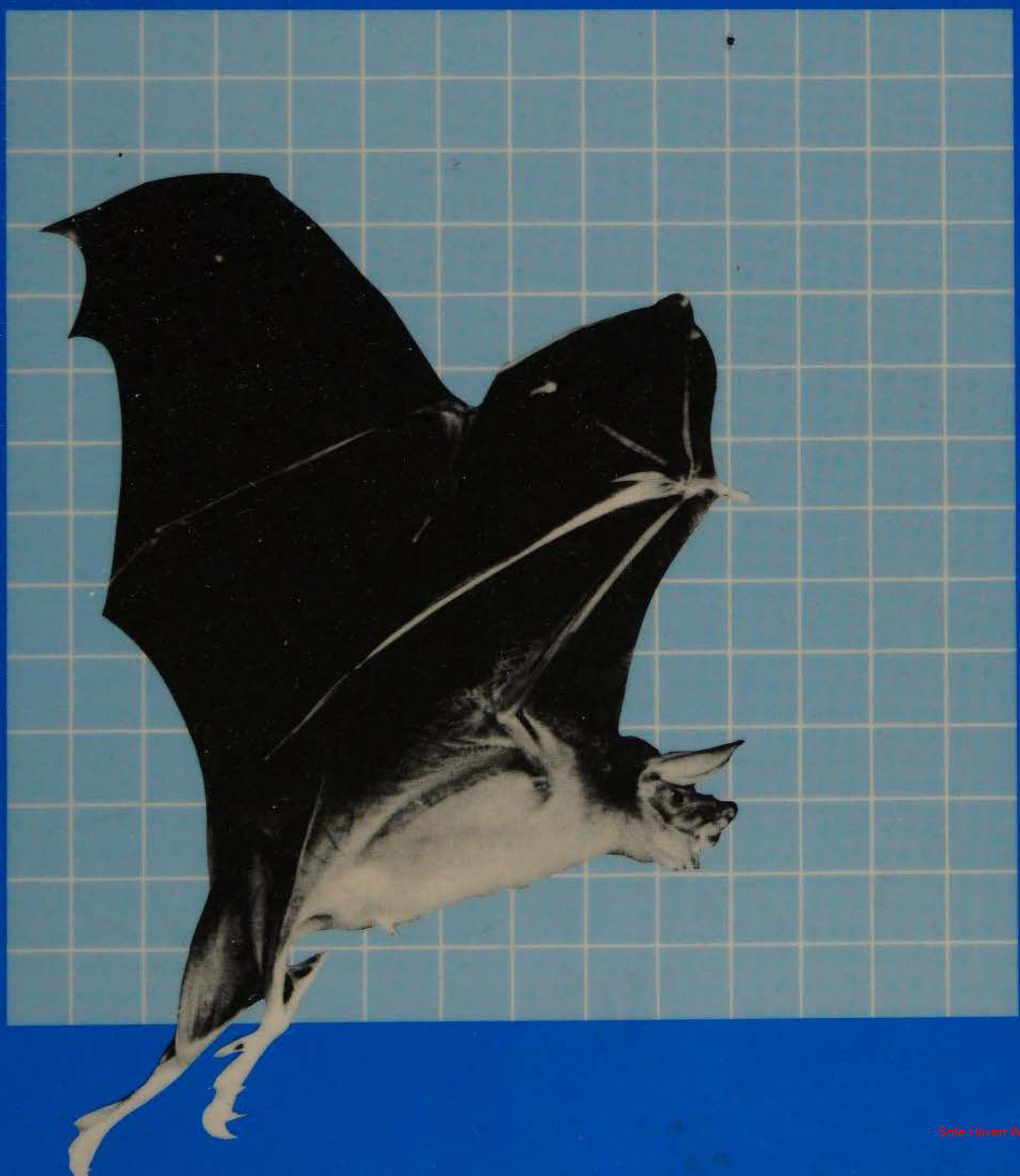
Ecological and Behavioral Methods for the Study of Bats

EDITED BY THOMAS H. KUNZ



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To Margaret, Pamela, and David,
who I hope will understand where my
mind was when it was not with them.

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Preface

During the past two decades there has been a growing interest in the ecological and behavioral study of bats. This interest reflects, in part, an increased appreciation for the extraordinary diversity of bats and their importance in pollination and seed dispersal (by plant-visiting bats in subtropical and tropical regions) and for the voracious insect-eating habits of many other species. Moreover, this interest has come at a time when both natural and man-made habitats of bats are being altered and destroyed at alarming rates. Deforestation (especially in the tropics), narrow-minded forest management practices, channelization of streams and rivers, widespread use of toxic chemicals, surface and subterranean mining operations, and generations of cultural misunderstandings about bats are among the most important factors that have historically threatened or endangered the continued existence of many of the known species. Disturbance by an uninformed public (including some biologists) has also threatened local populations.

Over 850 different species of bats are known worldwide, comprising about one-quarter of the living mammalian fauna. Bats have been reported from each continent (except Antarctica) and from many oceanic islands and archipelagos. They have successfully exploited deserts, grasslands, tropical, subtropical, and temperate forests, and some taxa range from sea level to mountaintops. The diversity of diets, roosting habits, reproduction, social behavior, population structure, physiological responses, sensory adaptations (echolocation), and varied ecological and geographic distributions make them ideal models for the study of evolutionary questions.

The idea for this book began over 20 years ago when, as a beginning graduate student, I was challenged to learn new methods and techniques to study these secretive and often elusive animals. Since that time my ideas and approaches to the study of bats have evolved, as I have learned from my mistakes and from the ideas and methods shared by colleagues. My approach to the study of bats has also been guided by a conservation ethic, which has been to minimize the impact of disturbance to populations. This view is shared by many individuals and has been reinforced recently by the enthusiastic support and commitment of numerous local, national, and international conservation organizations.

There are no books, presently available, that are comparable in scope or contents to the present volume. There are several published reviews of ecological and behavioral methods to study wild, terrestrial mammals, but none of these works include methods used to study bats. The emphasis on bats is especially important because many of the techniques required to study these flying, often highly gregarious, and nocturnal mammals are unique. In spite of the emphasis on bats, many of the methods and techniques reviewed in this book should be equally suitable for ecological and behavioral studies of other terrestrial vertebrates. Although there are several excellent books and monographs that have emphasized specific topics such as radio-telemetry, population censusing, and aging methods, most treatments are either highly specific (for other taxa) or too general to be of practical value to the bat researcher.

Most chapters include reviews of published literature and unpublished works through mid-1985. Chapter topics were selected to represent major areas of interest in modern ecological and behavioral research.

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Invariably, all readers will not agree on the breadth of topics or their depth of treatment. The coverage in the various chapters is necessarily varied; some topics include and draw from a wealth of relevant literature. Other chapters treat relatively specific topics on which there is little published literature. In most cases the chapter topics were discrete enough to allow authors freedom to develop their own ideas without the risk of redundancy.

Authors were instructed to prepare comprehensive reviews that summarize traditional as well as state-of-the-art methods and techniques. Each author or group of authors are acknowledged leaders in their respective disciplines. They have either pioneered methods or techniques for studying bats or have developed techniques that have not previously been, but should be, applied to bats. Each author has contributed significantly to his/her discipline through published literature or through works now in preparation.

Mention of commercially available equipment and supplies in the text does not constitute endorsement either by the editor or by the publisher. A selective list of commercially available equipment and supplies either mentioned in the text or otherwise useful to the bat researcher is available upon request from the editor.

I am grateful to the many people who have made this book possible. First and foremost, I want to thank my wife, Margaret, and my children, Pamela and David, for their assistance and companionship in the field, for their support and patience at home, and especially for their tolerance of my physical and (at times) mental absence. I owe special thanks to Duncan Phillips who has always taken the time to design and make special equipment when needed. Kirsten M. Klinghammer faithfully assisted with clerical work, proofreading, and the many other tasks needed to see this book to completion. John Kearney was invariably prompt in accommodating my needs for wordprocessing. Allen Kurta and Arrye Rosser were invaluable as proofreaders. My sincere thanks are extended to Charles O. Handley, Jr., for introducing me to Edward (Ted) Rivinus, Senior Science Editor, Smithsonian Institution Press, who agreed to publish this book before one word of it had been written. I am especially grateful to Ted who kept his patience and sense of humor throughout the gestation of this project. I am particularly grateful to Mary Frances Bell and Rebecca Browning, editors at the Smithsonian Institution Press, for their dedication and enthusiasm in making the final version of this book readable.

The following colleagues, listed in alphabetical order, unselfishly contributed their time and expertise to anonymously review one or more chapters of this book: C. D. Ankney, E. L. P. Anthony, K. B. Armitage, H. J. Baagøe, G. P. Bell, J. F. Bell, J. J. Belwood, J. W. Bickham, I. L. Brisbin, Jr., E. R. Buchler, M. A. Chappell, J. Chase, S. R. Duncan, H. Edgerton, M. B. Fenton, T. H. Fleming, S. C. Frantz, J. H. Fullard, J. Gaisler, K. N. Geluso, A. M. Greenhall, A. W. Gustafson, E. R. Heithaus, S. R. Humphrey, G. S. Jones, J. K. Jones, Jr., D. Klingener, B. F. Koop, A. Kurta, G. F. McCracken, B. K. McNab, A. G. Marshall, J. S. Millar, L. A. Miller, D. W. Morrison, J. D. Nichols, U. M. Norberg, R. L. Peterson, K. H. Pollock, W. B. Quay, P. A. Racey, R. L. Rausch, J. J. Rasweiler, IV, J. A. Simmons, U. Schmidt, J. R. Speakman, E. W. Stiles, E. H. Studier, R. A. Suthers, R. H. Tamarin, D. W. Thomas, C. V. Trimarchi, M. D. Tuttle, J. E. Ubelaker, P. J. Van Soest, and T. A. Vaughan.

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of Michigan-Flint, J. O. Whitaker, Jr. (Indiana State University), and D. E. Wilson (U.S. Fish and Wildlife Service).

Because this book represents a cooperative effort of many dedicated authors and reviewers, I want to thank each of them for helping to set new standards for future studies on the ecology and behavior of bats. It is my hope in bringing this book to completion that it will stimulate increased research and understanding of this fascinating group of mammals.

Thomas H. Kunz
Boston, Massachusetts

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Chapter 1

Capture Methods and Holding Devices

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1. INTRODUCTION

There are few, if any, topics in ecology and behavior that are more fundamental than methods used to capture animals. Bats can be captured during flight and in their roosts. Methods used and the success of capturing flying bats will depend mostly upon their flight speed and maneuverability, and the habitats being sampled. Methods used and the success of capturing bats in roosts will depend upon the type of roost, the number of bats present, the dispersion of bats within the roost, their physiological state (active vs. torpid), their age and reproductive condition (pregnant or lactating), their alertness to visual, auditory, or olfactory stimuli, and the location and accessbility of bats to the investigator.

Methods used to capture bats were reviewed by Greenhall and Paradiso (1968) and Tuttle (1976a). Recent reports have described new or improved methods of capturing bats (Tuttle, 1974b; Tidemann and Woodside, 1978; Rautenbach, 1985), or have included brief descriptions of novel capture methods (e.g., Bradbury and Emmons, 1974; Gaisler et al., 1979; McCracken and Bradbury, 1981; Kunz et al., 1983). Much of what is known about capture methods and related techniques is often transmitted informally among colleagues, leaving descriptions in research reports to brief statements such as "bats were captured by hand" or "mist nets were used to capture bats." Success in capturing bats requires a knowledge of roosting habits, nightly emergence and dispersal behavior, and foraging habits. Although space does not permit a review of these topics, the reader is encouraged to consult original sources and review papers for details (e.g., Dalquest and

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Walton, 1970; Erkert, 1982; Fenton, 1982; Fleming, 1982; Heithaus, 1982; Kunz, 1982).

The purpose of this chapter is to review methods used to capture bats that are applicable to ecological and behavioral research. Where there have been no previously published reports, or where the methods are not readily available in the published literature, we include additional details. We briefly discuss methods for holding bats in the field and for transporting them to the laboratory. Illustrations are often used in place of lengthy discussions to highlight various devices, techniques, and strategies. A brief treatment of laws and regulations governing collecting, import, and export of scientific specimens is given in Appendix 1. In addition to being a practical guide, we hope that this chapter will stimulate others to develop new methods and to improve existing ones.

2. GENERAL CONSIDERATIONS

Knowledge of where and when bats roost and forage is essential to the success of any study that requires captured animals. There is no "best" time to capture bats; the most appropriate time will depend upon the objectives of the study, the season, as well as the behavior, age, and life history stage of the bats. Barbour and Davis (1969) suggested that roosting bats are best captured in the late morning, when individuals are least active. We generally concur with this; however, flightless young are best captured in maternity roosts, following the nightly departure of adults (also see Chapter 18). Certainly the times and season of capture should be chosen carefully to minimize disturbance to the colony. Some census methods may require periodic capture (see Chapter 5). In practice, compromises between frequent and infrequent trapping are needed; frequent trapping may lead to abandonment, and infrequent trapping may mean that important life history events will be missed. Other factors to consider include the nutritional status of the animals at the time of capture and whether special care is required for transport. If bats are to be transported to the laboratory, it is advisable to capture them as soon as possible after they have fed and taken water. By contrast, if one wishes to compare daily or seasonal changes in body mass for a particular population, individuals that are captured and weighed at the time of nightly emergence will provide the most reliable data, since bats are postabsorptive at this time.

2.1. Light Sources

Reliable light sources are essential for most types of capture, since most bats are typically active at night and roost in dark or dimly illuminated places. Many different types of light sources are available commercially (see Appendix 2). Electric sources are preferable to those which use combustible fuels (kerosene, refined gasoline, calcium carbide, etc.). Electric light sources are safer, cleaner, and produce a minimum amount of heat (an important consideration when capturing bats during winter in caves and mines). Carbide lamps are reliable light sources used by many cavers, but they are not recommended for work with bats. Such lamps generate a measurable amount of heat, which can adversely modify the microclimate of roosting bats. Moreover, it is unsafe to use combustible fuels in buildings and where the risks of starting grass or forest fires is high.

