CACTOBLASTIS CACTORUM (LEPIDOPTERA: PYRALIDAE) IN NORTH AMERICA: A WORKSHOP OF ASSESSMENT AND PLANNING

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ABSTRACT

The cactus moth, *Cactoblastis cactorum* Berg (Lepidoptera: Pyralidae), has been an important biological control agent of introduced and weedy prickly pear cacti (*Opuntia* spp., Cactaceae) in many parts of the world. *Cactoblastis*, a native of Argentina, was introduced into the Caribbean in 1957 to control weedy, but native species of prickly pear infesting rangeland. It has spread through the Caribbean and in 1989 was first found in Florida. It has now spread as far north as coastal Georgia. There is a continuous distribution of acceptable host species of *Opuntia* from southern Florida across the southern United States to the Pacific Coast. Mexico is a center of endemism and has many species of *Opuntia*. Prickly pear cacti constitute a highly important and uniquely desert-adapted subsistence food and cash crop in Mexico. Prickly pears have other valuable uses, such as in the production of cochineal dye and in desert landscaping. Because *Cactoblastis* readily attacks many novel hosts within *Opuntia*, it will likely have serious impacts on the ecology of desert environments and on the agricultural and horticultural uses of prickly pears. Further, if *Cactoblastis* does result in significant damage, it is likely to serve as another source of criticism of classical biological control. *Cactoblastis cactorum in North America, A Workshop of Assessment and Planning*, was held in Tampa, Florida in September 2000. Major subject areas covered include the biology and economic importance of *Opuntia*, the biology, biological control history, and current status of *Cactoblastis*, and potential methods of controlling *Cactoblastis* in North America. This paper summarizes findings of the workshop and provides an introduction to the workshop proceedings.

Key Words: biological control, cactus moth, chemical control, F_1 sterility, *Opuntia*

RESUMEN

La palomilla del cactus, *Cactoblastis cactorum* Berg (Lepidoptera: Pyralidae), ha sido un agente de control biológico importante contra varias especies de cactus exóticos e invasivos pertenecientes al género *Opuntia* (Cactaceae) en varias partes del mundo. Esta especie, originaria de Argentina, fue importada al Caribe en 1957 para controlar especies nativas de cactus que estaban infestando las áreas de forraje para ganado. La especie expandió su distribución a través del Caribe y en 1989 fue detectada por primera vez en Florida. Hoy en dia, su distribución hacia el norte alcanza el área costera del estado de Georgia. Desafortunadamente, existe una distribución continua de hospederos del género *Opuntia* desde Florida a través de los estados del sur de los Estados Unidos hasta llegar la costa del Oceano Pacifico. Méjico es un centro de endemismo donde existen varias especies endémicas de *Opuntia*. Estas especies constituyen una fuente importante de alimento y forraje en Méjico y son utilizadas en la manufactura de tintes y como vegetación en la jardinización de áreas semidesérticas. Debido a que *C. cactorum* ataca muchas especies dentro del género *Opuntia* su distribución tendrá consecuencias negativas en la frágil ecología de las areas desérticas y en los usos agrícolas y hortícolas de estas plantas. Asimismo, si el daño causado por *C. cactorum* es excesivo, esto servirá como otro punto para criticar al area de control biológico clásico. Un taller de trabajo titulado *Cactoblastis cactorum* en Norte America: un taller de planeamiento y evaluación fue llevado a cabo en Tampa, FL en Septiembre, 2000. Los temas que se discutieron incluyen: (a) la biología e importancia económica de *Opuntia*, (b) la biología, historia de control biológico y estatus actual de *C. cactorum* y (c) posibles métodos de control para esta especie en Norte America. Este artículo resume las conclusions del taller y sirve como introducción para los otros artículos que se presentan.

Prickly pear cacti are members of the platyopuntia group of *Opuntia* (Cactaceae). There are about 200 members in the genus, and they have a distribution, primarily in more arid areas and in well-drained soils, from the southern plains of Canada to South America; the genus is especially well-represented in Mexico. Opuntias are dominant components of the natural environment in drier climates of the New World where they are native. They are highly important as nurse plants for other plant species and as food and habitat for a variety of birds, reptiles, mammals, insects, and other animals (Russell & Felker 1985). Native Americans have used prickly pear stems (cla-

