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DEVELOPMENT OF THE FIRST BLACK FLY (DIPTERA: SIMULIIDAE) MANAGEMENT PROGRAM IN ARGENTINA AND COMPARISON WITH OTHER PROGRAMS

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ABSTRACT. In response to increasing pest populations of black flies, the government of Argentina initiated a pilot program to evaluate the effectiveness of larval control in the irrigation system of the Negro River Valley, an 18,240-km^2 area in Patagonia. The extensive system of irrigation canals, drainage ditches, and natural waterways not only provides water for agriculture and general habitation but also affords habitat for immature black flies. Three species (*Simulium bonaerense, Simulium wolffhuegeli,* and *Simulium nigristrigatum*) are primary pests of humans and animals in this area. Trials were conducted using Vectobac® AS in representative irrigation canals, a drainage ditch, and a medium-sized river. Most trials resulted in effective larval mortality and insecticide carry. Based on a comparison with 11 black fly suppression programs throughout the world, a suppression program for the Negro River Valley has a projected cost of approximately $1,623,360/year. This study represents the initial steps in development of the 1st areawide black fly suppression program in Argentina.

KEY WORDS Black flies, management program, Argentina, *Bacillus thuringiensis* var. *israelensis*

INTRODUCTION

In 1991, the government of Argentina initiated a program to investigate the ecology and management of black fly populations in the Negro River Valley. This valley includes the Limay (721 m^3/sec) and Neuquen (302 m^3/sec) rivers that converge to form the Negro River (1,023 m^3/sec). The Negro River Valley is in Patagonia, which is characterized as desert, receiving an average of only 200 mm of rain per year. The valley has about 700,000 inhabitants, encompasses approximately 18,240 km^2, and is surrounded by desert plains. In the early 1900s, an extensive canal system was constructed to provide irrigation for farming. The Negro River Valley has approximately 87,316 ha of fruit and vegetable production. Substantial numbers of livestock, including cattle, sheep, horses, and poultry, also are raised in the valley. While providing the water necessary for agriculture and general habitation of this region, the canal system also provides ideal habitat for larval black flies.

The system incorporates 279 km of canal in the middle valley. The area considered the upper valley contains a similar canal structure. Each valley also has about 150 km of drainage ditches to remove excess irrigation water. The majority (>90%) of the canal system provides suitable black fly habitat. However, the drainage system has slower water velocities and larval habitat of lower quality, with only about 60% of the system producing black flies.

Initial studies identified 3 pestiferous species in the Negro River Valley: *Simulium bonaerense* Coscarón and Wygodzinsky, *Simulium wolffhuegeli* (Enderlein), and *Simulium nigristrigatum* (Enderlein) (Coscarón-Arias 1997). These species are biting and nuisance pests of residents, workers, and livestock. The purpose of our study is to provide information on a pilot-management program for black flies in the Negro River Valley and to compare projected costs with those of similar programs in other parts of the world. The establishment of an areawide black fly management program in this valley would constitute the 1st black fly suppression program in Argentina.

MATERIALS AND METHODS

Study sites: Five field evaluations, using *Bacillus thuringiensis* Berliner var. *israelensis* (*B.t.i.*), were conducted February 18–26, 1997 (late summer in southern hemisphere): 3 in irrigation canals, 1 in a medium-sized river channel, and 1 in a drainage ditch (Table 1). Irrigation canals in the Negro River Valley are typically steep-sided, flat-bottomed, and straight. Drainage channels have gradually sloped banks and slower velocities and lower discharges than canals.

Canal VI had a flow of 3.23 m^3/sec and was straight, with the exception of 2 45° bends in the evaluation area. Canal VII had a flow of 3.49 m^3/sec and was evaluated over a straight, 3,000-m section. This canal supports dense beds of aquatic vegetation (*Potamogeton* sp.) and is typical of many of the irrigation canals in the Negro River Valley. Canal VIII had a flow of 11.5 m^3/sec and originated at the same water-control structure as Canal VI. Canal VII originated 50 m downstream of the water-control structure that created Canal VIII. All of

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these canals are in the Lamarque farms area in the middle valley of the Rio Negro province.