It is preferable to use light sources that can be mounted on the head, freeing the hands to manipulate nets, traps, poles, and other devices for capturing bats. Lights that can be adjusted for intensity are ideal (Tuttle, 1979). When choosing a particular type of light, one should consider such factors as cost, performance, durability, reliability, and battery requirements. Koehler Wheat lamps and MineSpot miner's lamps come equipped with rechargeable batteries and are among the most durable and reliable light sources. These lamps are designed to accommodate lead-acid batteries or sealed, maintenance-free gel batteries. If lead-acid batteries are used, a

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small supply of distilled water and an injection syringe are needed. A line power-source or generator is needed to recharge batteries, and the lamps may be used continuously for up to 12 h between charges with little loss of intensity. Although the initial cost of these lamps (including the charger) is high (about U.S. $220 each), they more than pay for themselves when weighed against the cost of having to replace conventional batteries.

Other less expensive head lamps (e.g., Burgess and Justrite) are reliable and relatively inexpensive. They are designed to operate on four, 1.5 v, D-cell batteries or one, 6 v, lantern battery. Rechargeable gel or nickel-cadmium (ni-cad) batteries are preferable to alkaline batteries for reliability and service. Whichever light source is used, one should always be equipped with spare bulbs, extra batteries, and alternate light sources.

In many situations, a small pocket-sized pen-light can be invaluable. Pen-lights with clips can be attached to a hat or shirt collar when handling bats or recording notes. Pen-lights fitted with flexible necks are extremely useful for examining small crevices and cavities for roosting bats. A pen-light may be all that is needed to make an unobtrusive approach to capture bats roosting in a dark or dimly lit building or cave. They also provide a temporary light source if the primary one fails. When working alone in dimly lit and dark places, one should establish a "rule" to carry two alternate light sources. A Cyalume (chemical light) stick makes a good emergency light source. It can be tied to a cord around the neck and activated by bending, to break, the inner capsule when needed. Light emitted from a single Cyalume stick is often adequate to remove bats from mist nets or traps and to dismantle equipment in emergency situations. The use of Cyalume for marking bats is described in Chapter 4.

2.2. Handling Bats

Leather gloves are usually recommended for handling bats; other precautions to be taken are discussed in Chapter 29. Generally, gloves are not needed when handling suckling bats and adults of most small (<10 g) species. Lightweight leather gloves are adequate for handling most bats weighing between 10 and 30 g. Batter's gloves used in baseball are ideal for this purpose. Gloves made of thicker leather may be needed for handling larger species and small aggressive ones. Usually only one glove is needed to remove bats from mist nets (Section 3.5.5). We highly recommend that gloves be worn on both hands when handling vampire bats (e.g., *Desmodus, Diphylla*) and large carnivorous species (e.g., *Macroderma, Vampyrum*). Gloves should be as pliable as possible to enhance the sensitivity of the wearer to the form and movements of the bat. Generally, we prefer loose-fitting gloves to tight-fitting ones, since loose-fitting ones can be removed quickly when needed. Moreover, parts of loose-fitting gloves can provide places for bats to chew, especially when removing bats from mist nets.

3. CAPTURE METHODS

3.1. Hand Capture

Many roosting bats can be successfully captured without the aid of special devices. For example, bats that are specialized for roosting on the smooth inner surfaces of unfurled leaves of *Heliconia, Musa,* and *Strelitza* (see Kunz, 1982) may be captured by grasping the open end of a bat-occupied leaf and quickly bending it downward toward eye level (e.g., Brosset, 1976; LaVal and LaVal, 1977; D. E. Wilson, pers. comm.). By squeezing and prodding bats that occupy such leaves, individuals will eventually move to the open end where they can be removed by hand. Hibernating bats can often be taken from their roosting places using hands alone. At times, however, it may be necessary to use long tissue forceps to remove bats from crevices and cavities (e.g., Griffin, 1940; Barbour and Davis, 1969). In other situations, a blunt and flexible wire-probe may be helpful to prod or pull bats from crevices. When extracting bats from

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crevices and cavities using such devices, extreme care should be taken to avoid injury to delicate wing bones and membranes.

When bats are to be captured in small, enclosed roosts (e.g., small caves, buildings, buttress cavities, etc.), we suggest that the exit routes be covered with netting material (Section 3.7) to prevent bats from escaping. This may not be necessary in large caves where bats have alternate roosts within the same cave. However, in roosts that have small internal spaces, it is particularly important that netting be left up long enough after the colony has been disturbed so that bats have time to settle and reestablish social contacts before the nightly departure.

3.2. Hand (Hoop) Nets

Hand nets with adjustable-length handles are particularly valuable for capturing bats in caves, mines, buildings, tree and buttress cavities, and in foliage. Commercially available insect nets may be used, but the bag should be deep enough to prevent bats from escaping. Often simple hoop nets can be made from heavy-duty wire, mosquito netting, and almost any type of pole. Extension handles for hoop nets can be made in the field by securely taping the net handle to a bamboo or other pole. Handles should be as lightweight as possible so as not to impede rapid motion and maneuvering of the net. The Tropics Net (available from BioQuip Products) is excellent for capturing bats. It has a deep bag (85 cm) made from mosquito netting, a 45 cm diameter hoop, and it comes with four, lightweight aluminum extension handles (each 61 cm long) that can be quickly screwed together. Handles from these nets are interchangeable and can be connected to increase the length beyond four sections. Individual sections are short enough to be carried in a standard-size suitcase.

Hand nets in which the angle of the hoop can be adjusted relative to the handle can be invalulable in certain situations. Agaconi (1938a, 1938b) described such a net that included a joint of the type used on beach umbrellas. The angle of the net can be set by tightening a wing-nut. Hoop nets that have a "gimbal-like" frame may provide greater flexibility for capturing bats that roost on irregular ceilings (Hamilton-Smith, 1964). Net bags may be fabricated to include sleeves with drawstrings to facilitate the transfer of bats from a hoop net to holding bags.

Hoop nets have been used successfully in many roost situations, including hollow trees (Turner, 1975; Wilkinson, 1985), buttress cavities (Bradbury and Emmons, 1974; Bradbury and Vehrencamp, 1976), caves and mines (e.g., Bels, 1952; Barbour and Davis, 1969; Kunz, 1973; Tuttle, 1975, 1976a), buildings (Gaisler, 1963; T. H. Kunz, unpubl.), and foliage (e.g., Constantine, 1966; T. H. Kunz and G. F. McCracken, unpubl.). Constantine (1966) used a hoop net attached to a long extension pole to capture foliage-roosting *Lasiurus borealis* and *L. cinereus*. A flap of smooth plastic was attached to the hoop and extended inside the net bag to prevent bats from escaping. Bradbury and Emmons (1974) and Bradbury and Vehrencamp (1976) used a hoop net to capture bats inside buttress cavities that had been closed off with black nylon netting (see Section 3.7). When using hand nets to capture bats in hollow trees and foliage, one should remain alert to the presence of bees and wasps (see Brosset, 1966) and other potential dangers (e.g., snakes, ants, etc.).

Quickness and accuracy are extremely important in using hand nets. Approaches to foliage roosts, and other open-roost situations, should be made with considerable planning to minimize noise and disturbance of adjacent vegetation. For example, tent-making bats (T. H. Kunz, 1982) can easily evade capture unless one moves quickly with an upward sweeping motion when making the final approach to the roost (T. H. Kunz, pers. obs.). Use of the lightest, most maneuverable handle is essential in these situations.

If hoop nets are used repeatedly to capture roosting bats, one should be aware that

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some individuals (those that have been captured previously) may avoid capture. Tuttle (pers. comm.) has observed that previously captured *Myotis grisescens* may avoid subsequent captures in hoop nets. Harem males of *Artibeus jamaicensis, Phyllostomus hastatus,* and *Hipposideros caffer* remain in roost cavities after females have dropped into hoop nets and bucket traps thrust beneath roosting groups (T. H. Kunz and G. P. Bell, pers. obs.).

Hibernating bats that roost high on the ceilings of caves, mines, and buildings can sometimes be dislodged with long sections of bamboo poles or extension poles to which small hoop nets are attached (Barbour and Davis, 1969). Disturbance to bats during energy- or water-critical periods (e.g., hibernation, lactation) should be minimized to avoid depletion of critical fat reserves and body water (Tuttle, 1976b, 1979, and Chapter 4).

Although hand nets are most commonly used to capture roosting bats, they can also be used successfully to capture bats in flight as they depart from small openings in buildings and caves (e.g., Brown et al., 1983; Kunz, unpubl.) and at predictable feeding sites (Fenton and Bell, 1979). When hoop nets are used to capture flying bats, special care should be taken not to swing nets too vigorously, as this may break or damage wings or in other ways cause injury.

3.3. Bucket Traps

In some situations it may be more practical and convenient to use bucket traps to capture bats. McCracken and Bradbury (1981) modified a large cylindrical plastic trash bucket by removing the bottom half and replacing it with a hardware cloth basket (6-mm mesh). Harem groups of *Phyllostomus hastatus* were captured by quickly placing a bucket trap over the openings of solution cavities (potholes) formed in the ceilings of small caves. Roosting bats were dislodged by inserting a small wire "spatula" between the top edge of the bucket and the ceiling of the cave. This method works best when one person holds the bucket and the other person manipulates the spatula and watches for bats that may attempt to escape. Care should be taken with such a system to ensure that all individuals are dislodged from their roost before removing the bucket (see Section 3.2).

A similar device was used by Kunz et al. (1983) to capture groups of *Artibeus jamaicensis* that roosted high (>3 m) on cave ceilings. A cylindrical trash bucket, like that described in McCracken and Bradbury (1981), was attached to a long extension pole with durable tape. Instead of using a spatula that is not easily manipulated from such a great height, a small hole was cut into the bottom of the wire cage, and a long pole was inserted through the hole for use as a probe to maneuver and dislodge bats from their roost cavity. Care should be taken to ensure that bats do not escape from this hole when the pole is withdrawn after bats have entered the bucket.

3.4. Bag (Hopper) and Funnel Traps

Bag and funnel traps have been used successfully to capture bats as they depart from small holes and crevices in buildings and trees. Bag and funnel traps, originally described by Griffin (1940), were made from fabric supported by wire hoops. Polyethylene, however, works more effectively, since bats slide better on smooth surfaces than on fabric. Small bag-traps made from polyethylene, wire screen, and waterproof (duct) tape can be made inexpensively and positioned over roost exits to capture bats (Fig. 1 A). When bags are made from plastic, bats are unable to climb back into the roost and exit via alternative routes. Depending upon the height of the exit hole above the ground, a funnel (or "laundry chute") may be added to direct the departure of bats into a holding bag near the ground (Griffin, 1940). Morrison and Handley (*in press*) captured harem groups of *Artibeus jamaicensis* with laundry-chute traps as individuals departed from tree holes located up to 6 m above the ground.

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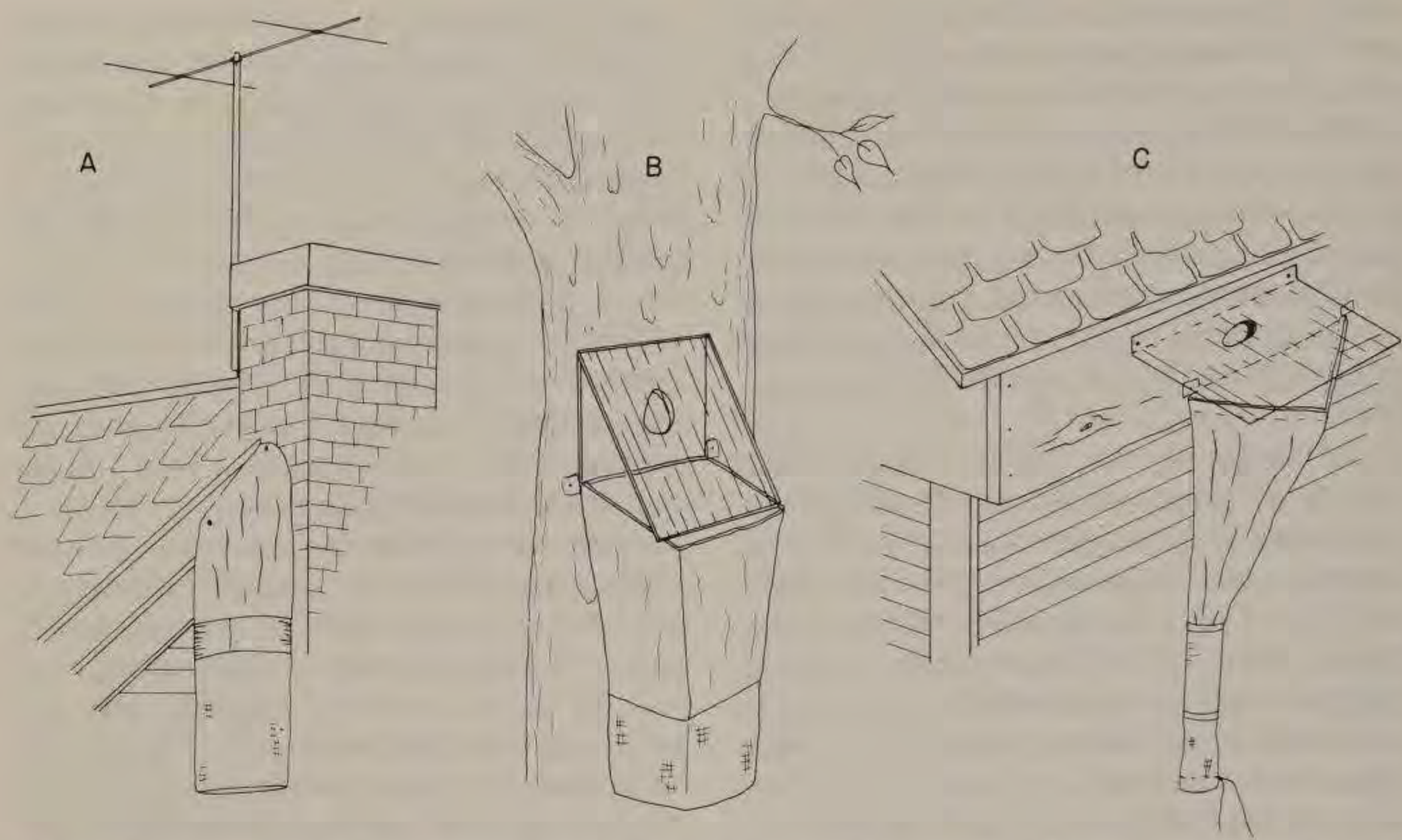

Figure 1. Bag (hopper) traps. Upper parts are made of polyethylene and bottom parts of wire screen. (A) Modified after Griffin (1940). (B) After Gaisler et al. (1979). (C) Davis' hopper trap, modified after Greenhall and Paradiso (1968).