dodes) and fruits as important dietary components for probably thousands of years. Prickly pear cacti comprise an important cultivated food crop in Mexico (see papers by Badii & Flores, Soberon et al., and Vigueras G. & Portillo in this proceedings) and, to a lesser degree, in the United States. They are also an important forage for domesticated livestock. Prickly pear cacti have other commercial uses as well, such as for the production of cochineal dye by *Dactylopius* spp. and as an important landscaping plant in arid areas. Because of their various beneficial attributes, especially for fruit production, forage and fodder, dye production, and as an ornamental plant, prickly pear cacti have been purposefully distributed by humans throughout many drier areas of the world where cacti are not native, including Europe, Asia, Africa, and Australia. Opuntias were being spread worldwide as a source of fruit and cochineal dye as early as the 16th century (Rowley 1997). Transport and colonization is facilitated by the fact that most opuntias are adapted to vegetative reproduction; cut stems can survive for months in transit and then readily establish roots when provided with soil and water. Unfortunately, some opuntias are capable of becoming invasive weeds and have done so in many areas where they have become naturalized. Because of their fierce spines and dense growth, they can produce impenetrable thickets that displace native plant and animal communities or make land unproductive for livestock grazing and other human uses.

One of the great early successes in the biological control of weeds was the liberation of millions of hectares of Australian farmland, rangeland, and natural habitat from the scourge of a complex of alien and highly invasive species of prickly pear cacti. Students of biological control are familiar with the classic "before and after" pictures (e.g., DeBach 1974). The biological control agent, still effective after over 70 years, is the cactus moth, *Cactoblastis cactorum* Berg (Lepidoptera: Pyralidae), a native of Argentina and neighboring areas.

In many successful cases of biological control, natural enemies that have proven their effectiveness are introduced elsewhere in the world where the same pests are creating problems; this is the case with *Cactoblastis* (Zimmermann et al. 2000, reprinted in this proceedings). Most of the redistribution of *Cactoblastis* has been to areas where the cactus family is not native, and some of these programs have resulted in successes similar to what occurred in Australia. In 1956, the decision was made to release *Cactoblastis* onto the island of Nevis, in the Caribbean (part of the Leeward Islands group of the West Indies). On Nevis, a complex of *native* prickly pears, dominated by *Opuntia triacantha* (Willdenow), were considered to be undesirable pests in over-grazed rangeland where they out-competed grasses and caused serious injury to livestock and handlers (Simmonds & Bennett 1966). Three species of natural enemies, including *Cactoblastis*, were shipped from South Africa and released on Nevis in early 1957. *Cactoblastis* was apparently the only natural enemy to establish; it rapidly spread, resulting in the collapse of prickly pear plants, and the biological control program was considered "outstandingly successful" (Simmonds & Bennett 1966). Based upon this success, *Cactoblastis* was introduced onto Montserrat and Antigua in 1960, where it also became established and resulted in substantial reduction of prickly pear populations (Simmonds & Bennett 1966). Simmonds & Bennett (1966) also reported that *Cactoblastis* had spread either naturally or by unofficial human transport to St. Kitts and the U.S. Virgin Islands. Since this period, *Cactoblastis* has spread, either naturally or with intentional or unintentional human involvement, through many regions of the Caribbean, including to Puerto Rico, the Dominican Republic, the Bahamas, and Cuba, where it now attacks both weedy and non-weedy native *Opuntia* spp. (see Zimmermann et al. 2000).

In 1989, *Cactoblastis* was first identified from mainland North America, namely, southern Florida (Habeck & Bennett 1990). How it arrived in Florida is unclear. It is unlikely but possible that it was intentionally and illegally introduced. It may have arrived through natural dispersal by flight, possibly storm-aided. Another possibility is that it was unintentionally introduced, such as by a hobbyist cactus grower traveling from the Caribbean. Perhaps the most compelling possibility was proposed by Pemberton (1995), who suggested that it may have been unintentionally introduced through commerce. Pemberton (1995) documents that 300,000 *Opuntia* plants, originating from the Dominican Republic and destined for nursery sales, annually arrived in Miami during the 1980s. He also documents 13 interceptions of *Cactoblastis* at Miami ports from 1981-1986, including larvae found in stems originating from the Dominican Republic (Pemberton 1995).

