protection Organization, Phytosanitary Alert System (NAPPO) <i>Cactoblastis cactorum</i> (Berg) 1885 http://www.pestalert.org/Detail.CFM?recordID=73
Cactoblastis: Classical Beauty or Invasive Beast? CABI http://pest.cabweb.org/Journals/BNI/Bni23-3/Gennews.htm
International Network on Cactus Pear, FAO http://www.fao.org/
International Atomic Energy Agency (IAEA) 2002. Mitigating the Threat of <i>Cactoblastis cactorum</i> to International Agriculture and Ecological Systems and Biodiversity. Report and recommendations organized by the Technical Co-operation Department of the IAEA and the Joint FAO/IAEA Division of Nuclear Applications in Food and Agriculture, Vienna, Austria, July 2002. http://www-tc.iaea.org/tcweb/abouttc/strategy/thematic/pdf/summary/Summary_report_cactus_moth.pdf

Step 3 Previous risk assessments, current status of importations and pertinent pest interceptions

Formal impact and risk assessments of *Cactoblastis cactorum* in the U.S. and Mexico have not been prepared, and are needed for an effective response strategy. Although previous risk assessments are not available, ongoing projects and recent documents will contribute to the process (e.g., IAEA 2002, Hight et al., 2003, Zimmermann et al., 2004, Garrett 2004). It is clear that further accidental or intentional introductions of the cactus moth in the U.S. and Mexico could cause great harm. Intentional releases for informal biological control (of weedy cactus species) must be prevented through outreach programs and information sharing on the potential impacts of the spread of this invasive species.

Since cactus moth larvae can move undetected in shipments of *Opuntia*, patterns in imports and trade of live cactus for horticulture and landscaping are particularly relevant. Illegal trade in wild cactus plants may be increasing (Robbins 2003). For example, Mexican authorities impounded more than 800 cactus specimens from travelers entering the United States from Mexico in 1998. Robbins (2003) cites evidence that nearly 100,000 succulents, with an estimated value of \$3 million, were harvested from the wild cactus population in Texas between 1998 and 2001. These plants were mostly destined for xeriscaping in Arizona, but may also supply markets in Europe, Australia, and the U.S. All species of the cactus family, and a number of other succulents are listed on CITES guidelines, with the most vulnerable species listed on Appendix I (<http://www.cites.org/eng/resources/species.html>, and an additional list is available regarding the taxonomic status of *Opuntia* species <http://www.cites.org/common/cttee/PC/12/E-PC12-14-02.pdf>). Distribution of produce could be another important pathway. For example, U.S. annual fruit (tuna) imports from Mexico have been estimated at 1.5 million pounds (Rakowitz 1997). Exact figures and routes on *Opuntia* trade are needed for risk assessment and early detection efforts.

The history of interceptions of *Cactoblastis cactorum* in the U.S. includes at least twenty-three occurrences from 1985 through 2003 (Table 4). This summary of interceptions of cactus moth larvae on *Opuntia* species at U.S. Ports of Entry is presented as an example, and is based on documented interception records from the USDA-APHIS-PPQ PIN 309 database (Joel Floyd, USDA, pers. comm., 2004). Infected plant parts including *Opuntia* cladodes (leaf), stems, and fruits have been detected in permit cargo and baggage. Interceptions have been documented from the Dominican Republic, Haiti, Hawaii, Puerto Rico, and Mexico. This summary is not a comprehensive history, as any one database underestimates the total formal and informal interceptions considerably. Initial reports of infected shipments in 1981 were followed by numerous interceptions from the Dominican Republic and Haiti that were reported from the early 1980's through the early 1990's (Pemberton 1995). Pemberton (1995) includes a discussion on additional pertinent data sources that should be included in the history of interceptions, including national and regional interception databases, cactus import statistics, and field and nursery observations.

The Mexican interceptions are also likely to be underestimated in official publications and databases, and additional observations may be tracked by several interested agencies and organizations. Although officials have not reported the moth from Mexico, interceptions such as the infected fruit found in baggage in Dallas (from Mexico, Table 4) suggests that the moth may already occur there. However, the Mexican plant protection authorities have been extensively monitoring the pest for the past two years and there is no indication of its presence. If the pest were established in Mexico the signs of damage would be very evident.

Efforts to synthesize and update all datasets including historical and new records of interceptions are needed. The identification of important interception locations and movement pathways will be critical for early detection and prevention efforts in both Mexico and the U.S.

Table 4**Summary of U.S. Interceptions**

(Records from the USDA-APHIS-PPQ PIN 309 database, Joel Floyd, USDA, pers. comm., 2004)

Origin	Port of Entry	Number of Interceptions	Inspection Type	How Imported
Dominican Republic	Miami, FL	3	Permit Cargo	Propagative Material
Haiti	Miami, FL	2	Permit Cargo	Propagative Material
Mexico	Dallas, TX	1	Baggage	Fruit
Hawaii	Lihue Kauai, HI	13	Baggage ¹	Propagative Material
Puerto Rico	Mayaguez, PR	3	Permit Cargo	Leaves
Puerto Rico	Mayagues, PR	1	Baggage ¹	Leaves

1. Represents predeparture inspections of domestic passenger baggage destined for US mainland.

***Cactoblastis cactorum* regulation status in the Mexico and the U.S.**

For Mexico, quarantine regulations are well-defined and fall under the Project of the Official Mexican Norm NOM-084-FITO-2004, which establishes the system to prevent the introduction, spreading and establishment of the cactus moth, *Cactoblastis cactorum* Berg, in the national territory. The Mexican regulation demands that importations of host plants and plant products from countries that have *Cactoblastis cactorum* must be accompanied by a phytosanitary certificate with a statement that the shipment was inspected and found free of the invasive moth (Alejandra Elizalde Jimenez, SAGARPA, pers. comm., 2004).

USDA, APHIS, PPQ's quarantine, 7 CFR 318.58, prohibits the movement of cactus plants and cactus parts from Puerto Rico, and the Virgin Islands and 7 CFR 318.13 to the U.S. mainland because of the cactus moth. There are currently no other federal domestic regulations restricting the movement of potentially infected *Opuntia* nursery stock or products for consumption within the continental US.

Nursery stock from foreign countries that have the cactus moth are not restricted by PPQ quarantine CFR 319.37, however all imported propagative material now requires phytosanitary certification and inspection at USDA, APHIS plant inspection stations. *Cactoblastis cactorum* is considered an actionable quarantine pest, so if intercepted in commercial shipments, the plant material will require fumigation, destruction or return to the country of origin.

Opuntia fruit and leaves for consumption are permitted from certain countries after a risk assessment is conducted. Currently 7 CFR 319.56 allows *Opuntia* for consumption from Mexico and Colombia, countries where the invasive moth is not known to occur.

There is some inconsistency in the U.S. regulations for preventing the entry of the cactus moth into new areas. Options include prohibition or import restrictions including inspection and certification or treatments applied domestically and internationally. With more support for applying sterile insect technique and other mitigations to prevent or contain the spread, a regulation on foreign imports of propagative material and a domestic regulation for all *Opuntia* plants and parts will be needed to protect uninfested areas.

Step 4 Pest categorization – List pests (cactus moth and co-occurring or associated species) and quarantine status. Determine pests that can be expected to follow the predicted pathways.

Kingdom	Animalia
Phylum	Arthropoda
Class	Hexapoda
Order	Lepidoptera
Family	Pyralidae
Subfamily	Phycitinae
Genus	<i>Cactoblastis</i> Ragonot
Species	<i>Cactoblastis cactorum</i> (Berg 1885)
Synonyms	<i>Zophodia cactorum</i>

Common Names	cactus moth, prickly pear moth
Common Host	Cactus, Mainly <i>Opuntia</i> species

Throughout this document, “the cactus moth” refers specifically to *Cactoblastis cactorum* Berg, which should not be confused with the other Lepidopteran species that feed on cacti. The cactus moth is one of at least 54 species of cactus feeding Phycitine moths recognized in the western hemisphere (Neunzig 1997, Solis et al., 2004), leading to significant challenges to field identification and increased potential for non-target effects of control to native plant and animal species. For example, the larvae of a related cactus-feeding moth, *Melitara prodenalis* Hight, feed on the same *Opuntia* hosts and occur in the same geographic area (Neunzig 1997), leaving this native moth at risk for non-target effects of control actions. At least 109 insect species are known to feed on *Opuntia* in Mexico (Vigueras and Portillo 2001). Many other native species can feed on *Opuntia* plants, including important pollinators, seed dispersers, and a diversity of wildlife species (Chavez-Ramirez et al., 1997, IAEA 2002, Garrett 2004). Although more research is needed on pollination interactions of prickly pear species, many specialist plant-pollinator interactions are associated with species in the Cactaceae family (Margrit McIntosh, University of Arizona, pers. comm., 2004). The Catalog of Hymenoptera (Krombein et al., 1979) lists numerous native bee taxa as visitors to prickly-pear and cholla cacti (*Opuntia* spp.; 88 bee species). Honeybees are also attracted to the showy *Opuntia* flowers.

Life History Summary:

The life history of *Cactoblastis cactorum* Berg is well documented (for reviews see Neunzig 1997, Zimmermann et al., 2000, Hight et al., 2003, Zimmermann et al., 2004), and several characteristics of the life stages contribute to the invasive potential of this terrestrial insect. First, the cactus moth feeds within the protective environment of the cactus pad. The cactus moth is one of several cactus-feeding Lepidoptera species of South American origin whose larvae feed inside *Opuntia* cladodes, consuming most of their contents but leaving the epidermis intact. Damaged *Opuntia* plants exhibit hollowed cladodes which turn white with age and characteristic exudates that the larvae expel through small holes made in the epidermis. Larval feeding can also lead to decay and rotting and high populations can cause enough damage to kill the plants.

Second, researchers have identified a multi-voltine pattern of generations in warmer areas, which may provide additional opportunities for dispersal and establishment in new areas. Three generations per year have been observed in Florida instead of the two well-defined generations in other temperate areas such as Australia and South Africa (Hight et al., 2003). In the southeastern U.S. there are three flights: spring (April - May), summer (July - August), and winter (October - November). In the Florida Keys, the generations are not distinct with moths present as adults year-round, although at varying population levels (Chris Bergh, TNC, pers. comm., 2004). Continuous presence of adults in warmer areas, such as the Caribbean, could provide more opportunities for rapid spread and establishment.

Third, suitable environmental conditions in Florida and other warm areas may favor a shortened life cycle. Recent rearing observations are only approximately 90 days from egg to adult. Adult moths usually emerge during early evening and mating can take place within the first night (Hight et al., 2003). Females live for approximately 10 days and oviposition usually starts during the second night.

