AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
Batch 58

1. SUBJECT CLASSIFICATION

A. PRIMARY
Food production and nutrition — AL72-0000-0000

B. SECONDARY
Pests of animals

2. TITLE AND SUBTITLE
The biology and control of vampire bats

3. AUTHOR(S)
Linhart,S.B.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1975	21p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Interior

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)
(In Natural history of rabies,v.2,p.221-241)

9. ABSTRACT

10. CONTROL NUMBER
PN-AAD-700

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Bats,vampire
Pest control
Research

13. PROJECT NUMBER

14. CONTRACT NUMBER
PASA RA(ID) 1-67 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

Reprinted from:
THE NATURAL HISTORY OF RABIES, VOL. II
© 1975
ACADEMIC PRESS, INC.
New York San Francisco London

CHAPTER 14

The Biology and Control of Vampire Bats

Samuel B. Linhart

I. Introduction 221
II. Biology of the Vampire Bat 222
III. Existing Control Methodology and Control Programs 229
A. Current Status of Control Techniques 229
B. Control Programs in Latin America 231
IV. Research 233
V. Social and Economic Considerations 238
Acknowledgments 239
References 239

I. Introduction

The early Latin American explorers and naturalists were the first observers to factually report vampire bat predation on humans and livestock (Villa-R., 1966; Constantine, 1970). The vampire was established as the vector following the widespread outbreak of rabies in southern Brazil in the early 1900's (Carini, 1911; Haupt and Rehaag, 1921; Queiroz-Lima, 1934; Pawan, 1936). Estimates of cattle deaths from vampire bat-transmitted rabies in Latin America are grossly inadequate since the vast majority of cases are unreported. However, recent reports place annual mortality at 1–2 million animals, with a value from 80,000,000 to 250,000,000 dollars (Acha, 1967, 1968; Steele, 1966, 1969; Málaga-Alba, 1959). Equine losses are significant in certain areas (Valdés-Ornelas and Atristain Aranalde, 1964) and vampire bats also transmit equine trypanosomiasis to horses and mules (Dunn, 1932; Clark and Dunn, 1933). In addition, blood loss in the bitten animals, the subsequent secondary infection of wounds, or their invasion by screwworm larvae, as well as the

human rabies aspects, all contribute to the seriousness of the problem (Greenhall, 1964; Constantine, 1970; Valdés-Ornelas and Atristain Aranalde, 1964; Nehaul, 1955, 1962; Málaga-Alba, 1962; Acha, 1967). The Fifth Report of the World Health Organization Expert Committee on Rabies (1966), concluded that vampire bat-transmitted rabies is a major obstacle to the expansion of the livestock industry in Latin America.

Although organized vampire control efforts began as early as 1934 in Trinidad (Greenhall, 1965b), research has traditionally been directed toward the development of effective cattle vaccines. However, vampire bat reduction, as well as cattle vaccination, is needed to alleviate the problem. A number of only partially effective reduction techniques are currently employed, but not until very recently was well-funded, sustained research by trained biologists undertaken to develop truly effective and economical control methods. A prerequisite to this objective is more adequate knowledge of the biology of the vampire bat and exploitation of its ecological, behavioral, or physiological "weak links."

II. Biology of the Vampire Bat

Villa-R. (1966), Wimsatt (1970), Ruiz-Martinez (1963), and others have partially summarized what is known about the biology of the vampire bat, but as yet no one monograph or single reference source has dealt with all aspects of their physiology, behavior, ecology, control, and disease relationships. I recently compiled a partial bibliography of the vampire bat literature with some 626 references (Linhart, 1971). While a certain number of these references contain data on the morphology, physiology, and distribution of vampires (primarily *Desmodus*), there is a paucity of quantitative data concerning their behavior and ecology under natural conditions. Very little is known of their social structure, behavior, movement, population dynamics, and interspecific relationships, nor are techniques available for determining their relative or actual abundance. Movement, based on trapping, banding and recovery, a technique used extensively to study the activity of other bat species, has received little or no attention in the family Desmodontidae.

The vampire bats appear to be closely related to the Phyllostomatidae (Forman *et al.*, 1968) and include three genera, each containing but a single species: *Desmodus rotundus*, *Diaemus youngi*, and *Diphylla ecaudata*. *Desmodus* is the most common and widespread

Fig. 1. The common vampire bat (*Desmodus rotundus*). (Courtesy of U. S. Fish and Wildlife Service, Department of the Interior.)

of the three and nearly all the vampire literature deals with this species (Fig. 1). It is a moderate sized bat with highly modified teeth for its specialized feeding habits. Walker (1964) gives the following measurements for adult *Desmodus:* length of head and body, 75–90 mm; no tail; length of forearm, 50–63 mm; weight of adults, 15–50 g.

Desmodus is found from northern Argentina to tropical Mexico (Walker, 1964) and while it normally inhabits tropical and subtropical regions, it has been collected in the Colombian Andes at an elevation of 2594 m (Tamsitt and Valdivieso, 1962). Reddell (1968) reported collecting a single *Diphylla* near Comstock, Val Verde County, in southwestern Texas, a locality considerably north of its previously reported range. Cockerell (1930) reported the remains of an extinct race of *Desmodus* from the Terlingua region of Texas, and Gut (1959) and Olsen (1960) have reported the occurrence of pleistocene *Desmodus* from Florida. Fossil remains have also been found in Cuba (Koopman, 1958). Several workers (Walker, 1964; Málaga-Alba, 1966; Greenhall, 1969, 1970a) suggest that vampires have increased their numbers and range, concurrent with the introduction of

domestic animals and the subsequent growth of the livestock industry in the New World. There are no data on vampire bat densities in relation to available food and habitat. Their mobility, secretive habits, and the fact that they are most often found in relatively small colonies, make it difficult to adapt or modify census techniques currently used for other mammalian or avian species.