Bels (1952) described a folding, wire trap that he placed over openings of hollow trees to capture members of a *Nyctalus noctula* colony as they departed at dusk. A disadvantage of this trap was that it required constant attention to prevent bats from crawling back into the cavity. Gaisler et al. (1979) described a bag (hopper) trap that was made from polyethylene and a wire-cloth bag, supported by a wire frame (Fig. 1 B). A trap guide, strung with monofilament fishing line, deflected departing bats into the bag below. Deployment of several such traps allowed bats to be captured at different roost cavities simultaneously without the requirement of constant attendance. A similar trap was used by Davis et al. (1962; see Greenhall and Paradiso, 1968) to capture *Tadarida brasiliensis* as individuals emerged from exit holes in buildings (Fig. 1 C). A transparent plastic "guide" covered and deflected the bats into the bag as they departed and prevented them from escaping.

3.5. Mist Nets

Mist nets are the most commonly used devices for capturing flying bats. Important practical guides have been written emphasizing their use with bats (e.g., Handley, 1968; Tuttle, 1976a). Some of the advantages of using mist nets to capture bats are that they are inexpensive, lightweight, compact, and easily transported and erected in the field. As recently as 20 years ago, Handley (1967) commented that "the great potential of mist nets as a tool for ecological study has been little tested or explored." Since that time, the use of mist nets for studies other than collecting has increased markedly (e.g., Jones, 1965; O'Farrell et al., 1967; O'Farrell and Bradley, 1970; Fleming et al., 1972; Gaisler, 1973; Kunz, 1973; Turner, 1975; LaVal and Fitch, 1977; Kurta, 1982).

3.5.1. Types of Nets

Generally, two types of mist nets [braided nylon and terylene (monofilament) nylon]

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are available commercially (see Appendix 2). Terylene nets are softer, stronger, and more durable than braided nylon, and are highly effective for capturing bats. Because of their softness and extremely fine fiber, however, some workers have found it difficult to remove bats from these nets. Both types of nets are available in the same mesh sizes and lengths. Black is the most common "color" and likely the most suitable for capturing bats. In addition to standard black, nets are available in dark forest-green, sand, and white. To our knowledge there have been no published reports comparing the success of bats taken in nets of different color.

Mist nets that are most preferred for capturing bats have a mesh size of 36 mm (ca. 1½ in), are of 50 or 70 denier/2 ply nylon, and have four shelves (Handley, 1968; Bleitz, no date). Mesh size is determined as the distance between two diagonal corners in the mesh of a stretched net. "Denier" is the number of grams in 9,000 m of fiber. For example, the specifications of a 50d/2 ply nylon net indicate that it is made of nylon fiber (9,000 m of which weighs 50 g) and that two strands are braided together to form the thread. Heavier denier nets are more durable than those of lighter construction, but they also are easier for bats to detect both visually and acoustically.

Four-shelf mist nets are typically about 2 m high and range in length from approximately 6 to 36 m. Short nets (<12 m) are the most versatile and are the easiest for one person to handle. Longer nets are often difficult for one person to erect alone and may require additional net poles in the middle for support. Several short nets may be stacked or butted end-to-end to increase the aerial coverage. Tethered and untethered nets are available but the former are slightly more expensive than the latter. Tethered nets are tied at regular intervals to horizontal shelf cords to keep the net from bunching at one end under windy conditions. Some nets come with extra-full netting that has the affect of increasing the depth of the bag.

3.5.2. Preparation of New Nets for Field Use

New nets are usually shipped in small transparent plastic bags. The small nylon cord that often secures the folded net should be removed and saved to repair damaged shelf-cords. A net should be carefully unfolded to expose the end loops. Many nets are supplied with color-coded top loops and different colors at opposite ends to facilitate handling. Even if the top loop is not color-coded, it still can be identified by its attachment to a double shelf-cord.

To prepare nets for field use, the loops at one end of the net should be arranged and tied in the appropriate order. To accomplish this, loops at one end of the net can be placed sequentially over the fingers of the left hand. This is done after first locating the top loop. Then, by lifting the right hand to extend the cord to the next loop, it in turn is placed over the fingers of the left hand. This procedure is continued until all five loops have been gathered and placed in order. Loops may be tied together by threading the top loop through the others, and by tying an overhand knot to secure them. Another method is to tie a small cloth string to the top loop (Fig. 2 A). When the loops are gathered, this string is used to tie them together (Handley, 1968). Wire and plastic "twist-ties" (Fig. 2 B), commonly used to close plastic trash bags or bread wrappers, work fairly well, but these can be easily misplaced in the field. Tying net loops together in the proper order before field use helps to keep the loops from becoming tangled when the net is deployed. Additional techniques on preparing mist nets for field use are given in Bleitz (no date).

3.5.3. Net Poles

In tropical regions one rarely experiences difficulty in obtaining poles for setting mist nets. Poles may be cut from bamboo culms or from small trees. Cut poles should be as straight as possible, rigid, and not more than 4-5 cm in diameter (Tuttle, 1976a). A cutlass or ma-

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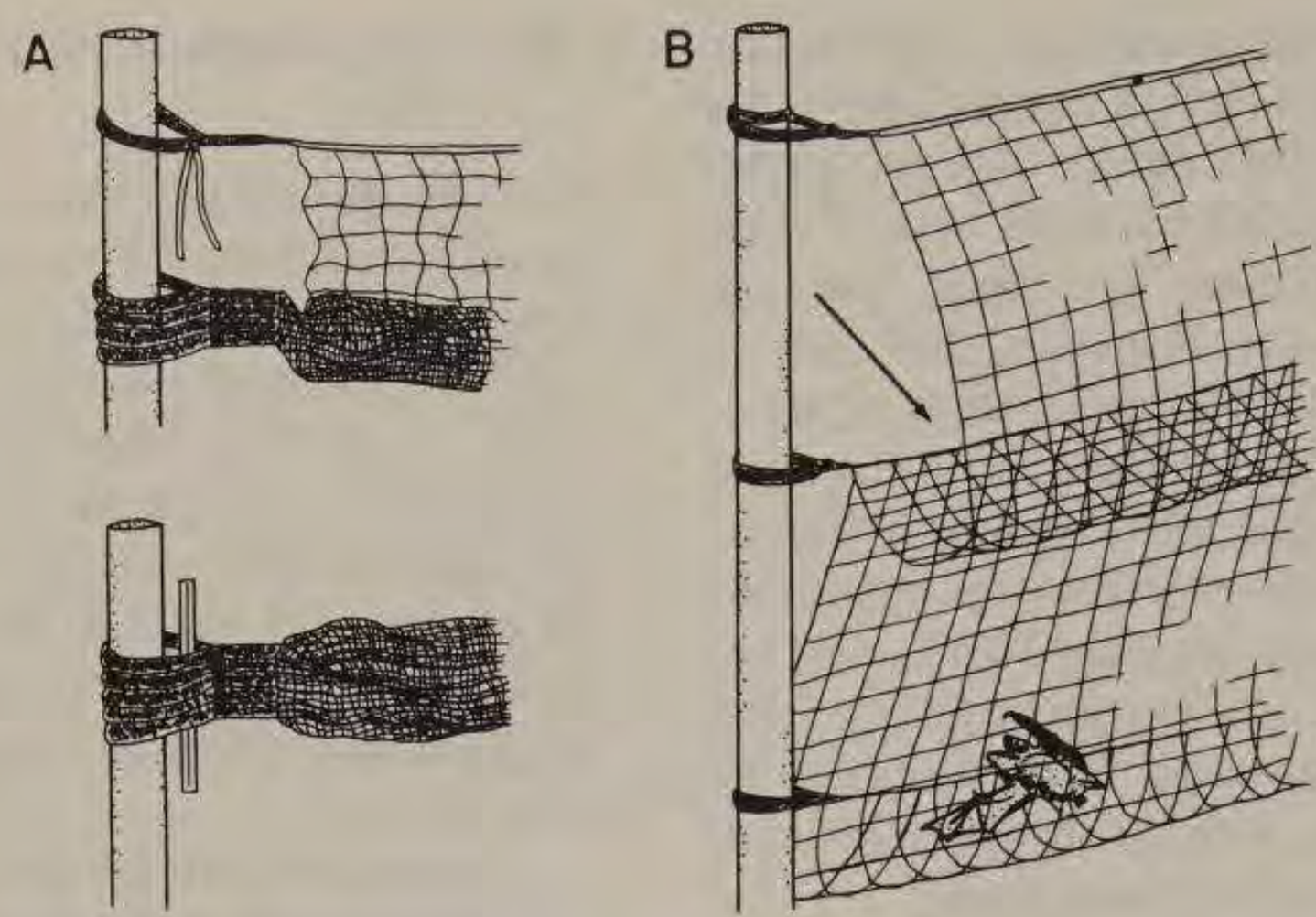

Figure 2. (A) One end of a mist net gathered on poles to illustrate two methods (cloth tie strings and wire "twist-ties") for securing net loops. (B) Properly adjusted vertical spacing of net loops and shelf-cords to form net pockets. A bat should be removed from the side of the net on which it entered, as determined from the position of the pocket relative to the shelf cord.

chete is invaluable for cutting poles, removing branches, and for sharpening the ends. One should obtain permission and use good judgment in cutting trees for net poles at local study sites.

Relatively inexpensive poles can be made from sections of electrical conduit. Simple poles can also be made from a single 10-ft (~3 m) piece of aluminum tubing. However, two, 5-ft. (~1.5 m) lengths often are more convenient to handle, assemble, and transport in the field. When short sections are used, the ends can be compressed or expanded, or joined with conduit couplers, so that two or more poles can be connected. Specially machined, aluminum net poles are available commercially in several different precut lengths.

3.5.4. Net Deployment

Mist nets may be deployed successfully at almost any site where bats are expected to fly. Strategies of net placement have a major influence on capture success. The most successful sites are near roosts, at water holes, and across trails that are used as flyways (Figs. 3 and 4 A–F). The most productive netting sites can often be identified from visual observations of flying bats, by listening to audible or ultrasonic sounds of echolocating bats (Chapter 6), and from the sounds made by falling fruit when plant-visiting bats are feeding. The use of ultrasonic detectors (Chapter 6) can be particularly valuable in distinguishing potentially productive from unproductive netting sites.

Bats can be netted at openings to caves, mines, and buildings, where bats regularly exit and enter. However, when mist nets are used in attics (Fig. 3 A) and in passages or openings of caves and mines (Fig. 3 B), bat populations should be relatively small and the nets should be monitored constantly to avoid the capture of large numbers of bats at one time. Appropriate spacing and horizontal tension on shelf cords can be maintained on high nets by tying net loops to net poles before the net is raised (Fig. 3 B).

When mist nets are set over streams and ponds (Fig. 3 C–E), the lower shelf-cord should be set near enough to the water surface to prevent bats from flying under the net, but high enough so that the lowest net-pocket

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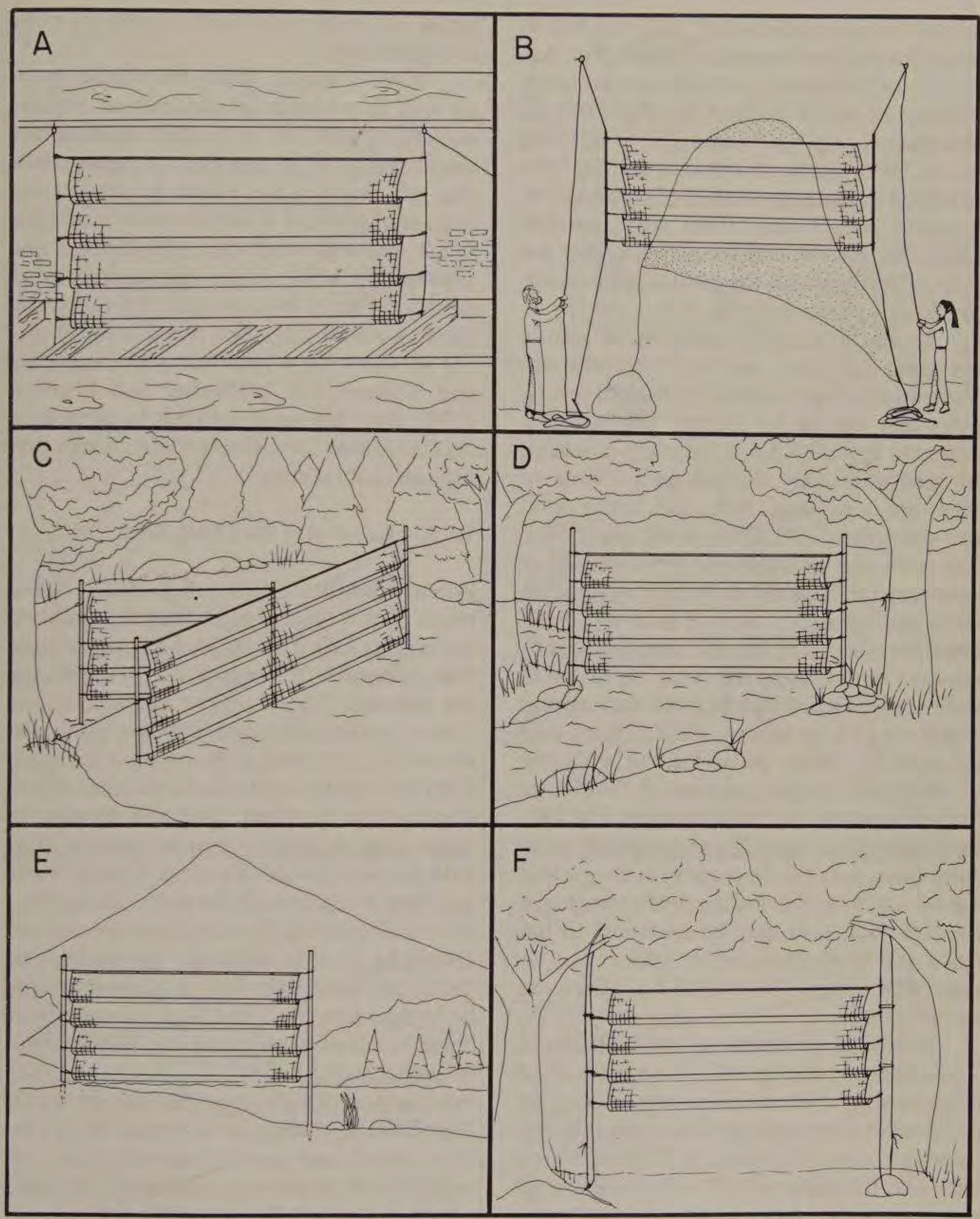

Figure 3. Placements and configurations of mist nets for capturing bats. (A) Attic of building. (B) Cave entrance. (C) Over a pond. (D) Over a stream. (E) Edge of lake. (F) Forest trail.