Another important characteristic is the unique pattern of oviposition (egg laying), that highlights the potential for remarkable fecundity. The eggs are stacked in the form of a small stick which looks like a spine. A single female lays two or more egg-sticks averaging about 300 eggs. First instar larvae hatch simultaneously and enter a cladode close to the oviposition site through a single hole. They feed gregariously in colonies varying between 20 and 50 larvae. Later instars are reddish in color with typical transverse black bands. The larval stage lasts between 5-7 weeks in summer and up to 2-3 months in winter. Larvae seldom leave the protection of a cladode in which they feed except when pupating. Pupation can take place in the soil but the preferred sites are in plant debris not far from the host plant.

Adult cactus moths are nocturnal and are not known to fly far when there are sufficient host plants available. However, with a scarcity of food the moths may fly several kilometers and individuals may be carried considerable distances with air currents. Adult moths could be attracted to lighted loading areas and

become live hitchhikers inside trucks, trains, and other vehicles. Other complex pathways of introduction may include the horticulture trade, garden plantings, the movement of infected plants (e.g., people moving households to new areas). Dispersal pathways for the different life stages will be difficult to survey and monitor, and both natural and intentional introductions must be prevented.

Step 5 Assess consequences of introduction for each pest expected to follow the pathway

Issues to consider include “ the establishment, spread and economic importance potential in the risk analysis area” FAO 1996. Environmental impacts are addressed, and undesirable outcomes being considered are the negative impacts resulting from the introduction of quarantine pests. After identifying those quarantine pests that could reasonably be expected to follow the pathway, the assessment of risk continues by considering the consequences of introduction. To evaluate the cactus moth as a quarantine pest, the potential consequences of introduction are rated using five Risk Elements. These elements reflect the biology, host ranges, and climatic/geographic distributions, and pests are assigned a rating of Low (1 point), Medium (2 points) or High (3 points). A Cumulative Risk Rating is then calculated by summing all Risk Elements.

Risk Element #1: Climate—Host Interaction

When introduced to new areas, pests can be expected to behave as they do in their native areas if host plants and climates are similar. Ecological zonation and the interactions of the pests and their biotic and abiotic environments are considered, and estimates are based on availability of both host material and suitable climate conditions. To rate this Risk Element, the U.S. "Plant Hardiness Zones" map, U.S. Department of Agriculture (USDA 1990) is used <http://www.usna.usda.gov/Hardzone/ushzmap.html>.

Due to the availability of host plants and suitable climate, the cactus moth, *Cactoblastis cactorum* Berg, has potential to establish a breeding colony:

Low (1): In a single plant hardiness zone.

Medium (2): In two or three plant hardiness zones.

High (3): In four or more plant hardiness zones.

The cactus moth is rated as a high risk based on climate/host interaction. Predictive maps based on suitable climates in the native range have indicated that there are no climatic restrictions to the cactus moth in Mexico (Soberon et al., 2001). The cactus moth is currently known to occur in three hardiness zones in the U.S. (Zones 8, 9, and 10), and the predicted potential distribution suggests that the cactus moth could occur in three additional zones. Exceptions may be areas of cold temperatures and extremely hot and dry desert areas. Furthermore, areas with the highest diversity of native *Opuntia* species and large commercial plantations all fall within the ideal climatic parameters of the insect.

Based on a comparison of mean low temperatures of South American locations, and selected U.S. sites, Pemberton (1995) suggested that the moth should be able to survive as far north as Charleston, South Carolina, San Antonio, Texas, and the lower altitude areas of New Mexico, Arizona, and California north to Sacramento. Dr. Jorge Soberón and colleagues of the Mexican National Commission on Biodiversity (CONABIO), applied data from *Opuntia* herbarium records and climatic tolerances of the cactus moth to predict the potential range and most likely routes of invasion of the cactus moth into Mexico (Soberon et al., 2001, <http://www.nappo.org/PRA-Symposium/PDF-Final/Soberon.pdf>), Figure 2).

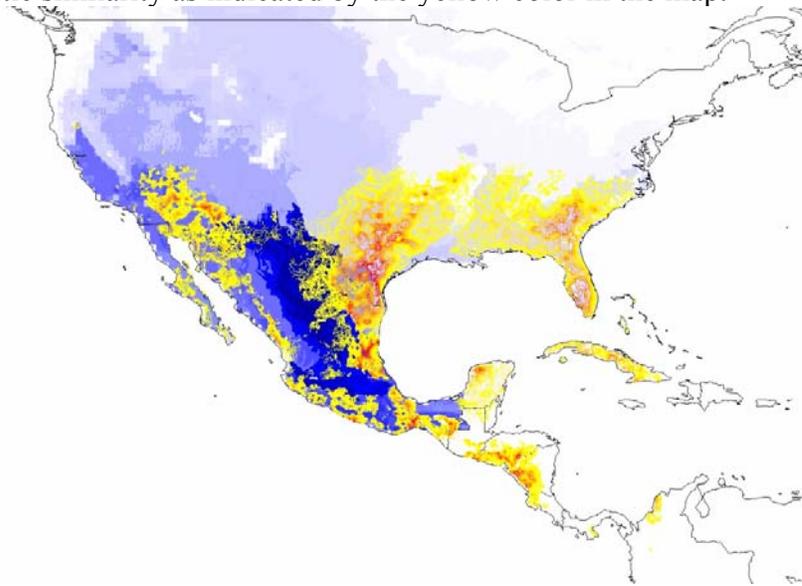
Efforts are underway to incorporate all new locations of the cactus moth and important areas of *Opuntia* species distribution for updated model predictions (Jordan Gubolov, pers. comm., 2004, Rachel Muir, Natureserve, pers. comm., 2004). Advances in computer software programs for modeling and database management, including FloraMap, Species Analyst, and the Genetic Algorithm for Rule Set Prediction, are already enabling scientists to provide resource managers and policy makers with projections of the potential range and impacts, thus helping them to make better informed decisions. USDA APHIS

researchers are also cooperating to develop a risk map for the cactus moth that will be made available through NAPFAST system, <http://www.nappfast.org/index.htm>.

Figure 1

This overlay of two predictive maps shows vast areas in the U.S. and Mexico that have a suitable climate and plenty of food species for the cactus moth (Figure courtesy of Jorge Soberon, CONABIO, 2003).

The red and yellow tones display predicted distribution of the moth based on data points from the Smithsonian. The yellow areas show low probability of climatic similarity to regions within the native range, and red lines mean high similarity, indicating the climatic niche of the cactus moth. The blue tones are based on distribution data for about 86 *Opuntia* species from collections (shared generously by the Smithsonian, Missouri Botanical Garden, San Diego Natural History Museum, the Mexican National Herbarium, the Mexican Scholl of Biological Sciences Herbarium, and other interested scientists). The map represents niche modeling of the ~5000 occurrence points, an analysis by the Mexican National Commission on Biodiversity, CONABIO. The darker blues indicate species richness hotspots of *Opuntia*, primarily prickly pear cactus of the subgenus *Platyopuntia*. Based on the continuous occurrence of *Opuntia* species and large areas with suitable climates, it is likely that potential distribution of the cactus moth will be widespread in the southwest U.S. (notice Texas in particular) and Mexico. It is interesting to note that the cactus moth has established and spread along the Coast of Florida despite being considered low probability of climatic similarity as indicated by the yellow color in the map.



Risk Element #2: Host Range

For arthropods such as the cactus moth, risk is assumed to be correlated positively with host range. Other related factors may include ability to establish a viable, reproductive population, potential for causing plant damage, and evidence of aggressiveness.

Low (1): Pest attacks a single species or multiple species within a single genus.

Medium (2): Pest attacks multiple species within a single plant family.

High (3): Pest attacks multiple species among multiple plant families.

The cactus moth ranks as a “medium” risk due to host range (based on the list of *Opuntia* species known to be acceptable hosts and the expected range of damage among low-growing, shrub, and tree species), and the risk would shift to “high” if spillover effects or host shifts occur.

At least 30 different species of *Opuntia* have been documented as suitable host plants for *Cactoblastis cactorum*, including tree, shrub and low growing species (Zimmermann et al., 2004). The

present knowledge of hosts of the cactus moth suggests that the threat may be limited to the species within the subfamily Opuntiae (particularly *Opuntia*, *Nopalea*, and *Consolea* species), and there is a range of host suitability and susceptibility to damage across *Opuntia* species (Zimmermann et al., 2004). Peter Stiling's research group at the University of South Florida is working on host testing of more U.S. species that will provide valuable information for predicting impacts in *Opuntia* rich areas (Joel Floyd, USDA, pers. comm., 2004). In general, small plants are extremely vulnerable to damage, including seedlings and young plants of larger species such as *Opuntia ficus-indica* and other commercial varieties. Damage is slightly less apparent in plants with hard woody stems, and mortality may not be as likely.

Damage is predicted to be highest in the *Platyopuntia* species (plants with typical flat prickly pear pads), but some species in the *Cylindropuntiae* (known as "chollas") and other cactus species (Cactaceae) are acceptable as food plants and might also be affected. Spill-over damage to other plant families happened when the cactus moth was first released as a biological control to manage problem cactus species (http://pest.cabweb.org/Journals/BNI/Bni24_3/Gennews.htm). Very large numbers of cactus moth larvae developed in the prickly pear, and in several places there was damage to tomatoes (Solanaceae), melons (Cucurbitaceae), and pumpkins (Cucurbitaceae) nearby (Dodd 1940). Once populations of the cactus moth fell, there was no more damage recorded to crops other than *Opuntia*. Still, it is important to note that the cactus moth is capable of host shifts to genetically and chemically disparate plant taxa of at least three plant families.

The cactus moth is established in Puerto Rico, nearby smaller islands and keys, and in the U.S. Virgin Islands, feeding on a variety of host cacti including *Opuntia dillenii*, *Opuntia antillana*, *Opuntia repens*, *Opuntia triacantha*, *Opuntia ficus-indica*, *Consolea rubescens*, and *Consolea moniliformis* (Garcia-Tuduri 1971). In Florida it feeds on all six native *Opuntia* species (*Opuntia humifusa*, *Opuntia corallicola*, *Opuntia cubensis*, *Opuntia triacanthos*, *Opuntia pusilla*, and *Opuntia stricta*), and has become a problem pest of both rare species and landscape plantings in coastal areas (Johnson et al., 1996, Johnson and Stiling 1998).

Since prickly pear cactus occurs from Florida to California, with no significant geographical barriers, the cactus moth can be expected to continue to expand its range where climates are suitable across the southern United States (http://plants.usda.gov/cgi_bin/plant_profile.cgi?symbol=OPUNT#distribution). Exceptions are expected in areas where the conditions are too cold for larval development. Information on local distribution of *Opuntia* species in the U.S. and Mexico is lacking or incomplete, mostly due to the difficulty of collecting and preserving these succulent plants (Rebman and Pinkava 2001).