The average size of a *Desmodus* colony is probably about 100, while on rare occasions as many as 2000 individuals may share the same roost (Fig. 2). Crespo *et al.* (1961) reported finding *Desmodus* males and females segregated within the same roost, although it is more common to find vampires of different sexes and ages sharing the same niche. In view of the vampires' food requirements, it is easy to see why dispersal throughout an area is necessary, otherwise excessive population densities might cause the death of the prey species through debilitating blood loss alone. In any event, it seems

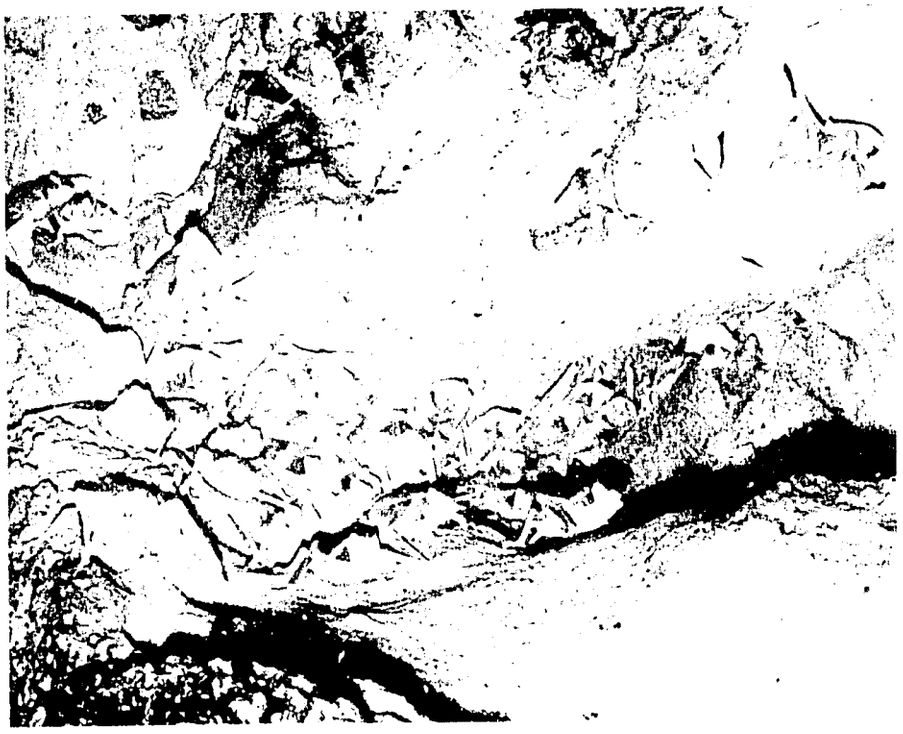

Fig. 2. A small roost of common vampire bats. (Courtesy of U. S. Fish and Wildlife Service, Department of the Interior.)

certain that availability of a food source, climatic requirements, and the presence of suitable roosting sites are the major factors limiting the abundance and distribution of the vampire.

Málaga-Alba (1966), Ruiz-Martinez (1963), and de Verteuil and Urich (1936) indicate that vampire densities are greatly reduced following rabies epizootics, their numbers returning to former levels after 2–4 years. Quantitative data are needed to better understand disease/vector density interrelationships.

Vampires utilize a variety of roosting sites but caves or abandoned mines, at least in Mexico, appear to be preferred. Their refuges can be identified by the presence of black, tarry pools or deposits of excrement beneath their roosts. In many areas vampires may be found living in hollow trees, culverts, abandoned man-made structures or dwellings, aqueducts, or other dark, undisturbed sites where their rather specific microclimate requirements are met. A study by Lyman and Wimsatt (1966) indicates that thermoregulation in *Desmodus* is extremely poor and restricts their geographic distribution. Villa-R. (1966) and Crespo *et al.* (1961) point out that as long as warm and relatively humid roosting sites are present vampires can survive where ambient winter temperatures fall as low as 0°C.

Ruschi (1952) mentions seasonal movement of *Desmodus* between summer and winter roosts, and I have observed similar seasonal movement in the state of Morelos, Mexico, at the upper extreme of their altitudinal range. Wimsatt (1969) and Villa-R. (1966), basing their conclusions on capture, banding, and recovery studies in Mexico, found that individual *Desmodus* shift from roost to roost on a daily or opportunistic basis, even though the size of the colony within a given roost may remain constant. Burns and Flores Crespo (1975) compare the extent of *Desmodus* interchange between roosts at varying distances apart. Wimsatt (1969) found "repopulation of another roost during biweekly intervals following two successive removals of almost all bats." Our unpublished studies in Mexico suggest that the rapidity and extent of repopulation following removal of the original colony varies according to geographic location, and is probably dependent on the number of optimal and suboptimal roosting sites in the area. Repopulation rates obviously have important implications with respect to vampire bat control.

Several workers mention the foraging range of *Desmodus*. Johnson (1948) states that the vampire ordinarily feeds within 10 km of its roost. Counter (1954) reports that they usually live within a mile of their prey; while Málaga-Alba (1954) indicates that feeding activity occurs within a radius of 15–20 km of their refuges. According to

Dalquest (1955), vampires may return to their roost engorged with blood within 30 min, while Wimsatt (1969), based on capture, banding, and recapture at the roost, found that the average time spent foraging was about 2 hours. Greenhall (1970b) mentions that vampires may stop to rest at "digesting places" before returning to diurnal roosts. Ruschi's (1952) interesting studies in Brazil provide additional movement data. Roosting *Desmodus* were marked with a fluorescent marker and were found to forage as far as 12–16 km distant from the roost, returning 3–8 hours later. Captured vampires which were marked and released 12–120 km from the roost returned 2–9 hours later (the same night). At distances over 120 km, some returned after two nights. On the basis of such studies, Ruschi states that they are capable of flying about 55 km/hour.