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does not hang into the water. Also, it is best to select sites where the water is calm (Fig. 3 C and D) and, if possible, where there are overhanging branches to direct the flight of bats into the net (e.g., Barbour and Davis, 1969; Kunz, 1973; Kunz and Brock, 1975). Nets stretched across large bodies of water can be attended using 2-man rubber rafts (Easterla, 1973). Nets set across forest trails also are most effective if they are positioned beneath overhanging branches (Fig. 3 F).

Several alternative methods of setting net poles (for single and multiple nets) are illustrated in Figs. 3 and 4. Methods of setting poles and rigging for canopy nets are discussed in Section 3.5.6. Sites where poles can be used effectively depend on the type of substrate (e.g., sand, rock, soil, water, etc.) and the presence of, and type of, vegetation. Net poles can be stabilized by placing large stones at the base of each pole, by bracing them against rock ledges (Fig. 4 A), or by inserting one end of the pole deep into a soft, sandy or muddy substrate. Guy ropes tied to the middle of a pole can be anchored to other objects (e.g., large stones, small bushes, etc.) for stability. When poles are not available or desirable, ropes suspended from tree branches may be used as substitutes (Fig. 4 B). Even if no lateral branches are available, as on palm trees, nets can be secured to a rope that has been strung from the trunk of a tree (Fig. 4 B). Net poles also may be anchored to bat traps set in shallow water where one or more mist nets can be extended out from the trap (Fig. 9 C).

It is often profitable to use mist nets in V-configurations (Fig. 4 C) or a combination of high and low nets in a T-configuration (Fig. 4 D). As bats attempt to avoid one net they frequently become captured in another. Often bats can be captured if the perimeters of roosts are either partially or completely surrounded by one or more nets (Fig. 4 E and F). Depending upon the length of the net and the space available for setup, angled configurations can be made using one net by looping the horizontal shelf-cords over a pivotal net pole (Fig. 5 A). Two nets can be attached to a single net pole (Fig. 5 B) to achieve the same configuration.

In most studies, mist nets should be set up well in advance of darkness to capture early flying bats, but not so early as to capture late flying birds. In attempts to capture bats that rely mostly upon vision for orientation (e.g., pteropodids), it may be more profitable to set nets well after dark (see Walton and Trowbridge, 1982). Often bats are easiest to capture in areas such as roost openings and flyways, where they often rely mostly on spatial memory for orientation (see Neuweiler and Möhres, 1967; Mueller and Mueller, 1979). Bats are more difficult to capture in nets at feeding sites, where their sensory perception is the keenest.

3.5.5. Removal of Bats from Mist Nets

When a bat flies into a net, it usually drops into a pocket formed by the netting and shelf cords (Fig. 2 B). To remove a bat, one should first determine from which side of the net the bat entered. There are no universally accepted methods of removing bats from mist nets. We usually start with one wing, pulling it gently to keep the net taut, and use the net tension to free the head, feet, and finally the other wing. At times it may be easier to start with the feet instead of a wing. A good "rule" to follow is to start with the part of the bat that last entered the net. In either case, special care should be taken in removing the wings from the net; the long, narrow wing bones can easily be broken by rough handling. It sometimes helps to allow a captured bat (especially a large species) to clasp its teeth onto a cloth bag or loose part of a glove, as this may prevent it from chewing the net (or the hand). With a little practice, bats can be removed from a net within seconds of being captured. The longer a bat remains in a net, the more difficult and time-consuming it may be to remove it without causing injury to the bat or damage to the net. Constant attendance at a net is important, since some bats are able to chew themselves out within minutes, often leaving gaping holes. If a bat should become badly entan-

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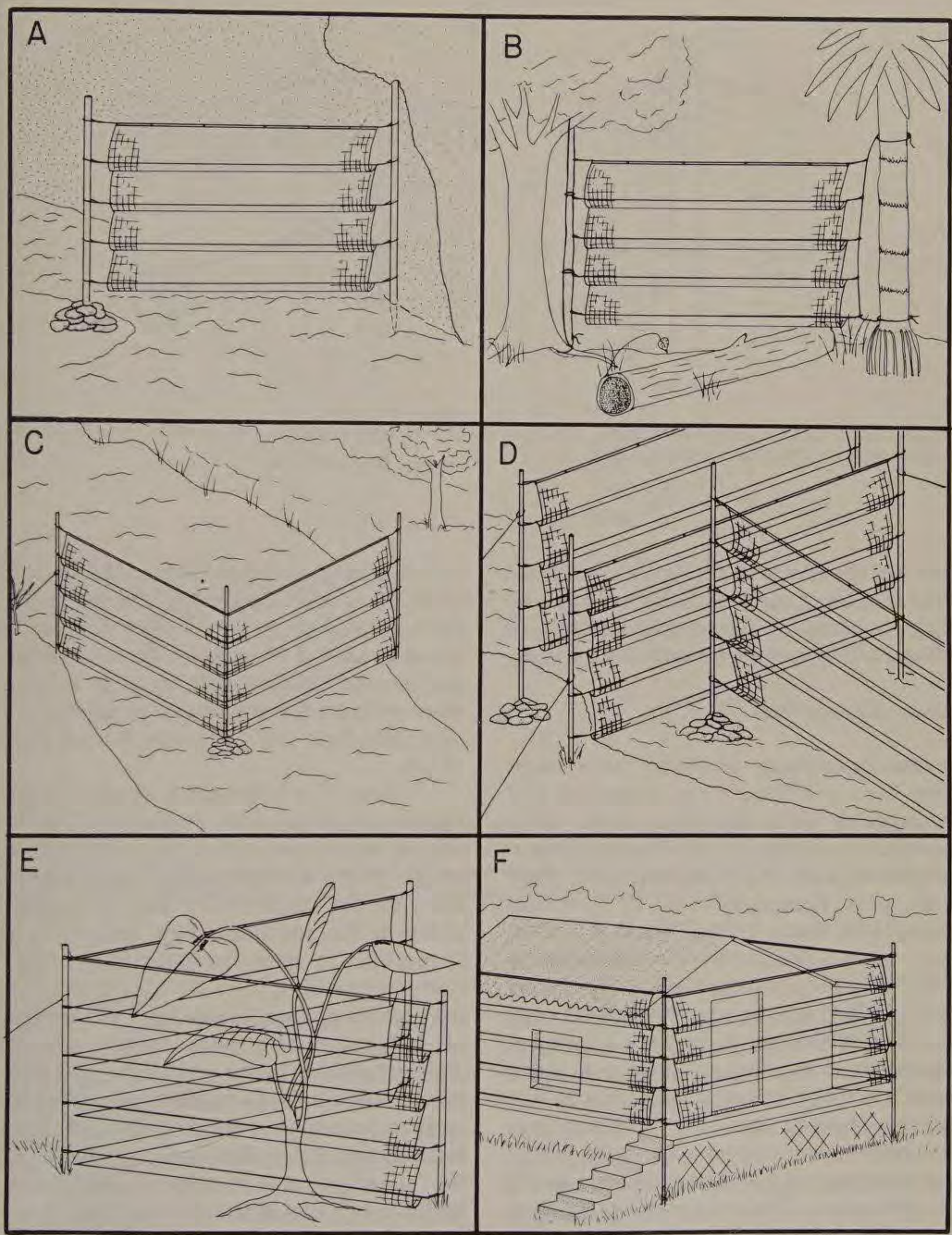

Figure 4. Multiple net configurations and alternative pole uses for setting mist nets to capture bats. (A) Use of large rocks and crevices in rock ledges to anchor net poles. (B) Use of ropes as "poles." (C) V-net configuration; poles anchored in soft substrate or with large rocks. (D) T-net configuration with a high and low net. (E) Foliage roost partially surrounded by a net. (F) Building partially surrounded by nets.

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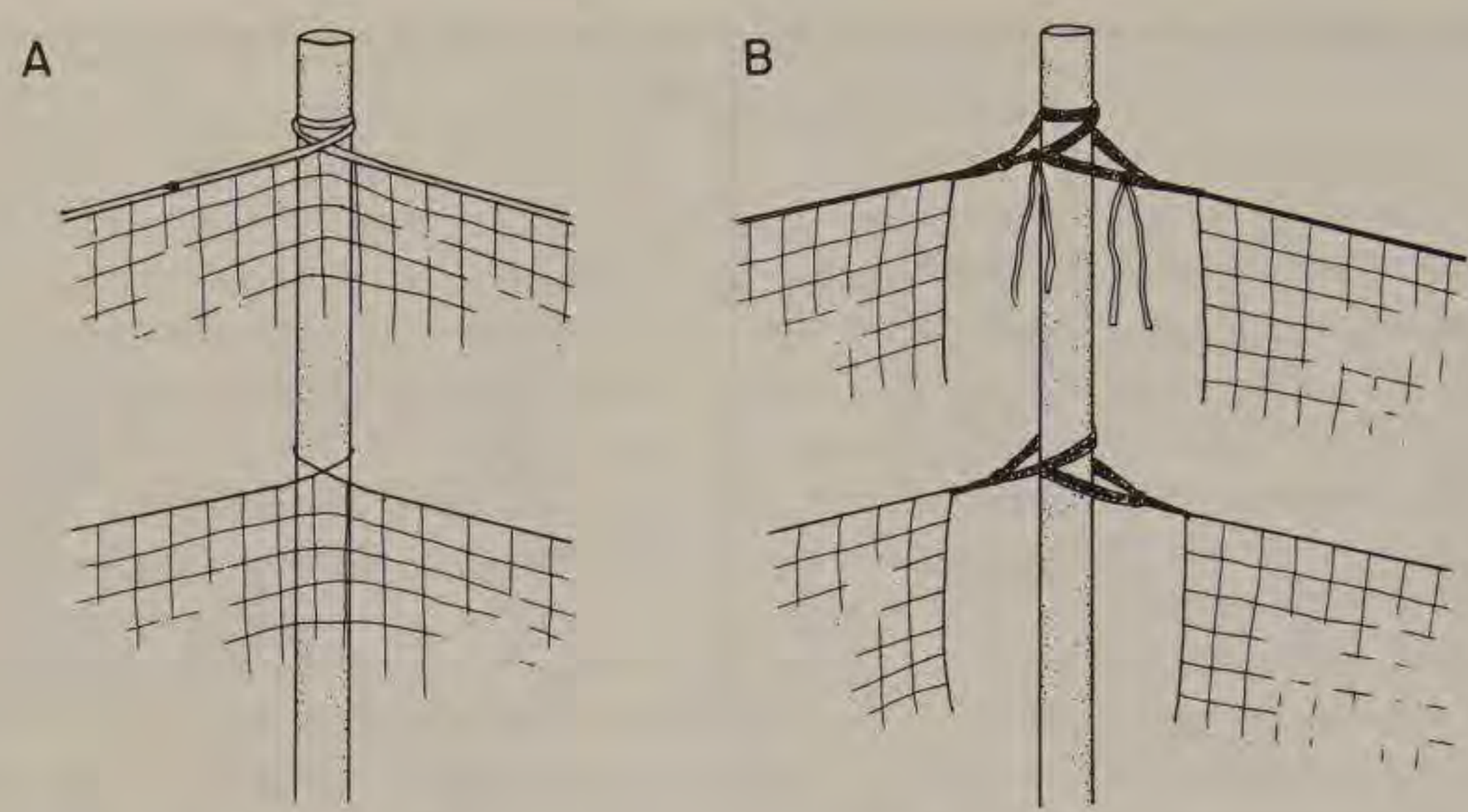

Figure 5. Alternative methods used to attach one or two mist nets to a pivotal net pole to form an angle in net. (A) Attachment of single net. (B) Attachment of two nets.

gled in a net, it may be necessary to cut some strands to free it, although this should only be done as a last resort. A small pair of scissors or a fingernail clipper comes in handy for this.

3.5.6. Canopy Nets

Several descriptions of canopy net-systems have been published (e.g., Greenlaw and Swinebroad, 1967; Humphrey et al., 1968; Rautenbach, 1985) or have been used by various investigators (e.g., Handley, 1967; Cope et al., 1974; Humphrey et al., 1977; Bonaccorso, 1979; Kurta, 1980, 1982; R. K. LaVal, pers. comm.). The canopy net-system used by Handley (1967) and described by Humphrey et al. (1968) employed a horizontal rope stretched between two forest trees. It included separate rope attachments to the ground and a series of metal (noncorrosive) rings used as pulleys. Three or four, 12-m mist nets were attached to a continuous nylon cord so that the entire system could be raised or lowered by one person. Nets were attached by tying the top loop of the first net to the vertical cord. The spacing and attachment of the other net loops was accomplished by tying vertical spacing lines to shower curtain rings that were then attached to each net loop. The shower curtain rings were clipped around the vertical cords to provide horizontal tension to the shelf-cords. This system allowed nets to be raised as high as 30 m above the forest floor and yielded striking differences in species when compared to captures in "ground-level" nets (Handley, 1967; also see Bonaccorso, 1979).