Risk Element #3: Dispersal Potential

A pest may disperse after introduction to a new area. The following items are considered:

- 1) Reproductive patterns of the pest (e.g., voltinism, biotic potential)
- 2) Inherent powers of movement
- 3) Factors facilitating dispersal (wind, water, presence of vectors, human, etc.)

Low (1): Pest has neither high reproductive potential nor rapid dispersal capability.

Medium (2): Pest has either high reproductive potential OR the species is capable of rapid dispersal.

High (3): Pest has high biotic potential, e.g., many generations per year, many offspring per reproduction ("r-selected" species), and evidence exists that the pest is capable of rapid dispersal, e.g., over 10 km/year under its own power; via natural forces, wind, water, vectors, etc., or human-assistance.

The cactus moth rates as a "high" risk based on dispersal potential, including reproductive potential, inherent dispersal ability, and facilitating factors of movement. Although adult cactus moths are not known to fly far from host plants, populations in the Southeast U.S. states show high reproductive potential and are dispersing at a much faster rate than previously observed in other areas (Hight et al., 2002). Recent dispersal

may be due to climatic conditions; wind dispersal; movement in trains, cars and other transportation vehicles; or through infested plants that are shipped from nurseries to stores (Bloem 2003).

Several characteristics of the cactus moth life history and reproductive patterns support the biotic potential for invasiveness: 1) multi-voltine pattern of three generations with short development time, 2) gregarious feeding within the protective cactus pad, and 3) the large number of eggs produced by one female. In the Florida Keys the generations overlap with moths present as adults year-round, although at varying population levels (Chris Bergh, TNC, pers. comm., 2004). Continuous presence in warmer areas such as the Caribbean could provide more opportunities for rapid spread and establishment.

The cactus moth spread from the Florida keys (Habeck and Bennett 1990) to South Carolina and Pensacola, Florida (Hight et al., 2002, Bloem 2003), and was recently found to occur in Alabama (Stephen Hight, USDA, pers. comm., 2004). The observed rate of spread of the moth in Florida during 1989-1999 was between 50-75 kilometers per year (Hight et al., 2002). During the past three years (through 2003), the spread has accelerated to a significantly higher rate of 158 kilometers per year (Bloem 2003). At this increased rate of spread, the moth could spread to the Louisiana-Texas border by 2007. The cause of this accelerating spread is not known, but *Opuntia* distributions in coastal habitats of Florida are sparse but continuous. Observations from South Africa suggest that dispersal distances are inversely related to prickly pear densities.

Subsequent to introductions for biological control, the cactus moth was observed to disperse to other locations. For example, it was introduced to the island of Hawaii in 1950, but was found on the islands of Lanai, Maui, Oahu, and Molaki by 1954 and on Kauai and Nihau by 1957. If humans were not responsible for that movement, the moth was capable of traveling roughly 47 km over water from Hawaii to Maui, and 110 km from Oahu to Kauai. Similarly, the moth rapidly dispersed in the Caribbean region to the Bahamas and Cuba. Biogeographic history of migration of floras following tropical wind and storm patterns may provide clues to likely movement of the moth (e.g., Florida to Cuba, and Cuba to Yucatan).

It is important to note that the cactus moth has been documented as a contaminant on horticultural shipments of cacti. Additionally, individuals may have purposely or inadvertently translocated the moth to new locations through informal biological control, movement of plants or plant parts, or unrelated transportation such as on vehicles. The risk of continued expanding distribution of this invasive moth is extremely high considering the increasing international trade in *Opuntia* species; widespread cactus cultivation across continents; increasing exchange of germplasm to support this cultivation; and the enrichment of collections in botanical gardens. The risk is high for movement from current locations in the Caribbean and the Southeast U.S. into Mexico unless natural and human-caused dispersal is controlled.

Risk Element #4: Economic Impact.

This economic impact refers to commercial cultivation. The economic loss to the US and Mexico would be huge if environmental costs were included. In addition, Mexico would incur huge social costs. Introduced pests are capable of causing a variety of direct and indirect economic impacts. These are divided into three primary categories (other types of impacts may occur):

- 1) Lower yield of the host crop, e.g., by causing plant mortality, or by acting as a disease vector.
- 2) Lower value of the commodity, e.g., by increasing costs of production, lowering market price, or a combination.
- 3) Loss of foreign or domestic markets due to presence of new quarantine pest.

Low (1): Pest causes any one or none of the above impacts.

Medium (2): Pest causes any two of the above impacts.

High (3): Pest causes all three of the above impacts.

The risk of cactus moth spread related to economic impacts in the Southwest U.S. and Mexico is high. In the case of Mexico the pest would cause all three impacts to market values thus the risk is very high. There would be negative impacts on the yield of crops (mortality, reduced plant size) and the value of products (plant damage, control costs). The risk of economic impacts in the U.S. would likely increase with

additional quarantine regulations that could lead to loss of foreign or domestic markets. Market and non-market values reflect the diverse uses of *Opuntia* species, such as food for humans, food for livestock, horticultural plantings, cochineal dyes, and medicine (see <http://www.dal.ca/~dp/cactus/economics.html>). Overall, economic risk categories related to the value of *Opuntia* species in the southwest and Mexico include: production and harvest of cactus, produce price & market effects, trade, food security & nutrition, human health and environment, financial impacts, tourism and recreation, and cultural and social identification.

Yield and Values at Risk:

Produce

A staple in Latin American and Native American cultures, prickly-pear cactus fruits (tunas) and vegetables (nopales, or nopalitos) are attracting growing interest as new products in non-traditional markets. Nopalitos and tunas represent a huge industry in Mexico and areas of the U.S., being consumed in fresh and processed form. The increased demand for edible cactus in the U.S. has been met largely through imports from Mexico where it is a significant agricultural crop, marketed as fresh produce. In Mexico, areas known to be in commercial cultivation for human consumption are estimated to include 60,000 hectares for tunas and 10,500 hectares for nopales. Total *Opuntia* production in Mexico is estimated at over 250,000 hectares, and 3,000,000 hectares of *Opuntia*-dominated areas are used for harvesting and collection of wild cactus (Vigueras and Portillo 2001).

Opuntia produce (nopales and tunas) imports (in metric tons per year) from Mexico for the years 2000-2003 reflect the increasing trend in consumer demand (Figure 2, Table 5; Garrett 2004). U.S. imports have significantly grown in recent years, and for the years 2000-2003 imports of nopales were estimated to range from 11,485 to 23,139 metric tons per year, and annual tuna imports ranged from 5,657 to 9,399 metric tons per year. Increased reporting of statistics for the specific *Opuntia* products is likely to improve and increase estimates. In 2002 the U.S. Census reported trade levels of the fresh vegetable import trade code that includes nopales at over 75,000 metric tons, valued at over \$27 million (Garrett 2004). One family-owned vegetable exporting company in Mexico reportedly ships 18 tons of edible cactus each day across the border into Texas (Rodriguez, 2003).

Figure 2

Summary of *Opuntia* Produce Imports from Mexico 2000-2003 (Garrett 2004)

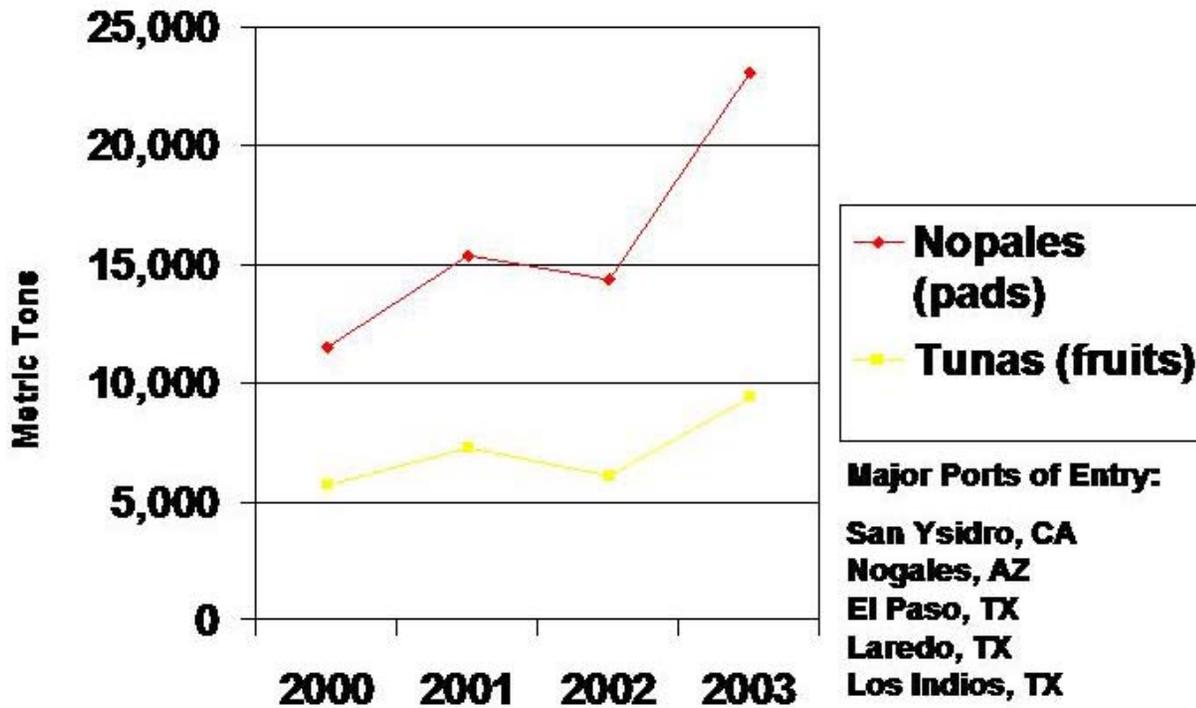


Table 5

U.S. *Opuntia* produce imports from Mexico by border crossing point for years 2000-2003.

U.S. Imports of Cactus Leaves (Nopales) from Mexico (Metric Tons)

	2000	2001	2002	2003
Border Crossing Point				
San Luis, Arizona	0	0	1	0
Nogales, Arizona	34	39	23	63
New Mexico Crossing Points	0	0	0	0
Houston, Texas	62	0	0	0
All Other Texas Crossing Points	5,613	6,755	7,918	9,579
Otay Mesa, California	5,759	8,580	6,420	13,497
Calexico, California	17	10	8	0
Total	11,485	15,383	14,369	23,139

Note: For CY2000 for Otay Mesa, CA includes only the period March 2000 - Dec. 2000.

