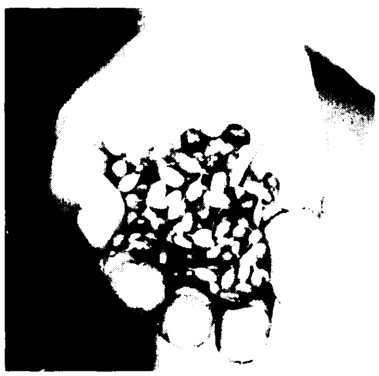
Coca Biological Control Issues 6

*Biocontrol is something akin to gambling-
it works, sometimes (13).*

Eradication[1] has been a component of U.S. supply reduction efforts for illegal narcotic crops (e.g., opium poppies, marijuana, and coca) for nearly two decades. Some experts believe that eradication must precede alternative development in the Andean nations. Others view coca eradication as futile and a threat to the culture and traditions of native Andean populations. Although key requirements, host country consent and cooperation are unlikely to be easily obtained (27,28).

INTRODUCTION

The level of coca reduction necessary to have a clear and measurable impact on cocaine availability is an unknown. Further, new processing technologies have changed the relationship between coca leaf production levels and cocaine availability. For example, an intermediate product of cocaine processing, "agua rica, ' appears to have excellent storage properties allowing processors to stockpile supplies. Thus, even with a reduction in cultivated area, a reduction in cocaine availability may not occur for years, if at all. Further, current cocaine extraction techniques are only about 50-percent efficient; improved extraction could yield the same amount of cocaine from a much reduced leaf production base (28).



U.S. DEPARTMENT OF STATE/INM

1 For the purposes of this discussion, *eradication* will refer to complete erasure of all traces of coca within a defined area. The area could be defined as small as a single plot or as large as a country.

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Eradication efforts have included voluntary and involuntary removal of the target crop. Although coca eradication programs have relied solely on manual techniques, possible application of chemical methods have attracted attention. Renewed interest in application of biological control methodology to coca reduction also is evident. The U.S. Department of Agriculture has responsibility for research and development of coca control methods, including research on chemical control methods and classified research on biological control.

MANUAL COCA CONTROL

Manual eradication of coca can be dangerous and inefficient. The Special Project for Control and Eradication of Coca in the Alto Huallaga, *Projecto de Control y Reducción de los Cultivos de Coca en el Alto Huallaga* (CORAH), in the mid- 1980s attempted manual coca eradication in Peru. CORAH workers destroyed 5,000 hectares of coca in 1985 with ''weed whackers' and machetes (15). Although the manual eradication program had some success, the problems were extensive. Between 1986 and 1988, 34 CORAH workers were killed by insurgent groups (31). CORAH'S association with the Mobil Patrol Unit of Peru's Civil Guard, *Unidad Móvil de Patrullaje de la Guardia Civil del Peru* (UMOPAR), an organization accused of using repressive and abusive tactics on local growers, led to great public resistance to eradication. Manual methods also can be ineffective. For example, some fields eradicated manually by coppicing coca shrubs showed invigorated growth later (10).

CHEMICAL COCA CONTROL

Chemical coca eradication thus became of greater interest as it was expected to reduce risk, achieve more uniform results, and increase the potential treatment area. Nonetheless, proposals met with some resistance. Largely driven by political, social, and economic realities in coca-producing countries (see chapter 2), resistance has been bolstered by public concern over the release of chemicals in the environment. Herbicide formulation, chemical properties, and application methods most affect their environmental fate and thus the potential for creating environmental or human health hazards.


ANONYMOUS

Uprooting coca shrubs is one method of manual eradication, but it can be a difficult and slow process, Here, workers are uprooting coca in an eradication program in Bolivia.

Formulation

Herbicides are formulated as liquids (aqueous, oil, emulsifiable concentrates), solids (dust, wettable powders, granules, encapsulated products), and gases (fumigants). The type of formulation depends on the chemical nature of the pesticide, target pest, and other pesticidal properties (29). Granular and pelletized herbicide formulations are preferred because the drift and volatilization concerns are reduced relative to sprays. However, the density of granular products can affect performance and deposition. Because moisture is needed to release the active ingredient, release rates can be highly variable depending on precipitation patterns. Controlled-release formulations (e.g., starch-encapsulated herbicides, ethylene vinyl acetate copolymers incorporated with active ingredients) could contribute to regulated release (29), particularly under high moisture conditions

Table 6-1—Overview of Some Coca Control Herbicides

• Hexazinone	Effective brush control through basal or injection application. Low toxicity, particularly to fish and birds, but potential for groundwater contamination. This herbicide is a persistent compound that will render the soil inhospitable to recropping for approximately one year.
• Imazapyr	Label restricts aerial application to helicopter use and may only be applied to noncrops. Low toxicity to fish and birds. Herbicide is slow-acting and may take up to several months to destroy the target completely.
• Picloram	Restricted use herbicide that can be used on rangeland, pastures, grains, and noncrop areas to control broadleaf and woody plants. Low acute toxicity although it is water soluble and persistant. It can move offsite in surface water and has been detected in surface and groundwater.
• Tebuthiuron	Registered in the United States for control of brush and woody plants in noncrop areas and, at reduced rates, in pastures and rangeland. Has low acute toxicity based on available data. Virtually non-toxic to fish and birds although concern exists about the potential for groundwater contamination. Product labeling bears numerous restrictions about risk to desirable vegetation as well as for livestock grazing and hay production.
• Triclopyr	Registered in the United States for noncrop, pasture, and rangeland uses. Label restricts aerial application to helicopters. Low to moderate acute toxicity and toxic to fish. For 1 year after application lactating animals cannot be grazed on affected soil, and grass may not be harvested.

SOURCE: T. Adamczyk, "Chemical Eradication of Coca," contractor paper prepared for the Office of Technology Assessment, 1991.

common in many coca-producing areas. Several herbicides have been identified as prospective eradication agents for coca. Public information about the toxicity and environmental fate of these herbicides has been derived mainly from tests conducted in the United States, although the U.S. Department of State conducted field tests in Peru in the late 1980s (l).

▌Application

Technologically, herbicide application is challenging. Irrespective of formulation, ground-based and aerial methods are the basic mechanisms for delivering an herbicide to its intended target. Ground-based application offers precision; however, the inaccessibility of most coca plots, steep terrain, and bulky, heavy equipment can make this type of application inefficient. Security for applicators further constrains potential for ground-based application.

Aerial application of herbicides may use rotary- or fixed-wing aircraft. Helicopters can treat small areas surrounded by obstructions, like many coca plots, and also lower special equipment to avoid major off-site dispersal problems for liquid formulations (l). Several herbicides screened for coca eradication (e.g., Imazapyr and Triclopyr) have restrictive labeling limiting aerial application to helicopters (table 6-l).

Disadvantages of using helicopters include the complexity and expense of maintenance, low fuel/distance efficiency, and susceptibility to hostile ground fire. Thus, helicopter application is unlikely to fulfill the needs of a broad-range chemical eradication effort (l). Fixed-wing aircraft are cheaper to maintain than helicopters, can cover large application areas, and have good fuel-to-distance efficiency. The faster application speed of a fixed-wing aircraft also may reduce the security risks associated with involuntary eradication programs. However, for accurate application, the optimum altitude is 5 to 20 feet above the target. Higher altitudes result in a wider dispersal swath and increased likelihood of herbicide loss due to wind drift, propeller and wing-tip vortices, and volatilization. Low-altitude application, however, requires clear, unobstructed approaches with ample space to allow a safe climb at the end of the run (l), conditions largely lacking in many coca production zones.