The Rio Salado is a medium-sized river extending from the town of Chimpay to the town of Choele Choel. This area also is located in the middle valley of the Rio Negro province. The Rio Salado had a flow of 5.58 m^3/sec on the date measured. Its flow, however, is directly related to the level of the Negro River and is typically higher than measured during this study. The Negro River Valley was experiencing a dry period, and all rivers were lower than normal during our study. Flow in the Rio Salado was relatively uniform through the first 1,500 m. Beyond 1,500 m, no suitable larval habitat was present until 2,200 m below the treatment site. The area between these 2 sites had slow water, with a 100-m stretch of dense aquatic vegetation.

Drainage Plottier (Neuquen province) represented a typical drainage channel in the valley region. It had a flow of 0.31 m^3/sec at the treatment site and 0.40 m^3/sec at the most distant evaluation site (2,300 m). The area between 1,200 m and 2,300 m was virtually inaccessible. A 200- to 300-m stretch of slow flow followed the 1,200-m site.

Application and evaluation: The 1st field trial (Canal VI) was conducted with a Vectobac® AS (600 ITU—Abbott Laboratories, N. Chicago, IL) *B.t.i.* product (lot no. 09-244-S1) that was produced in September 1995 and had a use-by date of September 1996. This product had been stored at room temperature since receipt by the Universidad Nacional Del Comahue in Cinco Saltos, Argentina. Vectobac AS (lot no. 20-628-S1) that was manufactured in August 1996 was used in all subsequent trials.

Flow measurements were conducted following the recommendations of Horosko and Noblet (1986), with the following exception. Velocity measurements on February 18 and 20 were conducted with a Fisons Scientific Equipment velocity meter (MJP—Geopacks, Cornwall, Trinidad). We used corks and a stopwatch to calculate velocity on the remaining treatment days. Surface velocities were multiplied by 0.8 to adjust for flow velocities throughout the water column (Colbo 1985, Molloy and Struble 1989).

Larval mortality was evaluated using techniques similar to those of Gray et al. (1996). Mortality evaluations were conducted at various distances downstream from the treatment site (Table 2), depending on individual waterway characteristics, larval substrates, and the dose. A minimum of 100 larvae were collected approximately 5 h posttreatment by removing pieces of substrate and returning them to the laboratory in ice chests. Samples were aerated with aquarium pumps. At approximately 24 h posttreatment each sample was poured in a white enamel pan and the percent mortality was determined.

Adult monitoring was conducted on 9 occasions from February 18 to 27, 1997, following the pro-

Table 1. Characteristics and treatment parameters for waterways in the Negro River Valley, Argentina, in February 1997.

Date	Waterway	Mean velocity (m/sec)	Mean depth (m)	Width (m)	Water temperature (°C)	Air temperature (°C)	Dose (ppm)
February 18	Canal VI	1.82	0.51	3.48	21.6	29.0	12.4
February 20	Canal VII	1.06	0.70	4.70	20.0	27.0	5.0
February 20	Canal VIII	1.27	0.95	9.50	20.0	27.0	4.5
February 25	Rio Salado	0.36	0.64	24.20	20.0	25.0	25.0
February 26	Drainage Plottier	0.28	0.36	3.10	19.5	30.0	25.0

Table 2. Larval mortality evaluations in 5 waterways in the Negro River Valley, Argentina, February 1997.

Site m down-stream	Percent mortality (*n*)				
	Canal VI	Canal VII	Canal VIII	Rio Salado	Drainage Plottier
Control (0)	0.3 (307)	0.0 (127)	0.3 (361)	2.4 (295)	0.0 (158)
500–1,000	100.0 (202)	—	—	100.0 (150)[4]	99.1 (213)
1,000–1,500	99.6 (264)[1]	—	—	95.5 (157)[4]	91.5 (236)
1,500–2,000	—	71.6 (278)	80.4 (224)	95.2 (210)	—
2,000–2,500	99.5 (222)	62.9 (307)	—	60.5 (778)	5.6 (199)
2,500–3,000	89.9 (139)[2]	40.2 (137)	87.9 (200)	—	—
3,000–3,500	92.7 (425)	—	88.8 (295)[3]	3.9 (383)	—
3,500–4,000	61.5 (191)	—	88.7 (363)[3]	—	—
4,000–4,700	—	—	74.3 (288)	—	—