U.S. Imports of Cactus Fruit (Tunas) from Mexico (Metric Tons)

	2000	2001	2002	2003
Border Crossing Point				
San Luis, Arizona	0	0	0	0
Nogales, Arizona	6	354	516	418
New Mexico Crossing Points	1	0	0	0
Houston, Texas	6	0	0	0
All Other Texas Crossing Points	3,102	3,931	4,430	5,289
Otay Mesa, California	2,542	2,958	1,104	3,692
Calexico, California	1	4	0	1
Los Angeles, California	0	0	0	0
Total	5,657	7,247	6,050	9,399

Source: Daily reports of border crossings for nopales shipments into the United States from Mexico report by APHIS/PPQ to the Agricultural Marketing Service.

The average income generated by *Opuntia* products over the period 1990-1998 is approximately \$50 million U.S. dollars per year (Soberon et al., 2001). Vegetable usage constituted much of the value (\$27 million), followed by cactus pears (\$20 million), and fodder (\$1 million). The Mexican export market of *Opuntia* products is valued at \$50 million per year (Soberon et al., 2001). The cultivation of prickly pear in Mexico involves some 20,300 fruit producers and 8,095 producers of nopalitos. In Mexico, prickly-pear cactus comprises 1.5% of total agricultural production and represents 2.5% of the value of agricultural production (Vigueras and Portillo 2001). The tonnage of nopalitos consumed annually in Mexico approximately equals the tonnage of cauliflower consumed in the U.S. (Rakowitz 1997), and exports are valued at \$30 million.

In the U.S., prices for nopales have ranged from 75 cents to \$1.50 per pound for small tender pads (Sandoval, 2001). A survey conducted by the Florida Department of Agriculture and Consumer Services found that 69% of Mexican-Americans would buy a pound package of frozen nopales (Florida Department of Agriculture and Consumer Services 2003). Nopalitos are consumed in the same way other fresh green vegetables are consumed (stir-frying, pickling, and roasting). Based on a Mexican-American population of 21 million, frozen nopales could result in sales of \$356 million a year nationwide (Salisbury 2003).

Prickly-pear cactus fruit (tuna) is also consumed as a fresh fruit in the United States. U.S. annual imports of fruit from Mexico have been estimated at 1.5 million pounds (Rakowitz 1997). Farm enterprise research done at Texas A&M University-Kingsville identifies cactus fruit as a potential cash crop in the Rio Grande Valley with some significant complementary value to citrus. Cactus fruit can be produced during the spring and summer off-season for citrus (Wang et al., 1998). Complimentary values include:

1. cactus fruit ripens from June to August when citrus packing sheds are normally idle;
2. cactus fruit can withstand lower temperatures (19 degrees F) than citrus without damage; and
3. cactus fruit varieties would require less irrigation water than citrus crops.

Currently, prickly-pear cactus is of minor importance as an agricultural crop in the U.S., limited largely to California where 70 to 80% of the national crop is produced from approximately 600 acres (USDA 2000). In 1998, the top producing county for prickly-pear cactus was Monterey County with 400-450 acres having a crop value of \$2 million (Monterey County 1998). However, demand in the U.S. may be increasing, as evidenced by the recent availability of price quotes for "cactus pears," reported daily at the South Carolina state farmer's market in Columbia, SC (Lynn Garrett, USDA, pers. comm., 2004). Prices for cactus leaves have been reported over the past several years but cactus pear prices are new. The Department of Agriculture and Consumer Services is promoting *Opuntia* growing in Florida as a niche crop and there is already some production there (Joel Floyd, USDA, pers. comm., 2004). These changes may reflect an increase in demand from the growing Central and South American populations in the SE United States. Agricultural values are particularly important to Mexico, where the prickly-pear cactus has significant economic importance from political, social, and economic perspectives. Some examples of this include: the appearance of the prickly-pear cactus on the national flag, increasing importance of exports, and employment, food, and income that enables marginal and subsistence farmers to remain on their land (De la Rosa & Santamaria 1998, Vigueras and Portillo 2001).

In Mexico, *Opuntia* has historically been used as both food and fodder (Soberon et al., 2001). Historically, the hunter-gatherer communities that roamed the Southwest U.S. and Mexico used products derived from *Opuntia* (mainly forage, fruit and vegetables) in 9,000 BC. The process of domestication of a few species of *Opuntia* may have started as far in the past as 6,000 BC. By 3000 BC, hunter-gatherers settled into small communities, where family owned plots contained species of *Opuntia* that had been collected from wild populations (Hoffmann 1995). During the 1850s *Opuntia* was commonly used in the growing cattle ranching industry of the Sonoran and Chihuahuan deserts which gave way to an extensive use of *Opuntia* as fodder.

Possible effects of moth invasion could include impacts on trade relations between Mexico and the U.S. *Opuntia* species are cultivated in many areas of the world (North and South African, the Americas, and Middle Eastern) for prickly pear fruit and related products. Emerging markets in Peru and Africa, and increasing Mexican exports to Europe and Asia, show an expanded demand. If the *Opuntia* industry is

severely damaged in Mexico, this will result in economic losses and a direct contribution to hunger. The food supplied by the *Opuntia* plants will not be available to people who harvest it from the wild and from family plots. These people may not have money to buy replacement food, and the loss of *Opuntia* resources will result in the unemployment of current producers, workers, and owners.

Prickly pear cultivation has provided some subsistence to communities with employment, food, income and enabled them to remain on their land (De la Rosa & Santamaría 1998). For example, Tlalnepantla is a small town of 6,000 inhabitants in Morelia, Mexico. The community is almost solely dedicated to cultivation and sale of nopales that they sell in Mexico City and export to the U.S. The establishment of sustainable systems of production based on *Opuntia* species may contribute to the food security of populations in agriculturally marginalized areas, and to the improvement of the soil. Cultivation of *Opuntia* species requires extensive labor and is an important source of employment in developing countries, particularly for women. Soil conservation in the fragile environment of the desert is an important activity of land stewardship. Prickly-pear cactus serves as an important resource for many of these natural areas to protect the soils from eroding.

Fodder and Range

A main concern is the likelihood that the moth will spread west as far as Texas, and into Mexico where the chopped plants serve as cattle fodder in dry seasons and times of drought. In Mexico, an estimated 150,000 hectares support valuable *Opuntia* resources for livestock and wildlife. In South Africa, it significantly reduced growth of spineless *Opuntia* species valued as cattle food (Annecke et al., 1976).

Since they grow in severely degraded land, *Opuntia* use as emergency forage is important because of their abundance in 900,000 hectares where few crops can grow. They also have high palatability, digestibility, and moisture content, reducing the need to supply water to animals.

During periods of drought, prickly-pear cactus is an emergency source of forage for cattle. As a forage, prickly-pear cactus has 70% dry matter digestibility and a 6% protein value (Han and Felker 1997). It has the highest conversion efficiency of water to dry matter of any other class of plant, and cactus can survive during dry periods when other forms of forage become absent. Both spine and spineless varieties are used as emergency forage. The spineless varieties are less cold hardy as compared to spiny varieties. A 1988 survey in south Texas indicated that 40% of ranchers use prickly pear as a regular part of a nutritionally managed plan (Garrett 2004).

The reported value of prickly-pear cactus to a small breeding herd of 50 head of cattle during the summer months when forage is limited could replace hay forage valued at up to \$700 (Whitehead, 2003). The potential value in the 14 county prickly-pear cactus rich Trans-Pecos vegetative region of West Texas would be \$4 million during a summer drought season.

Horticulture and Landscape

Prickly-pear cactus is an important plant resource to the nursery and landscape industry in both the U.S. and Mexico. The horticulture and landscape industry pertains to employment, landscape plantings, nurseries, trade in ornamentals, tourism, small business growers and water conservation in xeric areas. *Opuntia* species are regarded as extremely important “xeriscaping” plants, especially in arid and semi-arid regions where few plants can be grown. In the southwest region of the U.S., prickly-pear cactus is used as an ornamental plant material for commercial and residential landscape projects. The use of cactus in xeriscape landscape design has been promoted by state and local governments in high population growth areas such as Phoenix, Tucson, and Las Vegas. Unfortunately, the accelerated growth in demand for cactus for nurseries and landscape has utilized the wild native cacti and may stress populations of sensitive species. A 2001 survey in Arizona found the ornamental prickly-pear cactus industry in Arizona encompassed 550,000 plants with wholesale and retail value of \$4.5 and \$9.5 million, respectively (Irish 2001). Growth since this survey has been estimated to have increased by 10% (Irish, pers. comm., November 2003). The USDA 1998 Census of Agriculture listed 341 operations that sold cacti and succulent foliage plants (17% in California, 14% in Florida, and 5% in Arizona). Sales in 1998 of all size pots of cacti and succulent foliage plants from 341 operations totaled 11.2 million for a total sales value of \$23.9 million. The 2002 Census figures are expected to increase and will be available in December 2005.

Cochineal dyes

The cochineal insect (*Dactylopius coccus*) produces Carminic acid, which is a natural deep-red dye accepted by health authorities worldwide. In Mexico, cochineal dyes constitute a significant alternative to forage or fruit production because of high profitability and less intensive use of labor. The introduction of the moth could also have significant social impacts as many people are involved in processing industries and cochineal production (De la Rosa and Santamaría 1998).

Medicines

Economic activities at risk from the loss of prickly-pear cactus include current medicinal uses of the plant and health-related products in the United States and Mexico. Research has demonstrated promising results on the use of *Opuntia* products for gastritis; for diabetes due to the reduction of glucose in blood and insulin; for hypercholesterolemia by reducing total cholesterol, LDL cholesterol, and triglyceride serum levels; enlarged prostate treatment; and for obesity. *Opuntia* is also used as a topical ointment and sold as a dietary supplement. Medical values emphasize the importance of center of biodiversity of *Opuntia* in Mexico, with responsibility to protect future uses related to the genetic diversity of populations and possibilities of undiscovered medicines.

Other Products

The industrialization of *Opuntia* products is expanding into concentrated foods, juices, liquors, semi-processed and processed vegetables, nutritional supplements, and the cosmetic industry. An in depth valuation of all these products is needed but is beyond the scope of this report.

Tourism and Recreation

Risks to tourism and recreation could impact social, economic, and environmental values. Tourism and many recreational activities occur in the same areas in the southwest region of the U.S. where the prickly-pear cactus comprise a significant portion of the plant life. The U.S. Department of Interior and state and local governments manage well over half of the land area in New Mexico and Arizona. Many thousands of acres are available for recreational activities in parks, monuments, and natural areas. In recent years, eco-tourism has led to increasing interest in viewing plant life, particularly during the period of spring wildflower blooming. Many of these activities rely on aesthetic values and include sightseeing, hiking, walking, picnicking, camping and off-highway vehicle driving. An example of the economic significance of one of these activities is off-highway vehicle recreation where in Arizona the total expenditures in 2002 were \$3 billion creating a statewide economic impact of \$4.25 billion (Silberman 2002). Valuation of conservation interests can include concepts such as the willingness to pay, and international significance of the U.S. National Park system. However, there are real costs and these are legal considerations of protecting endangered species (e.g., rare cacti, wildlife species that feed on cactus such as rock iguanas).