Heavy rainfall may reduce foraging activities, and moonlight influences vampire activity, the bats preferring to forage when moonlight is minimal or lacking (Villa-R., 1966; Wimsatt, 1969; Flores Crespo *et al.*, 1972b).

Wimsatt (1954) and Wimsatt and Trapido (1952) have studied the histology of reproduction in *Desmodus*. They report that *Desmodus* breeds throughout the year and bears but a single young. Females may breed twice a year and gestation is probably more than 5 months. In Mexico, I have seen gravid females and females with young present in roosts throughout the year, but in certain parts of that country gravid females seem more abundant during the early spring months. Málaga-Alba (1954) reports that newborn bats appear to be more numerous in April and September. Burns and Flores Crespo (1975) provide information on the percent of females gravid and giving birth, and the percent of males with scrotal testes in roosts located near Colima, Mexico. Their data also support the concept of seasonal breeding under certain ecological conditions. Twins (in *Desmodus*) have been reported by Burns (1970), although they are probably rare. Burns (1972) has also presented data on the growth and dentition of known-age juvenile *Desmodus*, the period of nursing, and the age of sexual maturity.

Trapido (1946) reported a captive *Desmodus* that lived for 12 years and 9 months. Mean life expectancy and population turnover in free-living vampires has only recently been reported in the literature. I obtained age distribution data from a colony of 89 *Desmodus* taken in southern Mexico. Their age was estimated by counting the number of annuli present in their tooth cementum (Klevezal' and Kleinberg, 1967). The mean age in this colony was about 2.6 years, with the

oldest individual (a female) being 13–14 years of age (Linhart, 1973). The low reproductive potential of *Desmodus*, in addition to a rather long life expectancy, suggest that repopulation would occur rather slowly following rabies epizootics or effective control.

Sight and olfaction are well developed in *Desmodus* compared to other bat species (Mann, 1951, 1960, 1961), and it is probable that these senses play an important part in their foraging behavior and activity. Ruschi (1952) reported that five *Desmodus* were unable to return to a roost located 500 m distant following perforation of their tympanum. Griffin and Novick (1955) found that *Desmodus* emit very low-intensity echolocation pulses as opposed to those bat species that feed on insects. Henson (1970) and Suthers (1970) summarize much of the available data on hearing, vision, olfaction, and taste in the vampire; however, additional work is needed to establish the relationships between sensory mechanisms and movement and prey seeking under natural conditions.

Villa-R. (1966) reports that a few vampires briefly leave the roost and quickly return, presumably to determine the degree of obscurity, following which the entire colony flies out to forage. While proximity of an adequate food source determines foraging time and activity, *Desmodus* does not necessarily feed on livestock nearest the roost. I have observed cattle within a few hundred meters of sizable vampire colonies that showed no evidence of having been bitten. Vampires fly within a few meters of the ground when foraging and are usually taken in the lower portion of mist nets. Upon finding a suitable animal to feed upon they may alight nearby and approach their prey on foot.

Greenhall (1970b) used serologic precipitin tests of digested blood taken from vampire (*Desmodus* and *Diaemus*) gastrointestinal tracts to identify prey preferences. He found that *Desmodus* in Trinidad fed on a wide variety of domestic animals and wildlife, whereas in Mexico their diet consisted primarily of cattle blood along with that from a very small number of other domestic animals. *Diaemus* in Trinidad were found to feed more on mammalian blood than heretofore suspected. Earlier publications state that *Diaemus* feeds almost exclusively on avian blood. Greenhall also indicated that *Desmodus* does not have to feed nightly. He reported that five captive *Desmodus* survived following 3.7 days without feeding. In another study (Crespo *et al.*, 1961), a captive adult male *Desmodus* went without a blood meal for 3 days and survived.

Favored feeding sites on cattle are the neck, shoulders, tail, and

anal region, although bites may be found on nearly all parts of the body. Sanborn (1931) and Crespo *et al.* (1961) reported seeing up to eight vampires feeding on the same animal, but this no doubt represents the upper limits of predation. Schmidt *et al.* (1970) reported seeing seven vampires feeding from the same wound, one after another, within a 3-hour period, and calculated in the herd under study that an average of three vampires fed from the same wound. Crespo *et al.* (1961) reported that intraspecific competition may be a factor when vampire densities are high, and I have observed antagonistic behavior displayed by a feeding *Desmodus* upon the approach of another. de Verteuil and Urich (1936), Schmidt *et al.* (1970), Arellano *et al.* (1971), and others have noted that *Desmodus* shows a preference for certain breeds, ages, and colors of cattle; dark colored and immature animals are generally preferred. While little is known as to why vampires prefer to feed upon certain individual animals within a herd, docility of the "favored" individuals is probably an important factor. *Desmodus* apparently prefers to feed on prone cattle rather than those in an upright position (Flores Crespo *et al.*, 1971).

Many workers have described the act of feeding by *Desmodus* (among them Ditmars and Greenhall, 1935; Villa-R., 1966; Greenhall *et al.*, 1971). DiSanto (1960) and Hawkey (1966, 1967) demonstrated that there is an anticoagulating property (a proteolytic enzyme) in the saliva of *Desmodus*, this having been a point of considerable uncertainty for many years. Vampires have been reported to consume their own weight in blood daily, although average daily consumption is about 15–20 ml (Wimsatt and Guerriere, 1962; Villa-R., 1966; Greenhall, 1970a). On occasion they may have difficulty flying after a large blood meal and have been seen to climb up a nearby post or tree in order to launch themselves into the air (McFarland and Wimsatt, 1969). Micturition frequently occurs during feeding (Ditmars and Greenhall, 1935; Villa-R., 1966; McFarland and Wimsatt, 1969) and *Desmodus* is reported to spend considerable time grooming (Greenhall, 1965c; Flores Crespo *et al.*, 1972a).