[1] Additional mortality evaluations were made at 2 sites in a side channel downstream of a water-control structure located 1,100 m below the treatment site: 1,300 m, mortality = 98.2% (*n* = 327); 1,880 m, mortality = 92.4% (*n* = 238).
[2] Additional mortality evaluations were made at 2 sites in a side channel downstream of a 2nd water-control structure that was located 1,880 m below the treatment site on the 1st side channel: 2,520 m, mortality = 77.5% (*n* = 325); 2,580 m, mortality = 2.8% (*n* = 248).
[3] Additional mortality evaluations were made at 2 sites in a side channel downstream of a water-control structure that was located 3,400 m below the treatment site: 3,450 m, mortality = 21.2% (*n* = 113); 3,700 m, mortality = 41.3% (*n* = 189).
[4] Mortality was evaluated 5 h after application; all other samples were evaluated 24 h after application.

cedure of Gray et al. (1996). An individual stood at a site for 5 min before making 10 figure-8 sweeps with an insect net (38-cm diameter) above the head and shoulders. After the first 5 sweeps, a 15-sec pause allowed the flies to regroup. The same individual (E.W.G.) dressed in navy blue shirt and pants performed all sweeps.

The initial test was conducted in Canal VI. The *B.t.i.* (4.9 liters) was diluted with an equal amount of water to enhance mixing, and the mixture was applied from a 10-liter watering can at a dose of 12.4 ppm. The application was made over a 1-min period, 5 m downstream of a water-control structure where turbulence aided mixing. Mortality evaluations in Canal VI were conducted to a distance of 3,850 m downstream of the treatment site. Samples also were collected below 2 sets of water-control structures to determine how *B.t.i.* would flow through these structures that are integral to the irrigation system in this region. At 1,100 m below the treatment site, approximately 0.5 m^3/sec of water was diverted to a secondary canal. At 1,880 m from the treatment site on this secondary canal, a 2nd set of water-control structures subdivided the flow and reduced it to approximately 0.25 m^3/sec.

On February 20, Canals VII and VIII near the town of Lamarque were treated at 5.0 ppm for 1 min and at 4.5 ppm for 1 min, respectively. Both of these applications (*B.t.i.* diluted with equal amounts of water) were made with a 10-liter watering can from a water-control structure into an area of turbulence. On February 25, the Rio Salado near the town of Darwin was treated at 25 ppm for 1 min, with a 20-liter container, while crossing the current. On February 26, Drainage Plottier was treated at 25 ppm for 1 min in an area of swift flow below a water-control structure.

RESULTS AND DISCUSSION

Species composition

Simulium bonaerense represented 79–89% of the larvae in treated waterways and *S. wolffhuegeli* the remaining 11–21%. In addition to the canal and drainage system, all 3 rivers (Limay, Neuquen, and Negro) provided larval habitat, although the Limay River had low larval populations (<15 larvae collected/min) upstream of the City on Neuquen. Larvae of all 3 pest species (*S. bonaerense, S. wolffhuegeli,* and *S. nigristrigatum*) were present in the Limay River, and 84% were *S. bonaerense.* The Negro River near the town of Pomona City had heavy larval populations (>50 larvae collected/min), with *S. bonaerense* the most prevalent species (97%).

Adult monitoring indicated that *S. bonaerense* was the most important biting species. All but 1 of 143 females captured were of this species; 1 female of *S. wolffhuegeli* was captured. An average of 15.9 females (range: 6–28) was collected in 9 samples, with wind speeds ranging from 1.6 to 29.0 km/h. Female numbers were well above those warranting suppression programs in North America (Gray et al. 1996). In addition, the biting, as opposed to nuisance, activity of *S. bonaerense* makes these levels less tolerable.

B.t.i. treatments

The irrigation system in the Negro River Valley is composed of a series of water-control structures that continuously divides the flows until the irrigation water reaches its final destination. It was, therefore, crucial to test whether the *B.t.i.* provided effective larval mortality below the water-control structures. In Canal VI, the *B.t.i.* moved through the initial water-control structures and provided effective mortality (>90%) at distances of at least 3,000 to 3,500 m (Table 2). High larval mortality in Canal VI demonstrated the stability and longevity of the Vectobac even though it was 5 months beyond its use-by date.