Example: Hunting lease enterprises in the U.S. that may be vulnerable to a loss of *Opuntia*

The greatest value of prickly-pear cactus from year to year in the south Texas region is as a wildlife feed for game animals. Farm and rural residents that rent their land for hunting in hunting lease arrangements utilize natural plant life to maintain wildlife habit in range and natural areas. The value of these hunting leases are higher than land grazing leases for cattle. For example, hunting leases for white tail deer and quail are \$6 and \$4 per acre respectively while grazing leases for cattle are \$3 per acre (Rakowitz 1997). For large ranches, the income from hunting leases can be considerable. The King Ranch, in Kingsville, Texas has a total area of 860,000 acres (principally cattle and oil) with hunting lease rates ranging from \$6-\$8 per acre (Baen 1997). A Texas Agricultural Statistic Service 1996 study compiled a list of more than 1,233 highly managed, high-fenced hunting operations in 194 of 254 counties in Texas (Baen 1997). According to one study, hunting lease income has enhanced land value to the point that recreation becomes the best use of rural land for both market and income approaches to valuation (Baen 1997).

Prickly-pear cactus is important to wildlife habitat in much of the southwest U.S. Some estimates predict a 50 to 70% reduction in prickly-pear cactus population would have a “negative influence on most wildlife habitat in Texas” (Rakowitz 1997). Prickly-pear cactus comprises 21 to 33% of the diet of the white-tail deer in the south and west Texas region where white-tail deer are popular a hunting species (Rakowitz 1997).

The wildlife species in hunting lease situations most vulnerable to decreases in prickly-pear cactus include the javelina, where the cactus comprises as much as 85% of its diet (Rakowitz 1997), although some populations exist in areas where there is no prickly-pear cactus. Some experiments on captive javelina reveal that they can survive solely on a diet of prickly-pear cactus for up to 3 months. In Arizona, javelina habitat occupies 34% of the state with a population of 60,000 animals (Arizona Game and Fish Commission 2003 http://www.gf.state.az.us/h_f/game_javelina.html). Prickly-pear cactus would comprise a significant portion of the plant life in this area. If other species of cactus are found to be vulnerable to the moth, additional wildlife impacts could result. Future economic research priorities include development of a table showing all of these cost factors and their estimated cost for those where information is available.

Risk Element #5: Environmental Impact

The assessment of the potential of each pest to cause environmental damage (FAO 1995, Morse 2004) proceeds by considering the following factors and questions:

Environmental Impact: Consider whether or not the cactus moth, if introduced, could:

- (1) Cause impacts on ecosystem processes and system-wide parameters (alteration of hydrology, sedimentation rates, fire regimes, nutrient regimes, changes in productivity, growth, yield, vigor, etc.)
- (2) Cause impacts on community composition (e.g., reduce biodiversity, affect native populations, affect endangered or threatened species, impact keystone species, impact native fauna, pollinators, or microorganisms, etc.)
- (3) Cause impacts on ecological community structure (e.g., change density of a layer, cover the canopy, eliminate or create a layer, impact wildlife habitats, etc.)
- (4) Impact on individual native plant or animal species
- (5) Conservation significance of the communities and native species
- (6) Have impacts on human health and values, such as allergies or changes in air or water quality, sociological impacts on recreation patterns and aesthetic or property values, and risks of control programs including toxic chemical pesticides or introduction of a non-indigenous biological control agent.

Low (1): None of the above would occur; it is assumed that introduction of a nonindigenous pest will have some environmental impact (by definition, introduction of a nonindigenous species affects biodiversity).

Medium (2): One of the above would occur.

High (3): Two or more of the above would occur.

The risk related to environmental impact is high, as further introduction and spread of *Cactoblastis cactorum* in the southwest U.S. and Mexico is likely to cause significant, direct environmental impacts, including disruption of ecosystem processes, ecological interactions and patterns of native biodiversity. Considered within the context of the National Environmental Policy Act (NEPA), significance is qualitative and encompasses the likelihood and severity of an environmental impact. The cactus moth could have direct impacts by infesting and damaging *Opuntia* plant species listed by Federal Agencies as endangered or threatened, and by altering environmental conditions in sensitive and critical habitats. Furthermore, introduction and spread of the cactus moth would stimulate control programs that could have non-target effects on native plants, animals, and communities.

Significant environmental resources that could be under threat:

Landscape and ecosystem values

Opuntia species are a major component of the semi-desert regions of the Caribbean and the Americas and increasingly in other semi-arid regions of the world (Zimmermann et al., 2004). The species of the *Opuntia* subgenus have developed phenological, physiological, and structural adaptations favorable to their development in arid environments. This is an important characteristic as water is the main factor limiting the

development of most plant species. *Opuntia* species can develop in severely degraded soils, which are inadequate for other crops. *Opuntia* plants have a great capacity for harsh environments and are ideal for responding to global environmental changes. Their rooting characteristics reduce wind and rain erosion, encouraging their growth in degraded areas. *Opuntia* species are some of the best plants for the reforestation of arid and semi-arid areas within their native range because they can survive scarce and erratic rainfall and high temperatures.

Soil conservation in the fragile environment of the desert is an important concern. Prickly-pear cactus serves as an important resource for many of these natural areas to protect the soils from eroding. The loss of cactus will alter the nutrients available in soil profiles, thus affecting the microbial communities. This will in turn affect the composition and structure of the plant communities.

Species composition

An estimated 79 *Platyopuntia* (prickly pear) species are at risk: 51 species endemic to Mexico; nine species endemic to the United States; and 19 species common to both countries (Zimmermann et al., 2000). Many cultivated and wild *Opuntia* species are also vulnerable to attack by the moth, including at least 25 species in Mexico and three species in the United States, particularly the widely exploited and culturally important cultivars of *Opuntia ficus-indica*. Large-scale loss of *Opuntia* where they are the dominant species is likely to be accompanied by shifts in species composition of plant and animal communities.

Vegetation structure

Opuntia have been identified as nurse plants, facilitating the establishment of other plant species by providing a more moderate (cooler, moister, shaded) and protected growing environment. Reduction of nurse plants can lead to lower forage availability, increased bare ground, and erosion in arid landscapes.

Impact on plants and animals

Overall, the arrival of the cactus moth in the U.S. has been viewed with great concern because of its potential for adverse impact on native *Opuntia* species. Many species of bird, mammal, reptile, and insect species eat, nest in, or otherwise rely on *Opuntia* species (Chavez-Ramirez et al., 1997, <http://www.desertmuseum.org/books/opuntia.html>). There is expected to be a range of susceptibility of native species, but the cactus moth attacks all six native *Opuntia* species in Florida, and one of the rarest species, (*Opuntia corallicola* (= *spinosissima*) (Small) Werderm, is now threatened with extinction (Florida endangered, Federal candidate; Johnson and Stiling 1998, http://www.fg.org/research/CAP/CAP_O_corallicola.pdf). In the Florida Keys *Opuntia tricantha* (Willdenow) Sweet is also rare and on the "threatened" list. Other native species and non-native species either naturalized or grown as ornamentals in Florida are also at risk.

In arid areas of the U.S. and Mexico, prickly-pear cactus (cladodes or fruit) are consumed by deer, javelina (peccaries), rabbits, hares, bears, and other mammals including carnivores (Chavez-Ramirez et al., 1997, Hellgren 1997). The use of prickly-pear pads by a large number of herbivores is a well known phenomena (Janzen 1986) and they are an important source of food for jackrabbits, packrats, and javelina. Researchers have reported a loss of food for threatened gopher tortoises in Florida since the arrival of the moth in 1992 (Pierce 1995). In Mexico at least 109 insect species feed on cactus (Chavez-Ramirez et al., 1997). Several insects have coevolved with cacti as their sole food source, for example the giant cactus long-horned beetle (*Moneilema gigas*).

Many birds, mammals, and insects feed on the fleshy fruits; so may reptiles such as desert tortoises and spiny iguanas <http://www.desertmuseum.org/books/opuntia.html>. Based on observations in the Serranias del Burro, Coahuila, Mexico, when prickly pear fruits are abundant they can be heavily relied upon by bears (Bartoskewitz 2001). In this area, the fruit is a predictable late summer food resource, is high in water content, and is normally abundant even during drought periods. Although it may not be as common, this pattern is similar to concentrations of bears on berry patches in late summer in the Rocky Mountains. Nectar and pollen are also important food resources for the many pollinator species such as native bees and honeybees that visit the flowers of *Opuntia* species.

Prickly pear cactus plants provide nesting habitat for wood rats, other rodents, the cactus wren, the curve-billed thrasher, among other bird species (Hellgren 1997). Endangered or protected wildlife species that rely on prickly-pear cactus for food or cover include the Texas tortoise (protected species) and the lesser

long-nosed bat (USFWS endangered species) as well as several insects and nesting birds (Garrett 2004). For example, the Texas tortoise has been observed to stack opuntia pads like shingles to create cover and shelter. Direct losses of *Opuntia* food and nesting resources, as well as indirect impacts to native species interactions, habitat structure (shade, shelter, nesting areas), and sustainability of desert ecosystems, may reach a variety of wildlife species. Potential impacts of the unchecked spread of the cactus moth may also affect many valued plants not commonly associated with *Opuntia*.

Control actions to prevent or contain the spread could also threaten co-occurring native species. For example, in Florida, *Papilio aristodemus ponceanus* Schaus (Schaus swallowtail), *Anaea floralis* Johnson and Comstock (the Florida leafwing), *Strymon acis* (Drury) (Bartram's scrub-hairstreak) and *Gerstaeckeria fasciata* Pierce (the Gerstaeckeria cactus weevil) are rare and endangered insects that could be negatively impacted if broad spectrum insecticides were used in the habitats where they occur.

Conservation significance

Central Mexico is considered an important center of biodiversity for *Opuntia* (other important areas for *Opuntia* include the Andean region and Brazil (Rebman and Pinkava 2001). Cacti in the genera *Nopalea*, *Consolea*, and *Opuntia* (hereafter *Opuntia* or *Platyopuntia*) comprise more than 200 species world wide, of which 114 are present in Mexico (Vigueras and Portillo 2001). Native distribution of the *Platyopuntia* extends across the New World, with species in the Caribbean and throughout the Americas. Narrow endemism is characteristic of this group. There are at least 31 likely host *Opuntia* species for the cactus moth across the U.S. (9 endemic), and 56 in Mexico (38 endemic) (Johnson et al., 1996, Stiling 2002).