Liquid herbicide application also depends on mixing and loading sites within a reasonable distance of the treatment area. Sites require a water source, containment equipment, equipment for cleaning and decontaminating aircraft, mixing and pumping gear, and protective clothing for pilots and ground support personnel. While security concerns would be significant for such operations near coca production zones, long ferrying times between loading sites and target zones reduce application efficiency.

Herbicide Testing

Testing is a critical step in herbicide evaluation. Thorough testing investigates herbicide efficacy, environmental fate (e.g., mobility and persistence), effects on non-target species, and potential for adverse human health effects. Although a number of candidate herbicides have been tested, the most extensive testing has been performed on tebuthiuron (table 6-2). In addition to tests in the United States, field tests of tebuthiuron were conducted in Peru in 1987.

Executive Order 12114 requires an analysis of potential environmental impacts for certain extraterritorial activities that:

- May significantly affect the environment of the global commons outside the jurisdiction of any nation,
- May significantly affect the environment of an innocent bystander nation, or
- Provide a foreign nation with a product which is prohibited or strictly regulated by Federal law in the United States (e.g., herbicides).

Only actions falling in the first category require the preparation of an Environmental Impact Statement (EIS) under the National Environment Policy Act (NEPA). Second category actions require preparation of bilateral or multilateral studies or a Concise Environmental Review (CER). Final category actions, which would include coca eradication, require preparation of a CER. However, Executive Order 12114 also contains exemptions that might be applicable to a coca eradication effort. Exempted, for example, are actions determined not to have a significant environmental effect, actions taken by the President of the United States, and actions taken at the direction of the President or Cabinet in matters of national interest. Procedures may also be modified to account for unique foreign policy needs, confidentiality, and national security.

Although similar to an EIS, a CER is less rigorous and provides little guidance as to the content of the documents or the procedures by which those documents should be drafted. For example, Order 12114 states without elaboration that a CER may be composed of environmental assessments, summary environmental analyses, or other appropriate documents (9). The Department of State guidelines for implementing Order 12114 require the responsible officer of a proposed program to determine whether the action is likely to have a significant extraterritorial environmental impact. If so, the officer may prepare either an EIS, CER, or cooperative study to evaluate the effects subject to the requirements of Order 12114. Of these choices, only the EIS has specific requirements for document contents and public and Federal agency involvement (33).

Prior to testing tebuthiuron in Peru, the Department of State conducted a CER. However, the document was criticized for several reasons:

- Lack of Andean public and expert involvement in the review process,
- Reliance on existing data on the effects of tebuthiuron in temperate rather than tropical environments,
- Lack of discussion of the need for or alternatives to the proposed action, and
- Lack of review of measures for mitigating the effects of the herbicide.

The latter omission is especially important because of the assumption that applicators would use proper safety equipment and protective clothing, an assumption frequently not borne out in the developing world (6).

The Peruvian Government's agreement to the testing of tebuthiuron in April 1988 provoked

Table 6-2—Coca Herbicide Screening Summary

Chemical	Application rate (lb active ingredient/acre)	Success against target[a]	
		E. Coca	E. Novogranatense
Tebuthiuron [b]	2,4,6	S	S
Tebuthiuron [c]	1,2,4,8,16	S	S
Hexazinone[b]	2,4,6	S	S
Hexazinone[c]	1,3,6	S	S
Triclopyr [b]	3,6,9	M	M
Triclopyr [c]	4.5,9,13.5	S(13.5)	S(13.5)
Cacodylic Acid[c]	12	—	u
Cacodylic Acid[c] + Krenite	6	u	u
2,4-D [c]	1,2,4,8	M	M
Glyphosate[c]	4,8,16	M	s
Thidiazuron[c]	2	s	M
Picloram [c]......, a m	2,4,8	s	s
Ethyl metribuzin[c]	2,4,8	S	u
Imazapyr [c]	4	S	s

[a]Control Experiments were conducted inthe field and greenhouse. Control codes are: U-Unsuccessful; S-Successful; M=Marginal, in need of furtherstudy.
[b]Testing in Kauai, Hawaii
[c]Testing in Frederick, Maryland

SOURCE: U.S. Department of Agriculture, Agricultural Research Service, Beltsville Agricultural Research Center, 1992.

public outcry from those concerned over such a large-scale use of an herbicide and the lack of data on its use in tropical areas. In response, the CER was redrafted and the State Department consulted with the U.S. Environmental Protection Agency, the U.S. Department of Agriculture, and outside experts. However, environmental advocates and residents of the Alto Huallaga still were not incorporated into the process (6,31). Testing resumed in January 1989, but was quickly halted when the Peruvian Government withdrew its support for the project.

Although the new CER described plant recolonization and herbicide residue in the soil it did not include specific data on colonizing plant species and their value (e.g., economic, environmental). Also neglected was examination of the potential impacts on associated water resources even though tebuthiuron is known to leach through the soil profile (table 6-1) (34). The adequacy of the new CER became academic when the producer of tebuthiuron refused to sell any more of the product to the Department of State.

Analysts suggest a process more open to public participation might have resulted in better execution of the proposed program. Early involvement of interested parties would have made public the deep opposition of many Peruvians to herbicide use and the environmental concerns associated with large-scale herbicide use in tropical areas, and, thus, allowed the State Department to develop strategies to address these concerns and defuse opposition (6).

Rigorous analysis of the potential environmental and health impacts of the application of tebuthiuron and other herbicides has yet to be completed. Some proponents of herbicide-based coca eradication suggest the candidate herbicides pose no greater environmental risk than coca cultivation and processing in the long term. Critics maintain use of an herbicide designed to control brush and woody plants in the Andean region could generate numerous unanticipated adverse effects. However, such arguments remain anecdotal at this juncture, with little hard data to support either side.

The potential impact of coca control activities on nontarget species is a key concern, particularly since coca commonly is planted with or near other economic plants. Here is a coca plot with banana, papaya, and pepper on the back border.

BIOLOGICAL CONTROL

Biological control (biocontrol) uses living organisms or their byproducts to reduce a target pest population to a tolerable level. Biocontrol approaches are categorized by agent source (i.e., indigenous vs. exotic) and application criteria. The primary categories of biocontrol include:

- Classical—importation of exotic species and their establishment in a new habitat;
- Augmentative--augmentation of established species through direct manipulation of their populations or their natural products; and
- Conservative-conservation of established species through manipulation of the environment (20).

Some experts suggest an augmentative approach would be more likely to yield rapid short-term coca reduction, whereas classical or conservative approaches would be more likely to offer longer-lasting results. Further, the latter approaches would create a gradual target decline and allow a transition period for producers to adjust to alternative livelihoods (26).

Box 6-A—Erythroxylum Species That Are the Primary Sources of Cocaine

Cocaine is derived from certain plants of the genus ***Erythroxylum* (family Erythroxylaceae).** The **genus** name ***Erythroxylum,*** derived from the Greek **erythros** (red) and **xylon** (wood), denotes the reddish wood of some of the shrubs and small trees included in the genus. In all, some **250** species of ***Erythroxylum*** exist in tropical and subtropical habitats worldwide. Whereas most species grow in the New World, the genus is well known also in Africa and Asia. Two loosely related South American species of coca (***E.*** coca and ***E. novogranatense***) and varieties of these species are the primary sources of cocaine. The species differ largely in trunk, branch, and bark characteristics, whereas the varieties within species differ largely in leaf characteristics.

Although coca was scientifically described some 200 years ago, detailed studies of coca specimens were conducted only in the last century. They revealed **subtle** differences in leaf and stem anatomies, growth and branching habits; and characteristics of bark, **stipules,** flowers and fruits, breeding relationships, and geographic distributions. Coca is a perennial shrub ranging between 0.5 and 2.5 meters tall and has a short flowering and fruiting period.