Since its original discovery in southern Florida, *Cactoblastis* has moved northwards through natural dispersal (see Stiling & Moon, this proceedings) and now is present and causing noticeable damage in coastal areas of Georgia. Natural spread westward has been slower, but it was reported at our workshop that infested nursery stock had been found in the garden department of a large chain store in Pensacola in western Florida (N. Coile, Florida Department of Agriculture and Consumer Services) suggesting that dispersal through Florida and neighboring states may likely be facilitated through the nursery industry or by unintentional casual transport by home gardeners. Where it is established in Florida and Georgia, *Cactoblastis* is relatively com-

mon and noticeable to the general public, especially in regard to the collapse of specimen plants in the home landscape.

Workshop Rationale and Planning

My first awareness of the establishment of *Cactoblastis* on continental North America was from the paper by Pemberton (1995). As both a biological control scientist and a hobby cactus grower, the Pemberton paper was of significant professional and personal interest. That level of interest was raised substantially in 1999, when hobbyist cactus growers in Florida began to appeal to "cacti_etc", the largest international listserver devoted to the discussion of cacti and other succulent plants, for information on how to control this new "pest" that was damaging landscape opuntias. At this point it was clear that *Cactoblastis* would be an increasingly important issue with the general public.

Because there is a continuous distribution of prickly pear cacti from southern Florida through the Gulf Coast states, into the southern Midwest and Southwest (Benson 1982), and thereby into Mexico, there is the likelihood that *Cactoblastis* will spread throughout *Opuntia* habitat in climatically favorable regions of North America. Based upon its known impact on several species of *Opuntia*, both overseas and in their native habitat (e.g. Nevis), we must assume that there may be potentially substantial impact on both ecologically-important wild *Opuntia* populations as well as on agriculturally and horticulturally important opuntias in the southern United States and throughout Mexico. As *Cactoblastis* was originally intentionally introduced into the Caribbean Basin as a biological control agent, I was concerned that the science and practice of biological control could be held accountable, especially in light of recent critical commentary regarding non-target effects of classical biological control (for example, see Follett and Duan 1999, Strong and Pemberton 2000). For these reasons, I contacted several scientists familiar with the situation to determine if a workshop to explore the issues was advisable; the response was unanimously favorable, and an organizing committee was formed (see Acknowledgments).

It was our intent that this be a true workshop, necessarily limited in size to facilitate discussion and therefore open by invitation only, with each participant serving one or more specific roles. Further, it was our intent that a diversity of interests be represented including biological control, botany, conservation biology, ecology, entomology, and horticulture, and that there be representation from Mexico. The participants and their roles are presented in Table 1. The workshop was organized in such a way as to include formal presentations as well as discussion periods. The workshop agenda (Table 2) was organized to address several objectives, summarized by the following questions:

- How far is *Cactoblastis* likely to expand its range?
- What might be the impact on natural stands of *Opuntia* spp. and the other species of plants and animals that depend on opuntias as a resource? What will be the impacts on localized endemic *Opuntia* spp.?
- What will be the impacts on agricultural and horticultural uses of prickly pear?
- If the biological and economic impacts of *Cactoblastis* are substantial, what are possible means of control?
- How will this situation likely affect the science and application of classical biological control?

The workshop was conducted September 20-21, 2000, in Tampa, FL.

Workshop Results

At the conclusion of the workshop four working groups were formed to address research needs, education and outreach, risk assessment and regulatory issues, and international collaboration; the activities of these working groups is ongoing. A white paper detailing the findings and recommendations of the workshop is in preparation; therefore, full details will not be presented here. However, for the sake of completeness of this proceedings, the discussions held at the workshop are summarized below, in the context of the questions posed (above) to address the workshop objectives. For more information, references are provided to the appropriate papers published in this proceedings and elsewhere.

How far is *Cactoblastis* likely to expand its range?

Within 10 years of its first recorded appearance in southern Florida, *Cactoblastis* was known to be established in coastal Georgia (Stiling 2000), a distance of about 650 km. Its natural westward spread has been slower, but there is high potential for rapid spread over large distances by human transport as witnessed by infested nursery stock found at Pensacola.

Opuntia stricta Haworth, a favorable host for *Cactoblastis*, is common throughout Florida and extends westward through the Gulf states to southern Texas and into adjacent Mexico. The species diversity of *Opuntia* increases significantly in Texas, and even more so in Mexico. Soberon et al. (this proceedings) present bioclimatological mapping for the possible spread of *Cactoblastis* through Mexico. Based upon climate and favorable hosts, they conclude that the most likely route of invasion is through Texas. Once in Mexico, the potential area of infestation is sub-

TABLE 1. PARTICIPANTS AT THE *CACTOBLASTIS CACTORUM* WORKSHOP, SEPTEMBER 19-21, 2000, TAMPA, FL.