With the westward spread of this pest, several species of prickly-pear cactus that are either on the U.S. Fish and Wildlife Service's Endangered Species List or have other designated protection status in individual states have become even more vulnerable. The following are examples of *Opuntia* species of significant conservation concern that could be impacted by the invasive spread of the cactus moth. The invasive moth also threatens many rare and unique species of concern to local agencies and organizations.

Endangered Status:

Bakersfield cactus (*Opuntia treleasei*) in California, July 19, 1990 by the U.S. Fish and Wildlife Service, http://sacramento.fws.gov/es/plant_spp_accts/bakersfield_cactus.htm

Other Designated Status:

Florida semaphore cactus (*Opuntia corallicola*) – Candidate Notice of Review for Endangered Status by USFWS June 13, 2002; http://www.ftg.org/research/CAP/CAP_O_corallicola.pdf

Beavertail Prickly-Pear (*Opuntia basilaris*) Engelmann & Bigelow, in CA, NV, UT, AZ;

Golden-Spined Prickly-Pear (*Opuntia aureispina*) Pinkava & B.D. Parfitt, in Texas;

Yellow beavertail (*Opuntia aurea*) E.M. Baxter, in Arizona and Utah;

Sand Prickly-Pear (*Opuntia arenaria*) Engelmann, in New Mexico, Texas;

Keys Joe-jumper (*Opuntia triacanthos*) (Willd.) Sweet, in Florida – Endangered List.

Figure 3

The semaphore cactus (*Opuntia corallicola*) is an extremely rare species native to Florida that is threatened by the cactus moth, *Cactoblastis cactorum* Berg. Photo courtesy of Doria Gordon, TNC.



Human Environment

Environmental conservation values include the many important human resources in intact desert ecosystems. Centers of *Opuntia* species and genetic diversity in Mexico provide aesthetic landscapes, medicines (current and potential), wild harvestable plant resources, and habitats important to desert wildflowers and wildlife. Native prickly pear species and habitats are used in various ways and provide important economic values, including new varieties of fresh produce, free sources of emergency fodder, opportunities for subsistence farming, erosion control, water conservation, and tourism and recreation.

The value of a natural desert landscape is complex and difficult to measure. Different people see and value diverse aspects of native plants and environments, including aesthetic beauty of natural landscapes, sustainable ecosystems, clean air, and habitat for plants and animals. People in Mexico and the U.S. pride themselves on the beauty of their land. Native landscapes provide a sense of place and resilience to human activities and shifting climates.

Native cultures are also an important component of the human environment and there is a long history of dependence on *Opuntia* products by indigenous groups of North America, such as the Tohono O'odham people in the deserts of Arizona <http://www.desertmuseum.org/books/opuntia.html>. People who live with and use *Opuntia* plants often recognize more differences between them than do botanists. For example, Juanita Ahil was a Tohono O'odham who lived in the desert near Sells, Arizona. An ecologist recognized two species of *Opuntia* growing in Juanita's yard, while she was able to distinguish five different kinds from the appearance of the prickly pear pads alone. Later, it was confirmed that characteristics of the fruits these plants differed accordingly in color, taste, and keeping qualities.

Cumulative Risk Rating: This is considered to be a biological indicator of the potential of the pest to establish, spread, and cause economic and environmental impacts, and should be interpreted as follows: Low: 5 - 8 points, Medium: 9 - 12 points, High: 13 - 15 points

Overall pest risk rating for consequences of introduction of the cactus moth:

(5 Risk Elements, score 1-3 points)

Risk Element 1 Climate/Host Interaction (3)

Risk Element 2 Host Range (2)

Risk Element 3 Dispersal Potential (3)

Risk Element 4 Economic Impact (3)

Risk Element 5 Environmental Impact (3)

Estimated Cumulative Risk Rating (14) **High**

Step 6 Assess introduction potential

Datasets are needed, but based on available information we estimate that there is a high likelihood that the cactus moth will enter the southwest United States and Mexico, and in many areas conditions are expected to be suitable for survival and establishment.

Assign ratings as follows:

High	3	Introduction is very likely or certain, given the combination of factors above
Medium	2	Introduction is likely
Low	1	Likelihood is low, but clearly possible
Negligible	0	Extremely unlikely

Considerations related to introduction potential:

- Prevalence in area of origin (3) – The cactus moth is a pest within the native range and is established in many countries worldwide. The moth could potentially impact many cactus producers and an increasing trade of live plants, fresh produce and other products.
- The potential for contamination of commodities or conveyances by the species (3) – Larvae can survive and move undetected in shipments of plants and plant parts. Adults can be attracted to lights and may “hitchhike” on vehicles or storm movements.
- Whether the species can survive under the environmental conditions of shipment (3) Larvae can be expected to survive and develop within the protective cactus pad, even in harvested plant parts. Exceptions may be frozen or processed products.
- Ease or difficulty of detection through visual inspection (2) Distinctive damage exudates and egg sticks may be noticed by trained inspectors. However, damage is not always obvious, and adult males have been trapped in areas where no pad damage was seen. Furthermore, there are several taxonomic difficulties with differentiating co-occurring native cactus moth species.
- Probability of surviving existing phytosanitary procedures (2) Inspections are most likely to be effective for people that have declared fruits, vegetables, or plants, and there are some random inspections that may pick up smuggled material. From Hawaii and Puerto Rico, cacti are prohibited, and fruits and pads are prohibited from other countries where the cactus moth occurs. When the cactus moth is found in shipments of plant material, the cargo is fumigated or returned to the origin.
- Frequency and quantity of pest movement into the risk analysis area by named means (2) Data are needed, especially on patterns of movement and trade in Mexico, but there is considerable import of cactus into and within the U.S.
- Number and frequency of shipments of contaminated commodities (2) Twenty-three reported interceptions in the U.S. are likely to represent a small percentage of contaminated cactus products.

- Number of individuals of the species associated with each named conveyance or commodity (3) Due to the nature of the egg sticks and gregarious feeding in the pads, a single contaminated plant has the potential to produce many individuals that could establish in new areas.
- Intended use of named commodities (2) Landscape/horticultural plantings in proximity to native *Opuntia* habitats in particular may encourage new establishment.
- Season of arrival and distribution of commodities (3) in warmer areas of the Southeast U.S., additional introductions in areas with existing populations could overlap with adult flight generations three times per year (or even continuously throughout the year), making successful mating and dispersal events more likely.

The likelihood of introduction (High - 14) and consequences of introduction (High - 22) scores are rated as high, resulting in a high overall pest risk potential for the cactus moth.

Stage 3: Management. This is the integration of stages 1 and 2 (assessment) with management options, scenarios, data needs, and some speculation in lieu of a complete assessment (for more on cactus moth management options refer to Zimmermann et al., 2004).

Step 7 Conclusions and comments on pest risk potential of the cactus moth.

Phytosanitary measures: pest risk potential of quarantine pests and brief comments on the management options associated with the requested commodity importations.

The high risk of invasion of the southwestern U.S. and Mexico, with accompanying deleterious ecological, economic, and social effects, must be recognized due to the many values at risk in these areas. If an integrated and coordinated response were implemented this year, the future spread of the cactus moth may be slowed or prevented. If the spread is unchecked, in less than three years the costs may be prohibitive, and if allowed to spread for five years containment may not be possible. Economic, environmental and social costs of mitigation would be a significant burden, especially for Mexico. By taking early actions to predict future establishment and monitor in areas where infestations are likely, newly established populations can be detected and contained. Control is generally most successful and most cost-effective while populations are still limited in numbers and distribution. Management efforts could then be mobilized and concentrated in these areas to prevent further population expansion and to implement control efforts.

Preventive quarantines and regulatory measures could be strengthened for national and international ports. Regulations could cover aspects of: quarantine, phytosanitary certification, restrictions on plant movement, plant inspections, early detection, appropriate response and control measures, including sanitation and destruction of infested plants and crops. Preventative measures must be applied by all countries involved to avoid movement of the moth. National authorities could regulate the internal transportation of cactus plants or parts thereof and provide “*Cactoblastis cactorum*-free” certification to avoid movement of the cactus moth in any life stage. It could be included in lists of quarantine pests in countries exporting or importing *Opuntia* material, and prevention efforts could be made at the regional, provincial, or state level. Prevention should be combined with field surveillance and monitoring where distribution of the moth is limited.

Early detection is essential in the many locations that are under threat of invasion. Populations of the cactus moth have traditionally been detected by visual sampling for damage and for the presence of egg sticks. While visual scouting methods are effective for confirming the presence of pests through careful investigation of their damage, sparse populations can easily be overlooked. Traps baited with virgin females are very effective at capturing males and have proven invaluable in detecting low population levels, before damage is visible. While traps using female moths are powerful, their usefulness is limited by the fragile nature of the female moths, the costs of rearing moths and frequently replacing them in the traps, and the necessity of sterilizing females that are used in traps outside an infested area. There has been significant progress in the attempts to isolate, identify, and synthesize the active female-produced pheromones (Robert Heath, USDA, pers. comm., 2004). Recent identification of active pheromones was an essential step in

reducing the costs of deploying traps, and in facilitating the expansion of a monitoring system beyond the range of currently known infestations for early detection of further spread. New options for early detection are available now that the pheromone has been developed and its effectiveness has been demonstrated in large-scale field experiments (Stephanie Bloem, pers. comm., 2004).

With any plan to prevent the invasive spread, considerable value would be placed on the development and use of tools and efficient sampling designs to monitor populations in the field. Monitoring can be used to precisely delineate the existing range of insect pests, continuously monitor their movement or the “leading edge” of their population, and assess the effectiveness of control efforts. The most effective method of determining the distribution of this pest is to develop and deploy the semiochemical-baited traps beyond the currently known infestations and in areas that support valuable *Opuntia* resources. In addition to female-produced volatiles, the importance of host plant volatiles in the attraction of dispersing males and females needs to be investigated.

Once the populations have been delimited, barriers can be established using an integrated response to prevent further spread. Several methods of control have been considered and used for management of the cactus moth. This assessment does not include a comprehensive treatment of control techniques, rather a summary of the strategies and options that may be useful for prevention of spread and some of the concerns related to various options such as potential non-target effects to native plants and animals. Potential management tools include removing the egg sticks and infected pads by hand, chemical insecticides, insect pathogens, natural enemies, host plant destruction, and radiation techniques. The Sterile Insect Technique (SIT) has been identified as an appropriate tool in an effective response based on successful use as a barrier to prevent the spread of other lepidopteran pests such as the pink bollworm and codling moth.