Erythroxylum coca*—The** two varieties of this species are ***E. coca* var. *ipadu* and *E. coca var. coca. The former has large, elliptical leaves, whereas the latter has smaller, more pointed and broadly **lanceolate** to elliptic leaves with two parallel longitudinal lines on their undersides.

E. coca var. coca (Bolivian or **Huanuco coca)**
- Source of most of the world's cocaine.
- Believed to be the ancestral taxon of all cultivated coca.
- Cultivated and found in the wild.
- Restricted **arealy** to narrow zone of moist tropical forest known as ***montaña.***
- Little known outside South America.

E. coca var. ***ipadu*** (Amazonian coca)
- Restricted to the western Amazon, and geographically isolated from other coca varieties.
- Cultivated for its leaves by a few isolated Indian tribes of Brazil, Peru, and Colombia.
- True **cultivar,** unknown in the wild.
- Probably a recent derivative of ***E. coca* var. coca; the two** varieties share many morphological characteristics.

(continued on next page)

By definition, biocontrol is based on a density-dependent balance—the control agent abundance is directly dependent on the availability of the target (coca). As the target numbers decrease so does the control agent population. Thus, the biocontrol methodology is an unlikely eradication technique. It could, however, provide means to reduce the amount grown in target areas, and make coca cultivation difficult (20).

Understanding the traits of the various coca species and varieties is key to selection of a biocontrol approach. Information about the life-cycle, reproduction, and metabolic pathways can be used to focus a biocontrol strategy (box 6-A). For example, the coca (*Erythroxylum*) species of interest have short flowering and fruiting periods, propagation depends on seed production, and seed viability is brief (27). These botanical features might suggest that a biocontrol agent that hinders reproduction or seed viability could reduce opportunities for expanding coca production.

Box 6-A-Continued

Erythroxylum novogranatense*—The two varieties of this** species are ***E. novograntense* var. *novogranatense and *E. novogranatense* var. *truxillense* and both have complex distribution patterns. *E. novogranatense* var. *truxillense* **has** narrowly elliptic leaves that tend to be smaller than those of the other varieties whereas the leaves of *E. novogranatense* var. *novogranatense* are larger and more oblong in shape and have a distinct bright yellow-green color. Both varieties occur only as cultivated plants and are tolerant of arid conditions, growing where the *E. coca* varieties would not survive. Neither variety of *E. novogranatense* is a major world source of cocaine.

E. novogranatense var. *novogranatense* (Colombian coca)

- Found today as a plantation crop only in Colombia, where it is cultivated in drier mountain areas by a few isolated Indian tribes that harvest the leaves for chewing.
- Tolerant of diverse ecological conditions.
- Figured prominently in world horticultural trade in the **early** 20th century, and continues to be grown in many tropical countries as an ornamental piant.

E. novogranatense var. **truxillense** (**Trujillo** coca)

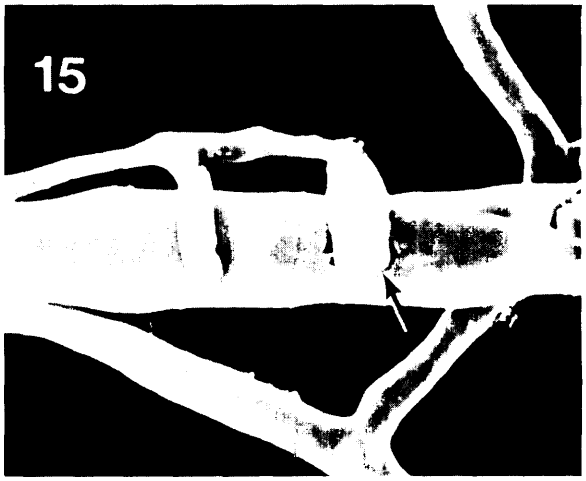
- Grows today only in the river valleys of the north coastal Peru and in the arid upper **Río** Mar#ion valley.
- **Leaves** are highly prized by chewers for their excellent flavor.
- **Due to difficulties of** extracting **and crystallizing** pure cocaine, it is a minor contributor to the illicit drug **market.**
- **Trujillo coca** is used primarily in the manufacture **of de-cocainized** extracts for soft drink **flavoring.**

The ecological conditions under which coca plants are cultivated in part determine their morphological characteristics, such that a continuum of leaf sizes and shapes exists among the four primary coca varieties. **Plants** grown in full sun develop thicker and smaller leaves, while plants grown in partial shade develop larger, thinner and more delicate leaves. Humidity and moisture availability also can affect the size, form, and **venation** of coca leaves. Because of these variations it is often impossible to identify a coca variety positively from **isolated** leaves or ieaf fragments alone. Integrated data on a number of **micromorphological** features of leaves and other plant parts are required, along with information on the geography and **ecology** of the specimen source.

Coca varieties differ in their physical properties and growth habits, as well as in the biochemical properties of their leaves. The alkaloid content of coca leaves is of particular concern. Coca leaves contain 13 different alkaloids, the most concentrated of which is cocaine, first isolated from coca leaves in the mid 19th century. Like **coca,** many plants contain economically important and naturally occurring alkaloids (e.g. caffeine in coffee, nicotine in tobacco, morphine in opium poppies, and **piperine** in black pepper).

Coca **leaves on** average contain about 1 percent cocaine, but typical values range between 1.02 **percent for** *E. novogranatense* var. ***truxillense,*** and 0.11 to 0.41 percent for Amazonian coca ***(E. coca* var. *ipadu*).** Average values for ***E. coca* var.** coca and ***E. novogranatense* var. *novogranatense*** are intermediary (0.23 to 0.93 percent). The potency of coca leaves with respect to cocaine content also depends on the plant's growing site. The *E. coca* var. coca leaves with the greatest cocaine content were found in **Chinchao,** in **Huánuco,** Peru, among the highest elevations where coca is grown. Plants grown in the ***montañas*** generally are thought to produce more potent leaves than plants at lower altitudes.

SOURCE: T. Plowman, "Coca Chewing and the Botanical Origins of Coca (*Erythroxylum* ssp.) in South America," D. Pacini and C. Franquemont (eds.), *Coca* and *Cocaine: Effects on People and Policy in Latin America*, Cultural Survival Report #23 (Peterborough, NH: Transcript Printing Company, 19S6), pp. 5-S3.



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Insects are the most widely used biocontrol agents for agricultural pests, although interest in using other organisms is increasing. Shown here is a fungal parasite penetrating the hyphae of its target.

Agricultural Application of Biocontrol

Examining biocontrol of weeds may offer some insight into the potential of this method for coca reduction. The first practical attempt at biocontrol of weeds dates from 1863, when efforts were made to control the prickly pear cactus with an insect observed to attack the cactus in northern India. Based on these observations, the insect was introduced to southern India and later to Sri Lanka, where it was successful in controlling wild populations of prickly pear. Initially, most of the weed targets for biocontrol efforts were exotic, terrestrial species, but, increasingly, aquatic and semi-aquatic native and exotic weeds have been subjects of biocontrol research.

Biocontrol has experienced a rapid expansion in the last three decades. By 1985, 214 exotic natural enemies had been introduced into 53 countries for the control of 89 weeds. Biological agents, primarily insects and plant pathogens, have achieved substantial control for many target weeds (e.g., klamath weed, prickly pear, lantana) (17), Additional examples of successful development and marketing of weed biocontrol agents include the use of pathogens to control northern joint vetch (biocontrol agent *Collectotrichum gloeosporioides)* and stranglervine of citrus (biocontrol agent *Phytophthora) (29).* Insects have been the most common successful biocontrol agents to date, yet nematodes, fungi, and mites have also been used.