Name, Title; Area of Interest	Affiliation	Role*
Mohammad H. Badii, Research Professor; biological control	Department of Biology, Univ. of Nuevo Leon, Mexico	IP, P
Duke Benadom, President, Cactus and Succulent Society of America; horticultural applications of cacti	Simi Valley, CA	S
Kenneth A. Bloem, Co-Director, Center for Biological Control; biological control, genetic control	USDA, APHIS, National Biological Control Institute, and Florida A&M Univ., Tallahassee	E, OC, P, S, W
James E. Carpenter, Research Entomologist; genetic control	USDA, ARS, Tifton, GA	P, S
Nancy Coile, Curator of the Herbarium and Botany Administrator; plant conservation	Division of Plant Industry, FL Dept. of Agriculture and Consumer Services, Gainesville	IP
James Cuda, Assist. Professor; biological control of weeds	Dept. of Entomology and Nematology, Univ. FL, Gainesville	E, OC, W
Jordan Golubov, Ecologist; natural resource and conservation biology	Comisión Nacional Para el Conocimiento y Uso de la Biodiversidad (CONABIO), Tlalpan, Mexico	P, S
Doria Gordon, State Ecologist and Courtesy Assoc. Professor; plant conservation	Florida Chapter, Nature Conservancy, and Dept. of Botany, Univ. FL, Gainesville	IP
Marjorie Hoy, Professor; biological control	Dept. of Entomology and Nematology, Univ. FL, Gainesville	S
Mary Irish, Horticulturist and author; landscaping in arid areas	Scottsdale, AZ	P, S
Norman Leppla, Professor; biological control	Dept. of Entomology and Nematology, Univ. FL, Gainesville	OC, S
Daniel L. Mahr, Professor; biological control; Research Chair, Cactus and Succulent Soc. America	Dept. of Entomology, Univ. WI, Madison	E, OC, P, S, W
Lance Osborne, Professor; pest management of nursery and landscape plants	Central FL Res. and Ed. Center, Univ. FL, Apopka	P, S
Robert W. Pemberton, Research Entomologist; biological control	USDA, ARS, Fort Lauderdale, FL	P, S, W
Donald Pinkava, Director of the Herbarium; systematics and biology of the Cactaceae	Dept. of Plant Biology, AZ State Univ., Tempe	P, S
Jackie Poole, Endangered Species Botanist; plant conservation	TX Dept. of Parks and Wildlife, Austin	IP
Mayra Perez-Sandi y Cuen, MacArthur Fellow; conservation, environmental and agricultural protection	San Diego, Churubusco, Coyocan, Mexico	P, S
Peter Stiling, Associate Professor; ecologist	Dept. of Biology, Univ. of South FL, Tampa	E, OC, P, S, W
Jon Rebman, Curator of Botany; biology of desert plants; systematics of Cactaceae	San Diego Natural History Museum, CA	P, S
Ana Lilia Vigueras G., Entomologist; plant protection	Dept. of Botany and Zoology, Univ. of Guadalajara, Mexico	P, S
Helmuth Zimmermann, Research Scientist; biological control	Agricult. Res. Council, Plant Protection Res. Centre, Pretoria, South Africa	P, S

*Roles: E = proceedings editor; IP = invited participant; OC = organizing committee; P = proceedings author; S = speaker or discussion facilitator; W = white paper author.

TABLE 2. AGENDA OF THE *CACTOBLASTIS CACTORUM* WORKSHOP, SEPTEMBER 19-21, 2000, TAMPA, FL.