Vampires frequently share their roosts with other species of bats; however, interspecific relationships have not been well studied despite the important epizootiologic implications. Villa-R. (1966), Crespo *et al.* (1961), among others, have found various bat species sharing the same roosts with vampires. Pawan (1948) states vampires may bite and repel fruit-eating bats occupying the same roost, although it is not known how frequently such contact occurs.

III. Existing Control Methodology and Control Programs

A. Current Status of Control Techniques

Constantine (1970), Greenhall (1963, 1968, 1970a), and Ruiz-Martinez (1963) have summarized existing techniques for the control of vampire bats. Constantine (1970), in his thorough resumé and bibliography of bats in relation to health, welfare, and economy, divides vampire control methods into two categories: (1) repellents, physical barriers, and roost destruction: and (2) lethal population reductional techniques. While nonlethal approaches, such as repelling vampires by lights (Sanborn, 1931), bat-proofing stables and barns, dynamiting roosts, cutting roost trees, and driving vampires from roosts by smoke may sometimes alleviate the problem, these methods frequently serve to disperse vampires to other roosting sites or simply cause them to seek alternate food sources.

Few techniques have been available for destroying vampires on or about their prey, although one, a strychnine-syrup mixture painted on the bite wounds of prey livestock, is reported to be somewhat effective. Vampires frequently return to feed from the same wound on successive nights and thereby may consume a lethal quantity of the mixture (de Verteuil and Urich, 1936; Greenhall, 1963). Williams (1960) reported that 661 poisoned bats were recovered after 4288 animals were treated in this manner. This method of control appears to be most useful where small numbers of prey animals are involved and under conditions of intense livestock management. Application of the technique is apparently not widespread.

One of the first workers to use mist nets for capturing bats was Dalquest (1954) (Fig. 3). Greenhall (1963) described their use around fenced cattle pastures in Trinidad and reported that he was successful in temporarily eliminating the vampire bat problem in one area for about 3 months. A similar approach was recently used in Mexico (Schmidt *et al.*, 1970); vampires in roosts and about corralled cattle were intermittently shot and trapped by mist-net over a period of 6 months and the biting incidence was thereby reduced on two ranches by 70–80%. Mist-netting remains one of the most useful techniques for capturing vampires at roosts and about corralled or tethered livestock, but is not suited for vampire control over large areas. Their use is further limited by the necessity for continual inspection of nets, good weather, and the need for trained personnel.

Fig. 3. Capturing vampire bats in a mist net. (Courtesy of U. S. Fish and Wildlife Service, Department of the Interior.)

Procedures for capturing bats with nets and traps are described in detail by Greenhall and Paradiso (1968).

Most of the existing control methods are aimed at vampire reduction in the roost. As previously mentioned, locating roosts is frequently difficult and time consuming, and the application of the techniques discussed below are thus limited. Shooting vampires with dust shot is one method still employed in Trinidad, Brazil, and elsewhere. Fumigants and toxicants such as smoke and gasoline fires, burning sulfur, gas cartridges, calcium cyanide (Cyanogas), Malathion, DDT, aluminum phosphide gas (Phostoxin), Toxaphene, dieldrin, and rodenticides have been widely used within roosts. Certain of these control agents are sprayed throughout the roost and persist for long periods of time (Venezuela Ministerio de Agricultura y Cría, 1962).

The Constantine bat trap consists of a wooden or metal frame

between which are strung numerous closely spaced fine, vertical wires under tension, and beneath which is located a plastic catch receptacle. When this trap is placed within or at the exit of a roost, flying bats strike the wires and slide down into the receptacle (Constantine, 1958, 1969; Constantine and Villa-R., 1962). Other control methods that have been used include flame throwers, seines and trammel nets, spiny vegetation, hand nets, dynamite, an elaborate network for electrocuting bats, the elimination of roost trees, and the closure of exits from the roost (Constantine, 1970; Greenhall, 1963, 1968, 1970a; Villa-R., 1969). Courter (1954) mentions that livestock may be protected by moving cattle 15–20 miles distant from rabies outbreak areas.

Many of the techniques mentioned above were developed years ago, and in light of current knowledge are no longer recommended for use. They are not only ineffective and extremely hazardous to humans but their use also results in the indiscriminate destruction of many beneficial bats. Nonselective control methods have been criticized by many biologists and conservationists, and this concern resulted in the passage of a resolution opposing such techniques (Latin American Conference on the Conservation of Renewable Natural Resources, 1968).

Although the use of a biological control technique is potentially hazardous, such a method has been described by Abello Fernandez (1966). He reported that bats in a Colombian cave were infected with Newcastle disease after spraying the virus into their niches. A colony of some 5000 bats was reported to be eliminated in less than 6 days. While biological control may have considerable theoretical potential with respect to effectiveness and cost, the possible infection and death of nontarget species, the hazard of viral mutations, and the lack of control over its duration, distribution, and intensity, suggest that alternate, safer techniques should most definitely be given prior consideration.

Despite the wide variety of control methods discussed, none have been effective in alleviating the vampire bat problem, or, if so, only in very localized areas and under conditions of intense livestock management.

B. Control Programs in Latin America

In 1970, I briefly visited several Latin American countries to learn first hand of the vampire bat rabies problem, related research, existing control programs, and control methodology employed. At that

time, research and control efforts were found to be handicapped by lack of within-country funds and the use of generally ineffectual control techniques.