The use of 5.0 ppm of Vectobac AS did not produce effective larval mortality in Canal VII (Table 2). Larval mortality in Canal VIII, although not as high as necessary for an adult suppression program, indicated the excellent carry potential of the canal system. At 4,700 m below the treatment site, 74.3% mortality was achieved with a dose of only 4.5 ppm. Why higher levels of mortality were not demonstrated at closer evaluation sites is not known; more testing is required to determine an effective dosage under these conditions.

The Rio Salado will pose a challenge to a black fly suppression program. This waterway is approximately 70 km long and contains areas of larval habitat interspersed with pools and dense aquatic vegetation. Aquatic vegetation reduces the carry of *B.t.i.* by lengthening the water path and increasing the surface area to which the water column is exposed (D. Kurtak, personal communication). Nonetheless, our tests showed that effective larval control could be achieved at reasonable distances in areas with adequate flow (Table 2). Larval samples collected at 2,200 and 2,350 m indicated that some material moved through the 700 m of unsuitable larval habitat upstream of these sites. This area included deep pools and 100 m of dense aquatic vegetation.

At Drainage Plottier, larval mortality was satisfactory (>90%) through 1,200 m (Table 2). Slow flow and increasing volume probably contributed to the drop in mortality beyond 1,500 m. An important consideration in treating drainage channels is that the flow volume increases with distance from the treatment site. This trend also applies to most rivers, but the smaller flow volumes of the drainage systems make the percentage of increased flow a more significant factor. In the future, flow should be measured at the farthest downstream site where effective control is to be achieved. This procedure will expose larvae at the downstream site to the target dose and not underdose them, as in this trial.

Comparisons with related programs

The cost of developing a suppression program for the Negro River Valley is an important issue for the government of Argentina. Costs of other black fly management programs can provide insight into this matter (Table 3). Although adulticiding is an effective technique for mosquito suppression, it is not a cost-effective means of reducing black fly populations. In the Adirondack Mountains of New York, larvicide applications required about $400/km^2 in the 1st year, with $240–380/km^2 for subsequent years (Molloy and Struble 1989). Treatments were conducted to 3.2 km from the center of the treatment zone, and adult levels were reduced by 86% at the center. Extensive time and effort were required to treat small (discharge <0.5 m^3), not readily accessible waterways, adding significantly to the cost of the management program.

In São Paulo, Brazil, the primary pest species (*S. pertinax* Kollar) developed resistance to temephos (Neto 1984), and biological control with *B.t.i.* was implemented. In 1992, 1,456 breeding sites were targeted to reduce adult levels to acceptable limits during peak tourist season (January–March) (Araujo-Coutinho 1995). Using the reported monthly figure of $48,904 and an average of 6 months/year, we projected a cost of $293,426/year to protect the affected area (893 km^2).

Recent expansion of the management program for *Simulium jenningsi* Malloch in Pennsylvania makes it 1 of the largest in the world. Twenty-eight of Pennsylvania's 67 counties treat the breeding waters of this pest, with a major focus on the large Susquehanna River. The total budget for the program in 1997 was approximately $3.75 million. In 1995, the year for which the most accurate information is available, control costs were about $89/km^2 (D. Arbegast, personal communication). Adult monitoring is conducted regularly with a technique similar to that of Gray et al. (1996). Monitoring sessions capturing 10 or more adults indicate a need for additional larval suppression.

The South Salt Lake County, UT, Mosquito Abatement program used Vectobac 12AS in irrigation ditches and natural waterways to suppress *Simulium vittatum* Zetterstedt cytospecies IIIL-1 in 1997 (K. Minson, personal communication). In nearby northern Nevada, the average cost to suppress black flies (primarily *Simulium meridionale* Riley), using methoxychlor and limited *B.t.i.* applications, was $70/km^2 (R. D. Gray, personal communication). This figure is based on the distance of river treated and a 3.3-km band on either side of the river, the distance at which significant nuisance levels were observed. In 1992, a low-flow year when only *B.t.i.* was used, the average cost in 2 counties was $30/km^2. The difference between low- and high-flow years demonstrates that the volume of water treated is a major determinant of costs for a management program. Flexibility, therefore, must be preserved when determining budgets and the amount of insecticide required. Reduced larval mortality after applications of methoxychlor in late 1997 and early 1998 suggests that resistance to this chemical has developed. Increased use of *B.t.i.* is expected.