Session	Presentation or Panel	Speakers
A. Field trip to view damage.		
B. Introduction to the Workshop	1. Introduction and welcome	K. Bloem
	2. Objectives and charge to participants	D. Mahr
	3. The role of the Cactus and Succulent Society of America	D. Benadom
C. The Plant. Biology, Economic Importance, and Conservation Status of *Opuntia*	4. The biology of *Opuntia*	D. Pinkava, J. Rebman
	5. Commercial uses of prickly pear: the nursery and landscape industries	M. Irish
	6. Commercial uses of prickly pear and the impact of *Cactoblastis* in Mexico	J. Golubov, J. Soberon, A. L. Vigueras G.
D. The Insect. Biology and Status of *Cactoblastis cactorum*	7. Biological control of *Opuntia*: a world summary	H. Zimmermann
	8. *Cactoblastis* in the Caribbean: history and impact—open discussion	Participants
	9. Biology, host range, distribution, and impact of *Cactoblastis* in Florida	P. Stiling
E. Panel Discussions	10. Potential impact of *Cactoblastis* on *Opuntia* and its environment	M. Irish, J. Rebman, P. Stiling, A. L. Vigueras G.
	11. Potential impacts of *Cactoblastis* on the practice of biological control	K. Bloem, M. Hoy, D. Mahr, H. Zimmermann
F. *Cactoblastis* Management Strategies	12. Host range testing and risk assessment in biological control—past and future	M. Hoy
	13. Potential for biological control of *Cactoblastis*	R. Pemberton
	14. Insecticidal controls	L. Osborne
	15. F_1 sterility: applications for research and management	J. Carpenter, K. Bloem
	16. Discussion session: should we embark on classical biological control of *Cactoblastis*?	Moderator: K. Bloem
	17. The proposed FAO *Cactoblastis* awareness program in Mexico	M. Perez-Sandi y Cuen
G. A Plan for *Cactoblastis*	18. Where to from here? A working session	Facilitator: N. Leppla
	19. Concluding comments	D. Mahr

stantial (see maps in Soberon et al., this proceedings). Similar predictive bioclimatic modeling has not been conducted for the U.S. Although *Opuntia* is native to most contiguous U.S. states (with the exception of the far Northeast), the northern distribution of *Cactoblastis* will likely be restricted by winter minimum temperatures. Further, its success in the hottest and most arid areas of the desert Southwest may be restricted by climatic conditions.

A recommendation of the workshop is that bioclimatic modeling be conducted to determine areas of the U.S. most likely to be successfully colonized by *Cactoblastis*.

What might be the impact of *Cactoblastis* on natural stands of *Opuntia* spp. and the other species of plants and animals that depend on opuntias as a resource? What will be the impacts on localized endemic *Opuntia* spp.?

Host plant testing of *Cactoblastis* has been minimal and information is primarily from observations of species attacked in its native habitat or from areas of biological control programs. Novel hosts are readily attacked, but not all prickly pears are susceptible. It does not generally utilize chollas (the cylindropuntia group of *Opuntia*) but is known to occasionally infest *O. imbricata* (Haworth) De Candolle in South Africa. *O. imbricata* is an abundant native arborescent cholla in the southwestern U.S., from Colorado in the north southward to central Mexico (Benson 1982) (see Soberon et al. 2000, and this proceedings, for a review of host information).

In many arid areas opuntias are dominant components of the plant community. They provide food and moisture for herbivores, and shade, shelter, and nesting sites for a variety of vertebrates and invertebrates. Although it is thought that the ecological roles played by opuntias in natural environments are very important, there is relatively little quantitative data on the subject (but see references in Soberon et al. 2000, reprinted in this proceedings). Therefore, it is difficult to predict the potential impact of *Cactoblastis* on the total biotic environment.

Some species of *Opuntia* are localized endemics that could be severely affected by *Cactoblastis*. Studies of the impact on and protection of one such species in the Florida Keys, *O. corallicola* Small, are presented in this proceedings by Stiling and Moon. There are at least six taxa of *Opuntia* in Texas that have very localized distributions and therefore would be especially vulnerable to *Cactoblastis* parasitism (J. Poole, pers. comm.).

One recommendation of the workshop is that documentation be developed on localized endemic and/or threatened species of *Opuntia* in the United States and Mexico. Another recommendation is that studies be conducted to determine the importance of the ecological roles of prickly pears in natural environments. These baseline studies must be conducted prior to further expansion of the range of *Cactoblastis*.

What will be the impacts of *Cactoblastis* on agricultural and horticultural uses of prickly pear?

Papers by Vigueras G. and Portillo, and Soberon et al. (this proceedings) fully document the extent of the prickly pear industry in Mexico. Over 30 species of *Opuntia* are used in Mexico for human food or livestock feed. Over 3,000,000 ha are harvested; of this, over 200,000 ha are cultivated on family farms or commercial plantations, with the remainder of production originating from natural stands. The average income generated by prickly pear products in Mexico averaged about $50 million/yr annually through the 1990s. Although some of the commercially-used Mexican opuntias are known to be susceptible to *Cactoblastis*, most uncultivated but utilized species have not been tested.