To date, 267 biocontrol projects have been undertaken worldwide and 48 percent have achieved a measurable degree of success. The majority of biocontrol projects have relied on importation of exotic organisms-classical biocontrol--and of these projects, 45 percent have been rated as successful. Whereas an introduced organism may become established, success is measured by the agents identifiable control effects on the target pest. Results of introductions tend to be mixed with only some of the introduced agents becoming established and effective (i.e., 64 percent of the natural enemies introduced in the biocontrol projects have become established and 26 percent of these have been rated effective). Nevertheless, nearly two-thirds of the target weed species have been brought under control using biological methods in at least one project (7).

Application of Biocontrol to Narcotic Crop Control

Agricultural biocontrol achievements have occurred under conditions where security risks and likelihood of countermeasures were not factors. The potential for achieving similar success within the framework of a narcotics control program may be less likely. Clearly, the need for international coordination and cooperation would be paramount.

Experts indicate development time for a biocontrol program for coca would be strongly influenced by the outcome of initial search for and identification of potential agents. Effective, indigenous candidates would be likely to have a shorter development period than candidates needing enhancement to meet safety and efficacy requirements. Common protocol for biocontrol research and development programs includes:

Box 6-B-Categories of Potential Biocontrol Agents

Numerous arthropod species feed on coca or related plants. Deliberate establishment of an arthropod pest in coca-growing regions would add to the complex of pests attacking cultivated coca. However, if heavy damage ensued, countermeasures would likely be undertaken by growers. Insects and mites generally can be controlled effectively with pesticides, particularly where there are no restrictions on the choice of materials or application rates. Stem borers and soil-dwelling root borers are more difficult to control, although there are chemical and cultural means for their control. Pesticide resistance is likely a critical requirement for these types of biocontrol agents.

Pathogenic fungi are becoming increasingly useful in classical biocontrol of weeds. However, they also can be controlled with pesticides. Alternatively, they could be used as mycoherbicides, although in this form application may become problematic.

Nematodes have been little used in weed biocontrol to date, although some gall- forming varieties have shown some promise (16). in general, nematodes are more difficult to diagnose and control than arthropods or fungi. However, little is known about nematodes attacking coca so that their use in biocontrol could require extensive research.

Viruses may offer the greatest potential because they cannot be controlled chemically, either before or after infection. Those transmitted by effective insect vectors can spread rapidly and are among the most virulent and devastating disease problems for legitimate agricultural crops. However, there is a general iack of biocontrol workers trained in virology and little has been done in this area of biocontrol. Further, currently very little is known about viral diseases of coca, or potential vectors.

SOURCE: D. Rosen, “Potential for Biological Control of Coca,” contractor report prepared for the Office of Technology Assessment, November 1991.

- Search and identification of natural enemies,
- Enhancement of candidate agents (if needed),
- Screening of candidate agents,
- Production of candidate agents, and
- Application.

SEARCH AND IDENTIFICATION

The frost step in a biocontrol program for coca entails international, interdisciplinary research to identify natural coca enemies (box 6-B). Existing literature reveals 44 arthropods, 24 fungi, one nematode, and one virus recorded from *Erythroxylum coca* alone (tables 6-3 and 6-4). Numerous others have been recorded from other *Erythroxylum* species, including some polyphagous (nonhost-specific) and notorious agricultural pests. However, most known natural enemies have been recorded from cultivated coca. No intensive study of the natural enemies of wild *E. coca, E. novogranatense*, and related species has been conducted (20). Approximately 250 species of *Erythroxylum occur in* South America and elsewhere, 24 of them just in Peru, (14,36), and many of the organisms attacking them may prove capable of infesting or infecting coca. Other potential agents might be identified through field surveys reviewing pests and diseases associated with wild and cultivated coca.

Desired characteristics for candidate biocontrol agents include:

- *Density-dependence*-The population density of the natural enemy increases or decreases with the population density of the target species.
- *Host specificity*—Agents should be highly adapted to the target species and unable to affect nontarget species adversely.
- *Searching ability*—Mobile agents should have great capability of finding the target species.
- *Reproductive capacity*-Agents should be capable of high levels of reproduction to

Table 6-3—insects and Mites Associated With Erythroxylum coca

Order	Family	Species	Activity	Known range
Acarina	Tetranychidae	*Tefranychus* sp.	Spider mites attack leaves and twigs.	Peru, Bolivia
Coleoptera	Curculionidae	*Conotrachelus* sp.	In seeds of fruits.	Cuba, Trinidad
		Mecostylus vittaticollis	Beetles feed on leaves and larvae develop as borers.	East Africa
		Pantomorus bondari	Beetles feed on leaves.	Brazil
	Scolytidae	*Stephanoderes hampei*	Beetles bore fruits for shelter.	Indonesia
		Xyleborus coffeae	Beetles and larvae tunnel in bark.	Indonesia
		Xyleborus morstatti	Twig borer.	Indonesia, Malaysia
Diptera	Trypetidae	*Trirhithrum nigerrimum*	Larvae infest fruits.	Ghana
Heteroptera	Pentatomidae	*Rhynchocoris piagiatus*	Bugs suck plant sap.	India, Sri Lanka
Homoptera	Asterolecaniidae	*Asterolecanium pustulans*	Scale insects suck from leaves and twigs. This is the pit scale-a polyphagous pest of deciduous fruit trees and ornamental.	Brazil, Cuba
	Coccidae	*Coccus elongatus*	Polyphagous scale insect.	Taiwan
		Coccus hesperidum	Scale insects suck sap from leaves and tender tips. This is the soft brown scale-a polyphagous pest of fruit trees and ornamental.	Brazil, Peru, Bolivia
		Lecanium sp.		Peru
		Saissetia coffeae	Scale insect feeds on twigs. This is the hemispherical scale-a pest of citrus and coffee.	Peru, Bolivia
		Tachardia gemmifera		Peru
		Tachardia Iacca		Guiana
		Tachardia silvestrii		India
	Diaspididae	*Aspidiotus* sp.	Scale insect feeds on twigs.	Peru, Bolivia
		Howardia biclavis	Polyphagous.	Sri Lanka
		Lepidosaphes sp.		Peru
		Quadraspidiotus sp.		Peru
		Selenaspidus articulates	This is the rufous scale-a major pest of citrus.	Cuba
	Kermesidae	*Kermes* sp.		Peru
	Pseudococcidae	*Pseudococcus* sp.	Mealy bugs feed on growing tips, twigs, and roots.	Peru, Bolivia
Hymenopteran	Formicidae	*Acromyrmex hispidus*	Leaf-cutting ants damage young plants.	Peru
		Atta sexdens	Leaf-cutting polyphagous ants.	Peru, Venezuela
		Atta sp.	Leaf-cutting ants.	Peru
	Megachilidae	*Megachile opposita*	Leaf-cutting bees.	Indonesia, Malaysia

(continued on next page)