Conventional sanitation techniques (removal of infected pads) are used worldwide and would be a component of any effective response program (Zimmermann et al., 2004, Lobos et al., 2002). Removal of heavily attacked host plants and destruction of infected plant parts has been used on a limited basis in the Florida Keys to reduce the population of the cactus moth in an effort to protect a rare and endangered cactus species (Doria Gordon, TNC, pers. comm., 2003).

Chemical control may play a role particularly in cultivated plantings, but widespread use of pesticides to control the cactus moth is not advisable for several reasons. The expense of treating large areas would be prohibitive and several rare and endangered fauna may be adversely affected (Carpenter et al., 2001). Studies from Argentina, where the cactus moth continues to cause damage to cactus plantings, conclude that pesticides are not very effective due to the protective cactus pad. The fact that the larvae eat inside the waxy protective cladode, with many entering through one hole, makes contact with any pesticide very limited (Lobos et al., 2002). Also of concern are the non-target impacts on beneficial insects including pollinators, fish, birds, mammals and other wildlife. In high-density production areas for the cactus pear market, hand removal of egg sticks and insecticides such as carbaryl have been successfully used to control recently emerged (neonate) larvae. The use of systemic insecticides injected into cactus stems has been investigated as a means of protecting ornamental cacti and small populations of endangered cacti, but are not recommended because many *Opuntia* species are associated with sensitive ecological areas and occur together with rare and endangered plants and animals. However, there is recent efficacy data for a number of new insecticides tested and the results were very good (Stephanie Bloem, pers. comm., 2004).

Sex pheromones have been used successfully in mating disruption for some pests where the populations are very low, the host plant density is high, and the plantings are contiguous. However, this approach, while critical for survey and monitoring, would be insufficient for the cactus moth because host plant density would be too sparse in the natural areas and the area of infestation would be too large.

Biological control may have potential as part of an integrated response (Pemberton and Cordo 2001). In its native habitat in South America, several natural enemies have been identified including: *Apanteles alexanderi* (Hymenoptera: Braconidae), *Phyticiplex doddi* and *P. eremnus* (Hymenoptera: Ichneumonidae), *Brachymeria cactoblastis* (Hymenoptera: Chalcididae), and *Epicoronimyia mundelli* (Diptera: Tachinidae). The problem with these available agents is that the known parasitoids attacking the moth in the native area (and elsewhere) lack the specificity to prevent impacts to native non-target insects, especially the many native cactus-feeding moths in North America (Pemberton and Cordo 2001). It is possible that additional

useful agents may be identified and developed, such as the potential of using several *Nosema* species. However, non-target effects of introducing new species in the environment may be significant and any releases should be made with great caution. Suppression of populations may be a useful strategy but the introduction of agents alone will not be likely to prevent the spread or contain existing populations.

The Sterile Insect Technique (SIT) has been identified as a potential tool to suppress populations. Preliminary studies on the radiation biology of the cactus moth indicate that sterility can be induced with a dose of radiation that should allow for the release of highly competitive moths (Carpenter et al., 2001b). The SIT could be useful for eradication or the establishment of barriers to prevent the continued expansion of populations (Carpenter et al., 2001a). SIT has been successful against a number of pest Diptera (including the screwworm fly, *Cochliomyia hominivorax*, tsetse flies, the Mediterranean fruit fly, *Ceratitis capitata*, and various other fruit fly pests), and numerous mass rearing facilities have been constructed worldwide to support these programs. However, compared to flies, moths are more expensive to rear and have a propensity to fly greater distances. Additionally, moths are more radio-resistant than dipterans. As a consequence, the larger dose of radiation required to completely sterilize moths may reduce their competitiveness and performance in the field (Bloem and Carpenter 2001). A related risk would be the possibility of unintended release of fertile individuals. In large scale operational programs this risk is mitigated through the routine application of quality assurance procedures. Two large-scale sterile insect technique programs are currently successfully operating against moth pests, namely the pink bollworm program in the U.S. <http://www.ars.usda.gov/is/AR/archive/nov02/pink1102.htm>, and the codling moth program in Canada http://www.cbc.ca/stories/2002/08/16/codding_moth020816.

The use of inherited or F1 sterility is one approach to reduce the negative effects of radio-resistance in Lepidoptera. F1 sterility was first documented in studies on the codling moth, and has since been reported in many Lepidopteran species of economic importance. Like sterile insect techniques, F1 sterility involves the mass rearing and release of genetically altered insects to insure that when matings occur in the field, a significant proportion involve a treated, released insect. Lepidopteran females generally are much more sensitive to radiation than are males of the same species. This allows the dose of radiation to be adjusted so that the treated females are completely sterile and males are partially sterile. When this partially sterile males mate with fertile females, the radiation-induced deleterious effects are inherited by the F1 generation. As a result, egg hatch is reduced and the resulting F1 offspring are highly sterile and predominantly male. The lower dose of radiation used in F1 sterility increases the quality and competitiveness of the released insects. Field release of partially sterile insects have demonstrated the potential of using F1 sterility to control many Lepidopterans, including the cabbage looper, *Trichoplusia ni*, the corn earworm, *Helicoverpa zea*, the gypsy moth, *Lymantria dispar* and the codling moth, *Cydia pomonella*. In addition many studies have shown that F1 sterility can be effective combined with other biological control such as pheromone mating disruption, entomopathogens, host plant resistance and natural enemies. As a result of these studies, F1 sterility is regarded as the most favorable genetic method for most applications against Lepidoptera (Bloem and Carpenter 2001). Sterilization is accomplished by exposing insects to a specific dose of gamma radiation emitted by radioisotopes (Cobalt 60 or Caesium 137).

Pilot studies on radiation techniques with the ultimate goal of containment at the leading edge are underway at the USDA-ARS laboratory in Tifton, GA., in collaboration with USDA-APHIS in Tallahassee, FL and the IAEA in Vienna. Further collaboration could facilitate the involvement of international experts to accelerate the refinement of inherited sterility procedures for this pest. For example, South Africa could be an appropriate location for conducting insecticide trials and host range studies under field conditions, and for collecting large numbers of cactus moths to augment the initiation of mass rearing in the U.S. laboratories. Since parts of the Caribbean have been infested with the cactus moth since the 1960's, some field testing could also take place there.

Because of the critical time window for taking action to prevent the cactus moth's natural dispersal from reaching Texas by 2007, researchers believe that they must conduct SIT validation studies and control on the leading edge in the Gulf Islands of Florida, Alabama, and Mississippi simultaneously. This effort will require immediate capacity building for production of sterile moths, delivery systems and volunteer

coordination to assist in pretreatment cleanup operations in those areas. If the cactus moth pest becomes established in Texas beyond the Gulf Coast, the cost of controlling its further spread will increase markedly.

Contingency plans and an alerting system for a rapid response to new outbreaks of the cactus moth are needed to prevent the establishment of this invasive species in the Southwest U.S. and Mexico. Early detection will be critical beyond the leading edge and in the many areas where *Opuntia* is native and/or cultivated. The Global Invasive Species Program recommends that when preventative measures have failed to exclude an invasive pest, eradication is the preferred course of action (published in “Invasive Alien Species: A Toolkit of Best Prevention and Management Practices”). Therefore, every country or region that would be negatively impacted by an infestation requires an emergency response plan with consideration for native species and habitats. Components of effective plans would include quarantine methods for the impacted area, survey plans and response protocols. Also critical for a successful response are an awareness campaign, destruction of infested host plants, intensive monitoring and surveillance, and appropriate integration of tools such as sterile insect techniques. Economic considerations include cost and time investment of potential control techniques (mechanical labor, physical barriers, chemicals, radiation, development of biological control options, economic risks of potential control techniques, and non-target effects on desired species and landscapes). The Mexican Government, through the Ministry of Agriculture and the Ministry of Environment, has been active in preparing the infrastructure to prevent introduction and establishment of the pest in the country and for eradicating an eventual introduction of the pest. A Cactus Moth National Campaign has been recently created by the Mexican Government and prevention activities in high-risk areas, including ports of entry and locations more likely to be affected by natural spread, are underway. A Federal Law allowing for emergency response activities to be enforced in case an outbreak occurs, has been published in the Mexican Federal Register (IAEA 2004 <http://www.iaea.org/programmes/nafa/d4/public/newsletter-jan04.pdf>).

The costs of any approach to prevent and manage the impacts of this invasive species will only increase if the spread is left unchecked. If proposed prevention and monitoring programs can be implemented early (within the next two years), there is a chance that risks and impacts may be curtailed. In order to be fully ready to apply sterile moths in the validation study beginning in 2005, researchers must begin increasing rearing capacity and gathering materials, equipment, and assistance immediately. Researchers projected that they required additional funding for a SIT validation study, further research on rearing, pheromones, remote sensing, and detection efforts in fiscal year 2005. The effort anticipated will implement a validation experiment on Santa Rosa Island and have additional sterile insects to apply to the leading edge on Dauphin Island, Alabama. There is hope that a barrier to the westward migration of *Cactoblastis cactorum* will begin to be established due to this effort. In fiscal year 2005, APHIS allocated \$500,000 from its contingency funds toward this goal. APHIS also assembled a strategic plan that details funds necessary for a more permanent program requiring additional funding and moving the rearing from a research facility to a state department of agriculture with the capacity to rear and irradiate 100,000 moths per week.

Additional funding from an appropriation or other sources is required for a permanent program once success of SIT is demonstrated. Mexico’s SAGARPA has expressed sincere interest in helping fund the U.S. program and further research. A request for increased funding on this problem was submitted as part of the fiscal year 2006 budget process, but the increase was not approved. The preliminary estimate for a full USDA APHIS SIT monitoring program is approximately \$1.5 million. If the moth continues to spread to the Southwest U.S. and Mexico, total costs will far exceed available estimates and resources, and impacts to natural resources are likely to be irreparable.

Conclusions:

- Establishment in cactus-producing areas of the Southwest U.S and Mexico will be devastating and further spread of the cactus moth, *Cactoblastis cactorum* Berg, is likely to cause deleterious ecological, social, and economic damage.
- Early detection (survey and data sharing) and rapid response (control) is needed to prevent the spread of the invasive cactus moth from the Southeast U.S., Cuba, and other Caribbean islands to the Southwest

U.S. and Mexico. Prevention, early detection and control efforts are needed, particularly along the leading edge of invasion while the chances of control are still possible.