In addition to the likely loss of an important food crop, there would be sociological consequences resulting from *Cactoblastis* damage. There are nearly 30,000 producers of prickly pear for fruit and vegetable use. In some areas, this is the only viable agricultural crop and revenues are important. Further, because prickly pear is such an important subsistence crop in many areas, loss of this food source would have substantial dietary impact on local residents.

There is a prickly pear food industry in the U.S. as well, but we were unable to gather information on its extent or value. However, we assume that the U.S. industry would also be affected by *Cactoblastis*.

Irish (this proceedings) documents the importance of prickly pear cacti as landscape plants in the arid Southwest. Arizona nurseries alone maintain an inventory of over a half million plants with a retail value approaching $10 million. It is not known what the impact of *Cactoblastis* may be on some of the commonly cultivated species, but the impact on the nursery industry and the ornamental landscape could be significant.

One recommendation from the workshop is that extensive host testing be conducted. Species tested should include those that are used for agricultural and horticultural purposes, those that are dominant components of natural ecosystems, and localized endemics that could be seriously affected by the introduction of *Cactoblastis*.

If the biological and economic impacts of *Cactoblastis* are substantial, what are possible means of control?

Cactoblastis is not the only insect pest of cultivated and wild *Opuntia*. Badii and Flores (this proceedings) summarize other insects that sometimes must be controlled in prickly pear cultiva-

tion. Both mechanical and chemical controls are employed. Because Mexican growers are already familiar with certain insecticide products, appropriate choices could be evaluated for use against *Cactoblastis*. Leibee and Osborne (this proceedings) summarize additional information on potential insecticides for use against the cactus moth. However, chemical control will not be a practical or an environmentally responsible practice for protecting the millions of hectares of natural *Opuntia* vegetation. Further, it may be difficult to provide adequate pesticide safety training to subsistence growers and users of prickly pear.

Carpenter and colleagues (papers in this proceedings) report on the potential usage of F_1 sterility to eradicate localized infestations and manage the spread of *Cactoblastis* and suggest potential uses of this technology for research purposes. F_1 sterility has the advantage of being species-specific and therefore environmentally friendly, and research on its potential use in reducing the rate of spread of *Cactoblastis* needs to be accelerated. However, F_1 sterility is not self-sustaining and, for practical and economic reasons, unlikely to be used over the millions of square kilometers likely to be ultimately infested with *Cactoblastis*.

Biological control of *Cactoblastis* would, on the surface, seem to be an ironic but logical solution to this problem; papers by Pemberton and Cordo (this proceedings) thoroughly examine this possibility. Several natural enemies of *Cactoblastis* are known, but a thorough search through its large native range has not been conducted. Most of the known natural enemies are generalists and therefore pose potential risk to several native pyralid moths that use *Opuntia* throughout North America. It is possible that these native pyralids may be regulating certain *Opuntia* spp. sufficiently to preclude them from becoming weedy pests, and introduced *Cactoblastis* natural enemies could conceivably upset any such relationships.

However, biological control is the only self-perpetuating control option as well as the only practical approach that might be useful in protecting opuntias in their vast native habitats; if biological controls are not available, we are resigned to accept the alternative environmental impacts that will result. Therefore, when considering arguments against the use of oligophagous natural enemies, it is imperative to also consider the consequences of not using them.

Education is an important component of pest management. Mexican scientists have submitted a proposal to FAO for funding a project on multiple aspects of dealing with *Cactoblastis*. One of the proposed components is educational, which will include printed media and radio and television programming for the general public, and also target cactus societies, cactus farmers, agricultural authorities, extension personnel, and the conservation community (Perez-Sandi y Cuen, this proceedings). No similar coordinated educational activity is underway in the U.S. Indeed, before being invited to the workshop, the environmental and horticultural communities in the U.S. Southwest were unaware of the impending threat of *Cactoblastis*.

The workshop resulted in the following recommendations regarding potential control methods.

Insecticidal controls must be explored. In addition to efficacy, studies must also be conducted on phytotoxicity (some insecticide solvents are known to be phytotoxic to cacti) and residual persistence that could be hazardous to consumers of treated fruits or stems. Application methods and timing must also be researched.

Research on F_1 sterility and its application to slowing the rate of spread of *Cactoblastis* must be accelerated.