Colbo (1985) developed a management program in the Labrador City–Wabush area of Canada. Waterways in the area had flows of 0.2 to 19.2 m^3/sec and were treated 4 times during the program. This program had a proposed goal of at least 80% reduction in adult levels and a treatment radius of 10 km.

Table 3. Estimated costs of black fly suppression programs on a km² basis.

Location—Year	Cost/km[1]	km²	Species	Source
New York, Adirondack Mountains—1984	$2,000[2] $240–380	103	*Simulium venustum* complex, *Prosimulium mixtum/fuscum, Stegopterna mutata* complex	Molloy and Struble (1989)
Sao Paulo, Brazil—1992	$329	893	*Simulium pertinax*	Araujo-Coutinho (1995)
Pennsylvania—1997	$89[3]	30,217	*Simulium jenningsi* group	Arbegast (personal communication)
Salt Lake City, UT—1997	$85	1,587	*Simulium vittatum* 'IIIL-1'	Minson (personal communication)
Northern Nevada—1997	$70,[4] $30[5]	625	*Simulium meridionale*	R. Gray (personal communication)
Labrador City, Newfoundland—1984	$69	314	*Prosimulium mixtum* group, *Simulium venustum* complex, *Simulium corbis*	Colbo (1985)
Minnesota—1984	$48	4,563	*Simulium venustum* complex	Simmons and Sjogren (1984)
Minnesota—1997	$39	4,563	*Simulium venustum* complex, *Simulium luggeri, Simulium johannseni, Simulium meridionale*	Sanzone (personal communication)
West Virginia—1997	$34	7,332	*Simulium jenningsi* group	Smithson (personal communication)
OCP–West Africa—1988	$26[6]	764,000	*Simulium damnosum* complex	Philippon (1988)
South Carolina—1997	$21	1,017	*Simulium jenningsi* group	E. Gray (unpublished data)
Western Kentucky—1998	$8[7]	4,149	*Cnephia pecuarum*	Buhlig (personal communication)

[1] Cost/km² = operational costs + materials.
[2] Aerial application of broadspectrum insecticides for adult control. All other costs are for larval control.
[3] Includes significant nontarget work.
[4] Methoxychlor used for larval control.
[5] 1992 costs, using *B.t.i.*
[6] Includes chemical and biological control agents, depending on seasonal flow levels.
[7] One treatment period per year.

The Metropolitan Black Fly Control Program (MBCP) in St. Paul–Minneapolis, Minnesota, operated on a budget of $218,000 (Simmons and Sjogren 1984) or $48/km^2 of area protected. The MBCP is part of the Metropolitan Mosquito Control District, capitalizing on the insect-control infrastructure already present in the area. The cost for the program in 1997 dropped to $39/km^2, with a total budget of $179,600 (J. Sanzone, personal communication). The 1997 program monitored approximately 150 sites on small to mid-size streams for the *Simulium venustum* Say complex and 240 km of large rivers (Mississippi, Minnesota, Rum, and Crow rivers) for *Simulium luggeri* Nicholson and Mickel, *Simulium johannseni* Hart, and *S. meridionale* Riley.

The West Virginia Division of Environmental Protection treats a 48.3-km radius (7,332 km^2) around the city of Hinton, West Virginia, targeting *S. jenningsi,* with a 1997 budget of approximately $250,000 (J. Smithson, personal communication). Based on the area protected, this program is currently the 3rd largest in the world. The Kentucky Department of Agriculture has a single treatment period during mid-January in 5 counties, targeting the univoltine *Cnephia pecuarum* (Riley). This program has an estimated budget of $32,680 (M. Buhlig, personal communication).

The Onchocerciasis Control Programme (OCP) in the Volta River Basin of West Africa—the largest vector-control program in the world—manages black flies over 764,000 km^2 at a cost of approximately $20 million (Philippon 1988). This program uses chemical and biological control agents, depending on seasonal flow levels. The level of reduction for disease vectors is far more critical than in nuisance situations where low pest populations can be tolerated. The OCP program, therefore, demands the highest standards for larvicide effectiveness.