The vampire bat range extends south to northern Argentina, where, in 1970, vaccination of cattle was the principal means used to combat rabies. Mist-netting and gassing of vampire roosts (primarily hollow trees and wells) with gas cartridges or calcium cyanide were also employed at the time of my visit. In Brazil, firearms, the burning (gasoline) and fumigation (aluminum phosphide) of roosts, and, occasionally, the strychnine syrup technique were used. The general ineffectiveness of vampire control at the roost was amply demonstrated when, in 1968, a search of nearly 7000 caves, wells, hollow trees, and other roosting sites resulted in the destruction of only 537 vampires (C. E. Autran de Freites, personal communication, 1970). Villa-R. (1969) reported that nonselective control was attempted several years ago in Rio Grande do Sul where "several thousand" caves were dynamited. Vaccination of cattle was widely practiced with only limited efficacy.

In 1962, the Venezuelan Ministry of Agriculture and Livestock was recommending the use of calcium cyanide, aqueous spray solutions of DDT, Toxaphene, Chlordane, Dieldrin, rodenticides, and the Constantine trap as means of controlling bats in roosts. In 1970, the principal control method used was that of spraying roosts with a solution of Toxaphene and diesel oil. From 1964 to 1967 over 44,000 roosts were fumigated, resulting in the destruction of an estimated 2 million bats of all species (P. Torres, personal communication, 1970). This indiscriminate approach has met with considerable opposition from concerned biologists and conservationists in Venezuela and elsewhere, particularly in view of the poorly understood epizootiologic relationships between the vampire and other bat species. A co-worker of mine (R. J. Burns, personal communication, 1973) reported that the above control technique has recently been discontinued.

Trinidad has had a long history of vampire bat-transmitted rabies, and many of the existing control methods were initially developed on this island (Goodwin and Greenhall, 1961; Greenhall, 1963, 1964, 1965a,b). The principal techniques used in recent years have been periodic population reduction at known roosts by shooting or netting, and the use of mist nets where livestock or humans are subjected to attack. Known vampire roosts are sometimes checked as frequently as every 3 or 4 months, since some are continually repopulated despite periodic control efforts. Vampires that attack cattle are cap-

tured by mist nets placed around corralled or tethered animals; this technique is used on moonless nights when vampires tend to feed shortly after dark. Strychnine syrup is applied to bat wounds only when small numbers of cattle are involved, and its application is the responsibility of the instructed livestock owner. The number of vampires killed in Trinidad has remained approximately the same year after year and its cost has been estimated at $10 per bat (Málaga-Alba, 1959). The apparent efficacy of the control methods used in Trinidad may be largely attributed to the small size of the island, a proportionately large field crew (12–14 men), a good communication and road network, and the intense management and small size of livestock herds.

The control of vampire bat transmitted rabies in Mexico is under the direction of the Campaña Nacional Contra El Derriengue, Dirección General de Sanidad Animal. Until recently, heavy reliance has been placed on the use of vaccines, since the effectiveness of existing control methods has been limited. Mist nets are occasionally employed around corrals in Yucatán and, although several different types of strychnine or arsenic syrup solutions are sold commercially, their use is not widespread.

Vampire bat-transmitted rabies is also a problem, in varying degrees of severity, in the Latin American countries of Bolivia, Colombia, Guatemala, and Nicaragua. According to G. Clay Mitchell (personal communication, 1974), the recent development of new and effective population reductional techniques has resulted in the funding of intensified vampire bat control efforts in Nicaragua, Panama, Venezuela, Mexico, Colombia, and Brazil.

IV. Research

Vampire bat research funded at the national level has been characterized by a low level of financial support and a lack of trained personnel experienced in animal damage control research. The responsibility for developing new control techniques has therefore been undertaken by several international agencies.

Three international groups were conducting vampire bat research in 1970: The Pan American Health Organization (PAHO) in Argentina, the FAO (UNDP) in Mexico; and a United States AID-funded cooperative project, also based in Mexico.

The PAHO project in Argentina, located at the Pan American Zoonoses Center in Buenos Aires, seeks to develop vampire census

techniques, to study vampire ecology and behavior as related to rabies epizootiology, and to explore new control methods.

The FAO project in Mexico, now terminated, consisted of three sections: virology, epizootiology, and bat ecology; the latter division dealt with the ecology, behavior, control, and food preferences of the vampire. The objectives of the FAO project also included the training of personnel, the application of technical advances elsewhere in Latin America, and coordination with research centers working in the same field in other countries (Arellano, 1968).

The AID-funded project was a cooperative program between the U. S. Fish and Wildlife Service and the Mexican Instituto Nacional de Investigaciones Pecuarias. Basic approaches to the development of new and effective means for vampire bat control were explored at the Services', Denver, Colorado, Wildlife Research Center, while advanced testing and field studies were conducted at the Mexican-based station.

The 4-year FAO project was reduced in scope in 1972 and was phased out in 1973. The AID program, having developed several promising new vampire control techniques, initiated field tests in other Latin American countries (Brazil, Bolivia, Colombia, Nicaragua, Panama, and elsewhere), and the Mexico-based field station was also closed down in 1973.

Vampire bat control should be envisioned in terms of population reduction in specific localities where livestock are exposed to rabies. Complete extermination of the vampire, whether desirable or not, is not a feasible concept in light of our present knowledge, since these bats are found throughout vast inaccessible parts of Latin America, including many uninhabited areas not utilized for livestock production. New control techniques should be developed in accordance with the following criteria:

a. The technique should be specific for vampire bats.

b. It should be effective, safe, and economical in terms of manpower, funds, and time.

c. Livestock owners should be able to utilize the technique with a minimum of instruction.

d. Primary consideration should be given to methods that can be applied on or about the prey species, although control at the roost may have application in some areas.

e. The efficacy of the technique should not be affected by adverse weather conditions.

f. Elaborate control devices, or equipment subject to mechanical breakdown, should be avoided.

g. Application of the technique should not result in deposition of harmful or persistent residues in the ecosystem.