Research must be conducted to determine the presence of specialized natural enemies of *Cactoblastis*, and to evaluate their potential for use in a classical biological control program. Also, research should be conducted on the possible environmental implications of releasing generalist natural enemies, should specialists not be found. Research must also be conducted to firmly establish the importance of opuntias in fragile arid environments; only with such information can the costs and benefits of classical biological control be fully evaluated.

It is imperative that an educational program be initiated immediately. Target audiences should include agricultural inspectors, extension personnel, the nursery industry, cactus and succulent societies, conservation groups, and the general public. Key target states should include Florida, Georgia, Alabama, Mississippi, Louisiana, Arkansas, Oklahoma, Texas, New Mexico, Colorado, Utah, Nevada, Arizona, and California.

How will the *Cactoblastis* situation likely affect the science and application of classical biological control?

This is a complex question without easy answers. The extent of the impact of *Cactoblastis* on biological control will likely ultimately depend on the extent of its impact on opuntias. Since Howarth's (1991) review article on the environmental impacts of biological control, there has been increased scrutiny of the science in general as well as specific projects. An easy explanation for the release of *Cactoblastis* onto Nevis is that the world was a different place 40 years ago, and societal priorities were more on protecting our food supply than on preserving biodiversity. Today, both ecologists and biological control researchers understand the need for selecting specialized natural enemies in biological control programs. What is less obvious is how to make de-

cisions when a pest is having a major impact in agricultural or natural environments, and the only natural enemies available are not strictly monophagous. In today's world, it is unlikely that *Cactoblastis* would be released onto Nevis, regardless of the degree of weediness of the native opuntias. However, given the potentially serious degradation of natural environments that could be caused by *Cactoblastis*, it is less obvious whether or not to use oligophagous natural enemies for classical biological control of the cactus moth. It is unproductive to condemn historical events that were perfectly acceptable within societal views of the day. But today it is incumbent upon the discipline of biological control to fully consider environmental (i.e., non-target) outcomes of a project. What we do not have is an adequate decision-making mechanism to weigh the risks vs. the benefits of both environmental and socioeconomic impacts of biological control projects that necessitate the use of natural enemies that are not strictly monophagous. This is very important because relatively few natural enemies of insects or weeds are strictly monophagous. The workshop participants agreed that an appropriate approach to *Cactoblastis* is to consider the use of biological control, but to do so in a fully informed context. This will require a concerted research program as outlined above. Such a project would be greatly facilitated by a decision-making process that currently is not provided by the U.S. Department of Agriculture. Further, research on the classical biological control of *Cactoblastis* should be conducted as a project of international cooperation, with collaboration between the United States, Mexico, and other affected countries.

A note on the sequence of papers in this proceedings will be helpful. The first two papers deal exclusively with the host plant, *Opuntia*: Rebman and Pinkava give a thorough summary of the biology and systematics of the group and Irish discusses the uses of prickly pear cacti as landscaping plants and as a nursery crop in the southwestern United States. The next four papers deal with the uses of prickly pears in Mexico and the potential threat of *Cactoblastis* to natural populations and cultivated plantings: Soberon and colleagues review the importance of *Opuntia* and provide results of research models to predict invasion by *Cactoblastis* to and spread within Mexico; Vigueras G. and Portillo provide specific information on opuntia uses; Perez-Sandi y Cuen outlines a Mexican proposal to deal with the impacts of *Cactoblastis*; and Badii and Flores discuss other pests of prickly pear and the chemical and nonchemical means used to control cactus pests in Mexico. The following six papers deal with aspects of research on *Cactoblastis*: Stiling and Moon discuss work on protecting rare Florida cacti; Leibee and Osborne suggest areas of chemical control research; Pemberton and Cordo present two papers on biological control; and Carpenter and colleagues discuss the application of F_1 sterility. The final paper is a reprint of the overview of *Cactoblastis* and its impacts in North America by Zimmermann and colleagues.

In summary, *Cactoblastis* has the potential to be devastating to fragile arid environments in the United States and Mexico by the destruction of its *Opuntia* hosts. Localized endemics may be especially impacted. Further, *Cactoblastis* may have severe socioeconomic implications in rural Mexico where opuntias are both a subsistence food and a unique desert-adapted cash crop. Although the destruction of landscape and nursery plants in the arid Southwest may be less traumatic than the loss of food, we are still facing potential losses to *Cactoblastis* of many millions of dollars annually. Workshop participants are hopeful that cooperative state, national, and international programs can be launched to be proactive in addressing this problem.

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