- Sanitation (mechanical removal of infected pads) remains a critical element of any effective response, and the sterile insect technique approach has been identified as a promising tool for control. However, it may be more effective when combined with systematic surveys, monitoring, integrated control, and other early detection and rapid response measures.
- The threat of this invasive species is not yet fully appreciated by decision makers and land managers. An effective awareness and regulatory national and international outreach program is needed.
- Continued program funding and support is needed to improve data collection methods and increase efficacy of prevention, monitoring and control efforts.
- The establishment of a barrier to prevent the dispersal of *Cactoblastis cactorum* along the Gulf Coast is critical as an initial step towards preventing its eventual introduction into Texas and Mexico where the costs of control may be prohibitive.
- Although the emphasis may initially focus on prevention of spread to the Southwest U.S. and Mexico, and containment of infestations in Cuba, other Caribbean islands and the Southeast U.S., an effective response will depend on a collaborative effort among all interested countries and experts.
- Future steps: Calculate benefit to cost ratios and other relevant economic indices for the different prevention and control options. Develop and improve predictive maps and models with the best available datasets. Implement large-scale monitoring and field survey data collection across natural, agricultural, and developed landscapes. Gain support for efforts on prevention and control of the invasive cactus moth, particularly at the leading edge of infestations and along potential dispersal pathways. Secure funding through congressional appropriation for a permanent program in the Southeast U.S. to maintain a barrier along the Gulf Coast, to prevent the dispersal of *Cactoblastis cactorum* to the Southwest U.S. and Mexico.

References Cited:

- Baen, J.S.. 1997. The Growing Importance and Value Implications of Recreational Hunting Leases to Agricultural Land Investors. *Journal of Real Estate Research*, 14 (3). pp. 399-414.
- Bartoskewitz, C.K. 2001. Spatial relationships related to reproductive status of female black bears in the Serranias del Burro, Coahuila, Mexico. Thesis, Texas A&M University-Kingsville, Kingsville, USA.
- Bloem, K.A. 2003. "Overview of the Cactus Moth Problem", Presented at the Cactus Moth *Cactoblastis cactorum* Planning Meeting, December 9-10, 2003 in Miami, Florida.
- Bloem, S. and J.E. Carpenter. 2001. Evaluation of population suppression by irradiated Lepidoptera and their progeny. *Florida Entomologist*. 84(2): 165-171.
- Carpenter, J.E., K.A. Bloem and S. Bloem. 2001a. Applications of F₁ sterility for research and management of *Cactoblastis cactorum* (Lepidoptera: Pyralidae). *Florida Entomologist*. 84: 531-536.
- Carpenter, J.E., S. Bloem, and K.A. Bloem. 2001b. Inherited sterility in *Cactoblastis cactorum* (Lepidoptera: Pyralidae). *Florida Entomologist*. 84: 537-542.
- Chavez-Ramirez, F., Wang, X., Jones, K., Hewitt, D. and P. Felker. 1997. Ecological Characterization of *Opuntia* Clones in South Texas: Implications for Wildlife Herbivory and Frugivory. *Journal of the Professional Association for Cactus Development*, 2: 9-19. <http://www.jpacd.org/Chavez.pdf>
- De La Rosa, H. J. P. and D. Santamaria A. 1998. El nopal, usos, manejo agronomico y costos de production en Mexico. Ed. CONAZA-UACH-CIESTAAM. Chapingo, Mexico. pp. 132.

- Dodd, A.P. 1940. The biological campaign against prickly pear. Commonwealth Prickly Pear Board, Brisbane, 1-177.
- Florida Department of Agriculture and Consumer Service. 2003. What are Nopalitos? The Florida Agri-Journal 11 (6): January 6.
- Garrett, L. 2004. White Paper: Economic impact from the spread of *Cactoblastis cactorum* in the United States. Draft report to USDA APHIS PPQ. April, 2004. 9pp.
- Habeck, D. H. and F.D. Bennett. 1990. *Cactoblastis cactorum* Berg (Lepidoptera: Pyralidae, a Phycitine New to Florida. Entomology Circular No. 333, Florida Department of Agriculture and Consumer Services.
- Hight, S.D., J.E. Carpenter, K.A. Bloem, S. Bloem, R.W. Pemberton, and P. Stiling. 2002. Expanding Geographical Range of *Cactoblastis cactorum* (Lepidoptera: Pyralidae) In North America. Florida Entomologist 85 (3): 527-529.
- Hight, S.D., S. Bloem, Kenneth Bloem, and J.E. Carpenter 2003. Mating Behavior of *Cactoblastis cactorum*: Observations of courtship and mating behaviors at two locations on the Gulf Coast of Florida. Florida Entomologist 86 (4): 400-408.
- Hellgren, E.C. 1994. Prickly-pear cactus (*Opuntia* spp.) and its use by wildlife. Proceedings, 5th Annual Texas Prickly Pear Council (Felker and Moss Eds).
- International Atomic Energy Agency (IAEA) 2002. Mitigating the Threat of *Cactoblastis cactorum* to International Agriculture and Ecological Systems and Biodiversity. Report and Recommendations of a Consultants' Group Meeting organized by the Technical Co-operation Department of the IAEA and the Joint FAO/IAEA Division of Nuclear Applications in Food and Agriculture, Vienna, Austria, July 2002.
http://www-tc.iaea.org/tcweb/abouttc/strategy/thematic/pdf/summary/Summary_report_cactus_moth.pdf
- Irish, M. 2001. The ornamental prickly pear industry in the southwestern United States. Florida Entomologist 84(4): 484-485.
- Janzen, D.H. 1986. Chihuahuan desert nopaleros: defaunated big mammal vegetation. Annual Review of Ecological Systematics. 17: 595-636.
- Johnson, D.M. and P.D. Stiling. 1996. Host specificity of *Cactoblastis cactorum* (Lepidoptera: Pyralidae), an exotic *Opuntia*-feeding moth, in Florida. Population Ecology 25(4): 743-747.
- Johnson, D.M. and P.D. Stiling 1998. Distribution and dispersal of *Cactoblastis cactorum* (Lepidoptera: Pyralidae), an exotic *Opuntia*-feeding moth, in Florida. Florida Entomologist 81:12-22.
- Krombein, K.V., Hurd, P.D. Jr., Smith D.R., and B.D. Burks. 1979. Catalog of Hymenoptera in America north of Mexico. Smithsonian Institution Press, Washington D.C., USA.
- Lobos, E., Ochoa, J. and Soulier, C. 2002. *Cactoblastis cactorum* Berg (Lepidoptera: Pyralidae) Preliminary studies for chemical control. Acta Hort. (ISHS) 581:247-251.
http://www.actahort.org/books/581/581_27.htm

- Monterey County, 1998. "Overall Economic Development Program 1998" Monterey County California. pp. 25.
- Morse, L.E., J.M. Randall, N. Benton, R. Heibert, and S. Lu. 2004. An Invasive Species Assessment Protocol: Evaluating non-native plants for their impact on biodiversity. Version 1. Natureserve, Arlington, Virginia, May 2004.
- Neunzig, H. H. 1997. Pyraloidea: Pyralidae (Part): Phycitinae (Part). *In*: Dominick, R. B. Moths of America North of Mexico. Fasc. 15.4. 157 pp. Allen Press.
- Pemberton, R.W. 1995. *Cactoblastis cactorum* (Lepidoptera: Pyralidae) in the United States: An immigrant biological control agent or an introduction of the nursery industry. *American Entomologist*. Winter: 230-232.
- Pemberton, R.W., and H.A. Cordo. 2001. Potential and risks of biological control of *Cactoblastis cactorum* (Lepidoptera, Pyralidae) in North America. *Florida Entomologist* 84(4) 513-526.
- Rakowitz, L 1997. The significance of prickly pear on south Texas rangelands. *Rangelands* 19 (6) 15-17.
- Robbins, Christopher S., ed. 2003. Prickly Trade: Trade and Conservation of Chihuahuan Desert Cacti. TRAFFIC North America. Washington D.C.: World Wildlife Fund. 48 pp.
http://www.traffic.org/news/press-releases/prickly_trade.html
- Rodriguez, O.R. 2003. Law aimed at protecting U.S. food supply takes effect; some exporters fear delays. *Business News* December 12, 2003.
- Salisbury, S. 2003. Florida Agriculture Officials Hope Mexican Nopalitos Take Root among Consumers. *The Palm Beach Post* February 24, 2003.
- Sandoval, R. 2001. Mexican Farmers Finding New Markets for Hearty Nopal Cactus. *The Dallas Morning News* August 31, 2001.
- Silberman, J. 2002. The Economic Importance of Off-Highway Vehicle Recreation. Arizona State University West. School of Management Study.
- Soberon, J., J. Gubolov and J. Sarukhan. 2001. The importance of *Opuntia* in Mexico and routes of invasion and impact of *Cactoblastis cactorum* Lepidoptera: Pyralidae. *Florida Entomologist* 84(4): 486-492.
- Solis, M.A., Hight, S.D. and D.R. Gordon. 2004. Tracking the cactus moth, *Cactoblastis cactorum*, as it flies and eats its way westward in the U.S. *News of the Lepidopterists' Society* 46(1): 3-7.
<http://www.sbs.utexas.edu/philjs/News/pdf/CactusMoth.pdf>
- Stiling, P. 2002. Potential non-target effects of a biological control agent, prickly pear moth. *Cactoblastis cactorum* (Berg) (Lepidoptera: Pyralidae), in North America, and possible management actions. *Biological Invasions* 4: 273-281.
- Vigueras G, A. L. and L. Portillo 2001. Uses of *Opuntia* species and the potential impact of *Cactoblastis cactorum* (Lepidoptera: Pyralidae) in Mexico. *Florida Entomologist* 84 (4) 493-498.

- USDA APHIS 2000. Guidelines for Pathway-Initiated Pest Risk Assessments. USDA, U.S. Department of Agriculture Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Permits and Risk Assessment Commodity, Risk Analysis Branch 4700 River Road, Unit 133 Riverdale, MD 20737-1236
- USDA, 2000. "Crop Profile for Cactus Pear in California", NSF Center for Integrated Pest Management, North Carolina State University. <http://pestdata.ncsuedu/cropprofiles.docs/Cactuspear.html>
- Wang, X., P. Felker, and A. Paterson. 1998. Environmental influences on cactus pear fruit yield, quality and cold hardiness and development of hybrids with improved cold hardiness. *Journal of Professional Association for Cactus Development* 2: 48-59.
- Whitehead, T. M. 2003. Prickly pear cactus has become fixture in Rio Grande Valley. *Lone Star Living* March 19, 2003.
- Zimmermann H., Moran V.C., and J.H. Hoffmann. 2000. The renowned cactus moth, *Cactoblastis cactorum*: its natural history and threat to native *Opuntia* floras in Mexico and the United States of America. *Diversity and Distribution* 6: 259–69.
- Zimmermann, H.G., S. Bloem, H. Klein. 2004. The biology, history, threats, surveillance and control of the cactus moth, *Cactoblastis cactorum*. Joint FAO/IAEA Programme, Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency. In Press.