Two promising new vampire control techniques have recently been developed that encompass most of the criteria outlined above. The control method developed by Thompson *et al.* (1972) takes advantage of "the daily requirements of vampire bats for blood, the tendency of anticoagulants to temporarily bind to the blood protein, and the differential sensitivity of cattle and vampire bats to diphenadione." These workers treated cattle with the anticoagulant 2-diphenylacetyl-1,3-indandione by means of single intraruminal injections (Fig. 4). They found the LD_{50} for *Desmodus rotundus* (single oral dose) to be less than 1.0 mg/kg, whereas a dose of up to 5 mg/kg did not adversely affect cattle (other than a temporary and moderate increase in plasma prothrombin clotting time). Their initial bioassay

Fig. 4. An intraruminal injection of an anticoagulant is effective in destroying vampires that feed upon treated cattle (Thompson *et al.*, 1972). (Courtesy of U. S. Fish and Wildlife Service, Department of the Interior.)

studies in the laboratory suggest that this method is not hazardous nor does it result in harmful, long-term residues in beef or dairy cattle. Excellent results were obtained in a field trial conducted on three adjoining Mexican ranches: a count of fresh vampire bites on 207 cattle immediately prior to treatment revealed an average of 1.1 bites per animal, but 2 weeks following the intraruminal injection of 1 mg/kg of diphenadione (suspended in 0.05% Carbopol 941) only 0.07 bites per animal (93% reduction) was recorded. This technique has several advantages: there is no need for physical contact with vampires, control is limited to the bat species causing damage, the method can be incorporated into normal livestock management programs, and an antidote (vitamin K) is available in the event of an accidental massive overdose to the cow.

Another new control technique reported by Linhart *et al.* (1972) has produced equally good results by taking advantage of the roosting and grooming behavior of *Desmodus*. This species commonly roosts in small colonies and habitually uses one or more separate and distinct niches within the roost, even when it shares the same cave with other bat species. The method involves a procedure whereby a relatively few vampires are caught with mist nets (placed near tethered or corralled cattle, or at the roost) and a toxic agent is applied directly to their backs. More precisely, 50 mg of chlorophacinone (2-[(*p*-chlorophenyl)phenylacetyl]-1,3-indandione), a slow-acting toxicant, dissolved in 1.5 ml of petroleum jelly, is applied topically to the dorsal surface of each captured vampire, before their release (Fig. 5). After their return to the roost, this slow-acting anticoagulant is transferred to other colony members through body contact and individual and mutual grooming, and widespread mortality occurs within the roost. Field trials in caves were carried out in the state of Morelos, Mexico, during which a few vampires were netted, treated with this substance, and released back into the caves; this resulted in the death of as many as 34 *Desmodus* for each one treated with the anticoagulant. The technique appears to be specific for vampires and has not resulted in any mortality of other bats (*Natalus*, *Pteronotus*, *Artibeus*, *Glossophaga*, *Macrotus*) roosting in the same caves. It appears effective regardless of the number of vampire bats occupying a cave so long as the ratio of treated to untreated bats is on the order of about 1:20–1:25. The technique was further evaluated on two ranches in the states of Oaxaca and San Luis Potosí, Mexico, by means of two indices: (1) pre- and post-treatment counts of fresh vampire bites from cattle in the study areas, and (2) the numbers of vampires mist-netted at corrals before and after application of the toxicant. The capture, treatment, and release of vampires netted

Fig. 5. Applying an anticoagulant, diphenadione, to a vampire bat. Treated bats return to the roost and contaminate other members of the colony. (Courtesy of U. S. Fish and Wildlife Service, Department of the Interior.)

during one night at both ranches resulted in a 95–98% post-treatment reduction in bites and captured *Desmodus* (Linhart *et al.*, 1972). Field trials in the state of Pernambuco, Brazil, in which the anticoagulant diphenadione was applied in the same manner, have

produced equally good results. Fresh vampire bites on 104 cattle were reduced 96% and 100%, respectively, on two ranches following the topical application of diphenadione on mist-netted bats. The biting incidence 27 months after application was still 93% and 81% less than pretreatment counts indicating, in this case at least, that vampire populations are slow to recover from the effects of control by this technique (G. Clay Mitchell, personal communication, 1974). Diphenadione (available from Motomco, Inc., 89 Terminal Ave., Clark, New Jersey 07066) is probably superior to chlorophacinone as a vampire toxicant, regardless of the method of application, as smaller quantities are required and cattle residue problems have already been investigated (Thompson *et al.*, 1972).

More recent unpublished field trials and demonstrations in Bolivia, Colombia, Nicaragua, and Panama undertaken by the AID-funded U. S. Fish and Wildlife Service program have resulted in equally promising results. Trinidad and Guyana have also shown interest in the new control techniques (G. Clay Mitchell, personal communication, 1974).

Diphenadione has also been used as a means of controlling vampire bats within their roosts by applying it to their roosting sites within caves, etc. (Flores Crespo *et al.*, 1974). However, this technique may not be as species-specific as those where control is conducted on or about the cattle.

Despite the apparent success of the new techniques described above, well-documented research is still needed to (1) learn more about the vampires' physiology, behavior, and ecology; (2) determine the optimal size of the areas that must be treated to reduce or eliminate rabies; (3) acquire data on vampire population recovery rates following control; (4) continue to seek new and better control methods; (5) establish epizootiologic relationships between vampires and other species of bats; and (6) develop quantitative means of estimating relative densities of vampires in order to establish in advance the rabies potential and the need for control.

V. Social and Economic Considerations

Factors other than adequate control techniques greatly influence efforts to combat vampire bat-transmitted rabies. Superstition, indifference to the problem, or resistance to new livestock husbandry practices render control less effective. Public education, technical training, and good communications media are also required to allevi-

ate the problem. Current control techniques commonly used in one Latin American country are unknown in others, and communication between professional workers should be improved. Adequate funds are needed for research and control programs operating within suitable organizational frameworks. All these factors must be given proper consideration if the vampire bat rabies problem is to be solved.