Where it is impractical to use a rope-system suspended from trees, use of poles allows nets to be raised to considerable heights (Fig. 6 A). Poles have the advantage of allowing net placement wherever desired, although the additional bulk makes them impractical in some field situations. Relatively inexpensive poles (at least 2.5 cm in diameter) can be made from 3 to 3.5 m lengths of electrical conduit or aluminum tubing. Two sections can be joined together by using tubes or solid rods of a smaller diameter, with larger tubes added to the outside of joints to increase the rigidity of the pole. Alternatively, the ends of each pole also can be machined so that they will fit together firmly. When three long poles (each ~ 3 m in length) are fitted together, the combined length is great enough to raise four standard-size mist nets or one extra large net (6 m high x 30 m wide) to a height about 9 m. Poles made from tubing

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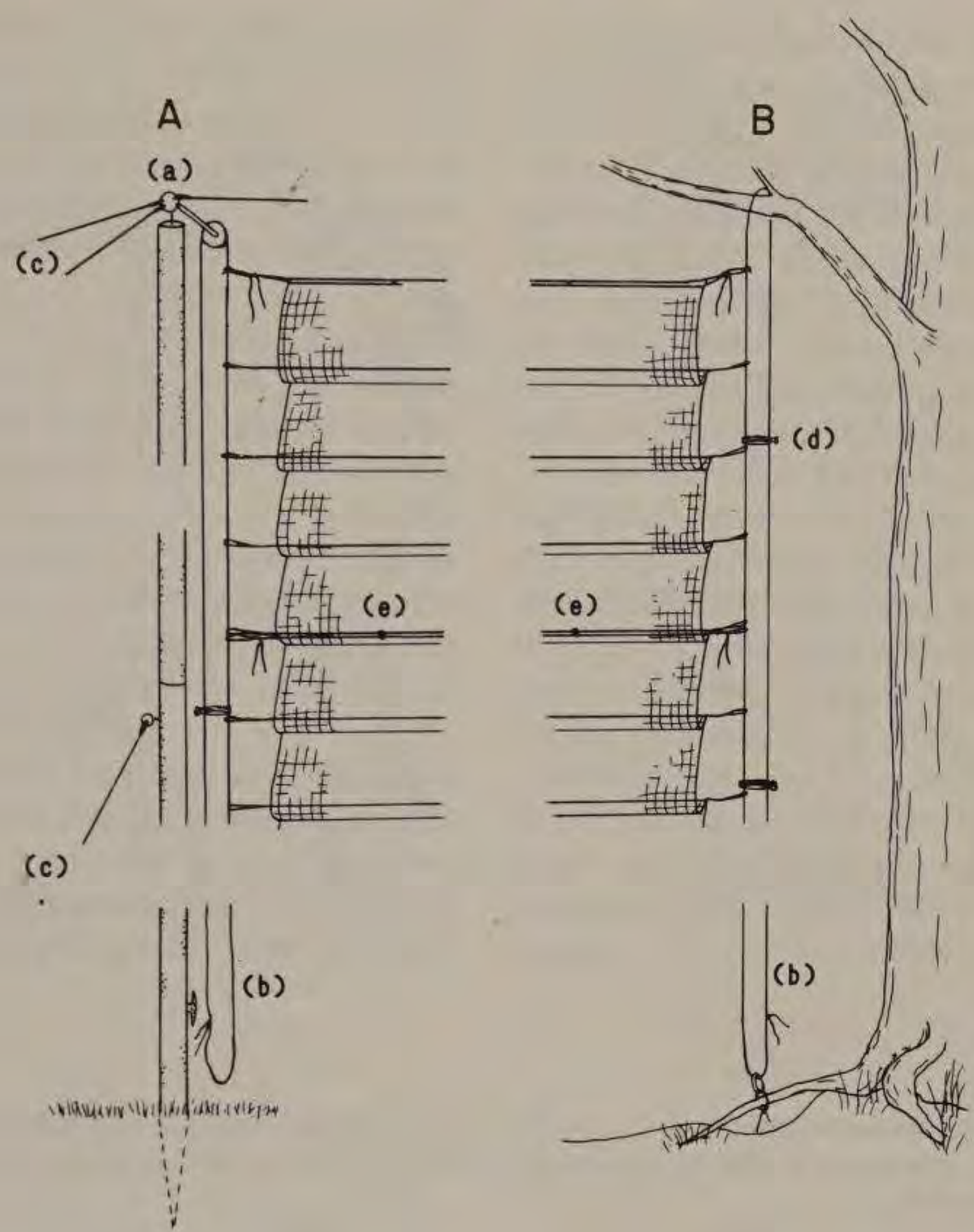

Figure 6. Two types of simple rigging used to erect canopy nets. Only one net and part of a second are shown. (A) Pole rigging. (B) Rope rigging. Guy lines are secured to eye-bolts on net poles with quick-release swivel snaps (a). The ends of the vertical net-ropes (b) guy lines (c) are secured with a quick-release knot (see Fig. 8). Nets are tied together with nylon string (e) and shower curtain rings (d) are used to help maintain horizontal tension on nets.

with a wall thickness of at least 1.6 mm are preferred; a pole with a lesser wall thickness may buckle under its own weight when raised, or it may bend as a net-rope is tightened. Poles greater than 10 m in height are generally impractical owing to the difficulty encountered in erecting and transporting them.

Large poles need at least two, and sometimes four, guy ropes to keep them upright. If two poles or one pole and one tree branch are used, a horizontal rope should be run from the tops to connect the two poles, or it should be run from one pole to the tree branch to stabilize the system. Guy lines can be secured to eyebolts at the top and middle of the pole (Fig. 7 A). Guy ropes are best attached to net poles with quick-release swivel snaps (R. K. LaVal, pers. comm.) to avoid the inconvenience of having to tie and untie knots. We recommend O-rings in place of mechanical pulleys when suspending net ropes from poles (Fig. 7 B). If a pulley sticks, or a rope slips off, the entire system may have to be dismantled to correct the problem.

When suspending nets from tree branches, accurate placement of the rope over

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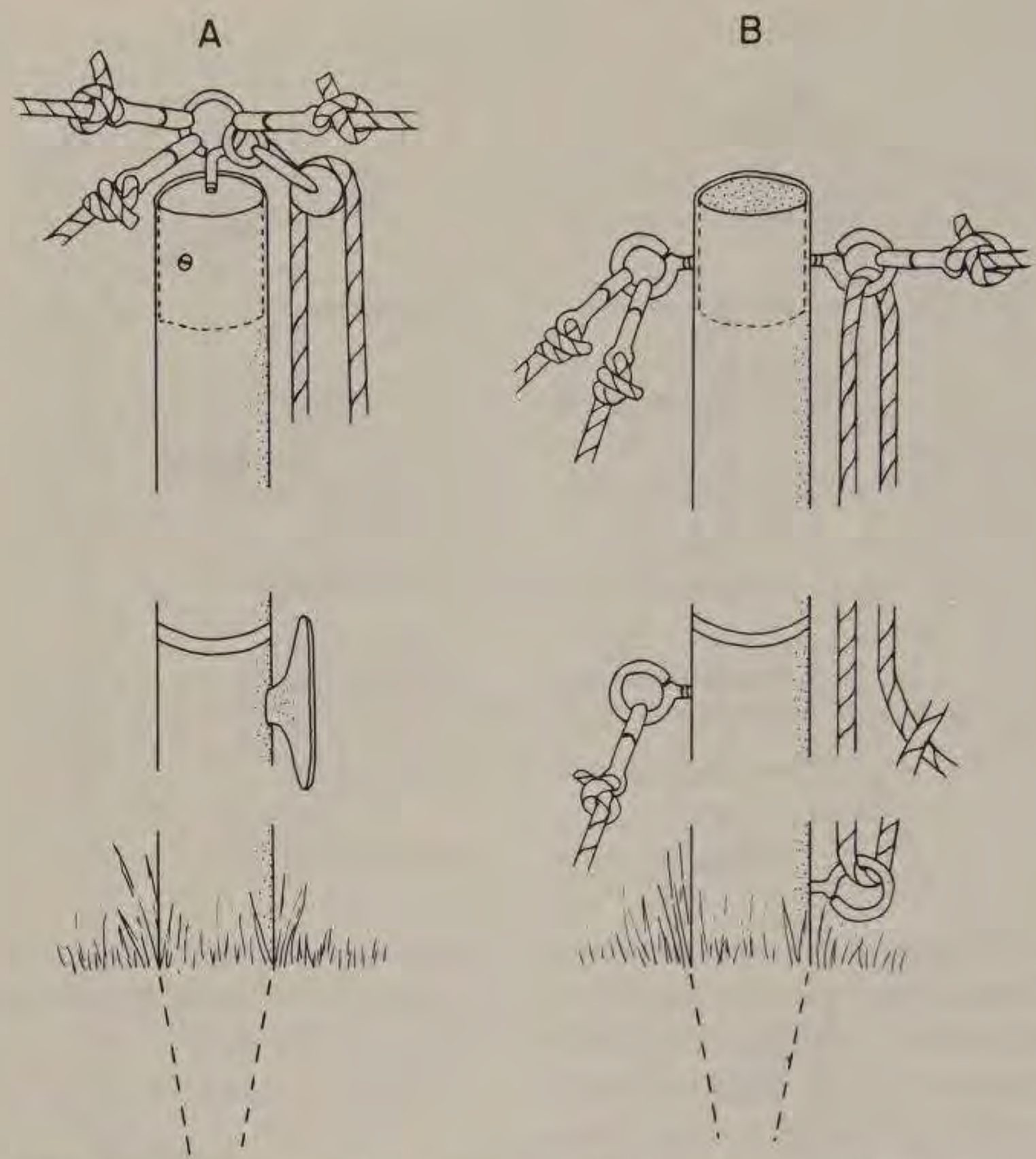

Figure 7. Two types of poles and rigging for erecting canopy nets. (A) Net pole equipped with eyebolts, O-rings, and vertical net-cord. (B) Net pole equipped with eyebolts, pulley, and net-cord. Guy lines are connected to poles with quick-release swivel snaps (see Fig. 6)

a branch 10 m or more above the ground may be difficult. Climbing the tree, especially with the aid of tree-climbing spikes, is a possibility, but this should only be done by experienced climbers. Rope-climbing techniques used by cavers (e.g., Daunt-Mergens, 1981) can be adapted for gaining access to areas within and above the forest canopy (e.g., Perry, 1978; Perry and Williams, 1981; Whitacre, 1981). Another method of getting a rope over a high branch is to use a bow and arrow or a slingshot. Virgil Brack (in litt.) used a compound bow and a blunt, one-meter steel rod as an arrow. An arrow can be shot over a desired branch pulling a lightweight nylon line along with it. A heavier rope used to support the nets is then tied to the line and pulled up and over a branch. Kurta (1980, 1982) used a baseball attached to a nylon string that was wound on a fishing reel. This method was satisfactory for reaching branches up to a height of 14 m. Use of sticks and stones make accurate placement difficult on branches over 4-5 m in height, and is not generally recommended. Once the rope is over the branch, a continuous loop is formed by passing the rope under a log, exposed root, or large stone. Another option is to tie a small length of rope around a log or root and through an O-ring, carabiner, or pulley (Fig. 7 B), allowing the main rope to move freely and reducing friction. Alternatively, the rope may be threaded through an eye-bolt screwed into the base of a tree or log.

Once the rope is placed over a branch or threaded through an O-ring (or eye-bolt) at

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the top of a pole, one end is passed through each loop of the mist nets (Fig. 6). The ends of the rope are securely tied to form a continuous net line. A quick-release knot (Fig. 8) is useful for joining the two ends of a net rope or for securing a guy line. The upper loop of the top net should be tied to the vertical net line (Fig. 6 B). The net rope is then raised, and each successive loop is placed at the desired spacing. Net loops seldom have to be tied to the vertical rope, as they seldom slip. If they do, it may be necessary to tie separate spacing-cords between each loop (see Humphrey et al., 1968). Individual nets may be joined together at 1.5 to 2 m intervals along their length with small pieces of string or monofilament fishing line.

The mass of the nets may cause the rope to bow out near the middle, causing the nets to sag. This can be overcome by placing a few shower curtain rings around both parts of the continuous net rope (Fig. 6 B). These rings are inexpensive, lightweight, and are easily attached and detached. They will slide up and down the rope, and they usually do not pull the net loops out of position. Small pieces of string tied around the rope will also work but they tend to abrade easily. When lowering the net, one simply pulls the vertical rope through the hand, and all the net loops will collect on top of the fist. The entire group of nets can be taken off the rope, folded and stored as one.

Rautenbach (1985) described an elaborate pole-system to support a large, 12-shelf mist net (6 m high x 30 m wide), using 6.2 m lengths of aluminum-alloy sailboat masts and a series of ropes and stainless steel pulleys. Each end of the net is attached to the mast by a series of curtain-rail runners, designed to slide freely up and down within the sail track of the mast. Each pole is secured in an upright position with four guy lines anchored with large tent pegs. Rautenbach (1985) noted that capture success was 300% better with one