In South Carolina, the primary pest species (members of the *S. jenningsi* species group) inhabit large streams and rivers in the treatment area, with the primary waterways having flows of 8 to 14 m^3/sec (Gray et al. 1996). Members of the *S. jenningsi* species group are strong fliers (Choe et al. 1984), necessitating a treatment radius of 10 km or greater. After 3 years of work, the program was expanded to an 18-km radius, with development costs spread over this period. Adult levels were reduced by 97% in 1998 compared with preprogram counts (E. Gray, unpublished data). The large, warm (18–25°C) streams and rivers inhabited by the target species are conducive to maximum carry and efficacy of the *B.t.i.* product, which contributes to lower program costs. The good carry in larger rivers allows treatments and dosages to be adjusted for applications at easily accessible points. In addition, the taxonomy of the pest species was resolved prior to initiation of the program (Moulton and Adler 1995).

The cost of a black fly suppression program depends on several factors, most of which are related to the ecology of the pest species. One factor is the frequency of larvicide applications relative to the generation time of the pest species. Colder waters produce fewer generations and require fewer larvicide applications. Programs targeting the multivoltine members of the *S. jenningsi* species group typically require 10 to 15 treatment sessions, regardless of location (E. Gray, unpublished data; D. Arbegast, personal communication; Smithson 1996). The flight range of the pest species is also important in determining the size of the proposed program. For strong flying species (e.g., members of the *S. jenningsi* species group), large areas must be treated to avoid immigration from outside the treatment zone. *Prosimulium* species, conversely, are not such strong fliers, allowing smaller treatment zones. *Prosimulium* species typically inhabit smaller waterways, increasing the cost of black fly suppression for 2 reasons. First, the carry of *B.t.i.* is less in waterways with less flow, requiring treatments at shorter distance intervals. Second, accessibility often becomes a problem as the number of treatment sites increases.

Additional developmental work is needed in Argentina. For example, little is known about the flight range of the primary pest, *S. bonaerense.* We, therefore, are not certain what percentage of the valley would require protection. However, because the canal system is constantly monitored and adjusted, treatment and evaluation of canals would be easy. In addition, warm water and high flow rates characteristic of irrigation canals are conducive to *B.t.i.* efficacy. If the entire valley requires treatments to reduce adult levels, the program would become the 3rd largest in the world, on a km^2 basis, after the West African and Pennsylvania programs.

Comparing the costs of various management programs on a cost/km^2 basis provides a means of estimating possible costs in the Negro River Valley. As a point of reference, projecting the costs of the São Paulo project to the entire area of the Negro River Valley (18,240 km^2) yields a program costing approximately $6,000,000/year. However, the canal structure and size of the Argentine program should be more conducive to cost-effective larval control than the area in Brazil. Extrapolating from the Pennsylvania program places the cost at about $1,623,360. The potential size of the program and need for governmental involvement make this estimate reasonable. If it is necessary to treat the large rivers (Limay, Neuquen, and Negro) in the Negro River Valley plus the irrigation system, the comparison with the Pennsylvania program might be the most accurate. Based on South Carolina figures, the cost of black fly suppression in the Negro River Valley would be $383,040. Although the South Carolina program is a 2-person operation, several factors make the estimate reasonable. Taxonomic work has been conducted in the Negro River Valley, the pests have been identified, and relevant larval habitats have been located. Because of the small volume of *B.t.i.* used in South Carolina, standard distributor pricing is used. The large volume of *B.t.i.* that would be required in the Negro River Valley might offset the additional distribution costs for international work through bulk purchasing. Finally, the cost of quality labor in this region of Argentina should be less than in the United States. To project the cost of any black fly suppression program, the delivered cost of the insecticide and operational costs must be included in the final figure. In addition, large-scale suppression projects require substantial technical infrastructure to be implemented and operated effectively.

Future work will require additional evaluation of larval black fly populations in the rivers of the Negro River Valley. Because the cost of treating rivers of this magnitude will be substantial, we targeted the smaller, more workable larval habitats as an initial step in developing a management program. Our trials represent the beginning of the task of delineating the carry characteristics of all breeding sites in the region. The basic structure of the canal system, however, should enable effective treatment of the waterways. In South Carolina, effective control (>95% mortality) can be achieved in natural river systems (6–14 m^3/sec) for over 10 km. Excellent carry in irrigation canals is evident from our trials. Considering the size, economic-impact potential, and benefits of a black fly management program in the Negro River Valley of Argentina, this study should provide some useful perspectives to the scientific and business communities of both North and South America.

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