Acknowledgments

I would like to thank F. T. Szatalowicz, Merle L. Kuns, Abel Fornes, Rexford D. Lord, Plinio Vieria Pinheiro, Odon Pontao de Alencar, Carlos Eduardo Antran de Freitas, Eugenio Trombini Pellerano, Renato Augusto de Silva, Adriano Peracchi, Augusto Ruschi, Edwardo Mondolfi Pacheco Torres, Omar Linares, Juhani Ojasti L, Leonard Butcher, F. Muradali, R. Lorregnard, and O. M. Buchanan for their generous cooperation and taking the time to inform me of vampire bat research and control activities in Latin America. Thanks are also due to Nelson Kommerup, Robert J. Tigner, G. Clay Mitchell, Richard J. Burns, Raul Flores Crespo, Nelson B. Kverno, Arthur M. Greenhall, George M. Baer, Pedro Solana, and Bernardo Villa-R., who contributed many ideas and influenced much of my thinking during my 2 years in Mexico while employed under the AID-funded research program.

References

Abello Fernandez, C. (1966). *Panamer. Congr. Vet. Med. Zootech., 1966* Doc. VVZ 51, pp. 1–21.

Acha, P. N. (1967). *Bol. Off. Int. Epiz.* **67**, 343–382.

Acha, P. N. (1968). *Bol. Of. Sanit. Panamer.* **64**, 411–430.

Arellano, C. (1968). *FAO-INIP. Circ.* **1**, 1–13.

Arellano, C., Sureau, P., and Greenhall, A. M. (1971). *Tec. Pec. (Mex.)* **17**, 23–29.

Burns, R. J. (1970). *J. Mammal.* **51**, 391–392.

Burns, R. J. (1972). *Tec. Pec. (Mex.)* **20**, 33–37.

Burns, R. J., and Flores Crespo, R. (1975). *Southwest. Natur.* **19**, 446–449.

Carini, A. (1911). *Ann. Inst. Pasteur, Paris* **25**, 843–846.

Clark, H. C., and Dunn, L. H. (1933). *Amer. J. Trop. Med.* **13**, 273–281.

Cockerell, T. D. A. (1930). *Proc. Colo. Mus. Natur. Hist.* **9**, 52–53.

Constantine, D. G. (1958). *J. Wildl. Manage.* **22**, 17–22.

Constantine, D. G. (1969). *Bol. Of. Sanit. Panamer.* **67**, 39–42.

Constantine, D. G. (1970). *In* "Biology of Bats" (W. A. Wimsatt, ed.), Vol. 2, pp. 319–449. Academic Press, New York.

Constantine, D. G., and Villa-R. B. (1962). *Bol. Of. Sanit. Panamer.* **53**, 7–12.

Courter, R. D. (1954). *Pub. Health Rep.* **69**, 9–16.

Crespo, J. A., Vanella, J. M., Blood, B. D., and de Carlo, J. M. (1967). *Cienc. Zool. (Argentina)* **6**, 131–160.

Dalquest, W. W. (1954). *Trans. Kans. Acad. Sci.* **57**, 1–10.

Dalquest, W. W. (1955). *Amer. Midl. Natur.* **53**, 79–87.
de Verteuil, E., and Urich, F. W. (1936). *Trans. Roy. Soc. Trop. Med. Hyg.* **29**, 317–347.
DiSanto, P. E. (1960). *J. Morphol.* **106**, 301–336.
Dittears, R. L., and Greenhall, A. M. (1935). *Zoologica (New York)* **19**, 53–76.
Dunn, L. H. (1932). *J. Prev. Med.* **6**, 415–424.
Flores Crespo, R., Burns, R. J., and Linhart, S. B. (1971). *Tec. Pec. (Mex.)* **18**, 40–44.
Flores Crespo, R., Linhart, S. B., and Burns, R. J. (1972a). *Southwest. Natur.* **17**, 139–143.
Flores Crespo, R., Linhart, S. B., Burns, R. J., and Mitchell, G. C. (1972b). *J. Mammal.* **53**, 366–368.
Flores Crespo, R., Burns, R. J., and Said Fernandez, S. (1974). *Bol. Of. Sanit. Panamer.* **76**, 427–432.
Forman, G. L., Baker, R. J., and Gerber, J. D. (1968). *Syst. Zool.* **17**, 417–425.
Goodwin, G. G., and Greenhall, A. M. (1961). *Bull. Amer. Mus. Natur. Hist.* **122**, Art. 3, 187–302.
Greenhall, A. M. (1963). *J. Mammal.* **44**, 396–399.
Greenhall, A. M. (1964). *Proc. Vertebr. Pest Contr. Conf. 2nd. 1964*, 108–116.
Greenhall, A. M. (1965a). *Congr. Latino-Amer. Zool., 2nd. 1962*, pp. 321–325.
Greenhall, A. M. (1965b). *Bol. Of. Sanit. Panamer.* **58**, 294–302.
Greenhall, A. M. (1965c). *Mammalia* **29**, 441–451.
Greenhall, A. M. (1968). *Int. Union Conserv. Nature Natur. Resour., Publ. [N. S.]* **13**, 94–102.
Greenhall, A. M. (1969). *Zoonooz* **42**, 14–18.
Greenhall, A. M. (1970a). *Proc. Vertebr. Pest Contr. Comp. Conf. 4th. 1970*, pp. 45–54.
Greenhall, A. M. (1970b). *Bijdr. Dierk.* **40**, 36–39.
Greenhall, A. M., and Paradiso, J. L. (1968). *U. S., Bur. Sport Fish. Wildl., Resour. Publ.* **72**, 1–48.
Greenhall, A. M., Schmidt, U., and Lopez-Forment, W. (1971). *Biotropica* **3**, 136–141.
Griffin, D. R., and Novick, A. (1955). *J. Exp. Zool.* **130**, 251–300.
Gut, H. J. (1959). *J. Mammal.* **40**, 534–538.
Haupt, H., and Rehaag, H. (1921). *Z. Hyg. Infektionsk. Haustiere* **22**, 76–88.
Hawkey, C. M. (1966). *Nature (London)* **211**, 434–435.
Hawkey, C. M. (1967). *Brit. J. Haematol.* **13**, 1014–1020.
Henson, O. W., Jr. (1970). *In* "Biology of Bats" (W. A. Wimsatt, ed.), Vol. 2., pp. 181–263. Academic Press, New York.
Johnson, H. N. (1948). *Amer. J. Hyg.* **47**, 189–204.
Klevezal', G. A., and Kleinberg, S. E. (1967). "Age Determination of Mammals from Annual Layers in Teeth and Bones (translated from Russian). Israel Program Sci. Transl., Jerusalem (Nat. Tech. Inform. Serv. TT69-55033).
Koopman, K. F. (1958). *Breviora* **90**, 1–5.
Latin American Conference on the Conservation of Renewable Natural Resources. (1968). *Int. Union Conserv. Nature Natur. Resour., Publ.* New Series, Suppl. Paper **12**, 146.
Linhart, S. B. (1971). *U. S., Bur. Sport Fish. Wildl., Denver, Colo.* Mimeo., pp. 1–53.
Linhart, S. B. (1973). *J. Mammal.* **54**, 493–496.
Linhart, S. B., Flores Crespo, R., and Mitchell, G. C. (1972). *Bol. Of. Sanit. Panamer.* **73**, 100–109.
Lyman, C. P., and Wimsatt, W. A. (1966). *Physiol. Zool.* **39**, 101–109.
McFarland, W. N., and Wimsatt, W. A. (1969). *Comp. Biochem. Physiol.* **28**, 985–1006.
Málaga-Alba, A. (1954). *Amer. J. Pub. Health* **44**, 909–918.