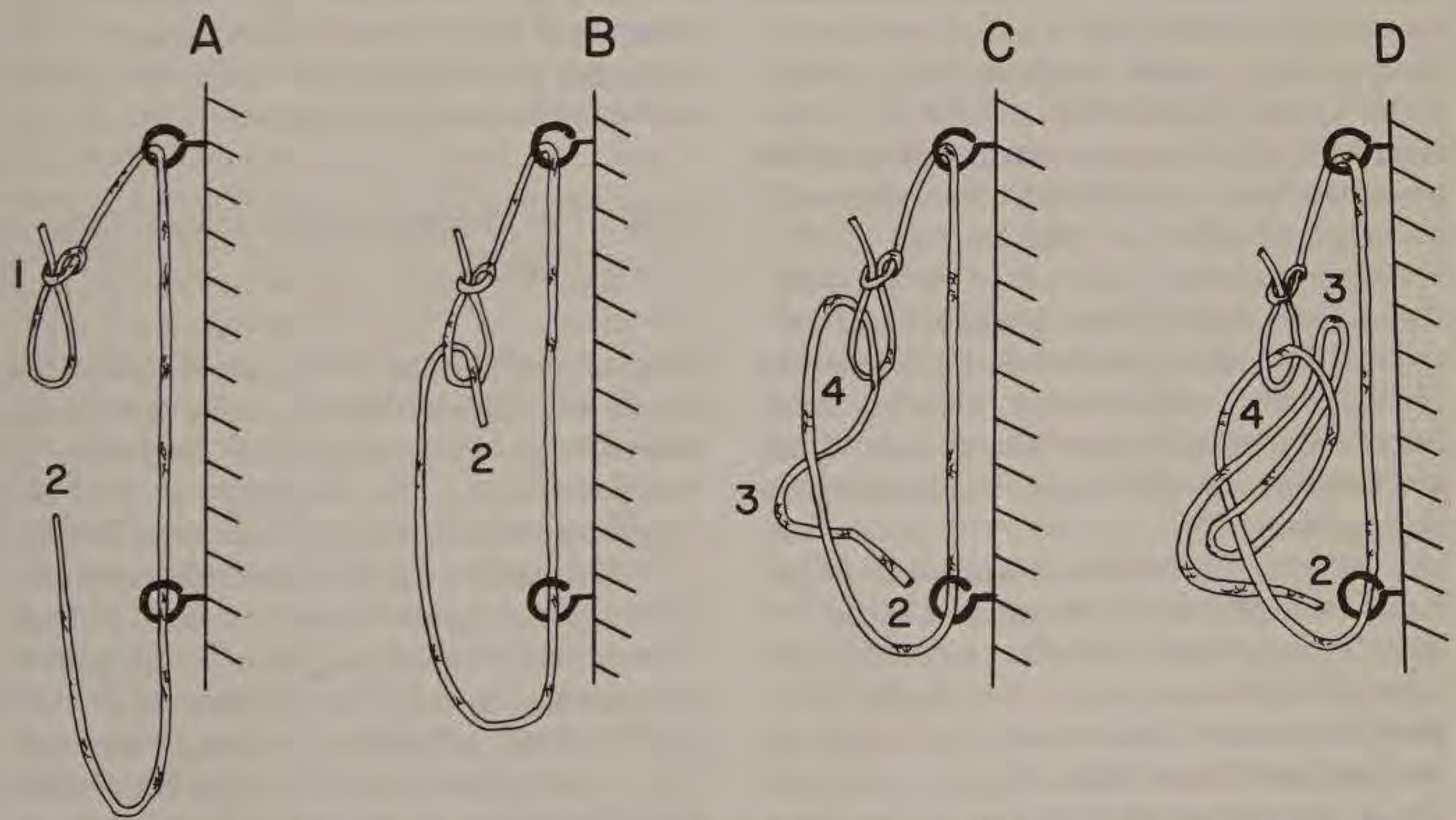

Figure 8. Quick-release knot used for joining two ends of continuous net-line and for securing guy lines. (A) Loop 1 is tied at the free end of rope. (B) End 2 is threaded through loop 1 and pulled downward to create desired tension. (C) Fold 3 is made near loose end of 2 and is passed behind the rope. (D) Fold 3 is then threaded through loop 4. By pulling on 3, the knot is tightened. By pulling on 2, the knot is released so that 2 can be quickly drawn back through 1, allowing a mist net to be added or removed from the rope, or to allow the release of a guy line.

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large net than when serially-strung conventional nets of comparable surface area were used.

3.5.7. Disadvantages and Potential Biases

The principal disadvantage of using mist nets is that they require constant attention. If nets are left unattended, captured bats may become badly entangled and difficult to remove before they cause damage to the net. Moreover, bats may drown, strangle, become injured, or die of stress if they are not removed promptly. Unattended nets set across trails and streams also pose a risk of entangling unsuspecting people, cattle, and other animals that may blunder into them. Predation on bats captured in mist nets is also sufficiently common (e.g., Fleming et al., 1972; Morrison, 1978; August, 1979) to warrant constant vigilance.

Potential biases of using mist nets have been discussed by several authors, including Dalquest (1954), Cranbrook and Barrett (1965), Kunz and Brock (1975), and Tidemann and Woodside (1978). Some bats are unusually proficient at avoiding nets especially on their second encounter (e.g., LaVal, 1970; Kunz, 1973; LaVal and Fitch, 1977). Reduced capture success on successive nights has often been attributed to "net shyness," although Cranbrook and Barrett (1965) found no statistical evidence of such bias for *Nyctalus noctula.* Several workers (e.g., Dalquest, 1954; Kunz and Brock, 1975; Turner, 1975) have noted that capture success can be improved markedly when net configurations and positions are changed on successive netting nights.

Other capture biases may reflect differences in food habits, energy and water requirements of the bats, habitat type, environmental conditions (e.g., moonlight, rain, wind, etc.), visual and acoustic resolution by the bats, and their flight behavior (altitude, speed, and maneuverability). Activity of bats netted over water may yield more information about drinking behavior than about flight and feeding behavior (see Fenton and Morris, 1976; Bell, 1980). Different species may commute and forage at different elevations in the forest. Handley (1967) reported that when mist nets were set in the forest canopy of Brazil, more fruit-eating bats were captured than insectivorous or carnivorous species. LaVal and Fitch (1977) captured a disproportionate number of plant-visiting bats along trails in secondary growth where there was an abundance of fruiting and flowering trees (also see Palmerim and Etheridge, 1985).

Several workers have commented on the effects of environmental conditions on the capture success of bats using mist nets. Wind causes pockets of mist nets to billow and often makes the netting accumulate at one end (see Section 3.5.1). Lower capture success was reported by Nyholm (1965) on windy nights, although O'Farrell and Bradley (1970) noted that capture success was not affected until wind speed reached 9 mph. Apparently, visually-oriented bats are quite adept at avoiding mist nets, but acoustically-oriented bats can vary considerably in their ability to detect mist nets. When mist nets get wet from rain they apparently are easier to detect, allowing bats to avoid capture.

3.5.8. Net Maintenance and Dismantling Procedures

If nets capture large insects, or if sticks and leaves accumulate during a netting session, these should be removed before the net is dismantled. Sticks may be removed by first breaking them into small pieces (Tuttle, 1976a). Large insects may need to be dismembered before they can be removed. If bats chew holes in nets, the holes can be repaired using nylon thread or monofilament fishing line. If a shelf cord is broken, it can be restrung with a section left over from a previously damaged net.

At the end of a netting session, when all bats and debris have been removed, the loops at each end of the net should be gathered and

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secured in the appropriate order (Section 3.5.2). Before removing the net from its poles, the netting may be twirled slightly to tighten it into a bundle. Then, by holding one set of loops in one hand, the other hand can be moved along the net away from the loops, gathering the net to form a single bundle about 1 m from the loops. The gathered net may be grasped at this point with the right hand, continuing to fold it into 1-m lengths until the opposite end is reached. The bundle of loops at this end can be wrapped around the folded net to ensure that the end loops do not become entangled and that the net can be easily unraveled at the next deployment. After folding the net into smaller lengths, the entire bundle can be placed into a plastic bag for storage and transport. Additional details for handling and dismantling mist nets are found in Handley (1968) and Bleitz (no date).

3.6. Harp Traps

Constantine (1958) first described an automatic trap for capturing Mexican free-tailed bats (*Tadarida brasiliensis*) as they departed from large cave openings. Constantine's trap essentially was one large frame with a single bank of fine wires, each individually attached to coil springs, spaced approximately 2.5 cm apart. The trap worked on the principle that the wires could not be easily detected by the echolocation cries of bats, and that the bank of wires was sufficient to stop the flight momentum of bats. A large bag attached beneath the trap served as a hopper to collect the falling bats. Although this single-frame trap proved successful in capturing flying *Tadarida*, it was less efficient at capturing other bats such as *Myotis* and it lacked portability (Constantine, 1958). Subsequent designs were smaller (Constantine, 1958, 1969; Constantine and Villa-R, 1962), have incorporated two frames instead of one (Tuttle, 1974a; Tidemann and Woodside, 1978), and can be folded for increased portability (Tidemann and Woodside, 1978).

3.6.1. Double-Frame Trap Design

The Tuttle trap consists of two rectangular frames of aluminum tubing, approximately 2 m high and 1.8 m wide (Fig. 10). The frame is typically supported by four tubular extension legs but the traps may be used without legs when suspended from above. A canvas bag, partially lined with polyethylene is supported beneath the trap frame to catch bats as they fall after having been intercepted by the trap. Plastic flaps or heavy wires also can be suspended inside the bag to prevent hovering bats and other highly maneuverable species from escaping (Tuttle, 1974b). In Tuttle's (1974a) original description, coil springs were attached to vertically-strung, steel wires to maintain tension. Many workers have found 6- or 8-pound monofilament fishing line preferable to the steel wire. Monofilament nylon line may be attached directly to horizontal tension bars using small, fishing swivels, or alternatively, they may be tied directly through the holes drilled in the tension bar. As with the Constantine trap, the recommended spacing for the vertical wires is 2.5 cm. The distance between the frames should be adjusted to not less than 7 or more than 10 cm (see Section 3.6.3). Net bags should include drain holes in the bottom to prevent the accumulation of water when it rains.

The Tuttle trap works on the same principle as the Constantine trap except, that with the addition of a second frame and associated bank of vertically-strung "wires," bats that are able to fly through a single bank of wires are usually stopped by a second. Such bats become temporarily "trapped" between the two banks of wires and drop or flutter into the bag which is suspended below.

Tidemann and Woodside (1978) described a folding, double-frame harp trap that is highly portable. This trap has the same basic features of the Tuttle trap, but it can be dismantled or set up in about 30 min. It also can be collapsed, for transport, into a bundle that is less than 1 m long, approximately 15

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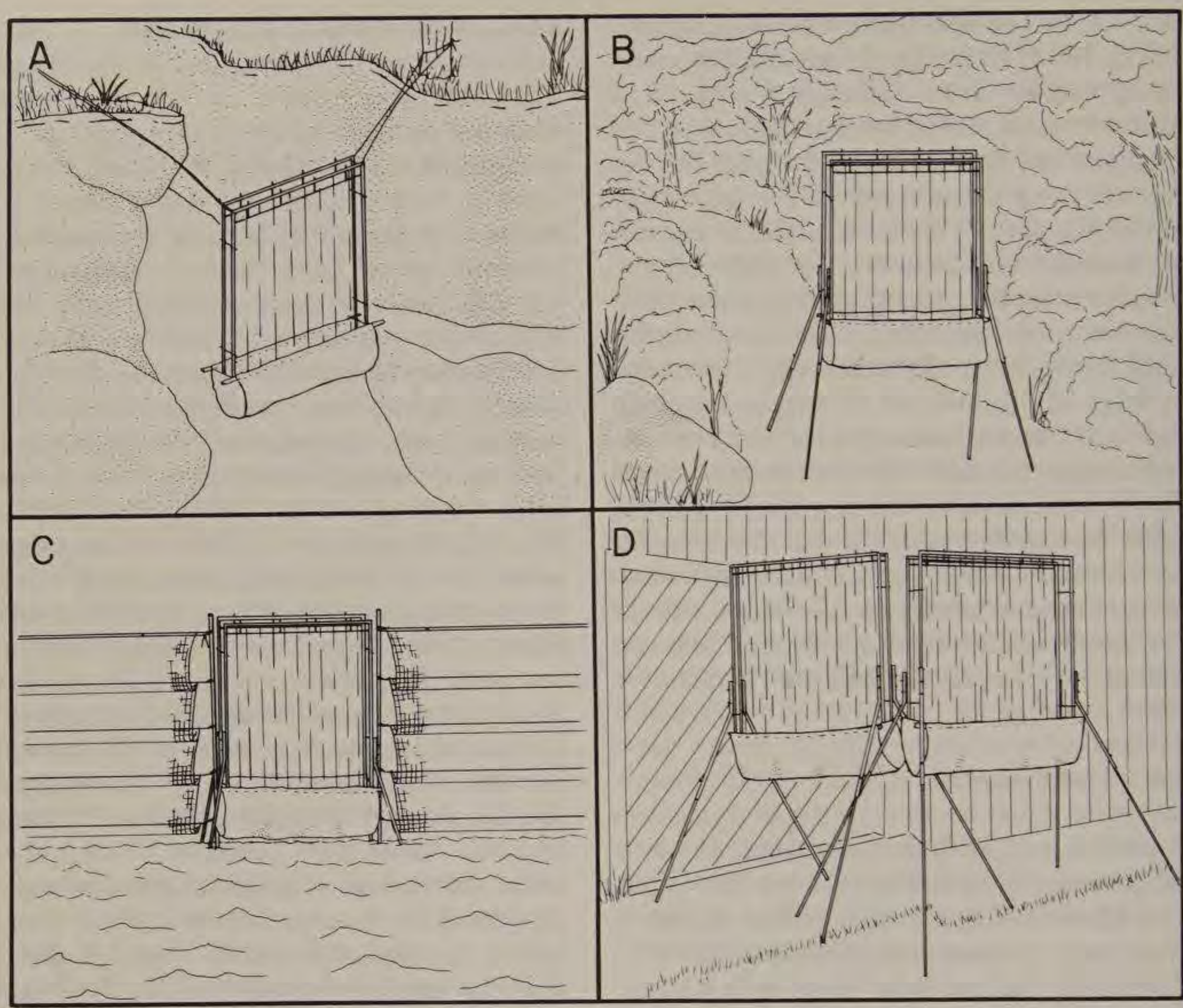

Figure 9. Alternative placements of double-frame harp traps. (A) Suspended in a canyon. (B) Set on forest trail. (C) Set in shallow pond for support of mist nets. (D) Two traps set in L-configuration in front of closed door (opposite crevice). (E) Suspended beneath ridge-pole inside barn. (F) Set in front of open barn door. (G) Set at cave opening. (H) Suspended outside building near roof-line.

cm in diameter, and weighs about 7 kg.

Harp traps have several advantages over other methods used to capture flying bats. Since only minimum attendance is required, several traps can be set and run simultaneously. Moreover, once bats are captured in the trap, they are reasonably well protected from inclement weather. However, one should be alert to the possibility that certain predators can take advantage of bats that enter a trap bag. One of us (THK) has observed snakes feeding on bats confined in harp-trap bags. Other potential problems that can occur when bats are in trap bags include biting and predation of one species on another, rabies transfer from one bat to another, and the suffocation of some bats if large numbers are caught in a short time.