Table 6-3-Continued

Order	Family	Species	Activity	Known range
Lepidoptera	Arctiidae	*Rhodogastria atrivena*		Uganda
		Rhodogastria bubo		Uganda
	Cossidae	*Zuezera* coffeae	Caterpillars tunnel in twigs and stems and feed on leaves,	India, Sri Lanka, Malaysia, Indonesia
	Geometridae	*Boarmia* spp.	Caterpillars attack twigs.	Indonesia
		Hyposidra talaca	Caterpillars feed on leaves.	Indonesia
	Limacodidae	*Phobetron hipparchia*		Venezuela
	Lymantriidae	*Eloria noyesi*	Caterpillars feed on leaves, stalks, and tender tips.	Peru
		Eloria sp.	Caterpillars feed on leaves and twigs,	Bolivia
	Noctuidae	*Spodoptera litura*	Caterpillars feed on leaves. Also a pest of *Cannabis* and *Papaver.*	Malaysia, Indonesia
	Nymphalidae	*Morpho catenarius*	Caterpillars feed on leaves.	Brazil
	Sphingidae	Protambulyx strigilis	Caterpillars feed on leaves.	Venezuela
	Tineidae	*Eucleodora cocae*	Caterpillars feed on leaves and tender tips.	Peru
		Linoclostis gonatius	Caterpillars bore in bark.	Taiwan
		Setomorpha rutella	Caterpillars feed on leaves and tunnel in dry leaves.	Malaysia, Indonesia
Thysanoptera	Thripidae	*Neosmerinthrothrips xylebori*	Thrips found in tunnels of *Xyleborus coffeae.*	Indonesia
		Selenothrips rubrocinctus	Thrips attack leaves.	Venezuela, Brazil

SOURCE: D. Rosen, "Potential for Biological Control of Coca," contractor report prepared for the Office of Technology Assessment, 1991.

assure sufficient populations to achieve the desired goal.

- *Adaptability--Agents* should be highly adaptable to the broad range of environmental conditions in which the target species may grow (20).

A comprehensive field survey team would require at a minimum, biocontrol experts, botanists, entomologists, and plant pathologists. A smaller search team might be required to collect samples from the field and bring them back to a secure site for comprehensive examination. Field surveys for potential control agents should include observations on their role in controlling the abundance and reproduction of coca, and on their life history (e.g., reproduction, fecundity, dispersal, overwintering, epidemiology, mode of attack, target plant parts, direct and indirect damage inflicted, and existence of distinct biotypes) (4,7). Search efforts should cover at least one season's activity of the plant and as much of its distributional range as possible to note variations in predator/prey relationships and plant vulnerability at different life stages.

Throughout the search and collection of natural enemies, sound biosystematics—the identification and classification of species and the reconstruction of their evolutionary history-proves essential. When live natural enemies of a plant are being sought, or are transferred from one region to another, correct identification of the plant host and the natural enemies and recognition of infraspecific entities may be of utmost importance. Biosystematic study may show a potential biocontrol agent rejected for its seemingly broad host range, is a combination of sibling species, each with a narrow host range and one of which may be an appropriate biocontrol candidate. Many serious failures of biocontrol agents have resulted from inadequate biosystematics (7).

Table 6-4—Pathogens Recorded From Erythroxylum *coca*

Order	Species	Activity	Known range
Fungi	*Armillanella mellea*	Broad spectrum; causes damage to peanuts and sweet potatoes.	South America
	Aschersonia turbinata	Entomopathogenic.	Bolivia
	Aspergillus cinereus	Occurs on poorly dried leaves.	Argentina
	Bubakia erthroxylonis	Rust, causing yellowing of leaves premature defoliation, not a serious threat; also on other *Erythroxylum* spp.	Argentina, Bolivia, Colombia, Peru, Ecuador, Panama, Costa Rica; possibly Brazil, Venezuela, Cuba, Puerto Rico
	Cercosporella cocae		Argentina
	Clavulina Ieveillei	Occurs on roots, probably not pathogenic.	Indonesia
	Colletotrichum cocae		Argentina
	Corticium invisum	Causes black rot, also affects tea.	Sri Lanka
	Corticium pervagum	Thread-blight, kills leaves and twigs.	Sri Lanka
	Corticium samonicolor	Causes pink disease on branches, twigs and leaves; attacks many tropical plants including rubber.	Sri Lanka, South America, Indonesia
	Fomes noxius	Ubiquitous in tropics on many hosts; causes brown root rot.	Sri Lanka, Indonesia, Taiwan
	Fusarium Spa	Soil borne disease.	Peru
	Gloesporium sp.	Attacks seedlings, losses of nearly 50 percent.	South America, Indonesia
	Hypochnus erythroxyloni	Attacks basal parts of young seedlings.	Taiwan
	Hypochnus rubrocinctus	Now considered a lichen.	Venezuela
	Hypocrella palmae	Entomopathogenic.	Peru
	Mycena citricolor	Broad spectrum; particularly damages coffee in South America and West Africa.	Peru, USSR
	Mycosphaerella erythroxyloni		Argentina
	Pellicularia sasakii	Causes banded sclerotial disease on leaves.	Japan, India, Indonesia, Phil ippines, Taiwan
	Phyllosticta erythroxylonis		Peru, Bolivia, Colombia
	Protomyces cocae		Argentina
	Ravenelula boliviensis	Occurs on dead wood.	Bolivia
	Verticillium sp.		Peru
	Xylaria apiculata	Black root disease, infecting roots, stem bases; may cause plant death; also found on potatoes and other hosts.	Brazil, Dominican Republic, Puerto Rico, China, Sri Lanka, Indonesia, Zimbabwe
Nematoda	*Pratylenchus branchyurus*	Occurs in roots.	Ivory Coast
Viruses	*Witches' broom*	Apparently a virus transmitted by an aphid.	Bolivia

a Fusarium oxysporum has been spreading in the Huallaga Valley, Although reports vary, between 10,000 and 15,000 hectares are reported to have been affected by the fungus (22).

SOURCE: D. Rosen, "Potential for Biological Control of Coca," contractor report prepared for the Office of Technology Assessment, 1991.

ENHANCEMENT OF CANDIDATE AGENTS

Enhancement of a natural enemy can improve its ability to provide the desired control safely and effectively. Conventional selection techniques can be used to develop a large, uniform population displaying a desired trait. Alternatively, genetic manipulation could be used to enhance a desired trait of a natural enemy. Currently, conventional selection and mass rearing offer the greatest possibilities for enhancing the capabilities of a natural enemy.

Arthropods are amenable to enhancement through conventional selection. Many adaptive races exist and there usually is considerable genetic variation in natural populations. Selective breeding has been used to increase tolerance for climatic extremes, alter host preferences, and increase pesticide resistance (11,12). Release and establishment of such a strain, however, could be considered equivalent to importing an exotic species (20). Pesticide resistance may be a desired trait since producers are likely to use chemicals to control pest infestations. For example, many coca producers already use insecticides to control such pests as *Eloria noyesi.*

Genetic variability is a primary concern to ensure agent vitality. Stock cultures would need to be established from abundant material collected at numerous and varied localities to maximize genetic variation. If natural variability is insufficient, it could be enhanced by irradiation or mutagenic chemicals, although mutagenesis can cause random, often deleterious, mutations and may require large numbers of organisms to be screened. Following the selection program, the improved strain should be tested to determine its ability to survive, as well as the genetic mechanism governing the selected trait (20).

An alternative to this more conventional, non-invasive method of enhancement of natural enemies would be to use genetic engineering technologies used to isolate genes from an organism, manipulate them in the laboratory, and insert them stably into another organism. In this way it may be possible to introduce a desired trait (e.g., pesticide resistance) into a natural enemy of coca. Although the technology in this area of biocontrol is not yet well-developed, significant advances have been made in recent years and possibilities for improvement exist (27).

Eventually, genetic engineering through recombinant DNA (rDNA) techniques maybe more efficient than conventional selection. Someday, desirable genes may be obtained from a given species, cloned, and inserted into another species. Some work has been done in this area, particularly with fruit flies. However, developments in fruit fly research have not been duplicated with other insects. With micro-injection techniques for inserting hybrid genes into insect eggs for germ-line transformation, it is believed methodology for genetic engineering of arthropods will be available within 5 or 10 years (35). However, conventional selection and genetic engineering are currently more feasible with plant pathogens than with arthropod biocontrol agents.