Málaga-Alba, A. (1959). *Cienc. Vet.* **4**, 520–531.
Málaga-Alba, A. (1962). *Bol. Of. Sanit. Panamer.* **53**, 105–114.
Málaga-Alba, A. (1966). *Symp. Ser. Immunobiol. Stand.* **1**, 255–259.
Mann, G. F. (1951). *Biologica* **12–13**, 3–24.
Mann, G. F. (1960). *Invest. Zool. Chil.* **6**, 79–99.
Mann, G. F. (1961). *J. Comp. Neurol.* **116**, 135–144.
Nehaul, B. B. G. (1955). *Amer. J. Trop. Med. Hyg.* **4**, 550–553.
Nehaul, B. B. G. (1962). *Bol. Of. Sanit. Panamer.* **53**, 13–17.
Olsen, S. J. (1960). *J. Mammal.* **41**, 458–462.
Pawan, J. L. (1936). *Ann. Trop. Med. Parasitol.* **30**, 401–430.
Pawan, J. L. (1948). *Ann. Trop. Med. Parasitol.* **42**, 3–12.
Queiroz-Lima, E. (1934). *Rev. Dept. Nac. Prod. Anim., Rio de Janeiro* **1**, 165–173.
Reddell, J. R. (1968). *J. Mammal.* **49**, 769.
Ruiz-Martinez, C. (1963). *Rev. Vet. Venez.* **14**, 71–173.
Ruschi, A. (1952). *Bol. Mus. Biol. "Prof. Mello-Leitao," Zoologia* **10**, 1–46.
Sanborn, C. C. (1931). *J. Mammal.* **12**, 312–314.
Schmidt, U., Greenhall, A. M., and Lopez-Fe[illegible] (1970). *Bijdr. Dierk.* **40**, 74–76.
Steele, J. H. (1966). *Mil. Med.* **131**, 765–778.
Steele, J. H. (1969). *J. Environ. Health* **31**, 474–483.
Suthers, R. A. (1970). *In* "Biology of Bats" (W. A. Wimsatt, ed.), Vol. 2, pp. 265–309. Academic Press, New York.
Tamsitt, J. R., and Valdivieso, D. (1962). *J. Mammal.* **43**, 106–107.
Thompson, R. D., Mitchell, G. C., and Burns, R. J. (1972). *Science* **177**, 806–808.
Trapido, H. (1946). *J. Mammal.* **27**, 217–219.
Valdes-Ornelas, O., and Atristain Aranadde, G. (1964). *Southern Vet.* **1**, 13–16.
Venezuela Ministerio de Agricultura y Cria. (1962). "Prevencion contra la rabia paralitica del ganado" (mimeo.). Div. San. Anim. Dir. San. y Ind. Anim., Caracas.
Villa-R., B. (1966). "Los murcielagos de Mexico." Inst. Biol. Univ. Nac. Auton. Mex. Mexico.
Villa-R., B. (1969). "The Ecology and Biology of Vampire Bats and their Relationship to Paralytic Rabies." Report to the Gov. of Brazil Rep. No. TA 2656. United Nations Development Programme/Food and Agriculture Organization, U. N., Rome.
Walker, E. P. (1964). "Mammals of the World," Vol. 1. Johns Hopkins Press, Baltimore, Maryland.
Williams, H. E. (1960). *J. Agr. Soc. Trinidad Tobago* **61**, 25–43.
Wimsatt, W. A. (1954). *Acta Anat.* **21**, 285–341.
Wimsatt, W. A. (1969). *J. Mammal.* **50**, 233–245.
Wimsatt, W. A., ed. (1970). "Biology of Bats," 2 vols. Academic Press, New York.
Wimsatt, W. A., and Guerriere, A. (1962). *J. Mammal.* **43**, 17–27.
Wimsatt, W. A., and Trapido, H. (1952). *Amer. J. Anat.* **91**, 415–446.
World Health Organization Expert Committee on Rabies. (1966). *World Health Organ. Tech. Rep. Ser.* **321**.