3.6.2. Trap Placement

As with mist nets, harp traps are best set at sites where bats use natural flyways, such as trails, along slowly flowing streams, between trees and rock faces, over water holes, and at roost openings (Fig. 9 A-H). Harp traps are

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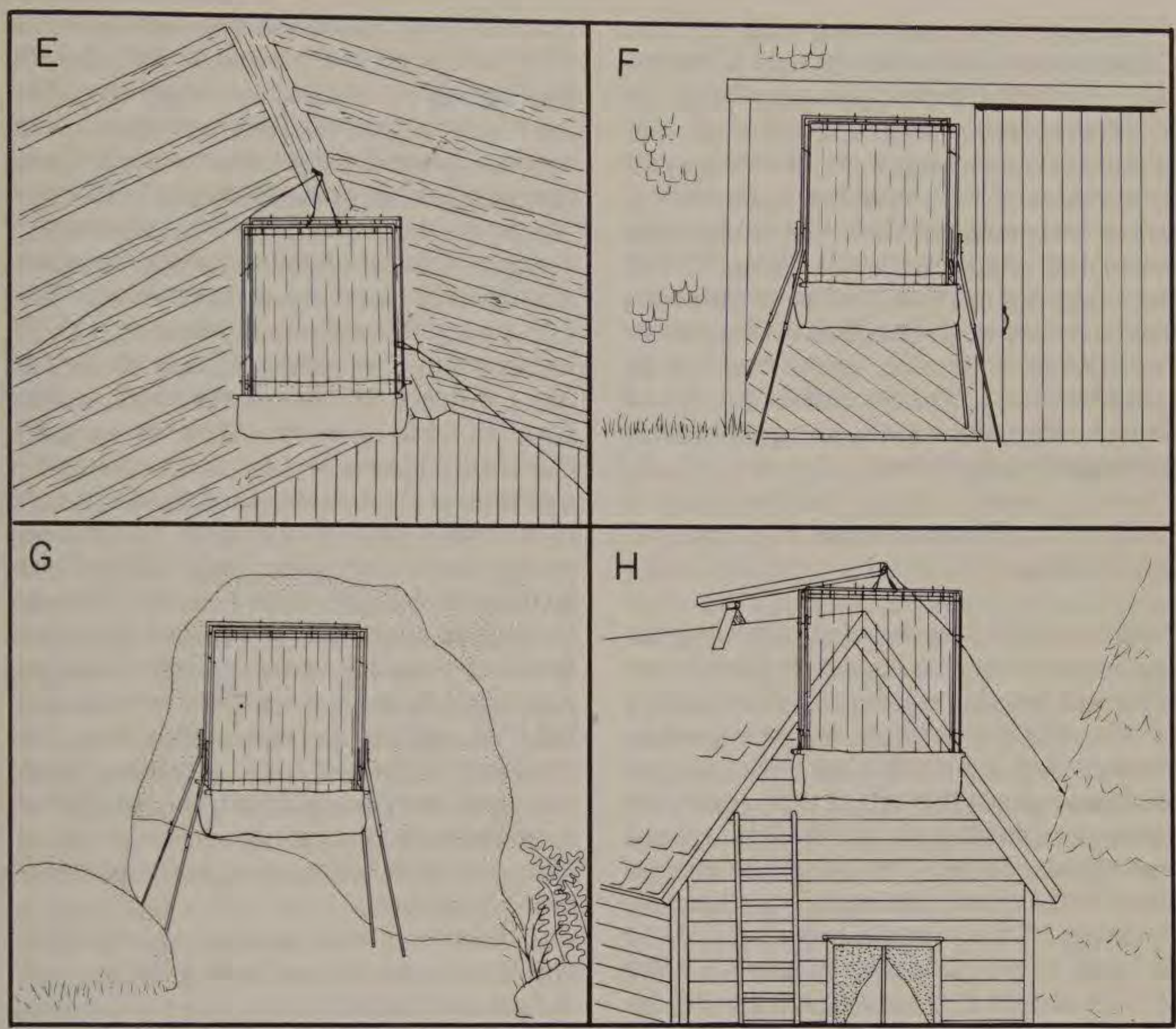

most effective when they are partially hidden by the natural terrain and adjacent to objects that form natural flyways, such as canyon walls (Fig. 9 A) and forest trails with overhanging tree branches (Fig. 9 B). A harp trap may also be used successfully if placed in the middle of a shallow pond or stream and abutted with mist nets that function much like a funnel (Fig. 9 C). In capturing bats that depart and return through small crevices in buildings, we have successfully used two harp traps set at right angles to each other, with one placed perpendicular to a closed barn door (Fig. 9 D). This configuration is analogous, in principle, to T or V sets using mist nets (see Section 3.5.4) and it takes advantage of the circling behavior of bats to capture them as they return to their roost. We have also used harp traps suspended in the attics of barns (Fig. 9 E), in front of open barn doors (Fig. 9 F), and caves (Fig. 9 G) to capture bats as they depart or return from feeding. Suspension of traps near the ridge pole of large barns is the only effective method to capture some bats as they return from feeding. If there is no access to the ridge pole of a barn or to the attic of a house, it may be necessary to suspend a harp trap outside of the building, in front of crevices used by bats for exit and entry (Fig. 9 H).

If harp traps are used to study emergence activity, only a small fraction of the opening should be blocked by the trap when bats are

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present in large numbers (Tuttle, 1976a). Otherwise, the normal flow pattern of departing bats can be disrupted, causing a distortion of activity. At sites where only a few bats may be present, one may want to block areas around the trap with branches, nylon netting, or some other material to funnel as many bats as possible into the path of the trap. When a harp trap begins to capture more bats than can be conveniently handled, the bag can be removed from the trap, or the trap can be turned sideways. The trap should not be laid down on the ground as the lines may become entangled in vegetation.

3.6.3. Trap Effectiveness and Potential Biases

Adjustments in wire tension and frame spacing appear to be two important factors that influence the capture success of harp traps (Tuttle, 1974b). Tension on the monofilament "wires" is adjusted using wingnuts on the threaded rods that support the tension bar at the top of the trap. Tuttle (1974b) suggested that tension on the wires should be proportional to the speed of the bat. If bats escape by bouncing off the wire, the tension should be reduced. If bats pass through the wires the tension should be increased. These adjustments usually are made empirically and some compromise in tension is usually needed when traps are used at places where several different species are present. When the spacing between frames is greater than 10 cm the number of bats that escape tends to increase. Species that are particularly adept at avoiding mist nets are often caught in double-frame harp traps. They are especially effective in capturing small bats that weigh less than 30 g. Bats weighing more than 30 g are seldom captured. However, certain species, such as gleaning and hovering bats, appear to be better at avoiding harp traps (and mist nets) than larger, heavy-bodied frugivorous bats.

Variations in size, shape, and position of openings used by departing bats pose unique challenges in trap placement. When traps are placed in doorways of buildings or at cave or mine entrances, the location of the trap with respect to the door frame or opening of the cave is an important factor governing trap success. To maximize capture success at cave openings and in open doorways, harp traps can be hidden from "view" by positioning them immediately outside the openings when bats are exiting and inside the openings when bats are returning. Kunz and Anthony (1977) compared capture results of Tuttle traps set in front of doors, crevices above doors, and in front of open windows of barns used by departing *Myotis lucifugus*. Capture efficiency (captures/encounters) varied with trap placement, ranging from 80% as they departed from a crevice into the pathway of the trap, to about 30% when bats flew directly through an open door or window. These differences were attributed to variation in flight speed and momentum as bats encountered the trap, angle of encounter, and the opportunities available for avoidance. Bats departing from crevices seldom had sufficient momentum to pass through the two banks of wires, whereas bats that were flying at full speed often did.

Prior experience, age, sex, and reproductive condition may also bias capture success. Adults are generally more adept at avoiding harp traps than are naive juveniles, and lactating bats are more adept at avoiding capture than are near-term pregnant bats (e.g., Kunz, 1973; Kunz and Anthony, 1977; LaVal and LaVal, 1980). In trapping *Myotis grisescens*, LaVal and LaVal (1980) found that a larger percentage of females avoided Tuttle traps than did males. Kunz and Anthony (1977) noted that banded bats were seldom recaptured on the same night and that capture success decreased over the period that a trap was used successively at a single site. LaVal and Fitch (1977) noted that the Tuttle trap was superior to mist nets in light rain. Tidemann and Woodside (1978) found that double-frame harp traps were 10 times more efficient than mist nets, when both number and diversity of species were considered.

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3.7. Miscellaneous Methods

Other methods have been used to capture bats when more conventional methods have not been effective. Although Bradbury and Emmons (1974) and Bradbury and Vehrencamp (1976) successfully captured harem groups of emballonurid bats with hoop nets, they only did so after enclosing buttress cavities with black nylon seine-netting. After bats had departed from their roosts to feed, one end of the net was nailed to the tree above the buttress cavity, and the other end was rolled onto a pole. After the bats returned, the net was allowed to roll down on the outside of the buttress cavity, trapping the bats inside (G.F. McCracken, pers. comm.). Roosting groups of emballonurids that occupied the sides of tree boles and cliffs were captured by approaching them with mist nets stretched between two hand-carried poles, or by using a 1.5-m diameter hoop net, strung with mesh from a mist net (Bradbury and Emmons, 1974). To contain previously marked *Mactotus californicus* for ease of capture, and to avoid disturbing an entire colony, mosquito netting and 6-mm mesh seine-netting was used to block off sections of caves and mine tunnels (G.P. Bell, pers. comm.). Turner (1975) attached a frame of poles to a hollow tree used by *Desmodus rotundus* and draped the frame with mist nets. Bats were captured in the nets as they attempted to emerge at dusk.

Night-roosting groups of *Myotis lucifugus* that often occupy mortices in barns (see Anthony et al., 1981) have been captured with a nylon-mesh (mosquito netting) bag sewn to a small (10 x 30 cm) frame. The frame and mesh bag are placed over an occupied mortice, and with one hand holding the frame over the mortice, the bag is inverted into the cavity with the other hand to dislodge the bats. Once the bats are in the bag, a drawstring is tightened to prevent bats from escaping.

Bats may be captured by attracting or luring them with insects, sounds or odors of other bats, and odors from ripe fruits and flowers. Bats are commonly attracted to insects active near lights (e.g., Constantine, 1958; O'Farrell and Miller, 1972; Fenton and Morris, 1976; Bell, 1980, 1985; Buchler and Childs, 1981). Youngson and McKenzie (1977) used such a response to attract bats to areas where they could be conveniently shot. Some bats appear to respond to the sounds produced by calling insects (e.g., Buchler and Childs, 1981; Bell, 1985), or the sounds of other bats feeding on insects (Fenton and Morris, 1976; Barclay, 1982). Nyholm (1965) used this type of response to capture bats by placing insects in a mesh bag and suspending it inside an open trap from the tip of a pole. When a bat landed on the bag, a cord was pulled capturing it inside the trap. Similarly, it should be possible to lure plant-visiting bats using lures made from ripe fruits and flowers set near harp traps or mist nets. Many bats respond to distress calls of conspecifics and to those of other species (Tuttle, 1976a; also see August, 1979). Tying holding bags containing bats onto mist net poles or traps may also increase capture success. Whether bats are attracted to distress calls or to odors of these captive bats is unknown.

4. HOLDING DEVICES

Holding devices are used to temporarily house captured bats as they await processing in the field or for use in transporting bats to the laboratory. The type of holding device that is used will depend upon the length of time that bats are to be held, the numbers and kinds of species, and the prevailing environmental conditions. Bats should not be housed in overly crowded conditions, left in potentially stressful environments, or held longer than absolutely necessary (Tuttle, 1979). When bats are to be transported by automobile or other forms of transport, they should be protected from extreme temperatures and forced convection.

Nylon mesh or muslin (cotton) bags make good, temporary holding devices for

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some species. They can be made by sewing the fabric into bags of a desired size (Fig. 10 A). We prefer bags that are 30 cm wide and 45 cm deep, with draw-strings or velcro tabs for securing the open end. The mesh of net bags should be small enough to prevent bats from escaping, to prevent their wings from getting caught, and to keep them from chewing escape holes. Ace and Delta style netting (3-mm mesh) is ideal for making holding bags. Net laundry-bags, often available as military surplus, commercially available "bird holding bags," and bags used for washing lingerie also make good holding bags. When using small, net bags it is advisable to house each species separately. One of the advantages of net or muslin holding bags, made from an absorbant fabric, is that they may be kept moist with water in hot, dry environments to help reduce overheating and water loss. Muslin bags may be preferred to open-mesh bags if bats are to be held separately to collect feces for food habits analysis (see Chapters 11 and 13) or for the examination of ectoparasites (Chapter 27). Some bats (e.g., *Lasiurus, Macrotus*) do not adjust well to small cloth holding bags (G. P. Bell, pers. comm.).

Several types of larger holding devices were described in Greenhall and Paradiso (1968) and Barbour and Davis (1969). The Myers bag (Fig. 10 B) is a versatile, collapsible bag made from 3-mm mesh seine-netting. The top is made from a piece of rubber from a tire innertube, secured between two pieces of plywood with staples and small bolts. A slit, cut into the rubber top, allows entry and removal of a bat with one hand without the risk of other bats escaping. A convenient size for a Myers bag is about 38 cm in diameter and 60 cm deep. Such a bag will hold up to 200 small (<12 g), active bats without causing injury or suffocation.

A nylon-net bag attached to a metal or plastic cylinder at one end also makes a good holding device. A large rubber band (cut as a cross section from a tire innertube) can be used to secure a net bag to a cylinder (e.g., stove pipe, PVC pipe, plastic paint cans, etc.). A nylon cord may be attached to the cylinder as a handle. The open end of the cylinder should be large enough to allow entry with a handful of bats but small enough to prevent bats from flying out. Bats can be prevented from escaping if the diameter of the cylinder is no greater than the wing span. Griffin (1940) described a cylindrical holding device in which the bottom part of the cage was made from ¼ inch (6-mm mesh) hardware cloth (Fig. 10 C). A wood disk was fitted into the end of the wire-mesh cylinder so that it would be self-supporting.

Metal or plastic minnow buckets also make good cages for holding and transporting bats (Easterla, 1973). The bottom half of the inner bucket is made of wire or plastic mesh and provides suitable roosting places. A small amount of water may be kept in the bottom of the outer bucket to help maintain humidity. Minnow buckets are especially valuable for holding and transporting hibernating bats (A. W. Gustafson, pers. comm.).