The debate over whether or not genetic engineering should be considered for a biocontrol program focuses largely on development time. Detractors suggest the complexity of genetic engineering would add to research and development time and reduce the potential for near-term production of a biocontrol agent (27).

SCREENING

Screening of candidate agents is a critical development step in a biocontrol program to determine whether a candidate can be released without the danger that it may also damage nontarget organisms. The procedure follows several steps, beginning with collection of information about the target plant and associated phytophagous and pathogenic organisms and their respective host spectra (i.e., if any of them are already known as pests of desirable plants). Information also is collected on host records of organisms closely related to the potential candidate. Only organisms likely to be host specific are selected for screening tests, beginning with those causing the greatest damage and possessing special adaptations likely to restrict host preference (20).

It is likely to be impossible to screen candidate species on all plants in coca production areas. At a minimum, potential targets chosen for the screening process would include:

- Recorded hosts of the candidate agent,
- Host plants of species closely related to the candidate agent,
- Desirable plants related to the target plant,
- Nonrelated plants having morphological or biochemical characteristics in common with the target plant, and
- Crop and ornamental plants in the target area whose pests and diseases have not been

identified and have not been exposed to the candidate biocontrol agent.

The common sequence is first to test the agent on other forms of the target species, other species of the same genus, and other members of the same subfamily, family, and order. However, laboratory tests alone are insufficient, for a broader range of plants may be accepted by the agent in the laboratory than in nature. Field tests are needed to corroborate laboratory data, preferably in the countries of origin (20).

Once an organism is screened and determined to be sufficiently host specific to be used as a biocontrol agent, it may be imported and checked for contaminants under strict quarantine. Prior to release, an agent normally is tested in the target area since climatic and ecological variations among areas make extrapolation of test results across target sites inappropriate.

Genetically engineered organisms also must go through an extensive screening process. Researchers and regulators have established five criteria for evaluating the potential environmental impact of a genetically engineered organism:

1. *Potential for negative effects-if* it is known that a recombinant organism will have no negative effects, there is no cause for concern. But predicting ecological effects, their probability, and assessing whether they are negative or positive is not straightforward.
2. *Survival--If* a genetically engineered organism does not survive, it is unlikely to have any ecological impact. It is also unlikely to fulfill the purpose for which it was engineered (unless brief survival is all that is required).
3. *Reproduction-Some* applications require not only the recombinant organism's survival but also its reproduction and maintenance. Increasing numbers could, in some settings, increase the possibility of unforeseen consequences.
4. *Transfer of genetic information-Even if the* engineered organism itself dies out, its environmental effects could continue if the crucial genetic material was favored by selection, and transferred to and functioned in a native species.
5. *Transportation or dissemination of the engineered organism—A* recombinant organism that moves into nontarget environments in sufficient numbers could interact in unforeseen ways with other populations or members of other communities (30).

PRODUCTION AND STORAGE

Stability, shelf life, and potential for mass production are key issues in developing a biocontrol agent. Agents often must be reared in a laboratory or controlled environment. Quality control is extremely important since inbreeding can have negative effects, causing future generations to lose vigor and efficacy. Cultures must be supplemented periodically with material collected from the field (19). Rearing methodologies for genetically enhanced agents would vary according to the nature of the agents. Artificial media are available for many pathogens and various arthropods, however, it may be better to rear them on the target plant to reduce the potential for undesirable adaptations.

Full exploitation of pathogenic agents is likely to require careful attention to formulation. Temperature, moisture, and growth media requirements are critical for producing and storing live agents. Formulation techniques can overcome some of the stresses associated with storage and application. For example, a well-proportioned adjuvant or surfactant may overcome certain environmental stresses, such as reduced moisture availability, to assist the activity of the agent (3).

APPLICATION

The approach (classical, augmentative, conservative) and the agent selected determine the range of suitable application technologies. Both factors will affect the timing and frequency of application. For example, under an augmentative approach application would be more frequent than under a classical or conservative approach. The biological activity of the selected agent may require that application occur during specific seasons. For example, some fungi depend on moisture availability to disperse effectively; thus, application during wet seasons could be a requirement (3). Other potential application concerns include photoperiod and dew period length, temperature, and inoculum concentration.

In general, the same application methods used for herbicides can be used to apply biocontrol agents (e.g., spray, broadcast) as well as release of mobile agents at the target. Thus, the constraints that apply to herbicide application also apply to biocontrol application (e.g., difficulty in precision using aerial application techniques). The formulation of the biocontrol agent (e.g., liquid, pellets, live insects) will determine the type of equipment suitable for application. Pathogens may lend themselves to liquid formulations and be easily applied using existing spray technology. For example, a mycoherbicide inoculum can be applied so every plant is deliberately inoculated (25). However, for a mycoherbicide to be effective, problems involving production of spores, efficacy, specificity, genetic variability, and timing of applications would have to be solved (5,24,25). Pelletized forms may be broadcast from aerial or ground-based systems.

Potential exists for developing biocontrol complexes using a number of discrete bioforms to accomplish search and attack of a target pest. For example, mobile vectors could be inoculated with a virus that would be introduced into the target as the mobile vector feeds. The mobile part of the complex would be selected for its searching ability, whereas the additional agent would be selected for its virulence. This technology is not yet well-developed but it could provide an option to simplify application. Another possibility may be combining chemical herbicides and biocontrol agents.

CONTAINMENT

Ability to contain or restrict movement of biocontrol agents once released poses a significant problem, yet would be key in addressing concerns about release of biocontrol agents. If the release of a biocontrol agent had unanticipated negative environmental, health, or economic impacts, containment could reduce the level of impact. However, only a few methods for eliminating a released agent have been identified, including applying pesticides, releasing a natural predator of the agent, and employing genetic controls (e.g., “suicide genes, ” sterile male release). A lethal pathogen of at least 40 weeds, *Sclerotinia sclerotiorum,* has been manipulated by deletion mutagenesis to have an absolute requirement for cytosine to activate its pathogenic traits. Thus, containment can be achieved by witholding the activating compound. In another instance, a pathogen was mutated to create a lifeform incapable of overwintering or producing dispersal structures. Thus, the initial population would die off with cold weather or old age (26).

There are concerns that some containment mechanisms could compound environmental or human health problems. Applying pesticides to destroy a biocontrol agent could have adverse environmental impacts such as affecting nontarget species and contaminating groundwater and surface waters. Releasing another enemy to control the coca agent also could have various unforeseen environmental consequences. Employing genetic controls would also raise concerns about the release of a genetically manipulated organism in the Andean region.

A containment mechanism, however, could be a valuable facet of a biocontrol program and could be an important research component for coca control. Identifying a natural enemy of coca could include research on ‘‘suicide genes, ’ susceptibility to pesticides, and identification of natural predators. Demonstrated ability to contain a control agent of coca could help achieve host country consent.

DEVELOPMENT NEEDS FOR BIOCONTROL OF COCA

A biocontrol program will face many obstacles, the most obvious being sociopolitical and economic constraints. The bulk of experience with biocontrol efforts has been in the realm of controlling unwanted pests. Coca is not a weed—it is a valuable crop and a source of income. Thus, coca biocontrol programs are likely to meet resistance from participants in the cocaine economy. Furthermore, biocontrol of coca hinges on cooperation and coordination with host governments. Implementing a biocontrol program for domestic marijuana production in the United States could demonstrate U.S. confidence in this technology as an eradication method (27). Such an effort might increase acceptance in potential host countries as well as highlight unforeseen pitfalls that might be associated with this technology.