Plastic trash (waste) containers have been modified for use as holding containers. Cockrum (1969) used 20-gallon, plastic garbage cans, in which ventilation holes were cut into the sides. These containers were partly lined with hardware cloth inserts, and a hole was cut into the lid which left a 10-cm wide rim to prevent bats from crawling out. We have successfully used rectangular trash containers (Fig. 10 E) to hold bats that were removed from small mortices and crevices in barns. A nylon cord is attached to the top rim so that the bucket can be carried around the neck, freeing the hands to capture bats. Wire-mesh screen may be inserted into the container to line the inner perimeter. McCracken and Bradbury (1981) used a large, round plastic trash bucket and modified it by removing the bottom and attaching a hardware cloth basket (Fig. 10 E). Although this bucket was used primarily as a device to capture harem groups of *Phyllostomus hastatus* (Section 3.1); it secondarily served as a holding device while bats were being processed (G. F. McCracken, pers. comm.).

One of the most serious problems en-

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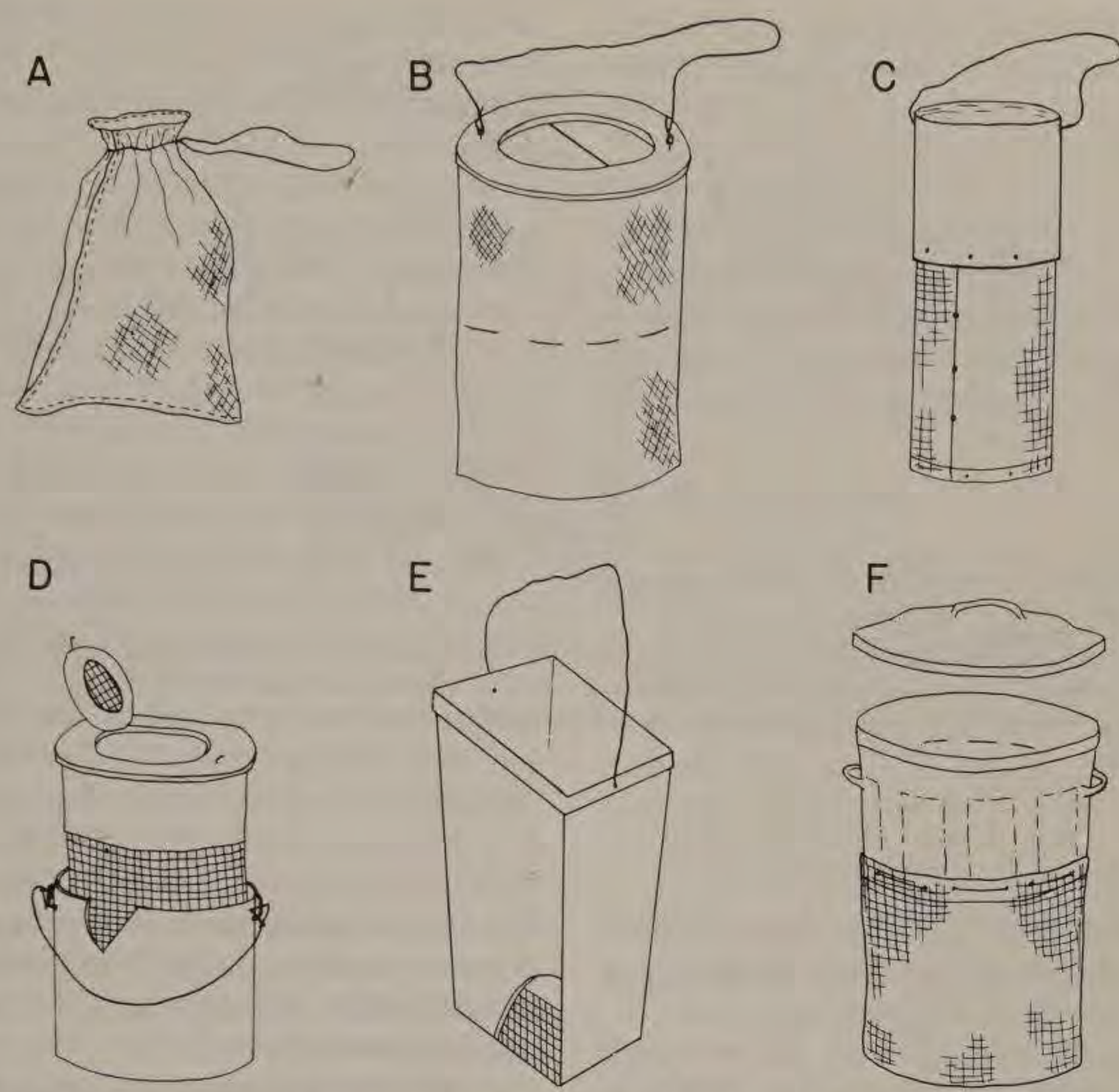

Figure 10. Portable bags and cages for temporarily holding bats in the field and for transport to the laboratory. (A) Net holding bag. (B) Myers bag. (C) Griffin cage. (D) Minnow bucket. (E) Rectangular, plastic trash container. (F) Cylindrical, plastic and wire-mesh "bucket."

countered when bats are held in environments that differ from their natural roosts is that they may become hyperactive, dehydrated, overheated, or hypothermic. An aluminum-frame insect rearing cage, lined with 6-mm mesh seine-netting and fitted into a plywood box that was painted white, was used to house and transport *Macrotus californicus* in desert regions. This device provided a stable thermal environment and allowed the bats to move freely as they were being transported (G. P. Bell, pers. comm.).

Holding cages that simulate roost environments offer many advantages for studies on field energetics, feeding ecology, and postnatal growth. We have regularly used a six-chamber, wooden holding cage that provides roosting conditions that approximate the natural roost environment of *Myotis lucifugus* and *Eptesicus fuscus* (Fig. 11). Each chamber (5 x 5 x 12 cm) is designed to hold up to 12 adult bats weighing 7-10 g or 6 adult bats weighing 12-20 g. The bottom of each chamber is covered with hardware cloth and the top is covered with a removable wooden lid. When these gregarious species are permitted to cluster, individuals stay warm and active, and theoretically have reduced metabolic requirements (see Kunz, 1980; Kurta, 1985). The metabolic heat that is produced by active bats becomes trapped in occupied cage-chambers comparable to that observed in

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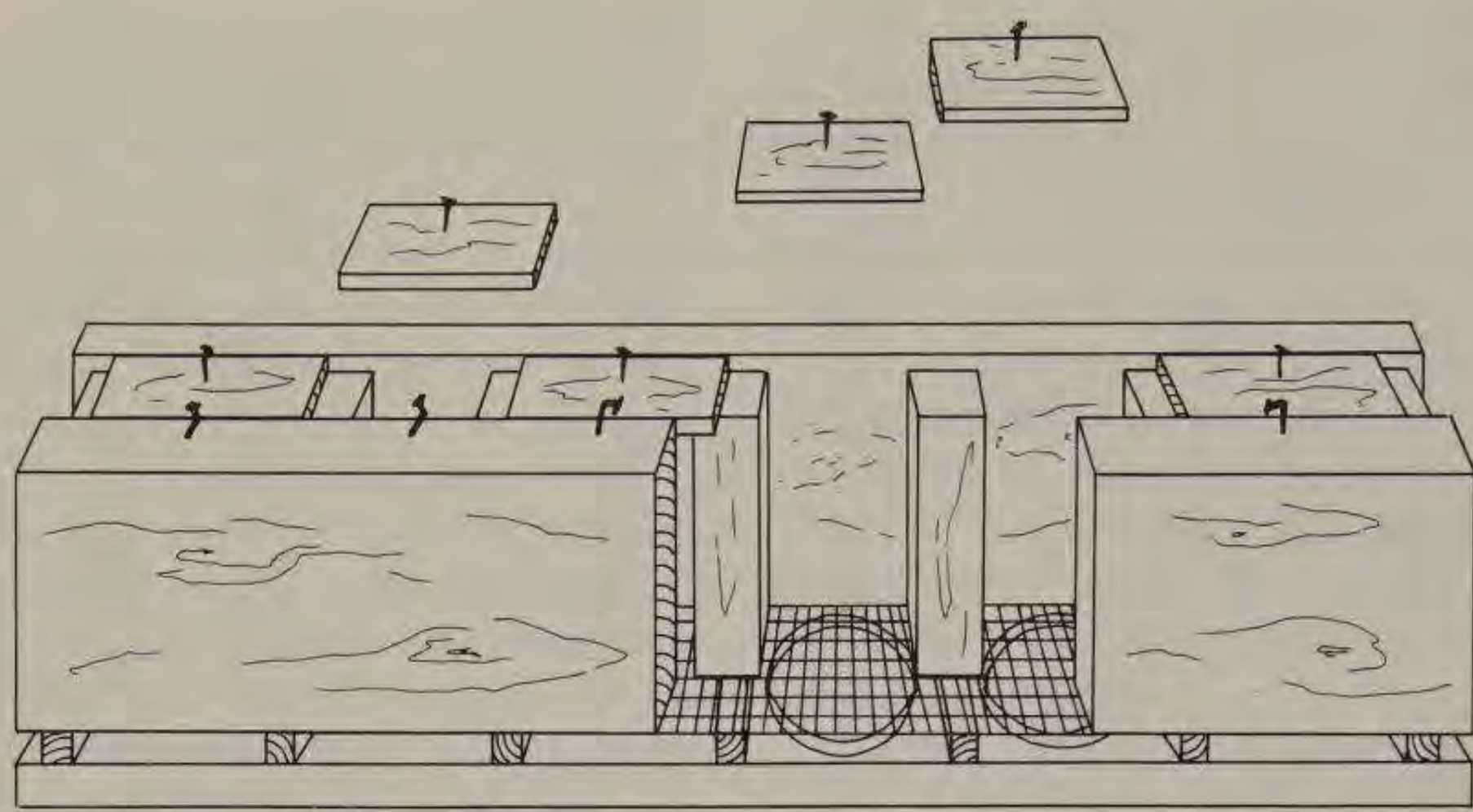

Figure 11. Wooden holding cage that simulates the roost environment of house-dwelling bats. A complete unit contains six separate chambers. The bottom of each chamber is covered with 3-mm mesh hardware cloth, and the top of each chamber has a removable wooden lid. Space beneath each chamber accommodates a Petri dish for collecting feces and urine, if needed.

their natural roost environments. At times it may be valuable to hold bats separately in these chambers (see Chapter 18).

Excellent holding cages can be made from styrofoam coolers by cutting small ventilation holds (covered with screen wire) and inserting a hardware cloth liner to provide roosting places. Adequate ventilation, however, is needed to prevent bats from overheating or suffocating in such devices. Bags of ice or gel coolants may be added to styrofoam coolers to hold and/or transport hibernating bats.

When live bats are to be shipped over long distances, special holding devices are required to reduce stress, minimize energy expenditure and water loss, and to prevent individuals from biting one another. Additional comments on cage design and requirements for shipping live bats can be found in Chapter 22.

5. SUMMARY

Methods used to capture bats will depend on the objectives of the study, the species in question, and whether bats are to be captured in the roost or during flight. Whichever method is used, efforts should be made to minimize disturbance to the bats.

Reliable light sources are essential for capturing flying bats at night or as they roost in dimly-lit or dark places. When selecting a light source, factors such as reliability, durability, and cost are important considerations. When working alone in the dark, at least two spare light sources should be carried. Leather gloves are recommended for handling most bats; they should be heavy enough to provide protection against bites, but pliable enough to allow sensitivity to the form and movement of bats which are being held.

Many bats can be captured by hand without the aid of special devices. Long forceps, hand (hoop) nets, and bucket traps are important aids to capturing bats in roost situations. Some bats can be captured as they depart from roost sites using hoop nets or with specially designed bag (hopper) traps positioned over or near exit holes. Mist nets and harp traps are the most successful devices used for capturing flying bats. Monofilament nets are preferred by many workers, but bats may be

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more difficult to remove from monofilament nets than from standard (2 ply) nylon nets. Canopy nets may be erected using a system of ropes and/or long poles, steel rings (or pulleys), quick release snaps, and guy lines. A major disadvantage when using mist nets is that they require constant attention. Double-frame harp traps can be used most successfully to capture bats as they emerge from or return to roost sites, and as they commute to and from foraging areas. Although harp traps cover a smaller area than mist nets, they frequently capture species that cannot be taken using mist nets. Harp traps offer the advantages of not requiring constant attention and that large numbers of bats can be captured and processed quickly.

There are several types of devices that can be used to hold bats in the field while they are being processed or transported. Small net or cloth bags are relatively inexpensive to make or purchase, and they are highly versatile. Other types of holding devices, such as trash (waste) containers, minnow buckets, styrofoam coolers, and large collapsible net bags may prove valuable for certain applications. Holding devices that provide protection from extreme environments and that simulate natural roost conditions are preferred so that energy expenditure, water loss, and physiological and psychological stress can be minimized.

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Appendix 1. Collecting, Import, and Export Laws and Regulations

Many countries have passed laws and regulations for collecting bats (and other animals) for research. These laws and regulations are often complicated and sometimes ambiguous; they usually require written permits. Researchers have an obligation to learn and comply with the laws and regulations of their own as well as that of the host country where research is to be conducted. Many bats are protected under local, state and federal legislation and international agreements for the capture, transport, and holding of endangered species. Bats that are protected under endangered species legislation should not be disturbed or collected except under special permit.

Many countries require import and export permits in addition to collecting permits. These should be obtained *before* departing for work in a host country. Addresses of permit issuing agencies in various countries are available from the Permit Branch, Federal Wildlife Permit Office, U.S. Fish and Wildlife Service, Washington, D.C. 10140. Applications for such permits should request authorization to possess, transport, and import scientific specimens. Copies of USFWS form 3-177 "Declaration for importation or exportation of fish and wildlife" also should be filed in the United States.

Export permits may be required before species can be removed from the country of origin. Usually the agency that issues scientific collecting permits also issues export permits. In the United States, fisheries and wildlife or customs inspectors at designated ports of entry are instructed to examine specimens and retain copies of customs papers for specimens carried by hand or in luggage. The same papers must accompany specimens shipped from other countries to the United States, and the package must be marked "Contains no protected species." Detailed information on federal and state guidelines is thoroughly treated in a three volume set entitled "Controlled wildlife."[1]

[1]Estes, C., and K. W. Sessions. 1983. Controlled wildlife. Vol. 2. Federally controlled species. Association for Systematic Collections, Allen Press, Lawrence, Kansas, 327 pp.

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