Technologically, biocontrol of coca faces several constraints as well. Several key research and development priorities are identified in box 6-C. Whereas there are several possibilities for enhancing an existing enemy (box 6-D), the most sophisticated type of enhancement—genetic engineering-is not likely to be feasible for nearly 5 years. Moreover, there is no way to determine the efficacy of any given control agent until it is actually released into the target area. Levels of control can only be estimated and there are no guarantees (20).

The environmental concerns over biocontrol focus on the potential for effects on nontarget species and the likelihood of increased use of pesticides by coca producers. Additional concerns relate to the lack of knowledge of the role of coca in the Andean ecology and the potential for adverse effects resulting from its removal. Incomplete knowledge of Andean ecology further means that comprehensive screening and host-specificity testing of potential agents are likely to be difficult.

SUMMARY AND CONCLUSIONS

Eradicating coca across its current range in the Andean region is most likely an unrealistic goal given the enormity of the task and the variety of barriers. The difficult environments of the coca-growing regions compound the technological constraints to eradication. Further, the overarching sociopolitical and economic features of the producing countries suggest that even if some success is achieved through eradication efforts, production would likely shift to other areas. Nevertheless, control efforts could play a role in overall narcotics reduction by increasing incentives to adopt alternative livelihoods (27,28). Without clear risks connected to coca production, little incentive exists for farmers to adopt alternative crops or enter into other livelihoods (27). Effective production control programs, particularly biocontrol, could increase the hardships associated with coca cultivation. However, for such activities to achieve the desired effect (i.e., decrease supply) viable, acceptable alternatives should be available.

Criteria for evaluating the suitability of different coca reduction opportunities include efficacy, minimal potential environmental and human health impacts, and current and easily demonstrated technological feasibility. At the moment, no single eradication method satisfies all of these criteria. Whereas a biocontrol approach may offer the least environmentally damaging and longest-term means of coca reduction, reduction levels are difficult to determine. Experiments measuring predation levels on targets in the laboratory are insufficient to extrapolate agent behavior once released (i.e., a 40-percent efficiency in the laboratory does not necessarily translate into 40-percent efficiency in the wild). Thus, biocontrol cannot guarantee specific reduction results (27). As long as coca remains a profitable crop and conditions promoting entrance into legitimate livelihoods are lacking, it is likely that producers will increase pesticide use to protect their investment.

Box 6-C-Priorities for Biocontrol Development

Developing a biocontrol agent or complex against coca species in the Andean region would require attention to a variety of unknowns. The following list summarizes priority areas identified by a panel of experts contributing to this Office of Technology Assessment study.

1. International, interdisciplinary search to identify natural enemies of coca—Wide-scale search for coca predators on cultivated and wild coca that may have potential as biocontrol agents.
2. National and international recognition of cocaine as a problem—Campaign to increase awareness of the adverse effects of cocaine on society to increase support for efforts to control cocaine production.
3. Host specificity screening-Rigorous screening tests of candidate species on coca and associated plants prior to field tests to determine the specificity of the agent and reduce risk.
4. Human and ecological health risk assessment—Environmental assessment of the potential adverse impacts of a biocontrol program in the Andean region.
5. Genetics, ecology, and biology of target plant and relatives—Detailed information on coca species, related species, and plants associated with coca to augment screening and search efforts.
6. Efficacy screening of candidate species—Screening programs todeterminethelevel ofpredationof candidate agents on coca and associated plants.
7. Production technologies and quality control—Techniques to produce candidate agent and ensure quality/conformity suitable to fulfill the goal of abiocontrol program.
8. Education on biocontrol—Education on the methodology, development regimes, andsafetymeasures to contribute to building public support for biocontrol.
9. Field trials—Carefully controlled field experiments to determine the activity of potential agents in the natural environment and identify potential areas of concern.
10. Environmental damage of coca productionlprocessing-information on the level of environmental damage from coca production and processing activities to be used as a comparative for assessing the value of a biocontrol effort.
11. Socioeconomic model--Model to assist in determining potential socioeconomic outcome of potential policy actions and identify needs to mitigate adverse impacts.
12. Application technology—Technologies to apply a selected biocontrol agent in a safe and efficient manner.
13. Identification of potential countermeasures-identification of actions that may be undertaken by groups/individuals against biocontrol efforts and development of mechanisms to thwart such efforts.

SOURCE: U.S. Congress, Office of Technology Assessment, "Biological Control Workshop," Washington, DC, January 23,1992.

The United Nations International Drug Control Programme (UNDCP) investigations into potential narcotic crop control opportunities highlight host country involvement and agreement. Biocontrol was identified as an opportunity for narcotic crop control in the late 1970s by the UNDCP, but little research was conducted beyond the initial scoping phase. The UNDCP is now conducting meetings with experts to determine biocontrol's potential. Any actions that might result from these activities will be conditional on host-country agreement and cooperation in all phases (22). The U.S. Department of State notes similar agreements would be sought for U.S. bilateral eradication activities in the Andean region, but little likelihood exists for obtaining them now (27).

The potential for successful biocontrol application in the Andean countries are affected by three factors:

1. *Cooperation and coordination*—Cooperation among potential host and donor countries to develop and implement a biocontrol

Box 6-D-Examples of Natural Enemies of Coca

One species particularly specific to coca and indigenous to Peru, **Eloria noyesi Schaus (Lepidoptera:Lymantriidae)**, could be a possibility y for **biocontrol** research. **The larva of the moth feeds on coca leaves and is a principal natural** pest of coca. With a short **lifecycle** (30 days) and repeated breeding throughout the year, larval populations can be sustained relatively easily. **Eloria noyesi** was reported **to "swarm" and destroy almost** 20,000 hectares of coca in Peru, causing losses to drug traffickers estimated to be at least $37 million. Another species from Peru, **Eucleodora cocae Busck (Lepidoptera: Tineidae),** could be a possible candidate for **biocontrol** research as well (20). Both species meet many of the listed **criteria,** although further screening would be necessary.

More **recently,** outbreaks of **Fusarium oxysporum** in Peru have increased awareness of the potential impact fungi can have **on** coca production. Under normal conditions fungi and lichen infestations of healthy coca shrubs are key factors in limiting the plant's productive life (8). The **Fusarium** fungus has contributed to widespread destruction of coca plantations near Santa Rosa in the Alto **Huallaga** (2). Peruvian farmers in the region have complained that the fungus and the blight it produces have affected legal crops as well as coca (21).

SOURCE: Office of Technology Assessment, 1993.

program effectively is a key need for success. primary needs include multilateral agreements to undertake eradication programs and broad-based public participation in the program assessment process. Experience with herbicide testing in Peru suggests greater government and public participation will be necessary (31). Incorporating public rev iew and comment periods, broad dissemination of environmental impact reviews and methodologies, and coordinated and cooperative efforts with national groups will be critical.

2. *Information* —Information on the potential benefits and costs of a biocontrol program for the Andean countries is needed. Areas needing investigation include the effects of coca production and processing on the Andean environment and the subsequent effects on future development options, mechanisms to improve environmental assessments of potential impacts of biocontrol efforts, and the role of coca in Andean ecology.
3. *Technological* feasibility—Although biocontrol methodologies exist, technological constraints to rapid implementation are overwhelming (21). If a biocontrol program is determined to be feasible, an extensive research and development period could be required. Further, ability to conduct needed field experiments is hindered by lack of political agreements, and the technology does not afford the certainty of a specific reduction level (i.e., in many ways biocontrol may be considered "applied experimentation' ').

Absent the political realities hindering any coca eradication effort, the current state of biocontrol development does not seem to offer a timely mechanism for reducing coca production in the Andean nations. Although opportunities exist to develop biocontrol, existing information, cooperation, and coordination needs will continue to have a profound effect on the possibilities for success.

CHAPTER 6 REFERENCES

1, Adamczyk, T., "Chemical Eradication of Coca, ' Contractor report prepared for the Office of Technology Assessment, December 1991.
2. Arroyo, A., and Medrano, O., ''Huallaga in Flames," CARETAS, Aug. 13, 1992, pp. 30-37, in: Joint Publication Research Service, "Peasant Army Expels Shining Path in Huallaga,'' JPRS-TOT-92-029-L, Aug. 28, 1992, p.10.
3. Bannon, J. S., ''CASST Herbicide (Alternaria cassiae): A Case History of a Mycoherbicide, '

American Journal of Alternative Agriculture 3(2&3):73-75.

4. *CAB* International, *Screening Organisms for Biological Control of Weeds, CAB* International Institute of Biological Control, Silwood Park, Ascot, UK, 1986, In: Rosen, 1991.
5. Charudattan, R., "The Mycoherbicide Approach With Plant Pathogens,'' in *Microbial Control of Weeds,* D.O. TeBeest (cd.) 1991, In: Rosen, 1991.
6. Christensen, E., ''The Environmental Impact Analysis Process and Coca Eradication programs,' Contractor report prepared for the Office of Technology Assessment, August 1991.
7. DeBach, P., and Rosen, D., *Biological Control by Natural Enemies,* 2nd Ed. (Cambridge: Cambridge University Press, 1991) In: Rosen, 1991.
8. Duke, J. A., Botanist, U.S. Department of Agriculture, Agricultural Research Service, Beltsville Agricultural Research Center, Beltsville, MD, personal communication, August 1989.
9. Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions," vol. 44 Federal Register 1957, Jan. 4, 1979, In: Christenson, 1991.
10. Genter, W., U.S. Department of Agriculture, Agricultural Research Service, retired, personal communication, August 1992.
11. Hey, M.A., "Use of Genetic Improvement in Biological Control," *Agricultural Ecosystems and Environment 15:* 109-119, 1986, In: Rosen, 1991.
12. Hey, M. A., ''Genetic Improvement of Arthropod Natural Enemies: Becoming a Conventional Tactic?" in New *Directions in Biological Control: Alternatives for Suppressing Agricultural Pests and Diseases,* R.R. Baker and P.E. Dunn (eds.) (New York: Alan R. Liss, 1990), pp. 405-417, In: Rosen, 1991.
13. Krebs, C.J., *Ecology: The Experimental Analysis of Distribution and Abundance,* (New York, NY: Harper & Row, 1972).
14. Machado Gazorla, E., "El Genero Erythroxylon en el Peru. Las Cocas Silvestres y Cultivadas del Pais,' ' *Raymondiana* 5:5-101, *1972, In:* Rosen, 1991.
15. Mardon, M., "The Big Push," *Sierra,* November/December 1988, p. 75.
16. Parker, P, E., "Nematodes as Biological Control Agents of Weeds," In: *Microbial Control of Weeds,* D.O. TeBeest (cd.) (New York, NY: Chapman and Hall, 1991) pp. 58-68, In: Rosen, 1991.
17. Perkins, J. H., *Insects, Experts, and the Insecticide Crisis (New* York, NY: Plenum Press, 1982).
18. Plowman, T., "Coca Chewing and the Botanical Origins of Coca (*Erythroxylum* ssp.) in South America," D. Pacini and C. Franquemont (eds.), *Coca and Cocaine: Effects on People and Policy in Latin America,* Cultural Survival Report #23 (Peterborough, NH: Transcript Printing Company, 1986), pp. 5-33.
19. Rosen, D., Vivigani Professor of Agriculture, The Hebrew University of Jerusalem, Rehovot, Israel, personal communication, February 1992.
20. Rosen, D., "Potential for Biological Control of Coca," Contractor report prepared for the Office of Technology Assessment, November 1991.
21. Rosenquist, E., U.S. Department of Agriculture, Agricultural Research Service, Beltsville, MD, personal communication, 1991.
22. Stevenson, S., "Peru Farmers Blame U.S. for Coca-Killing Fungus," *Miami Herald,* June *2, 1992,* p.A-19.
23. Szendri, K., Director, United Nations Drug Control Programme, Vienna, Austria, personal communication, September 1992.
24. TeBeest, D, O., "Conflicts and Strategies for Future Development of Mycoherbicides,' in New *Directions in Biological Control: Alternatives for Suppressing Agricultural Pests and Diseases,* R.R. Baker and P.E. Dunn (eds.) (New York: Alan R. Liss, 1990), pp. 323-332, In: Rosen, 1991.
25. Templeton, G.E., and Heiny, D.K., ''Mycoherbicides,'' in New *Directions in Biological Control: Alternatives for Suppressing Agricultural Pests and Diseases,* R.R. Baker and P.E. Dunn (eds.) (New York: Alan R. Liss, 1990), pp. 279-286, In: Rosen, 1991.
26. United Nations Commission on Narcotic Drugs, Report of the Expert Group Meeting on Environmentally Safe Methods for the Eradication of Illicit Narcotic Plants, meeting held in Vienna December 4-8, 1989, E/CN.7/1990/CRP.7, Dec. 14, 1989.

27. U.S. Congress, Office of Technology Assessment, "Biological Control Workshop," held in Washington, DC, Jan. 23, 1992.
28. U.S. Congress, Office of Technology Assessment, "Crop Substitution Workshop," held in Washington, DC, Sept. 30-Oct. 1, 1991.
29. U.S. Congress, Office of Technology Assessment, *Beneath the Bottom Line: Agricultural Approaches To Reduce Agrichemical Contamination of Groundwater*, OTA-F-418 (Washington, DC: U.S. Government Printing Office, November 1990).
30. U.S. Congress, Office of Technology Assessment, New *Developments in Biotechnology: Field-Testing Engineered Organisms—Genetic and Ecological Issues*, *OTA-BA-350* (Washington, DC: U.S. Government Printing Office, 1988), pp. 16-17.
31. U.S. Congress, Senate, Permanent Subcommittee on Investigations, *Cocaine Production, Eradication, and the Environment: Policy, Impact, And Options,* prepared by Congressional Research Service, 101st Congress, 2d session, 1990, S. Print 101-110.
32. U.S. Department of Agriculture, Agricultural Research Service, Weed Science Laboratory, "Coca Herbicide Screening Summary, ' Beltsville Agricultural Research Center, 1992.
33. U.S. Department of State, Department of State Foreign Affairs Manual Circular No. 807A, subpart B(2)(c), Sept. 4, 1979, reprinted Federal Register vol. 44, p. 67004 (Nov. 21, 1979) In: Christenson, 1991.
34. Weeks, J., "Control of Coca With Herbicides in Peru" in U.S. Congress, Senate Permanent Subcommittee on Investigations, *Cocaine Production, Eradication, and the Environment: Policy, Impact, And Options,* prepared by Congressional Research Service, 101st Congress, 2d session, 1990, s. Print 101-110.
35. Whitten, M. J., Commonwealth Science and Information Research Organization, Canberra, Australia, personal communication, 1991 In: Rosen, 1991.
36. Willis, *J. C., A Dictionary of Flowering Plants and Ferns, 7th* Ed. (Cambridge: Cambridge University Press, 1966) In: Rosen, 1991.